Transactions Second Congress on Large Dams

Compte Rendu Deuxième Congrès des Grands Barrages

Gesamtbericht Zweiter Talsperrenkongress

Actas y Memorias Segundo Congreso de Grandes Presas

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INTERNATIONAL COMMISSION ON LARGE DAMS
OF THE WORLD POWER CONFERENCE

Commission Internationale des Grands Barrages de la
Conférence Mondiale de l'Énergie

Internationale Talsperren-Kommission
der Weltkraftkonferenz

Comisión Internacional de Grandes Presas de la
Conferencia Mundial de la Energía

VOLUME II

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1938

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For sale by the
Superintendent of Documents, Washington, D. C.

VOLUME II

Question III

SPECIAL CEMENT

Question III—Frage III—Cuestión III

Ciment Spécial—Spezialzement—Cemento Especial

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REPORTS AND DISCUSSIONS

Rapports et Discussions—Berichte und Diskussionen

Memorias y Discusiones

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Questions I and II were discussed at the First
Congress, in Scandinavia in 1933

On a étudié les Questions I et II au Premier Congrès
en Scandinavie, 1933

Die Fragen I und II wurden während des Ersten Kongresses
in Skandinavien, im Jahre 1933, behandelt

Las Cuestiones I y II se discutieron en el Primer Congreso
en Escandinavia, 1933

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The "general reports" will be found in Volume I

Les "rapports généraux" se trouvent dans le Volume I

Die "Generalberichte" sind in Band I enthalten

Las "ponencias generales" se encuentran en el Volumen I

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Question III

Special Cement

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

ZUR FRAGE DER TEMPERATURERHOEHUNG IN TALSPERREN; THERMISCHE DAUERUNTERSUCHUNGEN AN ABGEBUNDENEM ZEMENT *

Dr. Ing. R. Sandri
Oesterreich

Der vorliegende Bericht bezieht sich auf Untersuchungen, die über Anregung und unter geldlicher Förderung des Österreichischen Nationalkomitees der Weltkraftkonferenz in der Zeit von Februar 1934 bis Februar 1935 im Institut für physikalische Chemie an der Technischen Hochschule in Wien durchgeführt wurden. Es handelte sich dabei um die Messung der beim eigentlichen Abbinden und darauffolgenden langsamen Erhärten von Portlandzement, bezw. Mörtel freiwerdenden Wärmemengen. Die Grösse dieser Wärmemengen, die Geschwindigkeit, mit der sie entstehen und die Einflüsse, die dabei eine Rolle spielen, sind vor allem wegen der Wichtigkeit der Abbindewärme für den Talsperrenbau von Bedeutung, sind aber auch insofern aufschlussreich, als die Hoffnung besteht, daraus wichtige Aufschlüsse über die chemischen und petrographischen Vorgänge während des Abbindens zu gewinnen.

Das Auftreten hoher Temperaturen im Innern grosser Staumauern aus Gussbeton ist eine Erscheinung, die seit geraumer Zeit allgemeine Aufmerksamkeit erregt und zu lebhaften Besorgnissen Anlass gegeben hat. Man hat mit Hilfe eingebauter elektrischer Thermometer in

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The question of temperature rise in large dams; protracted thermic research on cement after setting.

La question de l'élévation de la température dans les barrages; recherches thermiques de longues durées sur le ciment ayant fait prise.

La cuestión de la elevación de la temperatura en las presas; investigaciones térmicas de larga duración sobre el cemento ya fraguado.

zahlreichen Talsperren Messungen durchgeführt und je nach den Verhältnissen Temperaturen bis zu 50° C, 60° und darüber gefunden. Nicht wenige von den Berichten zum Ersten Internationalen Talsperrenkongress 1933 enthalten Angaben über derartige Messungen an fertigen Talsperren. Dagegen ist die Untersuchung der primären Ursache dieser Temperaturerhöhung — der Wärmeentwicklung des Zementes — im Laboratorium noch nicht oft in einwandfreier Weise gelungen, da solche Versuche wegen der monatelangen Dauer der Wärmeentwicklung nur mit Hilfe recht komplizierter und kostspieliger Apparaturen oder unter Anwendung besonderer Kunstgriffe ausgeführt werden können. Und doch ist gerade zur restlosen Klärung der Frage der Temperaturerhöhung die Durchführung derartiger Experimente unbedingt notwendig. So wertvoll nämlich direkte Temperaturmessungen an fertigen Staumauern auch sind, wird es wegen der grossen Mannigfaltigkeit der dort auftretenden Einflüsse doch nicht ohneweiters möglich sein, die in einem bestimmten Falle gefundenen Daten unmittelbar auf andere derartige Bauwerke zu übertragen. Es wird vielmehr notwendig sein, die Vielfalt dieser Einflüsse zu analysieren und jede Frage gesondert zu untersuchen, was am besten doch nur im Laboratorium geschehen kann. Der vorliegende Bericht soll ein Schritt auf diesem Wege sein.

Das Osterreichische Nationalkomitee hatte schon früher seine Aufmerksamkeit auf die Frage der Abbindewärme gerichtet und die Durchführung einer Untersuchung darüber im Institut für physikalische Chemie der Technischen Hochschule veranlasst, deren Ergebnisse in dem Bericht Nr. 8 zum Ersten Internationalen Talsperrenkongress 1933 unter dem Titel: "Bericht des Oesterreichischen Nationalkomitees der Weltkraftkonferenz. Zur Frage der Temperaturerhöhung in Talsperren: Thermische Daueruntersuchungen an abgebundenem Zement. Von Prof. Dr. E. Abel, Prof. Dr. P. Fillunger, Priv. Doz. Dr. O. Redlich, Dr. Ing. R. Sandri" niedergelegt worden sind. Diese Messungen waren mit Hilfe eines eigens dazu ausgebildeten adiabatischen Kalorimeters durchgeführt worden und führten auf dem Wege sehr empfindlicher Temperaturmessungen zu dem Ergebnis, dass beim Abbinden von Zement noch nach Monaten eine nachweisliche Wärmeentwicklung auftritt. Auf Grund der bei der abiabatischen Kalorimetrie gewonnenen Erkenntnisse war es weiterhin möglich, eine noch leistungsfähigere, nunmehr isotherme Methode zur Messung der Wärmeentwicklung auszuarbeiten, über deren Ergebnisse in einer Ergänzung zum Bericht Nr. 8 (Communication, verfasst von Dr. Sandri) kurz referiert wurde. Diese Methode ist auch bei den im folgenden beschriebenen Messungen an Zement angewandt worden.

Das Arbeitsprogram für die Fortsetzung der erwähnten Arbeiten wurde in seinen Grundzügen durch Richtlinien festgelegt, die von einem vom Nationalkomitee namhaft gemachten Ausschuss, bestehend aus den Herren Ministerialrat Ing. Kühnelt, Dr. Ascher, Dr. Grengg, Prof. Fillunger und Prof. Abel, am 23. Februar 1934 aufgestellt wurden. Diesen Richtlinien entsprechend wurde die Untersuchung der folgenden Punkte in Angriff genommen:

1. Vergleich bestimmter für den Talsperrenbau geeigneter Spezialzemente.

2. Einfluss von Trass und Puzzolanerde als Beimengung zu gewöhnlichem Portlandzement.

3. Einfluss von Zuschlagstoffen (Karbonaten und Silikaten).

4. Einfluss der Lagerung.

Wie schon eingangs erwähnt, ist die Messung der Abbindewärme des Zements im Laboratorium bisher noch nicht oft in einwandfreier Weise gelungen. Zu nennen wären hier vor allem die Arbeiten im Laboratorium der Riverside Cement Co., durchgeführt von Woods, Steinour u. Starke,[1] bei denen eine indirekte Methode angewandt wurde, sowie die von Davey,[2] der nach einer adiabatischen (wärmeverlustfreien) Methode-ähnlich der im genannten Bericht Nr. 8 geschilderten-arbeitete. Diese und andere dem gleichen Zweck dienenden Verfahren, insbesondere das isotherme, hat der Verfasser an anderer Stelle [3] eingehend besprochen.

Auf Grund der schon weit gediehenen Vorarbeiten im Institut Prof. Abels wurde im Februar 1934 mit der Ausarbeitung des oben umrissenen Arbeitsprogrammes begonnen. Zunächst galt es die messtechnischen Behelfe auszubauen. Es gelang, in etwa halbjähriger Arbeitszeit eine Apparatur fertigzustellen, bestehend aus einem Arbeits- und einem Reserve-Thermostaten, 8 isothermen Kalorimetern, die sämtlich im Institut hergestellt wurden, und einem Bändchengalvanometer, das auf Grund der von uns aufgestellten Anforderungen von der Wiener Instrumentenfabrik "Norma" geliefert wurde. Mit dieser Apparatur ist es möglich, gleichzeitig sechs Dauerversuche in Gang zu halten, sodass bei zweimonatiger Versuchsdauer etwa 30, bei einmonatiger Dauer etwa 60 Versuche jährlich durchgeführt werden können, eine Leistungsfähigkeit, die wohl auch den Anforderungen eines laufenden Betriebes genügen dürfte. Es wurde besonderer Wert darauf gelegt, zu einer derartigen Ausgestaltung zu gelangen.

Der Fassungsraum der isothermen Kalorimeter beträgt nur ungefähr 60 cm^3. Dies hat den Vorteil, dass man bei der thermischen Untersuchung eines Zementes mit fast ebenso geringen Mengen auskommt wie z.B. bei chemischen Analysen. Nach Beendigung all dieser recht schwierigen und heiklen experimentellen Massnahmen wurde an die Durchführung des Arbeitsprogrammes geschritten.

DURCHFUEHRUNG DES ARBEITSPROGRAMMES

Als Versuchstemperatur wurde bei sämtlichen Messungen 30,0° C eingehalten, der Wasserzusatz betrug bei reinen Zementen 40%. Als Vergleichsbasis für sämtliche Versuche wurde zunächst ein gewöhnlicher österreichischer Portlandzement (Marke Mannersdorf der Perlmooser A. G.), dessen sämtliche Daten genau bekannt waren, den wir als Vergleichszement (V) bezeichnen wollen, kalorimetrisch untersucht.

Es sei hier bemerkt, dass die früher im Institut untersuchten gewöhnlichen Zemente und frühhochfesten österreichischen Zemente I und II (vgl. Nachtrag zu Bericht 8) weder mit dem Vergleichszement noch mit den in der jetzigen Arbeit mit I und II bezeichneten Spe-

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[1] *Journal of Ind. and Eng. Chemistry, p. 1207, Nov. 1932.*

[2] *Concr. Constr. Eng., p. 572 (1931).*

[3] *Zement, p. 593 (1933, Heft 43).*

zialzementen identisch sind, sodass die jetzigen Resultate nicht ohneweiters mit den damaligen vergleichbar sind. Ausserdem konnte damals die Messung nach der adiabatischen Methode erst nach 34 Stunden (vom Beginn des Wasserzusatzes an gerechnet), nach der isothermen Methode nach zwei oder drei Stunden begonnen werden, sodass die in der ersten Zeit entwickelte Wärme durch die Messung nicht erfasst wurde, während die jetzigen Messungen schon nach einer Stunde einsetzen.

Es stellte sich als zweckmässig heraus, die Messresultate in doppelter Weise zur Anschauung zu bringen: einerseits durch die jeweilige Wärmeentwicklung (*q*) pro Zeiteinheit (Stunde), andererseits durch die seit Beginn des Wasserzusatzes bis zum betrachteten Zeitpunkt entwickelte Gesamtwärme (*Q*). Hiebei sind beide Grössen stets auf 1 kg reinen, trockenen Zement bezogen. Die erstgenannte, differentielle Grösse (*q*) findet sich in den Diagrammen für die ersten 54 Stunden als Funktion der Zeit *t* aufgetragen, wobei natürlich die von der Kurve begrenzte Fläche die zweitgenannte — integrale — Wärmemenge *Q* darstellt. Die Gestalt der so gewonnenen Kurve scheint für jeden Einzelfall besonders charakteristisch zu sein; denn es ist klar, dass Zusammenhänge zwischen der jeweiligen Intensität der chemischen Abbindereaktionen und der jeweiligen Wärmeentwicklung bestehen müssen, dass man also aus der Gestalt der Kurve Schlüsse auf den Chemismus der Reaktionen ziehen kann. So z.B. muss das Auftreten der beobachteten Maxima und Minima, Wendepunkte und dergl. auf die Überlagerung verschiedener Primär- und Sekundärreaktionen beim Abbinden zurückgeführt werden. Man

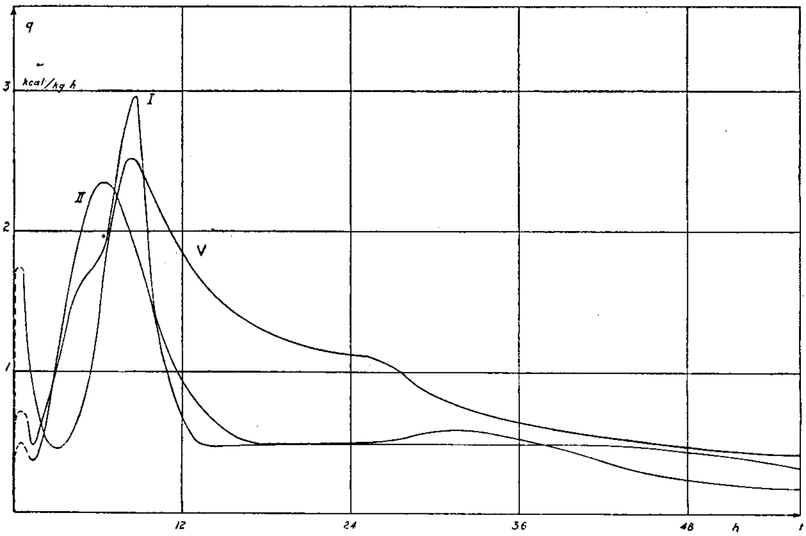

Abbildung 1*a*.—**Wärmeentwicklung amerikanischer low-heat-Zemente beim Abbinden.** — Heat development of American low-heat cement, during setting. — Dégagement de chaleur de prise des ciments américains à faible dégagement de chaleur. — Calor producido durante el fraguado por los cementos americanos que producen poco calor.

beachte, dass derartige charakteristische Merkmale nur innerhalb der Anfangszeit auftreten, weshalb dieses Anfangsstadium in den Diagrammen besonders zum Ausdruck gebracht ist. Die totale Abbindewärme dagegen ist lediglich aus den Tabellen zu ersehen, die sich auf die gesamte Versuchsdauer von 60 Tagen beziehen. (Die Wärmeentwicklung nach dieser Zeitdauer ist vernachlässigbar.)

Offenbar ist die chemische Reaktion die primäre Ursache sowohl der Wärmeentwicklung als auch der Änderung der verschiedenen Eigenschaften des Zements mit fortschreitendem Abbinden, also der Zunahme der Zug- und Druckfestigkeit, der Schwindung und dergl. Es ist darum zu erwarten, dass auch Zusammenhänge zwischen der Abbindewärme einerseits und der Änderung der genannten Eigenschaften andererseits bestehen müssen. Die Durchführung von Parallelversuchen zur Klärung derartiger Zusammenhänge wäre jedenfalls sehr interessant und aufschlussreich.

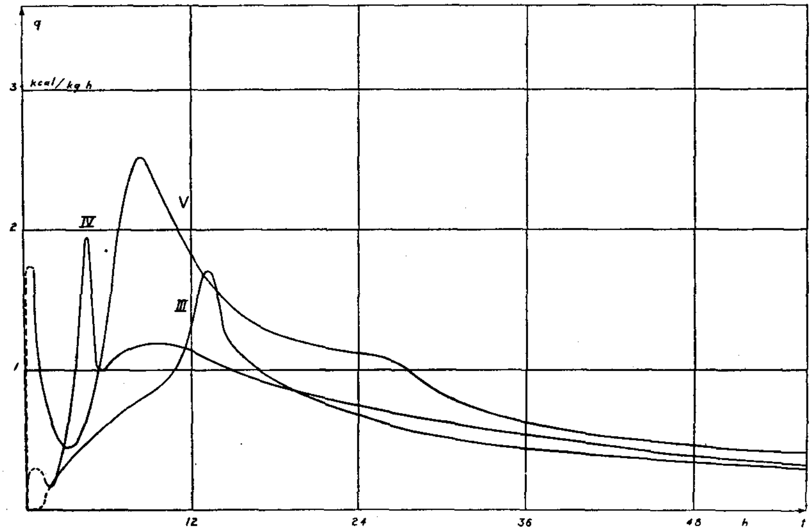

Abbildung 1*b*.—**Wärmeentwicklung skandinavischer low-heat-Zemente beim Abbinden.** — Heat development of Scandinavian low-heat cement, during setting. — Dégagment de chaleur de prise des ciments scandinaves à faible dégagement de chaleur. — Calor producido durante el fraguado por los cementos escandinavos que producen poco calor.

VERGLEICH FÜR DEN TALSPERRENBAU GEEIGNETER SPEZIALZEMENTE

Von einer grösseren Anzahl dem Institut zugesandter amerikanischer und skandinavischer Spezialzemente wurden vier Sorten ausgewählt und zwar zwei amerikanische low-heat-Zemente (I) (II), die beim Baue der Boulder-Talsperre Verwendung gefunden haben, weiterhin zwei skandinavische Spezialzemente (III) (IV). Bezüglich der Versuchsdaten vgl. Tabelle 1 und Diagramme 1*a* und 1*b*.

Tabelle 1.—*Wärmeentwicklung amerikanischer und skandinavischer Spezialzemente*

Zeit		stündliche Wärmeentwicklung q (kcal/kg h)					Gesamtwärme Q (kcal/kg)				
d	h	V	I	II	III	IV	V	I	II	III	IV
	1	1, 209	0, 625	0, 409	0, 000	0, 282	----	----	----	----	----
	2	0, 660	0, 621	0, 541	0, 243	0, 245	----	----	----	----	----
	3	0, 429	1, 116	1, 046	0, 329	0, 583	----	----	----	----	----
	4	0, 503	1, 422	1, 624	0, 406	1, 401	----	----	----	----	----
	6	1, 280	1, 761	2, 32	0, 623	1, 058	----	----	----	----	----
	8	2, 44	2, 73	2, 07	0, 767	1, 178	----	----	----	----	----
	10	2, 25	1, 378	1, 393	0, 888	1, 188	----	----	----	----	----
	12	1, 833	0, 676	0, 923	1, 303	1, 134	----	----	----	----	----
	15	1, 451	0, 504	0, 586	1, 162	0, 995	----	----	----	----	----
	18	1, 273	0, 483	0, 497	0, 932	0, 896	----	----	----	----	----
	21	1, 173	0, 499	0, 497	0, 791	0, 816	----	----	----	----	----
1	----	1, 121	0, 507	0, 497	0, 675	0, 744	33, 8	23, 5	22, 0	19, 4	22, 3
1	6	0, 827	0, 482	0, 497	0, 513	0, 624	----	----	----	----	----
1	12	0, 659	0, 452	0, 497	0, 439	0, 532	----	----	----	----	----
1	18	0, 561	0, 372	0, 481	0, 387	0, 448	----	----	----	----	----
2	----	0, 469	0, 257	0, 431	0, 337	0, 362	----	----	----	----	----
2	- 12	0, 379	0, 162	0, 281	0, 263	0, 260	----	----	----	----	----
3	----	0, 288	0, 118	0, 176	0, 196	0, 181	60, 0	37, 8	40, 6	36, 8	41, 8
4	----	0, 192	0, 0730	0, 110	0, 121	0, 108	----	----	----	----	----
5	----	0, 132	0, 0413	0, 0810	0, 0886	0, 0734	----	----	----	----	----
7	----	0, 0815	0, 0307	0, 0506	0, 0502	0, 0416	74, 6	43, 3	49, 5	46, 4	50, 2
10	----	0, 4093	0, 0231	0, 0250	0, 0303	0, 0250	----	----	----	----	----
14	----	0, 0312	0, 0179	0, 0174	0, 0214	0, 0164	83, 3	46, 2	54, 3	51, 8	54, 6
21	----	0, 0190	0, 0133	0, 0140	0, 0161	0, 0101	----	----	----	----	----
28	----	0, 0155	0, 0097	0, 0111	0, 0121	0, 0074	90, 4	51, 9	59, 1	57, 4	58, 3
42	----	0, 0085	0, 0088	0, 0082	0, 0105	0, 0053	----	----	----	----	----
60	----	0, 0053	0, 0051	0, 0055	0, 0076	0, 0039	97, 5	57, 8	65, 3	64, 9	62, 3

Ergebnis: Sichtliche Ähnlichkeit zwischen den beiden amerikanischen Zementen. Totale Abbindewärme (d.h. der Grenzwert, dem Q asymptotisch zustrebt) ist bei allen untersuchten Spezialzementen wesentlich geringer als bei gewöhnlichem Zement. Unterschiede in der stündlichen Wärmeentwicklung am grössten in den ersten Wochen des Abbindeprozesses.

Die Ergebnisse stehen mit den uns aus Amerika betreffs Wärmeentwicklung der Zemente (I) und (II) mitgeteilten Daten in gutem Einklang.

EINFLUSS VON TRASS- UND PUZZOLANERDE ALS BEIMENGUNG ZU GEWÖHNLICHEM PORTLANDZEMENT

Zement (Vergleichszement V) und Trass, bzw. Puzzolan, wurden im Verhältnis 1:1 gemischt. Im Hinblick auf die Aufnahmefähigkeit der genannten Beistoffe für Wasser wurde die Wassermenge so erhöht (auf 80% des reinen Zements, d.h. 40% der Mischung), dass sicher ein Überschuss an Wasser vorhanden war. Der Einfluss der Beimengungen auf die Wärmeentwicklung drückt sich dahin aus (vgl. Tabelle und Diagramm 2), dass die Beistoffe daran mitbeteiligt sind. Dies führt zu der Schlussfolgerung, dass die Komponenten Zement und Trass, bezw. Puzzolan, in Gegenwart von Wasser miteinander unter Wärmeentwicklung reagieren, allerdings nicht so weitgehend, dass die Abbindewärme eines solchen — aus Trass, bezw. Puzzolan und Portlandzement bestehenden — Gemenges der des reinen Portlandzementes gleichkäme. Um dies zu verdeutlichen, ist in den entsprechenden Spalten neben der auf die Gewichtseinheit reinen Zement bezogenen Wärmeentwicklung in Klammer daneben die auf die Gewichtseinheit des Gemenges bezogene Wärmeentwicklung angegeben. Man sieht, dass diese Werte stets wesentlich unter den entsprechenden für den reinen Zement V liegen.

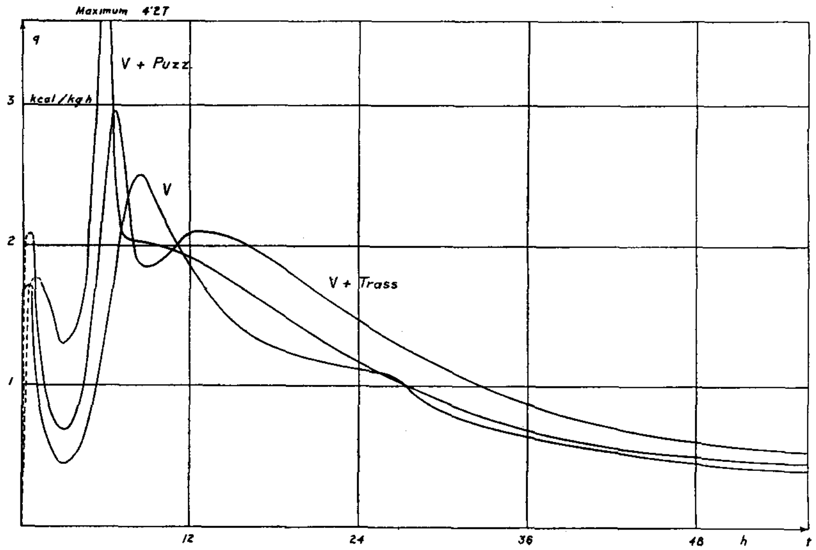

Abbildung 2.—**Einfluss von Trass und Puzzolan auf die Wärmeentwicklung von Portlandzement beim Abbinden.** — Influence of trass and pozzolana on the heat development of Portland cement during setting. — Influence de la trass et de la pouzzolane sur le dégagement de chaleur du ciment portland. — Influencia del trass y de la puzolana en el desarrollo de calor del cemento portland.

Von den beiden genannten Zusatzstoffen liefert Puzzolan die geringere Wärme.

Tabelle 2.—*Einfluss von Trass und Puzzolan*

Zeit		Stündliche Wärmeentwicklung q (kcal/kg h)			Gesamtwärme Q (kcal/kg)		
d	h	V	V+Trass	V+Puzz.	V	V+Trass	V+Puzz.
	1	1, 209	1, 680 (0, 840)	1, 770 (0, 885)	-----	-----	-----
	2	0, 660	0, 850 (0, 425)	1, 590 (0, 795)	-----	-----	-----
	3	0, 429	0, 680 (0, 340)	1, 296 (0, 648)	-----	-----	-----
	4	0, 503	0, 802 (0, 401)	1, 440 (0, 720)	-----	-----	-----
	6	1, 280	2, 46 (1, 230)	4, 27 (2, 135)	-----	-----	-----
	8	2, 44	1, 980 (0, 990)	2, 03 (1, 015)	-----	-----	-----
	10	2, 25	1, 900 (0, 950)	1, 993 (0, 997)	-----	-----	-----
	12	1, 833	2, 09 (1, 045)	1, 915 (0, 958)	-----	-----	-----
	15	1, 451	2, 06 (1, 030)	1, 739 (0, 870)	-----	-----	-----
	18	1, 273	1, 900 (0, 950)	1, 544 (0, 772)	-----	-----	-----
	21	1, 173	1, 672 (0, 836)	1, 377 (0, 689)	-----	-----	-----
1	---	1, 122	1, 466 (0, 733)	1, 174 (0, 587)	33, 8	42, 3 (21, 2)	42, 5 (21, 3)
1	6	0, 827	1, 134 (0, 567)	0, 882 (0, 441)	-----	-----	-----
1	12	0, 659	0, 883 (0, 442)	0, 700 (0, 350)	-----	-----	-----
1	18	0, 561	0, 701 (0, 351)	0, 568 (0, 284)	-----	-----	-----
2	---	0, 469	0, 605 (0, 303)	0, 502 (0, 251)	-----	-----	-----
2	12	0, 379	0, 453 (0, 227)	0, 422 (0, 211)	-----	-----	-----
3	---	0, 288	0, 346 (0, 173)	0, 360 (0, 180)	60, 0	75, 6 (37, 8)	70, 1 (35, 1)
4	---	0, 292	0, 263 (0, 132)	0, 224 (0, 112)	-----	-----	-----
5	---	0, 132	0, 199 (0, 100)	0, 152 (0, 0760)	-----	-----	-----
7	---	0, 0815	0, 124 (0, 0620)	0, 0859 (0, 0430)	74, 6	96, 2 (48, 1)	87, 5 (43, 8)
10	---	0, 0493	0, 0568 (0, 0284)	0, 0491 (0, 0246)	-----	-----	-----
14	---	0, 0312	0, 0266 (0, 0133)	0, 0312 (0, 0156)	83, 3	106, 7 (53, 4)	96, 5 (48, 3)
21	---	0, 0190	--------------	0, 0193 (0, 0097)	-----	-----	-----
28	---	0, 0155	--------------	0, 0123 (0, 0062)	90, 4	-----------	103, 8 (51, 9)

Einfluss von Zuschlagstoffen (Karbonaten und Silikaten)

Zur Untersuchung des Einflusses von Zuschlagstoffen wurde ein Teil Marmor bezw. Quarz in feingemahlenem Zustande mit einem Teil Vergleichszement V gemischt und dem Gemenge aus dem schon unter (2) genannten Grunde 80% Wasser (bezogen auf reinen Zement) zugesetzt. Das Ergebnis dieser Versuche ist sehr bemerkenswert; denn während man eigentlich vermuten sollte, dass die Zuschlagstoffe sich praktisch indifferent verhalten würden, zeigte sich, dass sie zur Abbindewärme des Zementes nicht unerheblich beitragen. (Tabelle 3 und Diagramme 3a und 3b). Dieser Beitrag ist am stärksten (etwa 30%) im Anfange, um dann späterhin langsam zu verschwinden. Die Messungen, die sich auf vier Wochen erstreckten, sind daher in der Tabelle nur für die erste Woche aufgenommen. (Die eingeklammerten Werte in der Tabelle beziehen sich wieder auf das Gemenge).

Der genannte Effekt ist offenbar ein Oberflächeneffekt. Dies erklärt auch seine verhältnismässig kurze Dauer. Man wird zweifellos annehmen müssen, dass er umso stärker ist, je grösser die Ober-

TABELLE 3.—*Einfluss von Zuschlagstoffen*

Zeit		Stündliche Wärmeentwicklung q (kcal/kg h)			Gesamtwärme Q (kcal/kg)		
d	h	V	V+$CaCO_3$	V+SiO_2	V	V+$CaCO_3$	V+SiO_2
	1	1, 209	1, 102 (0, 551)	1, 322 (0, 661)	---	---	---
	2	0, 660	0, 515 (0, 258)	0, 572 (0, 286)	---	---	---
	3	0, 429	0, 399 (0, 200)	0, 374 (0, 187)	---	---	---
	4	0, 503	0, 576 (0, 288)	0, 481 (0, 241)	---	---	---
	6	1, 280	1, 730 (0, 865)	1, 327 (0, 664)	---	---	---
	8	2, 44	3, 61 (1, 805)	3, 10 (1, 550)	---	---	---
	10	2, 25	2, 15 (1, 075)	2, 21 (1, 105)	---	---	---
	12	1, 833	2, 12 (1, 060)	2, 06 (1, 030)	---	---	---
	15	1, 451	2, 05 (1, 025)	2, 20 (1, 100)	---	---	---
	18	1, 273	1, 856 (0, 928)	2, 02 (1, 010)	---	---	---
	21	1, 173	1, 768 (0, 884)	1, 764 (0, 882)	---	---	---
1	---	1, 121	1, 358 (0, 679)	1, 506 (0, 753)	33, 8	41, 9 (21, 0)	42, 1 (21, 1)
1	6	0, 827	0, 990 (0, 495)	1, 116 (0, 558)	---	---	---
1	12	0, 659	0, 779 (0, 390)	0, 888 (0, 444)	---	---	---
1	18	0, 561	0, 638 (0, 319)	0, 720 (0, 360)	---	---	---
2	---	0, 469	0, 626 (0, 313)	0, 580 (0, 290)	---	---	---
2	12	0, 379	0, 407 (0, 204)	0, 432 (0, 216)	---	---	---
3	---	0, 288	0, 324 (0, 162)	0, 337 (0, 169)	60, 0	72, 2 (36, 1)	75, 0 (37, 5)
4	---	0, 192	0, 211 (0, 106)	0, 243 (0, 122)	---	---	---
5	---	0, 132	0, 153 (0, 0765)	0, 171 (0, 0855)	---	---	---
7	---	0, 815	0, 0911 (0, 0456)	0, 0872 (0, 0436)	74, 6	88, 9 (44, 5)	93, 1 (46, 6)

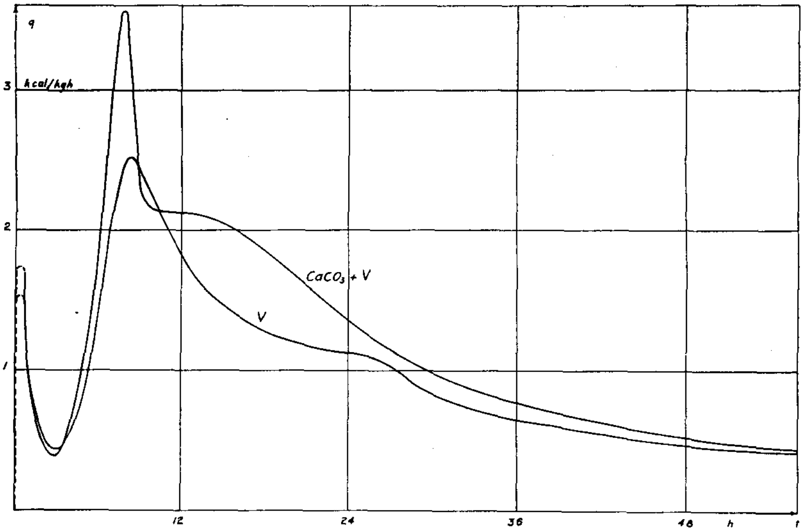

ABBILDUNG 3*a*.—**Einfluss von Kalkstein auf die Wärmeentwicklung von Zement beim Abbinden.** — Influence of lime on the heat development of cement during setting. — Influence du calcaire sur le dégagement de chaleur du ciment. — Influencia de la cal en el desarrollo de calor del cemento.

fläche der Zuschlagstoffe. Bei technischem Beton wird also der Einfluss der Zuschlagstoffe umso eher zur Geltung kommen, je feiner sie sind und je magerer die Mischung ist.

Der bei unseren Versuchen verwendete Quarz war viel feiner gemahlen als der Marmor; der Wärmebeitrag dagegen war bei unseren Versuchen für Quarz und Marmor ungefähr gleich gross. Bei gleicher Feinheit gibt daher offenbar Quarz einen grösseren Wärmebeitrag als Kalkstein; ein Ergebnis, das gewiss ebenfalls von technischem Interesse ist.

Die hier wiedergegebenen Versuche verfolgten zunächst nur den Zweck, nachzuprüfen, ob überhaupt ein Einfluss der Zuschlagstoffe auf die Wärmeentwicklung besteht. Da dies einmal einwandfrei nachgewiesen ist, würde es sich um eine quantitative Auswertung handeln. Hiebei wäre der folgende Weg einzuschlagen. Man müsste zunächst dem Zement Zuschlagstoffe von genau bekannter Oberfläche zusetzen und überprüfen, ob die Wärmeentwicklung, wie zu erwarten, für ein und denselben Zuschlagstoff und Zement der Oberfläche dieses Zuschlagstoffes proportional ist. Ist dies der Fall, dann könnte man für jede gegebene Betonmischung auf Grund der Kenntnis der Wärmeentwicklung des verwendeten reinen Zements, der Natur der verwendeten Zuschlagstoffe und ihrer Oberfläche pro Raumeinheit Beton die Wärmeentwicklung des Betons berechnen, sodass es nicht nötig wäre, jede Betonmischung eigens auf Wärmeentwicklung zu untersuchen.

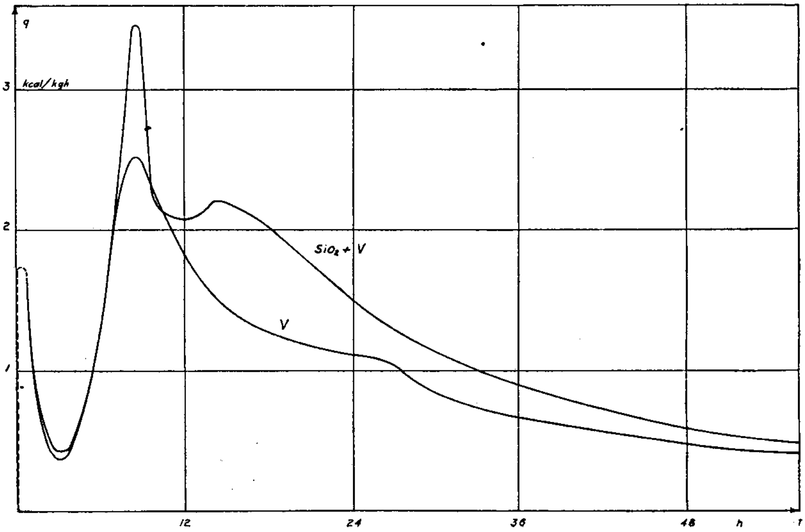

Abbildung 3*b*.—**Einfluss von Quarz auf die Wärmeentwicklung von Zement beim Abbinden.** — Influence of quartz on the heat development of cement during setting. — Influence du quartz sur le dégagement de chaleur du ciment. — Influencia del cuarzo en el desarrollo de calor del cemento.

Man darf übrigens annehmen, dass in vielen Fällen der Praxis der Wärmebeitrag der Zuschlagstoffe vernachlässigbar sein wird. Unter diesen Umständen ergäbe das Produkt aus der Wärmeentwicklung des verwendeten Zements und dem Zementgehalt des Betons direkt die Wärmeentwicklung des Betons.

EINFLUSS DER LAGERUNG

Dieser wurde in der Weise untersucht, dass ein Teil des Vergleichszements V zunächst ein halbes Jahr lang in einem offenen, ein anderer Teil in einem luftdicht geschlossenen Behälter aufbewahrt wurde und dann gleichzeitig beide mit Wasser gemischt und auf ihre Wärmeentwicklung untersucht wurden. Es zeigte sich, dass der unter Luftabschluss aufbewahrte Zement sich von ganz frischem nicht nennenswert unterschied, während die Wärmeentwicklung des an der Luft gealterten besonders anfänglich merklich herabgesetzt war. Allerdings holt der gealterte Zement diesen Vorsprung später grösstenteils wieder ein, sodass die totale Abbindewärme in beiden Fällen so ziemlich dieselbe ist (vgl. Tabelle 4). Man kann hier also nicht eigentlich von einer Verringerung, sondern nur von einer Verzögerung der Wärmeentwicklung sprechen. Diesen Effekt führt Prof. Abel auf den Einfluss des in der Atmosphäre vorhandenen Wasserdampfes und Kohlendioxyds zurück. Er nimmt an, dass sich bei offen gelagertem Zement eine dünne Kruste an der Oberfläche der Zementkörner bildet, die im Anfang des Abbindeprozesses das Eindringen des zugesetzten Wassers in das Innere der Zementkörner verzögert, sodass auch die Wärmeentwicklung verzögert erscheint. Der Einfluss auf die gesamte Abbindewärme dagegen kann nur ein verschwindender sein, weil ja das Volumen dieser dünnen Kruste an sich im Verhältnis zum Gesamtvolumen des Zements nur verschwindend klein ist.

TABELLE 4.—*Zusammenstellung der Gesamtwärme Q für alle Zemente, bzw. Mörtel*

[kcal/kg]

Zeit Tage	V	V (gealtert)	V+$CaCO_3$	V+SiO_2	V+Trass	V+Puzz.	I	II	III	IV
1	33, 8	29, 5	41,9 (21, 0)	42,1 (21,1)	42,3 (21,2)	42,5 (21,3)	23,5	22,0	19,4	22,3
3	60, 0	52, 1	72,2 (36, 1)	75,0 (37,5)	75,6 (37,8)	70,1 (36,1)	37,8	40,6	36,8	41,8
7	74, 6	68, 5	88,9 (44, 5)	93,1 (46,6)	96,2 (48,1)	87,5 (43,8)	43,3	49,5	46,4	50,2
14	83, 3	78, 8	----------	----------	106,7(53,4)	96,5 (48,3)	46,2	54,3	51,8	54,6
28	90, 4	87, 1	----------	----------	----------	103,8(51,9)	51,9	59,1	57,4	58,3
60	97, 5	95, 6	----------	----------	----------	----------	57,8	65,3	64,9	62,3

ZUSAMMENSTELLUNG

Tabelle 4 gibt zum Zwecke einer vergleichenden Übersicht eine Zusammenstellung der Gesamtwärme sämtlicher hier angeführten Versuche für die Zeiten: 1 Tag, 3 Tage, 7 Tage, 14 Tage, 4 Wochen und 2 Monate.

In Tabelle 5 sind schliesslich noch Daten über die Mahlfeinheit der Zemente V, I, II, soweit sie dem Verfasser bekannt waren, enthalten.

TABELLE 5.—*Daten über Mahlfeinheit*

VERGLEICHSZEMENT V

Siebrückstand auf dem		
900 M. S.	2500 M.S.	4800 M.S.
0,1%	0,9%	3,4%

SPEZIALZEMENT I

[Spezifische Oberfläche, 1,875 cm^2/g]

Gewichtsprozente gröber als							
7, 5μ	10μ	15μ	20μ	30μ	40μ	50μ	60μ
73,0	67,9	59,1	52,3	40,8	29,6	22,7	16,3

SPEZIALZEMENT II

[Spezifische Oberfläche, 1,920 cm^2/g]

Gewichtsprozente gröber als							
7, 5μ	10μ	15μ	20μ	30μ	40μ	50μ	60μ
72,2	66,3	58,0	51,5	41,8	3,16	21,3	14,9

TEMPERATURBERECHNUNG

Auf Grund der gewonnenen genauen Kenntnis der differentiellen Wärmeentwicklung lässt sich jene Wärmemenge berechnen, die beim schichtweisen Aufbringen eines grossen Betonblocks durch Leitung und Strahlung an die Luft abgegeben wird. Eine Formel zu diesem Zweck wurde zuerst von Prof. Vogt[4] angegeben; dem Verfasser ist es gelungen, eine andere Formel zu finden, die von der erstgenannten zwar äusserlich stark verschieden ist, indem sie einen viel einfacheren Bau aufweist, trotzdem aber numerisch zu genau denselben Resultaten führt.[5] Für die Wärmeverluste erhält man danach je nach den Verhältnissen Werte zwischen etwa 10% und 30% der totalen Abbindewärme. Numerische Beispiele hiezu werden an anderer Stelle veröffentlicht werden.

Da — wie in der zitierten Arbeit gezeigt wird — andere Wärmeverluste nicht auftreten, berechnet sich offenbar die Temperatur-

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[4] *Det. Kgl. Norske Videnskabers Selskabs Skrifter, 1933, Heft 3.*

[5] *Sitzungsber. d. Wiener Akademie d. Wissenschaften, math.-naturw. Klasse, IIa, 144, 607 (1935).*

erhöhung θ eines Betons von gegebener Zusammensetzung in einer unter gegebenen Bedingungen hergestellten Staumauer nach der Formel

$$\Theta=\frac{W}{\gamma c}(1-p/100).$$

Hiebei bedeutet W die Wärmeentwicklung pro m^3 Beton (gefunden gemäss Punkt 3), c die spezifische Wärme des Betons, γ sein spezifisches Gewicht und p die nach der Anleitung, die in der zitierten Arbeit gegeben wird, berechneten Wärmeverluste (in Prozent der totalen Abbindewärme W).

Es sei abschliessend darauf hingewiesen, dass es natürlich nicht möglich ist, an Hand verhältnismässig weniger Versuche Fragen von solcher Tragweite wie die hier behandelten restlos zu klären. Die vorhin mitgeteilten Ergebnisse können also selbstverständlich nicht als eine erschöpfende Behandlung der aufgeworfenen Probleme, sondern lediglich als ein erster Vorstoss in wohl erst durch die hier angewandte besondere Messtechnik zugänglich gemachte Gebiete technischer Forschung betrachtet werden.

Der Verfasser möchte den Bericht nicht beenden, ohne Herrn Prof. Dr. P. Fillunger für seine vielfachen wertvollen Anregungen und seine lebhafte und dauernde Anteilnahme an dieser Arbeit bestens zu danken. Ganz besonderen Dank schuldet er dem Vorstand des Instituts für physikalische Chemie, Herrn Prof. Dr. E. Abel, unter dessen wissenschaftlicher Leitung die Untersuchungen an Zement begonnen wurden und der auch späterhin dem Verfasser immer wieder seine wohlwollende Unterstützung und seinen Rat in schwierigen Fragen hat zuteil werden lassen.

ZUSAMMENFASSUNG

Der vorliegende Bericht ist als eine Fortsetzung des Berichtes Nr. 8 des Österreichischen Nationalkomitees "Zur Frage der Temperaturerhöhung in Talsperren. Thermische Untersuchungen an abgebundenem Zement" zum Ersten Internationalen Talsperrenkongress 1933 zu betrachten. Hier wie dort handelt es sich um die Messung der beim Abbinden und darauffolgenden langsamen Erhärten von Zement freiwerdenden Wärmemenge durch Laboratoriumsversuch. Da diese Wärme zum Auftreten gefährlich hoher Temperaturen im Inneren grosser Staumauern aus Beton führt, ist ihre genaue Kenntnis von hohem technischem Interesse. Die direkte Messung der Temperaturerhöhung im Innern fertiger Bauwerke reicht zur Klärung des Problems nicht aus und bedarf dringend der Ergänzung durch den Laboratoriumsversuch.

Es gelang, ein neuartiges, sehr leistungsfähiges, isothermes Verfahren auszubilden, das die unmittelbare Messung der von der Gewichtseinheit Zement pro Stunde entwickelten Wärmemenge ermöglicht, woraus sich die vom Beginn des Abbindens bis zum betrachteten Zeitpunkt insgesamt entwickelte Erhärtungswärme leicht ermitteln lässt. Der zeitliche Verlauf der Wärmeentwicklung scheint ausserdem besonders charakteristisch für den Abbindevorgang der betreffenden Zementsorte zu sein.

Schon bei den früheren Arbeiten (Bericht 8) waren einige interessante Ergebnisse betreffend die Abbindewärme gewonnen worden;

insbesondere war ihre starke Abhängigkeit von der Temperatur festgestellt worden. Es wurde nun die Untersuchung einiger weiterer, besonders interessanter Probleme nach der isothermen Methode eingeleitet. Zunächst wurden amerikanische und skandinavische low-heat-Zemente untersucht mit dem Ergebnis, dass die Wärmeentwicklung dieser Zemente tatsächlich als viel geringer befunden wurde als bei gewöhnlichem Portlandzement.

Ferner wurde die Wärmeentwicklung von Mischungen aus Trass — bzw. Puzzolanerde und gewöhnlichem Portlandzement gemessen, um den Einfluss der genannten Zusatzstoffe festzustellen. Es stellte sich heraus, dass Trass und Puzzolan zwar an der Wärmeentwicklung mitbeteiligt sind, aber doch nicht so stark, dass die Wärmeentwicklung eines derartigen Mischzementes der eines reinen Portlandzementes gleichkäme.

In diesem Zusammenhange interessiert auch die Frage, ob die eigentlichen Zuschlagstoffe des Betons sich beim Abbinden chemisch indifferent verhalten. In dieser Richtung durchgeführte Versuche an Kalkstein und Quarz als Vertretern der Karbonate und Silikate zeigten, dass dies nicht der Fall ist, indem besonders der Kalkstein unter Umständen einen nennenswerten Beitrag zur Wärmeentwicklung liefern kann. In vielen Fällen der Praxis wird allerdings der Beitrag der Zuschlagstoffe vernachlässigbar sein.

Schliesslich wurde noch der Einfluss der Lagerung von Zement auf die Wärmeentwicklung geprüft, mit dem Ergebnis, dass an freier Luft aufbewahrter Zement zwar im ganzen nahezu dieselbe Erhärtungswärme liefert wie frischer Zement, aber auf eine merklich längere Zeitspanne verteilt (Verlangsamung des Abbindevorganges).

Auf Grund der genauen Kenntnis der Wärmeentwicklung als Funktion der Zeit ist es möglich, die im Innern grosser Talsperren aus Beton zu erwartende Temperaturerhöhung unter Berücksichtigung aller massgebenden Umstände, insbesondere der Wärmeabgabe an die Umgebung, vorauszuberechnen. Eine nähere Anleitung hierzu ist an anderer Stelle gegeben worden.

SUMMARY

This report is to be considered as a continuation of Report No. 8 of the Austrian National Committee entitled: "The Question of Temperature Rise in Large Dams; Thermic Researches on Cement after Setting", submitted to the First International Congress on Large Dams, 1933. In both cases the reports deal with the amount of heat which is freed after setting and the subsequent hardening of the cement, and which is determined by laboratory tests. As this heat causes dangerously high temperatures in the interior of large dams, it is of great technical interest to obtain a complete knowledge of it. To measure directly the temperature rise in the inner part of completed construction works is not sufficient for the clarification of the problem; additional laboratory tests are needed.

A novel and efficient isothermic process has been successfully worked out which permits the direct measurement of the amount of heat developed by a unit weight of cement per hour; the hardening heat developed from the beginning of the setting up to the time of observation can easily be determined from that. Furthermore, the

chronic course of heat development appears especially characteristic for the setting period of the respective cements.

Already in previous researches (Report No. 8) some interesting results in connection with the setting heat were obtained. It was found that the setting heat was strongly dependent on the temperature. The examination of some further especially interesting problems was taken up under the isothermic method. First, American and Scandinavian low-heat cements were examined with the result that the heat development of these cements was found to be much smaller than that of ordinary portland cement.

The heat development of mixtures made of trass or pozzolanic earth and ordinary portland cement was measured in order to determine the influence of cement admixtures. It was found that the trass and pozzolana take part in the heat development, but not so strongly that the heat development of similar cement mixtures would be equal to the heat development of a pure portland cement.

In this connection the question of whether or not the real admixtures of the concrete remain chemically inert after setting is interesting. Tests carried out in this direction on lime and quartz, representing carbonates and silicates, show that this is not the case, inasmuch as lime especially may, under certain circumstances, add considerably to the heat development. In nearly all practical cases, however, this contribution of admixtures to the heat development can be neglected.

Finally, the influence of the storage of the cement on the heat development was examined. The result was that cement stored in open air develops nearly the same hardening heat as average cement, but the hardening takes a longer period of time; that means a slowing down of the setting process.

Due to an exact knowledge of heat development as a function of the time, it became possible to calculate aforehand the rise of temperature to be expected in the inner part of large dams, taking into consideration all possible circumstances, especially the heat lost to the environment.

RESUME

Ce rapport est la suite du rapport n° 8 du Comité Autrichien au Premier Congrès des Grands Barrages, intitulé: "La question de l'élévation des températures dans les barrages." Comme dans ce dernier rapport, il s'agit dans celui-ci des mesures des quantités de chaleur dégagées pendant la prise du ciment et le durcissement lent consécutif. Comme ce dégagement de chaleur produit dans l'intérieur des grands barrages des élévations de température dangereuses, leur connaissance exacte présente un grand intérêt technique. Mais la mesure directe des élévations de température dans l'intérieur des barrages déjà construits ne suffit pas pour élucider le problème; il est absolument nécessaire de compléter ces mesures par des essais de laboratoire.

Nous sommes parvenus à établir un procédé nouveau, isothermique, très efficace, qui permet des mesures directes de la quantité de chaleur dégagée par unité de poids de ciment et par heure, ce qui fait que l'on obtient aisément la chaleur de durcissement qui s'est dégagée à partir du début de la prise jusqu'à la date de la mesure. Il semble, en outre, que la durée du dégagement de chaleur soit une caractéristique spéciale de la manière dont le type de ciment considéré fait prise.

Déjà les travaux antérieurs (Rapport n° 8 au Premier Congrès) ont donné certains résultats intéressants sur la chaleur de prise; en particulier, on a déterminé la relation étroite qui la relie à la température. Ici, on a exécuté des recherches sur un autre problème particulièrement intéressant, en appliquant la méthode isothermique. On a d'abord étudié les ciments à faible chaleur de prise américains et scandinaves, et on a constaté que le dégagement de chaleur de ces ciments était effectivement bien inférieur à celui du ciment Portland ordinaire.

Ensuite, on a mesuré le dégagement de chaleur des mélanges de ciment Portland ordinaire avec du trass ou de la pouzzolane, en vue de déterminer l'influence de ces additions. On a constaté que si le trass et la pouzzolane contribuent au dégagement de chaleur, cette contribution n'est pas suffisante pour que la chaleur dégagée du mélange atteigne celle d'un Portland pur.

Dans cet ordre d'idées, il est également intéressant de savoir si les matières ajoutées au béton exercent ou non par elles-mêmes une influence chimique pendant la prise. Des essais exécutés à ce point de vue sur du calcaire et du quartz, représentant les carbonates et silicates, ont montré qu'elles ont une certaine influence, et qu'en particulier le calcaire peut, dans certaines circonstances, contribuer notablement au dégagement de chaleur. Cependant, dans la plupart des cas, l'addition de matières de cette nature peut, dans la pratique, être considérée comme d'une influence négligeable.

Enfin, on a examiné l'influence de la durée de mise en dépôt du ciment sur le dégagement de chaleur; on a constaté que le ciment conservé à l'air libre donne une chaleur de durcissement à peu près la même que le ciment frais, mais que ce dégagement de chaleur est réparti sur un plus long délai (ralentissement de la prise).

En se basant sur la connaissance exacte du dégagement de chaleur en fonction du temps, on peut calculer à l'avance, en tenant compte de toutes les circonstances qui interviennent, en particulier la transmission de chaleur dans l'espace ambiant, l'élévation de température que subira l'intérieur du béton des grands barrages. Des renseignements complémentaires sur cette question seront donnés ailleurs.

RESUMEN

Esta memoria es la continuación de la Memoria no. 8 presentada por el Comité Nacional Austriaco al Primer Congreso de Grandes Presas, intitulada: "La cuestión de la elevación de temperatura en las presas." Como en dicha memoria, en ésta se trata de las medidas de las cantidades de calor producidas durante el fraguado del cemento y el endurecimiento lento consecutivo. Como ese calor produce en el interior de las grandes presas elevaciones de temperatura peligrosas, su conocimiento exacto presenta un gran interés técnico. Pero la medida directa de las elevaciones de temperatura en el interior de las presas ya construídas no es suficiente para elucidar el problema; es absolutamente necesario completar estas medidas mediante ensayos de laboratorio.

Hemos conseguido establecer un proceso nuevo, isotérmico, muy eficaz, que permite medir directamente la cantidad de calor desarrollado por unidad de peso de cemento y por hora, lo cual permite obtener fácilmente el calor que se ha desarrollado desde el comienzo del fraguado hasta el tiempo de la medida. Por otra parte parece que la duración del desarrollo de calor es una característica especial de la manera en que se fragua el tipo de cemento considerado.

En los trabajos anteriores (Memoria No. 8 al Primer Congreso) ya se obtuvieron algunos resultados interesantes sobre el calor del fraguado; especialmente se determinó su estrecha relación con la temperatura. Aquí se ha investigado otro problema sumamente interesante, aplicando el método isotérmico. Primero se han estudiado los cementos que producen poco calor, norteamericanos y escandinavos, y se ha probado que el desarrollo de calor de estos cementos era efectivamente muy inferior al del cemento portland ordinario.

Se ha medido el desarrollo de calor de las mezclas de cemento portland ordinario con trass o puzolana, con el fin de determinar la influencia de estas adiciones. Se ha probado que si el trass o la puzolana contribuyen al desarrollo de calor, esta contribución no es suficiente para que el calor desarrollado por la mezcla alcance al de un cemento portland puro.

En este orden de ideas también es interesante saber si las materias añadidas al hormigón ejercen o no, por sí mismas, una influencia química durante el fraguado. Los ensayos que se han hecho en este sentido sobre cal y cuarzo, representando los carbonatos y silicatos, han demostrado que tienen cierta influencia y que especialmente la cal puede, en ciertas circunstancias, contribuir notablemente al desarrollo de calor. Sin embargo, en la mayor parte de los casos, la adición de materias de esta naturaleza puede, en la práctica, ser considerada como de una influencia insignificante.

Por fin se ha examinado la influencia del almacenaje del cemento en el desarrollo de calor; se ha probado que el cemento almacenado al aire libre desarrolla casi el mismo calor de endurecimiento que el cemento fresco, pero el endurecimiento toma un período de tiempo más largo, lo cual significa que se retrasa el fraguado.

A base del conocimiento exacto del desarrollo de calor en función del tiempo, se pudo calcular por adelantado la elevación de temperatura que sufrirá el interior del hormigón de las grandes presas, teniendo en consideración todas las circunstancias que intervienen, especialmente la transmisión de calor al medio ambiente. En otro lugar se suministra información complementaria sobre esta cuestión.

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QUESTION III
SPINDEL, AUSTRIA

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

SPEZIALZEMENTE*

Oberbaurat Ing. M. Spindel, Wien
Österreich

Der Begriff “Spezialzemente” ist zeitgebunden und schwer zu erfassen, In der unter Mitwirkung des Verfassers vom Öst. Zementnormungsausschuss im Jahre 1926 vorgeschlagenen “Einteilung der nichtbituminösen Bindemittel” (vgl. Spindel in der “Sparwirtschaft” 1926) waren die Zementeigenschaften wohl in erster Linie nach der Erhärtungsenergie in “spätfeste”, “frühfeste” und “frühhochfeste” unterteilt, doch waren da auch schon verschiedenartige Spezialportlandzemente vorgesehen, die abgesehen von den Mischzementen, entweder durch besondere Abstimmung der chemischen Zusammensetzung des Zementklinkers, oder durch kleine, güteregelnde Zusätze die angestrebten Sondereigenschaften erhalten sollten. Trotz der grossen Zahl von Spezialzementen, die heute schon erzeugt werden, und von welchen hier nur einzelne Typen hervorgehoben werden können, gibt es eigentlich nur wenige, deren vorteilhafte Sondereigenschaften eindeutig nachgewiesen sind und nicht durch etwaige andere, nachteilige Eigenschaften mehr oder weniger aufgehoben werden. Die Entwicklung der verschiedenartigen Spezialzemente ist daher auch keine so eindeutige und stetige, wie etwa die Entwicklung der reinen Portlandzemente, die von bescheidenen Anfängen schliesslich zu dem in Österreich vor mehr als zwei Jahrzehnten geschaffenen, und seither in der ganzen Welt mit ausgezeichnetem Erfolg verwendeten “Frühhochfesten Portlandzement’ führte. Darum ist auch die österreichische Zementindustrie unter Führung des hervorragenden Zementfachmannes Zentraldirektor Ing. Th. Pierus, vorerst noch nicht gewillt, ihren bewährten Standardzement zugunsten der nachstehend besprochenen andersartigen Spezialzemente irgendwie

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* *Special cements.*
Ciments spéciaux.
Cementos especiales.

zurückzustellen, bevor deren Spezialeigenschaften nicht einwandfrei festgestellt sind.

Der in Frankreich erfundene "Tonerdeschmelzzement", der ungefähr das gleiche Alter hat, wie der öst. "Frühhochfeste Portlandzement", war zweifellos ein neu erfundener Spezialzement von überragender Bedeutung. Grosse Hydratationswärme, die das Verarbeiten auch in grosser Kälte ermöglichte, ungewöhnlich hohe Festigkeiten nach nur eintägiger Erhärtung, die Verfasser durch besondere Zusätze sogar schon nach sechsstündiger Erhärtung erhielt (vgl. Spindel in "Beton und Eisen", 1927) und vor allem die Widerstandsfähigkeit gegen aggressive Wässer zeichneten ihn aus. Der ursprüngliche einzige Nachteil der abnorm hohen Kosten ist durch die spätere Erfindung des Brennens im Ringofen beseitigt worden. Und dennoch sind heute die Verbraucher diesem Spezialzement gegenüber sehr zurückhaltend geworden. Vielleicht gerade deswegen weil sie sich vom Tonerdezement an Spezialeigenschaften weit mehr versprochen haben, als man von einem hydraulischen Bindemittel naturgemäss verlangen kann und dabei die normalen Erhärtungsbedingungen vorerst weniger beachteten. Tonerdezemente kommen für Sperrmauern und Massivbauten schon wegen der grossen Hydratationswärme nicht in Frage, doch sollen sie trotzdem noch näher besprochen werden, weil gerade sie seit ihrem Bekanntwerden sehr wesentlich zur Klärung und Hebung der Güteeigenschaften aller andern Zemente beigetragen haben.

Zu den ihrem Wesen nach ebenfalls neuartigen Spezialzementen gehören die praktisch wiederum in Frankreich geschaffenen "Gips-Schlackenzemente" oder "Ciment Metallurgique Sursulfaté", die in Frankreich als "Le Cilor" und "Le Supercilor" und später auch in Belgien unter dem Namen "Sealithor" und in Italien unter dem Namen "Ilva" in Bagnoli erzeugt und geliefert werden. Diese Spezialzemente waren ihrem Wesen nach schon im Jahre 1909 vom bekannten Zementforscher Dr. Kühl erfunden und patentiert und später auch in dem Buche von Kühl und Knothe, 1915, beschrieben worden. Sie sind vornehmlich dadurch gekennzeichnet, dass der Rohgips, der bekanntlich dem Portlandzementklinker in grösseren Mengen als bis zu etwa 5% zugesetzt, sehr schaden kann, der Hochofenschlacke in einem 2–3 mal höheren Prozentsatze zugemahlen, deren Erhärtungsvermögen in hervorragender Weise hervorruft. Verfasser hat dieses Verfahren in den Jahren 1918–19 laboratoriumsmässig schon so weit ausgebildet gehabt, dass damals die pracktische Erzeugung solcher Zemente als Kriegsersatzstoff im Hinblicke auf die Brennstoffersparnis aufgenommen werden sollte und nur zufällig unterblieb. In den vorhin angeführten Ländern wurde die praktische Erzeugung der Gips-Schlackenzemente erst auf Grund weiterer gründlicher Forschungen aufgenommen, die sich auf die Beschaffenheit der Ausgangsstoffe und die besondere Art der Erzeugung beziehen, wobei sich Prof. Dr. F. Ferari, Ing. Dr. Servieri und Leon Blondieu besonders verdient gemacht haben. Nach den vorliegenden Berichten und teilweisen Erprobungen des Verfassers haben diese Zemente ganz hervorragende Festigkeiten bei geringer Wärmeentwicklung. Sie sollen auch eine kleine Schwindung und Widerstand gegen Meerwasser und sonstige aggressive Wässer aufweisen, doch hat Verfasser schon früher festgestellt und auch heute noch beobachtet, dass, wenigstens gewisse Marken, beim Erhärten an der Luft und bei kombinierter Lagerung leicht absanden und verhältnismässig niedrige Festigkeiten gegenüber der Wasserlagerung zeigen. Es wird daher noch abzuwarten sein, ob diese Spezialzemente sich unter den verschiedenen Verhältnissen der Praxis als vollgeeignet und beständig erweisen werden.

Ein anderer, derzeit im Vordergrunde des Interesses stehender Spezialzement ist der vom schwedischen Zementfachmann Dr. Ing. Forsén in Frankreich und England patentierte sog. "Pansar-Zement", der ebenso wie der von den bekannten französischen Zementwerken De Lafarge & Du Teil erzeugte neue "Ciment indécomposable" seinem Wesen nach auf den Erkenntnissen beruht, die Jules Bied, der Erfinder der Tonerdezemente, noch vor deren Erfindung im Jahre 1908 im Kongressbericht des I.V.M. eingehend mitgeteilt hat. Danach ergibt ein entsprechend zusammengesetzter und bei einer ganz bestimmten Temperatur gebrannter, stark kaolinhaltiger Ton eine besonders hervorragende künstliche Puzzolane, mit welcher die damalige Gesellschaft J. & Pavin de Lafarge schon seit dem Jahre 1904 die Erzeugung ihres "Ciment indécomposable" aufgenommen hatte, dem bis zur Hälfte derart hergestellte Puzzolane beigegeben war. Nach der Erfindung der Tonerdezemente war die Erzeugung dieses Spezialzementes fallen lassen geworden und ist erst vor kurzem durch den bekannten Zementfachmann E. Rengade unter teilweise abgeänderten Verhältnissen wieder aufgenommen worden. Die vorliegenden und auch vom Verfasser festgestellten Festigkeiten dieses neuen "Ciment indécompensable" sind hervorragend und weitaus besser, als von den meisten reinen und Mischportlandzementen mit natürlicher Puzzolane. Die erzeugende Zementfabrik hat auf Grund einer Rundfrage auch das gute, praktische Verhalten ihres vor mehr als 30 Jahren erzeugten damaligen "Ciment indécomposable" feststellen können. Infolge der guten Bindung des beim Erhärten des Portlandzementes abgespaltenen Kalkhydrates durch die vorangeführte künstliche Puzzolane zeigt dieser Zement sicherlich auch einen erhöhten Widerstand gegen aggressive Wässer, der konform geht mit den neuesten Versuchen von S. Nagai, K. Matsuoka und K. Nomi über die erhöhte Widerstandskraft gewisser Mischportlandzemente in sulfatischen Lösungen. Dennoch ist der durch den Puzzolanzusatz verursachte erhöhte Wasserbedarf und die dadurch bedingte höhere Schwindung, wie bei allen Mischzementen als Nachteil zu werten. Da durch diese wirksame Puzzolane auch die Hydratationswärme nicht herabgesetzt wird, dürften diese Puzzolanzemente den besonderen Anforderungen für Massivbauten auch schon des höheren Preises wegen kaum Rechnung tragen.

Auf die Spezialzemente übergehend, die ihren Charakter als reine Portlandzemente beibehalten, und ihre Sondereigenschaften nur einer besonderen Abstimmung der chemischen Zusammensetzung des Klinkers verdanken, muss vorerst darauf verwiesen werden, dass deren Ursprung zurückführt auf die alte Erkenntnis, über die Gefährlichkeit des in Sulfatwässern sich bildenden Calciumsulfoaluminats und auf die von Dr. Michaelis in Deutschland zuerst geschaffenen "Erzzemente" mit möglichst geringem Gehalt an Tonerde. Die

Erzzemente haben sich aber für die Dauer nicht durchsetzen können, weil deren Erzeugung immerhin gewisse Schwierigkeiten bereitete und weil sich die Praxis an der herabegesetzten Erhärtungsenergie stiess, die auf das Fehlen der Tonerde zurückzuführen ist. Die in Amerika erst in neuester Zeit geschaffenen "low heat cements" und die ähnlich ausgebildeten "Schwedischen Wasserbauzemente" sind bezüglich ihres wichtigsten Merkmals, wonach die an das Eisen nicht gebundene Tonerde möglichst gering sein soll, auf den von Dr. F. Ferari schon seit langem erfundenen Spezialportlandzement mit dem Verhältnis $Al_2O_3 : Fe_2O_3 = 0.64$ zurückzuführen, deren nach Bogue errechneter Gehalt an Tricalciumaluminat Null ist. Dieser heute als Brownmilleritzement angesprochene Zementtyp hat sich bisher noch weniger als der Erzzement in die Praxis eingeführt. Die für die amerikanischen "low heat cements" und auch für den "Schwedischen Wasserbauzement" fallweise vorgeschriebenen Maximalwerte für das theoretisch errechnete Tricalciumaluminat sowie die vorgeschriebenen Begrenzungen und Verhältniszahlen zwischen dem theoretisch errechneten Dicalicumsilikat und Tricalciumsilikat entbehren nicht einer gewissen Willkür, da die von Bogue berechneten Prozentgehalte der Klinkermineralien ausser von den in Rechnung gestellten Komponenten auch noch durch die andern Bestandteile des Klinkers und vor allem durch das Brennen und Abkühlen stark bedingt sind. Die Vor- und Nachteile derartiger bewusst energieschwach gehaltener Spezialzemente werden noch bei der Besprechung der einzelnen Güteeigenschaften besonders hervorgehoben werden.

Vom intern. "Subkomité für Spezialzemente" sind für diese insbesondere nachstehende Güteeigenschaften zur Diskussion gestellt:

(1) Hydratationswärme,
(2) Anfressung der Zemente durch Wasser,
(3) Schwindung,
(4) Durchlässigkeit,
(5) Verarbeitbarkeit.

Nebst diesen unter (1) bis (5) angeführten Güteeigenschaften soll in den folgenden Besprechungen auch noch auf ein weiteres wichtiges Betonmerkmal, nämlich auf die Wetter- und Frostbeständigkeit Bedacht genommen werden.

Die vorangeführten Eigenschaften des Mörtels und Betons sind jedoch nicht vom Zement allein, sondern in überwiegendem Masse auch von andern, bei der Mörtel- und Betonbereitung auftretenden Faktoren abhängig. Von diesen seien insbesondere erwähnt:

I. Petrographische und morphologische Beschaffenheit, Reinheit, maximale Korngrösse und Kornverteilung des Zuschlagsstoffes.

II. Mischungsverhältnis zwischen Bindemittel und Zuschlagsstoff.

III. Wassergehalt, Konsistenz, Verarbeitbarkeit, Art und Charakter der Verarbeitung.

IV. Temperatur von Aussenluft und Frischbeton, Wärmeleitung von Schalung und Beton.

V. Art der Erhärtung, Nachbehandlung und Beanspruchung.

Gegenüber diesen Faktoren (I) bis (V) der Betonbereitung tritt der Einfluss besonderer Zementeigenschaften stark zurück, was aber nicht hindern, darf, gerade die vom Zement herrührende Beeinflussung, zu untersuchen, um danach die geeigneten Spezialzemente schaffen, prüfen, und vergleichen zu können.

HYDRATATIONSWÄRME

Die im Mörtel und Beton während des erstmaligen Berührens der festen Stoffe mit dem Wasser entstehende sog. Benetzungswärme soll hier vernachlässigt werden. Die weitaus höheren Wärmemengen, die während des Abbindens und Erhärtens entwickelt werden, sind nun tatsächlich in erster Linie durch den Zement selbst bedingt, obzwar auch da die unter (I) bis (V) angeführten Betonbereitungsfaktoren eine grosse Rolle spielen, insbesondere für die jeweilig erreichte Höchsttemperatur des Betons. Die hervorragenden amerikanischen Zementforscher Bogue, Woods, Steinour, und Starke u.a. haben den Weg gewiesen, wie man die einzelnen Klinkermineralien aus der chemischen Zusammensetzung theoretisch errechnet und wie man weiter die Hydratationswärme berechnet oder als Differenz der Lösungswärme des unverarbeiteten Zementes gegenüber dem erhärteten bestimmt. Hiebei wurden auch Formeln für die gesamte Hydratationswärme nach verschieden langer Erhärtungsdauer angegeben. Alle diese Methoden und Formeln geben aber nicht den "kontinuierlichen" Verlauf der Wärmeentwicklung an und können daher auch nicht die vorangeführte Beeinflussung durch die Betonbereitungsfaktoren hinreichend erfassen. Mit den im chemisch-physikalischen Institut der Technischen Hochschule in Wien entwickelten Verfahren und Apparaturen ist es möglich geworden, den kontinuierlichen Verlauf der Wärmeentwicklung vom Zeitpunkte des Wasserzusatzes an bis zu jedem gewünschten Zeitpunkte zu bestimmen, wobei jeder Versuch bei einer beliebig gewählten, konstant gehaltenen Temperatur durchgeführt werden kann (vgl. Bericht für den I. Talsperrenkongress von Prof. Dr. E. Abel, Prof. Dr. P. Fillunger, Doz. Dr. O. Redlich und Dr. Ing. R. Sandri, und dessen Bericht für den II. Talsperrenkongress). Diese Versuche sind nicht nur im Hinblick auf die Wärmeentwicklung, vom Standpunkte der Erwärmung und Wiederabkühlung des Betons wichtig, sondern sie kennzeichnen auch alle wichtigen Vorgänge, die sich im abbindenden und erhärtenden Zement laufend abspielen und zeigen somit an, wie diese Vorgänge, ausser durch den Zement selbst, auch noch durch hydraulische Zuschläge und Zusätze, durch Zuschlagsstoffe, Wassergehalt, Temperatur, u.s.w. stark mitbeeinflusst werden.

Bei neuartigen Zementen ist es unbedingt nötig, nicht nur die Wärmeentwicklung, sondern auch den Einfluss der jeweiligen Höchsttemperatur auf die Festigkeits- und sonstigen Eigenschaften des Betons zu kennen. So zeigen z.B. die Zementbreie der Tonerdezemente oder vielleicht nur gewisser Typen derselben beim Abbinden noch nicht völlig erforschte sprunghafte Wärmesteigerungen von 50 auf 100 Grad Celsius, die sich auch im Beton sehr bedenklich auswirken können (vgl. Hofr. Jesser in "Zement" 1934). Es ist auch bekannt, dass Mörtel und Beton aus Tonerdezement schon durch Temperaturen von nur 30 Grad Celsius und darüber in den Festigkeiten sehr nachteilig beeinflusst werden. Grade dieses, von den Portlandzementen völlig abweichende Verhalten der Tonerdezemente hat die Baupraxis gelehrt, wie man die Vorteile der grossen Hydratationswärme und Erhärtungsenergie für die Betonierung in der Kälte ausnutzen und den Nachteilen der grossen Hydratationswärme durch planmässige Kühlung selbst schwach bemessener Bauteile entgegenwirken kann. Dieser Umstand weist aber auch darauf hin, dass man die verhältnismässig weit geringere, und vor allem unbedingt stetig vor sich gehende Wärmeentwicklung beim Portlandzement keineswegs so leicht entbehren kann oder bloss als Nachteil werten darf. Eine wesentlich herabgesetzte Erhärtungsenergie und Wärmeentwicklung bei Portlandzementen könnte bei Hinzutreten anderer energieschwächender Einflüsse durch die Betonbereitungsfaktoren, wie unreine Zuschlagsstoffe, viel Wasser, Kälte, u.s.w. unter Umständen zur vollständigen oder zeitweisen Lähmung der Erhärtung mit unabsehbaren Schäden führen, wie Ausfrieren oder mechanische Zerstörung des nicht genügend erhärteten Betons, Unfälle durch frühzeitige Ausschalung und Belastung, u.s.w. Diese Gefahren werden noch dadurch erhöht, dass das für die energieschwachen Zemente so sehr angestrebte Dicalciumsilikat selbst bei Luftabschluss stark altert und mit der Zeit den Zement noch weit weniger reaktionsfähig macht, als beabsichtigt war (vgl. Bericht No. 67 der E.M.P.A., Zürich, von P. Schläpfer und G. Berger). Der fallweise gewählte Ausweg, bei kühlerem Wetter die "low heat cements" auf den Baustellen mit normalem Portlandzement zu mischen, ist keine so ganz unbedenkliche Massnahme, die deswegen von den Baubehörden auch häufig verboten wird. Unter den verschiedenen gewöhnlichen und frühhochfesten Portlandzementen gibt es wohl auch Unterschiede in der Wärmeentwicklung, doch sind selbst bei den energischsten frühhochfesten Portlandzementen keine so grossen und plötzlichen Temperatursteigerungen beobachtet worden, wie bei den Tonerdezementen. Bei den in praktischen Bauwerken aus Portlandzementbeton bisher beobachteten Höchsttemperaturen wurde durch diese noch nie eine Schädigung des Betons hinsichtlich Festigkeit und sonstiger Güteeigenschaften festgestellt, wenn von den Rissbildungen infolge der Schwindung des Betons durch das Wiederabkühlen vorerst abgesehen wird. Wegen des engeren Zusammenhanges zwischen Wärmeentwicklung und Schwindung soll die Besprechung der letzteren gleich angeschlossen werden.

DIE SCHWINDUNG

Die Schwindung infolge der Abkühlung in Kombination mit der Schwindung des Betons beim Abbinden, Erhärten und Austrocknen an der Luft, kann sehr beträchtliche Werte erreichen, weswegen ihr in der Betonpraxis schon seit jeher mit konstruktiven und bautechnischen Massnahmen aller Art entgegengearbeitet wurde, ohne dass über die engen Beziehungen zwischen Wärmeentwicklung, Schwindung und Festigkeiten volle Klarheit geherrscht hätte. Wärmeentwicklung, Schwindung und Festigkeiten können nie als absolute Zahlen angegeben und verglichen werden, sondern nur als Funktion des Abbinde- und Erhärtungsprozesses der am zweckmässigsten vom Beginne des Wasserzusatzes an bis zum jeweils gewählten Zeitpunkte genommen werden sollte. Verfasser hat wiederholt festgestellt, dass es unzureichend ist und sogar irreführend sein kann, wenn man die Schwindung von Zement und Beton nur an schon erhärteten Körpern zu messen beginnt, da er nachgewiesen hatte, dass die Schwindung gleich nach dem Anmachen oder zumindest beim Beginn des Abbindens einsetzt. Mit dem vor zwei Jahrzehnten im Laboratorium der öst. Bundesbahnen in Innsbruck ausgebildeten optischen Messverfahren kann man die lineare Schwindung von Zement und Mörtel tatsächlich schon vom Beginn des Abbindens an messen (vgl. Spindel in Zeitschr. des Ö. I.A.V., Jg. 1925). Die Schwindung vom Abbindebeginn bis zum Abbindeende kann noch grössere Werte erreichen, als die Gesamtschwindung, die normal erst nach 24 stündiger Erhärtung gemessen wird. Selbst die Schwindung des bereits abgebundenen Zementes vom Abbindeende bis zur 24 stündigen Erhärtung kann noch grösser sein, als die normal gemessene Gesamtschwindung nach 24 stündiger Erhärtung. Die Schwindung während des Abbindens bis 24 Stunden, die Differenzschwindung von 24 Stunden bis 28 Tage, und die Gesamtschwindung vom Wasserzusatz an bis 28 Tage ist aus den Schwindkurven gemäss Abbildung 1a, 1b, und 1c zu ersehen, welche die Schwindung der Zementbreie in

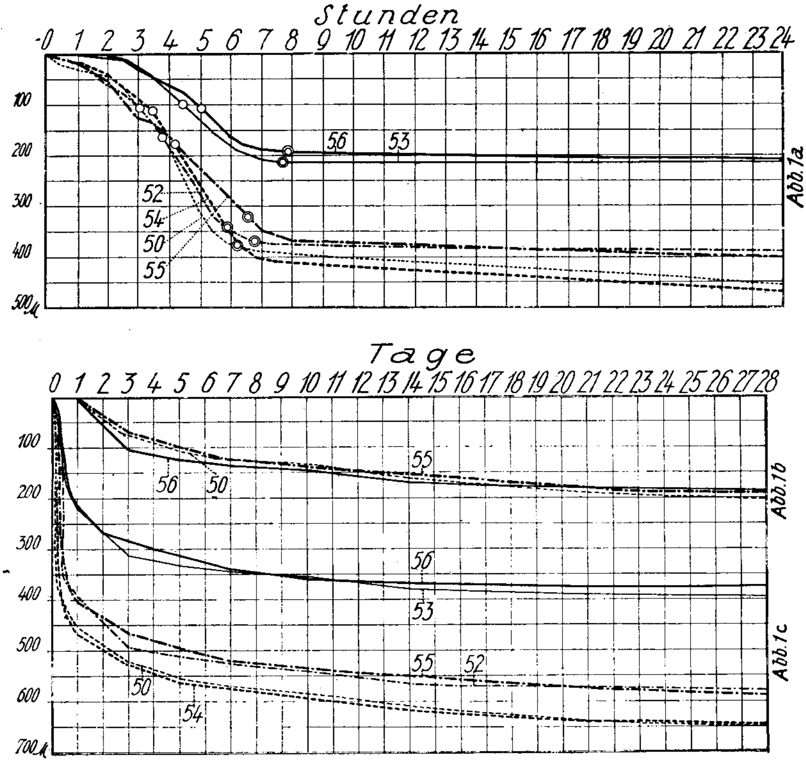

Abbildung 1a, 1b, und 1c.—**Schwindmessung von Portlandzementen nach Verfahren Spindel.** — Measurement of shrinkage of portland cements according to the Spindel process. — Mesures du retrait des ciments P. par le procédé Spindel. — Medidas de la retracción de los cementos portland por el procedimiento Spindel.

Normalkonsistenz von 3 verschieden feingemahlenen Zementklinkern bis zur 28 tägigen Erhärtung an der Luft zeigen. Auffallend hohe Schwindung während des Abbindens zeigen insbesondere gewisse Spezialzemente, fast alle Mischportlandzemente, manche Gips-Schlackenzemente und a.m. (vgl. Spindel in Beton u. Eisen).

Man muss wohl unterscheiden, ob es sich bloss darum handelt, die Längen- und Volumverminderungen bei hemmungsloser Schwindung zu erfassen oder auch die Spannungen festzustellen, die durch das Schwinden im Beton selbst und im eingeschlossenen Stahl entstehen. Nach den Versuchen des Verfassers im Innsbrucker Laboraterium haben die Druckspannungen in Rundeisen welche in Zementbreien eingebettet wurden, erst nach dem Abbinden beträchtliche Werte erreicht und zu entsprechenden Zugspannungen und Rissbildungen im erhärtenden Zementbrei geführt. Bekanntlich haben Dr. Hummel sowie Dr. Werner und S. G. Hedström nach ähnlichen Gesichtspunkten ein eigenes Verfahren für die Schwindprüfung von Zement ausgebildet, das aber nur schwer vergleichbare Werte ergibt. Das in neuester Zeit von Dr. Schwiete ausgebildete Verfahren, wonach im Zementbrei statt Stahl ein leicht zusammendrückbarer Messkörper (Dilatometer) eingebaut wird, dessen Zusammendrückung und Spannung gemessen werden kann, gibt einen Masstab für die Schwindspannung bei entsprechend herabgesetzter Schwindung, lässt aber die Messung der Gesamtschwindung nicht zu. In den praktischen Bauwerken beginnt die Schwindung des Betons in der Höhenrichtung schon mit Beginn des Abbindens und in der wagrechten Richtung zumindest gegen Ende des Abbindens, wobei für die Schwindspannungen und Rissbildungen die Dehnbarkeit des Betons im jeweiligen Abbinde- und Erhärtungszustand massgebend ist. Damit die Zemente und insbesondere neuartige Spezialzemente bezüglich ihrer Schwindeigenschaften verlässlich gewertet und verglichen werden können, müssen also die Schwindvorgänge und Schwindgrössen vom Beginn des Wasserzusatzes an einwandfrei erfasst und geklärt werden. Man muss hiebei, wie bei den erstarrenden Metallen, auch die Raumänderungen erfassen, die bei den verschiedenen Hydratationen in den Neubildungen auftreten.

Schon anlässlich der erstmaligen Einführung der frühhochfesten Portlandzemente hat Verfasser im Jahre 1916 festgestellt, dass der Schwindungs- und Festigkeitsverlauf der Portlandzemente annähernd parallel gehen und dass die frühhochfesten Portlandzemente den Hauptteil der Schwindung schon in der ersten Erhärtungszeit absolvieren, während die Schwindung der langsam erhärtenden Zemente und deren Schwindfolgen wie Risse, u.s.w. zum Grossteil erst viel später eintreten. Deswegen wurde schon damals verlangt, dass die Schwindung nicht bloss bei gleicher Erhärtungszeit, sondern auch im Verhältnis zu den jeweils erreichten Festigkeiten verglichen wird, welche Anschauung seither von den hervorragendsten Zement- und Betonfachleuten wie Graf, Kühl, Ros, u.a. wiederholt vertreten wurde. Trotzdem bisher erst wenige Kurven mit kontinuierlichem Verlauf der Hydratationswärmeentwicklung bekannt sind, kann angenommen werden, dass die drei Reaktionen: Wärmeentwicklung, Schwindung und Festigkeit zumindest bei reinen Portlandzementen ungefähr parallel gehen.

Wenn also für den Talsperrenbau Spezialzemente mit sehr geringer Hydratationswärme verlangt werden, so kann es sich nur um Portlandzemente handeln, welche überhaupt nur sehr geringe Festigkeiten erreichen, oder bei welchen Festigkeit, Wärmeentwicklung und Schwindung, ebenso wie bei den kalkarmen Romanzementen nur sehr lange hinausgeschoben werden. In beiden Fällen wird die Baupraxis solche Zemente nur dann akzeptieren, wenn ihr kein anderer Ausweg übrig bleibt. Die Herabsetzung der Hydratationswärme bei den amerikanischen "low heat cements" gegenüber unsern Portlandzementen, die sich bereits den frühhochfesten nähern, beträgt insgesamt etwa ein Drittel der in den ersten zwei Monaten entwickelten Gesamtwärme der letzteren. Die in den ersten 3–4 Tagen entwickelte Hydratationswärme unserer Portlandzemente beträgt aber schon ungefähr zwei Drittel der gesamten, in zwei Monaten entwickelten Wärme. Wenn man also durch geeignete Betonierungsmethoden und allfällige Abkühlungsmassnahmen in den ersten 3–4 Tagen der Erhärtung etwa die Hälfte der bis dahin entwickelten Wärme wieder ableiten könnte, würde das im Endeffekt der Verwendung besonderer "low heat cements" gleichkommen. In diesem Falle wäre es aber vorzuziehen, dass sich die Reaktionen: Wärmeentwicklung, Schwindung und Erhärtung, in der Hauptsache möglichst rasch abwickeln, was dann gerade umgekehrt für die Verwendung der energisch erhärtenden frühhochfesten Portlandzemente sprechen würde. Nur bei Bauwerken, deren ganz abnormale Grösse und Raschheit der Herstellung bei gegebenen hohen Aussentemperaturen eine entsprechende Abkühlung des Betons während der ersten Tage der Erhärtung nicht leicht zulassen, wie z.B. beim Boulderdamm, da war die Verwendung eigener "low heat cements" scheinbar gegeben. Solche Ausnahmsfälle dürfen jedoch keineswegs zu einer Bevorzugung dieses Zementes führen, wo er nicht gerade unbedingt nötig ist. Es sei denn, dass diesem Zementtyp ausser der niedrigen Wärmeentwicklung auch noch andere erwünschte Zementeigenschaften zukommen sollten, wie z.B. höhere Widerstandsfähigkeit gegen aggressive Wässer u.a.m. Im übrigen wäre zu beachten, dass man die Herabsetzung der Wärmeentwicklung der Portlandzemente nicht bloss durch eine besondere chemische Zusammensetzung, sondern auch durch andere Massnahmen erreichen könnte, welche die Zementerzeugung weniger irritieren; so z.B. einfach durch gröbere Mahlung, wobei hiedurch wiederum andere nachteilige Wirkungen, insbesondere hinsichtlich der Festigkeit und Dichtigkeit, eintreten würden.

Die Anfressung der Zemente durch Wasser

Diese Frage ist in theoretischer wie in praktischer Hinsicht ebenso schwierig und verwickelt, wie die Frage der Hydratationswärme und Schwindung. Es ist allgemein bekannt, dass Mörtel und Beton, sowie die verschiedenen aggressiven Wässer, zu welchen auch ganz reines Wasser gehört, angegriffen werden und fallweise auch zerstört wurden. Seit Jahrzehnten ist das Augenmerk von Wissenschaft und Praxis auf die Frage gerichtet, welche besondere Zementarten den in Betracht kommenden aggressiven Wässern am sichersten widerstehen können. Es wurden hiefür der Erzzement nach Michaelis, verschie-

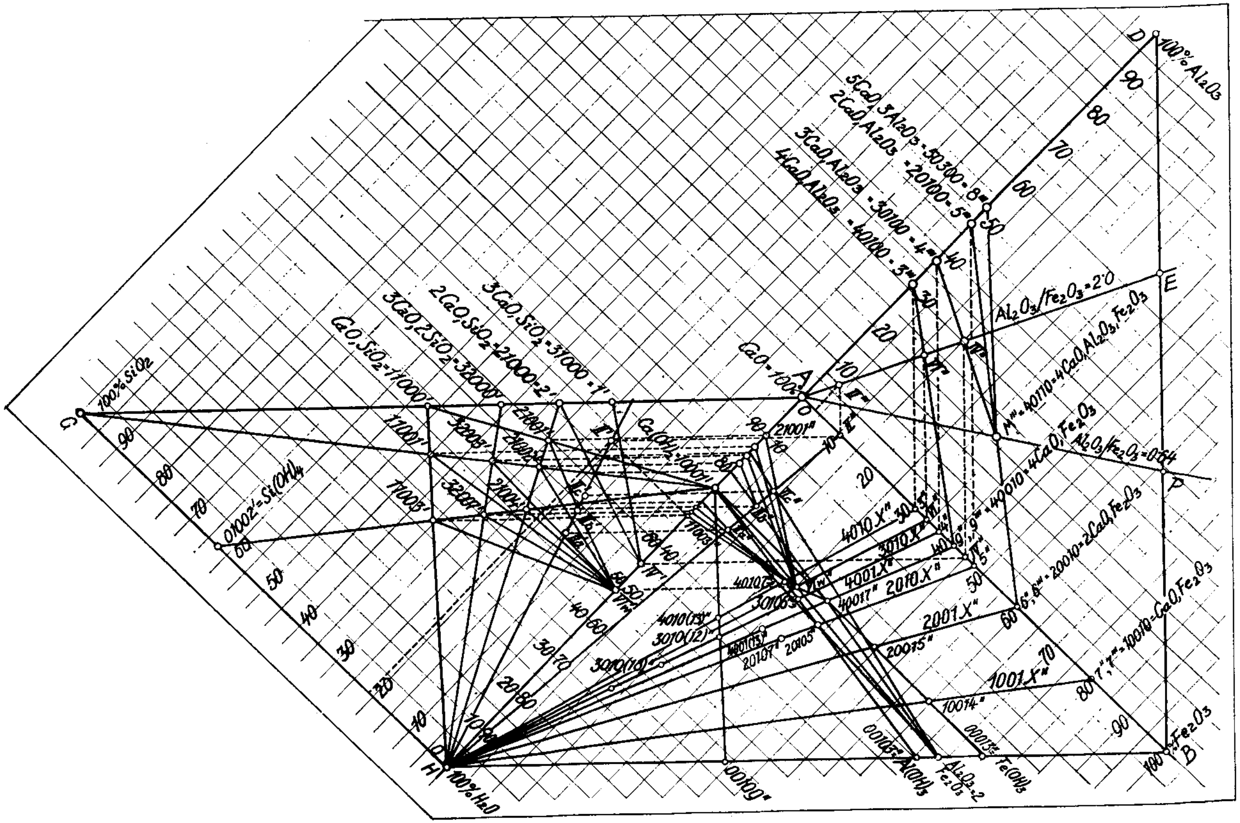

Abbildung 2.—**Darstellung der Zusammensetzung des Zementes, der Klinkermineralien und deren Hydrate im Spindel'schen Vierstoffparallelogramm und Fünfstoffpolygon.** — Showing the composition of the cement, the slag minerals and the hydrates thereof in Spindel's 4-material parallelogram and 5-material polygon. — Composition du ciment, cendres et hydrates dans celui-ci représentés dans le parallélogramme à 4 matériaux et dans le polygone à 5 matériaux de Spindel. — Composición del cemento, las cenizas e hidratos representados en el paralelogramo

dene Kalkmisch- oder Portlandmischzemente mit natürlichen und künstlichen Puzzolanen einschliesslich der Hüttenzemente u.a.m. empfohlen, ohne dass irgendeine dieser Zementarten sich als absolut widerstandsfähig erwiesen hätte. Später wurden die Tonerdezemente und neuestens wieder die "Ciments indécomposables", der "Schwedische Pansar-Zement" die "Gips-Schlackenzemente" und sogar die "low heat cements" und die "Schwedischen Wasserbauzemente" als besonders widerstandsfähig anempfohlen. Die gewöhnlichen und frühhochfesten Portlandzemente werden nur selten mehr als wasserbeständig genannt, obzwar diese am längsten und weitesten verbreitet und bisher die festesten und zuverlässigsten Bauwerke, auch für grosse Sperrmauern, ergeben haben. Dass der Portlandzementbeton durch aggressive Wässer öfter angegriffen und zerstört wurde, lag wohl nur selten am Zement oder am Zement allein, sondern vorwiegend an den übrigen, unter (I) bis (V) angeführten, unzulänglich berücksichten Faktoren der Betonbereitung. Bezüglich der Zerstörung des Portlandzementbetons in Betonröhren hat der Schweizer Hunzicker gleichzeitig Zement- und Betonröhrenfabrikant auf dem Kongresse des I. V. M. in Zürich sehr treffend bemerkt, dass nicht der Portlandzement den Betonröhren geschadet hätte, der darin war, sondern der, der nicht drin war. Man kann aber auch mit viel Portlandzement, ebenso wie mit jedem wie immer gearteten Spezialzement einen stark porösen, sehr minderwertigen Mörtel und Beton herstellen, der nicht bloss durch aggressive Wässer, sondern auch durch gewöhnliches Wasser und Frost zerstört wird. Es gibt wohl kaum einen Zement oder ein sonstiges hydraulisches Bindemittel, das man bei entsprechend intensiver Dauerbehandlung mit sich erneuerndem, ganz reinem Wasser nicht gänzlich zerstören könnte, ob nun der Zement etwas mehr oder weniger errechnetes Tricalciumaluminat, oder etwas mehr oder weniger Dicalciumsilikat statt Tricalciumsilikat enthält, welche Merkmale ja insbesondere für die low heat cements und die schwedischen Wasserbauzemente gelten. Auch bei diesen kann durch ausreichendes Schütteln in einem grossen Überschuss von Wasser die Zerstörung so weit getrieben werden, dass nicht bloss das normal abgespaltene Kalkhydrat, sondern auch der grösste Teil des Kalkes aus seinen Verbindungen mit der Tonerde und Kieselsäure ausgelaugt wird. Gerade derartige Schüttelversuche zeigen uns aber auch den Weg, wie dieser Zersetzung durch die Art der Betonbereitung und Nachbehandlung am wirksamsten begegnet werden kann. Von den diesbezüglichen zahlreichen Versuchen der hervorragenden Zementforscher aller Länder sollen hier vorerst die von Prof. Dr. Nacken durchgeführten Schüttelversuche mit reinem Tricalciumsilikat erörtert werden.

Beim wochenlangen Schütteln von bloss 3.40, 2.28, 1.62, 1.22, 1.00, 0.81, 0.60, 0.40, und 0.20 gr Tricalciumsilikat in je 1,000 gr destilliertem Wasser wurde das Tricalciumsilikat je nach der Konzentration der gebildeten Kalkbösungen auf bestimmte Kalksilikathydrate niedereren Kalkgehaltes stufenartig abgebaut. Aus dem $3\ CaO, SiO_2 + aqu$ erhält Nacken je nach der Pulvermenge die Kalksilikathydrate: $2\ CaO, SiO_2, nH_2O$; $3\ CaO, 2\ SiO_2, nH_2O$ und CaO, SiO_2, nH_2O und bei bloss 0.20 gr Tricalciumsilikat auf 1,000 gr Wasser sogar nur mehr $0.2\ CaO, 1\ SiO_2$, was fast einer vollständigen Herauslösung des

Kalkes gleichkommt. Mit β und γ Dicalciumsilikat hat Nacken leider nur vereinzelte Versuche durchgeführt und zwar bloss mit den grösseren Mengen von 3.44 und 1.72 gr Pulver auf den Liter Wasser, welche Mengen auch beim Tricalciumsilikat nur $2\ CaO, SiO_2, nH_2O$, d. i. Dicalciumsilikathydrat, ergaben. Trotz des von den meisten Forschern angenommenen streng kolloidalen Charakters der Kalksilikathydrate hat Prof. Macken, ebenso wie zwischen Kalk und Kieselsäure auch ganzzahlige Verhältniszahlen für das in den Hydraten gebundene Wasser festgestellt, wobei auch bei den gleichen Verhältnissen zwischen Kalk und Kieselsäure der Wassergehalt variierte. Ohne Prof. Nacken zu folgen, der daraus auf den kristallartigen Charakter der gebildeten Kalksilikathydrate zu schliessen glaubte, konnte ich doch die von ihm für die Neubildungen gefundenen ganzzahligen Verhältniszahlen zwischen Kalk, Kieselsäure und gebundenem Wasser mit Hilfe des Spindel'schen Vierstoff-Parallelogrammes, sehr übersichtlich darstellen. Da nach Zsigmundy das Verhältnis von zwei Teilen Wasser auf ein Teil Kieselsäure sogar für das reine Kieselsäuregel von besonderem Belang ist, konnten sämtliche von Nacken gefundenen Kalksilikathydrate im Vierstoffparallelogramm als Schnittpunkte der Verbindungslinien zwischen $Ca(OH)_2$ und $Si(OH)_4$, zwischen $Ca(OH)_2$ und SiO_2 sowie zwischen $Ca(OH)_2$ und CaO, SiO_2 mit den Linien $2\ CaSiO_2, nH_2O$; $3\ CaO, SiO_2, nH_2O$ und CaO, SiO_2, nH_2O ermittelt werden. In dieses System lassen sich bei entsprechendem grossen Masstabe ausser den festen Kalksilikathydraten auch die zugehörigen Gleichgewichtslösungen eintragen und in ein System bringen. Um die Neubildungen bei der Hydratisierung des Zementklinkers ersichtlich zu machen, müssen natürlich nebst den Kalksilikathydraten auch die Kalkaluminat- und Kalkferrithydrate systematisch dargestellt und in gegenseitige Beziehung gebracht werden, für welchen Zweck Verfasser jetzt das Vierstoffparallelogramm zu einem Fünfstoffpolygon ausgebildet hat, für die Darstellung des Fünfstoffsystems: Kalk, Kieselsäure, Tonerde, Eisenoxyd und Wasser. Sämtliche wirklichen oder auch nur hypothetischen Verbindungen aus diesen fünf Stoffen wurden in Abbildung 2 durch fünfstellige Ziffern bezeichnet, von welchen die erste CaO, die zweite SiO_2, die dritte Al_2O_3, die vierte Fe_2O_3, und die fünfte H_2O in Mol angibt. Das H_2O kann als chemisch gebundenes, adsorbiertes oder Kristallwasser enthalten sein, doch wurde letzteres nur für einige bekannte Kalkaluminat- und Kalkferrithydrate nicht eingezeichnet.

In der Abb. (2) sind im linken Dreiecke AHC eingetragen: sämtliche von Nacken gefundenen Kalksilikathydrate als Schnittpunkte der bereits angeführten Verbindungslinien, weiter die Klinkerbestandteile nach Bogue 1′, 2′ und IV′ für einen bestimmten Zementklinker II′, II‴ und dessen Hydrate verschiedenen Hydratationsgrades II_a', II_b' und II_c'. Hiebei können für den Klinker II′ die Prozentgehalte der Klinkerbestandteile nach Bogue im Dreieck 1′, 2′ und IV′ abgelesen werden. Die Prozentgehalte an Kalkhydrat, Kalksilikathydrat und (Kalkaluminat- + Kalkferrithydrat) können ebenso abgelesen werden für II_a' in den Dreiecken VI_w', 21004, 10001; VI_w', 32007, 10001 und VI_w', 11003, 10001. Für II_b^1 in den Dreiecken VI_w', 21002, 10001; VI_w', 32003, 10001 und VI_w', 11001

10001 und schliesslich für II_c' im Dreieck VI_w', 21001, 10001. Die Punkte VI_w'' und VI_w' wurden unter Zugrundelegung von Tetrakalkaluminat- und Tetrakalkferrithydrat im rechten Dreieck AHB ermittelt. Ähnliche Punkte können aber auch für die andern eingezeichneten Hydrate mit niederem Kalkgehalt eingetragen werden. Die Hydrate im rechten Dreiecke wurden hauptsächlich nach den Untersuchungen von Prof. Kühl und seinen Schülern als Schnittpunkte der zugehörigen Verbindungslinien eingezeichnet. Hierzu wurden die zweiten Projektionen der Hydrate des Zementklinkers II_a'', II_b'' und II_c'' eingetragen. Die vorstehend angeführten prozentualen Anteile der einzelnen Hydrate können ebenso wie im linken Dreiecke auch im rechten Dreiecke AHB aus den entsprechenden Projektionen direkt abgelesen werden. Im oberen rechten Dreiecke ACD wurden bloss die Klinkermineralien der Kalktonerde- und Kalkeisenverbindungen, sowie die Zusammensetzung des Zementklinkers II''' dargestellt, für welche die einzelnen Klinkermineralien nach Bogue aus dem Dreiecke A, 30100, 40010 direkt abgelesen werden können. (Näheres über diese Darstellung vgl. Spindel in "Zement" 1930/1936 und in "Beton und Eisen" 1935, Heft 17.)

Für die vollständige Beurteilung aller Neubildungen im erhärteten Zement ist noch die Heranziehung eines 6. Stoffes, nämlich des Gipses, nicht zu umgehen, der sich aber nach ähnlichen Grundsätzen in ein Sechsstoffpolygon einfügen lässt. Die Darstellung der bisher gefundenen Neubildungen weicht von den tatsächlichen Neubildungen bei der Erhärtung des Portlandzementes noch verschiedentlich ab, insbesondere auch deswegen, weil bei den Schüttelversuchen mit etwa der tausendfachen Menge des normalen Anmachwassers gearbeitet wurde und weil in Wirklichkeit die Klinkerkörner nicht gänzlich hydratisiert werden, sondern im Kern unhydratisiert bleiben. Trotzdem sind diese Versuche nicht bloss theoretisch, sondern auch für die Praxis wichtig. Vorerst ist die Festellung sehr wichtig, dass, insolange im erhärteten Zement noch abgespaltenes Kalkhydrat vorhanden ist, das dem einwirkenden Wasser zur Bildung von konzentrierten Kalklösungen zur Verfügung steht, kein Angriff des reinen Wassers auf die Kalksilikat- und Kalkaluminathydrate erfolgen kann. Es bildet also das so verpönte Kalkhydrat einen äusserst wirksamen Schutz gegen den Angriff des reinen Wassers auf den erhärteten Portlandzement. Weiter sieht man, dass die Menge des abgespaltenen Kalkhydrates nicht bloss von der chemischen Zusammensetzung des Zementklinkers abhängt, sondern auch von den Wasserverhältnissen bei der Betonbereitung, Erhärtung und Beanspruchung. Dem gegenüber fällt geradezu die Sicherheit auf, mit der viele Bauingenieure schon seit Jahrzehnten die Menge des abgespaltenen Kalkhydrates berechneten und mit einer ebenso grossen Sicherheit auch berechneten, wieviel Puzzolanerde, Trass, u.s.w. dem Beton zugesetzt werden mussten, um das abgespaltene Kalkhydrat vollständig zu binden. Fachleute (Rodt in "Zement" 1935) haben in einem mit Trasszusatz verarbeiteten Beton nach sechsmonatlicher Erhärtung nicht weniger Kalk gefunden, als beim gleichen Beton ohne Trasszusatz, woraus geschlossen wurde, dass eine Bindung zwischen Kalkhydrat und Trass noch nicht eingetreten war. Nach Dr. Ing. Forsén sollen die verschiedenen natürlichen und künstlichen Puzzolane im Stande sein, schon innerhalb 28 Tagen 10 bis 30 Teile CaO auf 100 Teile Puzzolane zu binden, woraus zu schliessen wäre, dass die bezüglichen Untersuchungsmethoden noch nicht eindeutig geklärt sind.

Statt durch die verschiedenartigen Puzzolanen kann die Bindung des abgespaltenen Kalkhydrates auch durch andersartige künstliche Zusätze anorganischer und organischer Natur bewirkt werden, die entweder als sog. Wasserdichtungsmittel dem Zement selbst oder bei der Verarbeitung zugesetzt werden, oder aber als Härtungsmittel zur Nachbehandlung des Betons dienen. Über diese Wasserdichtungsmittel, die den Normalzementen Spezialeigenschaften verleihen sollen, wird Verfasser an anderer Stelle berichten. Als Nachteil aller Puzzolanen oder sonstiger Zusätze in grösseren Mengen ist vor allem der höhere Wasserbedarf zu verzeichnen, der nebst der Einbusse an Festigkeit, zumindest an Anfangsfestigkeit, gewöhnlich auch eine höhere Schwindung zur Folge hat. Selbst bei höherem Bitumenzusatz, wie bei den bituminierten Portlandzementen von Dyckerhoff wurde der Wasseranspruch für die Normalkonsistenz von 24.7% auf 30%, d.i. um ca 21% erhöht, mit einem dementsprechenden Abfall an Festigkeit, während die Schwindung nur zu Beginn herabgesetzt, also eigentlich nur hinausgeschoben wird.

Selbst wenn das gesamte abgespaltene Kalkhydrat sehr gering ist, oder durch Puzzolane und ähnliche andere Mittel vollkommen gebunden werden könnte, so gäbe auch das noch keinerlei Gewähr gegen die Zersetzung durch stark aggressive oder auch nur ganz reine Wässer, wenn solche dauernd in grosser Menge einwirken. Deswegen können ja auch die Schüttelversuche mit erhärtetem und gepulvertem Zement, ebenso wie mit Zementpulver, bis zur völligen Zersetzung geführt werden. Ähnliche Wirkungen können aber auch entstehen, wenn durch einen porösen Mörtel und Beton dauernd sehr viel Wasser, insbesondere ganz reines Wasser, durchgepresst wird. Daher darf man sich bei Mörtel und Beton keinesfalls auf dessen sog. Selbstdichtung verlassen, denn jeder poröse, wasserdurchlässige Beton kann bei entsprechendem Porengehalt und Wasserdurchtritt statt einer Selbstdichtung eine namhafte Erhöhung der Durchlässigkeit, und sogar eine Zersetzung erfahren. Nach den vorstehenden Ausführungen gibt es also nur ein einziges sicheres Mittel, um nicht zersetzbaren und wasserundurchlässigen Mörtel und Beton zu erhalten, wenn man diese von Haus aus verlässlich wasserdicht herstellt. Hierbei spielen nebst einer ganzen Anzahl anderer Faktoren der Betonbereitung grade die "Verarbeitbarkeit" und der "Verarbeitungsgrad" des Betons eine sehr grosse Rolle.

Diese zuerst von Amerika ausgegangene Frage wurde in den letzten Jahren überall gründlich verfolgt. Einerseits bemühte man sich, Verfahren und Apparate zu ersinnen, um die Verarbeitbarkeit laboratoriumsmässig zu bestimmen, andrerseits wurden auch neue Einrichtungen geschaffen, um den Beton auf der Baustelle möglichst vollkommen zu verarbeiten. Parallel damit gingen auch die Bemühungen, die Verarbeitbarkeit durch Erfindung neuartiger Spezialzemente oder durch besondere Zusätze zu den Portlandzementen zu heben. In Österreich haben sich um die Klärung des ersten Teiles dieser Fragen der von Oberbaurat Dr. v. Emperger geleitete Eisenbetonausschuss mit dessen Unterausschuss für "Zielsichere Betonbildung" unter Leitung des Oberbauraest Dr. Tillmann besonders verdient gemacht. Die tiefgründlichen Forschungen des Referenten dieses Unterausschusses, Baudirektor Ing. O. Stern und seines Mitarbeiters Dir. Ing. Zeissel, sind in den Mitteilungen des österr. Eisenbetonausschusses 1933, Heft 14, zusammengefasst. Es wurde hierbei insbesondere der Einfluss der Korngrössen und Kornverteilung von Zuschlagsstoffen und Zement geklärt und für den daraus zu ermittelnden Wasseranspruch genaue Formeln aufgestellt. An neuen Geräten wurden hiebei die Stern'sche Kornpotenzwaage und das verbesserte Powers-Gerät mit gutem Erfolg verwendet. Im Rahmen dieses Berichtes seien nur einige ganz allgemeine Gesichtspunkte angeführt, die vom Verfasser beobachtet wurden, um einen Beton, dicht und wasserundurchlässig, wenig zersetzbar und vollkommen frostbeständig zu machen, welche Gesichtspunkte auch für die Wetterbeständigkeit der Naturgesteine und vom Standpunkte der Spezialzemente von Wichtigkeit sind.

1. Das Zuschlagsmaterial muss entsprechend fest, dicht und vollkommen wetterbeständig sein. Denn kein Zement kann ein nicht wetterbeständiges Zuschlagsmaterial vor Verwitterung schützen oder bereits verwitterte Steinkörner dauernd zusammenkitten.

2. Die einzelnen Körner des Zuschlagsmateriales müssen durch die Zementkörner ausreichend berührt, d.h. zementgebunden sein, da sonst die Zuschlagstoffkörner, insbesondere von feinem Korn, durch Wasser allein, oder durch Wasser und Frost aufgelockert und auseinandergetrieben werden.

3. Damit die Zementkörner in und zwischen den Sandkörnern eingebettet sein können, müssen zwischen den Mengen und den Korngrössen vom Zement einerseits, und Zuschlagstoff andererseits bestimmte Verhältnisse eingehalten werden. Nach der Berechnung des Verfassers in der "Tonindustriezeitung" 1913, dürfen die Zementkörner, die in den Hohlräumen der Zuschlagsstoffkörner noch Platz finden sollen, nur 1/5 bis 1/7 der Durchmesser dieser Zuschlagsstoffkörner aufweisen. Daher sollen die Korngrössen unter 0.2 oder 0.1 mm für das Bindemittel reserviert sein, und das Feinmaterial im Zuschlagsstoff möglichst ausgeschaltet werden. Je feiner der Zement ist, desto grösser kann der Gehalt an Feinmaterial im Zuschlagsstoff sein, ohne dass der Beton hierdurch an Festigkeit und Wetterbeständigkeit einbüsst. Es sollen die Zementkörner in den Hohlräumen des Sandes und die Sandkörner in den Hohlräumen des Schotters Platz finden, ohne sie auseinanderzudrängen, was mit gutabgestimmten Kornverteilungslinien leicht zu erreichen ist. Man darf aber nicht die Zementkörner etwa durch Steinmehl ersetzen wollen, da dann dieses ungebunden bleiben muss.

4. Da zur Hydratisierung des Zementes nur ein Bruchteil des für die gute Verarbeitung des Betons benötigten Wassers verbraucht wird und der verbleibende Wasserrest sich im Hinblick auf Schwindung, Dichtigkeit und Wetterbeständigkeit nur ungünstig auswirkt, ist die Herabsetzung des Wasserzementfaktors mit allen Mitteln anzustreben, doch ist dabei zu beachten, dass zu wenig Wasser noch schädlicher sein kann, als ein Zuviel an Wasser. Der für die gute Verarbeitung unbedingt nötige Wasserbedarf, ist u.a. auch von der

Art und dem Grade der Verarbeitung abhängig. Verschiedenartige Zemente benötigen nicht nur verschieden grosse Wassermengen zur Hydratisierung, sondern sie können auch schon im Frischmörtel verschieden grosse Wassermengen festhalten, bevor eine Verflüssigung eintritt, was als ein charakteristisches Merkmal der Zemente im Hinblick auf die Verarbeitbarkeit zu bezeichnen ist.

5. Bei stark plastischem und Gussbeton, aber auch schon bei steifplastischem und erdfeuchtem Beton stellen sich der Verarbeitung auch des richtig zusammengesetzten Betons gewisse Schwierigkeiten entgegen, welche auf die Wirkung der Oberflächenkräfte zurückzuführen sind. Die richtige Verteilung der feinsten Teilchen des Zementes in und zwischen den feinen Sandkörnern des Zuschlagsstoffes wird dadurch behindert, dass grade die feinsten Teilchen durch Agglomeration zusammenhaften und dabei nebst Luftblasen auch Wasserteilchen einschliessen. Dadurch wird das Feinkorn des Zementes seiner Funktion, die feinsten Zuschlagkörner zu verkitten, entzogen. Durch die Verarbeitung entstehen weitere Entmischungen durch Aufschlämmung der feinsten Teilchen von Zement und Zuschlagsstoff an die Oberfläche des jeweils bereiteten Betons. Je nach der Grösse der in einem Zuge betonierten Körper entstehen an deren Oberfläche mehr oder weniger starke Schichten aus sehr minderwertigem Beton oder gar nur aus Feinmörtel mit absolut unzureichender Festigkeit, Dichtigkeit und Wetterbeständigkeit auf die der neuaufgebrachte Beton nur sehr schlecht haftet. Derartige Trennungsschichten in den Arbeitsfugen sind gewöhnlich die schwächsten Stellen jedes Bauwerkes, die durch erhöhte Wasserangreifbarkeit und Durchlässigkeit und insbesondere durch mangelnde Frostbeständigkeit den Ausgangspunkt für die Zerstörung der Betonbauwerke durch Wasser und Frost bilden, wenn diesen Entmischungen nicht wirksam vorgebeugt wird.

6. Alle Untersuchungen und Erprobungen im Laboratorium und auf der Baustelle müssen unbedingt einen sicheren Zusammenhang haben mit der möglichen und tatsächlichen Verarbeitung des Betons auf der Baustelle. Verfasser hat wiederholt die grundsätzlichen Unterschiede zwischen laboratoriumsmässiger Erprobung und baumässiger Verarbeitung aufgezeigt. So hat er schon im Jahre 1913 in der "Tonindustriezeitung" darauf hingewiesen, dass die derzeitige Zementnormenprüfung wegen des zu groben Normensandes, wegen der Prüfung in erdfeuchter Konsistenz und wegen Bevorzugung der Druckfestigkeit nicht mehr entspricht, und seither auch die Unzulänglichkeit der Schwindversuche u.a.m. erörtert. In der "Tonindustriezeitung" 1928 wurde besonders darauf verwiesen, dass eine im Laboratorium mit sehr viel Stampfarbeit hergestellte vorzügliche Betonprobe auf der Baustelle in der gleichen Mischung und Konsistenz zumeist einen sehr minderwertigen, unzureichend verarbeiteten Beton ergibt. Letzteren Mängeln konnte durch pneumatisches Stampfen und durch die Einführung der Vibration nur zum Teil abgeholfen werden, da insbesondere bei letzterer der Wirkungsbereich und die Wirkung sehr genau angepasst und kontrolliert werden müssen. Die schwerwiegendsten Folgen wegen der Unterschiede zwischen laboratoriumsmässiger Erprobung und der Verarbeitung auf der Baustelle zeigten sich bei dem in grossen Bau-

werken erzeugten Massengussbeton, bei welchem wegen des besseren Fliessens, der rascheren Verarbeitung, der Ersparnis an Kosten u.a.m. grosse Abweichungen von den vorstehend angeführten Gesichtspunkten der Betonbereitung vorkamen. Verfasser hat in "Beton und Eisen", Jg. 1932, Heft 19, sowie in der "Wasserwirtschaft," Jg. 1932, Heft 17–19, dargelegt, weswegen die mit derartigem Gussbeton hergestellten Staumauern Schaden leiden mussten und dass man für diese Schäden keineswegs den Portlandzement verantwortlich machen darf. Die beiden Betonstaumauern am Spullersee, die von den österr. Bundesbahnen unter Direktor Ing. Dittes mit einem entsprechend bereiteten, gut verarbeiteten plastischen Beton in einer Meereshöhe von über 1800 m gebaut wurden, haben sich nach bisher zehnjährigem Bestande als vollständig wasserdicht und wetterbeständig erwiesen. Der aus den gleichen Baustoffen ganz gleich zusammengesetzte Beton hat dagegen bei unzureichend verarbeiteten Betonplatten gewisse Verwitterungsmängel erkennen lassen.

Verlässliche Versuche über die Erhöhung der Verarbeitbarkeit durch Spezialzemente liegen noch nicht vor. Es ist jedoch bekannt, dass gewissen hydraulischen Zuschlägen sowie insbesondere gewissen Wasserdichtungsmitteln u.a. auch eine gute Wirkung auf die Verarbeitbarkeit zugeschrieben wird, wobei aber zumeist auch das Raumgewicht herabgesetzt wird. Hier soll daher noch eines neuartigen Zusatzmittels gedacht werden, dessen Wirkung darin besteht, die Oberflächenkräfte zwischen fester, flüssiger und gasförmiger Phase chemisch-physikalisch derart zu beeinflussen, dass der Wasserzementfaktor herabgesetzt und die Verarbeitbarkeit gehoben wird. Die Wirkung dieses Zusatzmittels ist von Dr. Humm in "Beton und Eisen" 1934–35, sowie in der "Schweizerischen Bauzeitung" 1935 des näheren beschrieben. Dass mit einem Plastimentzusatz von bloss 1% des Zementgewichtes in der E.M.P.A., Zürich, eine Herabsetzung des Wasserzementfaktors bis zu 20% mit gleichzeitigen Festigkeits- und Dichtigkeitssteigerungen bis zu 50 and 80% nachgewiesen wurden, ist weniger überraschend und bedeutungsvoll, als der Nachweis, dass die Haftfestigkeit des ein bis mehrere Tage alten Betons an den frisch anbetonierten Beton bis zu 110% erhöht wurde. Eine namhafte Erhöhung der Haftfestigkeit ist auch zwischen dem Feinmörtel und dem Grobkorn des Zuschlagsstoffes, sowie zwischen dem Beton und dem Eisen nachgewiesen worden, wodurch nach den Versuchen von Prof. Bolomey auch eine Hebung der Frostbeständigkeit, insbesondere bei feinem Zuschlagsmaterial, festgestellt wurde. Nach dem Berichte Dr. Humms in der "Schweiz. Bauzeitung" sollen die Ergebnisse der Materialprüfungsanstalten auch an den Baustellen praktisch bestätigt werden, doch ist es selbstverständlich, dass derart wirkende Zusätze mit der jeweils in Frage kommenden Zementmarke und allenfalls auch mit den betreffenden Zuschlagsstoffen erprobt werden müssen. Falls sich die vorstehend angeführten Ergebnisse unter den verschiedenen Verhältnissen der Praxis auch nur annähernd bestätigen, wäre das ein sehr bedeutender Fortschritt im Hinblick auf die Herstellung eines auch in den Betonierungsfugen wasserdichten und wetterbeständigen Betons. Das vorstehende Beispiel der jüngsten Entwicklung sollte dartun, wie die entsprechend abgestimmte chemisch-physikalische Beeinflussung der Oberflächenkräfte von normalen Portlandzementen theoretisch und praktisch gegenüber einer besonderen chemischen Zusammensetzung von Spezialzementen hervortreten kann, wie es sich ja ähnlich auch bei der Flotation im Aufbereitungsprozess der Erze gezeigt hat.

Bei der üblichen Normenprüfung der Zemente in erdfeuchter oder sogar in plastischer Konsistenz werden die Probekörper in der Regel so hergestellt dass sich Entmischung, Aufschlämmung, u.s.w. gar nicht einstellen können, weil einerseits der Normensand überhaupt kein Feinkorn enthält, und andererseits auch bei Bausanden etwaig entmischter Oberflächenmörtel nicht mitgeprobt wird. Überdies lässt der gleich grosse Arbeitsaufwand bei der Herstellung der Normenkörper eine Beurteilung des besonderen Einflusses von Spezialzementen oder etwaiger Zusatzmittel auf die Verarbeitbarkeit nicht zu. Auch die abweichend von den Normenproben durchgeführten Sonderuntersuchungen stossen noch auf grosse Schwierigkeiten. Es ist daher sehr zu begrüssen, dass das Subkomitee für Spezialzemente sich in erster Linie mit der Ausarbeitung neuer Prüfmethoden für Zement, Mörtel und Beton befasst. Wie schwer sich aber neue Prüfmethoden gerade für Zement durchsetzen, geht daraus hervor, dass die schon seit mehr als zwei Jahrzehnten geforderte Prüfung auf Biegefestigkeit mit plastischem Mörtel bisher nur durch Prof. Ros in der Schweiz genormt wurde und die Einführung eines feineren Normsandes noch immer Gegenstand des Studiums ist. Unbeschadet dessen werden vom Verfasser die nachstehend angeführten Prüfverfahren empfohlen:

(*a*) Für die Bestimmung der Hydratationswärme das Verfahren von Dr. Ing. Sandri der Technischen Hochschule in Wien. (Ein von Dr. Ing. Honigmann am Technolog. Gewerbemuseum in Wien ausgebildetes ähnliches Verfahren ist bisher noch nicht veröffentlicht.)

(*b*) Für die Schwindmessung das Verfahren des Verfassers zur Messung der Schwindung vom Beginn des Wasserzusatzes an gem. Abbildungen 1*a*, 1*b*, und 1*c*.

(*c*) Für die theoretische Beurteilung der Dichtigkeit und Wasserdurchlässigkeit, die getrennte Erfassung der Dichtigkeitsverhältnisse für den Zementleim, für den eigentlichen Mörtel und für den Beton, und deren Ersichtlichmachung im Spindel'schen Vierstoffparallelogramm, bzw. Fünfstoffpolygon gemäss den Abbildungen (2) und (3). Für den Zementleim wären die Klinkerbestandteile das Wasser und die hydratisierten Bestandteile gem. Abbildung (2) darzustellen, wobei diese Bestandteile nicht nur in Gewichtsprozenten, sondern auch in Vollraumteilen einzutragen wären. Für den Mörtel und Beton wären die Vollraumteile von Zement, Zuschlagsstoff, Wasser und Luft im Vierstoffparallelogramm gem. Abbildungen (3) und (4) ersichtlich zu machen, woraus dann Dichtigkeit und Festigkeit direkt abgelesen werden können (vgl. Spindel in "Beton und Eisen" 1928 und 1930, Heft 1 und 2, und 1935, Heft 17). Für die praktische Erprobung des Betons auf Wasserdurchlässigkeit wird empfohlen, auch den bezüglichen Mörtel in etwa 2 cm starken Scheiben auf den jeweiligen Wasserdruck zu prüfen.

(*d*) Für die Prüfung der Verarbeitbarkeit von Mörtel und Beton wird die von Dr. Humm in "Beton und Eisen", Jg. 1934, veröffentlichte Methode empfohlen, mit dem vom Verfasser für dieses Verfahren im

"Beton und Eisen", Jg. 1935, Heft 17, vorgeschlagenen Ergänzungen. In Abbildung (4) wird gezeigt, wie die von Humm veröffentlichten Rüttelergebnisse in das Vierstoffparallelogramm eingetragen, sehr klare Beziehungen zwischen Rüttelzahl und Luftgehalt in Form der Rüttelkurven U, V, W, X, Y, Z, ergeben. Die von diesen Rüttelkurven mit den Luftlinien I'', Ia'' u.s.w. eingeschlossenen Flächen geben einen guten Masstab für die "Verarbeitbarkeit" und den "Verarbeitungsgrad" bei jeweiligem Raumgewicht. Nach den ergänzten Vorschlägen des Verfassers sollen also nach je einer Anzahl von

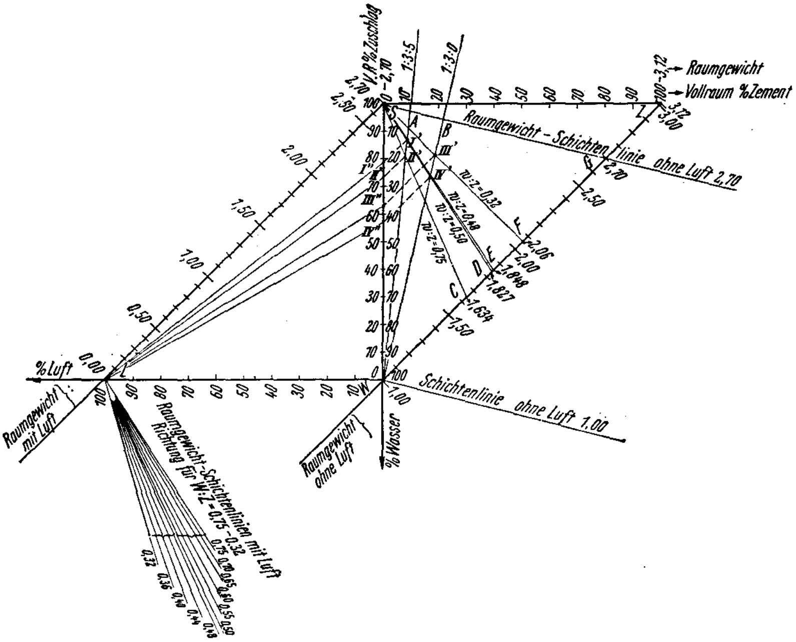

Abbildung 3.—**Darstellung der Zusammensetzung und des Raumgewichtes von Mörtel und Beton im Vierstoffparallelogramm.** — Showing the composition and specific weight of mortar and concrete in the 4-material parallelogram. — Composition, poids spécifique du mortier et du béton représentés dans le parallélogramme à 4 matériaux. — Composición, peso específico del mortero y del hormigón representados en el paralelogramo de 4 materiales.

Rüttelungen sowohl das zugehörige Raumgewicht des Betons, als auch die zugehörige Eindringtiefe des Humm'schen Eindringkörpers unter einem ermittelt werden und dann Luftgehalt, Eindringtiefen und Rüttelzahlen in das Vierstoffparallelogramm eingetragen werden. In erdfeuchten Bereichen für welche das Humm'sche Gerät weniger empfindlich sein sollte, wird das neu erfundene Gerät von O. Stern empfohlen, das in der Festschrift "75 Jahre Ziviltechniker Wien", 1935, näher beschrieben ist.

Für die Beurteilung der verschiedenartigen Spezialzemente oder der Normalzemente mit besonderen Zusätzen wird deren Erprobung auf Verarbeitbarkeit nicht zu umgehen sein.

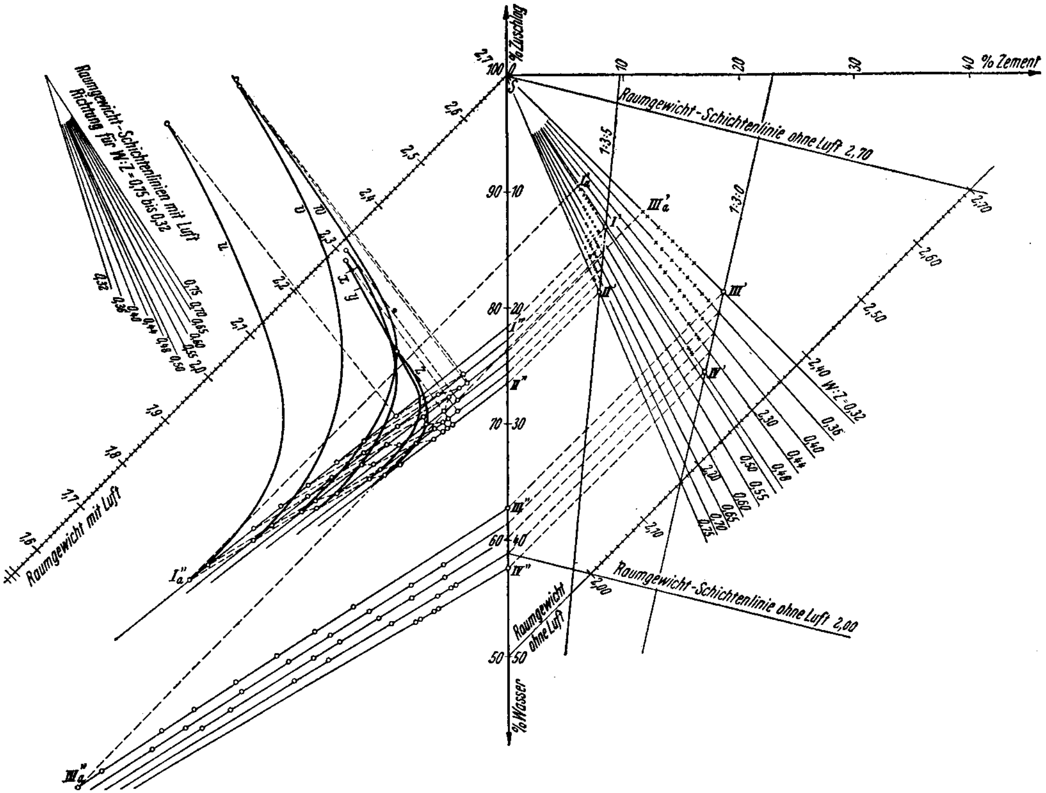

ABBILDUNG 4.—**Darstellung der Zusammensetzung des Raumgewichtes und Verabeitbarkeit nach der Prüfmethode Dr. Humm im Vierstoffparallelogramm.** — Showing the composition, the specific weight, and the preparation according to Dr. Humm's testing method in the 4-material parallélogram. — Composition, poids spécifique et préparation d'après la méthode expérimentale du Dr. Humm représentés dans le parallélogramme à 4 matériaux. — Composición, peso específico y preparación según el método experimental del Dr. Humm representados en el paralelogramo de 4 materiales.

ZUSAMMENFASSUNG

(1) Entwicklung und Eigenheiten der verschiedenen Typen von Spezialzementen werden besprochen und es wird dabei gezeigt, dass den vorteilhaften Eigenschaften auch gewisse nachteilige gegenüberstehen.

(2) Die vom Subkomitee für Spezialzemente zur Diskussion gestellten Güteeigenschaften von Zement und Beton werden eingehend erörtert und es wird gezeigt, dass der Einfluss der verschiedenartigen Spezialzemente auf die Güteeigenschaften des Betons stark zurücktritt gegenüber dem Einflusse der verschiedenen Betonbereitungsfaktoren.

(3) Die für eine zuverlässige Betongüte massgebenden Gesichtspunkte der Betonbereitung werden besprochen und es wird gezeigt, dass an den beim Portlandzement fallweise aufgetretenen Schäden nicht der heutige Portlandzementtyp als solcher schuld war, sondern das mehr oder weniger grosse Abweichen von den besprochenen Gesichtspunkten.

(4) Gewisse für den Beton sehr erwünschte vorteilhafte Sondereigenschaften können statt durch andersartig zusammengesetzte Spezialzemente auch durch eine entsprechende Beeinflussung des Portlandzementes durch geeignete Zusätze erreicht werden, die neuestens auf eine Beeinflussung der Oberflächenkräfte zwecks Herabsetzung des Wasserzementfaktors und Hebung der Verarbeitbarkeit und der Dichtigkeit, sowie insbesondere des Haftvermögens abgestimmt werden.

(5) Es werden einige grundsätzliche Unterschiede zwischen der Normenprüfung und der Verarbeitung auf der Baustelle aufgezeigt und verschiedene meistenteils in Österreich entwickelte neue Prüfverfahren vorgeschlagen, um die diskutierten Güteeigenschaften von Zement und Beton zuverlässiger prüfen zu können.

SUMMARY

The development and features of various types of special cements are discussed, and it is shown that besides some advantageous characteristics there are some disadvantageous ones.

The properties of cement and concrete, submitted for discussion by the Subcommittee for Special Cements, are thoroughly dealt with, and it is shown that the influence of various special cements on the quality of concrete is small in comparison with the influence of different factors in the preparation of the concrete.

The main points in the preparation of concrete which govern the quality of concrete are discussed, and it is shown that the present-day portland cement was not per se responsible for damages which sometimes occurred to portland cement, but that it was the improper observance of the discussed points.

Special features highly desirable for concrete which could be obtained by specially composed cements could also be obtained with portland cement properly treated with suitable admixtures. These have recently been the object of studies made for the purpose of lowering the water-cement ratio and increasing the workability of concrete, as well as to improve the watertightness and the tensile strength.

Some of the principal differences between the testing of standard samples and the actual preparation in the field are pointed out, and several new testing processes, developed mainly in Austria, are recommended in order to test more accurately the properties of cement and concrete under discussion by the subcommittee.

RESUME

On étudie les caractéristiques et l'évolution des divers types de ciments spéciaux et montre que s'ils présentent des propriétés avantageuses, ils comportent aussi certains inconvénients.

Les caractéristiques des qualités du ciment et du béton, discutées par la Sous-Commission Internationale des Ciments Spéciaux, sont examinées en détail et le rapport montre que l'influence des divers types de ciments spéciaux sur les propriétés a bien moins d'importance que l'influence des divers facteurs qui interviennent dans la préparation du béton.

On décrit les idées reconnues valables, concernant les qualités qui doit présenter un bon béton. Il montre que les défauts attribués dans certains cas au ciment portland n'incombent pas en réalité au type actuel de ce ciment, mais provient plutôt d'écarts plus ou moins grands dans la préparation du béton, à l'encontre des points discutés.

Certaines propriétés spéciales avantageuses, très désirables pour le béton, peuvent être obtenues par des additions convenables au ciment portland, au lieu de l'emploi ciments spéciaux. On a cherché, par ces additions, à diminuer le rapport eau/ciment et à augmenter la maniabilité et la compacité, ainsi que la résistance à la traction.

On fait ressortir certaines différences fondamentales entre les essais standard et la préparation sur le chantier, et on propose divers procédés d'essais nouveaux qui ont été, pour la plupart, imaginés en Autriche, et qui présentent toutes garanties au point de vue des cinq propriétés du ciment et du béton discutées par la Sous-Commission.

RESUMEN

Se estudian las características y la evolución de varios tipos de cementos especiales y se demuestra que presentan propiedades ventajosas pero también ofrecen algunos inconvenientes.

Las características de las cualidades del cemento y del hormigón, discutidas por el Subcomité Internacional de Cementos Especiales, se examinan en detalle y se demuestra que la influencia de los varios tipos de cementos especiales sobre las propiedades tiene menos importancia que la influencia de los diversos factores que intervienen en la preparación del hormigón.

Se describen las ideas que son de reconocido valor sobre las cualidades que debe presentar un buen hormigón. Se demuestra que los defectos atribuídos en ciertos casos al cemento portland no incumben en realidad al tipo actual de este cemento, sino que son causados por no seguir con exactitud los puntos discutidos.

Algunas propiedades especiales ventajosas, muy deseables para el hormigón, podrían obtenerse mediante adiciones apropiadas al cemento portland, en vez de emplear cementos especiales. Mediante estas adiciones se ha tratado de disminuir la relación agua/cemento y facilitar la preparación del hormigón, así como la compacidad y la resistencia a la tracción.

Se llama la atención sobre ciertas diferencias fundamentales entre los ensayos normales y la preparación sobre el terreno, y se proponen diversos procesos de ensayo nuevos que, en su mayor parte, han sido ideados en Austria y que ofrecen completa garantía desde el punto de vista de las cinco propiedades del cemento y del hormigón discutidas por el subcomité.

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

UEBER DIE BESTIMMUNG DER DRUCKFESTIGKEIT UND WAERMEABGABE DES BETONS IM INNEREN GROSSER BETONMASSEN MIT HILFE DES THERMOELEKTRISCHEN KALORIMETERS*

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Österreich

Bei Gewichtsstaumauern aus Beton ist die innere Temperatur und die Verformung von Bedeutung. Diese Grössen werden bestimmt durch die Wärmeabgabe des Zementes bei der Hydratation und die beim Abbinden und Erhärten des Betons auftretenden Drücke. Nicht nur zur Nachprüfung der Sicherheit von Gewichtsstaumauern durch Untersuchung des inneren Druckes, sondern schon zur Verfolgung des Abbinde- und Erhärtungsprozesses erschient demnach eine Methode erwünscht, die es gestattet, gleichzeitig an beliebigen Stellen im Inneren der Betonstaumauer sowohl die Temperatur als auch die Wärmeabgabe und damit die Druckfestigkeit des Betons, event. auch die gleichzeitig im Inneren der Mauer auftretenden Spannungen festzustellen.

Es wurde die Lösung der ersten drei Probleme mit Hilfe des im Folgenden beschriebenen Kalorimeters nach der vom Verfasser angegebenen Bauart gefunden. Mehrere solcher Apparate wurden in

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Determination of compressive strength and of heat given off by concrete in the interior of large concrete masses by means of the thermo-electric calorimeter.

Détermination de la résistance à la pression et du dégagement de chaleur du béton dans les parties centrales de grandes masses de béton au moyen du calorimètre thermo-électrique.

Determinación de la resistencia a la presión y del desarrollo de calor del hormigón en las partes centrales de grandes masas de hormigón por medio del calorímetro termoeléctrico.

der staatlichen Versuchsanstalt für Baustoffe am Technologischen Gewerbemuseum (Technisch-gewerbliche Bundes-Lehr- und Versuchsanstalt) in Wien IX. gebaut. Diese Apparate, die in unserer Versuchsanstalt in Verwendung stehen, wurden auch wiederholt in Vorträgen in Wien und Budapest vorgeführt. Eine weitere neue Anlage, die besonders die Verfolgung der Eigenschaften des unter Druck erhärtenden Betons bezweckt, ist im Bau.

Es obliegt mir noch auch an dieser Stelle dem Direktor des Technologischen Gewerbemuseums Herrn Prof. Ing. Wastl und dem Leiter der Versuchsanstalt Herrn Professor Dr. Ing. Romanowicz für ihre vertrauensvolle Förderung und fachliche Unterstützung meiner Arbeiten auf das herzlichste zu danken.

1. Ein neues trägheitsloses hochempfindliches thermoelektrisches Kalorimeter

Am 4. Mai 1933 habe ich im Oesterreichischen Ingenieur- und Architekten-Verein in Wien in einem Vortrage das erste Mal öffentlich von meiner, in engeren Betonfachkreisen schon seit Anfang 1932 vertretenen, und auf dem Gebiete der Gas- und Dampfthermodynamik seit 1929 angewandten Anschauung berichtet, derzufolge eine ganze Reihe von Problemen, z. B. auch das der Wörmetönung des Zementes, wesentlich leichter, einfacher und erfolgreicher zu behandeln ist, wenn, statt (wie bisher üblich) der Temperatur, der Wärmeinhalt in den Mittelpunkt der Betrachtung gestellt wird; wenn also z. B. im Falle des Zementes in erster Linie die *Abbindewärme*, statt, wie es früher fast ausschliesslich der Fall war, die Temperaturerhöhung beim Abbinden gemessen wird.

In einem Referat vor der Spezialkommission für das technische Versuchswesen am 4. Dezember 1933 konnte ich den schon in meinem ersten Vortrage angekündigten Apparat in seiner ersten Ausführungsform dem Auditorium in Funktion vorführen. Die Versuche damit wurden im Betonlaboratorium unserer Versuchsanstalt für Baustoffe durchgeführt; der Apparat war in unseren Werkstätten gebaut und in unserer physikalisch-technischen Versuchsanstalt für Wärme- und Schalltechnik geeicht worden.

Unsere Methode beruht auf einer neuen Anwendung des Wärmeflussmessprinzipes, das von Henky angegeben, von Schmidt für Isolationsmessungen an Rohrleitungen mit einer Empfindlichkeit von 20 kcal pro Stunde je mV thermoelektrischer Klemmenspannung praktisch durchgeführt und von Hofbauer am Technologischen Gewerbemuseum für Isolationsmessungen an Mauern auf eine Genauigkeit von rd. 2 kcal pro Stunde je mV Klemmenspannung verfeinert wurde. Die neuen Kalorimeter haben dagegen eine Empfindlichkeit von 0,04 kcal pro Stunde je mV Klemmenspannung praktisch erwiesen. Sie stehen damit aber erst am Anfange der mit dem neuen Verfahren erzielbaren Leistungen.

Einen Begriff von der Kleinheit der mit dem neuen Kalorimeter gemessenen Wärmemenge mag es bieten, dass die Messanordnung bei einer zu messenden Wärmemenge von nur 1 kcal je Stunde eine elektromotorische Kraft von rd. 25 mV gibt. Die mit einem Spiegelgalvanometer noch genau messbare Wärmemenge beträgt demnach 4 Millionstel (4.10^{-6}) kcal pro Stunde.[1]

Das Prinzip unserer Messmethode ist in Abbildumg 1 schematisch dargestellt. Im Unterschied zum "Hilfswandverfahren" der Wärmeisolationsmessung mit Wärmeflussmessern ist das neue Kalorimeterprinzip als "Messwandverfahren" zu bezeichnen. Die zu kalorimetrierende Wärmemenge 1 ist allseitig von Messwänden 4 umgeben, die sie durchfliessen muss. Zwei senkrecht zur Richtung des Wärmeflusses gelegene Flächen der Messwand haben dabei ein mittleres Temperatur gefälle Δt_H, dessen Abhängigkeit vom Wärmefluss auf das genaueste eingeeicht und damit ein Mass der Wärmemenge wird.

Da die Temperaturdifferenz Δt_H als integraler Mittelwert über die gesamte Oberfläche erfasst werden soll um von der Lage und Grösse des die Wärme abgebenden oder entwickelnden Körpers unabhängig zu sein, wählten wir zur Temperaturdifferenzmessung zunächst Thermosäulen, die in Serie geschaltet und über die Oberfläche gleichmässig verteilt, dieser Bedingung genügen.

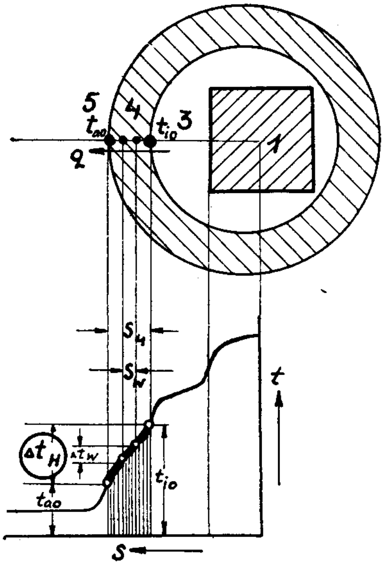

Abbildung 1.—**Prinzip der Messmethode.**—Principle of the measuring method.—Principe de la méthode de mesure.—Principio del método de medida.

Ausserdem sollte die zeitliche Veränderlichkeit der Wärmemengenabgabe bestimmt werden können. Als Bedingung hiefür gilt, dass die Reaktionsgeschwindigkeit der Messanordnung grösser sein muss als die Geschwindigkeit in der Schwankung der Wärmemengenabgabe und dass das spezifische Wärmespeichervermögen der Messanordnung im Verhältnis zur abgegebenen Wärmemenge vernachlässigt, rechnerisch oder experimentell erfasst werden kann.

Abbildung 2 u. 3 zeigten das Schema der Lösung dieser Aufgaben wie es in unserem ersten Kalorimeter verwircklicht wurde. Die Messwand Abbildung 2 besteht in wesentlichen aus den dünnen

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[1] *Mit dieser Mikro-"Flamme" müsste man bei Vermeidung aller äusseren Wärmeverluste ein Liter Wasser durch 22 Millionen Stunden oder durch rd. 2,500 Jahre heizen um es um 100° C zu erwärmen!*

Kupferplattenpaaren 1, 2 u. 3, 4 zwischen dem die Thermoelementendrähte 5 u. 6 durch den Luftzwischenraum hin- und hergehen. Die Platten sind vom Rahmen 8 gehalten, die Thermosäule an das Anzeigegerät 7 angeschlossen. Diese wärmetechnisch fast völlig trägheitslose Anordnung hat sich ob ihrer grossen Empfindlichkeit ausserordentlich gut bewährt und wurde auch beim Bau unseres zweiten Kalorimeters beibehalten.

Bei unserem ersten Kalorimeter, Abb. 3, wurden aus vielen Gründen die Abmessungen des Normalbetonwürfels 20 x 20 x 20 m³ als Lichtmasse des Kalorimeterraumes 13 gewählt. 6 Messplatten (9 bis 12 in der Schnittzeichnung) umgeben die zu kalorimetrierende Wärmemenge von allen Seiten, ihre Thermoelemente sind in Serie geschaltet. Die Wärme durchströmt nach den Messplatten eine Dämpfungsschicht 14 und wird durch die in der Rohrplatte 15 den Würfel allseitig umfliessende Flüssigkeit 16 abgeführt. Durch geeignete Regelung kann die Temperatur der Flüssigkeit konstant gehalten oder beliebig geregelt werden. Gegen äussere Wärmeeinflüsse ist der Apparat durch die hochwertige Isolierschicht 17 geschützt.

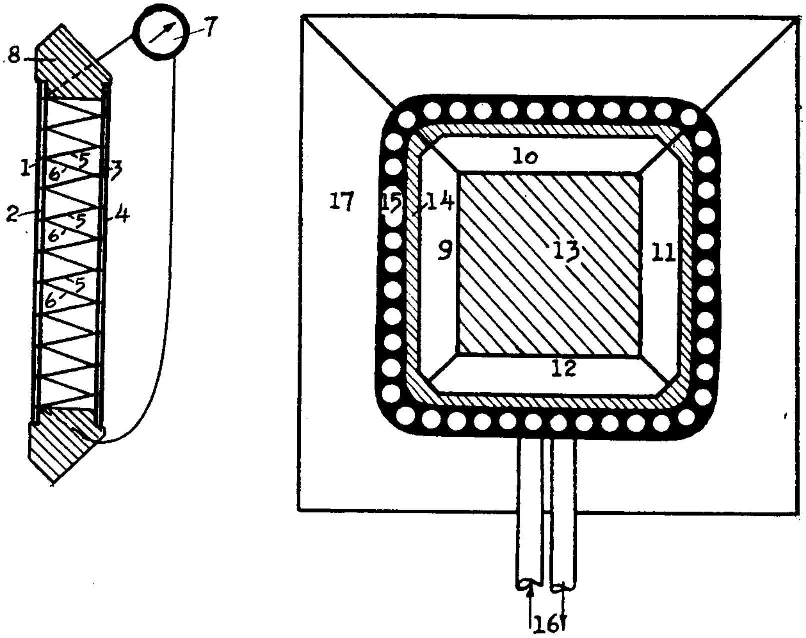

Abbildung 2, 3.—**Schema des grossen Kalorimeters.**—Scheme of the large calorimeter.—Dispositif du grand calorimètre.—Dispositivo del calorímetro grande.

Die Thermosäulen der Messplatten bestanden bei unseren ersten beiden Kalorimetern aus isolierten Eisen und Konstantandrähten. Abbildung 4 zeigt die Ansicht des grossen Kalorimeters mit den Apparaten, die der Eichung dienen.

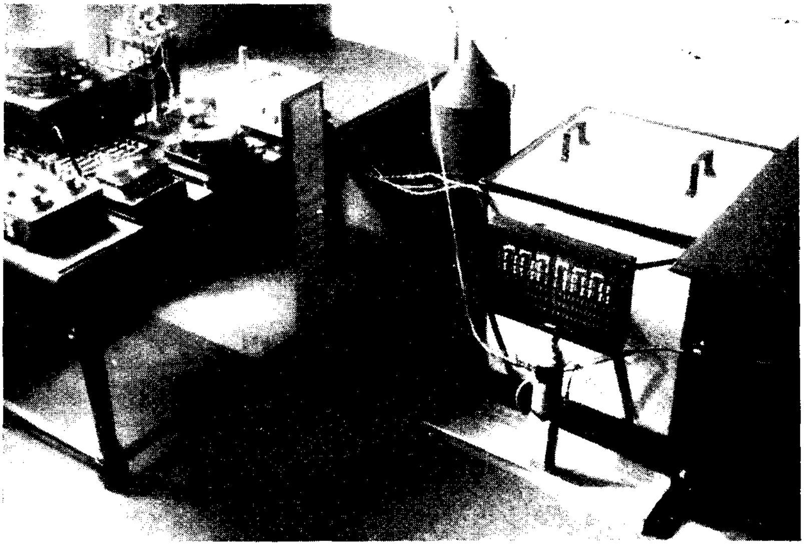

Abbildung 4.—**Ansicht des grossen Kalorimeters.** — View of the large calorimeter. — Photographie du grand calorimètre. — Vista del calorímetro grande.

Die Zahl der Thermoelemente die bei gegebenen Verhältnissen zur Erzielung eines bestimmten Zeigerausschlages des Anzeigegerätes erforderlich ist nach dem folgenden Schema ermittelt worden.

Anzeigegerat

Systemwiderstand	r_i Ω
Vorschaltwiderstand	r_v Ω
Zeigerausschlag bei x *m VEMK*	γ

Kalorimeter

Die beim Zeigerausschlag γ des Anzeigegerätes zu messende *Wärmemenge*	q kcal/h
Fläche der Messwände	F_1 m^2
Dicke der Luftschicht	s m
Querschnitt der Thermoelemente	F_2 m^2
Wärmeleitzahl der Luftschicht	λ kcal/h.m.°C.
Wärmeleitzahl der Thermoelementen drähte	$\Sigma\lambda$
Spezifischer elektrischer Widerstand der Thermoelementendrähte	$\Sigma\rho$ $\Omega m^2/m$
Zahl der in Serie geschalteten Einzelthermoelemente	z
Ihre mittlere Länge von der Kalt- zur Warmlötstelle näherungsweise	s m
Elektromotorische Kraft eines Thermoelementes	e $mVEMK/°C.$

Führt man folgende Koeffizienten zur Vereinfachung der Gleichungen ein

$$A=\frac{F_2}{s}\Sigma\lambda(r_i-r_v) \qquad B=\frac{F_1}{F_2}\lambda\Sigma\rho$$

$$C=e\frac{q}{\gamma}r_i \qquad D=2\Sigma\lambda\Sigma\rho \qquad 4\,AB=E$$

$$C-(A+B)=F$$

so ist ein thermoelektrisches Kalorimeter nur dann möglich, wenn

$$A+B<C \qquad (1)$$

$$E\leqq F^2 \qquad (2)$$

Es ergibt sich dann die Zahl der Thermoelemente z *zu*

$$z=(F\pm\sqrt{F^2-E})D^{-1} \qquad (3)$$

Eine eingehende Diskussion dieser für den Bau von Thermokalorimetern grundlegenden und besonder für die beste Ausnützung der Thermoelemente aufschlussreichen (unseres Wissens erstmalig angegebenen Beziehungen) muss hier leider Platzmangels halber unterbleiben, ebenso wie ihre Darstellung in Schaubildern.

Unserem ersten Kalorimeter folgte bald ein zweites, das ich am 4. Mai 1934 bei einem Vortrage vor Fachkreisen in Budapest erstmalig vorführte. Hat das erste hauptsächlichst der Bestimmung der Abbindewärme von Beton gedient, so sollte das zweite für die Messung der von kleineren Zementmengen oder Zementzugprobekörpern abgegebenen Wärmemengen dienen. Es hatte eine lichte Weite von 20 x 20 x 2.2 cm^3 und war im Wesen nach demselben Prinzip gebaut. Es hatte eine Dämpfungsschicht aus Öl, seine Temperatur wurde durch ein Wasserbad gergelt.

Die Erfahrungen die wir beim Bau, bei der Eichung und dem Arbeiten mit diesen Apparaten gewonnen, sprachen deutlich für die Richtigkeit des verfolgten Prinzipes. Wir werden demnächst mit dem Bau weiterer Kalorimeter auf dieser Basis beginnen, die für Spezialuntersuchungen dienen sollen.

Auch auf einzelne, das Arbeiten nicht unwesentlich beeinflussende Konstruktionsdetails soll hier nicht eingegangen werden.

2. BETONFESTIGKEIT UND ABBINDEWÄRME

Die Festigkeit von Beton mit stets gleichbleibendem Zuschlagstoff von gleichbleibender Kornabstufung (Sieblinie) hängt ausser vom Mischungsverhältnis, der Anmachwassermenge und etwas von den Temperatur- und Druckverhältnissen bei gleicher Verarbeitung nur vom Erhärtungsalter ab und strebt mit diesem meist asymptotisch einem Grenzwert zu.

Das Erhärten des Betons, herrührend von der Bildung des Zementsteines aus dem Zementleim verläuft als chemischer Prozess unter Abgabe der bei der Hydratation des Zementes frei werdenden Wärme. Diese Gesamtwärmeabgabe des Zementes kann geradezu als Mass des Fortschreitens des chemischen Umwandlungsprozesses angesehen werden. Auch sie ist ausser von der Temperatur bie welcher das Abbinden und Erhärten stattfindet und der Menge des zugesetzten Anmachwassers vermutlich vom Druck unter dem der Zementleim erhärtet abhängig.

Schaltet man zur einfacheren Behandlung vorläufig alle diese variablen Einflüsse aus und betrachtet einzig und allein die Druckfestigheitszunahme eines bestimmten Zementes ohne Zuschlagstoff bei bestimmter Wasserzugabe und bestimmter gleichbleibender Temperatur unter Luftdruck, so wird das Erhärten des Zementsteines unter Wärmeentwicklung vor sich gehen. Trägt man diese Gesamtwärmeabgabe in Abhängigkeit von der Druckfestigkeit auf, so ergibt sich folgendes charakteristisches Bild (Abb. 5). Eingetragen ist gleichzeitig das Erhärtungsalter (2, 7, 28 Tage). Der frühhochfeste Zement (FPZ) hat nach zwei Tagen nicht nur fast dieselbe Festigkeit wie der Portlandzement (PZ) nach 7 Tagen, sondern auch eine ungefähr verhältnisgleiche Wärmeentwicklung. Es ist dabei nur reiner Zementleim ohne Sandzusatz mit gleichem Wasserzusatz (ca 26%) im Vergleich gesetzt. Die Festigkeit ist an Druckwürfeln von 7 cm Kantenlänge die in Wasser von 22° C gelagert waren erhoben worden, ebenso die Wärmeabgabe bei derselben Temperatur. Die Festigkeits-Gesamtwärmeabgabe-Linie war hier nicht weit von einer linearen Proportionalität entfernt. Irgend eine derartige Beziehung war ja auch nach gesamtenergetischen Überlegungen zu erwarten; abgesehen von der formalen Ähnlichkeit der Festigkeitslinie in Abhängigkeit von der Zeit mit der Wärmeabgabe-Zeitlinie, die beide durch den Ursprung gehen und nach einigen Wochen ungefähr asymptotisch einem Höchstwert zustreben. Diese asymptotischen Grenzwerte bilden im vorliegenden Diagramm Abbildung 5 natürlich den Grenzwert und Schlusspunkt der Festigkeitszeitlinie. Wendet man die am reinen Zement gewonnenen Erkenntnisse nunmehr sinngemäss auf den Beton an, so sinkt dort mit abnehmendem Zementgehalt bei gleichem Wasserzementfaktor und gleicher Erhärtungsdauer die Festigkeit und infolge des kleineren Zementgehaltes die auf den kg Frischbeton bezogene Wärmeabgabe in kcal wenn man auch noch die geringen Verschiebungen berücksichtigt, welche die Wärmeabgabe-Zeit-Kurve durch die Speicherung des Zuschlagstoffes bei den geringen Temperaturschwankungen erfährt.

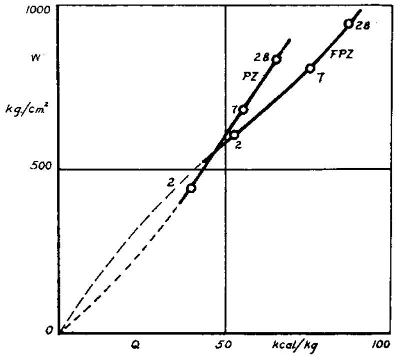

Abbildung 5.—Würfelfestigkeit — Abbindewärmediagramm. — Diagram of the strength of a cube and of its setting heat. — Courbes de la résistance d'un cube et de sa chaleur de prise. — Diagrama de la resistencia de un cubo y su calor de fraguado.

Es wird also auch beim Beton eine eindeutige Abhängigkeit der Druckfestigkeit von der Gesamtwärmeabgabe bestehen. Kennt man daher eine von beiden Grössen, so kann die andere angegeben werden. Selbstverständlich muss dabei die Abhängigkeit beider Grössen für die betreffende Betonmischung einmal unter den gleichen Umständen aufgenommen werden unter denen der Beton dann erhärtet. Folgende Einflüsse machen sich hier geltend und sind zu beachten:

(*a*) Bei höheren Temperaturen erhärtet der Beton in der ersten Zeit rascher, ebenso hat dabei die Wärmeabgabe zur gleichen Zeit einen höheren Wert. Ob dabei die Wärmeabgabe-Festigkeitslinie erhalten bleibt oder ihre Lage im Diagramm ändert wird festzustellen sein.

(*b*) Bei höherem Erhärtungsdruck dürften sich höhere Festigkeiten und vermutlich auch höhere Wärmeabgaben ergeben.

(*c*) Grösserer Wasserzusatz vermindert die Festigkeit des plastisch oder flüssig bereiteten Betons nach dem Erhärten bei entsprechender Aenderung der Wärmetönung; Verminderung der Wassermenge des erdfeucht bereiteten Betons kann zu überraschend plötzlichem Druckfestigkeitsabfall führen. Beide Erscheinungen finden in der Mechanik des Hydratationsvorganges ihre Erklärung.

(*d*) Die Kornzusammensetzung (Sieblinie), Kornform, mineralogische und chemische Beschaffenheit des Zuschlagstoffes haben wesentlichen Einfluss auf die Festigkeit des erhärtenden Betons. Diese Komponente dürfte vermutlich keine Parallele in der Wärmeabgabe haben, da es sich um eine rein granulometrische Einflussnahme handelt.

ad (*a*) *u.* (*b*) Druck- und Temperatureinflus hat Bedeutung bei grösseren Betonansammlungen (Talsperren usf.) auf das Erhärten im Inneren. Der Druck an diesen Stellen ist bedingt durch das Gewicht der darüberlastenden Masse und wird anfänglich fast als hydrostatisch allseitig wirkender Druck anzusehen sein um mit fortschreitender Erhärtung und nach dem Ausschalen ungeklärteren Verhältnissen zu weichen. Dieser reine Gewichtsdruck bewegt sich in der Grössenordnung von rd. 2.5 kg/cm^2 je 10 m Hohe des darüberlastenden Betons. Die Temperatursteigerung kann bei Kenntnis aller anderen Faktoren und Vornahme von Vorversuchen mit dem in Ausicht genommenen Beton ziemlich genau vorausgerechnet werden.

ad (*c*) Die Abhängigkeit der Festigkeit und Wärmeabgabe von der Anmachwassermenge ist für einen bestimmten Zuschlagstoff und bestimmte Zementmarke ebenfalls nur im Wege des Vorversuches festzustellen, da ja hier die Wasseraufnahme des Zuschlagstoffes, die zur Verminderung des Hydratationswassers führt und andere Umstände eine Rolle spielen.

ad (*d*) Die unter Beachtung der vorstehenden Gesichtspunkte durchgeführten Beobachtungen und Vorversuche sind also an einen bestimmten Zuschlagstoff bestimmter Kornform, Kornabstufung und Beschaffenheit gebunden. Ob und inwieweit durch eine Aenderung der Siebkurve, z.B. bei sonst gleichem Material, die Wärmetönung des Betons geändert wird, werden Versuche zeigen. Theoretisch wäre ohne weiteres eine Einflussnahme der durch die damit bedingten verschiedenen Hohlraumverhältnisse erforderlichen Verteilungsveränderung des Zementsteines im Beton auf den Hydratationsvorgang und seinen zeitlichen Ablauf denkbar. Liesse sich ein solcher Einfluss nachweisen, dann hätte eine Beobachtung der Wärmetönung des Zementes allein nur eine bedingte und wesentlich eingeschränktere Bedeutung als im gegenteiligen Falle, wo dann aus der Wärmetönung des Zementes, dem Mischungsverhältnis allein, ohne Rücksicht auf die Sieblinie, die Wärmetönung des Betons zu errechnen wäre. Selbstverständlich zunächst wieder nur für denselben Zuschlagstoff.

Es kann überhaupt hier nicht genug vor einer Überschätzung der an einzelnen Versuchsreihen bei Zement gewonnenen Erfahrungen und ihrer bedingungslosen Anwendungsmöglichkeit auf Beton ohne genaue Kenntnis der Technologie des Betons und der hier mitbestimmenden Einflüsse gewarnt werden. Ist schon die Erkenntnis der wichtigsten der drei hier zur Geltung kommenden Faktoren wie Wassergehalt, Konsistenz, Druckfestigkeit und Zementzusatz (bei gleicher Sieblinie und für dasselbe Zuschlagstoffmaterial!) und ihre Darstellung als Zustandsfläche des Betons erst eine Erkenntnis der letzten Jahre, so ist die Hinzufügung einer weiteren Variablen wie es die Gesamtwärmeentwicklung ist, nur schrittweise und durch Versuche gesichert möglich, wenn böse Trugschlüsse und Misserfolge vermieden werden sollen.

Dass gerade die Heranziehung der Wärmetönung des Zementes und Betons zur Beurteilung des Abbinde- und Erhärtungsvorganges dabei schliesslich zu wesentlichen Vereinfachungen unserer Auffassung über diese Zustandsänderung führen wird, ist eine vom Berichterstatter seit Jahren in Wort und Schrift immer wieder vertretene Anschauung, die durch anderweitige erfolgreiche thermodynamische und technologische Überlegungen gestützt wird.

3. Bestimmung der Betonfestigkeit im Inneren einer Talsperre aus Beton mit Hilfe der Messung der Abbindewärme

Bei einem grösseren ausländischen Talsperrenbau (Rauminhalt des Wehrs 300.000 m^3, 280 m Wehrkronenlänge, 70 m Höhe) sollte die Druckfestigkeitszunahme im Inneren der Staumauer während und nach der Fertigstellung in Abhängigkeit von der Zeit festgestellt werden. Zu diesem Behufe wurde in Zusammenarbeit mit einer Wr. Firma nach dem geschützten Verfahren des Verfassers folgender Apparat und Einbauplan ausgearbeitet.

(1) PRINZIPIELLES JEDER MESSTELLE

(*a*) *Kalorimeter.*—In den Staudamm werden an jenen Stellen an denen man den Verlauf der Druckfestigkeit zu kennen wünscht verlorene Kalorimetermessanordnungen mit einbetoniert. Das einzubauende Kalorimeter besteht am einfachsten nur aus den im Kapitel I beschriebenen Messplatten, ist ein Hohlwürfel mit 20 bis 35 cm innerer Kantenlänge 3 bis 8 cm Wandstärke, abnehmbarem und aufschraubbarem Deckel. Die Innen und Aussenhaut ist verschweisstes Eisenblech, 3 bis 5 mm dick, lackiert, aussen event. durch Winkeleisen versteift. Im Hohlraum zwischen den Eisenplatten befindet sich eine Isolierplatte von entsprechender Dicke und Beschaffenheit mit eingezogenen in Serie geschalteten, hart gelöteten Thermoelementen. Je Würfelfläche wurden ca. 20 bis 160 Stück vorgesehen, ausserdem 1 bis 4 Thermoelemente je Würfel in Serie, zur Bestimmung der Betontemperatur.

MESSAPPARATUR—ZULEITUNGEN

(*b*) *Messapparatur.*—Gummikabel-, oder Bleikabel-Kompensations, bezw. Kupferzuleitungen, die in ihrem ersten Teile mit einbetoniert werden, führen vom Kalorimeter zum Anzeigegerat, das im einfachsten Fall als Ableseinstrument (mit Umschaltern auf mehrere Messtellen) ausgebildet sein kann. Es zeigt dann die jeweilige Wärmeabgabe je Zeiteinheit und die Betontemperatur an. Bei Anschluss von Registriergalvanometern sind alle diese Grössen für mehrere Messtellen gleichzeitig aufzeichenbar. Am vorteilhaftesten ist aber die Wärmenmengenmessung mit einem Elektrolytzähler möglich, der direkt im kcal je kg Beton geeicht werden kann und sofort die bis zum Ablesezeitpunkt vom Beton im Kalorimeter abgegebene Wärmemenge oder direkt die Druckfestigkeit abzulesen gestattet. In diesem Falle ist nur ein getrenntes Registrier- oder Ablesegerat für die Bestimmung der Betontemperatur erforderlich.

(*c*) *Anbringung der Apparatur.*—Der Innenraum des Hohlwürfels wird bei der Mischmaschine oder an Ort und Stelle bis zum Rande mit dem gleichen Beton gefüllt wie er in der Umgebung der Messtelle in die Schalung eingebracht wird. Der Deckel des Kalorimeters wird aufgeschraubt und das gefüllte Kalorimeter an die Einbaustelle gebracht und mit einbetoniert. Das Anschlussgummikabel oder das Bleikabel wird im ersten Teile ebenfalls mit einbetoniert und nach einem geeigneten Plane zum Messraume geführt, wo es an die Verteilerbrücke oder an die Instrumente angeschlossen ist.

MESSUNG

(*d*) *Die Messung* erfolgt bei vollautomatischer Aufzeichnung selbsttätig, bei Ableseinstrumenten durch Ablesen in entsprechenden Intervallen, anfänglich die ersten 5 bis 10 Stunden ungefähr alle ¼ bis ½ Stunden, dann 6 mal, abnehmend auf 1 mal täglich. Aus den Aufzeichnungen bezw. Ablesungen ergibt sich die Temperatur des Betons an der Messtelle und entweder die Wärmeabgabe je Zeiteinheit bezw. die Gesamtwärmeabgabe seit dem Einbringen oder direkt die Druckfestigkeit des Betons an der betreffenden Stelle.

Genauigheit der Betonfestigkeit.

(*e*) *Die Genauigkeit* der Festigkeitsangabe des Betons wird wesentlich höher sein als die bei Betondruckfestigkeitsprüfungen an 20 cm Würfeln sich im Mittel aus drei Beobachtungen ergebende Streuung die normenmässig bis zu ±20% vom arithmetischen Mittelwert betragen kann. Die Mess- und Auswertungsgenauigkeit wurde beim vorliegenden Projekt mit ±5 bis 10% der angenebenen Druckfestigkeit veranschlagt.

MESSVORGANG

(*f*) *Zum Messvorgang* ist zu bemerken, dass heir jede Vorrichtung zum Konstanthalten der Temperatur fehlt, da ja der Temperaturverlauf ein innerhalb und ausserhalb des Kalorimeters ganz paralleler ist. Der im Inneren des Kalorimeters befindliche Beton gibt beim Abbinden und Erhärten Wärme ab ebenso wie der Beton in der Umgebung des Kalorimeters. Die im Inneren des Kalorimeters freiwerdende Wärme muss die Wandungen des Kalorimeters durchfliessen und erzeugt dabei zwischen dessen innerer und äusserer Oberfläche ein Temperaturgefälle, dessen integraler Mittelwert und mit ihm eben die abfliessende Wärmemenge durch die in Serie geschalteten Thermosäulen genau erfasst wird. Da die aussen das Kalorimeter umhüllenden Betonmassen, ebenfalls gleichzeitig abbindend, ähnliche Temperaturen haben, ist der Wärmefluss durch die Kalorimeterwandungen quasistationär und erübrigt sichdamit auch eine Vorsorge hinsichtlich besonderer Trägheitslosigkeit der Messanordnung.

(2) ANORDNUNG DER MESSTELLEN

Die Abbildung 6 zeigt im Grundriss die Anordnung der Staumauer. Symetrisch zur Mittelachse wurden nach rechts (*r*) und links (*l*) je 10 Vertikalebenen senkrecht zur Wehrkrone angenommen. Sie sind im Aufriss mit A bis K bezeichnet. Da die Austeilung eine symetrische ist werden die im Grundriss mit B_1, C_1, D_1 usf. bezeichneten linken Schnittebenen dieselbe Messtellenanordnung aufweisen wie die rechten mit B_1, C_1, D_1 usf. beschrifteten. Die Staumauer wurde ausserdem durch 14 horizontale Ebenen in gleich hohe Schichten unterteilt, in denen dann die Austeilung der 74 Messtellen in der in den Querschnitten eingezeichneten Weise erfolgte. Sie ist so durchgeführt worden, dass die Messtellen ein genaues Bild des Warmeabgabe- und Temperaturfeldes der gesamten Staumauermasse geben.

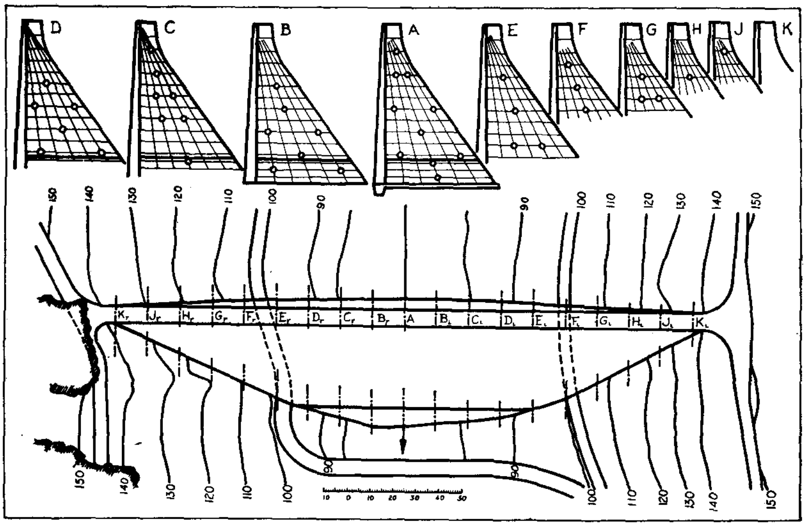

ABBILDUNG 6.—Schema der Messtellenanordnung. — Location of measurement points. — Emplacement des points de mesure. — Posición de los puntos de medida.

Mit Dieser Anordnung ist erstmalig die Klärung aller thermodynamisch-festigkeitstechnischen Fragen in befriedigender und erschöpfender Weise möglich.

(3) EICHUNG DER APPARATUREN

(*a*) *In Vorversuchen* wird mit Zuschlagstoff des gleichen Körnungsverhältnisses, mit gleicher mineralogischer Beschaffenheit wie er beim Bau zur Verwendung gelangen soll, bei gleicher Zementmarke und Menge und gleicher Wasserzugabe Beton bereitet. Er wird in Kalorimeter der gleichen Art wie sie beim Bau der Staumauer Verwendung finden sollen gefüllt, die aussen ebenfalls von Betonmassen umgeben werden, die Würfelform haben. Diese ganzen grossen Blöcke werden von einem Rohrsystem umschlossen in dem Flüssigkeit mit solcher Temperatur umgewalzt wird wie sie im Inneren der Staumauer nach den Vorausberechnungen auf Grund des genauen Betonierungsplanes in Abhängigkeit von der Bauzeit zu erwarten ist. Gleichzeitig wird, wenigstens in vertikaler Richtung ein Druck mittels hydraulischer Presstöpfe mit Einrichtungen zum Konstanthalten des Druckes oder auf eine andere für unsere Versuche vorgesehenen einfachere Art von allen Seiten wirkend auf den Beton ausgeübt. Es werden damit alle jene Einflüsse denen im Inneren der Staumauer vollständig und regulierbar angepasst.

Der unter diesen Bedingungen erhärtende Beton gibt nun Wärme ab, die im Kalorimeter nach dem System des Verfassers auf das genaueste gemessen wird. In bestimmten Zeitabständen werden einige der das Kalorimeter umhüllenden Betonwürfel entnommen und auf ihre Druckfestigkeit geprüft. Die Hohlräume werden durch andere unter ähnlichen Bedingungen erhärtende Betonwürfel ersetzt, so dass keine grössere Störung des Feldes zu erwarten ist. Wird nun die so erhobene Druckfestigkeit in Abhängigkeit von der bis zu diesem Zeitpunkte abgegebenen Wärmemenge aufgetragen so ergibt sich die Eichkurve der Apparartur für die Abhängigkeit der Druckfestigkeit von der Anzeige des Registrierzählers. Diese Eichung wird zweckmässig unter verschiedenen Bedingungen wiederholt.

(b) In einer zweiten oder parallelen Versuchsreihe wird das selbe Kalorimeter oder ein ganz gleich gebautes nicht mit Beton gefüllt. Es enthält dann eine beliebig angeordnete elektrische Heizspirale, die eine bestimmte und elektrisch genau aus Strom- und Spannungsmessung ermittelbare Wärmemenge abgibt. Auf diese Weise wird der Zusammenhang zwischen der Wärmemenge und der Galvanometeranzeige eingeeicht.

(*c*) Da die in die Messplatten eingebauten, der *Temperaturmessung* dienenden Thermoelemente oder die Widerstandsthermometer ebenfalls auf einfache Weise geeicht werden, ist die Anordnung damit betriebsfähig.

Bei allen weiteren Apparaten wird eine stichprobenweise Kontrolle der Wärmemengenmessung vollauf genügen, die rasch und einfach durchgeführt werden kann.

4. Weitere Ausbaumöglichkeiten

Mit der vorbeschriebenen Anordnung wird die Wärmeabgabe und Temperatur des Betons an den Messtellen und damit die in Abhängigkeit davon stehende Festigkeit des Betons ermittelt. Wird gleichzeitig in die Apparatur ein Gerät eingebaut, das die Hauptnormalspannungen an diesen Stellen zu messen gestattet, so sind so ziemlich alle auf den Aufbau und das Betriebsverhalten der Betonstaumauer Einfluss nehmenden Grössen festgelegt.

Ob zur Spannungsmessung die Wandungen des Kalorimeters herangezogen werden, wie es vom Berichterstatter beabsichtigt ist, oder ob einer der handelsüblichen und die Anzeige über Draht zu einem Fernschreiber leitenden Apparate benützt wird, ist an und für sich gleichgültig. Gefordert muss nur werden, dass der Anschaffungspreis des Kalorimeters sich dadurch nicht wesentlich erhöht. Denn das Kalorimeter ist heute eine relativ sehr billige und dabei hoch exakt arbeitende verlorene Messeinrichtung.

Die begonnenen Versuche und die praktische Erprobung werden in kurzer Zeit ein exaktes Bild der verschiedenen in Kapitel II angeführten Fragen klären. Ernste Mitarbeit und Anteilnahme aller an diesen Punkten interessierten Kreise und Faktoren wird hier sicher zum vollen Erfolg führen. Handelt es sich doch um eines der wichtigsten, um nicht zu sagen das wichtigste Kapitel des Baues moderner Betonstaumauern.

ZUSAMMENFASSUNG

Die beim Abbinden des Zementes frei werdende Wärme ist eine Funktion der Zeit, der Temperatur, des Wasserzusatzes, usw., demgemäss ist die beim Erhärten des Betons je Zeiteinheit frei werdende Wärme abhängig vom Mischungsverhältnis, Wasserzusatz, von der Erhärtungsdauer, der Temperatur und vielleicht auch vom Erhärtungsdruck. Von den gleichen Variablen hängt aber auch die Druckfestigkeit in erster Linie ab, weshalb ein ursächlicher Zusammenhang zwischen dieser und der Gesamtwärmeabgabe bestehen muss, wobei aber selbstverständlich nicht von vornherein auf die Eliminierbarkeit aller Variablen geschlossen werden wird.

Ein neues trägheitsloses und hochemfindliches Kalorimeter zur exakten Bestimmung der Wärmeabgabe des Betons und seine Anwendung zur Bestimmung der Druckfestigkeit im Inneren grosser Betonmassen wird beschrieben. Das Kalorimeter besteht aus Messplatten, zwischen deren Oberflächen die Temperaturdifferenz mittels in Serie geschalteter Thermoelemente gemessen wird. Die Temperaturdifferenz zwischen diesen Oberflächen ist der die Messwände durchfliessenden Wärmenge proportional. Die von einzelnen, innerhalb der Messwände befindlichen Körpern abgegebene oder entwickelte Wärmemenge fliesst durch die Wände ab und wird dabei gemessen. Das Kalorimeter misst infolge seiner Wandausbildung die Intensitätsänderung der Wärmemengenabgabe trägheitslos und zeichnet sie mittels eines Registrierinstrumentes auf oder summiert sie in einem Zähler.

Ein vereinfachtes Kalorimeter dieser Art wird in seiner Anwendung als Messgerät zur Ermittlung der Druckfestigkeit im Inneren grosser Betonmassen beschrieben. Es besteht ein fach aus sechs verlorenen Messplatten, die in die Betonmasse so einbetoniert werden, dass sie einen würfelförmigen Teil derselben allseits umschliessen. Die beim Erhärten vom Beton entwickelte Wärmemenge muss die Messwände durchfliessen und wird dabei mit Messgeräten bestimmt, die mit isolierten Leitungen an die einzelnen Kalorimeter angeschlossen sind. Die Skala von Zählwerken (Spannungszählern) kann auf Grund von Vorversuchen direkt in der Skala der Druckfestigkeit (z.B. kg/cm^2 oder lb./sq.inch) geeicht werden, so dass die Druckfestigkeit des Betons an den Messtellen in jedem Zeitpunkt der Erhärtung sofort am Instrument abgelesen werden kann. Die Eichung der Apparatur muss die Zunahme der Druckfestigkeit in Abhängigkeit von der Wärmeabgabe unter den genau gleichen Zustandsbedingungen erfassen, unter denen der Beton dann im Bauwerk erhärtet. Die Verteilung der Messtellen wird am Beispiel der geplanten Anordnung bei einem Staudamm (rd. 300.000 m^3, 280 m Wehrkronenlänge) gezeigt. Die Druckfestigkeit soll dabei an 76 Stellen gemessen werden. Die Ausmittlung erfolgte in 14 Horizontalebenen und 20 Vertikalschnitten in einer die ganze Masse umfassenden gleichmässigen Verteilung.

Gleichzeitig mit der Erfassung der beim Erhärten abgegebenen Wärmemenge wird auch die Temperatur an den Messtellen ermittelt und im Bedarfsfalle auch der Innendruck. Alle diese Zustandsgrössen geben dann ein genaues Bild des thermodynamischen und statischen Verhaltens des Betons.

SUMMARY

The heat freed during the setting of concrete is a function of the time, temperature, water added, etc.; therefore, the heat freed per unit of time during the hardening of concrete is dependent on the proportion of the mixture, the water added, the duration of hardening, the temperature, and perhaps the hardening pressure. Furthermore, the compressive strength is primarily dependent on the same factors, so that a close connection prevails between the strength and the total heat given off.

A new, highly sensitive calorimeter, without heat capacity, for the exact determination of heat given off by concrete, and its use for the determination of the compressive strength in the interior of large concrete masses, are described. The calorimeter consists of measuring plates, between the surfaces of which temperature differences are measured by means of thermoelements arranged in series. The temperature differences between these surfaces are proportional to the quantity of heat flowing through the measuring walls. The quantity of heat given off or evolved from the several bodies which are between the measuring walls flows off through these walls and is then measured. Due to the construction of the walls, the calorimeter measures without lag the variations in intensity of the heat given off and indicates such intensity by means of a graphic instrument or sums up the quantity by an integrating meter.

A simplified calorimeter of this kind, and its uses as a measuring device for the determination of compressive strength in the interior of large concrete masses, are discussed. It consists simply of six "lost" measuring plates which are so embedded in the concrete mass that they surround entirely a cubic part of the mass. The quantity of heat evolved during the setting of concrete permeating the measuring walls is then determined by measuring devices which are attached to the several calorimeters by means of insulated conductors. The scale of the integrating meters (integrating voltmeter) may, based on preliminary experiments, be calibrated directly on the scale showing the compressive strength (for instance, kg/cm^2 or lb./sq. in.), so that the compressive strength of concrete at the point of measurement may be read immediately on the instrument at any period of the hardening

process. The calibrating of the apparatus takes care of the additional compressive strength resulting from the heat given off under exactly the same circumstances under which the concrete will harden at the construction site itself. The distribution of points of measurement is shown by the example of a planned arrangement for a large dam (about 300,000 cubic meters; length of crest 280 meters). The compressive strength will be measured in this instance at 76 points. The application took place in 14 horizontal planes and 20 vertical sections, distributed equally over the entire mass.

Together with the determination of the amount of heat given off during hardening, the temperature is also ascertained at the points of measurement and if necessary also the internal pressure. All these factors give an accurate picture of the thermodynamic and static behavior of the concrete.

RESUME

La chaleur dégagée pendant la prise du béton est une fonction du temps, de la température, de la proportion d'eau contenue, etc.: en conséquence, le dégagement de chaleur par unité de temps pendant le durcissement du béton dépend de la composition du mélange, de la proportion d'eau, de la durée du phénomène, de la température, et peut-être aussi de la pression de durcissement. Mais la résistance du béton à la compression dépend aussi, en première ligne, des mêmes variables; c'est pourquoi il doit exister une relation de cause à effet entre cette résistance et le dégagement de chaleur; mais, naturellement, on ne peut, a priori, tirer de conclusions sur la possibilité d'éliminer toutes les variables.

Le rapport décrit un nouveau type de calorimètre, très sensible et sans inertie, destiné à la mesure exacte de la chaleur dégagée dans le béton et expose son emploi pour la détermination de la résistance à la compression dans l'intérieur de grosses masses de béton. Ce calorimètre se compose de plaques de laiton, entre lesquelles on mesure la différence de température au moyen de couples thermiques montés en série: cette différence est proportionnelle à la quantité de chaleur traversant les parois de mesure. La quantité de chaleur dégagée par les corps placés à l'intérieur des parois passe à travers ces parois et se trouve par conséquent mesurée: grâce à l'arrangement de ses parois, le calorimètre mesure sans inertie la variation d'intensité de dégagement de chaleur, et celle-ci est enregistrée au moyen d'un appareil spécial ou totalisée dans un compteur.

Le rapport décrit aussi un calorimètre simplifié de même type ainsi que son emploi comme appareil de mesure de la résistance à la compression du béton en grosses masses: il comprend simplement six plaques de laiton enrobées dans le béton, de telle sorte qu'elles entourent complètement une masse de ce matériaux en forme de dé. La quantité de chaleur développée pendant le durcissement du béton doit traverser les parois et se trouve par conséquent déterminée par les appareils de mesure qui sont reliés aux calorimètres individuels par des conducteurs isolés. L'échelle des compteurs peut être étalonnée d'après des essais préparatoires, sur l'échelle des résistances à la compression, par exemple en Kg/cm (ou en livres/pouce carré); de cette façon, la résistance du béton à la compression aux divers points peut être lue à tout moment sur l'instrument. L'étalonnage de l'appareil doit tenir compte de l'accroissement de résistance en fonction du dégagement de chaleur dans des conditions identiques à celles du durcissement du béton dans l'ouvrage. Le rapport donne un exemple de répartition des emplacements de mesure dans un barrage (300.000 m^3 et 280 m de longueur au couronnement); la résistance à la compression doit y être mesurée en 76 points différents. Cette répartition est faite suivant 14 plans horizontaux et 20 coupes verticales.

En même temps que les quantités de chaleur dégagées pendant le durcissement, l'appareil permet aussi de mesurer la température en divers points, et même, si besoin est, la pression interne. Toutes ces valeurs donnent une représentation exacte de la manière dont se comporte le béton aux points de vue statique et thermodynamique.

RESUMEN

El calor desarrollado durante el fraguado del hormigón es una función del tiempo, de la temperatura, de la proporción de agua contenida, etc.; por lo tanto el calor desarrollado por unidad de tiempo durante el endurecimiento del hormigón depende de la composición de la mezcla, de la proporción de agua, del tiempo requerido para el fraguado, de la temperatura y quizás de la presión de endurecimiento. Además, la fuerza de compresión depende, en primer lugar, de los mismos factores y por lo tanto existe una estrecha relación entre esta fuerza y la cantidad total de calor desarrollado.

Se describe un nuevo tipo de calorímetro, altamente sensitivo, sin inercia, destinado para medir exactamente el calor desarrollado por el hormigón y su empleo para determinar la resistencia en el interior de grandes masas de hormigón. El calorímetro se compone de planchas indicadoras entre las superficies de las cuales se miden las diferencias de temperatura por medio de elementos térmicos montados en series. Las diferencias de temperatura entre dichas superficies son proporcionales a la cantidad de calor que atraviesa las paredes de medida. La cantidad de calor desarrollado por los diversos cuerpos que están entre las paredes pasa a través de dichas paredes y es entonces medida. Gracias a la construcción de las paredes, el calorímetro mide sin inercia las variaciones de intensidad del calor desarrollado indicando tal intensidad por medio de un aparato registrador o totaliza la cantidad sobre un contador integrado.

También se describe un calorímetro simplificado del mismo tipo y su empleo como aparato medidor en la determinación de la fuerza de compresión en el interior de grandes masas de hormigón. Consiste simplemente de seis planchas de medida enterradas en la masa de hormigón en una forma tal que rodean completamente una parte cúbica de la masa. La cantidad de calor desarrollado durante el fraguado del hormigón y que cruza las paredes de medida se determina por los aparatos de medida conectados a los varios calorímetros por medio de alambres aislados. La escala de los contadores (registros de tensión) puede indicarse sobre la misma escala que muestra la fuerza de compresión y ser basada en el resultado de los ensayos hechos anticipadamente (por ejemplo, kg/cm^2 ó 1b/pulg. cuad.) de modo que la fuerza de compresión del hormigón en el punto de medida pueda leerse en cualquier momento en el aparato durante el período del fraguado. Las graduaciones del aparato incluyen la fuerza de compresión adicional resultante del calor desarrollado en idénticas condiciones en que el hormigón se endurecerá en la obra. Se da un ejemplo de la distribución de los puntos en que se toman las medidas en una grande presa (aproximadamente 300.000 m^3 y 280 m de longitud en la coronación). La fuerza de compresión será medida en este caso en los 76 puntos. La aplicación fué efectuada en 14 planos horizontales y 20 secciones verticales, igualmente distribuídos sobre la masa total.

Conjuntamente con la determinación de la cantidad de calor desarrollado durante el fraguado se averigua la temperatura también en los puntos de medida y si es necesario también las tensiones internas. Todos estos factores dan una idea exacta de la manera en que actúa el hormigón desde el punto de vista estático y termodinámico.

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

SPECIAL CEMENT*

Prof. Dr. Ing. O. KALLAUNER
Czechoslovakia

Experience with the use of portland cement for concrete dams built recently in Czechoslovakia is favorable. For the construction of the concrete dam at Vranov on the Dyje, the largest in the country, portland cement from two cement factories was used. The most uniform composition and properties were required of these cements. It was required that their fineness should not be excessive; it should correspond to a residue of about 8 percent on sieve no. 70. Further it was prescribed that the minimum tensile strength after 7 days should be 25 kg/cm^2, and after 28 days, 30 kg/cm^2; compressive strength after 7 days, 300 kg/cm^2, and after 28 days 400 kg/cm^2, on being stored in water in accordance with the standards for portland cements.

In the course of construction and after completion of the dam and filling the reservoir, no defects in the concrete were observed, nor have any been observed up to the present moment, resulting from excessive heat of hydration or from the action of water on the cement.

2. In Czechoslovakia the manufacture of special cements for water-retaining structures is in the course of development. Some sorts of normal portland cements with relatively low heat of hydration, also portland blast-furnace cements, and special cements for water-retaining structures, are coming to the fore.

The properties of the two last sorts of cement are given in table I.

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* *Ciment Spécial.*
Spezial-Zement.
Cemento Especial.

TABLE I

Cement	Portland blast-furnace cement		Special cement for water-retaining structures		
	A	B	C	D	E
Chemical analysis					
Insoluble residue in HCl, percent	1. 75	0. 32	27. 07	31. 10	26. 05
SiO_2	22. 80	29. 02			
Al_2O_3	11. 79	12. 04	11. 56	14. 74	11. 46
Fe_2O_3	1. 91	1. 46	1. 22	1. 41	2. 41
CaO	54. 86	50. 52	50. 56	44. 80	54. 30
MgO	2. 60	3. 69	3. 18	0. 49	1. 81
SO_3	1. 92	0. 85	1. 80	1. 52	1. 94
Loss on ignition, percent	2. 35	2. 20	4. 63	6. 20	2. 16
Heat of hydration					
Cal/g after 3 days	54	55	52	52	54
Cal/g after 7 days	69	64	57	55	59
Cal/g after 28 days	80	79	65	57	64
Standard properties					
Setting:					
a Initial set	3^h30^m	6^h	5^h50^m	2^h5^m	4^h50^m
b Final set	6^h5^m	8^h30^m	9^h35^m	4^h30^m	7^h40^m
At a temperature, °C	16–18	17–18	17–18	17–19	16–17
Water, percent	27. 0	30. 0	30. 0	35. 0	28. 0
Constancy of volume					
Test of pat, under water at normal temperature.	Good	Good	Good	Good	Good
Boiling test	Good	Good	Good	Good	Good
Drying test 110°C	Good	Good	Good	Good	Good
Steam test	Good	Good	Good	Good	Good
Le Chatelier test	1. 0	0. 5	1. 0	1. 0	0. 5
Fineness, percent					
Residue on sieve:					
No. 30	0. 20	0. 04	1. 40	0. 10	0. 05
No. 70	2. 10	1. 75	6. 80	4. 30	10. 50
Strength					
Water, percent	8. 75	8. 50	8. 50	9. 50	8. 00
Temperature, °C	16–18	16–18	16–18	17–19	16–18
Cured in water:					
Tensile strength after 7 days, kg/cm²	28. 9	32. 6	35. 1	31. 5	29. 0
Tensile strength after 28 days, kg/cm²	36. 3	39. 1	40. 1	41. 4	33 1
Compressive strength after 7 days, kg/cm²	328	300	334	332	302
Compressive strength after 28 days, kg/cm²	446	422	446	502	406
Cured in water and air:					
Tensile strength after 28 days, kg/cm²	42. 4	41. 7	45. 5	47. 7	42. 7
Compressive strength after 28 days, kg/cm²	514	476	482	526	500

3. Research into further possibilities for manufacturing special cements with low heat of hydration from suitable raw materials obtainable in the country, with especial regard to the production of mixed cements. Investigations into the relation between the composition, heat of hydration, constancy of volume, and resistance against dissolution by pure water.

Test methods:

Determination of hydration heats—solution and adiabatic methods.

Determination of the constancy of volume—combination of measuring with the Guttmann comparator, Bauschinger apparatus (for cements) and with Graf-Kaufmann apparatus (for mortar).

Determination of the resistance against dissolution of pure water—modified method according to Kühl, Parga-Poudal, Baentsch ("Zement", 1934, p. 69) (for mortar).

Studies on the destructive action of various chemical agents on different cement mortars and concretes, including also special cements for water structures.

4. Literature on special cements published in Czechoslovakia:

Prof. Dr. Ing. O. Kallauner and Ing. Dr. B. Bürgl: Hydration Heats of Cements ("Chemické Listy", 1935, p. 238; "Stavivo", 1935, p. 295). These articles deal in general with hydration heats of cements and their determination. The authors published the results of their tests on 12 different cements, including 2 special cements for water structures.

The authors measured the hydration heat indirectly by computing the heats which arise from the solution of cements in a mixture of nitric acid and hydrofluoric acid.

Equipment:

Platinum solution calorimeter (1.21).

Measuring of temperature: Beckmann's thermometer, which is protected from the influence of acids by a platinum shield.

Quantity tested: 2 g.

Dissolving liquid: 700 g $2nHNO_3 \div 10$ cm^3 HF (40%).

Total quantity of cement hydrated: 300 g.

Water added: 120 cm^3.

Placing temperature of cement: $35 \pm 0.3°$ C.

Results are shown in table II.

The authors also made chemical analyses of these cements, and determined their standard properties. They also ascertained that the results of hydration heat determined by tests do not sufficiently agree with the values calculated on the basis of their chemical composition (according to Bogue-Woods, Steinour-Starke, etc.).

In this article the authors examined qualitatively the course of the rise in temperature during setting and initial hardening, by using a special calorimeter, placed in a suitable, additionally insulated Dewar vessel. The rise in temperature was measured with a mercury thermometer divided in 0.1° C. Measuring was always carried out with 170 cm^3 of cement paste, made of 300 g of cement and 120 cm^3 of water. The temperature changes were recorded graphically. For certain sorts of cement, the curves have to some extent a characteristic course. In the case of portland blast-furnace cements and special cements for water structures, the course of heat evolution is calmer and is of longer duration.

TABLE II

No.	Kind of cement	Hydration heat evolved		Cal/g after 28 days
		3	7	
1	Aluminum cement (clinc)	83	89	94
2	Portland cement, rapid hardening	74	83	88
3	Normal portland cement	70	74	78
4	Normal portland cement	70	83	87
5	Normal portland cement	67	80	85
6	Normal portland cement	72	80	89
7	Normal portland cement	60	67	76
8	Iron portland cement	61	84	91
9	Portland blast-furnace cement	54	69	80
10	Portland blast-furnace cement	55	64	79
11	Special cement for water structures	52	55	57
12	Special cement for water structures	52	57	65
13	Special cement for water structures [1]	54	59	64

[1] The results of tests of this special cement are not published in the above article.

SUMMARY

This report gives concise information on points 1 to 4 of Question III, dealing with the following matters:

1. A short summary of the latest available experience in the normal use of portland cement, particularly with regard to unsatisfactory results arising from excessive heat of hydration, and to deterioration of the concrete caused by the action of water on the cement.
2. A detailed account of the present situation and of the experience acquired, more particularly with reference to the manufacture and use of special cements for large dams, giving data of the chemical, physical, and mechanical characteristics of these cements, including results of tests carried out by the routine methods to be recommended by the International Subcommittee on Special Cements, as well as by other appropriate tests.
3. An account of the program for future development and for research work in regard to special cements.
4. A bibliography giving short extracts of the most important recent literature published in the country submitting the report.

RESUME

(*1*) Expériences sur l'emploi des ciments Portland dans les constructions récentes, en Tchécoslovaquie, des grands barrages en béton, sont favorables. Pour la construction du plus grand barrage en béton, celui de Vranov sur la Dyje, on a employé le ciment Portland de deux fabriques. On a exigé de ce ciment une composition et des propriétés aussi constantes que possible. On a exigé que la finesse de mouture ne soit pas trop grande (Residu d'environ 8% au tamis No. 70, soit 4.900 au cm^2). On a prescrit une résistence minimum à la traction et à la compression. On n'a pas constaté le moindre défaut du béton dû soit à la chaleur excessive d'hydratation, soit à l'effet de l'eau sur le ciment.

(*2*) Fabrication des ciments spéciaux pour les constructions hydrauliques est en progrès en Tchécoslovaquie. On considère plusieurs sortes de ciments Portland courants, ceux à basse chaleur d'hydratation, des ciments de hauts fourneaux et enfin des ciments spéciaux appropriés aux constructions des grands barrages.

(*3*) Recherches de nouvelles possibilités de fabrication de ciments spéciaux à basse chaleur d'hydratation, avec addition de matériaux appropriés, spécialement en ce qui concerne la fabrication des ciments mixtes. Étude suivie des rapports entre la composition, la chaleur d'hydratation, la constance du volume et la résistance à l'action des eaux. Étude des influences corrosives de divers produits chimiques sur différents mortiers de ciment et sur des bétons, y compris les ciments spéciaux pour les constructions hydrauliques.

(*4*) Publications sur les ciments spéciaux, en Tchécoslovaquie: Le Prof. Dr. Ing. O. Kallauner et l'Ing. Dr. B. Bürgl ont publié: "Les Chaleurs d'hydratation des ciments" (Chemické Listy, 1935, page 238; Stavivo 1935, page 295).

Dans ce travail sont traitées les chaleurs d'hydratation des ciments en général ainsi que leur détermination. Ils publient les résultats de leurs essais sur 12 ciments, parmi lesquels se trouvaient aussi 2 ciments spéciaux pour les constructions hydrauliques. Les auteurs ont déterminé aussi les analyses chimiques de ces ciments et leurs propriétés standardisées. On a constaté que les chaleurs d'hydratation déterminées par des essais ne concordent pas suffisament avec les résultats calculés d'après la composition chimique.

Les auteurs ont suivi qualitativement le cours de l'accroissement de la température pendant la prise et le durcissement initial. Les changements de température sont représentés graphiquement. Pour certaines sortes de ciment, les courbes ont une forme caractéristique.

ZUSAMMENFASSUNG

(Zu Punkt 1). Die Erfahrungen mit der Verwendung der Portlandzemente bei den in letzter Zeit ausgeführten Betontalsperrenbauten sind günstig. Zum Bau der derzeit grössten Talsperre aus Beton in der Tschechoslovakei in Vranov an der Thaya wurde Portlandzement aus zwei Fabriken verwendet. Es wurde eine nach Möglichkeit ständig gleiche Zusammensetzung und gleiche Eigenschaften verlangt. Die Mahlfeinheit sollte nicht übertrieben fein sein (Rückstand ungef. 8% auf dem Siebe Nr. 70 (4.900 Maschen)). Anders wurden bestimmte minimale Festigkeiten vorgeschrieben. Es wurden keine Betonfehler konstatiert, die durch grössere Hydratationswärmen oder durch Wassereinfluss hervorgerufen werden sollten.

(Zu Punkt 2). In der Tschechoslovakei ist die Erzeugung der Spezialzemente für Wasserbauten in der Entwicklung. Es machen sich hier einige Gattungen der normalen Portlandzemente mit verhältnismässig niedrigeren Hydratationswärmen geltend, weiter Hochofenzemente und schliesslich Spezialzemente für Wasserbauten.

(Zu Punkt 3). Es wird geplant, Forschung über weitere Möglichkeiten der Erzeugung von Spezialzementen mit niedrigen Hydratationswärmen aus geeigneten Rohstoffen besonders mit Rücksicht auf Erzeugung der Mischzemente vorzunehmen. Es sollen die Abhängigkeiten zwischen der Zusammensetzung, Hydratationswärmen, Raumbeständigkeit und Beständigkeit gegen Auslaugen studiert werden. Anders arbeitet man über Korrosionseinflüsse verschiedener chemischen Mittel auf verschiedene Zementmörtel und Betone, unter anderem auch auf solche aus Spezialzementen für Wasserbauten.

(Zu Punkt 4). Veröffentlichte Abhandlungen in der Tschechoslovakei, welche Spezialzemente betreffen: Prof. Dr. Ing. O. Kallauner und Dr. Ing. B. Bürgl: Hydratationswärmen der Zemente (Chemické Listy, 1935, S. 238; Stavivo, 1935, S. 295).

In dieser Arbeit werden allgemein die Hydratationswärmen der Zemente und ihre Bestimmung behandelt. Es werden die Ergebnisse der eigenen Bestimmungen bei 12 verschiedenen Zementen angeführt; unter diesen sind auch 2 Spezialzemente für Wasserbauten. Sonst wurde gleichzeitig die chemische Zusammensetzung und Normeneigenschaften dieser Zemente bestimmt. Es wurde unter anderem gefunden, dass die Ergebnisse der versuchsmässig bestimmten Werte der Hydratationswärmen nicht gehörig mit den aus der chemischen berechneten Werten übereinstimmen. In dieser Arbeit wurde der Verlauf des Temperatursansteigens während des Abbindens und Anfangserhärtens qualitativ verfolgt und in Kurven gezeichnet. Diese haben für bestimmte Zementgattungen gewissermassen eine charakteristische Form.

RESUMEN

Esta memoria suministra datos sobre las siguientes materias:

1. Experiencias sobre el empleo de los cementos portland en las construcciones recientes de grandes presas de hormigón, en Checoeslovaquia, las cuales son favorables. Para la construcción de la presa de hormigón de Vranov en el Dyje, la más grande del país, se ha empleado cemento portland de dos fábricas. Se exigió que los cementos fueran de composición y propiedades lo más uniformes posible. Se exigió que la finura de la molienda no fuese demasiado grande (Residuo de unos 8% al tamiz No. 70, es decir 4.900 kg/cm^2). Se prescribió una resistencia mínima a la tracción y a la compresión. No se ha descubierto el menor defecto del hormigón debido al calor excesivo de hidratación o al efecto del agua en el cemento.

2. En Checoeslovaquia se está desarrollando la fabricación de cementos especiales para construcciones hidráulicas. Están siendo consideradas algunas clases de cementos portland corrientes, que producen poco calor de hidratación, los cementos de altos hornos y, por último, los cementos especiales apropiados a las construcciones de grandes presas.

3. Estudio de las nuevas posibilidades de fabricación de cementos especiales que producen poco calor de hidratación, con la adición de materiales apropiados, especialmente en cuanto se refiere a la fabricación de los cementos mixtos. Estudio seguido de la relación entre la composición, el calor de hidratación, la constancia del volumen y la resistencia a la acción de las aguas. Estudio de las influencias corrosivas de diversos productos químicos en los diferentes morteros de cemento y en los hormigones, incluyendo los cementos especiales para las construcciones hidráulicas.

4. Trabajos sobre cementos especiales publicados en Checoeslovaquia: El Prof. Dr. Ing. O. Kallauner y el Ing. Dr. B. Bürgl han

publicado: "Los calores de hidratación de los cementos" (Chemické Listy, 1935, página 238; Stavivo, 1935, página 295).

En este trabajo se tratan los calores de hidratación de los cementos en general así como también su determinación. Publicaron los resultados de sus ensayos con 12 cementos, entre los cuales se encuentran también 2 cementos especiales para las construcciones hidráulicas. Los autores han determinado también los análisis químicos de estos cementos y sus propiedades normales. Se ha averiguado que los calores de hidratación, determinados por los ensayos, no concuerdan suficientemente con los resultados calculados a base de la composición química.

Los autores han seguido cualitativamente el curso del aumento de la temperatura durante el fraguado y el endurecimiento inicial. Los cambios de temperatura se representan gráficamente. Para ciertas clases de cemento, las curvas tienen una forma característica.

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

TEMPERATURE EFFECTS IN MASS CONCRETE*

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Measurement of Heat of Hydration of Cement

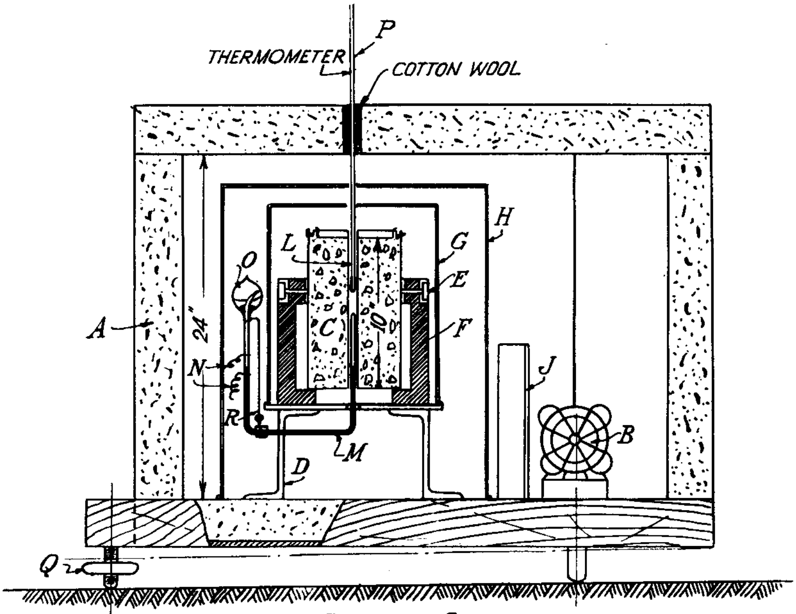
Of the various methods at present available for determining the heat of hydration of cements and the consequent rise in temperature produced in large masses of concrete during hardening, those of adiabatic calorimetry are possibly the most useful since they offer the advantage that the same mix can be employed as would be used in practice and the thermal history of the concrete specimen reproduces the thermal history of the concrete in the interior of a large mass of concrete.

Low-loss calorimeters and semiautomatic adiabatic calorimeters have been used by various investigators. A wholly automatic type of apparatus is, however, desirable. One such apparatus [1] has been in use for some years at the Building Research Station, but the equipment is rather costly. As a result of investigations made for the British Subcommittee on Special Cements a simple and much cheaper form of calorimeter has been built. This apparatus has been described in detail elsewhere.[2] Its general layout is shown in figure 1, and it will be noted that use is made of a differential vapor pressure regulator for controlling the temperature of the calorimeter. A detailed drawing of this regulator is shown in figure 2.

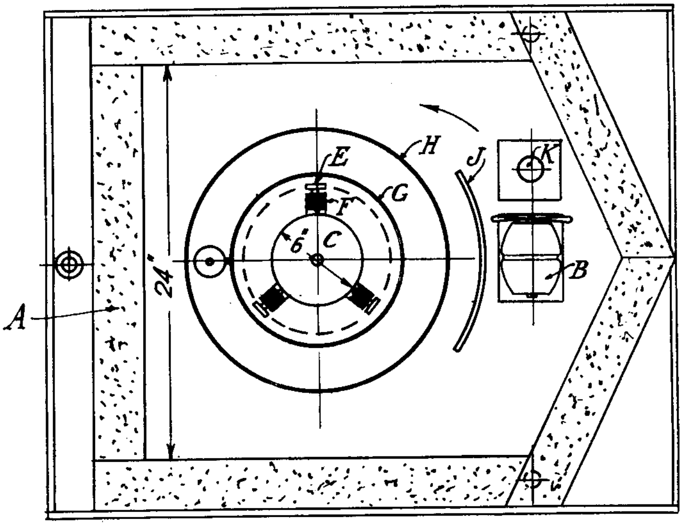
**Effets de la température sur le béton de masse.*
Temperatureffekt in Betonmassen.
Efectos de la temperatura en la masa de hormigón.

[1] *Davey, N. Temperature Rise of Concrete. Concrete Constr. Eng. 1931, 26 (10) 572–575.*

[2] *Davey, N., and Webster, C. T. A Simple Form of Adiabatic Calorimeter. The Structural Engineer, 1935, XIII, 7, 302–304.*



SECTIONAL ELEVATION.



PLAN.

FIGURE 1.—**Adiabatic calorimeter.** — Calorimètre adiabatique. — Adiabatischer Calorimeter. — Calorímetro adiabático.

A. Cork box.
B. Electric fan.
C. Concrete sample.
D. Tripod.
E. Set screws.
F. Ebonite supports.
G. Inverted copper can.
H. Metal screen.
J. Asbestos screen.
K. Lamp.
L. Copper foil tube.
M. Thermo regulator.
N. Mercury contacts.
O. Mercury reservoir.
P. Thermometer.
Q. Levelling scale.
R. Plummet and scale.

In table 1 are shown the ranges in the values for the heat liberated by a number of samples of commercial cements, during the first 3 days of the hydration process. The tests were made at the Building Research Station on concrete mixes composed of one part of cement, two parts of river sand, and four parts of river gravel by weight, with 60 percent of water by weight of the cement. It will be seen that the ranges for the normal portland cements and the rapid-hardening portland cements overlap, and there is at present no specified line of demarcation between them. The term "rapid hardening" appears to have been applied rather indiscriminately to some portland cements; it has been a common experience to find that some portland cements

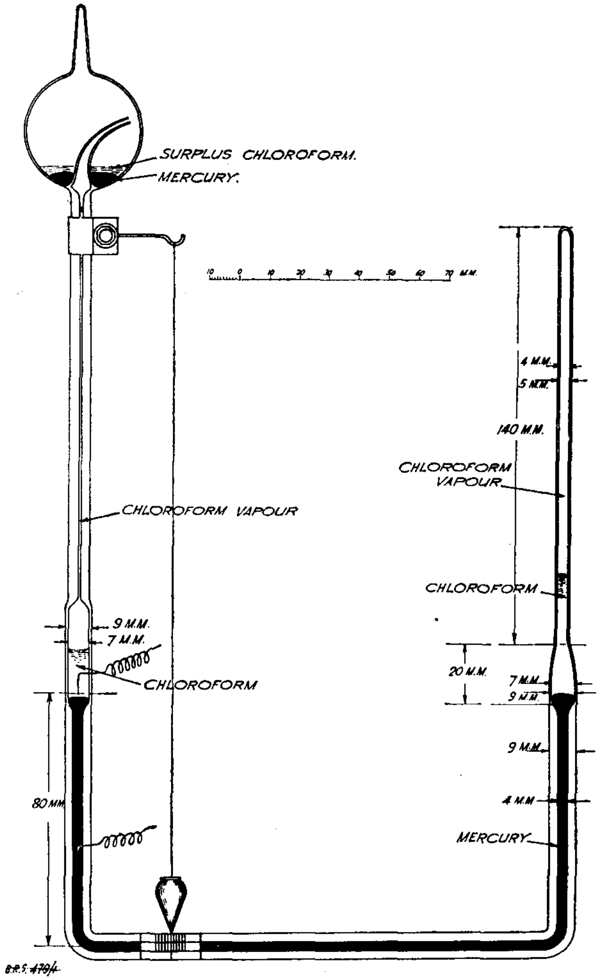


FIGURE 2.—**Chloroform vapor thermo-regulator.**—Thermo-régulateur à vapeur de chloroforme. —Chloroform-Dampf-Wärmeregler. — Termo-regulador de vapor de cloroformo.

of the normal type are superior as regards mechanical properties and may have a higher heat evolution than some cements of the so-called rapid-hardening type.

TABLE 1.—*Heat evolved by different types of cement*

Type of cement	Number of consignments tested	Heat evolved in g/calories per g cement at the end of—		
		1 day	2 days	3 days
Normal portland cement	13	23–46	42–65	47–75
Rapid-hardening portland cement	13	35–71	45–89	51–94
Portland blast-furnace cement	6	18–28	30–51	33–67
High alumina cement	3	77–93	78–94	78–95

Portland blast-furnace cements evolve heat more slowly than the portland cements in the initial stages, but at the end of 3 days the amount of heat generated approaches a similar value in some cases. High-alumina cements, on the other hand, evolve heat very rapidly during the first 24 hours, but the amount evolved subsequently is very small. On account of the consequent very rapid rise in temperature experienced with high-alumina cements it is advisable either to restrict their use to masses from which the heat generated during the

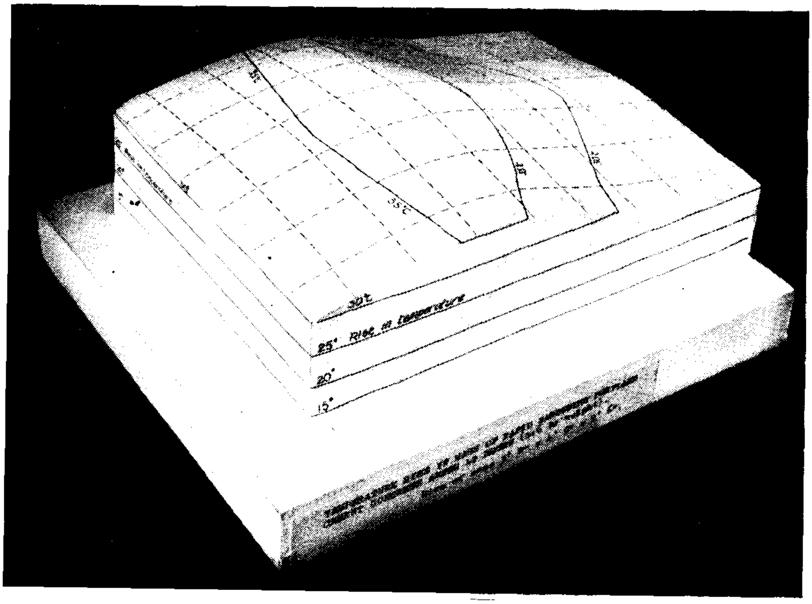


FIGURE 3.—**Temperature rise in rapid-hardening portland cement concrete after 42 hours.** — Elévation de température du béton de ciment P. à prise rapide au bout de 42 heures. — Temperaturansteig in Beton aus schnell-erhärtendem Portland-Zement nach 42 Std. — Aumento de temperatura en el hormigón de cemento portland de fraguado rápido después de 42 horas.

process of setting and hardening can be readily dissipated or to make some special arrangements for temperature control. It has been shown[3] that unless this is done the strength of high-alumina cement concrete may be seriously impaired.

TEMPERATURE DISTRIBUTION IN MASS CONCRETE

In very large masses of concrete the central portion of the mass loses heat very slowly and the concrete is cured under almost adiabatic conditions; as a result very high temperatures may be reached. The rise in temperature will depend on the type of cement used, as indicated by the figures in table 1, the mix proportions, the size of mass of the concrete, the rate of placing, the insulation afforded by the shuttering, and the external conditions.

Some attention has been given at the Building Research Station to the effect of heat evolution on the strength and other properties of concrete[3] and the photographs shown in figures 3 and 4 illustrate the results obtained on a mass of concrete measuring 3 feet by 4 feet by 2 feet 6 inches high. The first photograph, figure 3, is of a model which was constructed to represent the temperatures at various points across the horizontal midsection of the concrete after 42 hours. The proportions of mix by weight were one part of rapid-hardening port-

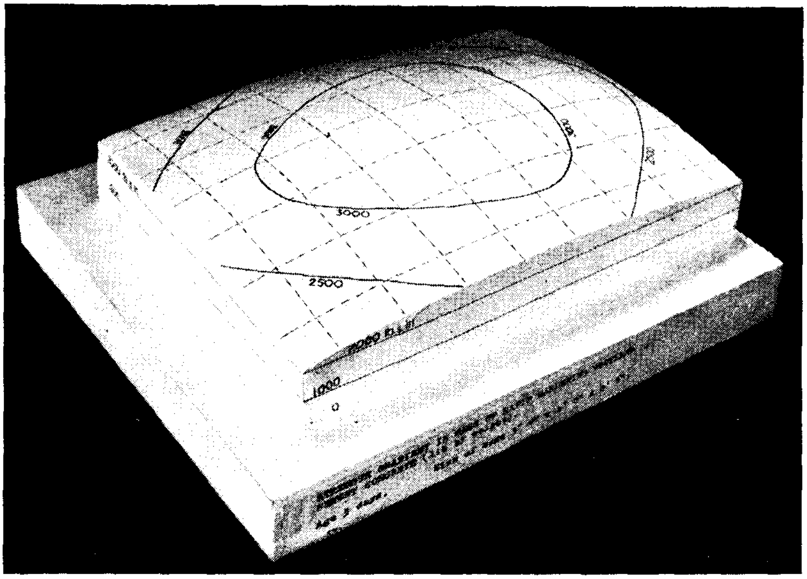


FIGURE 4.—**Strength distribution in rapid-hardening portland cement concrete after 3 days.** — Repartition de la résistance du ciment P. à prise rapide après 3 j. — Festigkeitsverteilung in Beton aus schnellerhärtendem Portland-Zement. — Distribución de la resistencia en el hormigón de cemento portland de fraguado rápido después de 3 días.

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[3] *Davey, N.: Influence of Temperature Upon the Strength Development of Concrete. Building Research Technical Paper No. 14, 1933.*

land cement, two parts of river sand, and four parts of gravel, and the water-cement ratio was 0.6 by weight.

The height of the model at each point represents the temperature rise at that point above the external air temperature. It will be seen that the temperature increase is higher at the center than at the edges where the loss of heat through the shuttering occurred. The second photograph, figure 4, represents the effect of this temperature gradient on the strength of the concrete after 3 days at various points across the same section of the concrete. The strengths were obtained from cubes of concrete which were cast in the mass of the concrete in specially prepared moulds. It will be seen that in the same way as the temperature was higher at the centre of the mass, the strength is also higher, and is over 50 percent greater at the center than at the corners.

Since both shrinkage and creep vary with strength it is reasonable to suppose that they also will vary throughout the mass of the concrete. In addition, concrete in large masses hardens at a time when the temperature increase, due to heat evolution, is considerable and consequently the return of the concrete to normal temperature, which in some cases may take many months or even years, must be accompanied by a heat contraction which is additional to any shrinkage effects.

PREDICTION OF TEMPERATURE RISE

It is particularly desirable that these temperature effects in mass concrete should be reduced to a minimum by the use of selected cement and by the careful design of the concrete mix, and that it should be possible to predict from the results of laboratory tests of the cement the temperatures that may be attained in a mass of concrete made with it. The study of the problem at the Building Research Station[4] has therefore been extended with the object of obtaining records of the temperatures attained in the concrete of three large dams, and to compare these records with the time-temperature curves given by laboratory tests of the cements used for these works. Although further tests are needed before an exact correlation can be established, approximate relations can already be given which may be used for the tentative prediction of the temperatures that will be reached in a large mass of concrete made with a given cement.

The observations may be conveniently grouped into two series: One series made on concrete deposited in the Tongland and Clatteringshaws Dams of the Galloway Water Power Works, and the other series on concrete deposited in the Laggan Dam of the Lochaber Water Power Works. The first-mentioned series of observations was made by Messrs. Sir Alexander Gibb and Partners and the other series by Messrs. Meik and Halcrow, who, in each respective case, were the consulting engineers.

The Tongland Dam, across the River Dee, near Kirkcudbright, is about 850 feet in length and includes an arch dam in reinforced concrete and a gravity section. The Clatteringshaws Dam is of the gravity type and has a total length of 1,450 feet across the Blackwater

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[4] *Davey, N.: Correlation Between Laboratory Tests and Observed Temperatures in Large Dams. Building Research Technical Paper No. 18, 1935.*

TABLE 2.—*Chemical analyses of the cements*

Structure	Cement		SiO_2	CaO	Al_2O_3	Fe_2O_3	TiO_2	MgO	Na_2O	K_2O	SO_3	Igneous loss	Free lime	Total
	Type	Batch												
Tongland Dam	Normal portland cement.	$P^{13}/10$	22. 84	63. 85	4. 76	2. 92	0. 27	0. 63	0. 50	0. 46	2. 00	1. 94	2. 2	100. 17
Do	Rapid-hardening portland cement.	$F^{13}/11$	23. 88	62. 90	5. 29	2. 64	. 27	. 92	. 26	. 36	1. 84	2. 06	2. 5	100. 42
Do	do	$F^{13}/15$	21. 98	64. 17	5. 34	2. 5	. 31	. 87	. 35	. 66	1. 29	2. 29		99. 76
Do	do	$F^{13}/19$	21. 46	63. 80	5. 66	2. 81	. 38	. 83	. 26	. 36	2. 18	3. 29		100. 03
Clatteringshaws Dam.	Portland blast-furnace cement.	$C^7/20$	23. 50	58. 85	6. 79	2. 58	. 28	3. 43	. 74	. 48	1. 56	1. 42		99. 63
Tongland Dam	Normal portland cement.	$P^{13}/16$	21. 02	62. 20	5. 90	2. 47	. 25	. 77	. 18	. 85	2. 26	3. 85		[a] 99. 80
Laggan Dam	do	63	21. 78	63. 50	5. 48	2. 86	. 41	1. 00	. 26	. 67	1. 70	2. 58		100. 24
Do	do	64	21. 96	63. 30	5. 69	2. 74	. 47	1. 01	. 27	. 64	2. 02	2. 34		100. 44
Do	do	66	21. 78	63. 50	5. 46	2. 78	. 44	. 98	. 25	. 58	2. 02	2. 43		100. 22

[a] Includes Mn_2O_3 0.05 percent.

TABLE 3.—*Heat tests made in the laboratory; tests carried out on completely insulated samples of concrete*

Structure	Cement		Heat evolved by samples of 1:2:4 concrete (by weight) w/c ratio 0.60 (by weight) placed at 17° C. calories per gm				Temperature rise in sample of the concrete as used on the job and placed at the same temperature								Placing temperature ° F.
	Type	Batch	1 day	2 days	3 days	7 days	1 day		2 days		3 days		7 days (Ta7)		
							° C.	° F.	° C.	° F.	° C.	° F.	° C.	° F.	
Tongland Dam	Normal portland cement	P¹³/10	32. 6	49. 4	58. 0	68. 6	16	29	26	47	31	55	36	65	50
Do	Rapid-hardening portland cement.	F¹³/11	34. 6	44. 6	50. 6	56. 2	11	20	19	34	23	41	29	52	45
Do	do	F¹³/15	32. 2	48. 4	54. 2	60. 0	12	22	20	36	23	41	29	52	55
Do	do	F¹³/19	29. 0	41. 2	45. 0	51. 2	18	33	23	41	24	43	28	50	73
Clatteringshaws Dam.	Portland blast-furnace cement	C⁷/20	28. 4	46. 2	56. 4	69. 0	7	12	16	29	22	39	30	54	65
Tongland Dam	Normal portland cement	P¹³/16					11	20	18	33	23	41	30	54	50
Laggan Dam	do	60					13	23	19	34	23	41	30	54	60
Do	do	63	30	47	56	67. 6	12	22	19	34	23	41	30	54	68
Do	do	64	32. 8	48	55	64. 4	12	21	18	33	23	41	30	54	63
Do	do	66					15	27	21	37	24	43	32	58	65

of Dee. The Laggan Dam, near Fort William, is approximately 700 feet long and 138 feet high, and is of the gravity type. In the Tongland and Clatteringshaws Dams the concrete was placed in lifts varying in depth from 4 feet 6 inches to 6 feet and in the Laggan Dam from approximately 3 feet 3 inches to 3 feet 9 inches.

It was possible to observe the temperature rise in masses of concrete placed in the Tongland and Clatteringshaws Dams. The observations were made by inserting a maximum thermometer in a pipe embedded in the mass. Details of the masses are given in tables 4 and 5.

Each mass constituted a lift poured in one operation, the depth of the lift varying from 4 feet 6 inches to 6 feet. Class O concrete (3 hundredweight cement, 12 cubic feet Gatehouse sand, and 20 cubic feet of Porphyrite aggregate) was used in all the masses, except at the Clatteringshaws Dam in which 12 percent of displacers were added. Samples of the cement and aggregates were forwarded to the Building Research Station and the temperature rise was measured on completely insulated samples of concrete using the same mix as used in the actual masses. Chemical analyses of the cements and a record of the heat tests are given in tables 2 and 3.

In the Laggan Dam the temperatures were observed in the central portion of the dam by means of a series of Cambridge resistance thermometers. The concrete was placed in lifts of approximately 3 feet 6 inches and the mix contained 370 pounds of cement per cubic yard. The water added to each batch varied considerably and depended on the amount of moisture present in the sand and aggregate, but the mix was of a stiff consistence. The granite displacers averaged approximately 5 percent of the total mass of concrete deposited. The shuttering was of tongued and grooved timber 2 inches thick with necessary bracing. The freshly deposited concrete was covered with heavy coconut matting immediately after placing. This matting was kept wet until it was necessary to lift it for placing the succeeding lift.

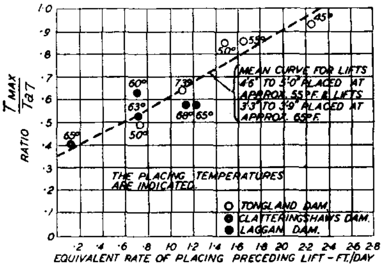

FIGURE 5.—**Temperature rise in mass concrete.** —Elevation de température dans une masse de béton. — Temperaturansteig in einer Betonmasse. — Aumento de temperatura en la masa de hormigón.

An examination of the rise in temperature at the interior of lifts of concrete shows that in the majority of instances, particularly in the Laggan-Trieg tests, two peaks are reached. The first rise in temperature is very rapid and, in actual practice, may exceed in rapidity the rise recorded on samples of similar concrete placed at the same temperature and cured in the laboratory under adiabatic conditions; the reason being that a certain amount of heat is received from the

TABLE 4.—*Details of concrete masses*

Structure	Cement		Mix			Depth of lift		Depth of embedment of thermometer below surface		Duration of pour	Protection to concrete
	Type	Batch	Cement	Sand	Stone						
			Cwt.		*Cu. ft.*	*Ft.*	*in.*	*Ft.*	*in.*	*Hours*	
Tongland Dam	Normal portland cement	$P^{13}/10$	3	12 cu. ft. (1:3:5) nominal.	20	4	6	2	3	8¼	Damp sacks for 7 days.
Do	Rapid-hardening portland cement.	$F^{13}/11$	3	12 cu. ft. (1:3:5)	20	6	0	3	0	8	Damp sacks for 3 days.
Do	do	$F^{13}/15$	3	12 cu. ft. (1:3:5)	20	4	6	2	3	8	Damp sacks for 5 days.
Do	do	$F^{13}/19$	3	12 cu. ft. (1:3:5)	20	4	6	2	3	8	Damp sacks for 5 days.
Clatteringshaws Dam.	Portland blast-furnace cement.	$C^{7}/20$	3	12 cu. ft. (plus 12% displacers.)	20	4	6	2	6	15½	Damp sacks for 4 days.
Tongland Dam	Normal portland cement	$P^{13}/16$	3	12 cu. ft. (1:3:5)	20	4	6	2	3	6	Cement bags.
			Cu. ft.								
Laggan Dam	do	60	[a] 9.36	20 cu. ft. (plus 3% displacers.)	53.5	3	2½	2	6	23	([b]).
Do	do	63	[a] 9.36	20 cu. ft. (plus 4% displacers).	53.5	3	3½		9	27½	([b]).
Do	do	64	[a] 9.36	20 cu. ft. (plus 6% displacers).	53.5	3	8½	1	9	17	([b]).
Do	do	66	[a] 9.36	20 cu. ft. (plus 3% displacers).	53.5	3	6	3	0	27	([b]).

[a] 370 pounds of cement per cubic yard concrete. 40 gallons water for cements no. 60 and 63. 35 gallons water for cement no. 64. 34 gallons water for cement no. 66.

[b] Fresh concrete covered with coconut matting immediately after placing was completed, and left in position until the succeeding lift was poured.

TABLE 5.—*Temperatures observed in structure and details of preceding and succeeding lifts*

Structure	Cement		Observed maximum temperatures		Ratio $\frac{T_{max.}}{T_{a7}}$	Ratio $\frac{T'_{max.}}{T_{a7}}$	$\frac{T'_{max.}-T_{max.}}{T_{max.}}$	Details of preceding lift				Details of succeeding lift			
	Type	Batch	$T_{max.}$	$T'_{max.}$				Depth		Age	Equivalent rate of placing	Depth		Time before placing	Equivalent rate of placing
			°F.	°F				*Ft.*	*in.*	*Days*	*Ft./day*	*Ft.*	*in.*	*Days*	*Ft./day*
Tongland Dam	Normal portland cement.	P ^{13}/10	55	37	0. 85	0. 57	−0. 33	4	6	3	1. 5	5	3	13	0. 4
Do	Rapid-hardening portland cement.	F ^{13}/11	48	56	. 93	1. 07	+. 15	4	6	2	2. 25	5	3	3	1. 75
Do	do	F ^{13}/15	44	44	. 85	. 85	0	5	0	3	1. 66	4	6	5	. 9
Do	do	F ^{13}/19	32	19	. 64	. 38	−. 40	4	6	4	1. 125	4	6	5½	. 8
Clattering-shaws Dam.	Portland blast-furnace cement.	C ^{7}/20	22	19. 5	. 40	. 36	−. 10	2	6	21	. 12	4	6	5½	. 8
Tongland Dam	Normal portland cement.	P ^{13}/16	26	8	. 48	. 15	−. 69		6	6	. 75	4	6	14½	. 3
Laggan Dam	do	60	34	42	. 63	. 78	+. 24	3	7	5	. 72	3	6	5	. 7
Do	do	63	31	42	. 57	. 78	+. 37	3	6	3	1. 17	3	8½	4	. 92
Do	do	64	28	47	. 52	. 87	+. 67	3	3½	4½	. 73	3	6	3	1. 17
Do	do	66	33	46	. 57	. 79	+. 39	3	8½	3	1. 23	3	7	4½	. 8

preceding lift. The first rise is followed by a less rapid fall in temperature, but this fall is arrested by the heat received from the succeeding lift of concrete and a second peak temperature is experienced.

As a general conclusion it may be stated that in placing concrete in lifts of equal thickness and of the same proportions of mix, the first peak temperature $T_{max.}$ in any particular lift is dependent upon the age of the preceding lift and the second peak temperature $T'_{max.}$ is dependent upon the time interval before the succeeding lift is placed.

In table 5 these peak temperatures ($T_{max.}$ and $T'_{max.}$) are expressed as ratios of the temperature rise in a completely insulated sample after 7 days (T_{a7}). Figure 5 gives the relation between the ratio $\frac{T_{max.}}{T_{a7}}$ and the equivalent rate of placing the preceding lift. In figure 6 is given the relation between the ratio $\frac{T'_{max.} - T_{max.}}{T_{max.}}$ and the rate of placing the succeeding lift. If, then, the value T_{a7} is known it is possible to determine with very fair accuracy the temperature rise likely to occur in a mass of concrete of similar thickness and placed under similar temperature conditions as those recorded here.

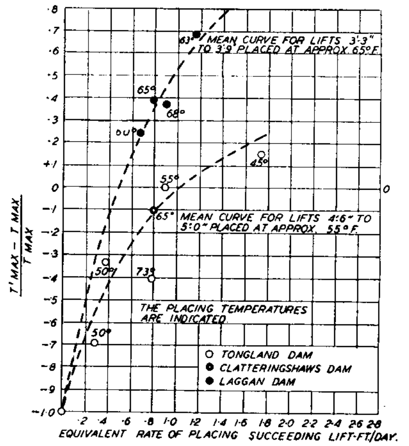

Figure 6.—**Temperature rise in mass concrete.** — Élévation de température dans une masse de béton. — Temperaturansteig in einer Betonmasse. — Aumento de temperatura en la masa de hormigón.

In table 6 the estimated temperature rise (°F.) in mass concrete placed in lifts approximately 5 feet in thickness at an average mix temperature of between 55° and 60° F. has been determined from figures 5 and 6 for mixes of varying cement content. Knowing, then, the cement content of the mix in pounds per cubic yard of finished concrete (Q), the equivalent rate of placing the concrete (R) and the heat evolved by the cement at 7 days (C), it is possible to obtain an estimate of the maximum temperature rise (t) likely to occur in the mass, assuming that the boundary conditions remain approximately

TABLE 6.—*Estimated temperature rise (° F.) in mass concrete placed in lifts approximately 5 feet in thickness at an average mix temperature of between 55° and 60° F.*

Time interval between lifts (days)	Equivalent rate of placing (ft./day = R)	Cement content of mix—lb./cu. yard finished concrete = Q																								
		300					350					400					450					500				
		Heat evolved by cement at 7 days—calories/gm = C.																								
		40	50	60	70	80	40	50	60	70	80	40	50	60	70	80	40	50	60	70	80	40	50	60	70	80
2	2.5	$t =$ 33	41	50	58	66	39	48	58	67	77	44	55	66	77	88	50	62	74	87	99	55	69	83	96	110
3	1.67	22	28	33	39	44	26	32	39	45	52	29	37	44	52	59	33	41	50	58	66	37	46	55	65	74
4	1.25	17	21	25	29	33	19	24	29	34	38	22	27	33	38	44	24	31	37	43	49	27	34	41	48	55
5	1.0	13	17	20	23	26	16	19	23	27	31	18	22	26	31	35	19	25	30	35	40	22	28	33	39	44

the same. For the conditions of placing outlined above the rise in temperature is found to be given quite closely by the relation:

$$t=k\times Q\times R\times C,$$

k being a constant over the range investigated and equal to 0.0011.

In the case of the Pine Canyon Dam recently constructed in the United States of America, there is sufficient published data[5][6] to afford a check on this empirical relation.

The following values are reported:

$Q=357$ pounds cement per cubic yard finished concrete,
$R=1.67$ feet per day (5-foot lift at 3-day intervals),
$C=55$ calories per gm cement at 7 days.

The estimated temperature rise would therefore be.

$$\begin{aligned} t&=0.0011\times Q\times R\times C\\ &=0.0011\times 357\times 1.67\times 55\\ &=36^\circ \text{ F.}\end{aligned}$$

This value of 36° F. agrees with the maximum rise that was observed 3 months after placing the concrete at the center of the dam where it was 210 feet in thickness.

CRACKING

The existence of high temperatures in the heart of the dam with a much lower temperature at the surface must result in the development of high stresses near the surface. It is therefore essential that some idea of the maximum temperature rise that can be allowed without the formation of cracking, due to temperature, should be obtained. Observations made on the Laggan Dam have been helpful on this point.

An examination of the Laggan Dam conducted by Halcrow[7] showed that the date at which the cracks developed corresponded very closely with the date at which the maximum difference in temperature occurred between the concrete in the heart of the dam and at the surface. This, he states, corresponded with the date at which the concrete in the heart attained its second maximum temperature ($T'_{max.}$). In the case of block IV south of the dam, this date was 4 to 5 weeks after depositing the concrete in the heart of the block.

An examination of the temperatures recorded at points nos. 5, 4, and 3, 3 feet, 23 feet, and 43 feet, respectively, from the upstream face of the dam during the 10 days following July 27, 1933, is interesting in that it shows how quickly the gradient changed near the surface of the dam.

The gradient observed on August 6, 1933, is shown in figure 7. From a point about 10 feet in the mass to the exposed surface the gradient is seen to be about 50° F. The difference in temperature

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[5] *Morris, S. Pasadena Builds Pine Canyon Dam. Civ. Eng., 1933, 3, (6) 309–313.*

[6] —— *Low Heat Cement for Dams. American Waterworks Association J., 1933, 25 (10) 1350–1361.*

[7] *Halcrow, W. T. The Design of Concrete Dams, With Special Reference to Deterioration Due to Moorland Water. Engineering, 1934, 137 (3568), 637; also private communication to Building Research Station.*

TABLE 7

	Thermometer no.			Air temperature
	3	4	5	
1933	° *F.*	° *F.*	° *F.*	° *F.*
July 27	109	106½	108	62
July 29	109	107	97	54
July 31	108½	107	90	60
Aug. 2	108	107	88	54
Aug. 4	108½	108	84	55
Aug. 6	108½	108	83	55

between the heart of the dam and the air at the exposed surface approached 55° F. This amount is not entirely due to the rise in temperature of the concrete due to the heat of hydration (approximately 45° F.) but also to a fall in the average air temperature of about 10° F. Cracks became visible in the concrete by the end of the month, but Halcrow states that the cracks had not penetrated as far as the inspection gallery, situated 8 to 11 feet from the upstream face of the dam, at the end of 20 months. The cracks are therefore confined to the surface and seem to be definitely accounted for by the development of the sharp temperature gradient in this region.

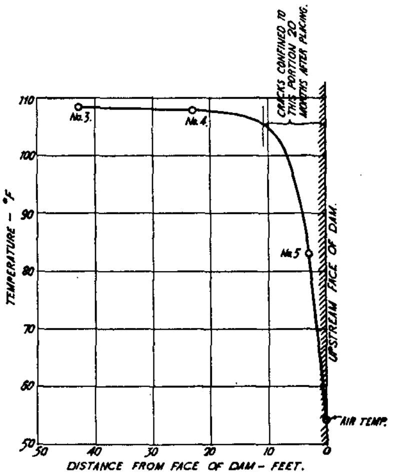

FIGURE 7.—**Temperature gradient in Laggan Dam, on August 6, 1933.** — Courbe des températures dans le Barrage de Laggan au 6 août 1933. — Temperaturabfall in der Laggan-Talsperre am 6. August 1933. — Curva de las temperaturas en la Presa de Laggan el 6 de agosto de 1933.

Taking a value for the effective modulus of elasticity of 1×10^6 pounds per square inch [8] for the concrete which had an average compressive strength of approximately 2,800 pounds per square inch at 28 days, and a coefficient of thermal expansion of 6×10^{-6} per 1° F., the tensile stress set up due to the temperature gradient alone would probably exceed 300 pounds per square inch. This value is excessive and would result in cracking. If the risk of cracking is to be reduced to within reasonable limits the tensile stress in the concrete (due to

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[8] *Glanville, W. H. Creep of Concrete Under Load. Struct. Eng., 1933, 11 (2), 67.*

temperature) should not be allowed to exceed at the most 150 pounds per square inch. This in turn means that the temperature difference between the center and the surface of a mass should not exceed about 25° F. To achieve this the rate of placing of a concrete similar to and placed at the same temperature as that used in the Laggan Dam, with a cement which generates 65 calories per gram at 7 days, would have to be restricted to 0.5 foot per day, i. e., lifts of 3 feet 6 inches placed at intervals of not less than 7 days. This figure assumes that the average air temperature, from the time of depositing the concrete to the time when the maximum gradient occurs, does not change appreciably. Seasonal temperature fluctuations will have the effect of increasing or decreasing the gradient through the dam. With a rising air temperature the gradient would tend to be less steep, and the reverse effect would be anticipated if the air temperature was steadily falling. If cement which generated only 55 calories per gram after 7 days were used, the rate of placing could be increased by about 20 percent without incurring additional risk of cracking.

It cannot be claimed that finality has been reached in this investigation, which must be extended to cover conditions of placing other than those of the Laggan and Galloway Dams.

SUMMARY

In any very large mass of setting concrete, the central portion of the mass loses heat very slowly and the concrete is cured under almost adiabatic conditions as a result of which very high temperatures may be attained. The temperature reached is primarily dependent upon the type of cement used.

Normal and rapid-hardening portlands often differ but little in this respect; portland blast-furnace cements evolve heat more slowly than the portlands in the initial stages, but also differ little in the amount of heat evolved at the end of 3 days; high-alumina cements cause a very rapid rise during the first 24 hours.

Other factors affecting temperature rise are the mix proportions, the size of the concrete mass, the rate of placing, the insulation afforded by the shuttering, and the external conditions. Investigation has shown that the temperature increase and the strength developed in hardened concrete is higher at the center than at the edges of a concrete mass except in the case of concrete prepared from high alumina cement, in which case the strength is lower at the center. Similarly, shrinkage and creep may vary throughout the mass and are accompanied by a heat contraction additional to any shrinkage effects.

These phenomena may have an important influence on the behavior of a structure, such as a concrete dam, and it is therefore desirable that these temperature effects in mass concrete should be reduced to a minimum by the use of selected cements and by careful mix design, and that it should be possible to predict from the results of laboratory tests of a cement the temperatures that may be attained in a mass of concrete containing it.

Study of these problems has been carried out at the Building Research Station, Watford, and has included a comparison of the temperatures attained in the concrete of three large dams with those reached in laboratory tests of the cements used in the structures This investigation is described and has shown that on the basis of such laboratory tests it is possible to establish approximate relations which may be used for the tentative prediction of the temperatures that will be reached in a large mass of concrete made with a given cement.

RESUME

Au milieu d'une très grande masse de béton en cours de prise, la partie centrale perd sa chaleur très lentement et le béton durcit dans des conditions presque adiabatiques; par conséquent, il peut se produire des températures très élevées. La température atteinte dépend principalement du type de ciment employé. Les ciments Portland ordinaires et ceux à prise rapide se comportent souvent presque également à cet égard; les ciments de laitier de haut-fourneau developpent leur chaleur de prise plus lentement que les ciments Portland durant les premières phases de la prise, mais au bout de trois jours il n'y a plus qu'une faible différence dans la chaleur atteinte; les ciments alumineux chauffent très rapidement pendant les premières vingt-quatre heures. La température dépend aussi du dosage, des dimensions de la masse de béton, de la vitesse de mise en place, de l'isolement dû au coffrage et des conditions extérieures. L'expérience a démontré que l'élévation de température et la résistance développée dans le béton durci sont plus élevées au centre qu'à l'extérieur d'une masse de béton, sauf dans le cas des bétons préparés au moyen de ciments alumineux, auquel cas la résistance au centre est plus faible. Également, le retrait et la déformation peuvent varier d'un bout à l'autre de la masse et, en même temps, il se produit une contraction d'ordre thermique qui vient s'ajouter aux effets de retrait. Ces phénomènes peuvent avoir une influence importante sur la manière dont se comporte un ouvrage tel qu'un barrage en béton; il serait donc avantageux de réduire au minimum les effets de la température par l'emploi de ciments appropriés et d'un dosage bien choisi, et de pouvoir prédire, d'après les résultats des essais d'un ciment au laboratoire, les températures qui peuvent être développées dans une masse de béton contenant ce ciment. Les problèmes de cette nature ont été étudiés au "Building Research Station", Watford, et on y a comparé les températures réalisées dans le béton de trois grands barrages avec les températures atteintes pendant les essais de laboratoire sur les ciments employés dans ces constructions. On donne une description de ces recherches et on démontre que, grâce à des essais de laboratoire de ce genre, il est possible d'établir des relations approximatives dont on peut se servir pour essayer de prédire les températures qui seront atteintes dans une grande masse de béton faite avec un certain ciment.

ZUSAMMENFASSUNG

In jeder grösseren Betonmasse ist der Abgang der während des Abbindens freiwerdenden Wärme sehr langsam. Infolgedessen erhärtet der Beton im Inneren beinahe adiabatisch und dabei können sehr hohe Temperaturen erreicht werden. Diese Temperaturen sind zunächst von der Zementart abhängig. Häufig unterscheiden sich gewöhnliche und hochwertige Portlandzemente sehr wenig in dieser Beziehung. Die Wärmeentwickelung der Hochofenzemente ist in den Anfangsstadien langsamer als die der Portlandzemente, die Gesamtmenge der freiwerdenden Wärme ist jedoch nach drei Tagen nicht wesentlich anders. Mit Tonerdzementen ist die Temperaturerhöhung in den ersten 24 Stunden sehr gross. Die Temperaturerhöhung wird auch durch das Mischverhältnis, die Grösse der Betonmasse, die Schnelligkeit des Betonierens, den von den Schalungen gebotenen Wärmeschutz und die Witterung beeinflusst. Untersuchungen haben ergeben, dass im Inneren des erhärteten Betons höhere Temperaturen und Festigkeiten erreicht werden als in den äusseren Schichten; eine Ausnahme bildet jedoch der Tonerdezementbeton, in dessen Innerem geringere Festigkeiten herrschen. In den verschiedenen Teilen der Betonmasse ist das Fliessen und Schwinden des Betons auch verschieden; hinzu kommt eine durch die Abkühlung hervorgerufene Zusammenziehung. Diese Erscheinungen üben einen bedeutenden Einfluss auf die Brauchbarkeit der Betonbauten (z. B. der Staumauern) aus. Es ist daher sehr erwünscht, dass diese Wärmeerscheinungen durch sorgfältige Auswahl der Zemente und Mischverhältnisse auf ein Minimum beschränkt werden. Es wäre auch von Vorteil, wenn die Möglichkeit vorhanden wäre, auf Grund von Versuchsergebnissen die Temperaturen zu berechnen, welche in einem Beton aus einem gegebenen Zemente erreicht werden. Die Bearbeitung dieser Probleme in der Building Research Station zu Watford erstreckte sich auf einen Vergleich zwischen den im Laboratorium gemessenen Temperaturen und denjenigen, welche im Beton aus demselben Zemente in drei grossen Staumauern erreicht wurden. Die Ergebnisse dieser Untersuchungen haben nachgewiesen, dass Vergleichsbeziehungen aufgestellt werden können, welche annäherungsweise die Vorausbestimmung der in einer grossen, mit einem gegebenen Zemente hergestellten Betonmasse erreichbaren Temperaturen ermöglichen.

RESUMEN

Durante el fraguado de una gran masa de hormigón, la parte central de la masa pierde calor muy lentamente y el hormigón se endurece bajo condiciones casi adiabáticas y, por lo tanto, pueden conseguirse temperaturas muy altas. La temperatura alcanzada depende principalmente del tipo de cemento empleado. Los cementos portland ordinarios y los de fraguado rápido a menudo difieren muy poco en este respecto; los cementos de altos hornos producen calor más lentamente que los cementos portland en el período inicial, pero al cabo de tres días también defieren poco en la cantidad de calor que producen; los cementos aluminosos producen temperaturas muy elevadas en las primeras veinticuatro horas. Otros factores que influyen en el aumento de la temperatura son las proporciones de las mezclas, el tamaño de la masa de hormigón, la velocidad de la colocación, el aislamiento debido al encofrado, y las condiciones externas. La investigación ha demostrado que tanto la elevación de temperatura como la resistencia del hormigón endurecido son más altas en el centro que en las orillas de una masa de hormigón, con excepción del hormigón preparado con cemento aluminoso, en cuyo caso la resistencia es más baja en el centro. Igualmente, la contracción y la deformación pueden variar en toda la masa y van acompañadas de una contracción de orden térmico además de los efectos de contracción. Estos fenómenos pueden tener una influencia importante en el comportamiento de una estructura, tal como una presa de hormigón, y por lo tanto es conveniente reducir todo lo posible estos efectos de temperatura usando cementos apropiados y una dosificación bien escogida; y por los resultados de los ensayos de laboratorio, hechos con el cemento, debiera ser posible predecir las temperaturas que pueden alcanzarse en una masa de hormigón. En el Building Research Station, de Watford, Inglaterra, se han estudiado estos problemas, y también se han comparado las temperaturas alcanzadas en el hormigón de tres grandes presas con las conseguidas en los ensayos de laboratorio hechos con el cemento usado en las estructuras. Se describe esta investigación y se demuestra que, a base de esos ensayos de laboratorio, es posible establecer relaciones aproximadas que pueden usarse para predecir aproximadamente las temperaturas que se alcanzarán en una gran masa de hormigón hecha con un determinado cemento.

QUESTION III
HALCROW and LEA
GREAT BRITAIN

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

SPECIAL CEMENT*

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With the development of concrete as a building material during the last 35 years the practice of building large dams of solid masonry is dying out and such structures are today generally built either with concrete and masonry facings or of concrete throughout. Under present-day conditions the use of mass concrete in place of solid masonry for large dam construction is cheaper and the work may be carried out more rapidly. Rate of construction is not, however, unlimited as one of the more important problems arising out of the use of concrete in the mass is the generation of heat during setting and hardening. The more rapidly the concrete is placed the greater is the temperature rise and the subsequent stressing and cracking due to shrinkage when cooling.

In a masonry dam the generation of heat due to the setting of mortar in the joints is negligible and no appreciable volumetric changes take place during the construction of the dam. The result is that no internal stresses are set up in the structure and the dam is free from cracks due to this cause. Seasonal changes of temperature, however, cause expansion and contraction which would result in the formation of cracks but the provision at intervals of suitably designed joints normal to the face of the dam limits the location of the cracks to definite positions.

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*Ciments spéciaux.
Spezial-Zemente.
Cementos especiales.*

With the use of ordinary portland cement for concrete in a large gravity dam, the temperature rise during hardening is considerable and during the cooling-off period, which may be spread over years, a shrinkage of the concrete mass takes place. As the base of the dam is tied to solid rock, tensile stresses are set up. These internal stresses are in many cases greater than the compressive stresses due to external loads, and cracks invariably form in the concrete mass.

In Great Britain two examples of this may be seen in the Blackwater and Laggan Dams in Scotland, built for the Kinlochleven and Lochaber Power Companies respectively, portland cement being used in each case. The Blackwater Dam, completed some 27 years ago, is 3,300 feet (1,006 m) long and 90 feet (27 m) high and is constructed in mass concrete with granite displacers. The dam was not provided with contraction joints and many cracks have developed, some of which pass completely through the dam from the upstream face to the downstream face. The Laggan Dam, completed in 1935, is 700 feet (213 m) long and 175 feet (53 m) high and is also constructed in mass concrete. The heart of the dam is formed of 7 to 1 concrete with large granite displacers while on the outer faces 4 to 1 concrete is used. On the upstream face the 4 to 1 concrete varies in thickness from 2 feet (0.6 m) at the top to 6 feet (1.8 m) at the lowest point of the dam, while on the downstream face the 4 to 1 concrete is 12 inches (0.3 m) thick throughout. The averages of results obtained from tests carried out on 6 in. by 6 in. (15 by 15 cm) cubes moulded from the concrete as it was placed in the dam are as follows:

	4 to 1 concrete	7 to 1 concrete
Weight	152.2 lb./cu. ft. (2,440 kg/m^3).	152.3 lb./cu. ft. (2,440 kg/m^3).
Crushing strength at 28 days.	300.6 tons/sq. ft. (3,288 tonnes/m^2).	174.4 tons/sq. ft. (1,907 tonnes/m^2).

Contraction joints are provided normal to the face of the dam at intervals of about 45 feet (14 m). Observations of temperature during setting of the concrete were made by means of distance thermometers buried in the concrete at various points as shown in figure 1. Nine thermometers are placed in a vertical plane at approximately the maximum section of the dam and two additional thermometers are placed at 3 feet (0.9 m) from adjacent contraction joints. Typical temperature curves are given in the accompanying chart figure 2. The maximum temperature registered during setting of the concrete was 118° F. (47.7° C.) and within an average period of 57 days from the date of placing the concrete small cracks developed on the outer faces running both normal to and parallel with the face of the dam. It was noticed that these cracks occurred along lines of sudden changes in direction of the concrete or foundation and, in addition to this, cracks formed at intervals of about 16 feet (5 m) or multiples of 16 feet (5 m) on the upstream face of the dam. The cracks on the upstream face have not yet reached the inspection gallery which runs parallel to and 8 to 11 feet (2.44 m to 3.35 m) from the dam face. The dates at which cracks developed corresponded closely with the date at which the maximum difference in temperature occurred between the concrete in the heart of the dam and that at the surface. Measurements were taken of horizontal shrinkage of the concrete both on the upstream face and in the inspection gallery by means of special contraction gage stops installed at the contraction joints and measurements of vertical shrinkage were made by taking precise levels on the crest of the completed dam. Examples of these observations are given in tables I and II.

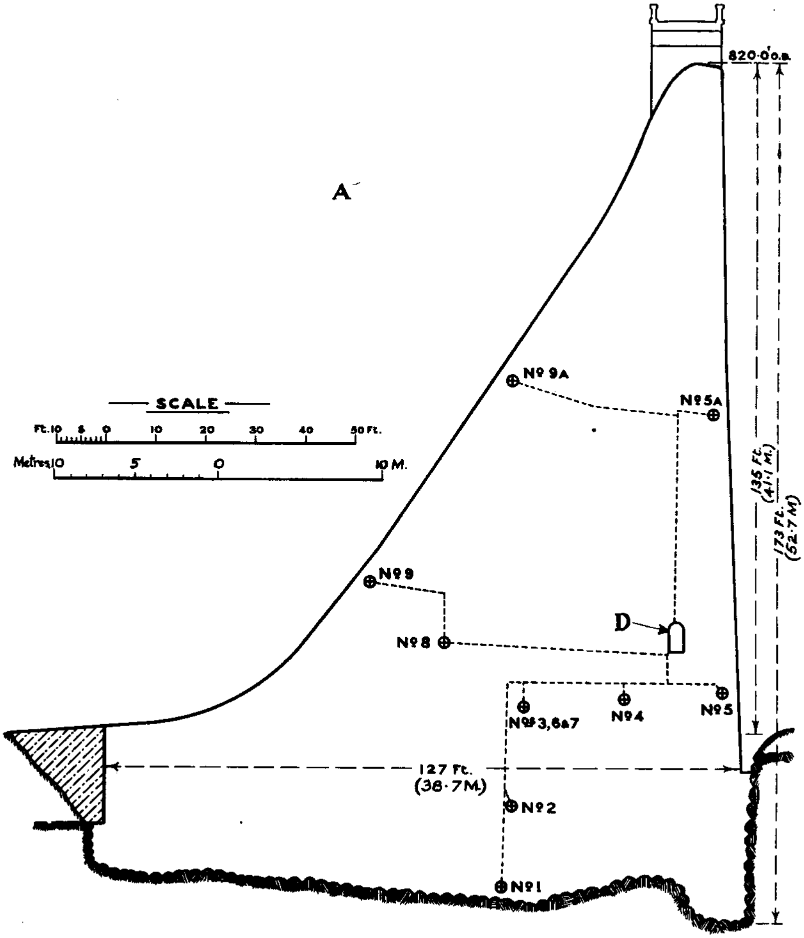

Figure 1.—**Cross section of Laggan Dam.**—Profile du barrage de Laggan. — Durchstrich durch die Laggan-Talsperre. — Perfil de la presa de Laggan.

A. Position of thermometers indicated thus ⊕. No. 6 is 21 ft. 6 in. S. of No. 3. No. 7 is 20 ft. 0 in. N. of No. 3. — Positions des thermomètres indiquées par ⊕. No. 6 est situé à 6 m, 56 S. de No. 3. No. 7 est situé à 6 m, 10 N. de No. 3. — Lage der Thermometer ⊕. Nr. 6 ist 6.56 m. S. von Nr. 3. Nr. 7 ist 6.10 m. N. von Nr. 3. — Las posiciones de los termómetros se indican así ⊕. Núm. 6 está situado a 6,56 m al S. de núm. 3. Núm. 7 está situado a 6,10 m al N. de núm 3.

D. Inspection gallery — Galerie d'inspection. — Revisionsgang. — Galería de inspección.

TABLE I.—*Measurements in inspection gallery of relative horizontal movement at contraction joint 4/5*

Concrete placed north side on Aug. 2, 1933. Concrete placed south side on July 5, 1932]

Date	Atmospheric temperature		Gauge reading	
	° F.	*° C.*	*Inch*	*Millimeters*
Oct. 31, 1933	36	2. 2	0. 128	3. 25
Jan. 29, 1934	39	3. 9	. 158	4. 01
Apr. 11, 1934	42	5. 6	. 177	4. 50
Aug. 30, 1935	49	9. 4	. 165	4. 19

TABLE II.—*Measurements of vertical shrinkage on crest of dam*

Height of crest above foundations		Vertical shrinkage approximately 1 year after completion	
Feet	*Meters*	*Inch*	*Millimeters*
12	3.66	0.07	1.78
30	9.14	.11	2.79
40	12.20	.10	2.54
77	23.47	.20	5.08
125	38.10	.23	5.84
160	48.77	.28	7.11
96	29.26	.24	6.10

Complete investigations of the Blackwater Dam were recently made by a series of core borings and these showed that the water percolating through the cracks had not affected the quality of the concrete to any great extent although the water is of the moorland type and acid in reaction. In Great Britain then, it might be said that the question of small temperature cracks forming in dams is comparatively unimportant insofar as deterioration of the concrete is concerned. In Scandinavian countries, however, where the water is extremely pure and also acid in reaction, a rapid deterioration of the cement in concrete has been found to take place, in some cases endangering the safety of the dam and necessitating costly repair work.

So far it has been found impracticable to provide sufficient contraction joints in large dams to eliminate completely the initial contraction cracks. Waterproof coatings on the water surfaces are not entirely satisfactory, especially in the case of fluctuating water levels. The best method of ensuring safety is to make the material of which the dam is constructed impermeable in itself and entirely free from cracks. It will be seen, then, that either some other material such as masonry should be used or the cement with which the concrete is made must be such that it will not generate excessive heat whilst setting.

The chief object aimed at by cement manufacturers during the last 25 years has been the production of a cement which will harden rapidly and which will, under test, give a high tensile strength at 7 days. This has been achieved partly by increasing the fineness of grinding. The sieve residues allowed in British standard specification for normal portland cements have been as indicated in table III.

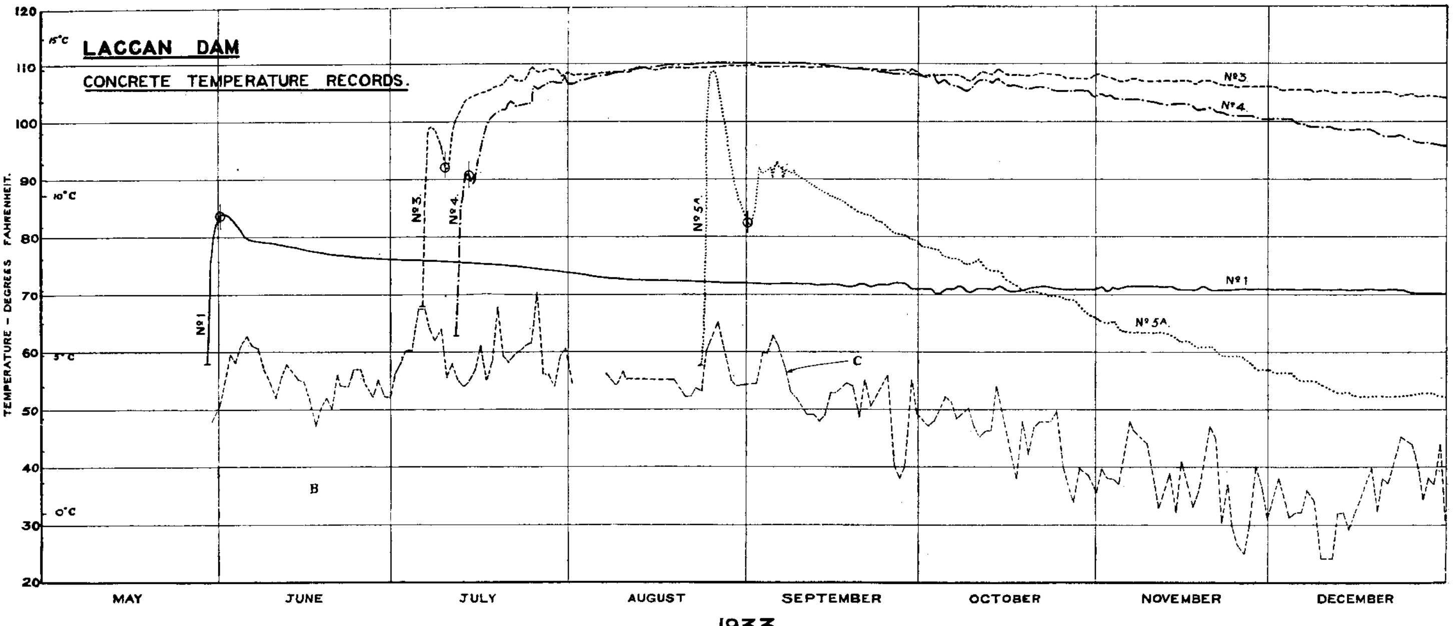

FIGURE 2.—**Concrete temperature records.** — Températures du béton enregistrées. — Registrierte Betontemperaturen. — Temperaturas del hormigón registradas.

B. Date of placing succeeding lift of concrete marked thus ø. — Dates du placement des couches successives du béton, indiquées par ø. — Datum des Auftrasgens der nächsten Betonschicht: ø. — La fecha de colocación de las capas sucesivas se indica así ø.

C. Air temperature 9 a. m. — Température de l'air, 9 h. matin. — Lufttemperatur 9 Uhr vormittags. — Temperatura del aire a las 9 de la mañana.

TABLE III.—*Maximum sieve residues specified in British standard specifications for portland cement*

	1904	1907	1920	1925	1931
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
280 mesh (5,022 holes/sq. cm.)	22. 5	18	14	10	[1] 10
76 mesh (896 holes/sq. cm.)	3	3	1	1	[2] 1

[1] 170 mesh (4,480 holes/sq. cm.) actually a slightly finer mesh than the 180 mesh (5,022 holes/sq. cm.).

[2] 72 mesh (804 holes/sq. cm.).

The actual average residues of cements on a 180-mesh (5,022 holes/sq. cm.) sieve in 1904 was about 22 percent whereas the present-day residue on a 170-mesh (4,480 holes/sq. cm.) is about 1 to 5 percent and on a 72-mesh (804 holes/sq. cm.) is about 0 to 0.5 percent for normal portland cements.

One effect of this fine grinding is to increase the heat rise in the concrete when setting. In the case of the Laggan Dam the cement used was ground more coarsely than ordinary cement, the residue being 6 to 8 per cent on a 170-mesh (4,480 holes/sq. cm.) sieve. Some small benefit to the work was derived from the use of this cement which took about 40 percent more time to set than normal cement and, moreover, attention of cement manufacturers in England was drawn to the question of producing a low-heat cement for use in the building of structures containing large masses of concrete. Attempts have already been made in several countries to produce a satisfactory cement for mass concrete to meet engineers' requirements.

New specifications for low-temperature-rise cements or for additions to ordinary portland cements have been put into use in America, Sweden, Germany, and Norway and the results obtained have been encouraging. The work of the International Subcommittees on Special Cements includes the review of the experience gained and the drawing up of a satisfactory specification with which manufacturers will be able to comply in the production of a new cement. No practical experience is as yet available in Great Britain on the use of low-heat cements, but manufacturers have now become interested in their production and in the tests to which such cements should conform.

EXPERIMENTAL WORK CARRIED OUT FOR BRITISH SUBCOMMITTEE ON SPECIAL CEMENTS

The British subcommittee has undertaken an examination of the methods of measurement of heat evolution and solubility of cements with the object of ascertaining the most suitable methods for use in specification. Cements of the portland, portland blast-furnace, and pozzolanic types were selected for test in order to determine that any methods finally recommended were equally applicable to all such diverse materials. Data on the strength, composition, and fineness of the cements used will also be given in order to make the results more complete.

(1) COMPOSITION OF CEMENTS

The cements used for the tests included three normal portland cements of differing ratio of silica to alumina plus ferric oxide, two portland blast-furnace cements and one experimental pozzolanic cement. The first five of these six cements were commercial products, but the pozzolanic cement was one produced experimentally as a cement of exceptionally low heat evolution, in order to make the range of cements tested as wide as possible. The compositions of the cements are shown in table IV.

TABLE IV.—*Analyses of cements*

Cement No.	207	210	208	209	212	220
Type	Portland	Portland	Portland	Portland blast furnace	Portland blast furnace	Experimental pozzolanic
SiO_2	18.97	20.91	23.29	23.90	24.70	38.60
CaO	64.35	63.78	63.45	60.90	56.83	39.50
Al_2O_3	7.45	6.00	5.14	8.61	9.48	8.99
Fe_2O_3	3.56	2.78	2.20	2.34	1.89	[1] 5.03
TiO_2	.24	.29	.26	.25	.28	.53
MnO	--------	--------	--------	.20	.53	--------
MgO	1.11	.96	1.30	1.50	3.22	1.86
Na_2O	.34	.43	.36	.28	.32	.46
K_2O	.46	1.07	.56	.56	.54	1.04
SO_3	2.61	2.21	2.74	1.32	1.36	2.09
Loss on ignition	1.35	1.36	1.31	.73	.82	2.40
Free CaO	1.0	1.7	1.8	2.1	.9	.3

[1] Includes 0.32 percent FeO.

(2) PHYSICAL PROPERTIES

The fineness and setting time of the cements are shown in table V, together with compressive strength data at 18° C. on 1:3 standard sand mortar cubes (7.14 cm. edge) of a plastic consistence (water/cement=0.50 (weight)). The data call for no comment beyond the observations that the strength of the experimental pozzolanic cement is considerably lower than normal for this type of cement owing to the particularly low heat evolution aimed at in its production.

TABLE V.—*Physical properties of cements*

Cement no.	Type	Percent residue on—		Per cent flour content[1]	Setting time				Compressive strength (lb. per sq. in.). 1:3 mortar. Water/cement=0.50			
		B.S. 170 mesh.	B.S. 72 mesh.		Initial		Final		1 day	3 days	7 days	28 days
					Hr.	*min.*	*Hr.*	*min.*				
207	Portland	7.04	0.15	63.3	2	0	3	53	452	2,305	4,028	5,293
210	do	9.50	.10	59.0	2	55	4	35	583	2,015	3,030	4,886
208	do	7.68	.15	60.4	3	18	4	18	359	1,466	2,453	5,110
209	Portland blast-furnace	5.06	.06	61.5	3	22	4	40	222	1,048	2,104	3,313
212	do	5.10	.30	65.0	4	45	6	10	288	1,006	2,200	4,580
220	Experimental pozzolanic	13.70	.38	62.7	2	45	5	25	82	418	637	1,377

[1] Corresponding approximately to particles less than 35μ in diameter.

(3) COMPARISON OF METHODS FOR THE MEASUREMENT OF THE HEAT EVOLUTION OF CEMENTS

The heat evolution of the cements has been measured by three methods:

Test material	Method of measurement	Conditions of storage
1. Concrete	Standard adiabatic calorimeter	Adiabatic.
2. Concrete	Simplified adiabatic calorimeter	Do.
3. Neat cement	Heat of solution	Arbitrary.

The standard adiabatic calorimeter was the standard type [1] in use at the Building Research Station, while the simplified adiabatic calorimeter was a cheap and simple apparatus [2] developed at the Building Research Station for the British subcommittee as mentioned by Davey in another paper submitted to this Congress. The calorimeter used for the heat-of-solution method was in general similar to that used for the same purpose in the U. S. A.[3]

In methods (1) and (2) tests were carried out on concrete mixes composed of 1 part cement, 2 parts sand 3/16 in. down, and 4 parts gravel 3/4 in.-3/16 in. proportioned by weight. The water content was 60 percent by weight of the cement in all cases. The sand and gravel aggregates were composed essentially of silica. The details of the method of preparing the test specimens, which are identical in methods (1) and (2), have been given in a Draft Specification for Determination of the Heat of Hydration of Cements by an Adiabatic Calorimetric Method, presented to the International Subcommittee on Special Cements. In calculating the heat evolved in calories per gram cement from the temperature rise observed in the concrete specimens, the specific heat of the concrete mix has been taken as 0.25 for the aggregates used. This value has been taken from recent measurements carried out at the Building Research Station on specimens up to 3 days old. The 1:2:4 concrete (water/cement=0.60) contains 1 part by weight cement in 7.6 parts by weight of the mixed concrete, from which it follows that a rise in temperature of 1° C. is equivalent to $7.6\times0.25=1.9$ calories per gram cement.

In method (3) the tests were carried out on the neat cement gaged with 40 per cent by weight water and stored 1 day at 22° C. and thereafter at 38° C., as specified in the U. S. A. specification to which reference has been made above. In the case of the pozzolanic cement no. 220 complete solution of the cement could not be obtained in the nitric-hydrofluoric acid solvent used (the solvent was 20 cc of 40 per cent hydrofluoric acid in 640 grams of 2.5 N nitric acid). The weight of undissolved residue was determined for the anhydrous cement and for the cement hydrated for 7 and 28 days, and found to be 11.9, 11.7, and 11.1 per cent, respectively, by weight of the anhydrous cement. In view of the small difference between the amounts of these undis-

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[1] *N. Davey and C. T. Webster. Concrete & Constructional Engineering, 1931, 260 (10) 572; N. Davey, Building Research Station Technical Paper No. 15 (1933).*

[2] *N. Davey. Structural Engineer, 1935, 13 (7) 302.*

[3] *Specification No. 566. Portland Cement for Boulder Dam. U. S. Bureau of Reclamation, Washington, D. C.*

solved residues, it is concluded that the accuracy of the values obtained for the heat of hydration of this cement is not appreciably affected.

The results obtained by the three methods are shown in table VI.

TABLE VI.—*Comparison of heat evolution of cements by different methods*

Cement no.	Type	Heat evolution (calories per gram cement)							
		B. R. S. standard adiabatic calorimeter			B. R. S. simplified adiabatic calorimeter			Heat-of-solution method	
		1 day	3 days	7 days	1 day	3 days	7 days	7 days	28 days
207	Portland	47. 4	76. 0	88. 1	50. 0	76. 6	86. 4	95. 9	99. 7
210	do	38. 6	62. 3	74. 3	43. 7	63. 2	74. 3	79. 4	94. 4
208	do	31. 9	57. 0	67. 4	34. 8	53. 8	66. 5	72. 0	113. 9
209	Portland blast-furnace	22. 8	50. 2	63. 2	24. 1	54. 0	66. 5	68. 9	102. 4
212	do	25. 9	48. 7	58. 9	26. 6	49. 6	62. 3	62. 1	87. 5
220	Pozzolanic	21. 2	32. 9	37. 7	20. 1	34. 4	42. 4	65. 2	79. 7

The agreement between the values obtained with the simplified and standard adiabatic calorimeters is satisfactory and it is concluded that the former apparatus is adequate for the measurement of heat evolution in concretes under adiabatic conditions. For portland and portland blast-furnace cements the heat-of-solution method gives somewhat higher results than the adiabatic methods at an age of 7 days, and for the pozzolanic cement a very much higher value. The greater difference in the case of the pozzolanic cement is probably to be attributed to the relatively low temperature attained under adiabatic conditions in the concrete made from this cement. For this cement the temperature rise only reached 20° C. and the actual temperature of the concrete 38° C. after 7 days, while in the heat-of-solution method the temperature is maintained at 38° C. after the first 24 hours. It seems that with cements which evolve heat fairly rapidly, so that the temperature of the concrete stored adiabatically rises quickly, the values obtained by the heat-of-solution and adiabatic methods may not differ very considerably. With cements which evolve heat more slowly, so that the temperature of the adiabatically stored concretes remains below 38° C. for most of the first 7 days, the heat-of-solution method may be expected to give much higher results than the abiabatic method.

The investigations reported by Davey in another paper to this Congress have shown that the temperatures reached in large concrete masses placed at a defined rate can be predicted with a satisfactory degree of accuracy from measurements of the temperature rise in similar concretes measured in the laboratory by the abiabatic calorimetric method. The adiabatic method may be preferred therefore, on this account, to the heat-of-solution method. It is also simpler to carry out and the apparatus required is less costly, but the latter advantage is offset by the necessity of providing a number of sets of apparatus to carry out the same number of tests as can be made in a single heat-of-solution apparatus. The adiabatic method enables the complete heat evolution curve to be determined over the period of the test, but it is not very suitable for test periods of 28 days and over.

In considering the use of the adiabatic calorimetric method for tests on the heat evolution of cements it may be well to divide into two groups the purposes for which such tests may be made.

(1) *Standard tests* to determine the heat evolved in calories per gram of cement. For this purpose the proportions of the concrete mix should be standardized as in the present tests. It does not seem essential that the aggregate should necessarily be a quartz sand and gravel, but if any other aggregate is used the specific heat value of the aggregate needs to be known before converting the temperature rise observed into calories per gram of cement.

(2) *Comparative tests* to check and compare cements supplied for use on works under construction. For this purpose it is unnecessary to specify any particular concrete mix or aggregate, and it may often be most useful to carry out tests using the same aggregate and mix as for the works under construction, modifying only the size of the coarse aggregate, if necessary, so that it shall not be too large in relation to the test specimen. If the mix and aggregate are kept constant, different cements can then be compared directly by the temperature rise without the necessity of converting to calories per gram. The results will also be directly applicable to the work under construction.

(4) COMPARISON OF STRENGTH OF CONCRETE CURED AT ORDINARY TEMPERATURES AND UNDER ADIABATIC CONDITIONS

When carrying out the heat-evolution tests with the standard adiabatic calorimeter[4] a second water bath was connected with the calorimeter so that its temperature rose at the same rate as that of the concrete specimen under test. This second bath was used for the storage of concrete cylinders which were thus subjected to precisely the same thermal history as the control specimen. Strength tests were carried out on these cylinders at ages of 1, 3, and 7 days and also on corresponding specimens stored at 18° C.

TABLE VII.—*Comparison of compressive strength (lb. per sq. in.) of concretes stored at 18° C. and under adiabatic conditions*

[6- by 3-inch cylinders 1: 2: 4: 0.6 (weight) concrete]

Cement no.	Type	1 day		3 days		7 days	
		18°	Adiabatic	18°	Adiabatic	18°	Adiabatic
207	Portland	360	1, 050	1, 500	2, 800	2, 860	3, 750
210	do	440	1, 010	1, 370	2, 420	2, 200	3, 380
208	do	190	550	940	1, 780	1, 870	3, 170
209	Portland blast-furnace	170	360	840	1, 710	1, 700	2, 730
212	do	170	440	740	1, 600	1, 420	2, 910
220	Pozzolanic	------	220	270	799	458	1, 858

All results are means of 4 specimens.

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[4] *Cf. N. Davey, Building Research Technical Paper No. 14 (1933).*

The results are shown in table VII. The particularly marked increase in the rate of strength development of the pozzolanic cement may be noted, for it is characteristic of this type of cement.

(5) COMPARISON OF METHODS FOR TESTING THE SOLUBILITY OF CEMENTS

The solubility of cements has been recognized as one factor requiring consideration in connection with the deterioration of concrete dams exposed to the action of pure and slightly acid natural waters. Various methods have been proposed for comparing the solubility of different cements, such as the Swedish extraction methods, Rengade's method, and percolation methods using mortars or concretes.

The extraction methods utilize set neat cement as the test material. The set neat cement, after curing in water for the time desired, is crushed to a given grain size and the crushed material extracted with water in accordance with a defined procedure. The amount of lime dissolved from the cement is taken as the measure of the relative solubility. Three variations of this method have been described by Swedish investigators.[5] The method used in the present tests was that of the Swedish Cement Laboratory.[6]

In the method developed by Rengade [7] 1:3 mortar specimens are subjected to the action of a jet of water impinging on their surface. The extent of wear or erosion is used as a measure of the relative solubility of cements.

The percolation methods involve the collection of water which has percolated through mortar or concrete test specimens and the estimation of the lime extracted from the cement in the test specimen. Such tests have sometimes been made in conjunction with permeability tests on normal concrete using a high water pressure, or, in order to obtain a greater rate of flow, on lean concretes. Percolation tests on lean mortars were used in the present investigations to obviate the necessity for the use of high water pressures.

The results of tests on normal concretes seem preferable as the final criteria of the relative solubility of cements, but for a test method the use of normal concrete is open to certain objections. The results of permeability tests are subject to large variations and, though the quantity of lime extracted may not vary so considerably as the total volume of water passed, the variation between duplicate tests appears to be undesirably high. The method further involves the provision of sufficient high-pressure permeability apparatus to permit of a considerable number of specimens being tested concurrently.

Lean mortars, through which water can be passed under relatively low pressures, afford a simpler method for carrying out tests of the percolation type, but the reproducibility of the results is still poor. The tests on crushed neat cements offer the advantage of simplicity in operation and a satisfactory reproducibility. Since, however, this

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[5] *These methods are described together by J. O. Roos of Hjelmsäter. Internat. Assoc. Test. Mat. Proc. Zurich Congr. 1931, p. 606; and individually in various other papers.*

[6] *D. Werner, Zement 1931, 20, 626.*

[7] *E. Rengade, Rev. Mat. Constr. 1932, 276, 365; 14th Congress Industrial Chemistry Paris 1934, "Action des eaux pures sur les mortiers ou betons."*

form of test involves the crushing of the set material, with a corresponding partial destruction of its structure, it seemed uncertain whether results obtained from it would correctly indicate the relative behavior of cements in concrete or mortar. The method developed by Rengade is simple in operation, but it involves a mechanical erosive factor in addition to a solvent action. Rengade has stated, however, that the mechanical erosive action does not actually play any important part in this form of test since, if hard waters of low solvent power are used, no erosion occurs. The test in the form described by Rengade is qualitative and requires a long period of time.

Methods of Test.

(*a*) *Extraction tests on neat cement.*—Cubes (50 sq. cm surface) of the neat cement, gaged with 28 percent water by weight, were cured for 3 days in moist air at 18° C. and then in water at 18° C. until 1 or 3 months old. The set cement was crushed and a fraction of grain size 0.21–0.09 mm (British standard sieves nos. 72 and 170) used for the test. The sample was then extracted with 15 successive volumes (20 cc each) of distilled water as described by Werner (loc. cit.). The loss on ignition of the set cement was determined and the total amount of lime extracted calculated as grams CaO per gram anhydrous cement. This method was found simple to carry out, and a satisfactory reproducibility was obtained between triplicate determinations on specimens from three separate neat-cement cubes. The maximum range of three determinations was about 15 percent and the average range about 7 percent. Only fairly small differences were found between the results obtained on specimens 1 and 3 months old when tested.

(*b*) *Tests by Renegade's method.*—The specimens used were circular mortar plaques 3 in. diameter and ½ inch thick. Six plaques, made from six different cements, were tested in any one series. The plaques, after curing as required, were placed under jets of water impinging on the center of their upper surface. The six plaques were moved daily so that each came successively under every jet. The jet orifice was 5 cm above the specimen, the water flow about 2,000 cc per hour for each jet, and the average water pressure about 90 cm water. The water was rain water with a P_H value of 6.8. The tests were carried out in an open shed without control of the temperature, but the results within a series of six specimens should be strictly comparable. The amount of erosive wear was determined by weighing the plaques in water at intervals instead of depending on visual observation as in Rengade's description of the method.

Results can be obtained by this method within 1 month, using 1:8 cement: sand mortars as test specimens, but with 1:3 mortars, as used by Rengade, the rate of attack is considerably slower and the test period correspondingly prolonged. No complete results are at present available on the 1:3 mortars. It has been observed in tests by this method that the first action is a solution of the cement surrounding the sand grains, and only subsequently are the sand grains washed away. The loss of sand does not apparently commence until the cement has been weakened by leaching. This would appear to support Rengade's contention that the solution of the cement is the primary factor in this test, and that the mechanical impact of the jet of water is only of secondary importance.

Insufficient data are at present available to determine the degree of reproducibility of the method.

(*c*) *Mortar percolation tests.*—The test specimens were circular mortar plaques 3 in. diameter and ½ in. thick, made with a 1:8 cement: sand mortar and stored for 1 month in water at 18° C. Two types of this mortar were used, the one being made with standard sand (0.85–0.60 mm, British standard sieves nos. 18 and 25) and the other with a sand composed of 2 parts (by weight) 0.85–0.60 mm (British standard sieves nos. 18 and 25) and 1 part 0.295–0.152 mm (British standard sieves nos. 52 and 100).

It was found in preliminary tests that when thicker plaques, or richer mixes were used, the mortar was not sufficiently permeable to permit of an adequate flow under the water pressure used.

TABLE VIII.—*Mortar percolation tests*[1]

Mortar		1:8 standard sand mortar.	1:8 graded sand mortar.	1:8 graded sand mortar.
Flow rate		30–50 cc per hour.	30–50 cc per hour.	Uncontrolled flow under pressure of about 10 lb per square inch.
Cement no.	Type	CaO extracted by 5 litres water	CaO extracted by 2 litres water	CaO extracted by 2 litres water
		Grams	*Grams*	*Grams*
207	Portland	0.70 .80 } 0.82 .97	0.91 } 1.01 1.12	1.29 .82 } 1.13 1.29
210	do	.51 .55 } .64 .87	1.37 .80 } 1.30 1.72	1.08 1.20 } 1.17 1.23
208	do	.91 .94 } .85 .70	1.22 .60 } 1.12 1.53	1.02 .96 } 1.13 1.40
209	Portland blast-furnace	.79 .79 } .81 .85	1.46 } 1.26 1.07	1.09 1.00 } 1.06 1.09
212	do	.71 1.10 } .98 1.12	.56 .57 } .57 .58	.64 .68 } .73 .88
220	Pozzolanic	[2] n. e.	.08 .08 } .11 .18	[2] n. e.

[1] Plaques contained about 12 gm anhydrous cement.

[2] n. e.=not estimated.

The percolation tests, with the exception of one series, were carried out at a roughly controlled flow rate (30–50 cc per hour) using a maximum applied water pressure of about 10 lb. per sq. in. and adjusting the flow through each specimen by taps. This method was adopted as preliminary tests showed that the amount of lime extracted in a given time was not independent of the flow rate. One series of tests, however, was carried out under a constant water pressure of about 10 lb. per sq. in.; the flow rates under this condition varied very widely and ranged from 30 cc per hour to over 1 liter per hour. The tests were carried out at 18° C. and, in the case of those at roughly controlled flow rates, for a period of 1 week, the water (distilled) percolating through the specimens being collected and analyzed daily.

The results obtained on triplicate specimens for the amount of lime extracted in 7 days showed very considerable variations. These variations are somewhat reduced when the lime extracted by a given volume of water passed, rather than in a given time, is considered. The reproducibility of the values obtained still, however, remains unsatisfactory, as may be seen from table VIII, where the results of, in most cases, triplicate determinations are shown.

Comparison of the Three Methods

The results obtained by the three test methods are shown in table IX. For each test the average value for the six cements has been equated to 100 and the results for the individual cements recalculated to this basis. This has been done, rather than presenting the detailed experimental data, in order to facilitate a comparison between the relative order in which cements are placed by the various methods. The results by Rengade's method refer only to a single set of specimens and require confirmation.

TABLE IX.—*Comparison of different methods of measuring solubility of cements*

Cement no.	Type	Extraction tests on neat cements		Percolation tests (specimens age 1 month)			Rengade's method
		Age 1 month	Age 3 months	1:8 standard sand mortar (controlled flow rate)	1:8 graded sand mortar (controlled flow rate)	1:8 graded sand mortar (uncontrolled flow under 10 lb. per sq. in. pressure)	1:8 standard sand mortar (age 1 month)
207	Portland	124	131	100	113	109	94
210	do	131	121	78	145	112	105
208	do	112	114	104	125	109	97
209	Portland blast-furnace	119	130	99	141	102	143
212	do	73	66	119	64	70	107
220	Pozzolanic	42	37		12		53

Results expressed as percentage of the average value for the 6 cements in each type of test.

All the methods agree in showing that the experimental pozzolanic cement has the greatest resistance to attack, but the order in which the other cements are placed differs with the various methods.

It does not appear possible, until further information has been obtained, to reach any definite conclusion as to the method which should be recommended for testing the solubility of cements. The Swedish extraction method is rapid and shows a good reproducibility, but it is still uncertain whether it differentiates correctly in all cases between different cements. Further work is being carried out with concrete specimens subjected to high water pressures, the water passing through the specimen being collected and analyzed as in the mortar percolation tests.

In a paper entitled "Some Problems of the Design of Concrete Dams with Special Reference to Deterioration due to Moorland Waters" Halcrow [8] has discussed the attack of moorland waters on concrete. Linings of portland cement concrete in conduits at Kinlochleven (Scotland) have undergone considerable surface attack with consequent roughening of the surface of the concrete and exposure of the aggregate. Tests with various lining materials and surface treatments have shown that after period extending to 11½ years the only material to remain unaffected is aluminous cement concrete. A lining of aluminous cement concrete has been used for the invert of the Ben Nevis tunnel, 15 miles long and 15 feet average diameter, in the Lochaber Water Power Scheme completed in 1929, and throughout the shorter Ericht-Rannoch tunnel, 2¾ miles long and 12 feet average diameter, of the Grampian Water Power Scheme.

An examination of the Blackwater Dam, 24 years old, is also reported. Though numerous cracks, mostly fine hair cracks, are visible, the general condition of the dam as determined by core borings is satisfactory. Some deterioration has, however, taken place and may be expected to continue. Temperature measurements on Laggan Dam are also included.

Davey [9] has examined the correlation between the results of laboratory tests and the observed temperatures in large dams. This, and earlier work [10] by the same author on the temperature rise of concrete, is summarized in a separate communication to this Congress.

SUMMARY

The substitution of concrete for masonry in the modern construction of large dams has introduced troubles attributable to the temperature rise during hardening and in some cases to the leaching effect of pure moorland waters. Data are given of the temperature rise and crack formation in the Laggan Dam which was completed in 1935. A recent examination of the Blackwater Dam completed some 27 years ago has shown that no serious deterioration of the concrete owing to the action of water percolating through cracks has taken place.

Reference is made to the changes which have occurred over the last 25 years in the characteristics of manufactured cements and their influence on mass concrete construction. No practical experience is at present available in Great Britain on the use of low-heat cements.

The British Subcommittee on Special Cements has undertaken an examination of the methods of measuring the heat evolution and solubility of cements.

Tests on heat evolution have been carried out on concrete using two forms of adiabatic calorimeter and on neat cement by the heat-of-solution method. A simple and inexpensive adiabatic calorimeter has been developed and found satisfactory. It is considered that tests with this apparatus offer an advantage over the heat-of-solution method in that the test is simpler to carry out, and the results show a

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[8] *Trans. Inst. Water. Eng. 1934, 39, 31; Engineering, 1934, 137, 609.*

[9] *Building Research Technical Paper No. 18 (1935).*

[10] *Building Research Technical Papers Nos. 14 (1933) and 15 (1933) (with E. N. Fox); Concrete Constr. Eng., 1931, 26, 572.*

direct correlation with observations made on large dams. The apparatus is also less expensive, but it is necessary to provide a number of sets of apparatus to carry out the same number of tests as can be made in a single heat-of-solution apparatus.

Tests on the solubility of cements have been carried out by the Swedish extraction method with ground set neat cement, by percolation methods with lean mortar plaques, and by Rengade's method in which mortar specimens are subjected to the action of a jet of water impinging on their surface. The Swedish extraction method has been found simple in operation and shows a good reproducibility. Tests by the percolation method on mortar plaques have not shown a satisfactory degree of reproducibility. Insufficient data have at present been obtained to draw any conclusions regarding the degree of reproducibility of Rengade's method.

Tests on neat cements, as in the Swedish method, have been criticized on the ground that the results may not be applicable to normal concretes. Further investigation is required before any definite conclusion can be reached as to the method which should be recommended for testing the solubility of cements.

A brief summary is presented of recent British papers bearing on the subjects discussed.

RESUME

En conséquence de l'emploi du béton au lieu de la maçonnerie dans la construction moderne des grands barrages, se présentent des difficultés à cause de l'élévation de la témpérature pendant la prise et, quelques fois, à cause de l'action dissolvante des eaux pures de marécage. On présente les résultats des observations d'élévation de température et de fissuration au barrage de Laggan, achevé en 1935. Un examen récent au barrage de Blackwater, qui fut achevé depuis 27 ans, n'a pas exposé une détérioration considérable en conséquence de l'action de l'eau infiltrée par les fissures.

On remarque les changements qui ont pris place depuis 25 ans, dans les charactéristiques des ciments artificiels et leur influence dans la construction en béton massif. Jusqu'à présent en Grande Bretagne, on manque d'exemples pratiques de l'emploi de ciments dégageants peu de chaleur de prise.

La Sous-commission Britannique aux Ciments Spéciaux a entrepris l'examen des méthodes de mésure de l'éxothermie du béton et de la solubilité des ciments purs. On a mis au point un calorimètre adiabatique simple et peu coûteux mais donnant des résultats satisfaisants. On est d'avis que cet appareil présente des avantages sur la méthode de chaleur de dissolution, car l'essai se fait plus facilement et on trouve une corrélation entre les résultats obtenus et les observations faites sur les grands barrages. L'appareil coûte moins cher, mais on a besoin de plusieurs appareils semblables pour un essai qu'on peut faire avec un seul appareil pour mesurer la chaleur de dissolution.

On a fait des essais de solubilité des ciments par les méthodes suivantes: la méthode suédoise d'extraction, employant les ciments purs, durcis et broyés: les méthodes à filtration employant les plaques de mortier maigre; et la méthode de Rengade, par laquelle on fait jouer un jet d'eau contre la surface des éprouvettes. La méthode suédoise d'extraction se montre facile à exécuter et elle est susceptible d'être répetée avec exactitude. Les essais d'après la méthode sur des plaques de mortier ne donnent pas aux répétitions des résultats suffisament semblables. À présent, on n'a pas l'expérience nécessaire pour exprimer une opinion conclusive sur la méthode de Rengade.

On a critiqué les résultats des essais faits sur des ciments purs, par la méthode suédoise, parce qu'ils ne sont peut-être pas susceptibles d'être appliqués aux bétons ordinaires. Avant de pouvoir se prononcer définitivement sur la meilleure méthode d'essai pour la solubilité des ciments, il est nécessaire d'en pousser les études.

Finalement, on présente un résumé des contributions britanniques les plus récentes sur les questions en discussion.

ZUSAMMENFASSUNG

Durch die Verwendung von Beton an Stelle von Bruchsteinmauerwerk für die Errichtung von grossen, neuzeitlichen Staumauern traten verschiedene Schwierigkeiten auf, welche auf die Temperaturerhöhung während der Erhärtung und stellenweise auf die auslaugende Wirkung der reinen Hochmoor-Gewässer zurückzuführen sind. Für die im Jahre 1935 fertiggestellte Laggan-Talsperre werden ziffernmässige Werte bezüglich der Temperaturerhöhung und der Rissbildung angegeben. Eine in der letzten Zeit durchgeführte Untersuchung der 27 Jahre alten Blackwater-Staumauer hat gezeigt, dass keine wesentliche Zerstörung des Betons durch Sickerwasser stattgefunden hat.

Die während der letzten 25 Jahre entstandenen Änderungen in der Beschaffenheit der künstlichen Zemente und deren Einfluss auf die Herstellung von Betonmassen-Bauten werden kurz gestreift. In Gross-Britannien liegen keine praktischen Erfahrungen bezüglich der Verwendung von Zement von geringer Abbindewärme vor.

Der englische Unterausschuss für Spezial-Zemente hat eine Überprüfung der vorhandenen Mittel zur Bestimmung der Wärmeentwicklung and Löslichkeit der Zemente vergenommen.

Die Wärmeentwicklung für Beton wurde mittels zwei Ausführungen eines adiabatischen Wärmemessers und für den reinen Zement durch Bestimmung der Lösungswärme gemessen. Hierzu wurde ein einfacher und billiger adiabatischer Wärmemesser hergestellt, der sich bewährte. Für Versuchszwecke bietet die Verwendung dieses Apparates einen Vorteil vor der Lösungswärme-Bestimmungsmethode, da die Versuche leichter durchzuführen sind und die Ergebnisse mit den in grossen Staumauern gemachten Beobachtungen unmittelbar verglichen werden können. Hinzu kommt, dass der Apparat billiger ist; es werden aber mehrere Apparate benötigt, um dieselbe Anzahl Versuche durchzuführen wie mit einem einzigen Lösungswärme-Apparat.

Untersuchungen über die Löslichkeit der Zemente wurden nach der schwedischen Arbeitsweise durchgeführt: durch Auslaugung von reinen gemahlenen, erhärteten Zementen, durch Sickerversuche mit Platten aus magerem Mörtel, und nach der Rengade'schen Arbeitsweise, wobei Probestücke aus Mörtel der Einwirkung eines auf die Oberfläche treffenden Wasserstrahles ausgesetzt werden. Die schwedische Arbeitsweise ist einfach in der Handhabung und gibt gut reproduzierbare Werte. Die Reproduzierbarkeit der aus Sickerversuchen gewonnenen Werte ist nicht zufriedenstellend. Die mit der Rengade'schen Arbeitsweise erlangten Werte reichen nicht aus, um Schlüsse bezüglich der Güte der Reproduzierbarkeit zu ziehen.

Es ist gegen das Prüfen von reinen Zementen z.B. nach dem schwedischen Verfahren der Einwand erhoben worden, das die Ergebnisse für die Beurteilung eines normalen Betons nicht gelten können. Erst nach weiteren Versuchen wird es möglich sein, für das zur Bestimmung der Löslichkeit der Zemente zu empfehlende Verfahren bestimmte Schlüsse zu ziehen.

Es wird über die in der letzten Zeit auf diesem Gebiete veröffentlichten englischen Arbeiten kurz referiert.

RESUMEN

El empleo del hormigón en vez de la mampostería en la construcción moderna de las grandes presas ha introducido dificultades que pueden atribuirse al aumento de temperatura durante el fraguado y en algunos casos a la acción disolvente de las aguas puras de pantano. Se suministran datos sobre el aumento de temperatura y sobre la formación de grietas en la presa de Laggan que fué terminada en 1935. Un examen reciente de la presa de Blackwater, terminada hace unos 27 años ha demostrado que el hormigón no ha sufrido ningún deterioro serio a causa de la acción del agua infiltrada por las grietas.

Se hace referencia a los cambios que han sufrido durante los últimos 25 años las características de los cementos artificiales y su influencia en la construcción de masas de hormigón. Hasta la fecha no existen en la Gran Bretaña ejemplos prácticos del empleo de cementos que producen poco calor.

El Subcomité Británico de Cementos Especiales está investigando los métodos empleados para medir la evolución del calor y la solubilidad de los cementos.

Se han hecho ensayos sobre la evolución del calor en el hormigón usando dos clases de calorímetros adiabáticos y sobre cemento puro por el método de calor de solución. Se ha construído un calorímetro adiabático sencillo y poco costoso que ha dado buenos resultados. Se opina que los ensayos hechos con este aparato ofrecen ventajas sobre el método de calor de solución, pues el ensayo se hace más fácilmente, y los resultados obtenidos demuestran una correlación directa con las observaciones hechas en las grandes presas. El aparato también es menos costoso, pero es necesario emplear varios aparatos para llevar a cabo el mismo número de ensayos que se pueden hacer con un solo aparato para medir el calor de solución.

Se han hecho ensayos sobre la solubilidad de los cementos empleando los métodos siguientes: método de extracción sueco con cemento puro, fraguado y molido; método de infiltración con placas de mortero magro, y el método de Rengade por el cual la superficie de las muestras de mortero se somete a la acción de un chorro de agua. El método de extracción sueco es de fácil ejecución y puede repetirse con exactitud. Los ensayos con el método de infiltración en las placas de mortero no se han podido repetir satisfactoriamente. En cuanto al método de Rengade no se han obtenido aún suficientes datos para llegar a conclusiones respecto a la exactitud con que puede repetirse.

Los ensayos hechos en cementos ricos, como los del método sueco, han sido criticados porque los resultados pueden no ser aplicables a los hormigones ordinarios. Es necesario hacer más investigaciones para poder determinar definitivamente cual es el mejor método para ensayar la solubilidad de los cementos.

Se hace un resumen de los trabajos británicos, publicados recientemente, sobre los asuntos discutidos.

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

SUI CEMENTI SPECIALI PER LE OPERE IDRAULICHE IN GENERE E IN PARTICOLARE PER LE GRANDI DIGHE DI SBARRAMENTO*

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I

Lo sviluppo moderno dei cementi Portland verso le alte resistenze meccaniche ha tenuto conto sopratutto delle esigenze delle costruzioni in calcestruzzo armato (edifici, ponti ecc.) per le quali la massima resistenza alla trazione ed alla compressione costituisce la preoccupazione fondamentale del consumatore e quindi anche del produttore.

I mezzi adottati per il conseguimento delle resistenze meccaniche più elevate: più alto contenuto di calce nel klinker, temperatura di cottura più elevata, macinazione più fine, hanno avuto però la conseguenza di accentuare maggiormente alcune caratteristiche negative dei cementi Portland: sviluppo di calore di idratazione più rapido e fors'anche complessivamente più intenso, ritiro di presa più forte, formazione di maggiore quantità di calce libera nel cemento idratato.

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*Special cements for hydraulic works in general and for large dams in particular.
Ciments spéciaux pour travaux hydrauliques en général et pour grands barrages en particulier.
Spezialzemente für Wasser-Kraftwerke im Allgemeinen und für Staudämme im Besonderen.
Cementos especiales para las obras hidráulicas en general y para las grandes presas en particular.

Fra questi inconvenienti, il più sensible nelle costruzioni in calcestruzzo armato è il ritiro; infatti, in esse per il loro spessore generalmente ridotto, il calore di presa non può dar luogo a rialzi di temperatura notevoli, essendo il rapporto tra il volume e la superficie di contatto con l'aria molto favorevole ad una rapida dissipazione del calore di presa. Queste costruzioni sono anche, quando sono ben concepite, sottratte ad eventuali azioni chimiche, alle quali particolarmente sono sensibili i cementi che idratando liberano molto idrato di calcio, mediante adeguati rivestimenti.

Il fenomeno dell'intenso ritiro accompagna inevitabilmente la presa dei cementi ad alta resistenza; esso può essere tutt'al più ritardato con l'inumidimento dei getti, rimandando il grosso del fenomeno ad un'epoca posteriore in cui le resistenze più elevate del conglomerato, possono efficacemente opporsi agli eventuali sforzi interni, ma data il prosciugamento successivo, il fenomeno prima o dopo apparirà ugualmente, probabilmente nella sua intera grandezza. Al ritiro si oppongono quindi provvedimenti di progetto come armature metalliche speciali, giunti di contrazione, strutture poco sensibili alle deformazioni dovute al ritiro ecc.

Sostanzialmente diversa è la situazione nel campo delle costruzioni idrauliche ed in modo particolare nel campo delle dighe di ritenuta e ciò per due circostanze importanti: la prima consiste nelle dimensioni notevoli dei manufatti, nei quali di conseguenza il ritiro dà luogo a notevoli tensioni interne e la dissipazione del calore di idratazione è lentissima; la seconda circostanza è costituita dalla possibilità di azioni chimiche (dilavamenti) delle acque filtranti sull'idrato di calcio. ($Ca(OH)_2$) contenuto nel cemento idratato.

Particolarmente grave si presenta poi il problema chimico per le opere idrauliche esposte al contatto di acque agressive come quelle purissime, carboniche, marine, selenitose, ecc.

L'interpretazione delle fessurazioni osservate su alcune dighe presenta evidenti difficoltà per la sovvrapposizione dei due effetti che possono contribuire a produrle: il ritiro ed il raffreddamento successivo al riscaldamento di idratazione. Sembra però che nell'interno delle grandi masse di calcestruzzo che costituiscono le dighe massicce, il grado di imbibizione resti sempre talmente elevato che il cemento avrà la tendenza piuttosto a rigonfiarsi anzichè a contrarsi, cosicchè le fessure attribuibili al solo ritiro si limiterebbero alle parti superficiali soggette ad un sensibile prosciugamento. Nel caso di una diga italiana ad arco le misurazioni delle deformazioni, molto accuratamente eseguite, indicano abbastanza nettamente un rigonfiamento del calcestruzzo.

Così, le fessure più pericolose sembrano doversi attribuire prevalentemente al raffreddamento del calcestruzzo successivo al riscaldamento di idratazione, e di conseguenza l'eliminazione di quest'ultimo fenomeno costituisce oggi una delle preoccupazioni principali dei costruttori di dighe.

I provvedimenti costruttivi, come la suddivisione del volume dei getti ed il raffreddamento artificialmente accelerato, con tutto il loro innegabile beneficio, sono però, e giustamente, da molti considerati come palliativi, sopratutto in confronto col mezzo più radicale consistente nell'impiego di cementi speciali che per la loro composizione chimica diano luogo ad un calore di idratazione minimo possibile.

Per quanto riguarda l'azione chimica dell'acqua, l'impoverimento dei calcestruzzi e delle malte per effetto del dilavamento dell'idrato di calcio da parte delle acque filtranti è stato rilevato da molti anni in diversi manufatti dalla formazione di depositi travertinosi, sia nei pozzi di drenaggio che sul paramento a valle.

Anche in questo campo oggi tende a prevalere il concetto che, oltre ed al disopra dei provvedimenti costruttivi, come le protezioni con manti impermeabili, il conseguimento di conglomerati molto compatti, ecc. l'impiego di un adeguato cemento, che dia luogo alla formazione di un quantitativo minimo possibile di idrato di calcio ($Ca(OH)_2$) sia il mezzo più efficace per eliminare, o per lo meno ridurre, le azioni chimiche sul cemento.

II

Per le applicazioni speciali e per eliminare od almeno attenuare gli inconvenienti dei Portland fortemente calcarei, l'industria italiana si è orientata negli ultimi anni verso diversi tipi di cementi speciali.

I cementi pozzolanici si ottengono con la macinazione di una miscela di klinker di Portland con pozzolana. La funzione principale dei costituenti delle pozzolane, la cui attività si può esaltare con una preventiva tempra, è quella di entrare in combinazione chimica con l'idrato di calcio liberato nell'idratazione del silicato bicalcico e tricalcico, fissandolo ed impedendo il suo dilavamento. E' da attendersi che la diluizione del contenuto di calce, dovuta all'aggiunta di pozzolana e la conseguente riduzione della quantità percentuale del silicato bicalcico e tricalcico, influisca favorevolmente sulla quantità di calore sviluppato durante l'idratazione di questi componenti. Oltre alle numerose applicazioni nel campo delle costruzioni marittime, per le quali è stato destinato principalmente ed originariamente questo tipo, esso ha avuto un'importante applicazione nella costruzione della Diga di Suviana, la più alta diga costruita in Italia.

Il comportamento del conglomerato di tale opera, terminata ormai da 4 anni, è eccellente sotto ogni rapporto. Le filtrazioni si limitano ad entità minime; le osservazioni riguardanti le temperature nell'interno della massa sono ancora in corso.

Funzione, in un certo senso, analoga a quella delle pozzolane hanno le aggiunte di loppe basiche di alto forno al klinker, nella fabbricazione di cementi siderurgici nei quali pure lo scopo principale dell'aggiunta è la fissazione dell'idrato di calcio nel cemento idratato, o per lo meno di aggiungere al klinker un prodotto idraulicamente attivo, l'idratazione del quale non dia luogo alla formazione di $Ca(OH)_2$.

Il comportamento ottimo dei cementi siderurgici in presenza di acqua marina è confermato da un'esperienza ormai lunghissima su numerosi manufatti.

Per quanto riguarda lo sviluppo del calore di presa, esperienze comparative di laboratorio hanno dimostrato una netta superiorità di tali cementi rispetto ai Portland normali, comportamento questo attribuibile con molta probabilità al basso calore di idratazione delle loppe di alto forno.

Tanto i cementi pozzolanici, quanto quelli siderurgici si producono correntemente nelle due qualità previste dalla legislazione vigente: nel tipo normale e nel tipo ad alta resistenza.

Per il tipo normale (sia cemento Portland, siano cementi speciali) si richiedono le resistenze seguenti (della malta normale):

a 7 giorni 25 Kg/cmq. alla trazione
350 Kg/cmq. alla compressione
a 28 giorni 30 Kg/cmq. alla trazione
450 Kg/cmq. alla compressione

Per i tipi ad alta resistenza si richiedono i seguenti valori:

a 3 giorni 20 Kg/cmq. alla trazione
250 Kg/cmq. alla compressione
a 7 giorni 30 Kg/cmq. alla trazione
450 Kg/cmq. alla compressione
a 28 giorni 35 Kg/cmq. alla trazione
600 Kg/cmq. alla compressione

Un posto del tutto particolare è occupato dal cemento fuso o alluminoso nel campo dei cementi speciali prodotti in Italia.

Lo sviluppo di calore molto intenso, sopratutto nel primo periodo della presa, costituisce un certo ostacolo al suo impiego nel getto delle grandi masse murarie, giacchè al costo elevato (rispetto agli altri tipi di cemento) del prodotto stesso, si aggiungerebbero sensibili oneri per i provvedimenti costruttivi destinati ad eliminare gli effetti dello sviluppo di calore. L'eccellente comportamento chimico del cemento fuso ha invece giustificato il suo impiego — avvenuto con pieno successo — in alcune opere idrauliche: fondazioni di centrali elettriche, rivestimenti di gallerie per condutture d'acqua, ecc. esposte all'azione di acque agressive.

Così pure l'elevata resistenza immediata del cemento fuso ha permesso il suo vantaggioso impiego nella costruzione di sbarramenti fluviali minori nei quali l'opera ha dovuto essere sottoposta all'azione dell'acqua a brevissimo tempo dalla sua esecuzione.

Ritornando ai cementi più strettamente affini ai Portland classici, due tendenze fondamentalmente divergenti caratterizzano gli sforzi odierni dell'industria italiana rivolta alla produzione di cementi speciali, particolarmente adatti per opere idrauliche.

I klinker dei cementi Portland sono notoriamente costituiti dai seguenti composti principali:

Silicato tricalcico (Alite) $3CaO. SiO_2$
Silicato bicalcico (Belite) $2CaO. SiO_2$
Alluminato-ferrito tetracalcico (Brownmillerite) $4CaO.Al_2O_3.Fe_2O_3$
Alluminato tricalcico $3CaO.Al_2O_3$

Con l'analisi chimica di un klinker cotto a sufficenza si è in grado di determinare con una certa esattezza la proporzione di questi costituenti e quindi in base alla conoscenza delle proprietà di essi, prevedere il comportamento del cemento ed in definitiva dei calcestruzzi con esso confezionato.

I risultati delle ricerche, condotte come è noto da Tecnici Americani, sull'influenza dei singoli costituenti sulle proprietà fisiche, chimiche e meccaniche del cemento, possono riassumersi così:

Silicato tricalcico: idratazione piuttosto rapida con sviluppo di calore totale notevole (120 Cal/gr) buona resistenza agli agenti atmosferici, ritiro basso; ottima resistenza meccanica con incremento sufficientemente rapido della stessa.

Silicato bicalcico: idratazione lenta, basso e lento sviluppo di calore (62 Cal/gr.), resistenza meccanica ottima ma lentamente crescente; buona resistenza agli agenti atmosferici; ritiro basso.

Alluminato tricalcico: idratazione, sviluppo di calore e incremento della resistenza meccanica rapidi; calore totale di idratazione alto (207 Cal/gr); scarsa resistenza agli agenti atmosferici, ritiro elevato. Tale costituente può presentare il pericolo di retrogradazioni e non presenta alcuna resistenza alle acque solfatate.

Alluminato-ferrito tetracalcico: idratazione, sviluppo di calore e incremento della resistenza meccanica lenti; calore totale di idratazione (100 Cal/gr) e resistenza meccanica finale bassi; scarsa resistenza agli agenti atmosferici; ritiro basso. (I valori del calore di idratazione totale sono quelli determinati da Lerch e Bogue, Bureau of Standards Journal of Research, May 1934, pag. 645.)

Una delle vie da seguire nel ridurre al minimo il calore di idratazione è evidentemente, in base a quanto qui esposto, quella di arricchire il klinker di silicato bicalcico e ridurre il contenuto di silicato tricalcico, di alluminato tricalcico e possibilmente anche di Brownmillerite, concezione questa alla quale si sono inspirati noti cementi speciali Americani e Svedesi.

Tentativi analoghi si stanno facendo anche in Italia, allo scopo di produrre un tipo di cemento speciale da impiegarsi in un'importante diga ad arco. Una certa difficoltà si incontra nella ricerca delle materie prime adatte a distanze economicamente possibili dallo stabilimento; la difficoltà sostanziale è però dovuta alle due esigenze contemporanee, non facilmente conciliabili, di ottenere un cemento che offra resistenze meccaniche elevate pur essendo ricco di silicato bicalcico, costituente questo che dà luogo ad un prodotto avente resistenze meccaniche tendenzialmente basse.

Un'altra concesione particolarmente seguita, anche nel campo industriale, in Italia, è scaturita dalla preoccupazione di conferire al cemento la massima resistenza chimica alle acque aggressive.

La rassegna delle proprietà dei singoli costituenti porta alla constatazione che l'alluminato tricalcico è un costituente poco desiderabile sopratutto nei riguardi della resistenza chimica, ed è quindi vantaggioso eliminarle.

E' dovuto al Prof. F. Ferrari la proposta di un cemento speciale in cui il modulo dei fondenti

$$\frac{Al_2O_3}{Fe_2O_3}$$

sia uguale a 0,64 ossia al rapporto dei pesi equivalenti dei sesquiossidi di alluminio e di ferro

$$\left(\frac{101.94}{159.68}\right);$$

in esso i due sesquiossidi vengono tutti assorbiti dalla formazione di Brownmillerite, evitando il formarsi di alluminato tricalcico.

Il "Cemento Ferrari" rappresenta un caso limite dei cosidetti cementi ferrosi, per i quali il modulo dei fondenti

$$\frac{Al_2\,O_3}{Fe_2\,O_3}$$

è minore od eguale a 0,64.

In questi cementi il ferro risulta in eccesso rispetto all'allumina e dà luogo alla formazione di ferrito bicalcico $2CaO.\,Fe_2\,O_3$ che rimane in soluzione solida nella Brownmillerite.

Essi vengono prodotti su scala industriale nello Stabilimento di Albino della "Italcementi" partendo da calcari siliciosi del Lias ai quali si aggiunge silice e ceneri di pirite.

Le caratteristiche chimiche di tale prodotto sono: modulo dei fondenti alcuanto inferiore a 0,64; contenuto percentuale di Brownmillerite (o meglio di soluzione solida di ferrito bicalcico in essa) non superiore al 15%, e ciò in considerazione dello scarso valore idraulico della Brownmillerite in confronto ai silicati attivi. Facendo variare il modulo calcare, definito dal rapporto

$$\frac{\text{CaO combinata a } SiO_2}{SiO_2}$$

si ottengono diverse resistenze meccaniche, in modo da soddisfare le varie esigenze. Con alti moduli calcari (fra 2.6 e 2.7) si ottengono cementi ad alta resistenza esenti da calce libera, mentre col valore del modulo attorno a 2.0 si hanno cementi normali a piccolo calore di idratazione e di moderato ritiro.

Con cemento ferroso di Albino si è costruito negli anni 1928–31 la Diga del Barbellino, un manufatto il cui comportamento si è dimostrato ottimo in 5 anni di esercizio.

Così pure numerose ricerche sperimentali hanno confermato le buone qualità dei cementi ferrosi, non solo per quanto riguarda la resistenza chimica, ma anche nei riguardi del calore di idratazione.

Un'ulteriore e notevole progresso nel campo dei cementi speciali si è conseguito recentemente con il cosidetto cemento ferroso-pozzolanico, ottenuto con l'aggiunta di pozzolana a cemento ferroso del tipo sopradescritto.

Con tale cemento si raggiungono contemporaneamente tre scopi:

(1) Eliminazione dell'alluminato tricalcico e conseguente elevata resistenza alle acque aggressive in genere.

(2) Fissazione della calce, che si libera durante l'idratazione, da parte della pozzolana, ciò che assicura una maggiore resistenza al dilavamento dovuto alle permeazioni d'acqua.

(3) Sensibile abbassamento del calore di idratazione, dovuto, da una parte alla già accennata diluizione del contenuto di calce nella miscela klinker-pozzolana, dall'altra parte all'eliminazione dell'alluminato tricalcico che è uno dei costituenti del klinker che dà luogo alla più elevata quantità di calore di idratazione.

Tale tipo di cemento, per questi vantaggi offerti, è attualmente considerato come uno dei più addatti per le costruzioni idrauliche, esso viene prodotto industrialmente nello stesso Stabilimento di Albino ed è stato su richiesta prodotto sempre in quantità industriali anche dallo Stabilimento di Padova della Soc. Cementi del Veneto. I metodi di produzione dipendono dalle materie prime delle quali si dispone nelle vicinanze degli stabilimenti.

La pozzolana viene aggiunta in un rapporto percentuale che può variare dal 25 al 40% della miscela.

Come nei cementi ferrosi, anche in quello ferroso-pozzolanico, con l'opportuno variare del modulo calcare, si possono ottenere tutte le resistenze meccaniche ottenibili con i cementi Portland, senza menomare i pregi chimici sopraelencati, ciò che gli conferisce una notevole importanza applicativa.

Numerose applicazione importanti hanno collaudato le qualità di tale cemento, sopratutto in casi di acqua molto aggressive (selenitose ed anche leggermente acide) tra questi in rivestimenti di gallerie per condutture di acqua ed in rivestimenti di sponde di canali. Fra parecchi anni il comportamento di tali opere, sinora ottimo, fornità un complesso prezioso di dati sperimentali.

III

I risultati molto favorevoli ai quali è giunta l'industria italiana nella produzione dei cementi speciali è dovuta alla più chiara conoscenza che oggi abbiamo sulla costituzione chimica del klinker dei cementi Portland. E' naturale che ogni ulteriore perfezionamento dei cementi speciali non può scaturire che dalle più approfondite ricerche sulle proprietà dei singoli costituenti del klinker, sul loro contributo alle singole proprietà del cemento: resistenza meccanica, resistenza alle diverse azioni chimiche, ritiro di presa, sviluppo di calore di idratazione.

Particolare attenzione dovrà essere rivolta all'influenza della finezza di macinazione che si sovrappone, rendendone più complessi gli effetti, all'azione della costituzione chimica.

I metodi di controllo dei risultati ottenuti richiedono ancora molti perfezionamenti.

Per quanto riguarda il calore di presa, i due metodi attualmente usati: metodo calorimetrico e metodo del calore di soluzione, sono abbastanza perfezionati per poterli mettere a base di metodi di controllo normalizzati.

Per una valutazione preventiva globale del comportamento del klinker potrà bastare l'analisi chimica. Con questa si puo dedurre il contenuto percentuale di singoli costituenti e quindi, in base ai valori del calore di presa totali indicati da Lerch e Bogue, il calore totale di idratazione del cemento. Ma per l'impiego, soprattuto nelle dighe di sbarramento, la conoscenza dell'andamento dello sviluppo di calore è di capitale importanza.

Quindi la necessità di ricorrere alla determinazione diretta del calore di idratazione, rilevandone l'andamento per un periodo il più lungo possibile.

Per quanto riguarda gli effetti di dilavamento esercitati dalle acque di permeazione, i metodi di ricerca e di controllo abbisognano di un notevole perfezionamento.

Scarso valore si può attribuire alle semplici prove di permeabilità eseguite generalmente senza preoccuparsi della qualità chimica dell'acqua di permeazione.

Oltre a normalizzare le modalità delle prove di permeabilità per quanto riguarda la durata, la pressione idrostatica, le dimensioni del provino e le condizioni idraulico-geometriche prescritte al flusso di permeazione, è necessario definire la qualità dell'acqua da usare nelle prove stesse.

Oltre alla prove eseguite con acqua avente caratteristiche ben definite dal caso di applicazione concreto, s'impongono prove di carattere generale che forniscono una base di controllo e di confronto dei cementi. Per questo occorrerà adoperare una qualità d'acqua normalizzata: conviene che la scelta cada sull'acqua distillata.

Lo studio comparativo sistematico dei singoli cementi speciali mediante prove di permeabilità sui calcestruzzi con essi confezionati, costituirà senza dubbio uno dei compiti prossimi più importanti del lavoro di ricerca in questo campo.

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P. S.—Ringraziamo sentitamente i Sigg. Prof. Sestini, Prof. Ferrari, Ing. Nicolai, Dott. Malignani, Dott. Bolaffio che hanno cortesemente comunicato informazioni essenziali.

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RIASSUNTO

Si passano in rassegna i diversi cementi speciali prodotti in Italia ed impiegati nelle costruzioni idrauliche: pozzolanico, siderurgico, ferroso, ferroso-pozzolanico e fuso.

La produzione italiana mostra un evidente orientamento verso i tipi preparati con l'aggiunta di ingredienti idraulicamente attivi: cementi pozzolanici, siderurgici e ferroso-pozzolanici.

Con questi si raggiungono notevoli resistenze meccaniche, congiunte alle seguenti qualità, preziose per l'impiego nelle costruzioni idrauliche: elevata resistenza chimica; ridotta quantità di calce liberata nell'idratazione a causa del ridotto contenuto complessivo di calce nel cemento; presenza di costituenti capaci di fissare la calce liberata; ridotto calore di idratazione e ritiro.

Insomma, essi, mentre tendono a ridurre al minimo le variazioni di volume, dovute al ritiro ed alla dissipazione del calore di idratazione, oppongono agli effetti di queste l'alta resistenza meccanica.

SUMMARY

The writers point out the several kinds of special cements produced in Italy and employed in the hydraulic constructions: Pozzolana cement, metallic cement, ferro-concrete, ferro-pozzolana, and melted cements.

Italian production shows an evident tendency toward the types prepared through the addition of hydaulic ingredients: Pozzolana, metallic, and ferro-pozzolana cements.

By means of these cements, considerable mechanic resistances are attained, in connection with the following qualities, which are valuable in hydraulic constructions: High chemical resistance; reduced amount of lime discharged in the hydration owing to the reduced lime con-

tents in the cement; presence of constituents capable of fixing the lime discharged; reduced heat of hydration and contraction.

They, therefore, while aiming at reducing to the minimum the volume variations due to the contraction and to the wasting of hydration heat, oppose, in this respect, high mechanical resistance.

RESUME

Dans ce rapport, on passe en revue les différents ciments spéciaux fabriqués en Italie et employés dans les travaux hydrauliques: ciment pouzzolanique, de laitier, ferreux, ferro-pouzzolanique et fondu.

L'examen de la production révèle une orientation évidente vers les types préparés avec addition de gangues hydrauliques: ciments pouzzolaniques, de laitier et ferro-pouzzolaniques.

On obtient avec ceux-ci de hautes résistances, en même temps que les qualités suivantes, précieuses pour l'emploi dans les travaux hydrauliques: haute résistance chimique; faible quantité de chaux libérée par l'hydratation, à cause de la faible teneur totale de chaux dans le ciment; présence de constituants capables de fixer la chaux libérée; chaleur d'hydratation réduite et faible retrait.

En définitive, ces ciments, tout en tendant à réduire au minimum les variations volumétriques, dues au retrait et à la dissipation de la chaleur d'hydratation, opposent aux effets de celles-ci une haute résistance mécanique.

ZUSAMMENFASSUNG

Der Bericht betrachtet nacheinander die verschiedenen Spezialzemente, die in Italien hergestellt und im Wasserbau verwendet werden, nämlich den Puzzolan-, Eisenportland-, Schlacken- und Schmelzzement.

Wenn man die Erzeugnisse näher betrachtet, so fällt auf, dass man gegenwärtig entschieden dazu neigt, diejenigen Qualitäten zu benutzen, denen ein hydraulischer Zuschlag zugegeben worden ist, wie Puzzolan-, Eisenportland- und Schlackenzement.

Mit diesen Zementsorten erreicht man hohe Festigkeitszahlen, sowie folgende, im Gebrauch im Wasserbau wertvolle Eigenschaften: hohe chemische Beständigkeit, — es wird durch die Hydratisierung wegen des niedrigen Kalkgehalts des Zements nur wenig Kalk frei — Gegenwart von Bestandteilen, die die Fähigkeit haben den frei gewordenen Kalk zu binden; Entwicklung von wenig Wärme bei der Hydratisierung; geringe Schwindung.

Endlich neigen diese Zemente dazu, die Volumenänderungen, die durch die Schwindung und die Entwicklung der Hydratisierungswärme hervorgerufen werden, auf ein Minimum zu reduzieren, und halten durch ihre grosse mechanische Festigkeit den Einflüssen dieser Volumenänderungen stand.

RESUMEN

La memoria menciona los diferentes cementos especiales producidos en Italia y empleados en las obras hidráulicas: puzolánico, de escorias, férreo, ferro-puzolánico y fundido.

La producción italiana presenta una orientación evidente hacia los tipos preparados con la adición de ingredientes hidráulicos: cementos puzolánicos, de escorias y ferro-puzolánicos.

Con estos cementos se obtienen elevadas resistencias mecánicas, además de las cualidades siguientes, valiosas para el empleo en las obras hidráulicas: elevada resistencia química, poca cantidad de cal libertada durante la hidratación a causa de contener poca cal el cemento; presencia de constituyentes capaces de fijar la cal libertada; reducido calor de hidratación y poca retracción.

Por último, estos cementos, aunque tienden a reducir al mínimo las variaciones volumétricas debidas a la retracción y a la disipación del calor de hidratación, oponen a los efectos de este calor una alta resistencia mecánica.

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

EFFECT OF INTERNAL TEMPERATURE OF GRAVITY DAMS ON THE STRENGTH OF CONCRETE*

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Japan

The author of this paper presented before the first Congress on Large Dams, held in 1933, a paper entitled "On the Effect of Internal Temperature and Deformation of a Gravity Dam" with respect to the Komaki Dam which had been built under his supervision. In section 4, article II, of that paper, namely, "Effect of the Internal Temperature of Dam Body to the Strength of Concrete", the author expressed the opinion that the effect of temperature rise during the setting of concrete would have a favorable effect on its strength and that the internal concrete of the Komaki Dam, which was cured in a high temperature would be stronger than that of test pieces; and concluded that the effect of the internal temperature in the dam need not be questioned, so far as it affects dam strength, but stated that the exact effect of heat generated during setting on the strength of concrete requires further study.

For the purpose of ascertaining the exact effect of temperature on the strength of concrete, the author conducted for the duration of 1 year, from 1933 to 1934, various tests, by curing mortar as well as concrete in high temperatures in the Unatsuki testing laboratory of the Nippon Electric Power Co. on the Kurobe River—where the company has the Yanagawara hydraulic plant of 50,000 kW in opera-

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**Effets de la température interne dans les barrages-poids sur le résistance du béton.*

Die Wirkung der Innentemperatur einer Schwebgewichtsmauer auf die Festigkeit des Betons.

Efectos de la temperatura interna en las presas de gravedad sobre la resistencia del hormigón.

tion and the Kanetsuri hydraulic plant of a capacity of 65,000 kW under construction—by utilizing a hot spring in the vicinity. By the results of the tests the author intends to determine the actual effect of high internal temperatures generated inside the dam on the strength of concrete.

I. TEST TEMPERATURES

In the inside of a massive concrete body such as a gravity dam the temperature rise by heat generated during setting often reaches as high as 60° C. In view of this fact, the maximum temperature for this test was taken at 70° C. The method of test was divided into two parts, in one the curing temperature being kept constant during the whole period from moulding to breaking test, and in the other the curing temperature being varied along a certain specified line. That is, in the latter the curing temperature was varied along the four representative records out of 26 temperature records obtained in the test on the Komaki Dam. In this paper the test is subdivided into eight groups, as stated below, according to the temperatures in which test pieces were cured.

Group I. Those cured in the temperature varied along the line by no. 1 thermometer in the observation of the Komaki Dam. (See fig. 1, in which during the period from the one hundred and fourty-fourth day from moulding to the two hundred and twenty-sixth day, desired temperature adjustment was impossible due to high water temperature in the summer season.)
II. Same as group I, but temperature was varied along the line shown by no. 22 thermometer. (See fig. 2.)
III. Same as group I, but temperature was varied along the line shown by no. 3 thermometer. (See fig. 3.)
IV. Same as group I, but temperature was varied along the line shown by no. 6 thermometer. (See fig. 4.)
V. Those cured under constant temperature of 70° C.
VI. Those cured under constant temperature of 50° C.
VII. Those cured under constant temperature of 30° C.
VIII. Those cured under constant temperature of 20° C.

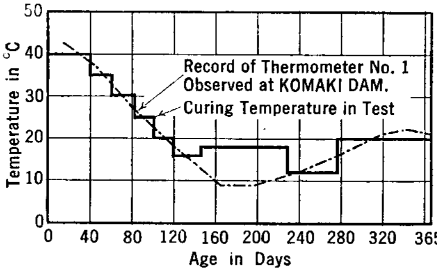


FIGURE 1.—**Variation of curing temperature for group I.** — Variation des températures maintenues pour le Groupe I. — Verschiebungen in der Behandlungstemperatur für Gruppe I. — Variación de las temperaturas mantenidas por el Grupo I.

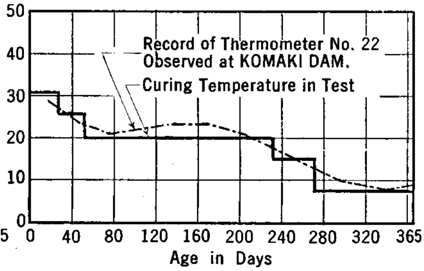


FIGURE 2.—**Variation of curing temperature for group II.** — Variation des températures maintenues pour le Groupe II. — Verschiebungen in der Behandlungstemperatur für Gruppe II. — Variación de las temperaturas mantenidas por el Grupo II.

II. Test Method

Test piece.

Tests were carried out mainly with mortar specimens due to the lack of equipment and for other reasons, and comparatively few tests were conducted with concrete specimens on the assumption that the strength of concrete may be assumed from the tests on the mortar. Mortar test pieces were of 5.5 cm diameter and 11 cm height, and those of concrete 15 cm diameter and 30 cm height, in accordance with the standardization rule of the Civil Engineering Society of Japan.

Materials.

Cement was from the Hokkaido plant of the Asano Portland Cement Co., made on December 15, 1932, shipped in a barrel, and meeting the standard specification tests.

The sand was a mixture of good quality from the Kurobe River with a sieve analysis gradation as follows:

TABLE 1.—*Sieve analysis of sand*

Sieve:	*Retarned percentage by weight*
No. 8	1. 3
No. 14	40. 3
No. 28	67. 3
No. 48	86. 3
No. 100	97. 8
Fineness modulus	2. 930

Gravel used for concrete was of granite of good quality from the Kurobe River with a sieve analysis gradation as follows:

TABLE 2.—*Sieve analysis of gravels*

Sieve:	*Retained percentage by weight*
1½ inch	0.
¾ inch	32. 1
⅜ inch	70. 2
No. 4	100. 0
Fineness modulus	7. 023

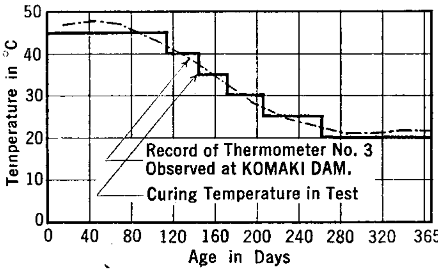


FIGURE 3.—**Variation of curing temperature for group III.** — Variation des températures maintenues pour le Groupe III. — Verschiebungen in der Behandlungstemperatur für Gruppe III. — Variación de las temperaturas mantenidas por el Grupo III.

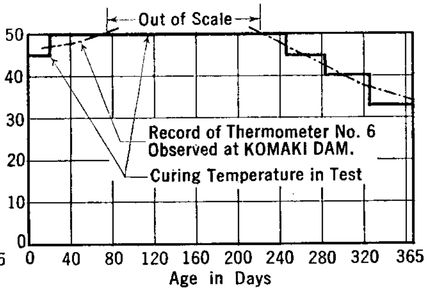


FIGURE 4.—**Variation of curing temperature for group IV.** — Variation des températures maintenues pour le Groupe IV. —Verschiebungen in der Behandlungstemperatur für Gruppe IV. — Variación de las temperaturas mantenidas por el Grupo IV.

Proportion of mixture—water-cement ratio and age.

Tests on mortar specimens were conducted for each group at 7, 14, 28, 90, 183, and 365 days, respectively, but for concrete specimens only a compression test was performed at the age of 28 days for groups V to VIII. The proportion of mixture and water-cement ratio are shown in table 3. The test was generally conducted on three specimens from one batch, but in some cases nine specimens were placed under test as repetition was required.

TABLE 3.—*Proportion of mixture and water-cement ratio*

Mortar		Concrete	
Proportion of mixture by weight	Water-cement ratio by weight	Proportion of mixture by weight	Water-cement ratio by weight
1:2	0. 45	1:2:4	0. 55
1:2	. 55	1:2:4	. 70
1:3	. 55	1:3:6	. 65
1:3	. 65	1:3:6	. 80

Curing.

In the test, in order to maintain test pieces in certain specified temperatures, there were provided specially designed curing containers in which test pieces were kept in tanks with water the temperature of which was regulated. The general description of the device is as follows:

The construction of the curing tank is shown in figure 5. Hot spring water is conducted through a pipe branched from the main pipe of the Unatsuki hot spring into a tank with electric heating elements in the curing room. As the temperature of the spring water averaged 55° C., it was raised to 70° C. by means of the electric heaters and flowed to no. 1 tank where it was maintained at 70° C. From no. 1 tank the hot water flowed to no. 2 tank, in which it was cooled to a temperature of 50° C. by the addition of a small quantity of cold water. In a similar manner the water in the remaining tanks was maintained at a specified temperature and was regulated as desired along the temperature curves for each group. In case an especially low temperature was desired, the tank was immersed in cold spring water outdoors.

Actual temperature variations for each group are shown in figures 1 to 4, and average curing temperatures for each age group are shown in table 4 (temperatures during 2 days for molding excluded). It should be noted that table 4 shows the average curing temperature during the period from molding to breaking test and figures 1 to 4 the actual variation of curing temperatures during that period.

FIG. 5a SPECIMEN CONTAINER

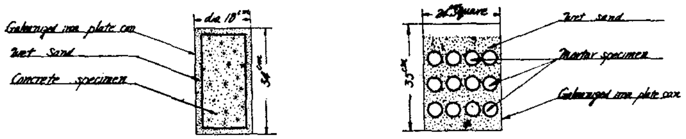


FIG. 5b ARRANGEMENT OF CURING TANK

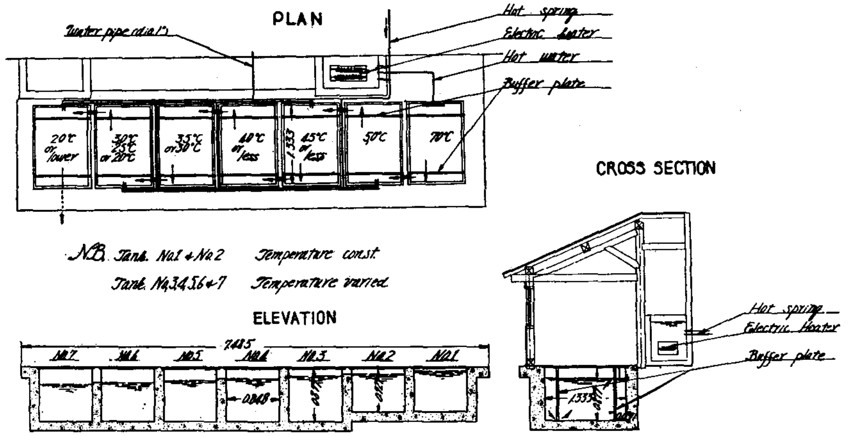


FIGURE 5.—(a) **Specimen container.** (b) **Arrangement of curing tank.**—(a) Boîte à éprouvettes. (b) Dispositif de la cuve. — (a) Gefäss für Versuchsproben. (b) Versuchsanordnung im Behandlungstank. — (a) Caja de pruebas. (b) Distribución del depósito.

TABLE 4.—*Average temperature during curing period, ° C.*

Group	I	II	III	IV	V	VI	VII	VIII
AGE								
7 days	40. 5	31. 0	45. 0	45. 0	57. 3	50. 0	31. 0	20. 5
14 days	40. 1	30. 9	45. 2	45. 2	68. 5	50. 7	30. 9	20. 4
28 days	40. 4	29. 8	45. 2	45. 9	70. 0	50. 5	30. 5	20. 3
90 days	35. 5	24. 4	45. 2	49. 2	70. 0	50. 3	30. 5	20. 1
183 days	23. 6	20. 9	42. 0	49. 6	69. 6	50. 3	30. 5	20. 2
365 days	21. 7	17. 2	32. 5	46. 5	70. 0	50. 0	30. 3	20. 0

Unatsuki is a hot-spring resort on the Kurobe River, but the hot spring itself is located 8 km upstream, and the water reaches the town by means of a 15-cm pipe. The temperature of the water at the spring is about 100° C., but when it reaches Unatsuki, it has fallen to about 55° C. The water has neither odor nor taste and contains no chemical element which may affect the strength of concrete. A precaution was, however, taken against any possible chemical action upon concrete by keeping the specimens under cure in wet sand in closed containers immersed in the water tank as shown in figure 5.

TABLE 5.—*Result of compression test*

(a) MORTAR

Age (days)	Mix	$\frac{W}{C}$	Compressive strength (kg/cm²)							
			Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII	Group VIII
7	1:2	0.45	366	282	396	396	329	377	282	217
		.55	198	156	263	263	226	226	156	120
	1:3	.55	208	176	237	237	198	254	176	121
		.65	133	102	150	150	118	160	102	80
14	1:2	.45	444	372	456	456	398	466	372	340
		.55	298	252	296	296	300	309	252	245
	1:3	.55	274	222	298	298	310	297	222	214
		.65	185	159	196	196	190	204	159	127
28	1:2	.45	514	470	510	511	513	530	496	440
		.55	385	311	383	374	375	380	351	311
	1:3	.55	337	281	358	359	331	347	316	270
		.65	241	200	242	236	244	257	212	182
90	1:2	.45	549	568	588	600	590	580	572	542
		.55	429	436	455	462	427	439	422	441
	1:3	.55	395	392	402	403	410	409	400	380
		.65	300	302	309	303	287	306	304	277
183	1:2	.45	586	619	629	628	------	------	------	------
		.55	485	496	504	463	------	------	------	------
	1:3	.55	412	460	479	412	------	------	------	------
		.65	349	361	325	312	------	------	------	------
365	1:2	.45	598	640	638	631	670	627	660	645
		.55	502	535	540	------	561	477	508	531
	1:3	.55	447	481	481	------	521	448	452	470
		.65	372	382	340	333	411	344	385	388

(b) CONCRETE

Age (days)	Mix	$\frac{W}{C}$	Compressive strength (kg/cm²)			
			Group V	Group VI	Group VII	Group VIII
28	1:2:4	0.55	230	251	226	213
		.70	153	154	129	112
	1:3:6	.65	155	163	150	125
		.80	106	105	98	89

III. TEST RESULT

The results of compression tests on specimens are shown in table 5 (a) and 5 (b). Some observations are given below.

1. *The relation between water-cement ratio and compression strength.*

Abrams represents the relation between water-cement ratio and compression strength by a formula:

$$S=\frac{A}{B^x}$$

in which

S=compressive strength of concrete
x=water-cement ratio
A and B=constants

Whether the above formula is applicable to mortar cured under high temperature and age as in this test is problematical, but for the water-cement ratio used here, it appears to hold true. The formula shows that when the logarithmic values of S are taken as ordinate and water-cement ratio as abscissa, a straight-line relation results and when the results of this test are plotted as a curve, they generally satisfy the same condition.

Under the above assumption, after having determined the values of constants A and B by means of least square for empirical values of each group and age, if an equation showing the relation between water-cement ratio and compressive strength is plotted (using true values for both ordinate and abscissa) figure 6 (a) (for mortar) and figure 6 (b) (for concrete) are obtained.

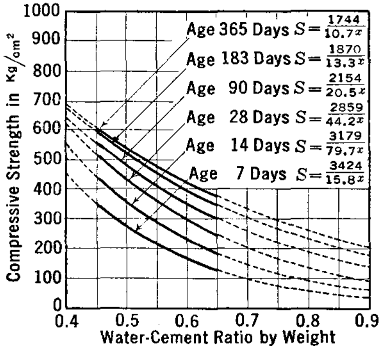
As shown in table 5 (a), in a majority of cases, except in a few cases of specimens having an age of 7 days, as seen by the results of this test, the specimen having a proportion of mixture 1:2 shows a greater strength than that having a proportion of mixture 1:3 prepared under the same water-cement ratio. Therefore it would be inaccurate to represent compressive strength by a curve or a formula in which only the water-cement ratio is considered, and the effect of proportion of mixture is disregarded. Especially it will be so when the curve is extended beyond the limit of water-cement ratio within which the test was conducted (see dotted lines in Fig. 6a and 6b). Within the limit it will be fairly accurate, as will be seen in tables 6 (a) and 6 (b). If the calculated values in tables 6 (a) and 6 (b) and empirical values in tables 5 (a) and 5 (b) are compared, this is more apparent. Out of 174 empirical values (mean value for each specimen), there are only 9 cases which show error above 8 percent $\left(\frac{\text{calculated value}-\text{empirical value}}{\text{empirical value}}\right)$. Table 7 shows particulars.

GENERAL EQUATION $S=\frac{A}{B^x}$ where S = Compressive Strength of Mortar or Concrete in $\mathrm{Kg/cm^2}$

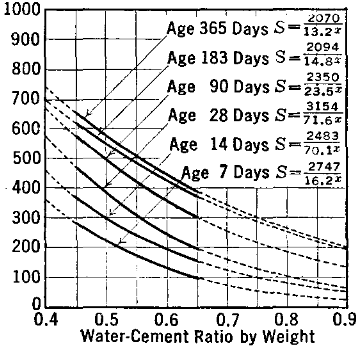
x = Water-Cement Ratio by Weight

A & B = Constant

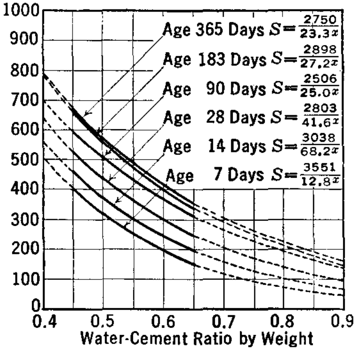
GROUP I



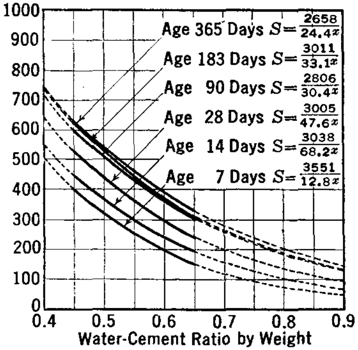
GROUP II



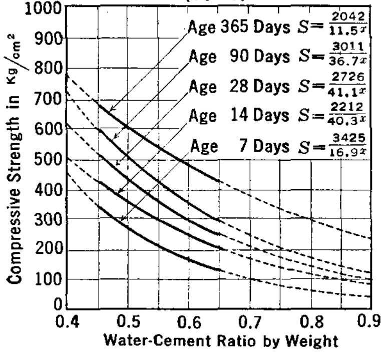
GROUP III



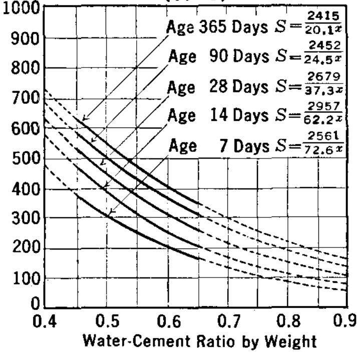
GROUP IV



GROUP V
(70 °C)

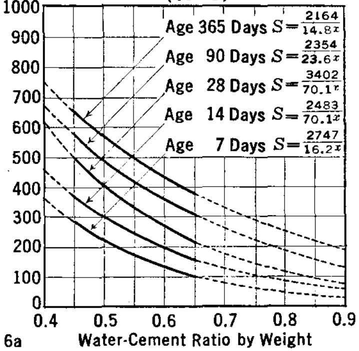


GROUP VI
(50 °C)

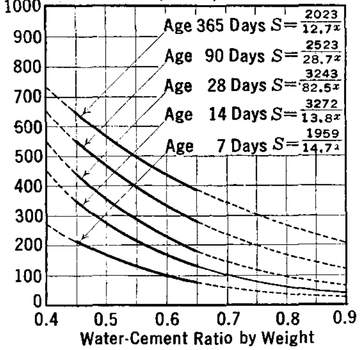


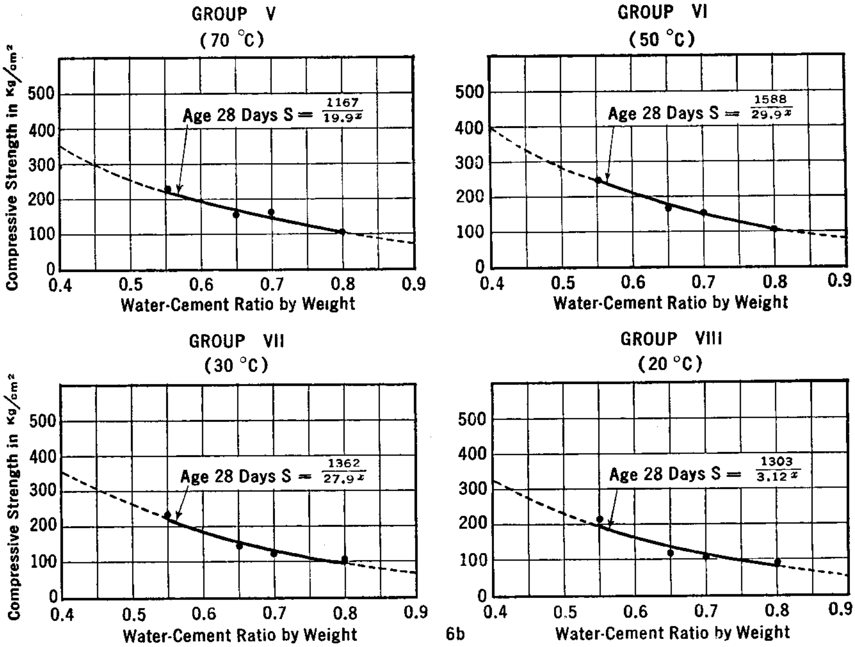
6a

GROUP VII
(30 °C)



GROUP VIII
(20 °C)





6b

FIGURE 6.—**Water-cement ratio strength curve.** (a) **Mortar.** (b) **Concrete.** — Courbe de la résistance envers le rapport eau/ciment. (a) Mortier. (b) Béton. — Diagramm, veranschaulichend den Wasser-Zement-Prozentsatz im Verhältnis zur Druckfestigkeit. (a) von Mörtel. (b) von Beton. — Curva de la resistencia de la relación agua/cemento (a) mortero, (b) hormigón.

Errata: After the plates had been made and the report printed, the author discovered that the decimal point in the denominator of the fractions in the following instances should be moved one place to the right.

Page 130 Age 7 days, in Groups I, II, III, IV, V, VII, and VIII, and Age 14 days in Group VIII.

Page 131 Age 28 days, Group VIII.

TABLE 6.—*Compressive strength computed from the equation* $S=\frac{A}{B^x}$

(a) MORTAR

Age (days)	$\frac{W}{C}$	Compressive strength in kg/cm²							
		Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII	Group VIII
7	0.45	351	278	398	398	339	373	278	210
	.55	213	167	246	246	203	244	167	127
	.65	128	100	151	151	121	158	100	77
14	.45	438	363	453	453	414	461	363	354
	.55	283	239	297	297	286	305	239	217
	.65	184	155	195	195	197	200	155	132
28	.45	515	461	522	530	510	523	498	446
	.55	355	301	361	360	352	365	328	287
	.65	243	196	248	244	243	255	214	183
90	.45	552	567	590	603	593	577	570	553
	.55	406	413	430	430	417	423	416	396
	.65	300	299	310	305	288	306	300	282
183	.45	585	620	657	627	------	------	------	------
	.55	451	477	470	442	------	------	------	------
	.65	347	362	338	310	------	------	------	------
365	.45	598	651	669	631	685	628	648	464
	.55	473	500	485	458	535	464	490	497
	.65	372	387	354	333	420	343	374	386

(b) CONCRETE

Age (days)	$\frac{W}{C}$	Compressive strength in kg/cm²			
		Group V	Group VI	Group VII	Group VIII
28	0.55	224	245	217	196
	.65	166	173	155	138
	.70	143	147	131	117
	.80	106	105	94	83

Therefore calculated values are not only accurate enough to represent the empirical values but check the empirical values and their error, if any. It will also be quite convenient for comparing the strength of mortar and that of concrete if calculated values are adopted, and in that sense calculated values are used instead of empirical values in many cases hereafter.

TABLE 7.—*Accuracy of equation* $S=\frac{A}{B^x}$

$$\left[\text{Error percent}=\frac{\text{calculated value-empirical value}}{\text{empirical value}}\right]$$

Error percent	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	Total
Mortar	43	19	19	22	13	16	10	9	2	1	3	1	158
Concrete	2	1	2	1	4	0	3	1	1	0	1	0	16
Total	45	20	21	23	17	16	13	10	3	1	4	1	174

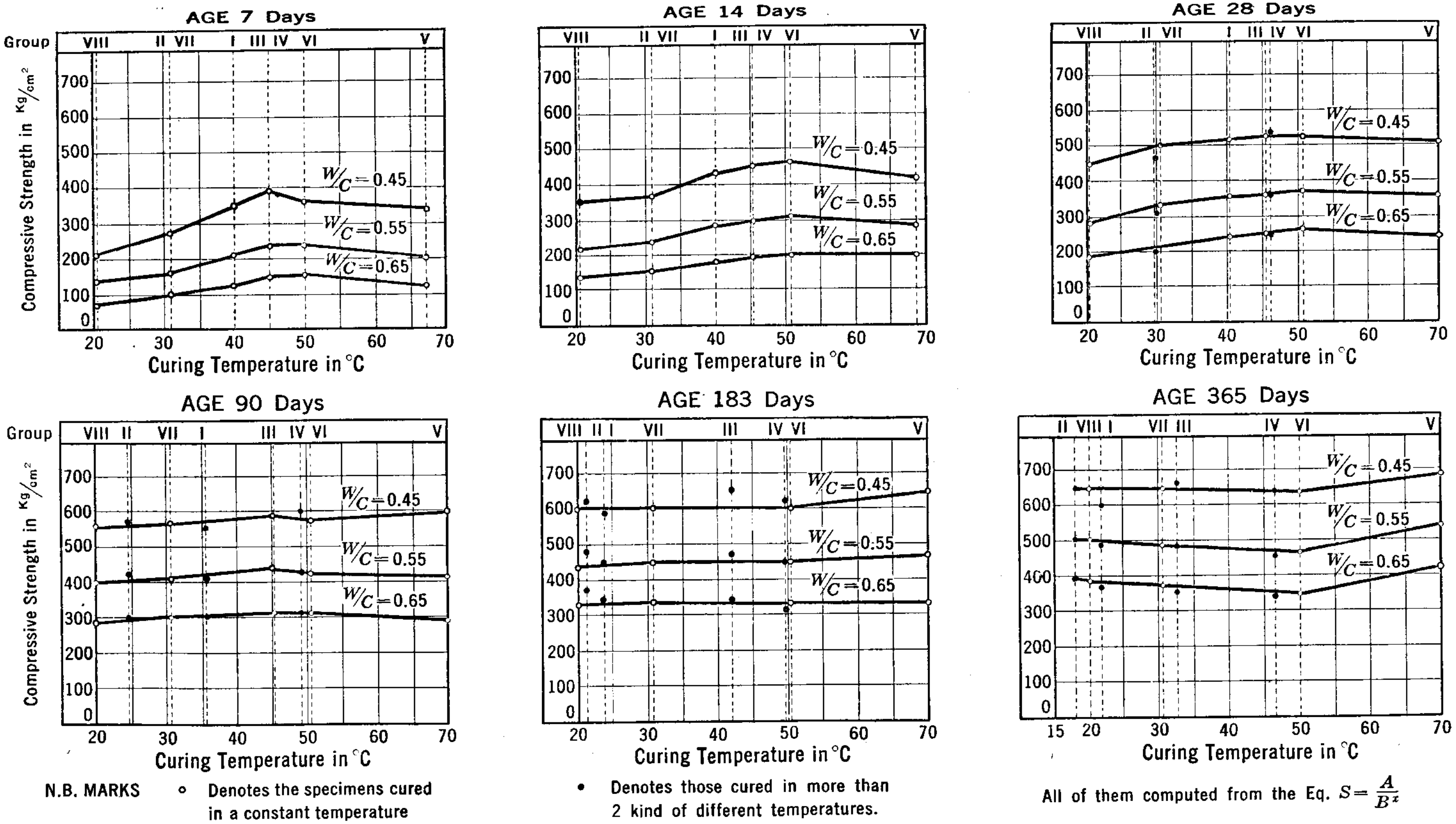


FIGURE 7a.—**Relation between the strength of mortar and curing temperature.** — Rapport entre résistance du mortier et les températures maintenues pendant la pénàde de prise. — Verhältnis der Druckfestigkeit von Mörtel zur Behandlungstemperatur. — Relación entre la resistencia del mortero y las temperaturas mantenidas.

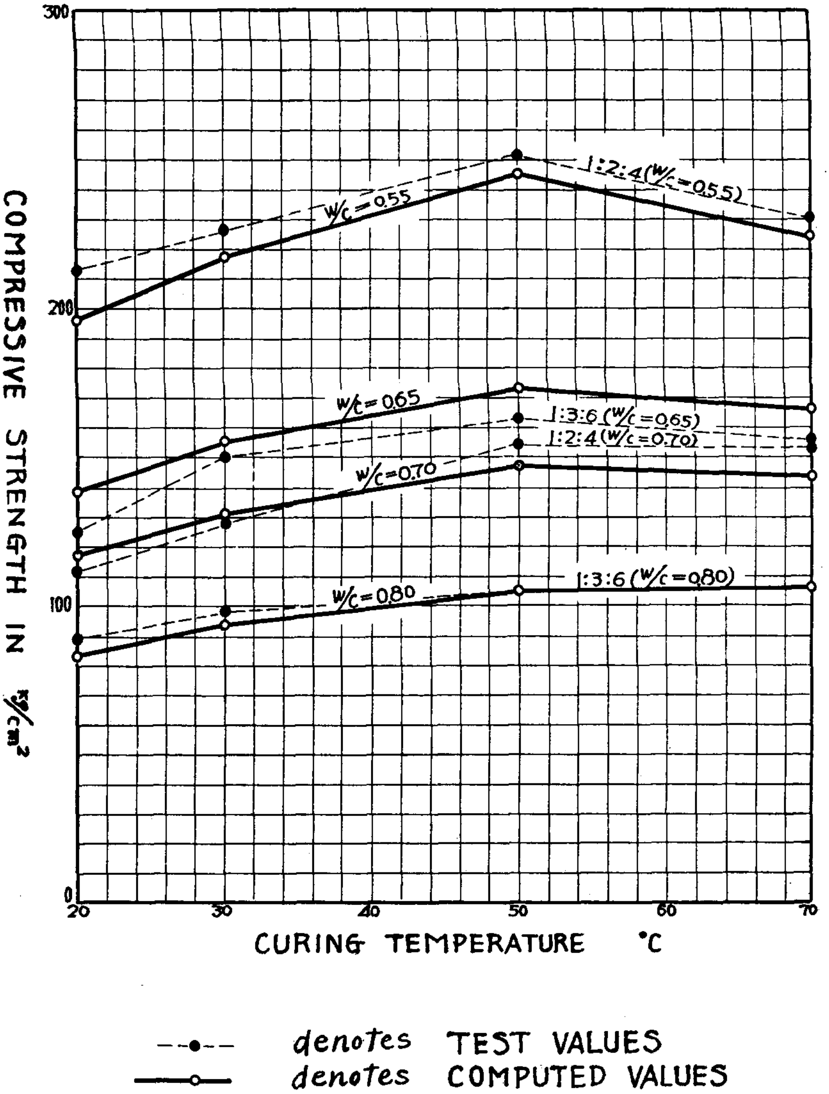


FIGURE 7b.—**Relation between the strength of concrete and curing temperatures at 28 days.** — Rapport entre résistance du béton et les température maintenues pendant la pénàde de prise. — Verhältnis der Druckfestigkeit von Beton zur Behandlungstemperatur. — Relación entre la resistencia del hormigón y las temperaturas mantenidas.

2. *Relation between curing temperature and compressive strength.*

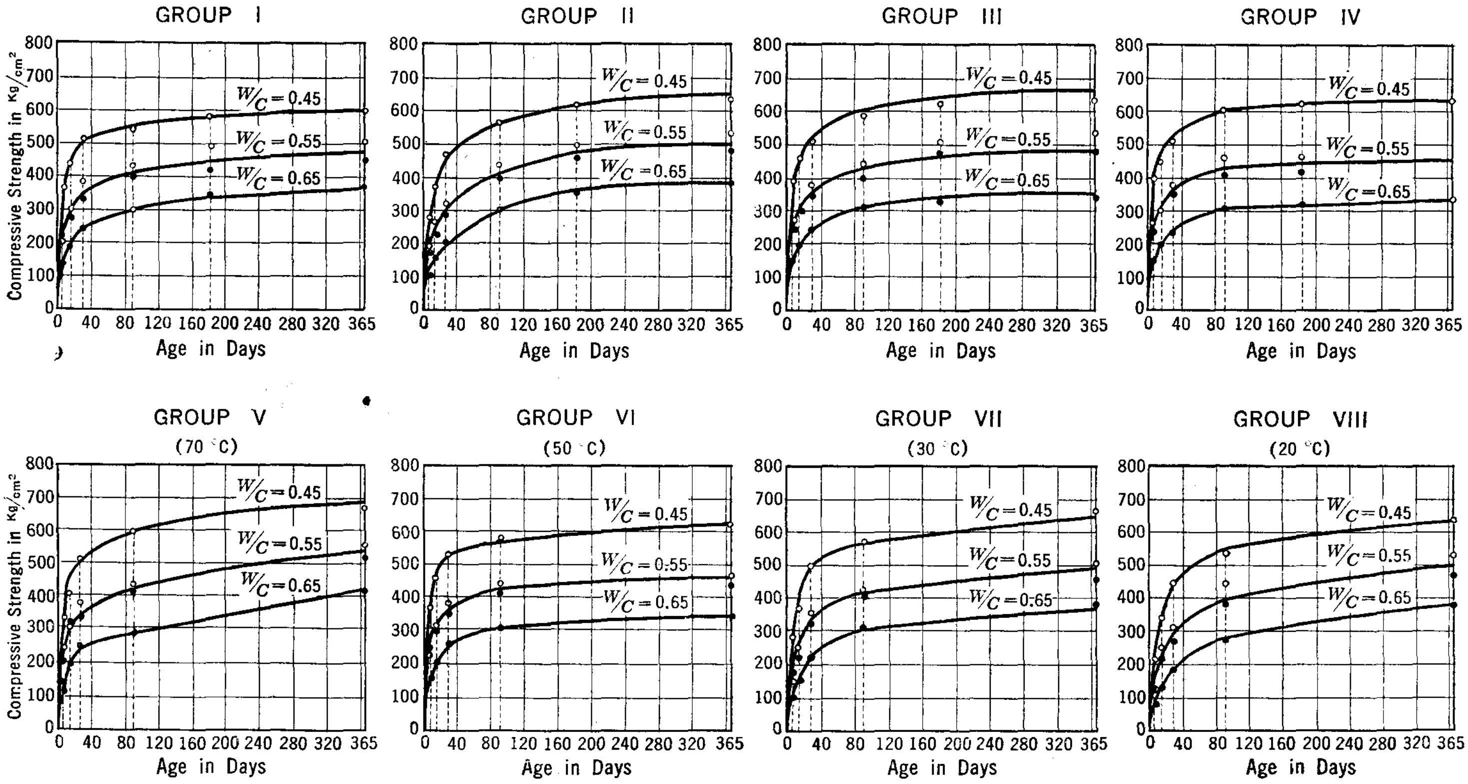
The relation between the mean values of curing temperature and compressive strength of mortar is shown in figure 7a, which shows the fact that in comparative early age, ranging from 7 to 28 days, those cured in 40° to 50° C. show the greatest strength, and below these temperatures, the higher the curing temperature, the greater the strength. Those cured in the temperature of 70° C., however, show smaller strength than the above. This phenomenon is more apparent with rich proportion of mixture and smaller water-cement ratio; but as age becomes greater, this phenomenon gradually disappears; and after 90 days the specimens cured in the same temperature show about equal strength regardless of proportion of mixture and water-cement ratio. Therefore, so long as conditions are similar, those which showed a greater strength at an earlier age (for example those cured in the temperature of 50° C.) show a slower increase in strength compared with other specimens (for example those cured in the temperature of 20° C.). That means that the final strength simply depends on the proportion of mixture and water-cement ratio and at the same time it shows that below the temperature of 70° C. there is no ill effect on the strength of cement.

The above is the fact that could be established regarding mortar specimens, but as is shown in figure 7b, at the age of 28 days concrete specimens cured in the temperature of 50° C., show greater strength and, therefore a similar conclusion may be drawn for other concrete specimens, similar to mortar specimens, though not tested.

It is therefore considered that the temperature below 70° C. produces no ill effect upon concrete, and although the curing conditions provided in this test might differ from those in the internal conditions of a gravity dam, so far as temperature is concerned a similar condition would exist. Figure 8 shows the progress in the strength of mortar with age.

3. *Comparison of compressive strength of mortar and concrete.*

In comparing the compressive strength of specimens of mortar and concrete at the age of 28 days which are included in groups V to VIII, it is found that with the increase of water-cement ratio the strength of concrete tends to go over above that of mortar of the same water-cement ratio as shown in table 8, and moreover the difference is greater in accordance with curing temperature (at average water-cement ratio of 0.4 being 60 percent and at 0.9 85 percent). As mentioned, the increment of strength with age also varies with curing temperature, so the comparison at the age of 28 days in table 8 cannot be applied to specimens of different ages. Hence it would be necessary to have further tests before determining the accurate strength of concrete at different ages from the results obtained with mortar specimens. It may, however, be possible to draw approximate conclusions from this test.



N.B. CURVES are drawn with COMPUTED VALUES.
MARKS ○ (for 1 : 2 mortar) & ● (for 1 : 3 mortar)
denote TEST VALUES.

TABLE 8.—*Comparative strength of concrete and mortar in percent*

[Taking strength of mortar as 100 percent]

Water-cement ratio	Group V	Group VI	Group VII	Group VIII	Mean
0.4	58.0	64.5	57.6	59.0	59.8
.5	61.6	66.5	63.3	65.3	64.2
.6	66.1	68.0	69.0	71.7	68.7
.7	70.9	69.0	75.8	79.0	73.7
.8	76.4	71.0	83.1	87.4	79.5
.9	82.0	72.4	90.6	95.9	85.2

IV. Conclusion

In conclusion, it may be said that in the hardening of mortar or concrete in the temperatures ranging from 20° to 70° C., those cured in a temperature around 50° C. show the greatest strength at an earlier age, but this phenomenon disappears with the increase in age; and in 90 days all cured in different temperatures approach the same strength and no ill effect on hardening of mortar or concrete has been observed at all. From this fact it is assumed that even if the internal temperature of massive concrete, as in gravity dams, reaches as high as 60° C. no ill effect would be brought on the strength of concrete by the heat generated in the process of setting and hardening. (Deformation due to the rise and fall of temperature is another phase of the problem.)

SUMMARY

For the purpose of determining the effect upon the strength of concrete of high temperatures produced within the inner part of a massive concrete body, such as a gravity dam, observations and compression tests were carried out for 1 year on test pieces of mortar, as well as of concrete, cured in temperatures ranging from 20° to 70° C. The observations have revealed the fact that specimens cured in temperatures of 40° to 50° C. show the highest strength at an early age, but that as the age increases all specimens, at whatever temperature cured, ultimately reach an almost equal degree of strength.

RESUME

Dans le but de déterminer l'effet, sur la résistance du béton, des hautes températures qui se developpent dans la partie interne d'un corps massif en béton, tel qu'un barrage-poids, on a fait pendant un an des observations et des essais de résistance à la compression sur des éprouvettes en mortier et en béton, maintenues à des températures échelonnées de 20° à 70° C.

Les observations ont montré que les échantillons maintenus aux températures de 40° à 50° C. présentent dans les premiers âges la plus grande résistance, mais que lorsque l'âge augmente tous les échantillons, quelque soit la température à laquelle ils ont été maintenus, atteignent finalement presque la même résistance.

ZUSAMMENFASSUNG

Um die Wirkung von hohen Temperaturen zu bestimmen, die innerhalb eines massiven Betonkörpers, wie z.B. einer Schwergewichtsmauer auftreten, sind Beobachtungen und Druckproben für die Dauer eines Jahres an Versuchsproben von Mörtel wie von Beton angestellt, die einer Behandlungstemperatur von 20° bis 70° C. unterworfen waren. Die Beobachtungen haben gezeigt, dass in jungen Jahren die Festigkeit von Probestücken mit einer Behandlungstemperatur von 40° bis 50° C. sehr hoch liegt, dass aber bei zunehmendem Alter alle Probestücke, gleichgültig welcher Behandlungstemperatur unterworfen, schliesslich nahezu gleiche Festigkeit annehmen.

RESUMEN

Con el fin de determinar el efecto causado en la resistencia del hormigón por las altas temperaturas producidas en la parte interior de un cuerpo macizo de hormigón como el de una presa de gravedad, se hicieron observaciones y ensayos, durante un año, con muestras de mortero y hormigón, sometidas a temperaturas que oscilaron entre 20° y 70° C. Estas observaciones han demostrado que las muestras sometidas a temperaturas de 40° a 50° C presentaban mayor resistencia a una edad temprana, pero a medida que la edad avanzaba todas las muestras, cualquiera que fuera la temperatura a que se habían sometido, finalmente alcanzaron casi el mismo grado de resistencia.

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

FABRICATION OF LOW-HEAT PORTLAND CEMENT IN JAPAN*

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Japan

Due to the recent progress in the development of the hydroelectric industry in Japan, a number of concrete dams of the gravity type having a magnitude more than 60 m in height above the lowest foundation have been undertaken and some of these are now under construction. Consideration of the heating phenomena and the resulting stresses in the mass of concrete, led the Japanese cement chemists to research in special cement of portland or portland-pozzolanic type during the last few years. Many properties of this special cement, such as the low heat of hardening, constancy of volume, high density and durability are discussed very often from the standpoint of test results in laboratories, but the users as yet have not expressed their opinion about the quality requirement on a scientific basis, and most of them seem to consider that, under proper condition and working practice in Japan, standard or a slightly modified portland cement with a higher index of activity (SiO_2/Al_2O_3) is satisfactory for dam use, even with a rapid pouring rate of concrete. Most of the Japanese cement manufacturers have delayed the commercial exploitation of this special cement in the absence of sufficient data concerning the properties of the cement under conditions in Japan, which differ in many respects from those of foreign countries. However, the Kyushu Soden Co. (Kyushu Electric Power Transmission Co.) in Kyushu has in the last year prepared a specification for the purchase of about 60,000 metric tons of modified low heat value

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**Fabrication du ciment de Portland à faible dégagement de chaleur au Japon.*
Herstellung des Tieftemperatur-Portland-Zements in Japan.
Fabricación en el Japón del cemento portland que produce poco calor.

portland cement for Tsukahara dam (80 m in height, 69 m wide at its base and 4 m at its crest, 215 m in length at the crest, containing 282,000 m^3 of mass concrete and impounding about 34,326,000 m^3 of water) as follows:

Moderate-Heat Cement Specifications

The cement shall conform to the Japanese standard specifications for portland cement (JES 28) with the following additions:

(1)

SiO_2	23.5 percent minimum.
Al_2O_3	5.0 percent maximum.
CaO	64.0 percent maximum.

(2) Cumulative heat of hydration by heat-of-solution method:

7 days	80 cal/g maximum.
28 days	95 cal/g maximum.

(3) Continued increase in strength at 180 and 365 days over 28 days.

This is the first specification ever issued in which a large quantity of cement was purchased with a provision specifically limiting the heat of hydration at 7 and 28 days.

In the central laboratory of the Asano Portland Cement Co., a quite thorough investigation has long been made of special portland cement, and they have marketed a low-heat cement in the name "Asano Mascon" for mass concrete structures since the beginning of 1934. The following is a brief description of a typical test results of "Mascon" cement in direct comparison with the corresponding properties of standard portland and high-early-strength (Velo) cement.

Properties of the Low-heat Cement

Trial manufacture of special cement has many times been made on a large scale exclusively in the wet plants in Nishitama, Hokkaido, and Kawara, in order to obtain very fine grinding (1.0~1.5 percent residue on 4,900 mesh (per square cm) sieve), perfect uniformity and intimate mixing of raw materials, and proper burning of clinker (no free lime). The results have indicated that the physical properties of the raw materials as well as the manufacturing process of cement, in addition to the effort spent on the question of chemical compound have been the most important factor which contributes to the great variation in quality of the cements of the same chemical composition, and each plant may have its own proper formulas for various characteristics of special cement. The following range in the composition was observed in a series of trial manufacture:

Analysis	*Percent*	*Compounds*	*Percent*
SiO_2	23.8~26.0	C_3S	40 ~54
Al_2O_3	3.4~ 4.6	C_2S	26 ~38
Fe_2O_3	3.2~ 4.5	C_3A	1.5~ 7
CaO	62.0~63.8	C_4AF	7.3~14

(1) HEAT OF HYDRATION

In table 1 is data showing the physical and chemical properties of standard, rapid-hardening and low-heat cement. The specific surface was calculated for each of the fractions obtained by means of air elutriation. The difference of importance between these cements is that the low-heat cements are greater in specific gravity, very slow in time of setting, and are characterized by high percentage of di-calcium silicate (C_2S) and tetracalcium alumino-ferrite (C_4AF).

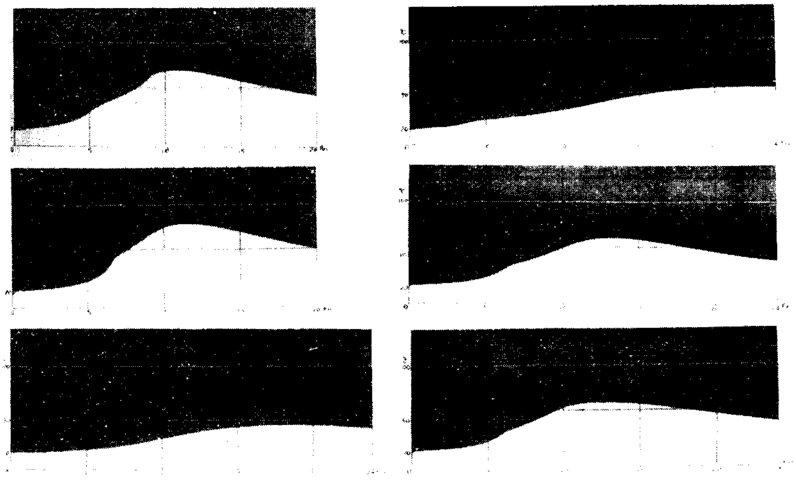


FIGURE 1.

(1) **Standard portland cement N–1.** (4) **Portland blast furnace slag cement PB–1.**
(2) **Rapid-hardening cement R–1.** (5) **Portland-puzzolan cement PP–1.**
(3) **Low-heat portland cement L–1.** (6) **Portland-puzzolan cement PP–2.**

(1) Ciment Portland ordinaire. — Gewöhnlicher Portland-Zement. — Cemento portland ordinario.

(2) Ciment à prise rapide. — Schnell erhärtender Zement. — Cemento de endurecimiento rápido.

(3) Ciment P. à faible dégagement de chaleur. — Tieftemperatur Portland-Zement. — Cemento que produce poco calor.

(4) Ciment P. de laitier de hauts-fourneaux. — Portland-Hochofen-Schlacken-Zement. — Cemento portland de escoria de altos hornos.

(5) Ciment P. de possolane. — Portland-Puzzolan-Zement. — Cemento portland de puzolana.

(6) Ciment P. de possolane 2. — Portland-Puzzolan-Zement 2. — Cemento portland de puzolana 2.

TABLE 1.—*Comparison of physical and chemical properties of standard, rapid-hardening and low-heat portland cement*

PHYSICAL

No.	Type of cement	Specific surface (cm^{2}g)	Percent passing 4,900 mesh (cm^2)	Specific gravity	Weight per liter		Initial set, hours-minutes (18° C.)		Final set, hours-minutes (18° C)	
					Loose, kilograms	Shaken (kilograms)				
N-1	Standard	1, 240	96. 7	3. 16	1. 031	1. 772	2	0	3	56
R-1	Rapid-hardening	1, 500	98. 5	3. 16	. 960	1. 764	2	46	4	57
L-1	Low-heat	1, 240	97. 0	3. 24	1. 052	1. 919	3	55	6	35

TABLE 1.—*Comparison of physical and chemical properties of standard, rapid-hardening and low-heat portland cement*—Continued

CHEMICAL COMPOSITION

No.	Type of cement	Chemical analysis (percent)						
		Ignition loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
N-1	Standard	1.55	22.53	4.94	2.94	64.81	1.25	1.21
R-1	Rapid-hardening	.56	21.36	5.24	2.78	66.04	1.58	1.49
L-1	Low-heat	1.28	24.79	3.98	4.04	62.42	.85	1.58

No.	Type of cement	Bogue compounds (percent)				
		C_3S	C_2S	C_3A	C_4AF	$CaSO_4$
N-1	Standard	51.78	25.53	8.11	8.95	2.06
R-1	Rapid-hardening	63.04	13.69	9.20	8.46	2.53
L-1	Low-heat	49.44	28.68	3.71	12.29	2.69

The cumulative heat of hydration of the cements is determined by the heat-of-solution method and the results are given in table 2. Low-heat cements result in considerably less heat of hydration for both standard and mass curing, and it appears that at the age of 90 days their heat evolution becomes nearly equal for both types of curing.

The typical curves of temperature rise of neat cement pastes (200 g cement in normal consistency) of commercial cements of various types, when measured in a thermo-flask during the first 24 hours after gaging, are presented in the accompanying photographs, from which the rate of heat evolution may be observed.

TABLE 2.—*Heat of hydration of standard, rapid-hardening, and low-heat Portland cements*

No.	Type of cement	Heat of hydration cal/g						
		W/C by weight	Standard curing (18° C.)			Mass curing (38° C.) [1]		
			7 days	28 days	90 days	7 days	28 days	90 days
N-1	Standard	0.4	68	95	100	93	97	106
R-1	Rapid-hardening	.4	90	101	107	104	108	112
L-1	Low-heat	.4	51	64	83	58	72	84

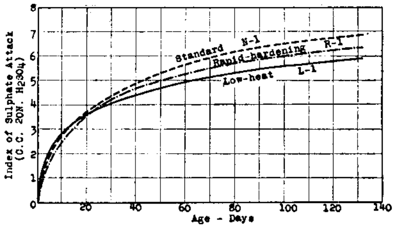
[1] 1 day at 18° C, followed by 38° C.

The chemical composition of the cements PB-1, PP-1, and PP-2 are as follows:

No.	Ignition loss	Insoluble residue	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
PB-1	0.13	0.24	28.96	11.91	1.69	51.61	3.53	0.84
PP-1	1.43	23.90	16.06	4.29	2.61	47.75	1.31	1.30
PP-2	1.95	11.60	20.78	4.67	2.45	55.25	1.16	1.29

(2) ALKALI RESISTANCE

The durability tests of cement slabs in 10 percent sodium sulphate solution were made in accordance with the test methods of Thaddeus Merriman. The test results of the cements N–1, R–1, and L–1 are presented in figure 2, from which it may be seen that slow strength developing portland cements like low-heat cement give a little higher alkali index at an earlier age than high-heat cement, due to their properties of slow development of the initial hardening. Figure 3 shows another series of the comparison tests of three portland cements of different type (N–2, R–2, and L–2), in which the standard cement N–2 (analysis: SiO_2, 22.35; Al_2O_3, 4.94; Fe_2O_3, 2.94; CaO, 65.31; MgO, 1.25; SO_3, 1.01) failed after 20 weeks in spite of its higher index of activity. From a number of experiments, it is to be emphasized that beside the chemical composition of cements the manufacturing process contributes in a great extent to their alkali-resisting properties in the majority of cases.



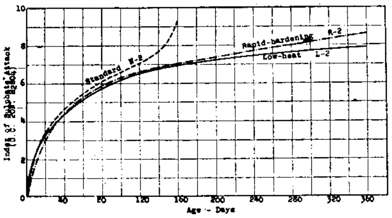


Figure 2.—Sodium sulphate test of cement slabs. — Essais au sulphate de sodium sur des plaques de ciment. — Natriumsulphat-Versuch an Zement-Platten. — Ensayo al sulfato de sodio sobre placas de cemento.

Figure 3.—Sodium sulphate test of cement slabs. — Essais au sulphate de sodium sur des plaques de ciment. — Natriumsulphate-Versuch an Zement-Platten. — Ensayo al sulfato de sodio sobre placas de cemento.

(3) STRENGTHS OF MORTAR AND CONCRETE

The results of the mortar strength tests for both fresh and sea water storage, made in accordance with Japanese Portland Cement Specification JES 28, are given in table 3. It will be noted that, although the low-heat cement evolves less heat of hydration than the normal products, the compressive and tensile strength at 90 days exceed those of the latter and indicate a higher rate of continued increase on strength. This fact may also be seen in the strength tests of standard concrete cylinders (15 by 30 cm), as shown in table 4.

Table 3.—*Compressive and tensile strength of standard mortar specimens*

No.	Type of cement	Storage condition	Compressive strength, kg/cm^2 (1:3 standard mortar)							
			1 day	2 days	3 days	7 days	28 days	3 months	6 months	1 year
N–1	Standard	Fresh water	142	286	394	524	647	736	754	775
		Sea water	272	362	391	442	514	595	648	655
R–1	Rapid-hardening.	Fresh water	336	476	559	656	736	769	787	797
		Sea water	481	523	580	597	648	679	720	749
L–1	Low-heat	Fresh water	144	255	322	436	639	795	837	853
		Sea water	226	340	393	465	577	706	712	728

TABLE 3.—*Compressive and tensile strength of standard mortar specimens*—Contd.

No.	Type of cement	Storage condition	Tensile strength, kg/cm^2 (1:3 standard mortar)							
			1 day	2 days	3 days	7 days	28 days	3 months	6 months	1 year
N–1	Standard	Fresh water	18.7	27.8	30.7	34.7	40.0	45.3	44.5	45.0
		Sea water	28.7	30.9	31.6	33.1	37.9	41.2	41.3	42.3
R–1	Rapid-hardening.	Fresh water	34.3	41.1	42.0	43.6	44.7	45.9	45.0	46.7
		Sea water	37.1	41.1	42.2	43.4	43.6	42.9	43.9	44.2
L–1	Low-heat	Fresh water	19.1	26.5	29.5	32.7	42.5	52.4	54.8	56.9
		Sea water	26.2	29.4	31.6	36.8	47.0	52.6	54.4	53.8

TABLE 4.—*Compressive and transverse strength of standard concrete (proportion 1:2:4, w/c=0.6)*

No.	Type of cement	Storage condition	Compressive strength, kg/cm^2 (15 by 30-cm cylinder)							
			1 day	2 days	3 days	7 days	28 days	3 months	6 months	1 year
N–1	Standard	Fresh water	11	33	61	130	236	336	344	355
		Sea water	37	82	102	149	204	260	------	---
R–1	Rapid hardening.	Fresh water	22	64	110	267	348	359	------	375
		Sea water	99	164	200	251	294	324	------	---
L–1	Low heat	Fresh water	16	35	46	74	183	340	394	436
		Sea water	32	67	90	141	229	303	349	363

No.	Type of cement	Storage condition	Transverse strength (15 by 15 by 80 cm beam)		
			3 days	7 days	28 days
N–1	Standard	Fresh water	19	36	53
		Sea water	--------	--------	--------
R–1	Rapid hardening	Fresh water	29	49	61
		Sea water	--------	--------	--------
L–1	Low heat	Fresh water	17	26	48
		Sea water	26	38	54

The strength test of concrete (proportion 1:3:6) by the use of 36- by 72-cm. cylinders with large-sized aggregate for both methods of compaction by mechanical vibration and hand-tamping is also given in table 5. The aggregate used is in four sizes as follows:

Sand	4 mm. down (fineness modulus 2.77).
Gravel	4– 16 mm., 20 percent by weight.
	16– 32 mm., 24 percent by weight.
	32– 60 mm., 25 percent by weight.
	60–100 mm., 31 percent by weight.

Here it is again noted that the concrete made with low-heat cement has a much higher proportion of its potential strength at the later ages and also that the strengths of concrete made with standard or high-early-strength cements with the same water-cement ratio approach very close at the age of 90 days for both types of curing, while the effect of curing condition at the early ages is very appreciable.

(4) SHRINKAGE

Six or twelve specimens for one series of tests with neat cement pastes of water-cement ratio 0.4∼0.415 by weight were cast in the collapsible mold, each 2.5 cm by 2.5 cm by 20 cm. When the specimens were sufficiently strong and almost no linear change had been observed, usually at the end of 10 days, they were removed from the mold and subjected to drying in a constant temperature (18° C.) and humidity (67 percent) room for 4 weeks. The changes in length were measured with dial micrometers, each bar being set underneath individual micrometer and the initial reading was taken immediately on removal from the mold. Figure 2 shows linear changes of the cements of various type. In all cases of the tests, the low-heat cements show the least shrinkage, followed by the rapid-hardening cement, while the blended cement shows always the greatest linear change of high rate at early ages, as usually expected.

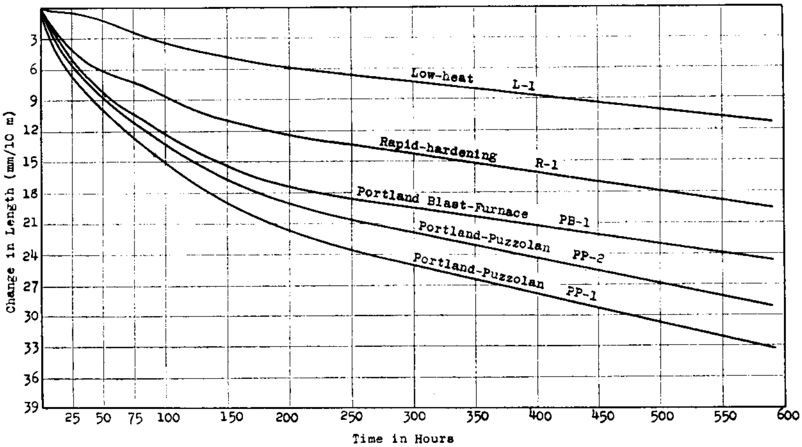


FIGURE 4.—**Contraction of Neat Cement Specimens in Air.** — Contraction d'éprouvettes de ciment à l'air. — Schrumpfung von Zement-Probekörpern in der Luft. — Contracción de las muestras de cemento al aire.

TABLE 5.—*Compressive strength of 36 cm by 72 cm concrete cylinders (proportion 1:3:6)*

No.	Type of cement	Mechanically vibrated (kg/cm²)								
		Solidity ratio	Standard curing (18° C.) $w/c=0.55$				Mass curing (38° C.) $w/c=0.55$			
			3 days	7 days	28 days	3 months	3 days	7 days	28 days	3 months
N-3	Standard	0.879	96	167	207	291	148	202	264	310
R-3	Rapid-hardening	.875	169	254	313	377	242	301	327	370
L-3	Low-heat	.876	46	69	128	275	57	105	216	320

TABLE 5.—*Compressive strength of 36 cm by 72 cm concrete cylinders (proportion 1:3:6)*—Continued

No.	Type of cement	Hand-tamped (kg/cm³)								
		Solidity ratio	Standard curing (18° C.) *w/c*=0.7				Mass curing (38° C.) *w/c*=0.7			
			3 days	7 days	28 days	3 months	3 days	7 days	28 days	3 months
N-3	Standard	0. 858	50	88	138	194	78	119	162	195
R-3	Rapid-hardening	. 855	109	159	223	254	149	191	232	260
L-3	Low-heat	. 858	22	49	72	187	30	58	135	206

Summing up these studies of low-heat cement, although the test data is incomplete in many respects, it was evident under the condition of the tests that the physical character of raw materials and the method of manufacture of cement may be of considerable significance on the quality of actual commercial cement of the same chemical composition, and consequently, for important work the selection of the brand of cement must seriously be taken into consideration.

SUMMARY

This paper presents the results of an investigation of the chemical and physical properties of low-heat cement manufactured in Japan. Although the data of these tests is incomplete in many respects, it is evident that the physical character of the raw materials and the method of manufacture of actual commercial cement may be of considerable significance on the quality of cement of the same chemical composition, and consequently, each cement plant may have its own proper formulas for various characteristics of special cement.

RESUME

Le présent rapport donne les résultats de la recherche des propriétés chimiques et physiques du ciment à faible dégagement de chaleur qui est fabriqué au Japon. Quoique les éléments relatifs aux essais soient incomplets sous bien des rapports, il est évident que le caractère physique des matières premières et la méthode de fabrication du ciment commercial actuel ont une grande importance sur la qualité de ciment d'une même composition chimique; par suite, chaque fabrique de ciment peut avoir sa formule propre pour les diverses caractéristiques de ciment spécial.

ZUSAMMENFASSUNG

Die vorliegende Abhandlung behandelt das Ergebnis der Untersuchung der chemischen und physikalischen Merkmale des in Japan hergestellten Tieftemperatur-Zements. Auch wenn die Daten dieser Versuche in manchen Punkten unvollständig sind, ist es doch klar, dass die Beschaffenheit der Rohmaterialien und das Herstellungsverfahren eines tatsächlich marktfähigen Zements für die Qualität eines Zements von gleicher chemischer Zusammensetzung von beträchtlicher Bedeutung sein kann, und folglich, dass jede Zementfabrik ihre eigenen Formeln für verschiedene charakteristische Special-Zemente haben mag.

RESUMEN

En esta memoria se suministran los resultados de una investigación de las propiedades químicas y físicas del cemento que produce poco calor fabricado en el Japón. Aunque los datos de estos ensayos son incompletos en muchos respectos, es evidente que el carácter físico de las materias primas y el método de fabricación del actual cemento comercial pueden ser de gran importancia en la calidad del cemento de la misma composición química y, por lo tanto, cada fábrica de cemento puede tener su fórmula propia para las diversas características de cemento especial.

QUESTION III

BAALSRUD and FRIIS
NORWAY

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

FIFTY YEARS' EXPERIENCE OF CONCRETE IN NORWEGIAN DAMS*

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Norway

It was approximately 50 years ago that concrete made with portland cement was first utilized as building material for large dam structures in Norway. But it was not until the years immediately following the turn of the century that the rapid growth of water-power development caused this convenient building material to be used on a large scale in dam construction. It should be noted, however, that topographical conditions in Norway, particularly the great abundance of lakes and mountain tarns, do not call for particularly large dams. On the other hand, the climatic conditions in connection with the acid and pure water derived from melting snow have afforded material for interesting experiences, which will be briefly dealt with here.

At one time a belief in the increasing strength and resisting power of cement was unqualified. It may be mentioned by way of example that in 1890 a comparatively large river dam was built of a mixture proportioned "not leaner than 1:6:10", mixed by hand and with a comparatively dry consistency. This dam is now badly deteriorated and is to be replaced by a new one. At the time it was obviously held that the concrete as proportioned would yield more than the satisfactory strength and that concrete was a strong and impregnable building material. Later dams have almost invariably been constructed with mixtures proportioned 1:3:5, many of them with a tightening apron about 25 cm in thickness, for which the preferred proportions are 1:2½:3, and further with a mortar coating or stone dressing against the water side. After the introduction of machine

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***Cinquante années d'expérience pour le béton des barrages Norvégiens.*
Fünfzigjährige Erfahrungen mit Beton bei norwegischen Talsperren.
Cincuenta años de experiencia en el hormigón de presas noruegas.

mixers and subsequently of compressed-air rams, etc., and after the workmanship had been generally improved, correspondingly better results were anticipated, and there is no doubt that in manv cases good results were achieved. Frequently, however, the results have proved to be either indifferent or, in a few cases, even altogether unsatisfactory. Generally it may be said that the large, rationally constructed river dams have endured best, whereas a number of small river dams as well as a number of storage dams in the mountain regions have served less well or even badly.

The indifferent results obtained were for many years exclusively attributed to bad workmanship in connection with exaggerated economy in applying cement. It was gradually discovered, however, that these were not the only causes. On the contrary, the concrete question turned out to be an extremely complicated problem.

The history of concrete in Norwegian dam construction is not, of course, materially different from that recorded in other countries, but owing to peculiar climatic and geological conditions in Norway those forces of nature which militate against concrete have led to comparatively greater disappointments than appears to be the case in many other countries.

It is not the object of this paper to discuss the chemical, physical, and technological sides to the question from a scientific point of view, but only to give a general idea of some practical experiences and reflections derived from concrete dam construction in Norway.

In 1925 the Norske Ingeniörforening (Norwegian Engineers' Association) appointed a committee to investigate the question: "Concrete in dams." The report of that committee is embodied in a printed publication which appeared in 1930, but unfortunately only in the Norwegian language. This publication gives inter alia an account of experiences obtained at 87 plants, whose conditions and technical properties as dam structures have been closely investigated and commented upon, accompanied by a number of illustrations. After having discussed the causes of trouble at the various plants, the extent of the damage sustained, and such remedies as the technical knowledge of that time could suggest, the committee submitted the following conclusions:

(*1*) *Extent of Damage.*

As stated in chapter II, pages 126 and 127, it may be recorded as the general impression of the dams investigated that very few of them, and particularly of the regulative dams, are entirely faultless. Damage is found both in concrete and in masonry dams, and it is largely of the same nature and behaves in the same way.

Generally the damage is local and seldom extends to the whole of the dam, which seems to indicate inequality in the composition of the concrete or the mortar as well as in the workmanship. The damage is most frequently located in the construction joints. Organic matter as well as iron and often manganese compounds are generally found to be deposited in the damaged parts.

Although none of the dams investigated is in danger of breaking down on account of the destruction of the concrete, this committee begs to draw attention to, and strongly to emphasize, the necessity for the several dams to be made the subject of a thorough examination with a view to ascertaining their condition. The great value represented by the dams themselves and, still more, by the plants situated below the dams, calls for efficient maintenance both in view of the undertakings and also on grounds of national economy.

(2) *Cause of Damage.*

With reference to the information supplied in chapter III, A, pages 127 et seq., and in chapter III, page 148 and page 152, it may be stated that the main cause of damage to concrete structures through the action of water is that lime is carried away from the concrete. Possibilities for the penetration of the water arise by the formation of cracks in the surface owing to shrinkage and temperature changes. The water will enter such cracks and thence penetrate through more or less porous parts in the concrete. The water analyses show that the river water in Norway is generally acid and lime-dissolving.

The comparatively rapid progress of the distruction is due to too lean mixture proportions and uneven preparation of the material, which is a regular occurrence at the plants investigated.

Some special conditions and chemical reactions which contribute to the destruction of the concrete and the dissolution of the lime and which have some connection with the content of organic matter and of iron and manganese compounds in the water, ought to be made the subject of further investigations. As a matter of fact, any concrete structure exposed to the percolation of acid water will sooner or later be completely or partly destroyed, on account of the dissolution of lime and lime compounds effected by the water. First the calcic hydrates are dissolved and then comes the turn of the less easily soluble calcic silicates and aluminates. The rate at which the destruction will progress after the water has once started penetrating into the concrete, depends on the nature of the water and on the quality of the concrete and its content of cement. In the case of more extensive leakages the mechanical wear of the water will also be telling.

The 6 years which have elapsed since have borne out the correctness of this conclusion. In the first place the large Norwegian dams are invariably built on firm rock foundations, and practically all of them are, since 1911, subject to public control as regards proper maintenance. On the other hand, such maintenance has in many cases been both troublesome and expensive. In view of the more rapid deterioration particularly ascertainable in the case of regulative dams situated in the mountain regions, it has moreover been necessary to revise the opinions formerly held as to the life of the dams and their period of amortization.

Any accurate appraisal of the economical importance of the concrete damages is difficult, for very obvious reasons. Surveys or statistics do not suffice for that purpose. Thus it has often happened that dams which were apparently intact have proved to be badly deteriorated on removal of the mortar coating or stone dressing. In some large structures it has been attempted by core drilling to ascertain the condition in the interior parts of the dam wall. This method also has its shortcomings, however, and often leaves great uncertainty as to the reliability of the result. The method is also both circumstantial and expensive. (Cf. report no. 40, I a, by Engineer Groner, to the First Dam Congress.) Anyone attempting to draw inferences from working reports and the maintenance expenses in previous years according to statistical returns is faced with the same uncertainty. Among other things it has to be borne in mind in this connection that so far the maintenance has in all essentials been restricted to the surfaces of the dams and can accordingly afford no sure basis for estimating the internal condition of a massive dam structure.

Under these circumstances it is obvious that future maintenance costs cannot possibly be completely gaged.

What can be said on that subject today may be summarized as follows:

Three important storage dams in the industrially best-utilized watercourse have been entirely rebuilt owing to bad concrete; two large storage dams in the western part of the country have been partly rebuilt; and it has been decided that a large river dam in southern Norway should be replaced by a new one. A long, but low, river dam in the greatest Norwegian river will have to be rebuilt as conditions permit.

In addition to these seven instances of total deterioration after a life of from 10 to 46 years, there are a large number of dams, intakes, concrete pipe lines, etc., which have had to be wholly or in part rebuilt, reinforced, or repaired.

As mentioned, the making of concrete has improved, resulting in greater resisting power against injurious influences. A number of large and small dams of recent construction have not at all, or only to a very small extent, shown signs of diseased concrete; but the time elapsed is still too short for further inferences to be drawn.

The concrete damage is distributed over the whole of the country, having been found in the mountain regions as well as in the valleys and on the lowland. Its causes are the eroding forces usually at work in nature added to injurious chemical reactions, which are either due to the quality of the sand or its impurities, or to the unstable colloidal substances of the cement.

In Norway it is above all the frost which affects concrete structures, partly by causing contraction cracks in the outer surface, thereby facilitating the access of leakage water to the interior parts of the concrete, and partly by giving rise to bursting action through the expansion of the moisture when freezing in the porous and frost-cracked concrete. In the regulative dams in the mountains there occur very low temperatures, which may drop to −40° C. and which during the month of January may keep about −30° C. This may give rise to great tensile stresses even if the dam is fitted with vertical dilatation joints. It is a well-known fact that in a large massive dam the inner bulk will cool down slowly, whereas the dam surfaces will cool much more rapidly and extensively. The consequence is that, when drained in the winter season, the dam will get an outer shell which is contracted by frost, whereas the interior core of the dam retains its dimensions practically unaltered. In this way tensile stresses are engendered in the vertical direction as well, whereby minute hair cracks are bound to arise in the weak horizontal construction joints. As a matter of fact, it has been ascertained that these construction joints are particularly liable to be affected.

It is hardly possible to compute the tensile stresses which may arise in this manner, one of the reasons being that the moduli of elasticity, etc., of water-soaked frozen concrete are not known; but that the tensile stresses induced by temperature changes of the magnitude referred to here are important factors does not admit of doubt and is also borne out by experience. If, for instance, the medium temperature differences are supposed to be 20°–30° C. (E=150,000 and α=0.0000127), the probable approximation will be in the range of 40 to 60 kg/cm ^{2}, when the elastic adjustments which will take place are disregarded.

It is interesting to note in this connection that the parts of the dams which are submerged under the lowest working water level and which are accordingly not exposed to frost have been found in some cases to keep excellently, whereas such parts as are alternately exposed to frost and to water pressure are very badly damaged.

Concrete which has recently been submerged will be saturated with moisture for some time afterwards. When water-soaked concrete freezes, there may arise a bursting action which will contingently be aggravated by the above-mentioned temperature shrinkage. Such bursting action will presumably increase with capillarity and with the existence of the hair cracks. A probable proof of this bursting action is furnished by the fact that porous, lean concrete which is exposed to moisture and freezing will be destroyed and crumble away in a comparatively short time, whereas similar concrete which is not exposed to frost will generally keep fairly well. A similar bursting effect may be observed in the frozen crust of certain capillary earths, etc. It should be noted, however, that porous concrete in dams is liable to be washed out. A correct analysis of the causes is therefore impossible. Nor can this matter be verified by laboratory experiments, since these will not reflect the conditions obtaining in a large and exposed dam structure when the water level is declining during the winter season. It is worthy of note that a good mortar surface may keep apparently intact, though crossed and recrossed by minute hair cracks, but not washed out, seeing that the mortar is otherwise tight owing to its greater proportion of cement, whereas the interior more porous concrete will be destroyed. But this result may also be partly attributable to other causes, such as diffusion and ionic interchange, which shows at any rate that the phenomenon is a complicated one. For the time being it has to be noted that the low winter temperatures in Norway constitute an essential and most frequently a primary cause of damage to concrete in dams.

Then, clean and acid water is characteristic of Norwegian water courses and owes its existence there partly to the rock being poor in lime and partly to the fact that during a great part of the year the flow is made up of water from recently melted snow, such water being clean and free of lime but abounding in dissolved carbonic acid. According to investigations made snow and water from melted snow contain far greater quantities of free dissolved carbonic acid than ordinary water. In terms of the hydrogen ion coefficient pH the acidity is between 5.6 and 6.7 for a number of the more important water courses. Table 1 gives the result of investigations carried on for 1½ years in 21 Norwegian water courses.

TABLE 1.—*Water analyses of Norwegian streams*

No	Place	pH values	Content of dry matter (mg/l)	O_2 consumption (mg/l)	Free CO_2 (mg/l)	Bottom CO_2 (mg/l)
1	Elverum	6. 7	43	5. 8	3. 52	21. 30
2	Mörkfoss	6. 7	36	6. 3	2. 74	13. 69
3	Sarpsfossen	6. 7	37	6. 4	2. 64	15. 31
4	Nore	6. 2	17	3. 4	2. 59	6. 65
5	Kongsberg	6. 3	17	4. 3	2. 68	7. 04
6	Skollenborg	6. 2	18	5. 7	3. 52	5. 28
7	Vittingfoss	6. 3	19	4. 3	2. 36	8. 15
8	Rjukan	6. 0	10	2. 3	2. 49	5. 54
9	Notodden	6. 0	13	2. 8	2. 64	6. 06
10	Skien	6. 3	16	3. 5	2. 64	7. 31
11	Kragerö, Dalsfoss	5. 9	19	5. 4	2. 77	6. 86
12	Böylefoss	5. 7	13	3. 7	2. 64	5. 66
13	Rygene	5. 7	13	3. 5	2. 64	7. 04
14	Nomeland	5. 7	12	3. 2	2. 64	5. 80
15	Flekkefjord, Sagfoss	5. 9	24	3. 2	2. 79	5. 28
16	Sauda	5. 7	23	2. 2	2. 64	4. 52
17	Tyssefallene	5. 9	7	1. 0	2. 30	3. 62
18	Samnanger	5. 7	12	2. 1	2. 75	5. 47
19	Dale	5. 7	13	2. 2	2. 64	4. 99
20	Höyanger	5. 6	7	1. 3	--------	--------
21	Leirfoss	6. 8	26	3. 9	2. 05	12. 79

The water in Norwegian rivers, more particularly in the higher regions, is thus in a very high degree lime-dissolving. The result has been that washing out of lime with formation of deposits on the downstream side of the dams has been a frequent occurrence, often to such an extent that the surface of the dam has been completely covered by a white coating of lime.

On the other hand there have been a number of cases where impure sand containing humine has been ascertained to be the unquestioned cause of the destruction wrought on the concrete. Finally the sand itself has in some cases been derived from species of rock possessing little strength, sometimes containing too much pulverized potassic mica. This applies mainly to the older dams, however, since subsequent to about 1906 the sand has in the case of large dams invariably been submitted to a public materials test station for examination, also in respect to its purity and general fitness for the purpose.

As to Norwegian cement, it may be stated that it has always kept abreast of modern requirements. It is characteristic of Norwegian cement that only one prime quality has been turned out. Its chemical proportions are shown by the following analyses for one individual factory, which are considered to be sufficiently representative:

TABLE 2.—*Chemical analyses of Norwegian portland cement*

	1911	1916	1924	1930
SiO_2	19. 43	19. 54	19. 77	19. 83
Al_2O_3	6. 82	7. 94	6. 86	6. 70
Fe_2O_3	3. 72	2. 62	3. 47	3. 32
CaO	57. 21	61. 60	63. 12	63. 24
MyO	2. 92	3. 25	3. 22	3. 17
SO_3	2. 60	2. 75	2. 01	2. 59
Loss by ignition	4. 66	. 98	. 35	. 65
Insoluble	2. 64	1. 32	1. 20	. 50
	100. 00	100. 00	100. 00	100. 00
Hydraulic modulus	1. 93	2. 04	2. 1	2. 12

As will be seen, the percentage of lime contained in Norwegian cement has been increasing. The physical (technical) properties of the cement have as a result of improved manufacturing methods—rotating furnaces, fine grinders, etc.—been rapidly changing for the better. The following table is illustrative of this development, which has been aimed primarily at meeting the growing requirements of the building industry:

TABLE 3.—*Norwegian portland cement characteristics*

	109 tests before 1913	173 tests 1915–20	12 tests 1925–26
Loss by ignition	2. 81	1. 86	0. 60
Specific gravity	3. 09	3. 10	3. 13
Fineness modulus, retained on 900 meshes	1. 11	. 41	. 11
Fineness modulus, retained on 5,000 meshes	20. 30	10. 30	5. 60
Setting started after hours	3. 45	3. 21	2. 90
Setting completed after hours	7. 24	6. 78	5. 80
Le Chatelier's test	3. 40	1. 76	2. 00
Tensile strength after 7 days	20. 80	24. 20	28. 40
Tensile strength after 28 days	26. 60	28. 90	32. 00
Compressive strength after 7 days	203. 00	263. 00	349. 00
Compressive strength after 28 days	275. 00	333. 00	423. 00

Otherwise the cement must conform to the requirements of the Norwegian standards, which are mainly identical with other European standards.

As long as some 30 years ago opinions differed in Norway as to what consistency was preferable, the moist or the plastic one. The moist consistency was advocated by many who relied upon laboratory tests and standards, but as water-power development and the use of reinforced concrete increased, this view changed. As regards water-power development the requirement of impermeability induced a steadily increasing adoption of the plastic consistency, in which connection a suitable grading has to be taken into consideration.

The question as to aggregates for the portland cement has also been to the fore ever since the turn of the century. Rhine trass has thus been made use of to some extent, but the results achieved cannot be claimed to have in practice increased the resisting powers of concrete against the action of acid water.

At a recently constructed large river dam there was further used as aggregate basic blast-furnace slag, which has been dealt with in detail in Engineer Rolfsen's report no. 48 I a to the First Dam Congress. The result promises very well, although it would be premature to make any definite statement at the present time. At this plant particular care was taken in making the concrete, grading it, etc., to obtain the tightest possible concrete, and it may accordingly be difficult to gage the part played by the aggregate used in the cement.

The special experiences obtained in Norway in the course of these 50 years may be summarized in the following points:

(1) *Portland cement concrete* which is exposed to one-sided water pressure will be affected and washed out by pure and acid water as soon as the water is allowed to penetrate the concrete.

(2) *Frost* is often a primary and otherwise an important contributory cause of cracks in the surface of dams, whereupon it is instrumental in bringing about a rapid destruction of washed-out or affected concrete.

(3) In view of the destructive forces mentioned under (1) and (2) it is indispensably necessary to make provision for the tightest possible concrete, the proper constructive measures, as well as for suitable subsequent treatment whilst the concrete is setting so as to avoid undesirable temperature rises.

(4) The experiences obtained do not as yet give any clue to methods of improving the portland cement used in dam construction, and from a strictly practical point of view the difference in chemical proportions which may be obtained in portland cement is of less importance than the difference occurring in the quality of the concrete on account of variation in the materials (sand and stone) and on account of the manner in which the concreting itself is carried out

It is therefore of the greatest importance that the practical way of carrying out the job should first of all be improved, so as to guarantee the invariable outturn of a uniform high quality product without any weak parts such as construction joints, etc.

SUMMARY

This paper reviews the practical experiences had with concrete in connection with Norwegian dams for the last 50 years. Among other things it directs attention to the conclusions submitted by the Norwegian Committee on Concrete, after examination of 87 dams. It points out that seven important dams have had to be completely rebuilt because of the poor quality of the concrete, and also that there are very few dams wholly free from possible damages to which concrete is liable. Effects due to freezing are particularly pointed out. These are important as far as Norway is concerned because the temperatures prevailing in winter may be as low in the mountains as 40° C. below zero. It is also pointed out that the water of Norwegian streams is both pure and acid, therefore possessing a strong dissolving action on lime. In reference to this, it should not be forgotten that snow, and water due to melting snow, possess a much larger proportion of carbonic acid, whether in a free or a dissolved state, than ordinary water.

After having noticed that the Norwegian cement used has been of a standard type and quality and that such aggregating materials as trass, etc., have been tried out without apparent benefit, the practical results which 50 years of experience are presumed to have brought out are mentioned.

RESUME

Le rapport donne un aperçu des expériences pratiques recueillies au sujet du béton dans les barrages norvégiens pendant 50 ans. Entre autres choses le rapport indique les conclusions soumises par le comité norvégien du béton après avoir examiné 87 barrages. Il signale que 7 barrages importants ont dû être complètement reconstruits à cause de mauvais béton et en outre qu'il y a bien peu de barrages qui soient à l'abri des dégâts ordinaires auxquels le béton est sujet. Les auteurs signalent plus particulièrement les effets du gel. Ceux-ci sont importants en ce qui concerne la Norvège à cause des températures basses d'hiver atteignant dans les montagnes jusqu'à 40 degrés centigrade au-dessous de zéro. Ensuite on indique que l'eau des rivières norvégiennes est à la fois pure et acide ayant par conséquent

une forte action dissolvante sur la chaux. À ce sujet on rappelle que la neige et l'eau provenant de neiges fondantes a des quantités bien plus grandes d'acide carbonique à l'état libre et dissous que l'eau ordinaire.

Après avoir constaté que le ciment norvégien de type et de qualité normaux a été employé et que des matériaux d'agrégation comme le Trauss, etc., ont été essayés sans profit apparent, on mentionne les résultats pratiques que 50 ans d'expérience sont censés avoir amenés.

ZUSAMMENFASSUNG

Der Bericht gibt eine Übersicht über die praktischen Erfahrungen, die im Laufe von 50 Jahren mit Beton bei norwegischen Dämmen gemacht worden sind. Unter anderem werden die von dem norwegischen Beton-Ausschuss an 87 Dämmen angestellten Untersuchungen und deren Ergebnisse berichtet. Man kam zu dem Resultat dass 7 Talsperren vollständig umzubauen sind infolge der schlechten Qualität des Betons; dabei wurde bemerkt, dass sehr wenige Dämme den üblichen Betonschäden entgangen sind. Die Verfasser machen besonders auf die Gefahr des Frostes und seiner Wirkungen aufmerksam. Des weiteren wurde festgestellt, dass das Wasser in den norwegischen Flüssen sehr rein und sauer und infolgedessen sehr kalklösend ist. In diesem Zusammenhang wurde darauf hingewiesen, dass der Schnee und das von geschmolzenem Schnee herrührende Wasser weit grössere Mengen an freier aufgelöster Kohlensäure als gewöhnliches Wasser enthält.

Unter Hinweis darauf, dass der norwegische Zement von normalem Typ und durchschnittlicher Qualität war und dass Trass-Zusätze usw. ohne nachweisbaren Nutzen versucht wurden, sind die praktischen Erfahrungen punktweise aufgeführt, die während der vergangenen 50 Jahre gemacht wurden.

RESUMEN

Esta memoria describe las experiencias prácticas obtenidas con el hormigón en presas noruegas durante los últimos 50 años. Entre otras cosas, la memoria indica las conclusiones sometidas por el Comité Noruego del Hormigón, después de haber examinado 87 presas. Indica que 7 presas importantes han tenido que ser reconstruídas completamente a causa de la mala calidad del hormigón, y también que hay muy pocas presas totalmente libres de los posibles deterioros a que está sujeto el hormigón. Especialmente se indican los efectos debidos al hielo. Estos son importantes para Noruega porque la temperatura en el invierno puede bajar en las montañas hasta 40° centígrado bajo cero. También se indica que el agua de los ríos noruegos es a la vez pura y ácida, y por lo tanto posee una fuerte acción disolvente sobre la cal. A este respecto se recuerda que la nieve, y el agua causada por el derretimiento de la nieve, poseen una proporción mucho mayor de ácido carbónico, ya esté en estado libre o disuelto, que el agua ordinaria.

Después de hacer constar que el cemento noruego empleado ha sido de un tipo y una calidad normales y que las adiciones de materiales como trass etc., se han ensayado sin beneficio aparente, se mencionan los resultados prácticos que se cree haber alcanzado en los 50 años de experiencia.

QUESTION III
VOGT and RUTLE
NORWAY

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

NOTES ON SPECIAL CEMENT TESTS *

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Norway

The question, as to what extent the standard tests are suitable as a basis for selection of cements, has always been important, and it has obtained a new actuality by the introduction of radically new types of cements for dam construction. For the regular portland cements the quality may, according to general experience, be fairly well judged by means of a rather small group of routine tests. While these tests are fairly suited to a rather definite type of cement, an extrapolation for quite different types is not warranted without new and very broad investigations. The five items already taken up by the subcommittee on special cements (heat of hydration, attack of water, shrinkage, permeability and workability) cover important phases of the problem, but not all of them. Some particular features are mentioned below. The meager information now available does indicate that the present standard tests are, in some cases, either misleading or incomplete, and great care should be exercised before the proposed standards can assure the desired control.

I. STRENGTH

As the main standard tests on cements, most countries have adopted the compressive tests on mortar cubes or cylinders mixed 1:3 and "earth-moist", and stored wet. The water content varies, according to the different specifications, from 10 or 11 percent $W/C=0.40$ or

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**Notes sur des essais de ciments spéciaux.*
Bemerkungen über Prüfungen an Spézial-Zementen.
Notas sobre ensayos de cementos especiales.

0.44) with gentle tamping, to 8.5 or 8.0 percent ($W/C=0.34$ to 0.32) with machine molding. The standard sands are screened to approximately uniform size, about 1 mm. After being stripped of the molds at the age of 1 day, the specimens are stored under water at definite room temperatures until testing, the temperature is specified with means ranging from 15° to 21° C. according to the different standards. The specimens are tested at ages of 3, 7, and/or 28 days. While the details vary, the main features of these standards are the same in most countries.

The specifications also include tensile tests on "8-shaped" specimens. Some countries demand only tensile tests, while the compressive tests are omitted.

The use of a "plastic" mortar instead of the "earth-moist" seems to be an important improvement, and in some countries the plastic mortar is either adopted for strength tests or is being discussed for future standards.[1] In most cases two screenings of sand are mixed, the coarser, old standard sand, and a finer one. In this manner it is possible to increase the water content without being troubled by separation, for instance to 15 percent, giving a $W/C=0.60$ similar to the W/C for regular concretes.

It is an old, but still existing, opinion that "the tensile strength has very little connection with the usefulness of the cement." [2] Compare also a recent statement: "It is the compressive strength of mortar or concrete which is of principal importance in construction, but, for reasons of convenience, tensile tests have been widely used." [3] These statements may be partly true as far as reinforced concrete in buildings is concerned, but they seem to be very erroneous as regards concrete for dams.

Only very seldom can the compressive strength of concrete be fully utilized in dam construction or has it been so in the past. No dam failures and hardly any important damages can be traced to deficits in compressive strength of the concrete. The deterioration of concrete in dams can, on the other hand, in many, perhaps in most, cases, be traced back to cracks in the concrete—fine hair cracks (sometimes hardly visible) or to more open cracks,[4] and these cracks are obviously developed because of deficits in the tensile strength (or extensibility); i. e., not only the compressive strength, but also the tensile strength is a factor of principal importance.

It is, however, a deplorable fact that the results of the direct tensile tests are much more erratic than those from compressive tests. This fact may to some extent justify the complete abandonment of all tensile tests from some specifications.[5] The principal properties should, if possible, always be tested directly, and a measure on the *tensile strength* as well as the *extensibility* can be obtained by very simple bending tests.

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[1] *Haegermann "Die Prüfung von Zement mit weich angemachten Mörtel", Zement 1935 nos. 35, 39, and 44.*

[2] *Transact. A. S. M. E. IX, p. 183.*

[3] *Lea and Desch "The Chemistry of Cement and Concrete", London 1935.*

[4] *Den Norske Ingeniörforening, Meddelelse nr. 1, Oslo, 1930.*

[5] *See for instance the specifications on cements for the Boulder Dam.*

Both the bending and compressive testing methods are particularly improved by use of a "plastic" mortar instead of the "earth-moist". The strength of the concrete is found to be more closely correlated to the strength of the plastic mortar than to the strength of the earth-moist.[1] Older investigations affirm this result as well as some recent Norwegian investigations.[6] The superiority of the plastic mortar method depends mainly on the fact that a water-cement ratio which is comparable with that used for ordinary concrete may be used. Furthermore by use of only one screening of sand in the earth-moist mortar, cements with a low specific weight obtain a certain advantage since in these mortars the free space is better filled than in the case of normal cements. This advantage is not as great when well-graded sand is used, and the results obtained by the use of only one screening are therefore unreliable for comparison cements. This error is avoided or reduced by the use of plastic mortar with two sand screenings.[1]

One of the authors has found that for wet mortar beams, the actual tensile strength is close to two-thirds of the bending strength, and the actual extensibility was found to be 9/8 of the one computed by elementary means from the deflection of beams exposed to constant bending moments over the entire length of the beam.[7] Although these ratios may vary slightly with conditions, the variations are small for wet beams, and the bending tests may therefore give a fair measure on strength and extensibility. It should be mentioned that the ratios for dry beams are not the same. (See the investigations referred to.)

It seems to be a general experience that the tensile and the bending strength is proportional to the two-third power of the compressive strength of the mortar. This old rule given by Feret has recently been confirmed not only for regular portland cements, but also for pozzolanic cements (but not for alumineous cements, which have a comparatively lower tensile strength) according to Swedish investigations.[8] The relation is particularly close for the bending and compressive strength of the plastic mortar. Norwegian tests confirm this relation as an approximation, and the attempt at verification is extended also to blast-furnace slag cements. (See fig. 1.[9])

Hence, it does not seem necessary to test both the compressive and the bending strengths; *the bending strength alone may suffice*. We should like to recommend the bending strength test on plastic mortar as the principal strength test for cements.

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[1] *See footnote 1 on page 160.*

[6] *Roscher-Lund: "Beziehungen zwischen Mörtelfestigkeiten des Zements und Druckfestigkeiten des plastisch giessbaren Betons." D. Kgl. Norske Vid. Selskap, Skrifter 1935 nr. 3, Trondheim.*

[7] *F. Vogt "On the Flow and Extensibility of Concrete" Norges Tekniske Höiskole, papers at the 25 years anniversary, Trondheim 1935 (also published by D. K. N. V. S 1935 no. 17, Trondheim).*

[8] *Werner and Giertz-Hedström "Physical and Chemical Properties of Cement and Concrete", The Engineer, March 1934.*

[9] *Test carried out by Rutle at the laboratories of the Christiania Portland Cement Manufacturing Co.*

The next point is the storage temperature. The hardening is retarded for all cements if the temperature is lowered toward the freezing point, but for normal portland cement the 28 days' strength is either increased or only slightly reduced by storage at 1° C. instead of 18°. On the other hand, it is known that some pozzolanic cements hardened at low temperatures, may only reach a small fraction of their strength by standard storage conditions.[3] Tests made by one of the authors [9] give the indication that the blast-furnace slag cement in question is not suitable for work at low temperatures in spite of the good results from the standard tests at 18° C. (See table 1.)

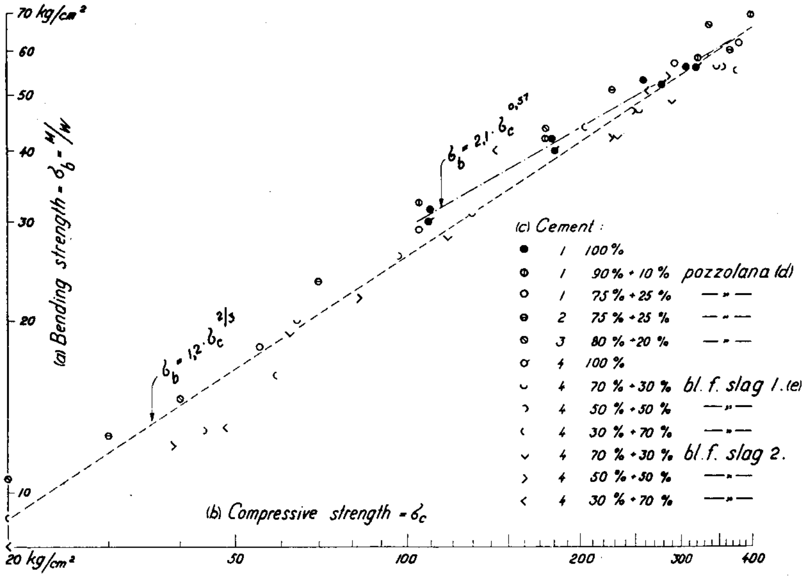

FIGURE 1.—**Bending and compressive strength of plastic cement mortars at the ages of 3, 7, 28, and 90 days for each type of cement. — The scale is logarithmic.** — Résistance à la flexion et à la compression de mortier plastique en ciment âgé de 3, 7, 28 et 90 jours, par types de ciment. L'échelle est logarithmique. — Biege—und Druckfestigkeit von plastischem Zementmörtel nach 3, 7, 28 und 90 Tagen für jede der Zementarten. Der Masstab ist logarithmisch.— Resistencia a la flexión y a la compresión de los morteros de cemento plástico de edad de 3, 7, 28 y 90 días, por cada tipo de cemento. La escala es logarítmica.

(*a*) **Bending Strength.** — Résistance à la flexion. — Biegefestigkeit. — Resistencia a la flexión.

(*b*) **Compressive Strength.** — Résistance à la compression. — Druckfestigkeit. — Resistencia a la compresión.

(*c*) **Cement.** — Ciment. — Zement. — Cemento.

(*d*) **Pozzolano.** — Pouzzolane. — Puzzolan. — Puzolana.

(*e*) **Slag.** — Laitier. — Hochofenzement. — Escoria.

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[3] *See footnote 3 on page 160.*

[9] *See footnote 9 on page 161.*

TABLE 1.—*Strength at different storing temperatures*

Strength in kg/cm² of—	Portland cement		Blast-furnace slag cement	
Storage temperature	1° C.	18° C.	1° C.	18° C.
Earth-moist compression:				
3 days	193	382	43	148
7 days	399	420	112	209
28 days	520	487	232	324
Earth-moist tension:				
3 days	24	28	7	21
7 days	34	30	15	23
28 days	37	33	27	28
Plastic compression:				
3 days	29	135	(*)	25
7 days	99	202	(*)	59
28 days	257	287	45	130

* Strength too low to be measured, the specimens could be crushed by hand.

Wet storage is used in most countries for standard tests, while the "combined" storage is used in some, among them Germany (the specimens are stored in water to the age of 7 days, then in air). By combined storage the strength of normal portland cements is known to be increased. For the blast-furnace slag cements in question the strength is, however, found to be *reduced* by combined storage, a result which sounds a warning note.[9]

TABLE 2.—*Strength by wet and combined storage*

Strength of earth-moist mortar according to German norm tests	Portland cement		Blast-furnace slag cement	
	Compression	Tension	Compression	Tension
Wet storage, 28 days	462	33	432	40
Combined storage, 28 days	572	54	374	37

Quite astonishing results may be obtained by drying throughout a long period. (See the report on some tests on specimens stored under water for different periods up to 3 months and then dried in air till testing at age about 9 months.[10])

A natural sand was used, mix 1:3 and $W/C=0.50$ by weight, and the bending strength was measured by subjecting the 4×7 cm beams to a constant bending moment over the entire length. Some of the beams were stored under water until the time of testing, while some were stored under water for various ages up to 3 months, and subsequently dried in air of 50 to 60 percent humidity at room temperature. As the test was not made before the age of 9 months, the beams were thoroughly dried out, and errors due to nonuniformities in the shrinkage and the corresponding shrinkage stresses were thereby

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[9] *See footoote 9 on page 161.*

[10] *F. Vogt, "The Strength of Air-Dried Cement Mortar in Relation to the Remaining Water Content." D. K. N. V. S. Forhandl., Trondheim, 1935, nr. 24.*

reduced. Three types of cements were tested, namely (*a*) normal portland cement, (*b*) and (*c*) different types of slow-hardening cements, the latter being of a pozzolanic type. All weight changes, including those obtained before the beams were taken out of the forms, were also measured, whereby the amount of water remaining in the beams could be approximately determined in proportion to the cement content.

TABLE 3.—*Bending strength in kg/cm², and remaining water content in proportion to the cement, after drying to 9 months of age*

	Cement (*a*)		Cement (*b*)		Cement (*c*)	
	Strength	Remaining *W/C*	Strength	Remaining *W/C*	Strength	Remaining *W/C*
Wet stored till test	58	--------	53	--------	58	--------
Dried after 3 months	75	0. 30	39	0. 19	26	0. 17
Dried after 28 days	61	. 28	29	. 17	25	. 17
Dried after 7 days	52	. 25	26	. 18	20	. 16
No water storage	44	. 22	18	. 16	11	. 11

From table 3 it is evident that the cements (*b*) and (*c*) were not able to hold the water during this drying and that they lost a great part of their strength even after 3 months of hardening under water. Dry storage alone was entirely ruinous. The strength of cement (*a*) was, however, increased by drying after an initial storage in water of at least 28 days, and even by early drying the strength was fairly well maintained. A relation was found between the strength and the remaining water content. (See further details in the paper referred to.)

The main point is that the grave deficiencies of the cements (*b*) and (*c*) could not be detected by means of the standard tests and that these, therefore, are inadequate.

It ought to be emphasized that such deficiencies can only be measured on small samples, which actually are dried throughout, and they can only be expected at the very surface of large structures. The conditions at the surface have a bearing on the problem of hair-cracking, but not much on the total mechanical strength of the structure.

II. SHRINKAGE

It has usually been assumed, that the shrinkage is reduced by prolongation of the storage in water before drying. Compare for instance a recent authoritative German statement:[11] "Durch längeres Feuchthalten des Betons wird das spätere Schwinden vermindert." Accordingly, it has been suggested to limit the standard shrinkage tests to specimens stored under water till the age of 7 days, and then in air of 50 percent humidity.

Again here, the experience from normal portland cements, rich in CaO, seems to have been extrapolated to other types of cements, and this extrapolation may not be warranted for several of the cements in, question.

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[11] *Graf "Erkenntnisse über Strassenbeton", Zementverlag, 1935.*

By concrete tests, in connection with the arch-dam model investigations of United States Bureau of Reclamation, one of the authors made the observation that the shrinkage was increased by prolongation of the storage in water.[12] Chemical analysis was not made for this particular cement, but the normal product of the company which manufactured it has a comparatively low content of CaO and a high content of SiO_2. Recent tests on plastic mortar (1:3 mix) specimens made with two normal unblended portland cements and other made with the same cements blended with a pozzolana gave results shown in table 4.

TABLE 4.—*Ratio W/C as mixed and after storage to an age of 80 days (free + bound water : cement). Swelling (+ ϵ) and shrinkage (— ϵ) in mm per m*

Type of cement	*W/C* as mixed (constant slump)	At age 80 days by storage—					
		Under water		In air after—			
				7 days		28 days	
		W/C	ϵ	*W/C*	ϵ	*W/C*	ϵ
100 percent portland (1)	0.59	0.659	+0.05	0.260	−1.27	0.283	−1.23
100 percent portland (2)	.59	.661	+.05	.266	−1.14	.283	−1.09
75 percent (1) + 25 percent pozzolana	.67	.728	+.20	.209	−1.25	.265	−1.60
75 percent (2) + 25 percent pozzolana	.64	.704	+.23	.211	−1.17	.230	−1.61

By the use of this normal portland cement, the shrinkage is slightly reduced by prolongation of the storage in water. By blending with the pozzolana, the shrinkage is the same as for unblended cement, by drying after 7 days, but is about 40 percent greater by drying after 28 days. The swelling was also increased by the blending. The increase of the shrinkage is still somewhat more pronounced by prolongation of the storage in water to 90 days before drying.

These tests were made on standard plastic mortars, with fine and coarse sand, and with water added until constant consistency was obtained, which required more water for the blended than for the unblended cements. The blended cements did not hold the water as well as the unblended. In spite of a larger *W/C* when mixed, the relative water content was appreciably lower after drying, particularly when dried at early ages.

By parallel tests on standard plastic mortars and mortars with natural sands, the former are found to be representative of the latter. Whether the mortar is mixed to constant consistency or with a constant *W/C* was found to be of secondary importance.

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[12] *Savage, Houk, Gilkey and Vogt, Report of Arch Dam Committee, vol. 2, New York, 1934.*

Tests with some blast-furnace slag cements have given results analogous to those referred to for pozzolanic cements, according to tests made by the authors.[13]

The explanation for this behaviour of the pozzolanic and blast-furnace slag cements, with respect to strength and shrinkage after drying, may be that the pozzolanos and slags react very slowly with water. During the first week these ingredients are more or less inert, and only after wet storage for some weeks do they participate fully in the reactions which may also contribute to the strength and to the increased shrinkage and swelling. The large loss of water during the drying period indicates, that the water is only loosely bound, and a large loss of water is a warning with regard to the strength. (Compare table 3.)

The results referred to were obtained by use of special pozzolanos and slag cements, but other kinds may possibly be found which do not have the same unfavorable effects. However, it seems probable that all pozzolanos or slags, which retard the hardening, may act more or less in the same manner regarding the shrinkage. The same is probably true for low-heat portland cements, i. e. cements low in CaO and high in SiO_2. For all such slow-acting cements conclusive information regarding the shrinkage can hardly be obtained with less than 28 days' storage in water before drying. The investigation of the strength of such cements should include also the conditions after longer drying periods, since some of them may be sensitive to this condition.

III. Flow and Extensibility

A concrete mass must crack due to shrinkage or temperature changes if it is restrained by the rock foundation or if the surface is restrained by the inner mass, and if, thereby, the strain exceeds the extensibility. This extensibility cannot be expressed directly in terms of strength. Even if the modulus of elasticity (tangent modulus at zero stress) is measured, the ratio of strength to modulus of elasticity has to be corrected by a factor which can only be determined experimentally, and which may depend on different characteristics, particularly on the flowing. The flow is dependent on the tempo of the straining and on the momentary moisture condition.

One of the authors has taken up such investigations by means of bending tests on plain mortar beams.[7] Certainly, the bending tests are indirect tests only, and tensile tests would have the advantage of being direct. However, by use of bending tests on plain mortar beams, instead of direct tensile tests, the corrections for shrinkage are practically eliminated from the flow measurements, and all measurements are facilitated. The conditions are altered to such an extent by steel-reinforcements that the flow of mortar in tension can hardly be determined. Hence plain mortar was used.

Most of the tests are conducted on mortar of normal portland cements, and it is too early to make a comparison of the different types of cements on the available basis. Since tests on flow and

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[7] *See footnote 7 on page 161.*

[13] *Roscher-Lund "Bautechnischer Bedarf and Schwind-Quellungsversuchen." N. T. H. papers at the 25 years anniversary, Trondheim 1935 (also published by D. K. N. V. S., 1935, no. 25, Trondheim).*

extensibility in the future may be of value for the selection of cements, it seems proper to quote some of the results in this connection:

By wet storage of the beams it was found that the extensibility by rapid loading to failure was increased with the age; i. e., the fresh mortar is not only weaker, but also more brittle than the old wet mortar. After 28 days the increase in extensibility was small, however, and tests at greater ages are therefore hardly needed for normal portland cements. A sustaining of moderate loads does not seem to have an important bearing on the ultimate strength, and the extensibility is increased thereby only at low ages. By applying sustained loads of magnitude close to the breaking load, the extensibility may also be increased for old specimens. For such loads it is difficult to avoid fortuities in the results since the breaking load can never be predicted exactly for each individual beam.

The extensibility during the drying period can hardly be measured accurately because of the disturbing effects of the shrinkage and the nonuniformity of shrinkage stresses. After the specimens are thoroughly dried (possible only for old specimens) the extensibility can again be measured fairly accurately. If the specimens are removed from the water storage at early ages, the extensibility is found to be much reduced, while it is greatly increased by drying after wet storage for some time. Particularly, the extensibility of the cements (*b*) and (*c*), referred to in table 3, was very much reduced by an early drying. The value of the wetting of concrete is thereby emphasized.

The ratio of flow under sustained load to initial deformation due to this load is termed below as "relative flow." Other things being equal, this relative flow is found to be approximately the same for all loads except those close to the breaking load. It is well known that the relative flow may be as large as 0.7 to 1.0 in wet stored specimens, and that it may be three to five times as large on exposure to sustained loads immediately after the specimens have been stored in air. The previous investigators seem to have overlooked the fact that the condition during the "drying period" (length up to some months) may be quite different from the conditions after the specimens are completely dried, and only in this manner can it be explained that the test results during the drying period have been interpreted to mean that the "dry" mortar or concrete may flow several times as much as the wet. According to the author's tests, *this large flow is attributed to only the drying period.* By loading first after this period has passed, i. e., on *thoroughly dry* specimens, the relative flow is found to be only one-third to one-half of that for the wet condition. These tests were all made on beams subjected to bending.

In addition to the momentary deformation after unloading the mortar also slowly recovers by "reflowing." The author found this reflow after unloading to be considerable, for instance, one-half of the flow under load.[7] If the concrete did not flow under sustained loads, a cracking due to shrinkage and temperature variations at the surface would in most cases be inevitable. It is therefore a highly valuable property of concrete that it is able to flow, and it would seem reasonable to make corresponding tests, particularly in the selection of special cements for dam construction.

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[7] *See footnote 7 on page 161.*

SUMMARY

The present standard cement tests are in some cases found to be either misleading or incomplete as a basis for selection of cements, particularly by comparison of normal portland cements with pozzolanic cements, blast-furnace slag cements and other slow-hardening cements in question for dams.

The bending test on plastic mortar (two sand screenings and high *W/C*) is recommended as the principal strength test for cements. Tests on specimens stored at low temperatures and on thoroughly dried specimens ought to be included for cements sensible to such exposures.

The shrinkage should be measured on specimens stored under water to the age of 28 days before being dried.

The ability to flow is a very important property of concrete, and corresponding tests should be made on a selection of cements for dams. It is emphasized that the magnitude of the flow is very different for the wet condition, during the drying period, and for the thoroughly dry condition. All tests should, therefore, distinguish between these three conditions.

RESUME

Les essais normaux auxquels on soumets les ciments se trouvent parfois être soit trompeurs, soit insuffisants en raison de la détermination du choix des ciments, plus particulièrement quand il s'agit de comparer les ciments portland ordinaires avec les ciments de pouzzolane, les ciments de haut-fourneau et d'autres ciments à prise lente, qui pourront être employés dans des barrages.

L'essai de flexion pour le mortier plastique (deux triages de sable et forte teneur en eau) est recommandé comme le principal essai de résistance pour les ciments. Des éprouvettes conservées à des températures basses et des éprouvettes fortement desséchées devront être incluses dans les essais de ciments sensibles à de telles influences.

Le retrait doit être mesuré sur des éprouvettes noyées jusq'a l'âge de 28 jours avant d'être desséchées.

La flexibilité est une propriété très importante pour les bétons, et des essais appropriés devront être effectués toutes les fois qu'on aura à choisir des ciments pour les barrages. On fait ressortir que le degré de flexibilite, est très différent pour l'état humide, pendant la période de séchage, et pour l'état complètement sec. C'est pourquoi, dans tous les essais, il faut faire une distinction entre ces trois états.

ZUSAMMENFASSUNG

Die gegenwärtigen Normen für Prüfung von Zementen sind in einigen Fällen entweder misweisend oder unvollständig als Grundlage für die Auslese von Zementen, insbesondere beim Vergleich von Normalen Portlandzementen mit Puzzolanzementen, Hochofenzementen und anderen langsambindenden Zementen bei Verwendung für Talsperren.

Die Biegeprüfung an plastischem Mörtel (Grobsand und Feinsand, hohes Wassergehalt) ist als grundsätzliche Festigkeitsprüfung für Zemente empfohlen. Versuche an Proben bei niedrigen Temperaturen gelagert sowie vollständig getrocknete proben sollten für

Zemente, die gegenüber solchen Einwirkungen empfindlich sind, eingeschlossen werden.

Das Schwinden sollte an Proben, die vor dem Trocknen 28 Tage unter Wasser gelagert sind, gemessen werden.

Das Fliessvermögen ist eine sehr wichtige Eigenschaft des Betons, weshalb entsprechende Versuche bei der Auslese der Zementen für Talsperren angestellt werden sollten. Es wird nachdrücklich darauf hingewiesen, dass die Grösse des Fliessens während der feuchten Lagerung, während des Trocknens und während des vollkommen trocknen Zustandes sehr verschieden ist. Bei allen Versuchen ist deshalb zwischen diesen drei Zuständen zu unterscheiden.

RESUMEN

Los ensayos normales a que se someten los cementos a veces se encuentra que son engañosos o incompletos para determinar la selección de los cementos, especialmente cuando se trata de comparar los cementos portland ordinarios con los cementos de puzolana, los cementos de altos hornos y otros cementos de fraguado lento, que podrían emplearse en la presas.

El ensayo de flexión para el mortero plástico (dos graduaciones de arena y gran contenido de agua) se recomienda como el principal ensayo de resistencia para los cementos. Las probetas conservadas a temperaturas bajas y las probetas muy secas deben incluirse en los ensayos de cementos sensibles a tales influencias.

La retracción debe medirse en las probetas colocadas en agua durante 28 días antes de secarse.

La flexibilidad es una propiedad muy importante del hormigón, y deben efectuarse ensayos apropriados siempre que haya de elegirse cementos para presas. Se hace notar que el grado de flexibilidad es muy diferente en el estado húmedo, durante el período de desecación, y en el estado completamente seco. Por esta razón, en todos llos ensayos, es necesario hacer una distinción entre estos tres estados.

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

TESTS ON COMPOSITION OF CONCRETE*

E. CZETWERTYNSKI
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This paper deals with test methods used in determining the composition of concrete for construction of a dam on the River Dunajec near Roznow.

TESTING OF GRAVEL

The gravel for the concrete is to be obtained from a gravel pit located near the Dunajec River. Samples of gravel for the tests were taken from 11 pits sunk along the river.

For screening, for the purpose of determining the granulometric composition of the gravel, sets of the following screens arranged according to Polish standards were used: 0.25, 0.5, 1, 2, 4 mm, and also 10, 20, 40, and 80 mm. Apart from these, as it is anticipated that material of up to 120 mm diameter may be used, a screen of suitable diameter was also added.

As a result of the tests, curves of screening for the various borings were obtained. These curves show considerable divergence of the natural composition of the material, according to the various pits from which samples were taken.

Volumetric and specific gravity as well as porosity have been investigated (fig. 1) as regards the various samples, and tests have also been carried out to determine the amount of dust and organic particles in the natural mixture. Finally, the petrographical composition of the various coarser fragments of gravel has been determined.

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*Essais sur la composition en graviers des bétons étanches.
Versuchsmethoden zur Bestimmung der Beton-Zusammensetzung.
Ensayos sobre la composición de la grava de los hormigones impermeables.

TABLE I.—*Petrographical composition of Witkowka gravel*

Sample no.	Weight of sample	Size of gravel	Petrographical composition							
			Granite		Sandstone		Limestone		Silica	
	Grams	*Mm*	*Grams*	*Percent*	*Grams*	*Percent*	*Grams*	*Per-cent*	*Grams*	*Per-cent*
1	4, 990. 4	80–40	1, 700. 5	34. 1	3, 151. 2	63. 1	------	----	138. 7	2. 8
2	1, 993. 0	40–30	571. 0	28. 6	1, 328. 4	66. 7	62. 7	3. 2	30. 9	1. 5
3	2, 002. 0	30–20	481. 1	24. 1	1, 416. 4	70. 7	104. 5	5. 2	------	----
4	997. 5	20–10	206. 7	20. 7	725. 0	72. 7	55. 4	5. 6	10. 4	1. 0

The curves of specific gravities have an interesting feature in that they clearly show the passage through the minimum for average grain screenings. This is due to the greater sandstone content in the average grain fragments, whereas the larger grain fragments contain more granite and the smallest ones quartz. In order to amplify these superficial characteristics of the natural mixture, it must be added that the sandstone grains are, on the average, rather flattened whereas the granite grains have a more spherical shape.

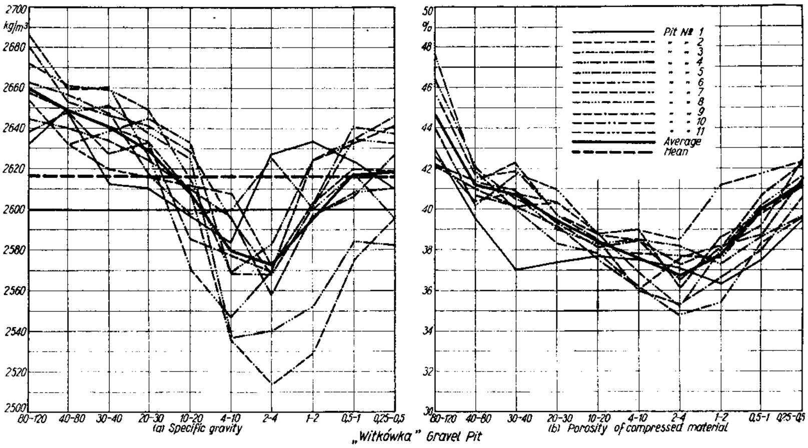

FIGURE 1.—**Witkowka gravel bed.**—Lit de gravier de "Witkowka". — "Witkowka" Kiesuntergrund. — Yacimiento de grava de "Witkowka."

(*a*) **Specific gravity.** — Poids spécifique. — Spezifisches Gewicht.— Peso específico.
(*b*) **Porosity of compressed material.** — Porosité des matériaux comprimés. — Porosität der zusammengedrückten Baustoffe. — Porosidad del material comprimido.

REQUIREMENTS WITH WHICH THE CONCRETE MUST COMPLY

In determining the composition of the concrete for the construction of the dam, the following criterions of minimum requirements with which the mixtures have to comply have been adopted:

(1) For the concrete cover-coat on the water side of the dam, which coat is to have a thickness of up to 2 m:

(*a*) Resistance to compression after 28 days—not less than 175 kg/cm^2.

(*b*) Permeability of 28-day old samples of a thickness of 10 cm—zero at 0.5 atm. pressure; slight permeability at 3 and 6 atm. pressure is permissible, provided the permeability drops to zero during a 12-day test of the sample. The sample is subjected to a pressure of 0.5 atm. for the first 24 hours, to 3 atm. for the next 24 hours, and to 6 atm. for the remainder of the test period.

(*c*) Least possible contraction during the hardening of the concrete and greatest possible resistance to frost.

(*d*) Consistency to permit efficient settling of the concrete in the structure (it is intended to use plastic concrete).

(2) For concrete intended for the construction of the remaining parts of the dam structure:

All requirements as above, with the exception of the permeability requirements.

The aforesaid requirements have been determined on the basis of the following considerations:

The scheme provides for compression stresses in the concrete amounting up to 3.5 kg/cm^2; considering that, according to Polish standards, the factor of compression stress is equal to 0.02, this would correspond to a compression resistance of $\frac{3.5}{0.02} = 175$ kg/cm^2. The figures of compression stresses as computed in the scheme lead to less onerous requirements.

The considerations which attended the determination of the requirements concerning permeability are described below. The maximum pressure of water at the dam amounts to approximately 50 m which corresponds to 5 atm. Taking into consideration that the thickness of the test samples is 10 cm and the actual thickness of the layer is to be $\sim$ 2 m, and assuming that with the increase of thickness there is also at least the lineal increase of resistances for the permeating water, absolute impermeability of the sample would be arrived at under a pressure of a mere 0.25 atm. However, in view of the uncertainty as to whether the concrete prepared in the laboratory would not prove superior to that which would be obtained on site in mass production, it was decided to fix the absolute impermeability of the concrete at 0.5 atm. Further, bearing in mind the impossibility of avoiding construction joints, which always constitute a danger point as regards permeability, further requirements were added for self-sealing of the samples at pressures up to 6 atm; that is to say, at pressures in excess of the natural pressure at the dam. Compliance with this provision leads to the assumption that leaks likely to occur in the dam, given accurate preparation of the mixture, would be due solely to permeability of construction joints and unavoidable cracks in the concrete, and not to permeability of the concrete mass, and that they might thus be reduced to a minimum.

The increase of pressure during the tests at intervals of 24 hours, and not at more frequent intervals, was influenced by the fact that in cases where the pressure was increased more rapidly, small particles were being washed out of the samples, forming a white deposit in the measuring vessels, the samples in consequence showing a considerable permeability; whereas if the pressure is increased at a slower rate, the internal compactness of the concrete takes place more easily. In practice, the filling of the reservoir will proceed at a much slower rate than the rate at which the test pressure was increased, so that there is no risk of failure under the system adopted.

CEMENT FACTOR

In determining the composition of concrete, the proportion of cement has been fixed in advance, namely 300 kg per m^3 of concrete in the case of the cover coating, and at the rate of 250 kg per m^3 of concrete for the remainder of the dam structure. A rate of 300 kg per m^3 of concrete in the case of the cover coating is considered to ensure efficient waterproofing of the concrete. The reason for fixing a comparatively high proportion of cement for the remainder of the concrete was the likelihood of considerable difference in shrinkage between the cover coating and the remainder of the structure in the event of larger differentiation in the cement content. Further, this ensures sufficient resistance of the concrete against the influence of frost. Possibly further research will enable the cement content to be somewhat reduced. Nevertheless major variations are not anticipated, as any saving effected in cement may be offset by serious losses should shrinkage and freezing have detrimental effects on the concrete.

DETERMINATION OF THE CURVE OF SCREENING

The closest approximation to the curve of screening gravel to be adopted for the concrete, is that which within limits of practical application would provide the densest mixture (fig. no. 2, curve no. 1). This curve has been determined on the assumption of the application of three grain assortments, viz Ø 0.25–10 mm; Ø 10–30 mm; Ø 30–80 mm, it being anticipated that in actual practice particles smaller than 0.25 mm would be eliminated by suitable washing, whereas the separation of the other grain sizes would be effected by means of screens. The shape of this curve within the individual divisions has been adopted according to the average curve of screening for the gravel field. By consecutive selection of mixtures of varying percentage of the two coarser assortments, and subsequently of the densest mixture containing the third assortment, a mixture was obtained consisting of 0.25 to 10 mm, 40 percent; 10 to 30 mm, 30 percent; and 30 to 80 mm, 30 percent. The porosity of this mixture amounts to 19.87 percent. For purposes of comparison, a mixture was prepared from the same gravel according to Fuller's curve, the porosity in this case amounting to 21.6 percent.

By comparing results it is evident that Fuller's curve in this particular instance does not provide the densest mixture. It may be assumed that this is influenced by the considerable divergence in the shape of the grain from practically a spherical one in the case of granite down to a very flat one in the case of sandstone.

Further experiments in determining the composition of gravel were carried out in accordance with the opinions expressed in the works of Professor Paszkowski ("Concrete of a Given Resistance" and "Method of Experimental Computation of the Dosing of Concrete and Cement Compositions"). On the basis of the differentiations laid down by Professor Paszkowski, grains of up to 2 mm were considered as sand and the larger ones as gravel. It then became necessary to select the proper ratio of these two components in order that the mixture could be effected in practice, on the assumption of the three previously selected assortments. With this object in view, curves were prepared which, theoretically ought to yield satisfactory results, after which a further series of curves was worked out which, in actual practice, would yield results coincident with those previously obtained. By experiments the densest mixtures of the material were determined within the limits of from 0.25 to 2 and 2 to 280, the components consisting of assortments obtained by screening through laboratory screens.

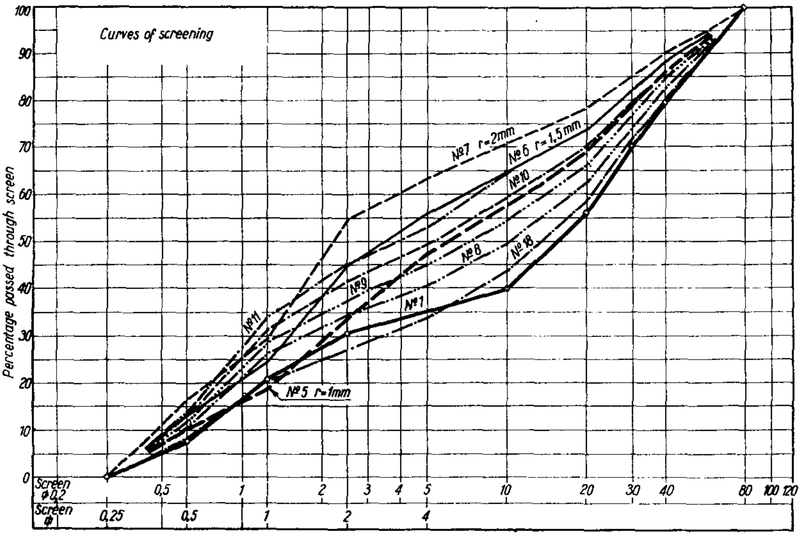

FIGURE 2.—**Curves of screening.** — Courbes de tamisage. — Gitterkurven. — Curvas de tamizado.

On the basis of the works referred to above, the percentage of the individual components was computed, assuming a cement content at the rate of 300 kg per m^3 of concrete and a cement mortar coat of the grain of $r=1$, 1.5, and 2 mm. These computations resulted in the compilation of three curves for screening nos. 5, 6, and 7 (fig. 2). These curves, however, were not feasible under the assumed practical distribution of the material, so that by adopting the aforesaid division into three components, the composition of the gravel in each assortment corresponding to the average natural curve, four curves for screening were determined, on the following principles: Ratio of assortment 10–30 and 30–80 mm as 1:1, that is to say, according to previous tests of the densest mixture, and the quantity of 0.25–10 mm material being such as to ensure that the percentage content of sand up to 2 mm was within the limits determined in the curves computed, nos. 8, 9, 10, and 11 (fig. 2). It must be added that the figures denoting the cement mortar coating of the grain in the practical curves referred to vary within the limits of from $r=1.22$ to $r=1.51$ mm.

The curves obtained run considerably above those of Bolomey and Fuller and also above a number of curves applied in the construction of a number of dams (compare figs. nos. 2 and 3). They are also above the average curve for screening of the natural mixture. From a number of experiments carried out it was found that the most satisfactory results are obtained with curves 8 and 9, that is to say, with curves of a smaller sand content. The deflection of the curves from the average natural curve which, eventually, would have led to the necessity of crushing the material, thus rendering work more difficult and introducing the less desirable crushed material, as well as the satisfactory results obtained with the lowest curves, prompted us to direct our research towards reducing the percentage of sand. It must be added that at this time (January 1936) provision could be made in the tests for a most important factor, namely, the application of four practical components (0.25–2; 2–10; 10–30; 30–80) instead of three, as previously provided for, due to the fact that the equipment placed on order for the construction is suitable for such grading.

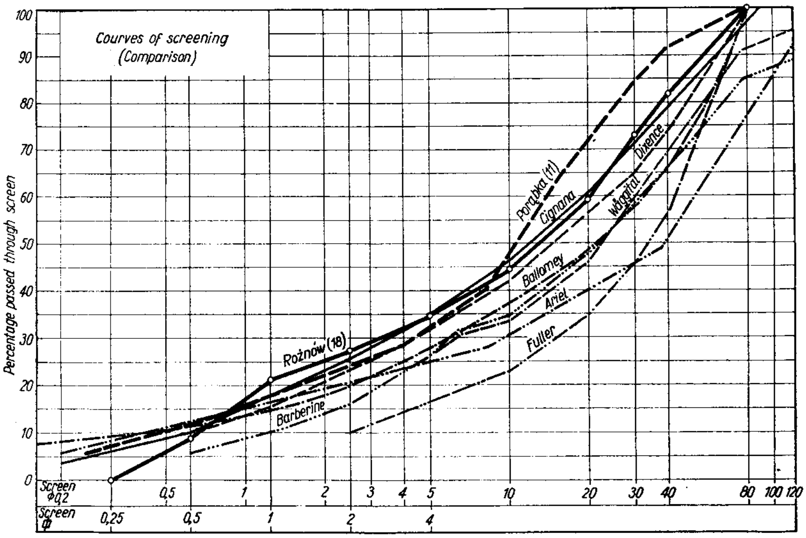

FIGURE 3.—**Comparison of curves of screening.** — Courbes de tamisage (comparaison). — Vergleichende Gitterkurven. — Curvas de tamizado (comparación).

In order not to unduly reduce the cement mortar coating of the grain, r was fixed as $r=1$ mm, and by applying the new division to practical grading, curve 18 was evolved (fig. 2). This curve runs very close to the average curve for natural screening and is close to the scope of curves so far applied in practice. Research so far carried out prompts us to assume that this curve will comply entirely with the requirements put forward for concrete. Moreover it will probably be possible to bring the upper parts of this curve closer to the average natural curve.

In the case of concrete containing cement at the rate of 250 kg per m^3, tests have been carried out with regard to curves with a slightly lower sand content than provided for in curves 8, 9, 10, and 11, providing for three practical components, as previously. For this grade of concrete, gravel of up to 120 mm Ø was originally provided for. Later on, however, this principle was abandoned due to practical difficulties in preparing mixtures of varying grain size, more so as the natural gravel layers contain comparatively little material of a grain between 80 and 120 mm. The tests have led to the conclusion that the most satisfactory method will be to adopt one uniform curve of screening for both grades of concrete.

In order finally to determine the curve of screening, it now remains necessary to carry out a series of experiments over the curve selected and to fix the tolerances within which deviations from the curve selected are permissible in actual practice.

Proportioning of Water

Professor Paszkowski's method referred to above provides for determination of the quantity of water required for mixing the concrete according to consistency and composition of the concrete. Experience, however, has proved that in spite of adopting a water index corresponding to plastic concrete, the mixture at the computed quantity of water was usually too dry. Therefore, in order to obtain a concrete mixture which would be readily workable, and at the same time avoiding an excessive quantity of water, in consideration of the resistance, the test samples were made with the quantity of water determined by computation, after which this quantity was increased, the proportion of all other components remaining unchanged.

On the basis of the tests so far carried out, it is considered that the proper quantity of water to obtain the necessary consistency cannot be determined by fixing the quantity of water required individually for the cement and each individual size of grain of gravel, as it also depends on their mutual relationship as regards the petrographical composition of the gravel and the shape of the gravel. This point will be investigated in detail in the course of subsequent research at the concrete laboratory at Roznow.

Compression and Permeability Tests

The compression tests were carried out with cylindrical test samples of 196 mm diameter and of a similar height (according to Polish standards, type A). The tests were carried out 7 and 28 days from the date of manufacture of the samples. The samples after manufacture are stored in a cellar at a temperature above 10° C. and are covered by damp rags. The samples are removed from the moulds after 24 hours. The samples are crushed on a surface of plywood. The samples for the permeability test are made in the form of round dies, 30 cm diameter by 10 cm thick. In order to compare the effects of the influence of thickness on permeability, some of the samples were made 15 and 20 cm thick. The samples after 28 days from manufacture are subjected to water pressure during a period of 24 hours at 0.5 atm., 24 hours at 3 atm. and thereafter at 6 atm. The

Length of time during which the samples are kept under a pressure of 6 atm. depends on when the test apparatus is required for subsequent tests.

Figure no. 4 shows the course of permeability of one of the samples, as an instance of the distinct self-sealing property of concrete. The course of the experiment quoted differs from the standard test method, the pressure being increased by smaller steps and brought up to 12 atm. A striking feature is the breaking down of the leakage curve after approximately 48 hours of test, after which permeability decreases to an insignificant figure, in spite of a steadily increasing pressure.

VIBRATED CONCRETE

The tests with vibrated concrete were carried out in moulds 50 by 50 by 50 cm, using a needle vibrator, as well as in ordinary moulds for resistance test under outside vibration. From blocks 50 by 50 by 50 cm, cubes are cut 20 by 20 by 20 cm which are subjected to compression tests, as well as test plates 10 cm thick for permeability tests. The application of the difficult test method requiring the cutting of cubes from large blocks was governed by the desire to determine whether under vibration the concrete does not disintegrate into layers, and was also due to the fear that in using small moulds the influence of vibration would not be sufficiently apparent, particularly when using a needle vibrator. In view of the difficulties in the manufacture of such cubes, parallel tests were carried out with small moulds.

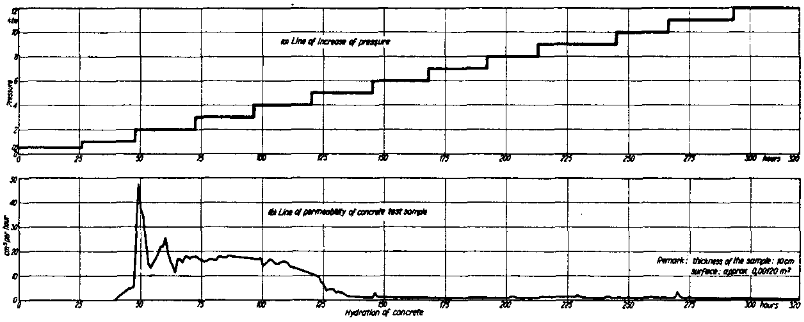

FIGURE 4.—**Hydration of concrete.**—Hydratation du béton. — Hydration des Betons. — Hidratación del hormigón.

(a) **Line of increased pressure.** — Ligne de pression croissante. — Linien des zunehmenden Druckes. — Línea de presión creciente.

(b) **Line of permeability of concrete test sample.** — Ligne de perméabilité d'une éprouvette en béton. — Linien der Wasserdurchlässigkeit von Beton-Probestücken. — Línea de permeabilidad de una probeta de hormigón.

So far the number of tests carried out with vibrated concrete has been insufficient to enable final deductions to be made. Nevertheless the tests already carried out appear to substantiate the opinion expressed, among others, by Awakow in his publication Vibrated Concrete for the Construction of the Dniepr Plants that vibrated concrete does not show an increase in resistance, as compared with rammed or pounded concrete, when using a similar proportion of water. Vibrated concrete, on the other hand, has this advantage, that drier mixtures may be used than is the case with other methods of laying.

Vibrated concrete is easily workable at a dry consistency, which is rather doubtful with pounded concrete.

SUMMARY

The grain of gravel from pits along the river Dunajec depends to a considerable extent on the ratio of the components thereof, i.e. sandstone, granite, and limestone.

The facing of the dam at Roznow on the water side is being made of concrete assuring an absolute watertightness.

Considering that sandstone and limestone gravel has usually a flat shape, and that granite gravel has a spherical shape, and that the size of grain depends on the nature of the rock, it was possible, in carefully selecting the grain of the components, to obtain a mixture entirely waterproof, having a porosity of only 19.87 percent. This mixture corresponds to a porosity of 21.6 percent according to the Fuller curve.

The quantity of water added depends on the nature of the gravel and sand.

The author quotes instances of rapid self-sealing of the samples of concrete under water pressure up to 12 atm.

The experiments carried out with vibrated concrete have shown that, even with a small proportion of water, a watertight and plastic mass may be obtained.

RESUME

Le grain des bancs de gravier situés le long du Dunajec, dépend dans une large mesure de ses éléments constituants, savoir: grès, granit, calcaires.

Le revêtement de la face amont du barrage de Roznow est fait d'un béton qui assure une étanchéité absolue.

Comme le grès et le calcaire donnent d'ordinaire des graviers plats, et le granit des gravier de forme sphérique, et que d'autre part la dimension des grains dépend de la nature de la roche de formation, on a pu, en sélectionnant avec soin le grain des éléments constituants, obtenir un mélange très étanche possédant une porosité de seulement 19,87%.

Cette composition de grains correspondrait, d'après la courbe de criblage de Fuller, à une porosité de 21,6%.

La quantité d'eau qu'il faut ajouter dépend de la nature des roches qui constituent le gravier et le sable.

On donne des exemples de l'étanchement naturel rapide d'échantillons de béton supportant des pressions d'eau allant jusqu'à 12 atmosphères.

Les essais faits sur du béton vibré ont montré que même avec de légères additions d'eau on peut obtenir une masse étanche et plastique.

ZUSAMMENFASSUNG

Die Kornzusammensetzung des Schotterbänke am Dunajez ist in hohem Grade von des Mengenverhältnisses der sie bildenden Hauptfelsen: Sandstein, Granit, Kalkstein, abhängig.

Der wasserseitige Teil der Talsperrenmauers in Rożnów wird aus der Betonmischung, welche eine vollständige Wasserdichtigkeit gewährt, ausgeführt.

Da Sandstein und Pieninenkalkstein grösstenteils flache, dagegen Granit runde Schotterkörner bilden und da es sich erwiesen hat, dass auch die Korngrösse von der Felsengattung abhängt, konnte bei der gewählten Korngrösse der Zuschlagstoffe eine sehr dichte, mit einem Porenvolumen von nur 19,87%, Zusammensetzung gebildet werden. Nach der Fullerschen Siebkurve würde dieser Kornzusammensetzung ein Porenvolumen von 21,6% entsprechen.

Die nötige Menge des Wasserzusatzes wird auch im hohen Grade durch den Charakter der Felsen, die den Schotter und Sand bilden, beeinflusst.

Der Verfasser gibt Beispiele der schnell vor sich gehenden Selbstdichtung der Betonproben bis zu dem Wasserdrücken von 12 at.

Die Untersuchungen mit vibriertem Beton haben, in gewissem Masse, erwiesen, dass man, selbst bei Verwendung von kleinen Wasserzusätzen eine genügend dichte und fliessbare Masse erhält.

RESUMEN

La granulación de la grava en los bancos situados a lo largo del río Dunajec depende en gran parte de sus elementos constituyentes, a saber: arenisca, granito, piedra calcárea.

El revestimiento de la cara de aguas arriba de la presa de Roznow está construído de un hormigón que asegura una impermeabilidad absoluta.

Como la arenisca y las piedras calcáreas generalmente forman gravas planas y el granito gravas de forma esférica, y que de otro lado, el tamaño de los granos depende de la naturaleza de la roca, al seleccionar cuidadosamente el grano de los elementos constituyentes se pudo obtener una mezcla muy impermeable y teniendo una porosidad de sólo 19,87%.

Esta composición de granos corresponde, según la curva de tamizado de Fuller, a una porosidad de 21,6%.

La cantidad de agua que se debe agregar depende de la naturaleza de las rocas que constituyen la grava y la arena.

Se dan ejemplos de la rápida impermeabilización natural de las muestras de hormigón bajo presiones de agua hasta de 12 atmósferas.

Los ensayos que se hicieron con el hormigón vibrado mostraron que aun con pequeñas adiciones de agua se puede obtener una masa impermeable y plástica.

QUESTION III

FORSEN, LALIN
WESTERBERG
OHMAN and BERG
SWEDEN

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

SWEDISH CEMENTS FOR HYDRAULIC STRUCTURES*

LENNART FORSÉN

Chief Chemist of the Skånska Cementaktiebolaget

Sweden

As most of the Swedish rivers are composed of both hard and soft waters, there is a special interest shown here for a cement that is peculiarly adapted to hydraulic structures exposed to one-sided water pressure.

In 1931 the Royal Board of Waterfalls invited offers of a special cement for large dams in which the following properties were demanded:

Evolution of heat	As low as possible.
Setting time	Long, about 5 hours before initial set.
Workability	Good.
Concrete strength	High after 90 days' storage in water. No special demands for shorter terms.
Density and water resistance	Good.

These demands led to the manufacture in 1932 of the "Silikat cement", a portland cement containing an increase of silica and iron oxide but decreased lime and aluminium oxide contents.

The question of making a pozzolanic cement was taken up by the Swedish cement industry and the best way of producing an artificial pozzolana thoroughly investigated. It was found that the best product in respect to lime-combining capacity was obtained by using kaolin as a raw material. This product is called "Pansar pozzolana" and contains about 75% SiO_2, 12% Al_2O_3, 1% Fe_2O_3, and sustains 11% loss on ignition. About 60% silica is soluble in a 5% solution of sodium carbonate.

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*Ciments spéciaux suédois pour constructions hydrauliques.
Schwedische Spezial-Zemente für Wasserbauten.
Cementos especiales suecos para construcciones hidráulicas.*

In 1934 two pozzolanic cements, "Pansar A" and "Pansar Silikat", were marketed. The former contains 20%–25% pansar pozzolana interground with standard portland cement klinker and the latter 10%–15% pansar pozzolana interground with "Silikat cement" klinker.

The most outstanding properties of these three cements are given in the following tables which also show the standard portland cement used for the "Pansar A cement."

The lime-combining power of divers pozzolanas, when mixed with portland cement in the proportions of 2 parts of cement to 1 part of admixture, is illustrated in table 1. The amount of free calcium hydroxide has been determined according to the method used by Schläpfer and Bukowski [1] in set pastes of standard portland cement, and mixtures of this and pozzolana after curing in airtight tins for 7, 28, and 90 days, respectively. From the figures obtained, the amount of lime taken up by the pozzolana has been deduced. The best result was obtained with the "Pansar pozzolana."

The composition of the various cements, expressed in moduli, is given in table 2. The fineness is determined with the Andreasen[2] apparatus, methyl alcohol being used for the suspension and determination of the amounts of particles smaller than 0.8, 2, 5, 10, and 20 microns.

In table 3 the values of the heat of hydration using the heat-of-solution calorimeter are recorded.

Tables 4 and 5 show the respective compressive and tensile strengths as tested according to the Swedish standard specifications (similar to the German specification). The results are averages from the regular factory tests.

Table 6 gives the compression strength of concrete containing 350 kg cement per cubic meter. The consistency was plastic and the water-cement ratio was varied to give a slump test of 5 cm.

Table 7. Shrinkage has been determined according to a German method—the 4 by 4 by 16 cm mortar specimens having been dried over burnt lime after having been cured in water for 7 days. The specimens were prepared in the same way as those used for strength tests according to Haegermann.[3]

Table 8 shows the amount of free lime in set cement pastes, as determined by the Schläpfer-Bukowski method. From the analyses it is evident that for straight portland cements the amount of free lime in the mortar continually increases with age until a limiting value is reached which then remains constant, whereas, in pozzolanic cement mortars, the amount of free lime continually decreases with age.

Table 9. Extractions with water have been carried out according to a Swedish method. An amount of set cement (powdered) containing 300 mg of calcium oxide is treated with 250 ml of water a number of times, the solutions being sucked off after an interval of 15 minutes and titrated. The amount of lime dissolved is then calculated in

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[1] *P. Schläpfer and R. Bukowski. Eidg. Mat. Prüf. anstalt an der ETH, Zürich. Bericht Nr. 63.*

[2] *A. H. M. Andreasen, Kolloidchemische Beihefte, 26, 349 (1928).*

[3] *G. Haegermann, Zement, 24, 529 (1935).*

percent of the total amount originally present. The results show that lime is much more easily extracted from mortars of portland cements than from those of pozzolanic cements.[4]

Table 10 shows the permeability of concrete as measured according to the German specifications. The specimens were 100 days old when tested. The Pansar pozzolana addition has evidently had a favorable influence on the watertightness.

Table 11 gives the results of some corrosion tests with 0.2 M sodium sulphate solution. The 4- by 4- by 16-cm specimens were prepared of one part of cement to seven parts of German standard sand, and were cured in water for 28 days before being immersed in the sodium sulphate solution. Specimens of standard portland cement were speedily destroyed, whereas, those made of slow-hardening portland cement or of pozzolanic cements showed a marked resistance.

On account of the properties mentioned above, the new cements have been extensively used for monoliths, dams, reservoirs, and other hydraulic structures.

Pansar cements, however, have a comparatively short setting time. Endeavors are being made to remedy this inconvenience and it is hoped that very soon they will have the same setting time as the straight portland cements from which they are made.

Separate treatises on the practical use of these cements, written by Mr. G. S. Lalin and Mr. G. Westerberg of the Royal Board of Waterfalls, and Mr. A. Öhman of the Krångede A. B. and Mr. N. Berg of the Vattenbyggnadsbyrån, are included in this report.

	Basic blast furnace slag	Pansar pozzolana	Kaolinite anhydrous	Danish moler	English artificial pozzolana	Italian pozzolana
TABLE 1						
Lime-combining capacity of pozzolanas:						
Parts of lime combined with 100 parts of pozzolana after—						
7 days	0	10	8	7	8	9
28 days	0	30	20	11	10	10
90 days	0	32	22	12	------	10
SiO_2 soluble in 5% Na_2CO_3 after extraction with HCl, percent	------	60	43	19	9	18

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[4] *During the first stage, it is mostly the free lime that is dissolved in the manner already described by N. Sundius. Investigations—hitherto unpublished—carried out in Sweden by L. Forsén and Chr. Enberg have shown that calcium hydroxide extracted from set cement dissolves very rapidly while the lime in silicate gels extracted from set cement becomes hydrolized and dissolves very slowly. This directly confirms Sundius' opinion, which is the basis on which the Swedish method for the calculation of the degree of solubility of lime contained in set cement is founded.*

	Pansar silikat cement	Pansar A-cement	Slow-hardening portland cement	Standard portland cement
TABLE 2				
Chemical composition:				
CaM			1. 95	2. 10
SiM			4. 00	3. 00
AlM			1. 30	1. 80
Standard portland cement + Pansar pozzolana, percent		20–25		
Slow-hardening portland cement + Pansar pozzolana, percent	10–15			
Fineness:				
Residue on DIN 70 sieve, percent	6	4	8	5
Surface, cm^2/g			1, 800	2, 400
Setting time:				
Beginning, hours	2	1	5	3
Final, hours	8	5	9	8

$$CaM=\frac{CaO}{SiO_2+R_2O_3};\ SiM=\frac{SiO_2}{R_2O_3};\ AlM=\frac{Al_2O_3}{Fe_2O_3};$$

	Pansar silikat cement	Pansar A-cement	Slow-hardening portland cement	Standard portland cement
TABLE 3				
Heat of hydration: Calories per gram after—				
3 days	57	61	57	80
7 days	66	75	69	94
28 days	72	85	86	104
TABLE 4				
Compressive strength in kg/cm^2 after water storage for—				
2 days	165	119	114	223
7 days	336	228	235	423
28 days	395	602	400	570
90 days	483	651	559	622
360 days	593	790	637	648
TABLE 5				
Tensile strength in kg/cm^2 after water storage for—				
2 days	22	14	14	26
7 days	27	36	23	35
28 days	43	51	28	40
90 days	45	51	33	41
360 days	48	55	38	39

	Pansar silikat cement	Pansar A-cement	Slow - hardening portland cement	Standard portland cement
TABLE 6				
Compressive strength of concrete in kg/cm² after—				
3 days	--------	180	--------	205
7 days	109	225	237	325
28 days	248	450	450	405
90 days	348	450	558	490
Water-cement ratio	0. 57	0. 58	0. 54	0. 54
TABLE 7				
Shrinkage in o/oo after—				
28 days	0. 37	0. 37	0. 54	0. 65
56 days	0. 81	0. 69	0. 76	0. 84
90 days	1. 12	1. 03	0. 82	0. 88
150 days	1. 21	1. 12	0. 88	0. 93
TABLE 8				
Content of free calcium hydroxide in set cements after—				
7 days	11. 5	13. 5	17. 0	20. 0
28 days	8. 5	9. 0	21. 5	25. 0
90 days	7. 5	6. 5	22. 0	27. 5
180 days	7. 0	6. 0	--------	27. 5
360 days	6. 5	6. 0	--------	27. 0
TABLE 9				
Extraction by water: Amount of CaO dissolved in extraction no.—				
1	13. 0	16. 1	22. 0	29. 5
2	7. 0	9. 8	9. 7	10. 4
3	5. 6	7. 2	6. 1	6. 1
4	5. 2	5. 6	5. 1	4. 4
5	4. 1	4. 8	4. 0	3. 7
TABLE 10				
Permeability of concrete containing 250 kg cement per cubic meter: Amount of water leaking through after—				
24 hours at 1 atm	Dry	Dry	Dry	Dry
Next 48 hours at 1 atm	Dry	Dry	14	3
24 hours at 3 atm	Dry	Dry	78	38
24 hours at 7 atm	Dry	Dry	167	177

TABLE 11

	Pansar silikat cement	Pansar A-cement	Slow - hardening portland cement	Standard portland cement
Corrosion in 0.2 M sodium sulphate solution:				
Expansion in o/oo after—				
4 weeks		0. 0	0. 0	0. 5
8 weeks		0. 2	0. 4	5. 5
12 weeks		0. 2	0. 4	11. 5
Tensile strength in kg/cm^2 after—				
4 weeks		32	18	13
8 weeks		39	19	8
12 weeks		40	21	0

EMPLOYMENT OF LOW-HEAT CEMENT IN CONSTRUCTION OF VARGON POWER STATION

G. S. Lalin

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and

G. Westerberg, C. E.

The Royal Board of Waterfalls, Sweden; Major, the Royal Corps of Engineers

Vargön power station, the construction work for which was carried out during the years 1932–1934, is shown in figure 1. Especially noticeable is the low head which, combined with the large flow of water, necessitated wide water openings with complicated concrete structures and heavier reinforcement. The spiral lies partially higher than the upper water level and the water is conducted to the turbines through a siphon arrangement. This design imposed great tightness in the concrete, not only against water but also against air.

The demands on the concrete structures were thus exceedingly high. In addition to the demand for tightness, there existed difficulty in carrying out the work due to the heavy reinforcement and the comparatively massive construction work. Moreover, the restricted space available on the job limited the capacity of the transport arrangements to and from the mixers so that it was not possible—if normal cement were employed—to provide for pouring in one operation over a surface greater than 80 to 100 m^2.

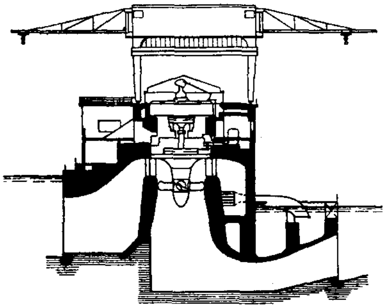


FIGURE 1.—**Vargön power station.** — Usine de Vargön. — Vargön-Kraftwerk. — Central de Vargön.

The Royal Board of Waterfalls placed these special requirements before Skånska cement A/B and requested them to propose a cement combining a considerable time of hardening with low heat reaction. A satisfactory cement was forthcoming and a description of it by Dr. Forsén is given above.

Due to the slow hardening it was possible to increase the sizes of the monoliths to nearly double the above-mentioned 80 to 100 m^2. This allowed adequate time for the concrete to be well worked around the reinforcements, thus permitting a reduction of the number of vertical construction joints. The low heat reaction rendered it possible to make the monoliths fairly large without risk of cracks arising. The cement used proved in addition to be subject to less calcium dissolution than ordinary cement, a property which was obtained without having been foreseen.

After the completion of the work it has been possible to summarize the experience gained in the following manner:

a. The slower setting of concrete made with low-heat portland cement than that prepared with ordinary portland cement is of great practical advantage in large concrete structures. It is desirable to limit the number of construction joints to a minimum, and the distance between these may be governed by the quantity of concrete needed for a layer 20 to 30 centimeters thick, mixed and placed by means of the available equipment.

b. Parallel experiments made upon similar structures both in air and water with precisely the same ingredients, mixing, and treatment, have shown practically complete freedom from cracks in the cases of concrete prepared from low-heat portland cement, while with that made from ordinary portland cement they have been found to be unavoidable.

c. The workability given by low-heat portland cement was inferior to that given by ordinary portland cement. It was therefore found advisable to use an admixture, and good results were obtained by the addition of a small amount (equal to 3% of the weight of the cement) of diatomaceous earth.

d. In wintertime special care should be observed in the use of low-heat portland cement as the cold still further retards the setting.

e. Low-heat cement has a tendency to develop short cracks in the top of the concrete. This trouble can be avoided, however, by working the concrete for a longer period than usually required. How long this period should be extended is dependent on the temperature of the air and other factors.

EMPLOYMENT OF PANSAR CEMENT IN CONSTRUCTION OF KRANGEDE POWER STATION

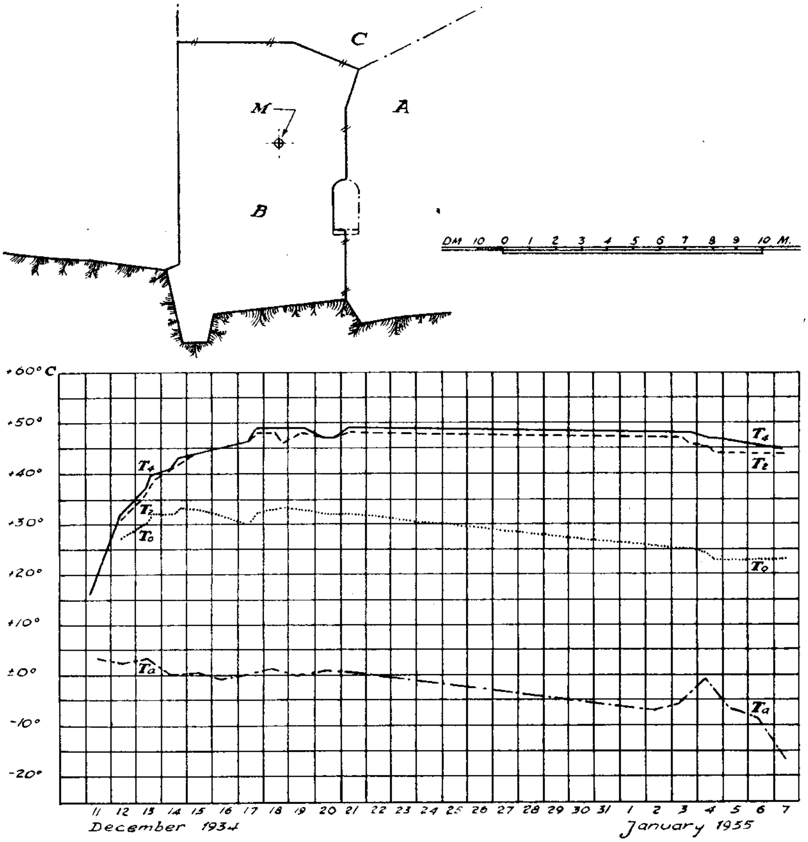
A. Öhman, C. E.

Krångede Company

At the construction of the regulation dam at Krångede power station a special cement manufactured by Skånska Cementaktiebolaget was employed for the heavy concrete work exposed to water pressure. This cement which has been given the name of "Pansar cement" has the special property of hardening more slowly and with less generation of heat than is the case with ordinary portland cement and the resulting concrete has more resistance to dissolution of calcium.

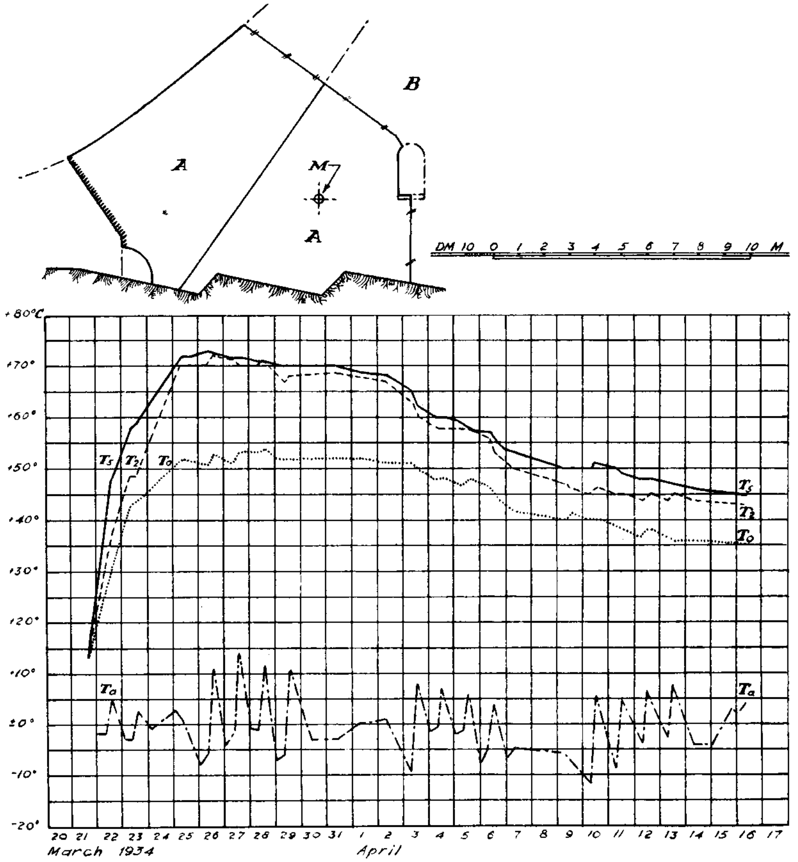
Experience gained in carrying out the concrete work with Pansar cement may be summarized as follows:

1. Temperatures taken in the Pansar cement concrete during hardening are given in annex 1. For purposes of comparison annex 2 gives the temperatures developed in concrete of ordinary class A portland cement. The figures show that the highest temperature for A-cement concrete was about +75° C., while for concrete with Pansar cement in a corresponding monolith it was only about +49° C. In both cases the mix contained 350 kg cement per cubic m and the consistency was viscous. Temperatures were taken by means of a thermometer inserted in a tube cast into the concrete.
2. Dissolution of calcium could only be investigated in laboratory tests. These tests, carried out by the Institute of Engineering Science, showed that with test pieces over a period of 92 days the calcium dissolved in the Pansar cement corresponded to 62% of the calcium dissolved in A-cement.
3. Concrete made of Pansar cement was equivalent to concrete of A-cement as regards workability.
4. Pansar cement was shown by the tests to possess lower resistance than A-cement concrete.
5. The risk of drying cracks arising on the horizontal surfaces appeared to be greater than for A-cement.
6. Pansar cement is more susceptible to damage than A-cement when used in cold conditions, so that more protective devices are required.
7. On account of comparatively slow hardening, the stripping of the forms and consequently the pouring of the concrete as a whole are delayed, especially when the concrete work is of a size necessitating its division into smaller sections for pouring.



APPENDIX 1 (FIG. 2).—Concrete construction: Pier. Nature of cement: Pansar cement. Amount of cement: 350 kg per cubic m concrete. Consistency of concrete: Viscous.

A=first placing.
B=second placing, thickness 7 meters, concrete volume 518 cubic m.
C=third placing.
M=position of tube for temperature reading.
T_a=temperature of air.
T_o=temperature of concrete at surface.
T_2=temperature of concrete 2 m below surface.
T_4=temperature of concrete 4 m below surface.



APPENDIX 2 (FIG. 3).—Concrete construction: Pier. Nature of cement: Portland cement, class A. Amount of cement: 350 kg per cubic m concrete. Consistency of concrete: Viscous.

$A+A_1$=first placing, section A has a thickness of 9 meters, section A_1 1.5 meters, concrete volume in A and A_1 together 569 cubic m.
B=second placing.
M=position of tube for temperature reading
T_a=temperature of air.
T_o=temperature of concrete at surface.
T_2=temperature of concrete 2 m below surface.
T_5=temperature of concrete 5 m below surface.

PRACTICAL EXPERIENCE OF PANSAR CEMENT

NILS BERG, C. E.

Of Vattenbyggnadsbyrån (VBB)

For the purpose of contributing to a comprehensive knowledge of the properties of Pansar cement, an account is given below of the experience gained in the use of such cement at the construction of the Dejefors hydroelectric power plant in Sweden, recently carried out under the supervision of Vattenbyggnadsbyrån (VBB), consulting engineers, of Stockholm.

As ordinary Swedish portland cement, referred to as A-cement, was also used, it was possible to make comparisons in the field, and the properties of concrete made of Pansar cement, may therefore be summarized as follows:

Water content.—To obtain a plastic consistency of the concrete an increased amount of water is required when Pansar cement is used. For mixes of concrete suitable for structures subject to unilateral water pressure, this increase must be at least 15 liters per cu. m of finished concrete.

Proportion of cement and sand aggregate.—Owing to the increase in water content and the rather low specific gravity of Pansar cement (2.88, compared with 3.15 for A-cement) a saving of about 4% in weight of aggregate is effected when proportioning a mix of a specified amount of cement per cu. m of finished concrete. As a matter of course, the specific gravity of concrete made of Pansar cement will be somewhat lower than that of concrete made of A-cement.

Setting time and workability.—At tests carried out according to the Swedish standard method, setting starts after about 1 hour for the particular brand of Pansar cement used as compared with 2–3 hours normal time for A-cement. Owing to the short setting time, certain difficulties were experienced in placing and working the concrete in the molds, but these difficulties were overcome by avoiding interruptions in the process of concreting.

Consistency and workability —Concrete made of Pansar cement has a greater internal cohesion than that made of A-cement; it is "tough" and retains water well. This is an advantage, in so far as the concrete can be subjected to more work in the molds without segregation of water. On the other hand, it decidedly requires more working to obtain a mass that is free from cavities. Consequently, the concrete surfaces are often liable to show more air voids when the shutterings are removed. Certain difficulties have also been experienced in keeping the mixers and chutes clean, particularly if the coarse aggregate be natural stone or if cement mortar has been mixed in.

It is also of advantage to use Pansar cement when concrete has to be transported comparatively great distances owing to the material being less inclined to segregate.

Interval of workability.—In a report on workability submitted to the International Subcommittee on Special Cements, Dr. A. F. Samsioe has introduced the term "interval of workability" as the interval between the "point of workability" and the "point of segregation." The point of workability is defined by the minimum amount of water required, under given conditions, for barely handling the concrete mass in the molds. The point of segregation is defined by the water content at which the concrete just starts to segregate and water is isolated. The greater the interval of workability, the easier it is for the operators of the mixers to supply a concrete which can be satisfactorily worked into the molds without segregation.

Trials were made during actual practice in order to establish the water content corresponding to these two characteristic points. These comprised A-cement as well as Pansar cement under similar conditions, i. e., the same amount of cement (350 kg per cu. m of finished concrete), the same composition of fine and coarse aggregate were employed, and as far as possible the same amount of work, etc. The following figures were obtained:

	A-cement water content	Pansar cement water content
	Liters per cubic m	*Liters per cubic m*
Point of workability in slabs	165	180
Points of segregation:		
Without working the concrete	----------	280
Concrete worked into walls	210	245
Concrete worked into slabs	200	230

Under the conditions in question, the interval of workability can thus be estimated at 50 and 35 liters per cu. m of finished concrete for Pansar cement and A-cement respectively. In this respect, therefore, Pansar cement is considerably better than A-cement. Consequently, in actual practice a greater margin in regard to water content can be allowed over and above the point of workability, and a somewhat greater variation in the water content has no detrimental effect in regard to workability. The continuous check of the moisture in the materials can thus be reduced to a certain extent.

Influence on the age of concrete and of atmospheric temperature.—Judging from successive work tests, as well as from other special tests in the field, it appears that a longer time is required for the concrete to obtain a specified strength and watertightness if Pansar cement is used. After 28 days, however, both these properties are at least as good as with concrete made of A-cement.

The slowness characteristic of Pansar cement is accentuated at low temperatures, and the experience gained seems to indicate that a risk of failure exists at temperatures of the concrete slightly above those generally considered critical. Thus it would appear necessary that special precautions be taken at low temperatures when Pansar cement is used.

Laitance.—Formation of laitance has not been observed on surfaces of concrete made of Pansar cement.

Judging by the experience related above it obviously is of great importance that when Pansar cement is used, the supervising engineers as well as the laborers have a thorough knowledge of the special properties of the cement. Without such knowledge great difficulties may be experienced during the first period of the work and inferior concrete be obtained. For small but important concrete structures, Pansar cement should not be employed unless the laborers have had previous experience in the use of this particular brand of cement.

SUMMARY

Mr. Forsén describes the composition and properties of four different kinds of cement produced and used for technical purposes in Sweden.

The kinds of cement are:

(1) Portland cement class A (standard portland).
(2) Silicate portland (low-heat cement).
(3) Pansar A cement (80% standard portland plus 20% highly active pozzolana).
(4) Pansar silicate cement (90% low heat, 10% highly active pozzolana).

The properties have been gaged and tabulated in 11 tables:

Table 1. Lime-combining capacity of pozzolanas.
Table 2. Chemical composition, fineness, setting time.
Table 3. Heat of hydration.
Table 4. Compressive strength according to Swedish (=German) standards.
Table 5. Tensile strength according to Swedish (=German) standards.
Table 6. Compressive strength of concrete.
Table 7. Shrinkage according to German standards (about lime).
Table 8. Content of free calcium hydroxide in set cements.
Table 9. Extraction by water according to a Swedish method.
Table 10. Permeability of concrete according to the German standard method.
Table 11. Corrosion in 0.2 m sodium sulphate solution.

The results have been obtained from practical experience by Lalin and Westerberg in the case of silicate cement, by Öhman in the case of Pansar silicate, and by Berg where Pansar A is concerned.

Messrs. Lalin and Westerberg state that for the construction of Vargön power station a special cement was required, capable of fulfilling the demands in respect of impermeability to air as well as to water in the heavy concrete structures in question. The result was the introduction of a high-silica cement. Experience in the execution of the work has shown that the lengthy setting time is a great advantage. Parallel experiments have demonstrated that concrete with high-silica cement is practically free from cracks, such as are unavoidable with ordinary portland cement. High-silica cement displays some disadvantages which, however, can be overcome. It gives, for instance, lower workability than ordinary cement, requires greater care at low temperatures, and besides it seems to have a tendency to form cracks on the top surface of the concrete.

Mr. Öhman gives the experience obtained with Pansar cement in the construction of the Krångede Dam. The results of taking temperatures are shown, on figure 2 for Pansar cement (max. +49° C.) and on figure 3 for ordinary portland cement (max. +75° C.). Compared with portland cement the Pansar cement displays similar workability, but lower resistance and a greater tendency to form drying cracks on horizontal surfaces. It requires more protective devices at low temperatures and hardens more slowly.

Mr. Berg states that Pansar cement was used in the construction of Dejefors power station in Sweden. In certain parts ordinary portland cement was employed so that it has been possible to make a comparison of the two kinds.

In the field Pansar cement requires a greater amount of water to obtain suitable plasticity than does ordinary portland cement.

Under conditions in question the interval of workability of Pansar cement was about 50 liters of water per cu. m of concrete, as compared with about 35 liters for portland cement. Consequently, when using Pansar cement the obtaining of a concrete which can be satisfactorily worked into the forms without segregation of water is much facilitated.

Due to the "toughness" of the cement, concrete of Pansar cement requires more working to obtain a mass free from cavities, as compared with portland cement concrete of the same plasticity.

It appears necessary to take special precautions at low temperatures to avoid risk of failure.

RESUME

M. Forsén décrit les compositions et les propriétés de quatre types de ciment fabriqués et employés techniquement en Suède.

Les qualités en question sont:

(1) Ciment portland classe A (ciment portland standard).

(2) Ciment portland siliceux (ciment basse-température).

(3) Ciment Pansar A (80% Portland standard, 20% pouzzolane de haute activité).

(4) Ciment Pansar siliceux (90% ciment basse-température, 10% pouzzolane de haute activité).

Les propriétés constatées sont données dans des tableaux:

Tableau 1. Capacité de différents pouzzolanes à combiner avec la chaux.

Tableau 2. Composition chimique, finesse de mouture et temps de prise.

Tableau 3. Dégagement de chaleur selon la méthode "heat of solution."

Tableau 4. Résistance à la compression selon les essais normaux suédois (=allemands).

Tableau 5. Résistance à la traction selon les essais normaux suédois (=allemands).

Tableau 6. Résistance du béton à la compression; la consistance étant fixée, contenu en ciment=350 kg/m^3.

Tableau 7. Retrait selon les essais normaux préliminaires allemands.

Tableau 8. Contenu du ciment durci en hydrate de chaux.

Tableau 9. Dissolution de la chaux dans l'eau selon une méthode suédoise.

Tableau 10: Perméabilité selon la méthode normale d'Allemagne.

Tableau 11: Résistance à l'action d'une solution de sulfate de soude.

Les résultats obtenus dans la pratique avec le ciment siliceux sont présentés par Lalin et Westerberg, avec ciment Pansar siliceux par Öhman et avec ciment Pansar A par Berg.

MM. Lalin et Westerberg disent qu'on demandait lors de la construction de l'usine hydro-électrique de Vargön un ciment spécial, capable d'être imperméable à l'eau ainsi qu'à l'air dans des constructions épaisses. Il en résulta un ciment fort en silice. L'expérience acquise a démontré que le long delai de durcissement constitue un grand avantage. Des expériences comparatives indiquent que le ciment siliceux est, pratiquement parlé, exempt de fissures, contrairement au ciment Portland ordinaire. Le ciment fort en silice possède un bas degré de "workability", demande des soins tout spéciaux aux basses températures, et montre une tendance à former des fissures dans la couche supérieure du béton bien que ces désavantages puissent être évités en travaillant le béton à fond dans le moule.

M. Öhman présente les résultats obtenus avec du ciment Pansar lors de la construction du barrage de Krangede. Les températures constatées sont indiquées (fig. 1) pour le ciment Pansar (max. 49° C) et (fig. 2) pour le ciment portland ordinaire (max. 75° C). En comparaison avec du ciment portland, on constate pour le ciment Pansar une égal "workability", une moindre résistance, une plus grande tendance à la formation de fissures de prises sur des surfaces horizontales. Ce ciment nécessite des mesures de protection aux basses températures et durcit plus lentement.

M. Berg dit que l'on s'est surtout servi du ciment Pansar pour la construction de la centrale de Dejefors. Toutefois on a employé aussi du ciment ordinaire de sorte que l'on est à même de faire la comparaison des deux qualités.

On a trouvé que dans la pratique le ciment Pansar demande une plus grande quantité d'eau que le ciment portland ordinaire pour obtenir la plasticité nécessaire.

Dans les conditions citées, on a constaté que l'intervalle de "workability" (différence entre l'état de maniabilité et le point de séparation de l'eau) en employant le ciment Pansar était de 50 litres d'eau par mètre cube de béton, comparée à 35 litres dans le cas du ciment portland. Par conséquent l'emploi du ciment Pansar facilite beaucoup l'obtention d'un béton qui peut être travaillé dans les formes sans ségrégation de l'eau.

À cause de la "ténacité" du ciment, le béton composé avec du ciment Pansar demande, afin d'obtenir une masse sans cavités, un plus long travail qu'un béton en ciment portland ayant la même plasticité.

Il semble nécessaire de prendre aux basses températures des précautions toutes spéciales afin d'éviter un mauvais résultat.

ZUSAMMENFASSUNG

Forsén beschreibt die Zusammensetzung und Eigenschaften von vier verschiedenen in Schweden hergestellten und technisch verwendeten Zementsorten.

Die Zementsorten sind:

(1) Portlandzement Klasse A (Standard-Portland-Zement).

(2) Silikatportlandzement ("Low-heat" Zement).

(3) "Pansar A"-Zement (80% Standardportlandzement, 20% hochaktives Puzzolan).

(4) "Pansar Silikat"-Zement (90% "Low-heat", 10% hochaktives Puzzolan).

Die gemessenen Eigenschaften sind in Tabellen angegeben und beziehen sich auf:

Tabelle 1. Kalkbindungsfähigkeit verschiedener Puzzolane.

Tabelle 2. Chemische Zusammensetzung, Feinheit und Abbindezeit.

Tabelle 3. Wärmeentwicklung nach der Lösungswärmemethode.

Tabelle 4. Druckfestigkeit nach den schwedischen (=deutschen) Normenvorschriften.

Tabelle 5. Zugfestigkeit nach den schwedischen (=deutschen) Normenvorschriften.

Tabelle 6. Druckfestigkeit des Betons bei gleichem Setzmass. 350 kg Zement/m^3.

Tabelle 7. Schwindung nach den deutschen vorl. Normenvorschriften (über Kalk).

Tabelle 8. Gehalt des abgebundenen Zements an freiem Kalziumhydroxyd.

Tabelle 9. Auslösung des Kalks nach schwedischem Verfahren.

Tabelle 10. Wasserdurchlässigkeit nach deutschem Normalverfahren.

Tabelle 11. Widerstandsvermögen in Natriumsulfatlösung.

Die Erfahrungen von praktischen Arbeiten mit Silikatzement sind von Lalin und Westerberg zusammengestellt, mit "Pansar-Silikat" Zement von Öhman und mit "Pansar A"-Zement von Berg.

Lalin und Westerberg berichten, dass man beim Erbauen des Kraftwerkes Vargön nach einem Spezialzement suchte, welcher die Forderungen der Wasser- und Luftdichtheit bei dicken Betonkonstruktionen zu erfüllen vermochte. Dies führte zur Verwendung von Silikatzement. Die Erfahrungen bei der Ausführung des Bauwerkes haben ergeben, dass die lange Abbindezeit von grossem Werte ist. Parallele Versuche haben erwiesen, dass Beton aus Silikatzement praktisch frei von Rissen ist, während solche bei Verwendung von gewöhnlichem Portlandzement nicht vermieden werden können. Der Silikatzement weist eine geringere Arbeitbarkeit auf, fordert grössere Vorsicht bei Kälte und hat Neigung zu Rissbildungen an der Oberfläche, welche jedoch, durch gründliche Bearbeitung in den Formen, vermieden werden können.

Öhman berichtet über Erfahrungen betreffend Pansar-Zement, welche sich bei dem Bau des Krångededammes ergeben haben. Die Ergebnisse der Temperaturuntersuchungen sind in Abbildung 1 für Pansar-Zement (max.+49° C) und Abbildung 2 für gewöhnlichen Portlandzement (max.+75° C) dargestellt. Die verarbeitbarkeit von Pansar-Zement und Portlandzement war ungefähr die gleiche. Der Beton aus Pansar-Zement hatte aber geringere Festigkeit, grössere Neigung zu Rissebildungen an wagrechten Flächen, erforderte Schutzanordnungen bei Kälte, und erhärtete langsamer.

Berg berichtet, dass beim Bau des Dejefors Kraftwerkes in Schweden Pansar-Zement verwendet worden ist. Zu gewissen Partien wurde gewöhnlicher Portlandzement verwendet. Hierdurch ergaben sich folgende vergleichende Erfahrungen.

Pansar-Zement erfordert, um eine geeignete Plastizität zu erhalten, einen grösseren Wasserzusatz als gewöhnlicher Portlandzement. Das

Intervall für die Verarbeitbarkeit des Pansar-Zementes ist etwa 50 Liter Wasser pro Kubikmeter Beton gegen etwa 35 Liter bei Portlandzement. Demnach ist es mit Pansar-Zement viel leichter einen Beton zu erhalten, welcher ohne Abscheidung des Wassers zufriedenstellend in den Giessformen verarbeitet werden kann.

Zufolge der "Zähigkeit" des Zementes, muss Beton aus Pansar-Zement mehr bearbeitet werden als Beton aus Portlandzement gleicher Plastizität, um eine Masse, die keine Hohlräume enthält, zu erzielen.

Um die Gefahr eines Misslingens zu vermeiden, ist es notwendig, bei niedrigen Temperaturen besondere Vorsichtsmassregeln zu treffen.

RESUMEN

El Sr. Forsén describe la composición y las propiedades de cuatro tipos de cemento fabricados y empleados técnicamente en Suecia.

Dichos tipos son:

(1) Cemento portland clase A (cemento portland normal).

(2) Cemento portland silíceo (cemento que produce poco calor).

(3) Cemento Pansar A (80% portland normal, 20% puzolana muy activa).

(4) Cemento Pansar silíceo (90% cemento que produce poco calor, 10% puzolana muy activa).

Las propiedades constatadas se dan en las tablas:

Tabla 1. Capacidad de diferentes puzolanas de combinarse con cal.

Tabla 2. Composición química, fineza de molido y tiempo de fraguado.

Tabla 3. Calor de hidratación.

Tabla 4. Resistencia a la compresión según los ensayos normales suecos (=alemanes).

Tabla 5. Resistencia a la tracción según los ensayos normales suecos (=alemanes).

Tabla 6. Resistencia del hormigón a la compresión; la consistencia estando determinada, contenido de cemento=350 kg/m^3.

Tabla 7. Retracción según los ensayos normales preliminares alemanes.

Tabla 8. Contenido de hidrato de cal del cemento endurecido.

Tabla 9. Disolución de la cal en el agua según un método sueco.

Tabla 10. Permeabilidad según el método normal alemán.

Tabla 11. Resistencia a la acción de una solución de sulfato de soda.

Los resultados obtenidos en la práctica con el cemento silíceo los presentan Lalin y Westerberg, con cemento Pansar silíceo los presenta Öhman y con cemento Pansar A los presenta Berg.

Los Sres. Lalin y Westerberg dicen que durante la construcción de la central hidro-eléctrica de Vargon se exigió un cemento especial capaz de ser impermeable al agua como también al aire en estas construcciones. Como resultado se tuvo un cemento fuerte en sílice. La experiencia adquirida demostró que la larga dilación en el endurecimiento constituye una gran ventaja. Las experiencias comparativas indican que prácticamente el cemento silíceo carece de grietas contrariamente al cemento portland ordinario. El cemento fuerte en sílice posee un bajo grado de trabajabilidad, demanda cuidados muy especiales cuando la temperatura es baja y muestra tendencia a formar grietas en la capa superior del hormigón aunque esas desventajas pueden evitarse trabajando bien el hormigón en el molde.

El Sr. Öhman presenta los resultados obtenidos con el cemento Pansar durante la construcción de la presa de Krangede. Las temperaturas constatadas se indican (fig. 1) para el cemento Pansar (max. 49° C.) y (fig. 2) para el cemento portland ordinario (max. 75° C.). En comparación con el cemento portland, se constata para el cemento Pansar una igual trabajabilidad, una menor resistencia, una mayor tendencia a la formación de grietas en las superficies horizontales. Este cemento requiere medidas de protección contra las temperaturas bajas y se endurece más lentamente.

El Sr. Berg dice que mayormente se empleó el cemento Pansar para la construcción de la central de Dejefors. Sin embargo también se empleó el cemento ordinario y por lo tanto se ha podido hacer una comparación entre las dos calidades.

Se ha encontrado que en la práctica el cemento Pansar requiere mayor cantidad de agua que el cemento portland ordinario para obtener la necesaria plasticidad.

Dentro de las condiciones citadas se ha constatado que el intervalo de trabajabilidad al emplear el cemento Pansar fué de 50 litros de agua por metro cúbico de hormigón, comparado con 35 litros en el caso del cemento portland. De consiguiente, el empleo del cemento Pansar facilita mucho el obtenimiento de un hormigón que puede trabajarse en los moldes sin segregación del agua.

A causa de la "tenacidad" del cemento, el hormigón compuesto con cemento Pansar demanda, a fin de obtener una masa sin cavidades, un trabajo más largo que un hormigón compuesto con cemento portland teniendo la misma plasticidad.

Parece necesario tomar precauciones muy especiales para evitar malos resultados en bajas temperaturas.

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

NEW TENTATIVE STANDARD SPECIFICATION FOR CEMENT IN SWEDEN*

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To promote further development and research work in the specialization of cement a new cement specification has been drawn up. It has not as yet been adopted but is important enough to justify a summary being given herewith.

The specification has been worked out by Messrs. Werner and Giertz-Hedstrom, at the Cement Laboratory of the Royal Swedish Institute for Engineering Research, in cooperation with the Swedish cement industry, and is based on 3 years' experimental work and on experience gained in other countries.

The suggested specification concerns the following kinds of cements:

Rapid-hardening portland cement.
Standard portland cement.
Slow-hardening portland cement.
Pozzolana-cement.
Blast furnace slag cement.
Aluminous cement.

The following tests, it is suggested, be compulsory:

Setting time according to the method by Vicat.

Compressive and tensile strength according to the method by Haegermann [1], used on plastic mortar.

**Nouvelles spécifications standardisées et proposées pour les ciments en Suède.*
Neue versuchsmässige Normalisierung von Zementen in Schweden.
Nuevas especificaciones para los cementos normalizadas en Suecia.

[1] *G. Haegermann, Zement, 24, 529 (1935).*

Soundness according to the method by Le Chatelier.

Heat of hydration, for low-heat cement only, according to the method adopted by the International Committee on Special Cements.

Lime-combining capacity of admixtures (definite minimum percentage when tested as previously described in this report).

Chemical composition of the slag as defined in the German Standard Specification.

The amount of pozzolana (slag) is to be printed on each bag.

It is suggested that the following tests be carried out for purposes of information only:

Fineness—sieving and sedimentation, by means of Andreasen's apparatus.

Specific gravity.

Shrinkage, according to the method by Graf,[2] adopted by the International Committee on Special Cements.

Solubility, according to the extraction method previously described.

Free lime, in pastes of set cement according to the method of Schläpfer and Bukowski.

Water separation, according to the method of Giertz-Hedström.[3]

The methods employed for testing and analysis are described in detail in the proposed specification, and hope is entertained that it will be adopted as soon as sufficient experience is gained in its application by the Government Testing Institute and by private laboratories.

Cement was formerly judged only by its strength, but it is hoped that with increased knowledge a suitable cement will be available for every purpose.

The Swedish cement industry will continue the work on cement specialization with portland cement as well as with pozzolana cement.

SUMMARY

Based on 3 years' experimental work combined with experience in other countries, new specifications for cement have been worked out in Sweden. Particulars are given of a number of essential tests together with informative tests.

RESUME

On a rédigé en Suède de nouvelles spécifications pour le ciment, basées sur des essais exécutés durant 3 ans ainsi que sur des expériences faites dans d'autres pays. On donne des détails sur un nombre d'essais essentiels ainsi que sur quelques autres essais considérés comme documentaires.

ZUSAMMENFASSUNG

Der Verfasser berichtet, dass man in Schweden neue Forderungen für Zement ausgearbeitet hat, welche sich auf seine eigenen 3-jährigen

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[2] *O. Graf, Zement 24, 347, 1935.*

[3] *S. Giertz-Hedström, IVA (Stockholm) Nr. 3, 1935.*

Versuchsarbeiten und in anderen Ländern erworbenen Erfahrungen stützt. Es werden Angaben gemacht über solche Prüfungen, die unbedingt notwendig sind, und andere, die nur Informationszwecken dienen.

RESUMEN

Se han formulado en Suecia nuevas especificaciones para el cemento, basadas en los ensayos hechos durante 3 años así como también sobre las experiencias obtenidas en otros países. Se dan detalles de una cantidad de ensayos esenciales así como también de algunos otros considerados como documentarios.

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

SEPARATION OF WATER FROM A CEMENT PASTE*

S. Giertz-Hedström

Sweden

When a mass of concrete has been mixed of cement, fine and coarse aggregate and the water necessary to obtain the required consistency, it is in all normal cases desirable that the water be entirely retained by the concrete during placing in the molds and during hardening. Otherwise an inconvenient separation of water may occur during transport or handling of the concrete, and there are risks of obtaining an inhomogeneous concrete, poor construction joints in the finished structure, etc.

The capacity of the concrete for retaining water is governed by the quantity and quality of the cement and of the fine and coarse aggregate, as well as by the consistency necessary for transport and depositing. Of these factors the quality of the cement is of some considerable importance. This is particularly noticeable when more or less extreme kinds of cement are used.

Laboratory Method of Determining the Separation of Water

The following laboratory method has been used.

Fifty grams of cement and an adequate amount of distilled water are shaken for 4 minutes in a cylinder of a volume of about 100 cubic centimeters and with an inner diameter of about 2.6 cm. The cement paste is subjected in the cylinder to reduced air pressure during 1 minute on three subsequent turns for the purpose of extracting air enclosed in the cement paste. The cylinder is then placed on a solid foundation free from vibration. The level of the surface of the water and of the cement paste is measured at intervals, and in any case when no more separation of water takes place (generally 2 hours).

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* *Séparation de l'eau d'une pâte de ciment.*
Wasserausscheidung von Zementbrei.
Separación del agua de una mezcla de cemento.

The water retained in the cement paste is converted into water-cement ratio, and also estimated in percent of the total amount of water used. The tests have been carried out at ordinary room temperature. The diagram in figure 1 shows the time required for the water separation to obtain a constant value for different cements.

WATER SEPARATION OF DIFFERENT CEMENTS

Fifteen different Swedish cements have been tested according to this method and the results show that the cements can suitably be divided

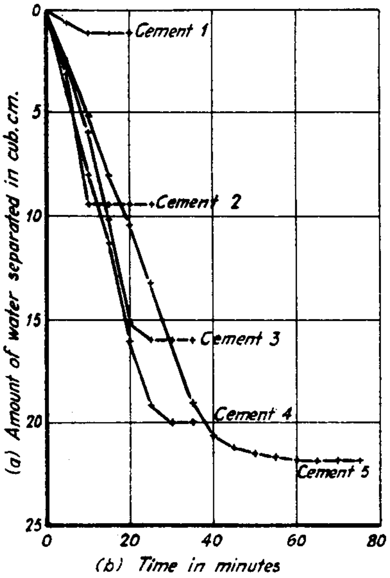

FIGURE 1

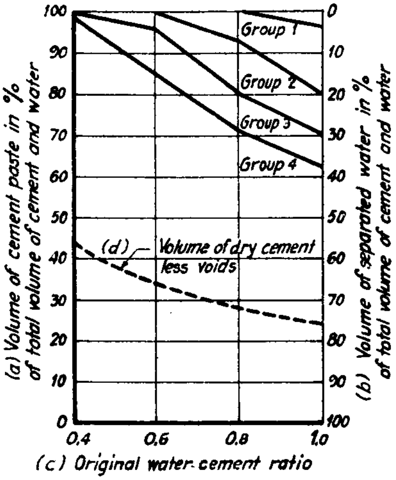

FIGURE 2

FIGURE 1.—**Rate of water separation of different cements.** — Degré de la séparation d'eau de différents ciments. — Grad der Wasserausscheidung verschiedener Zemente. — Proporción de la separación de agua de diferentes cementos.

(*a*) **Amount of water separated in cubic centimeters.** — Quantité d'eau séparée en cm³. — Menge des ausgeschiedenen Wassers in cm³. — Cantidad de agua separada en centímetros cúbicos.

(*b*) **Time in minutes.**— Durée en minutes.— Zeit in Minutes.— Tiempo en minutos.

FIGURE 2. — **Water separation of different cements.** — Séparation d'eau de différents ciments. — Wasserausscheidung verschiedener Zemente. — Separación del agua de diferentes cementos.

(*a*) **Volume of cement paste in percent of total volume of cement and water.** — Volume de pâte de ciment en pourcentage du volume total de ciment et d'eau. — Volumen des Zementbreies in Prozent des Gesamtvolumens von Zement und wasser. — Volumen de la mezcla de cemento en comparación con el volumen total del cemento y el agua.

(*b*) **Volume of separated water in percent of total volume of cement and water.** — Volume de l'eau séparée au pourcentage du volume total de ciment et d'eau. — Volumen des ausgeschiedenen Wassers in Prozent des Gesamtvolumens von Zement und Wasser. — Volumen del agua separada en comparación con el volumen total del cemento y el agua.

(*c*) **Original water-cement ratio.** — Proportion primitive d'eau et de ciment. — Ursprünglicher Wasserzementfaktor. — Proporción inicial de agua-cemento.

into four definite groups, corresponding to a classification of the cements according to other properties. The average results of each group are given in figure 2, showing the volume of separated water in percent of the total volume of cement and water. The cements of the first group, which have the smallest amount of water separation, comprise the aluminous cement tested and a special pozzolana cement. Group 2 comprises rapid-hardening Portland cements, and the Swedish Pansar cement. Group 3 comprises typical standard Portland cements, while group 4, with the greatest water separation, comprises slow-hardening Portland cements, and a brand of Eisen Portland cement. The differences between the groups of cement are considerable. For a water-cement ratio of 1.0 the water separated from cements under group 4 is about half of the total amount of water, while for cements under group 1 it is only about 5 percent. Naturally the water separation is increased as the water-cement ratio is increased, confirming that a low water-cement ratio is a suitable means of preventing excessive separation of water.

The water separation of cement, or the inverse property, the water-retaining capacity of cement, seems to be significant in many respects. Apart from the inconvenience of water separation mentioned above in connection with handling and placing of concrete, it also gives rise to water films on the underside of the coarse aggregates in the concrete, as has been shown by American investigators. (Cfr. L. E. Hough, Eng. News-Record *1931*, II, 618 and L. S. Brown, Ind. Eng. Chem. *1935*, 79.) This results in a lower mechanical resistance of the concrete and is very probably also of importance for the permeability and the resistance against weathering of the concrete.

Furthermore there is a strong indication that the influence of the cement on the consistency and nonsegregation of concrete, i. e., on the workability, is intimately connected with the water separation of the cement. As a matter of fact the classification of the 15 cements according to water separation, given above, corresponds closely to a classification according to workability as experienced in actual practice, which fact has been pointed out by Dr. Forsén.

The tests described are limited and can give only an indication of the significance of the water separation of cement. Nevertheless it is obvious that this property plays an important role in the utilization of the cement in concrete. Further studies are indicated, especially concerning the correlation of water separation and workability.

SUMMARY

Separation of a part of the water from a fresh concrete mix before hardening is discussed. A simple laboratory method for studying this property of separation is described. Among other factors, the quality of the cement has been found to have a considerable influence on the degree of water separation. It is pointed out that several important properties of the concrete have a connection with water separation. Mention is made in this respect of mechanical resistance, watertightness, durability and workability. In regard to the last-named particularly, it is recommended that further investigations of this kind be carried out.

RESUME

Ce rapport traite de la propriété que possède un mélange de béton fraîchement établi de se séparer, avant de durcir, d'une partie de son eau. Un procédé simple pour l'étude de cette propriété est indiqué. Entre autres facteurs, on a constaté que la qualité du ciment a une influence remarquable sur le degré de séparation de l'eau. On fait ressortir que plusieurs caractéristiques importantes du béton sont liées à la séparation de l'eau. On cite notamment la résistance mécanique, l'imperméabilité, la durabilité et la maniabilité. Pour cette dernière caractéristique surtout on recommande d'effectuer des études plus complètes de cette nature.

ZUSAMMEMFASSUNG

Es wird die Eigenschaft einer frischen Betonmischung, einen Teil ihres Wassers vor dem Erhärten auszuscheiden, behandelt, und eine einfache Methode für die Untersuchung dieser Eigenschaft beschrieben. Unter anderem wurde gefunden, dass die Qualität des Zementes erheblichen Einfluss auf den Grad der Wasserausscheidung hat. Es ist hervorgehoben, dass verschiedene wichtige Eigenschaften des Betons mit der Wasserausscheidung zusammenhängen. Erwähnt sind die mechanische Festigkeit, Wasserdichtheit, Dauerhaftigkeit und Verarbeitbarkeit (workability). Besonders mit Rücksicht auf die letztere Eigenschaft werden weitere Untersuchungen dieser Art empfohlen.

RESUMEN

Se discute la separación de parte del agua de una mezcla fresca de hormigón antes de endurecerse. Se describe un proceso sencillo para estudiar esta propiedad de separación. Entre otros factores se ha encontrado que la calidad del cemento influye considerablemente en el grado de separación de agua. Se indica que varias propiedades importantes del hormigón están relacionadas con la separación de agua. Con este motivo se hace mención de la resistencia mecánica, la impermeabilidad, la durabilidad y la trabajabilidad. Con referencia a esta última se recomienda que se continúen las investigaciones de esta clase.

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

SPECIAL CEMENTS FOR MASS CONCRETE*

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FOREWORD

This paper is a brief summary of a comprehensive treatise on the subject prepared by the author in collaboration with others for the consideration of the Second Congress on Large Dams. The complete paper has been published as a United States Bureau of Reclamation bulletin and may be obtained from either the Washington, D. C., or Denver, Colorado, U. S. A., offices of the Bureau.

The parts herein designated General Discussion, Evolution of Special Cements in the United States, General Conclusions Regarding the Use of Special Cements For Mass Concrete, and Future Developments are essentially a reproduction of the introductory part of the complete paper. The published bulletin also contains:

1. Description, summarized results, and principal conclusions of 11 of the more important recent laboratory investigations of cements in the United States.
2. A detailed description of a method of mathematical analysis of temperature movements in mass concrete containing the solution of certain problems with typical examples. Portions common to the bulletin and to the summary are the results of an extensive series of tests to determine the thermal properties of mass concretes, and examples of typical temperature history curves illustrating the effect of various controlling factors. This section of the bulletin also gives the comparison of the results of a number of mathematical studies with actual records.

**Les ciments spéciaux pour la masse du béton.*
Spezialzemente für Betonmassen.
Cementos especiales para el hormigón de masa.

3. Detailed accounts of the experiences of nine prominent mass concrete structures in the United States using various types of cements.
4. A selected bibliography with abstracts of 53 of the more important recent articles published in the United States relative to special cements.

The printed bulletin contains approximately 300 pages, including 78 figures, 21 of which are photographs.

General Discussion

This paper is devoted primarily to that most important, yet least stable, ingredient of concrete, the cement; however, it should be clearly understood that any consideration for improvement of mass concrete through the cementing medium must necessarily include a number of closely related and, in some cases, inseparable factors. The undesirable characteristics of good concrete as a building material for massive dams can be only partially remedied by attention to the cement, and full appreciation of this fact is essential for the correct interpretation of the discussions presented herein.

Foremost among mass concrete problems is the control of volume changes due to temperature variations during and subsequent to construction, and before the mass as a whole attains a stable condition of temperature. One of the controlling factors is the shrinkage occurring in the concrete as it cools from the maximum temperature reached to the more or less stable level assumed after cooling. This temperature difference is made up of two components; (*a*) the difference between the final and placing temperatures, and (*b*) the temperature rise due to hydration of the cement. From figure 1, it is apparent that the placing temperature may have a much more important bearing on the temperature drop and consequent contraction of the concrete than any reduction that may be effected by heat-generating characteristics of the cement.

Other factors which affect the total volume change occurring in the finished structure before it attains substantial volume constancy may be briefly summarized as follows:

(1) Rate of construction.
(2) Methods of construction.
(3) Thermal characteristics of the concrete.
(4) Elastic and plastic properties of the concrete.

The first two of the above listed factors have little direct relation to the cement except as it may affect the placeability of the concrete. They are, however, intimately related to the time-heat generating characteristics of the cement in determining the temperature rise occurring in the hardening concrete. The last two of the above factors are probably affected but little by the cement, either directly or indirectly. It is perhaps worthy of mention, that the volume changes in very massive structures occasioned by seasonal variations in temperature or moisture conditions are of little consequence because only a relatively small percentage of the total volume of concrete is affected. In thin arch dams, the alternate shrinkage and expansion resulting from drying and wetting or cooling and heating constitute a problem. These may even be the controlling conditions in designing the concrete, and may have an important influence in fixing the construction procedure.

Cement has an important influence on the useful life of a mass concrete dam as affected by the distintegrating influences of weathering and aggressive waters and dissolution by percolating waters. Again, it should be emphasized that the effect of type of cement upon the durability of a massive concrete structure is usually much less than that of other ingredients, or than the methods employed in construction. However, worthwhile prolongation of the serviceable life of a mass concrete dam by minimizing maintenance costs may be effected through the proper application of cement technology. In some instances it is also possible to materially reduce the initial cost and at the same time realize increased quality by use of the proper type of cement.

Many of the mass concrete problems have their origin in, or have been greatly magnified by modern methods of construction which have made possible much more rapid rates of placing. These modern methods have, however, resulted in far greater economy in mass concrete construction and have made feasible large projects that would have been wholly impractical with earlier practices. Modern practice in mass concrete construction must therefore be accepted by both designer and builder, and, although some compromise may at times be possible, the designs and program of construction must be commensurate with the new regime.

No less than six types of cements have been used for mass concrete structures in the United States; these are briefly described as follows:

(1) Standard or normal portland, the common portland cement in general use for all types of work at the present time.

(2) Modified normal portland, differing only from standard cement in that it contains lower percentages of tricalcium aluminate and is usually somewhat finer.

(3) Low-heat portland, so compounded as to materially reduce the total heat of hydration. The compound composition is quite different from that of normal portland cement.

(4) Portland-pozzolan cement, a combination of portland cement and any type of natural or artificial, so-called "pozzolanic" materials.

(5) Natural cements and combinations of portland and natural cements used more extensively a few years ago for massive sea-water construction.

(6) Sulphate-resistant portland cement specially compounded to resist the attack of sulphate waters and differing but slightly from the modified normal cement.

No well-established or fixed rules can be given for determining the most suitable type of cement to be used for mass concrete structures. Each job is characterized by its individual set of controlling factors as to design, construction, and economy. The designer now has at his disposal data and information from extensive laboratory investigations of cements, well-established mathematical processes for analyzing temperature movements in mass concrete and the results of experience with various types of cements on typical jobs. The complete analysis of any particular job must balance the above considerations with problems of construction and the economic aspects of cement manufacture, materials production, and job manipulation.

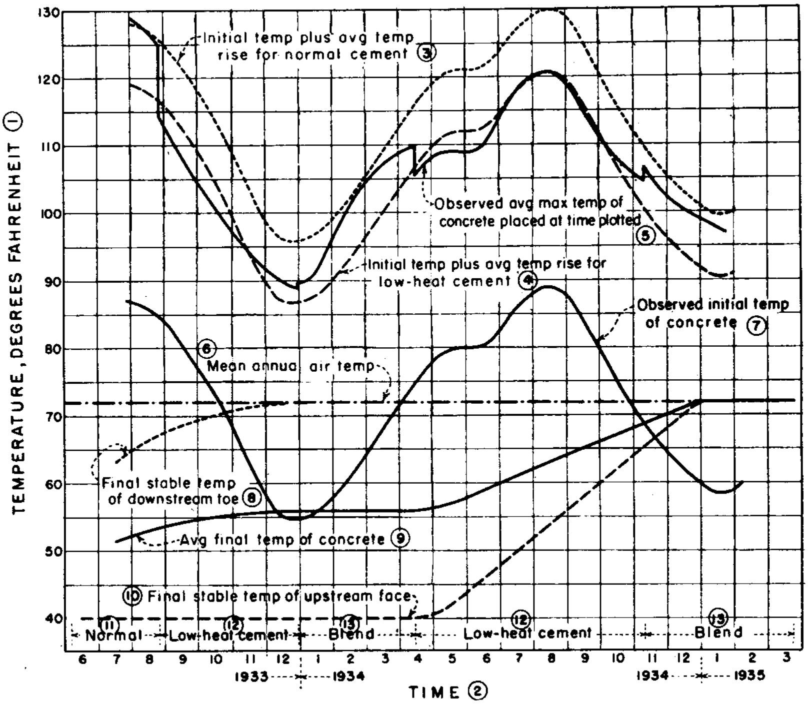

Figure 1.—**Average placing, maximum, and final temperature in Boulder Dam.** — Température moyenne de mise, maxime et finale de "Boulder Dam". — Durchschnittliche Einführungs-, Höchst- und Endtemperaturen im "Boulder Dam". — Temperatura de colocación, temperatura media, y temperatura máxima en la Presa Boulder.

1. **Temperature, degrees F.** — Température, en degrés Fahrenheit. — Temperatur, Grad F. — Temperatura, grados F.
2. **Time.** — Durée. — Zeit. — Tiempo.
3. **Initial temperature plus average temperature rise for normal cement.** — Température initiale, plus augmentation moyenne de la température pour le ciment ordinaire. — Anfangstemperatur plus durchschnittliche Temperaturerhöhung für gewöhnlichen Zement. — Temperatura inicial más promedio del aumento de temperatura en el cemento normal.
4. **Initial temperature plus average temperature rise for low-heat cement.** — Température initiale, plus augmentation moyenne de la température pour le ciment basse-température. — Anfangstemperatur plus durchschnittliche Temperaturerhöhung für Zement mit niedriger Hydrationswärme. — Temperatura inicial más promedio del aumento de temperatura en el cemento de poco calor.
5. **Observed average maximum temperature of concrete placed at time plotted.** — Température moyenne maxima observée du béton mis en place aux heures levées. — Beobachtete durchschnittliche Höchsttemperatur von zu einer bestimmten Zeit eingeführtem Beton. — Promedio de temperatura máximo observada en el hormigón colocado en el tiempo designado.
6. **Mean annual air temperature.** — Température moyenne annuelle de l'air. — Mittlere jährliche Lufttemperatur. — Media anual de la temperatura atmosférica.
7. **Observed initial temperature of concrete.** — Température initiale observée du béton. — Beobachtete Anfangstemperatur des Betons. — Temperatura inicial observada en el hormigón.

EVOLUTION OF SPECIAL CEMENTS IN THE UNITED STATES

The cement industry in the United States really originated about 1820 when requirements for the construction of the Erie Canal led to the discovery of a natural cement rock and the inception of the natural cement industry. The discovery in England by Joseph Aspdin of the portland cement process in 1824 followed by its general recognition about 1851, led to the importation of portland cements into the United States on a substantial scale by 1878, which was about the time the first portland cement was manufactured in this country. From that time, portland cement gradually replaced natural cement for all types of construction.

The portland cements manufactured in the United States during the 20-year period starting about 1890 were characterized by coarse grinding (about 80 percent passing the 200-mesh screen), were low in lime and hence contained relatively low percentages of tricalcium silicate, high percentages of dicalcium silicate, and tricalcium aluminate. These cements gained strength slowly, developed relatively low ultimate strength, and in many cases displayed weakness against the ravages of disintegrating elements. In composition, the early portland cements were somewhat comparable to the present low-heat type although the latter is ground much finer and contains only about one-third as much tricalcium aluminate. The construction industry gradually demanded higher and more rapid strength development from which evolved the present-day so-called "standard" or "normal" portland cement, which differs from the earlier product in that it contains a relatively high amount of tricalcium silicate, low dicalcium silicate, and lower tricalcium aluminate, and is ground considerably finer.

As larger and more important concrete projects were proposed, many new problems of design and construction were encountered and others, previously unimportant, became magnified to such an extent as to constitute major factors. One of the logical developments in the attempts to find solutions for these new and unusual problems was the demand for special types of cements having properties particularly adapted to specific conditions.

Reduction in heat of hydration was the first quality to receive attention in developing special cements for concrete dams, and gave rise to the "low-heat" type. Low-heat portland cement was obtained by decreasing the compounds responsible for most of the heat generation; namely, the tricalcium silicate and tricalcium aluminate. This in turn necessitated higher percentages of dicalcium silicate and

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8. **Final stable temperature of downstream toe.** — Température stable finale du base d'aval. — Endgültige feste Temperatur des luftseitigen unteren Endes. — Temperatura estable final de la base de aguas abajo.
9. **Average final temperature of concrete.** — Température moyenne finale du béton. — Durchschnittliche endgültige Temperatur des Betons. — Temperatura media final del hormigón.
10. **Final stable temperature of upstream face.** — Température stable finale de la face d'amont. — Endgültige feste Temperatur der Wasserseite. — Temperatura estable final del paramento de aguas arriba.
11. **Normal.** — Normale. — Normal. — Normal.
12. **Low-heat cement.** — Ciment basse-température. — Beton mit niedriger Hydrationswärme. — Cemento de poco calor.
13. **Blend.** — Mélange. — Mischung. — Mezcla.

tetracalcium alumino-ferrite and resulted in much slower strength development. Increased fineness of grinding was employed in the manufacture of low-heat cements to increase their naturally slow strength gain. Low-heat cement was used in the construction of the recently completed Morris Dam in California, and, in conjunction with artificial cooling, in the building of Boulder Dam. Both of these structures have developed unusually little cracking.

The slow strength gain of the low-heat cements introduced real or imagined complications in construction procedure at lower placing temperatures and rapid rates of construction. As a compromise, and also because of the newly discovered unfavorable influence of tricalcium aluminate in portland cement, the "modified" or "moderate-heat" type was evolved. In composition, this type reverted back to the standard type as to tricalcium and dicalcium silicates, but retained the low percentage of tricalcium aluminate established for the low-heat cements. Increased fineness of grinding was also specified for the modified type because the advantages accruing from finer cements in improved workability and other characteristics of the concrete were quite pronounced. The average modified cement develops strength at practically the same rate as standard. It attains higher ultimate strength under mass concrete conditions and generates 10 percent less heat, as compared with low-heat, which develops about 27 percent less heat than standard.

Modified cement was used in Norris Dam in Tennessee and is being employed in the construction of Grand Coulee Dam in Washington, for which artificial cooling is also being employed.

Possibilities for lower cost, improved workability of concrete, lower heat generation, greater impermeability of concrete, greater resistance to sulphate and alkali waters, and more stable composition after hydration have very recently led to renewed and accelerated interest in "portland-pozzolan" cements, obtained by combining suitable pozzolanic materials with portland cements. As yet there is comparatively little basic information available concerning this type of cement but actual experience with its use in massive structures indicates reduced tendency toward crack formation. Portland-pozzolan cement was used in portions of some of the massive piers for the San Francisco-Oakland Bay Bridge and at present is being used in the construction of Bonneville Dam in Oregon. A blend of portland and slag (an artificial pozzolan) cements was used in the construction of several dams in Southeastern United States about 10 to 15 years ago.

GENERAL CONCLUSIONS REGARDING THE USE OF SPECIAL CEMENTS FOR MASS CONCRETE

The complete edition of this paper, published as a Bureau of Reclamation bulletin, presents discussions on the theoretical analyses of temperature movements in mass concrete, the results of recent laboratory investigations of cements, and accounts of experiences in the use of various types of cements on typical projects. This fund of information has been collected from widely separated sections of the United States and represents contributions from many of the leading authorities on cement and concrete in this country. It is believed, therefore, that a general summary of these data and experiences represents about as authentic a cross section of recent mass concrete practice in the United States as can be compiled at the present time.

Probably the fact least generally appreciated and therefore of most popular interest is the very small effect that type of cement alone, without consideration to other factors, plays in governing the total temperature drop that will occur in a given concrete structure of massive proportions. For smaller dimensions such as might be found in thin arch dams or the buttresses of multiple-arch dams, wherein the rate of cooling equals or exceeds the rate of heat generation at relatively early ages, the average maximum temperature attained by the concrete might be reduced as much as 10° F. to 15° F. by the use of low-heat cement as compared with standard cement.

The fact that the cement factor cannot be considered alone in analyzing the results obtained on any given mass concrete structure or in predicting what might take place in the way of temperature movements, volume change, crack development, and durability under a given set of conditions, cannot be overemphasized. Some of the more important factors which combine to establish controlling conditions may be listed as follows:

(1) Climatic conditions:
  (*a*) Concrete placing temperatures.
  (*b*) Average final stable temperatures of concrete.
  (*c*) Seasonal variations in moisture and temperature.
  (*d*) Conditions of exposure to disintegrating elements.
(2) Composition of concrete:
  (*a*) Water-cement ratio.
  (*b*) Type and amount of cement.
  (*c*) Type and character of aggregate.
  (*d*) Thermal characteristics of concrete.
  (*e*) Physical properties of concrete.
(3) Methods of construction.
  (*a*) Size of section.
  (*b*) Spacing of contraction joints.
  (*c*) Methods for cooling concrete—artificial or natural.
  (*d*) Special treatment of concrete materials to reduce placing temperatures.
  (*e*) Methods of mixing, transporting, and placing concrete.
(4) Rate of construction.
  (*a*) Thickness of lifts.
  (*b*) Time interval between lifts.
  (*c*) Time of exposure at contraction joints.
  (*d*) Seasonal limitations for placing concrete.
(5) Character of foundation.
  (*a*) Temperature.
  (*b*) Elastic properties.
  (*c*) Thermal characteristics.
  (*d*) Profile and preparation.

The above factors are not listed for detail consideration at this time, but are given for the purpose of conveying a clearer conception of the complicated problems involved. Further discussion will be limited to the effect of cement and related factors insofar as practicable.

The low-heat cement used in the major portion of Boulder Dam proved eminently satisfactory in every respect. The maximum temperature attained by the concrete was reduced about 10° F. below what it would have been had standard cement been used, because artificial cooling of the concrete was employed. If artificial cooling had not been used, the ultimate maximum temperatures of the concrete would have been practically the same regardless of the type of cement used, under the same conditions and rates of placing. Standard cement generates heat rapidly at early ages and very slowly at later periods, consequently the peak temperatures in concrete are attained before any practical cooling scheme can become effective in preventing additional temperature rise. Low-heat cement, developing heat of hydration much more slowly, would normally reach peak temperatures at considerably later ages, thus permitting the cooling process to become effective in reducing the maximum value.

Boulder Dam is practically free of cracks, all contraction joints have been satisfactorily grouted, and insofar as can be observed, the structure is functioning as a monolith in accordance with its design. It may be said that such satisfactory completion of the largest concrete structure ever built was made possible by a combination of factors including low-heat cement, artificial cooling, correct spacing of transverse and radial contraction joints, also favorable conditions of construction, rate of placing concrete and exposure at contraction joint faces. The program for artificial cooling and conditions of exposure combined with low-heat cement, rate of placing, and contraction joint spacing permitted the concrete to be cooled uniformly to the final stable temperature without the formation of surface cracking which so frequently develops into more serious continuous fractures.

The laboratory investigations and tests of low-heat cements together with acceptance tests of the cement and job tests of the concrete, all indicate most gratifying qualities of the concrete in the finished structure. A blend of standard and low-heat cement was used during colder weather to obtain higher early strengths but it is probable that rather slight changes in form anchorages and modifications in construction procedure would have eliminated the necessity for such an expediency. Since no undesirable results were obtained with the use of the blended cement, no particular objections could be raised to the blended cement method of handling the situation.

Prior to its use in Boulder Dam, low-heat cement without artificial cooling had been used in construction of the gravity-type Morris Dam in California with excellent results. Cracks in this dam are comparatively few and are generally small, with the exception of those occurring in the lower portion of one of the blocks, where a combination of exposure conditions and delayed construction contributed to the formation of two large vertical cracks across the block parallel to the axis of the dam. The absence of cracking in other sections is not so readily explained since the ultimate temperature rise of the concrete without cooling cannot have been much lower than would have been the case with normal cement. It is believed that the slower development of heat and therefore more favorable temperature gradient from exposed surfaces to the interior, and the fairly rapid, continuous construction permitted the surfaces to be covered before the development of surface cracks. More serious cracks, which are usually the continuation of local cracking at the surface, either did not develop or could not be observed. In this connection an opportunity would seem to have been presented for the development of continuous cracks from certain surface cracks which were known to have formed at reentrant angles of an open joint in the dam but at this place inspection of the interior is not possible.

A most exemplary use of low-heat cement with other remedial measures for the prevention of cracking was observed in the construction of the buttresses of the slab-and-buttress type Rodriquez Dam in Mexico. With the method of placement under the original design, which included temperature reinforcement, and the use of normal cement, cracks of importance, extending through the buttresses, developed at regular intervals in all of the buttresses placed. The use of low-heat cement, with an improved system of placement in sections separated by open joints which were filled later, and the judicious use of a comparatively small percentage of temperature reinforcement, entirely eliminated all cracking. In this instance, in buttresses varying from 4 to 2 feet in thickness, low-heat cement in comparison with normal cement, showed to its best advantage. The rate of cooling in these thin sections exceeded the rate of heat development in a few days' time, materially reducing the maximum temperature of the concrete and the ultimate temperature drop from the maximum to the air temperature.

The experience with normal cement under the conditions of placement at Owyhee Dam contrasts sharply with the behavior of low-heat cement in Boulder and Morris Dams. During the time that construction of Owyhee Dam was suspended for several months in the first of two winter seasons within the construction period, cracks developed which extended in a circumferential direction entirely across several of the blocks. The traces of these cracks were also observed in galleries in the blocks. The rate of placement was fairly rapid during the summer seasons and although the depth of the lift was limited to 4 feet, the temperature rise and maximum temperatures were high. The drop from the maximum to the comparatively low final stable temperature was in the neighborhood of 70°. Artificial cooling was not used during the construction period. Extensive cracking developed on the surfaces and in the galleries at the time that the temperature gradients from the interior to the surfaces and to the galleries were steepest and it is known that a number of these cracks later extended across one or several blocks in the circumferential direction. A change in type of cement alone would probably not have altered the behavior greatly.

At Norris Dam, where a modified cement was used with no artificial cooling, and where the sides of some blocks were exposed for rather long periods, surface cracks developed, a number of which later extended entirely across the blocks. A rather large number of cracks was observed in Norris Dam but consideration should also be given to the importance attributed to cracking on this job, and to the corresponding care and diligence exercised in searching for cracks.

One extensive vertical crack, which is probably not entirely due to temperature variations, in the longitudinal direction in the base of Tygart Dam, under construction, is being carefully observed. Modified portland cement is being used in Tygart Dam, a straight-gravity structure, with no artificial cooling. Temperature rises and maximum temperatures are fairly high, which, with a comparatively low fianl stable temperature contributes to large temperature drop conducive to cracking.

Very little can be said of the behavior in the structure of the modified portland cement used in Grand Coulee Dam. Construction is not far enough along to warrant definite conclusions. The temperature rises are high for several reasons; the use of modified cement, having an early rate of heat development nearly as great as normal cement, the rapid rate of construction over the confined area under construction, and the very low diffusivity of the concrete. It is interesting to note that under the same conditions of cooling it will take five-thirds times as long to remove a given amount of heat from Grand Coulee Dam as from Boulder Dam. The construction level is maintained uniform over the entire area under construction so that very little heat should be lost to the sides of the blocks. Contraction joints in longitudinal and transverse directions divide the section into blocks not exceeding 50 by 50 feet in size. Artificial cooling will be used to reduce the temperatures uniformly to the final stable temperature. With these expedients, it is believed that cracking will be controlled.

The downstream face of Arrowrock Dam, in which a sand cement was used, has disintegrated as much as 18 inches in depth. The concrete of Elephant Butte Dam, also containing sand cement and constructed at about the same time, shows no disintegration except near the outlet conduits. The difference in behavior is believed to be due entirely to the freezing and thawing to which the former dam is subjected. In other respects, the behavior in both structures is satisfactory. Very little cracking can be observed in the galleries of either dam.

The use of a special sulphate-resistant portland cement in the construction of the massive concrete piers and anchorages on the San Francisco-Oakland Bay Bridge and the San Francisco Pier and Fender of the Golden Gate Bridge gives promise of much greater resistance to the corrosive effects of exposure to sea water than if normal cement had been used. "High-silica," a portland-pozzolan cement, was also used on these projects where the concrete was subject to exposure to sea water, with satisfactory behavior in construction and with noticeably less crack development than was observed with portland cement. Time alone will determine which of these two cements is superior in this type of construction.

Bonneville Dam in Oregon is being built with portland-pozzolan cement developing relatively low heat of hydration and high tensile strength. This type of cement in combination with a rather lean mix, low placing temperatures and moderate rate of construction, has resulted in very little cracking to date. The cement produced a very workable mix, but it had a tendency to stiffen appreciably during transportation from mixer to forms in hot weather. Some slight inconvenience in construction has been experienced at times because of the slow strength development of the portland-pozzolan cement at very early ages.

General data relative to the mass-concrete dams mentioned herein are shown in table 1.

This table summarizes descriptions of a number of mass-concrete dams, and is included here for convenient comparison of the conditions of construction of some of the more prominent dams in this country in which special cements were used.

FUTURE DEVELOPMENTS

It might be said that the ideal concrete dam would be one involving sufficiently low volume changes to permit its being built as a monolith without fear of cracking, and of concrete which would withstand indefinitely the rigors of severe climatic or other disintegrating conditions. It is probably too much to expect that such an idealized dam can ever be attained but, most certainly, there is great opportunity for future improvement.

Past researches, investigations, and experiences have shown the differences that exist between concretes and have indicated methods by which these differences may be controlled, within certain limits. However, comparatively little is known regarding the basic reasons for many of these differences, and there is urgent need for fundamental knowledge concerning the influences of various factors on the properties of concrete and its ingredients.

Definite needs for improving mass concrete include cements with reasonably high early strength which will develop lower heats of hydration, and concrete having reduced volume change characteristics, greater extensibility or resistance to cracking and improved resistance to disintegration. Information is needed regarding the elastic and plastic properties of concrete at very early ages and the influences of restraint under conditions obtained in massive concrete structures. More definite data on the heat of hydration of cement at ages of one year or more are also needed. Such information would make possible more accurate stress analyses of concrete undergoing temperature changes and prediction of cracking tendencies, and would in turn suggest more effective remedial measures.

The field of mass concrete is a broad one and much of it yet remains to be explored, particularly as pertains to hydraulic structures. As has been repeatedly stressed, the cement is but one element in the complex pattern that constitutes the satisfactory completion and proper functioning of a mass concrete structure. However, as more basic or fundamental knowledge concerning the constitution and hydration process of cement become available, such information will in turn point the way to more direct and effective treatment of related factors and problems.

Recent Laboratory Investigations Related to Special Cements

In an effort to secure a cement more suitable for mass concrete construction at Boulder Dam, the Bureau of Reclamation initiated a series of investigations to determine more fully the characteristics of portland cements in mass concrete, and the effects of variations in their chemical composition and fineness upon their properties. These endeavors focused upon the desire for lower heat of hydration with attendant lower concrete temperatures and reduced volume changes and cracking.

The studies were aided by the developments of Messrs. Woods, Steinour, and Starke, who had devised methods and apparatus for

TABLE 1.—*General data relative to mass-concrete dams*

Item	Units of measurement	Name of dam			
		Arrowrock	Elephant Butte	Owyhee	Morris
General description:					
When built		1912–14	1913–16	1930–32	1932–34.
Type		Arch gravity	Gravity	Arch gravity	Gravity.
Built by		U. S. B. R.	U. S. B. R.	U. S. B. R.	City of Pasadena.
Stream		Boise River	Rio Grande River	Owyhee River	San Gabriel River.
Location		22 miles above Boise, Idaho	60 miles northwest of Las Cruces, N. Mex.	Southeastern Oregon	18 miles east of Pasadena, Calif.
Height	Feet	349	290	417	328.
Crest length	Feet	1,100	1,200	810	780.
Maximum thickness	Feet	238	213	267	280.
Mean air temperatures:					
Annual	Fahrenheit	50	60	52.2	61.7.
Lowest minimum monthly.	Fahrenheit	20 (January)	26 (December)	20.2 (January)	39.4 (January).
Highest maximum monthly.	Fahrenheit	87 (July)	92 (June)	94.1 (July)	88.8 (August).
Cement:					
Type		"Sand"	"Sand"	Standard	Low-heat.
C_3S, average	Percent	32 (portland cement)	35 (portland cement)	49.3	24.2.
C_3A, average	Percent	13 (portland cement)	10 (portland cement)	11.9	4.8.
C_2S, average	Percent	41 (portland cement)	37 (portland cement)	25.5	48.4.
C_4AF, average	Percent	7 (portland cement)	11 (portland cement)	7.8	14.9.
Fineness, 200	Percent	90	90	90	93.6.
Specific surface	Sq cm/g			1,400 (Wagner, approximate)	
Pozzolan proportions	Percent by weight	45 (pulverized granite)	48 (pulverized sandstone)	None	None.
Heat of hydration average	Calories per gram			79.9 @ 7 days 86.3 @ 28 days	55.3 @ 7 days. 64.2 @ 28 days.
Standard mortar strength	Pounds per square inch.	241 @ 7 days 335 @ 28 days } tensile	199 @ 7 days 303 @ 28 days } tensile		1,770 @ 7 days. 4,000 @ 28 days.
Aggregate:					
Natural or crushed		Natural	Natural sand and crushed gravel.	Natural	Natural.
Maximum size	Inches	4½	3½ (with plum stones)	8	6.

Concrete:					
Total volume	Cubic yards	578,000	605,200	537,000	500,000.
Cement content	Barrels per cubic yard	0.96 (interior)	1.00 (interior)	1.00	0.95 (interior). 1.10 (upstream face).
W/C (net)	By weight		0.8± (interior) 0.65± (face)	0.66	0.59 (interior). 0.54 (upstream face).
Compaction method		Spading and tamping	Spaded	Hand	Vibration.
Slump, average	Inches	Fairly dry, no water on top of placements.		1.5	About 1.0.
Mix proportions, average	By weight	Interior 1:2.5:5.0:2.75 (volume). Faces 1:2.0:4.0:2.5 (volume)	Interior 1:2.8:5.45 Face 1:1.7:3.85	1:2.7:6.45	1:2.7:7.4 (interior).
Construction data:					
Length of lifts	Feet	150, 50, 25	Thickness of dam	Thickness of dam	Thickness of dam.
Width of lifts	Feet	15 to 120	50 and 100	50 (on axis)	25 to 50.
Depth of lifts	Feet	4 (approximate)		4	5.
Time between lifts	Days			5	5.
Temperatures in dam:					
Temperature rise, average	Fahrenheit	30		46	40.
Temperature rise, maximum.	Fahrenheit			64	44.
Maximum temperature	Fahrenheit			125	118.
Cracking or defects		Cracks at most construction joints, with leakage, and lime deposits. Downstream face disintegrated for thickness as much as 10 inches.	No cracks of importance, mostly fine, caused by surface shrinkage. Leakage is very small. No noticeable disintegration.	Principal cracks during construction were circumferential, all closed by grouting; no leakage.	Cracks few and small, mostly not more than 5 to 10 feet deep.

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[1] Data given are for present contract which is for building the lower 177 feet of the full dam which will ultimately be 550 feet high.

TABLE 1.—*General data relative to mass-concrete dams*—Continued

Item	Units of measurement	Name of dam				
		Boulder	Bonneville	Norris	Grand Coulee [1]	Tygart
General description:						
When built		1933–35	Under construction	1933–36	Under construction	Under construction.
Type		Arch gravity	Gravity	Gravity	Gravity	Gravity.
Built by		U. S. B. R.	Corps of Engineers, U. S. Army.	Tennessee Valley Authority.	U. S. B. R.	Corps of Engineers, U. S. Army.
Stream		Colorado River	Columbia River	Clinch River	Columbia River	Tygart River.
Location		25 miles southeast of Las Vegas, Nev.	40 miles east of Portland, Oreg.	25 miles from Knoxville, Tenn.	10 miles west of Spokane, Wash.	Grafton, W. Va.
Height	Feet	727	70 (to top of spillway)	253	177	235.
Crest length	Feet	1,282	1,080	1,600	4,200	1,850.
Maximum thickness	Feet	640	200	210	440	207.
Mean air temperatures:						
Annual	Fahrenheit	71.9	52.9	58.1	45.8	52.8.
Lowest minimum monthly.	Fahrenheit	30.8	27.4 (January)	30.6 (January)	13.6	21.1 (February).
Highest maximum	Fahrenheit	107.7	86.5 (July)	86.9 (July)	86.2	84.9 (July).
Cement:						
Type		Low-heat and a blend with normal.	Portland-Pozzolan	Modified	Modified	Modified.
C_3S, average	Percent	23	45.0 (in clinker)	35 to 55 (specified)	46	44.9.
C_3A, average	Percent	5	5.0 (in clinker)	6.0	5	6.1.
C_2S, average	Percent	50			29	
C_4AF, average	Percent	14			13	
Fineness, 200	Percent		96.8			49.0.
Specific surface	Sq cm/g	1,930 (Wagner)	1,900 (hydrometer)	1,750 to 1,950 (Wagner)	2,010 (Wagner)	1,860 (Wagner).
Pozzolan proportions	Percent by weight	None	25 (specified)	None	None	None.
Heat of hydration average.	Calories per gram	55 @ 7 days 64 @ 28 days	59.0 @ 7 days 61.1 @ 28 days	80 @ 28 days	79 @ 7 days 86 @ 28 days	80 @ 28 days.
Standard mortar strength.	Pounds per square inch.	1,770 @ 7 days 3,760 @ 28 days		750 @ 3 days 1,500 @ 7 days specified	2,750 @ 7 days 5,100 @ 28 days	2,394 @ 7 days. 4,146 @ 28 days.
Aggregate:						
Natural or crushed		Natural	Natural	Crushed	Natural	
Maximum size	Inches	8	6 (specified)	6	6	

Concrete:							
Total volume	Cubic yards	3,250,000	871,000	1,000,000	3,100,000	1,200,000.
Cement content	Barrels per cubic yard.	1.00	0.90 (warm weather) 1.00 (cold weather)	0.9 (interior) 1.1 (exposed faces)	1.00	1.00 (interior). 1.12 (exposed faces).
W/C (net)	By weight	0.52 (average)	0.63	0.67 (interior) 0.58 (exposed faces)	0.60	0.53 (interior). 0.49 (exposed).
Compaction method		Spading and tamping		Vibration	Internal vibration	Vibration.
Slump, average	Inches	3.8 (average)	3.25	1.0	2.25	1.0.
Mix proportions, average.	By weight	1:2.45:7.05 1:2.37:7.13		1:3.72:7.43 (interior) 1:3.04:6.08 (faces, approximate).	1:2.7:7.0	1:2.44:7.05 (interior). 1:2.17:6.15 (exposed).
Construction data:						
Length of lifts	Feet	30 to 50	One longitudinal joint	Thickness of dam	50	
Width of lifts	Feet	25 to 60	60 (transverse)	56	50, 40, and 25	
Depth of lifts	Feet	5	5	5	5	5 (hot weather).
Time between lifts	Days	4.7 (average)	Minimum (specified), 3	3½	Minimum (specified), 3	10 (cold weather).
Temperatures in dam:						
Temperature rise, average.	Fahrenheit	32	35 (approximate)	35 (approximate)		35.
Temperature rise, maximum.	Fahrenheit	42	39			
Maximum temperature.	Fahrenheit	124	103	97 (approximate)		116 (approximate).
Cracking or defects		Only surface shrinkage cracks. Negligible leakage.	Very little cracking. 2 vertical cracks with 0.03 inch opening in blocks the bases of which were cast in warm weather.	About half the blocks have vertical cracks on sides midway between contraction joints and horizontally at lift planes about every 50 feet.	Only a few small surface cracks found.	One major crack (longitudinal) about ⅛ inch. Horizontal and vertical cracks about 20 feet apart in bottom 2 or 3 lifts.

determining heat of hydration and subsieve fineness. They also received invaluable stimulus from the works of L. T. Brownmiller and R. H. Bogue of the Portland Cement Association Fellowship at the National Bureau of Standards in identifying and developing a method for computing the compounds of portland cement from the oxide analysis.

According to Bogue, the following major compounds are found, in the order listed, when properly proportioned amounts of lime (CaO), silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), and magnesium oxide (MgO) are burned together at high temperatures:

	Chemical formula	*Abbreviated formula*
Tetracalcium alumino-ferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF
Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A
Dicalcium silicate	$2CaO.SiO_2$	C_2S
Tricalcium silicate	$3CaO.SiO_2$	C_3S
Magnesium oxide	MgO	----

The fact that strength, heat evolution, and other properties of cement are intimately related to the amounts of these compounds present has been fairly well established by those investigations. Classification of portland cements into four main types according to their properties and the percentage of these compounds, as shown in table 2, has followed.

Preliminary studies for heat of hydration, compressive strength, fineness, and a correlation of these with compound composition were made on 51 commercial cements by the National Bureau of Standards. These were followed by more extensive tests at the University of California, for which some 50 special cements were manufactured, burned, and ground in the laboratory to include a wide range of variable compositions. Volume changes, durability, and resistance to saline waters were also observed for the several compositions. The effects of fineness were studied upon cements ground to different degrees of fineness as expressed by the term "specific surface," or the total surface area per gram.

Selected laboratory and commercial cements were further investigated at the laboratories of the Bureau of Reclamation in Denver, Col., incorporated in mass concrete mixes and tested in specimens as large as 36 inches in diameter and 72 inches in height. Facilities included apparatus for curing the concrete adiabatically, following the temperature rise conditions existing in large structures, for measuring modulus of elasticity, Poisson's ratio, volume changes, permeability, extensibility, plastic flow, thermal properties, and for determining durability under freezing and thawing.

These researches resulted in the choice of "low-heat" cement for Boulder Dam, characterized by low percentages of C_3A and C_3S with high percentages of C_2S and C_4AF, producing about one-third less heat than developed by the normal type of cement and exhibiting substantial strengths at later ages, particularly under conditions of mass curing.

Considerable renewed interest has developed recently in the United States for the portland-pozzolan combinations as cements for mass concrete work. Adoption for use on two large projects has given them a position of importance and investigations of their properties have been undertaken by the University of California, the Bureau of Reclamation, and others.

The following statements constitute a brief synopsis of the principal conclusions drawn from the various recent laboratory investigations conducted in the United States. In general, the results obtained in similar investigations by different investigators, and the conclusions stated, are in remarkably close agreement.

1. Compound composition and fineness are outstanding factors affecting the properties of cement and the resulting concrete and constitute practical means for controlling cement according to desired characteristics.

2. The major cement compounds, C_3S, C_2S, C_3A, and C_4AF have definite effects on compressive strength, heat of hydration, durability, and other properties of cement and concrete. C_3A is definitely shown to be the least desirable compound in portland cement and C_3S and C_2S are the most desirable constituents.

3. Cements manufactured in the laboratory under closely controlled conditions in general exhibit more consistent and somewhat more desirable properties than do commercial cements of the same composition.

4. Tricalcium silicate and dicalcium silicate are the chief strength-giving compounds in portland cement. Early[1] strength of mortars and concretes is largely derived from the C_3S which affords the greater part of its contribution during the first week of the hardening period. Gain in strength after the first week is largely attributable to C_2S, which contributes little strength at earlier ages. Weight for weight, the C_3S and C_2S contribute about equally to ultimate strength.

5. Tricalcium aluminate usually increases the strength somewhat at ages of 7 and 28 days, but at later ages it is detrimental.

6. Tetracalcium alumino-ferrite has little effect on compressive strength; it lowers the strength slightly at all ages.

7. Finer grinding increases the compressive strength at all ages, but more particularly at early ages.

8. Mass or adiabatic curing from an initial temperature of 70° F. accelerates the strength development at early ages, but at later ages the strength of the mass-cured specimens is slightly less than that of similar specimens cured in fog rooms, at a constant temperature of 70° F.

9. High initial temperature of mass curing (100° F. or higher) is detrimental to ultimate compressive strength.

10. Low-heat cements, as compared with standard cements, are lower in C_3S and C_3A, and higher in C_2S and C_4AF. Modified cements are practically identical in composition with standard cements except that they contain about one-half as much C_3A, and correspondingly higher percentages of C_4AF. Both low-heat and modified types are ground finer than the standard types.

11. At early ages, modified and standard portland cements show more strength than low-heat cements, but at extended ages, all three types exhibit about the same strength under similar conditions of test.

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[1] *The use of the term "early" with respect to strength or age has reference to an initial period of 28 days or less. The expression "later ages" pertains to ages greater than 28 days.*

TABLE 2.—*Chemical and physical characteristics of various types of portland cements*

Type of cement, number tested	High-early strength			Standard			Moderate-heat			Low-heat		
Test results	Maximum	Minimum	Average 34	Maximum	Minimum	Average 11	Maximum	Minimum	Average 12	Maximum	Minimum	Average 14
Chemical analysis (percent):												
SiO_2	21. 8	18. 4	19. 9	22. 6	20. 7	21. 8	23. 8	20. 3	21. 6	26. 4	22. 2	23. 5
Al_2O_3	7. 0	4. 1	5. 8	7. 3	5. 0	6. 1	6. 2	3. 9	5. 3	6. 2	2. 7	5. 1
Fe_2O_3	4. 2	2. 0	2. 9	3. 4	2. 0	2. 7	6. 0	3. 3	4. 6	6. 0	2. 0	4. 7
CaO	67. 2	62. 7	64. 6	66. 4	62. 1	64. 2	65. 0	62. 0	62. 9	63. 2	58. 4	60. 5
MgO	4. 0	0. 8	2. 3	3. 8	0. 7	2. 4	4. 4	1. 5	3. 1	4. 1	1. 0	3. 0
SO_3	2. 9	1. 8	2. 3	1. 9	1. 3	1. 7	2. 0	1. 6	1. 7	2. 3	1. 5	1. 8
Ignition loss	2. 5	0. 8	1. 6	2. 3	0. 6	1. 2	2. 0	0. 5	1. 1	1. 9	0. 6	1. 1
Insoluble residue	0. 7	0. 1	0. 2	0. 8	0. 0	0. 2	0. 5	0. 1	0. 2	0. 3	0. 1	0. 2
Compound composition (percent):												
C_3S	73	47	58	54	29	43	50	29	42	33	10	20
C_2S	22	0	13	43	22	31	46	22	30	61	41	52
C_3A	14	6	10	14	9	12	9	3	6	8	3	6
C_4AF	15	6	9	10	6	8	18	10	14	18	6	14
$CaSO_4$	4. 9	3. 0	3. 9	3. 3	2. 2	2. 8	3. 3	1. 9	2. 9	4. 0	2. 5	3. 1
Free CaO	6. 0	0. 2	1. 4	1. 5	0. 0	0. 8	1. 8	0. 1	0. 6	0. 9	0. 1	0. 3
MgO	4. 0	1. 0	2. 3	3. 8	0. 7	2. 4	4. 4	1. 5	3. 1	4. 1	1. 0	3. 0
Ignition loss	2. 5	0. 8	1. 6	2. 3	0. 6	1. 2	2. 0	0. 5	1. 1	1. 9	0. 6	1. 1
Physical properties:												
Fineness:												
Percent passing No. 200 sieve, dry	100. 0	96. 4	98. 8	96. 4	90. 3	94. 4	98. 2	93. 5	96. 1	98. 1	91. 8	94. 9
Percent passing No. 325 sieve, wet	99. 9	91. 8	97. 6	87. 6	78. 8	84. 6	92. 7	82. 2	88. 1	91. 0	77. 8	86. 2
Specific surface, square cm per gram [1]	3, 040	1, 950	2, 532	1, 980	1, 530	1, 770	2, 170	1, 750	1, 930	2, 140	1, 500	1, 930
Time of set, Gillmore needle:												
Initial, hours and minutes	5 00	1 10	3 31	4 45	2 45	3 35	4 45	2 55	3 40	5 10	1 15	3 00
Final, hours and minutes	8 20	3 05	5 44	6 55	4 45	5 40	7 10	4 50	5 30	7 10	3 30	5 20
Specific gravity	------	------	------	3. 23	3. 08	3. 15	3. 23	3. 15	3. 19	3. 19	3. 14	3. 16
Normal consistency	29. 5	23. 5	25. 5	26. 4	22. 0	24. 1	25. 4	22. 0	23. 4	25. 0	21. 6	22. 7
W/C ratio by weight [2]	------	------	------	0. 56	0. 52	0. 54	0. 54	0. 50	0. 52	0. 57	0. 52	0. 54

Compressive strength (pounds per square inch), average 2- by 4-, 3- by 6-, and 6- by 12-inch cylinders												
Standard curing 3 days				2, 830	1, 640	2, 070	2, 230	1, 440	2, 060	1, 230	520	890
Standard curing 7 days				3, 720	2, 720	3, 190	3, 400	1, 960	2, 940	2, 270	1, 000	1, 590
Standard curing 28 days				5, 320	3, 870	4, 460	4, 870	3, 760	4, 430	4, 300	2, 720	3, 390
Standard curing 90 days				5, 790	4, 210	5, 010	5, 940	4, 620	5, 420	5, 770	4, 040	4, 880
Sealed, mass curing 3 days				4, 000	2, 610	3, 240	2, 980	1, 610	2, 660	2, 300	680	1, 420
Sealed, mass curing 7 days				4, 290	3, 300	3, 950	4, 230	3, 070	3, 720	3, 240	1, 640	2, 400
Sealed, mass curing 28 days				4, 990	3, 960	4, 520	5, 600	4, 490	4, 910	5, 300	3, 290	4, 210
Sealed, mass curing 90 days				5, 370	3, 840	4, 580	5, 770	4, 600	5, 060	5, 350	3, 830	4, 480
1:2.77 mortar cubes:												
1 day	2, 110	1, 050	1, 480									
3 days	4, 610	2, 550	3, 580									
7 days	5, 940	3, 500	4, 970									
28 days	7, 540	4, 230	6, 060									
90 days	7, 790	4, 540	6, 330									
1:2.72:4.32 concrete cylinders:												
1 day	2, 580	1, 330	1, 690									
3 days	4, 570	2, 860	3, 910									
7 days	5, 630	3, 860	4, 940									
28 days	6, 590	4, 660	5, 870									
90 days	7, 400	5, 250	6, 530									
Temperature rise, ° F.:												
1 day				50. 3	30. 8	37. 1	34. 4	25. 1	30. 5	25. 8	12. 8	20. 3
3 days				65. 8	47. 9	56. 9	49. 3	38. 0	45. 9	40. 2	25. 8	32. 6
7 days				68. 2	53. 4	62. 0	56. 8	45. 8	53. 8	45. 5	31. 8	38. 4
14 days				69. 5	56. 0	64. 1	59. 9	50. 8	57. 1	51. 0	36. 6	43. 1
28 days				70. 4	57. 6	65. 2	62. 4	53. 8	59. 1	55. 9	40. 5	47. 6

[1] By Wagner turbidimeter.

[2] For 1 barrel cement per cubic yard mass concrete, 3-inch slump.

TABLE 2.—*Chemical and physical characteristics of various types of portland cements*—Continued

Type of cement, number tested	High-early strength			Standard			Moderate-heat			Low-heat		
Test results	Maximum	Minimum	Average 34	Maximum	Minimum	Average 11	Maximum	Minimum	Average 12	Maximum	Minimum	Average 14
Heat of hydration (calories per gram):												
1 day	------	------	------	69. 0	41. 6	50. 4	46. 5	33. 8	41. 0	34. 8	17. 0	27. 1
3 days	100	72	86	91. 6	65. 5	78. 6	67. 6	51. 5	62. 6	54. 9	34. 7	44. 1
7 days	106	78	91	95. 1	73. 4	86. 0	78. 0	62. 4	73. 9	62. 2	43. 1	52. 2
14 days	------	------	------	97. 1	77. 1	89. 1	82. 5	69. 6	78. 6	69. 6	49. 8	58. 8
28 days	111	85	98	98. 5	79. 4	90. 7	86. 2	73. 9	81. 6	76. 6	55. 1	65. 2
90 days	------	------	------	103. 4	92. 6	95. 2	92. 2	86. 9	87. 3	90. 4	65. 0	76. 9
6 months	------	------	------	------	------	98. 0	------	------	90. 6	------	------	80. 8
1 year	------	------	------	108. 4	97. 7	99. 7	98. 3	91. 7	92. 2	98. 8	71. 1	84. 1

12. Low-heat cements, when used under suitable conditions, are eminently satisfactory for mass-concrete construction.

13. Modified cements give satisfactory strengths at both early and later ages. They generate less heat than do standard cements and seem to be better suited for general purposes than the low-heat or standard types.

14. The various compounds in portland cement hydrate and liberate heat at different rates. C_3A hydrates chiefly during the first day, C_3S during the first week, and C_2S after the first week. The heat liberated by C_4AF is small, and the rate of hydration is indefinite.

15. At ages up to one year, C_3A develops approximately twice as much heat as does an equal percentage of C_3S. C_3S generates more heat than either C_2S or C_4AF.

16. Reduction in heat of hydration at all ages can be obtained to best advantage by decreasing the percentage of C_3A with a consequent increase in C_4AF. A decrease in the percentage of C_3S, with a consequent increase in C_2S, results in a large reduction in heat of hydration at early ages and a moderate reduction at later ages.

17. By the application of proper contribution factors, the heat of hydration at a given age can be computed with fair precision, if the chemical composition, fineness, method of curing, and ignition loss are known.

18. The increase in heat of hydration between the ages of 28 days and 1 year is small except for cements that are high in C_2S.

19. Finer grinding results in increase of heat of hydration at early ages. Fine grinding has a much less pronounced effect on heat of hydration than on strength.

20. Different types of cements exhibit marked differences in heats of hydration. This is in contrast with the findings for compressive strength. Average values of heat of hydration for four types of cements are as follows:

Type	Number of cements averaged	Specific surface (cm^2 per gram)	C_3S (per cent)	Heat of hydration (calories per gram of cement)		
				3 days	7 days	28 days
High-early strength	12	2, 030	56	102	108	114
Standard	11	1, 770	43	79	86	91
Modified	12	1, 930	42	63	74	82
Low-heat	14	1, 930	20	44	52	65

21. The strength-heat ratio, or compressive strength divided by the heat of hydration, at the same age, is sometimes taken as a measure of the efficiency of a cement for mass-concrete construction. Low-heat cements exhibit lower strength-heat ratios at the early ages and greater strength-heat ratios at the age of 1 year or later than do either the standard or modified types.

22. Results of tests performed by a number of independent investigators show very definitely that mortars and concretes containing cements of high C_3A content offer poor resistance to freezing and thawing.

23. Cements that are high in C_3A offer poor resistance to the aggressive action of sulphate waters.

24. Cements that exhibit the greatest resistance to weathering and to the aggressive action of sulphate water are those that have a low percentage of C_3A and high combined percentages of C_3S and C_2S.

25. Low-heat cements show somewhat less resistance to freezing and thawing than do standard cements.

26. In general, there seems to be no consistent relation between compound composition or type of cement and expansion and contraction due to wetting and drying.

27. No consistent relation appears to exist between compound composition or type of cement and Young's modulus of elasticity. Poisson's ratio is very nearly the same for all conditions of test.

28. Regardless of the type of cement, the plastic flow of concrete increases with time, increases with the magnitude of unit loading, and decreases with the age of specimen at loading.

29. The rate of plastic flow is relatively rapid when the specimens are first loaded, but gradually decreases with time.

30. When several portland cements of the same type, or different types, are blended together the heat of hydration of the blend is very nearly equal to the weighted average for the cements tested separately.

31. Mortars and concretes containing portland-pozzolan cements are in general more workable than those containing all-portland cements.

32. Portland-pozzolan cements containing suitable pozzolanic material exhibit greater tensile strength, especially at the later ages, than do all-portland cements, and they exhibit slightly higher compressive strength at later ages.

33. On the whole, it appears that high-lime clinker in portland-pozzolan cements results in the greatest relative benefits as compared with the corresponding portland cement.

34. For a portland-pozzolan cement, the optimum amount of pozzolanic material usually lies within the limits of 20 to 30 percent.

35. It has been found that nearly all pozzolan materials are improved by heat treatment. The average optimum temperature for all materials that have been tested is close to 1,450° F.

36. In general, mortars and concretes containing portland-pozzolan cements of a suitable type are more impermeable and more resistant to freezing and thawing, and to the action of sulphate waters than those containing all-portland cements.

37. As compared with all-portland cements, portland-pozzolan cements exhibit greater relative compressive strengths in lean mixes than in rich ones.

38. The heat of hydration of portland-pozzolan cements is at all ages lower than that of all-portland cements. The difference is greater for greater amounts of pozzolan.

39. When concrete cylinders were subjected to sustained tensile load in the Denver laboratories of the Bureau of Reclamation, the ratio of plastic deformation to elastic deformation at the time of breaking was greater for cylinders containing portland-pozzolan cements than for those containing all-portland cements.

40. At the time a concrete cylinder broke that was subjected to sustained tensile lead, the ratio of the total unit deformation to the total unit load was taken as an index of the extensibility. As judged by this ratio, the low-heat cements exhibited slightly greater exten-

sibility than the modified cements, and both types exhibited greater extensibility than did the standard cements.

41. Tests on mortars and concretes at Purdue University showed that a blend of portland and natural cements showed at all ages about the same tensile strength and the same expansion and contraction due to wetting and drying as did the all-portland cement. At all ages the blend exhibited slightly lower compressive strength, slightly greater durability, and greater plastic flow.

42. Fatigue tests on concrete beams at Purdue University showed that a blend of portland and natural cement was definitely superior to an all-portland cement.

MATHEMATICAL ANALYSIS OF TEMPERATURE MOVEMENTS IN MASS CONCRETE

Introduction.—Studies of the various factors affecting the temperature history of mass concrete have been made to determine the importance of the cement factor and the extent of improvement in the thermal history to be had by judicious selection of the type of cement.

The cement is not the only factor and indeed may not be the major factor. If concrete were placed with its initial temperature far above the final stable temperature, the excess heat would eventually be lost, with attendant volume change and tendency to crack even though the cement used had no heat of hydration. Other factors which must be considered are the relation of placing temperature to the stable temperature, the thermal relations between the mass and the foundation, size of the mass, rate of placement, construction schedule, and exposure conditions, as well as more general factors such as the operation and use of the structure.

The mathematical approach to the thermal history is an important step in evaluating the contribution of special cements to the thermal control of concrete, and a discussion of such mathematical analysis is therefore pertinent.

Problems in the flow of heat have been studied for many years and the existence of the mathematical theory of heat conduction may be said to date from the publication in 1822 of a treatise by the French mathematician Fourier entitled, "Théorie Analytique de la Chaleur." Since then a number of forms of the equations for the solution of particular types of problems have been derived. The results of these labors may now be found in texts dealing with the subject,[2] to which the reader is referred for the detail of the mathematical processes.

It is only quite recently, however, that mathematical forms have been applied to the solution of the particular problems relating to flow of heat in concrete dams; problems which include such considerations as heat generation due to hydration of the cement, thermal characteristics of the concerete, and effects of exposure conditions peculiar to these structures.

In the United States, studies of this nature have been made at the University of California, and by the Bureau of Reclamation at

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[2] *References: Carslaw: "The Conduction of Heat," McMillan and Company; Ingersoll and Zobel, "Mathematical Theory of Heat Conduction," Ginn and Company.*

Denver, the Tennessee Valley Authority, and others. Dr. Fredrik Vogt, of Trondhjem, Norway, has also made noteworthy contributions.[3]

Statement of the problems.—In illustration of the method of attack, this statement of the problems will describe the approach by the engineers of the Bureau of Reclamation.

(*1*) *Cooling from the surface of a lift.*—The temperature of the concrete of the first few days, which constitute the period of exposure of the surface of a lift, changes rapidly because of the development of the heat of hydration of the cement. Loss of heat from the surface of a lift, therefore, is dependent on the shape of the temperature rise curve. The rate of heat evolution and adiabatic temperature rise curve can be determined by heat of solution or adiabatic calorimeter methods. An empirical exponential curve may be chosen to fit the characteristic temperature curve. With mathematical constants so chosen, solutions may be obtained which give the loss of heat at any time or the temperature distribution throughout the lift at any time. In a similar manner, the temperature distribution in the concrete near the foundation and into the foundation rock may be determined. The form of the empirical curve to represent the adiabatic temperature rise curve, and curves for computing the loss of heat from the surface of a lift are included in the complete bulletin of which this paper is a summary.

(*2*) *Cooling of a flat slab.*—Solutions are available for the cooling of a flat slab exposed on both sides and insulated around the edges with surfaces maintained at zero temperature and with uniform initial temperature distribution. The temperature history at any point in the slab or the mean temperature history can be obtained. In application, the dam at any point is considered to be a slab of the thickness of the dam at that point exposed on the upstream and downstream faces. The assumption of uniform initial temperature introduces no appreciable error into the computations. A curve of this solution for the computation of the mean temperature of any slab at any time has been published[4] and an example computed. This case may be extended to that of a prismatic body of rectangular cross section exposed on four sides, or further to the case of a rectangular parallelepiped exposed on six faces.

(*3*) *Slabs exposed to variable temperatures.*—The solutions of this problem find application in estimating the temperature changes to which dams are subjected because of the variation of the temperatures of the air and water with which the surfaces of the dam are in contact. Items of particular interest and which have been solved[5] are: The reduction of temperature variation with distance from the exposed surface, the change of temperature distribution through the dam, the variation of mean temperature through the dam, and the time lag of the mean temperature of the dam with respect to the external temperature variation.

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[3] *Fredrik Vogt, "Analyses of Rise in Temperature During Hardening of Concrete," 1933; obtainable from F. Bruns Bokhandel, Trondhjem, Norway.*

[4] *R. E. Glover, "Flow of Heat in Dams," Journal of the American Concrete Institute, Proceedings, vol. 31, November–December, 1934, pp. 113–124.*

[5] *R. E. Glover, "Flow of Heat in Dams," Journal of the American Concrete Institute, Proceedings, vol. 31, November–December, 1934, pp. 13–124.*

(*4*) *Cooling of hollow cylinders.*—The proposal to cool the concrete by pumping cold water through pipes embedded in the concrete presented a series of problems, the solution of which indicated that such cooling was feasible and eminently adaptable. Complete studies of cooling were made based upon the solutions and the calculated results subsequently verified by experimental installations before the method was used for cooling Boulder Dam. Studies were also made of the temperature distribution in the concrete surrounding the cooling pipe and of the effect of cooling by this method on the stresses in the concrete. Curves for computation of the problems have been developed and are published in the complete bulletin.

Determination of thermal properties.—In the solutions of all of the problems of heat flow the use of a characteristic number called the diffusion constant or diffusivity of the concrete is required. The diffusivity is numerically equal to the conductivity divided by the product of the specific heat and density. An important step preliminary to the mathematical analysis is the determination of the thermal properties of the concrete. In some instances it may be possible to select aggregates producing a concrete having the most desirable thermal properties.

The diffusion constant may be determined experimentally in several ways—directly, by observing the flow of heat through a test specimen and computing the average diffusion constant that is indicated;[6] or by determining the conductivity, specific heat, and density separately and computing the diffusion constant from those values. The latter method permits the determination of the variation of the thermal properties and diffusion constant with temperature. An example of the variation with temperature is given in table 3 of values of the thermal properties of the concrete used in Boulder Dam.

TABLE 3.—*Thermal properties of concrete of Boulder Dam*

Mix proportions (parts by weight)	W/C ratio (by weight)	Barrels of cement per cu. yd. concrete	Temperature of concrete in F.	Conductivity K (B. t. u./ft./hr./F.)	Specific heat c (B. t. u./lb./F.)	ρ, density, (lb./cu. ft.)	Diffusivity, $h^2=\frac{K}{c\rho}$ (ft.^{2}/hr.)
1 : 2.45 : 7.05, 9 inches maximum size, No. 4 sand division, natural sand and gravel	0. 58	1. 01	50	1. 699	0. 212	156. 0	0. 0514
			70	1. 688	0. 216	156. 0	0. 0501
			90	1. 677	0. 221	156. 0	0. 0486
			110	1. 667	0. 229	156. 0	0. 0467
			130	1. 657	0. 239	156. 0	0. 0444
			150	1. 648	0. 251	156. 0	0. 0421

Variation of the thermal properties with temperature of test specimens representing concrete from various dams have been published.[7]

In the idealized mathematical problems, however, a constant value of the diffusivity is assumed throughout the range in temperature and the single value obtained by the direct method is satisfactory.

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[6] *R. E. Glover, "Flow of Heat in Dams," Journal of the American Concrete Institute, Proceedings, vol. 31, November-December 1934, pp. 113–124.*

[7] *Boulder Dam Cement and Concrete Studies, R. F. Blanks, Engineering News Record, November 22, 1934, pp. 648–651.*

Values of the thermal properties at 70° F. of concrete representing various dams as determined in the laboratories of the Bureau of Reclamation are given in table 4.

TABLE 4.—*Thermal properties at 70° F. of concrete representing various dams*

Dam	Conductivity K (B. t. u./ft./hr./F.)	Specific heat c (B. t. u./lb./F.)	Density ρ (lb./cu. ft.)	Diffusivity $h^2=\frac{K}{c\rho}$ (ft.²/hr).
Norris	2. 105	0. 239	160. 6	0. 0548
Boulder	1. 688	0. 216	156. 0	0. 0501
Gibson	1. 667	0. 222	155. 2	0. 0484
Owyhee	1. 373	0. 214	152. 1	0. 0422
O'Shaughnessy	1. 338	0. 218	152. 8	0. 0402
Morris	1. 291	0. 216	156. 9	0. 0381
Ariel	0. 884	0. 235	146. 2	0. 0257
Bull Run	0. 847	0. 225	159. 1	0. 0237

Test data have been accumulated and analyses made by the Bureau of Reclamation of the effect of the type of rock used as coarse aggregate, and of the effects of the water content and the temperature, on the thermal properties of concrete. From these data studies were made enabling the prediction of the thermal properties, given the percentage composition of the mineral content as computed from the mix data and petrographic analysis of the aggregates, the water-cement ratio, and the density, and applying empirical factors to the percentage composition.

Temperature histories of the concrete.—With the formulas and curves representing the solutions of the aforementioned problems and with the diffusion constants determined or assumed, studies were made yielding complete temperature histories from the time of placing to the ultimate stable temperature of concrete of different thermal characteristics under many different exposure conditions.

A few simplified temperature history curves are presented in illustration of the factors affecting a choice of cements, or a choice of control of the size and exposure of the block. The curves also serve as a basis for determination of the necessity for artificial cooling in order to secure the most favorable conditions of temperature change and distribution.

In the interior of a large dam where the construction surface is kept practically level, as at Boulder Dam, the concrete is under virtually adiabatic conditions except during the time that the surface of the lift is exposed. Subtracting the loss of heat from the surface of the lift during the time of exposure between lifts from the heat gained due to hydration of the cement during that time yields a measure of the mean temperature rise of the concrete. This simple computation does not take into consideration the transfer of heat from the concrete into the lift below and gives no indication of the temperature distribution throughout the mass on the early period following placement. After the surface of the lift is covered and the temperatures become equalized, such a computation yields very closely the actual temperature conditions of the mass. Figure 2 shows curves computed in this manner as a comparison of the mean temperatures in the interiors of large masses of concretes made with standard and low-heat cements.

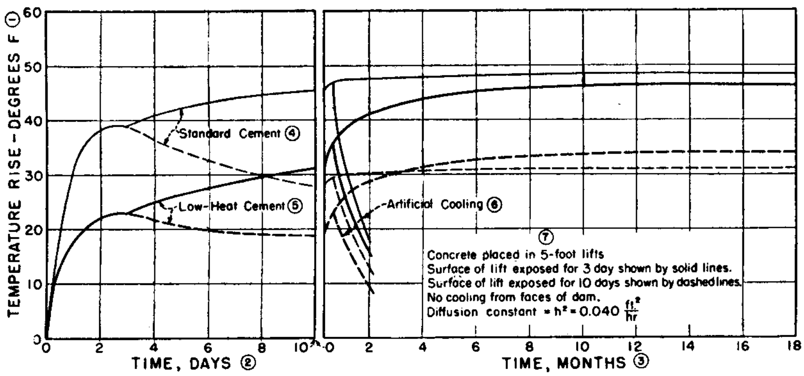

Figure 2. — **Simplified average temperature-rise history of concrete of an extremely large dam.** — Histoire simplifiée de l'augmentation moyenne de température du béton dans un barrage très grand. — Verienfachte Darstellung der durchschnittlicher Temperatureerhöhung in dem Beton einer sehr grossen Talsperre. — Historia simplificada del aumento medio de temperatura en el hormigón de una presa sumamente grande.

1. **Temperature rise, degrees F.** — Augmentation de la température, en degrés Fahrenheit. — Temperaturerhöhung, Grad F. — Aumento de temperatura, grados F.
2. **Time, days.** — Durée, en jours. — Zeit, Tage. — Tiempo, días.
3. **Time, months.** — Durée, en mois. — Zeit, Monate. — Tiempo, meses.
4. **Standard cement.** — Ciment standard. — Einheitszement. — Cemento normal.
5. **Low-heat cement.** — Ciment basse-température. — Zement mit niedriger Hydrationswärme. — Cemento de poco calor.
6. **Artificial cooling.** — Refroidissement artificiel. — Künstliche Kühlung. — Refrigeración artificial.

The solid lines show the comparison for an exposure of 3 days between lifts and the dotted lines for an exposure of 10 days. The exposed surface is assumed to be maintained at the initial temperature. It is apparent that artificial cooling definitely lowers the maximum temperature of the low-heat-cement concrete which has been exposed for only a short period. If any advantage is to be had of the lower temperatures using low-heat cement as compared with those of standard cement, cooling must be started very shortly after the concrete is placed. It is evident that artificial cooling is required in a large mass of concrete regardless of the time of exposure of the top of the lift or of the cement used if the temperature is to be reduced to the final stable value within a reasonably short length of time.

As curves of this type depict only the average temperatures, they do not quite so well represent the conditions in a smaller dam. For smaller structures the temperature distribution from the top of the lift, and from the concrete of the dam into the foundation, or from any exterior surface into the interior should be investigated in determining the temperature stresses and the formation of cracks. This can best be depicted by a series of curves, each representing the momentary distribution at a certain time. Figure 3 shows average temperature curves of the concrete in a dam 50 feet thick, for the principal purpose of illustrating that after several months the temperature of the concrete is essentially the same whether standard or low-heat cement is used. A comparison may also be made of the difference in amount and time of attainment of maximum average temperature for each concrete.

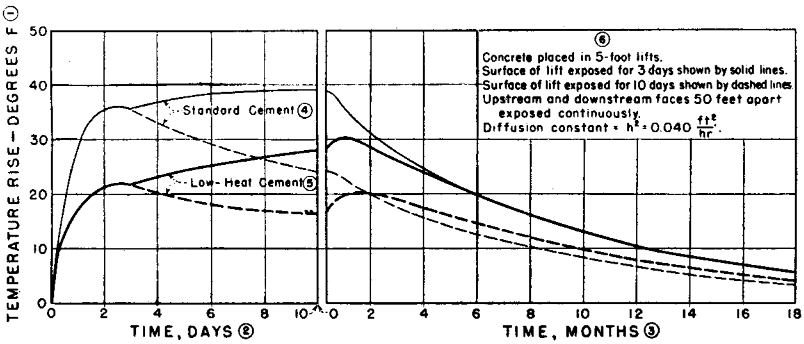

Figure 3.—**Simplified average temperature-rise history of concrete of a moderate-sized dam.** — Histoire simplifiée de l'augmentation moyenne de température du béton dans un barrage de grandeur moyenne. — Verienfachte Darstellung der durchschnittlichen Temperaturerhöhung in dem Beton einer kleineren Talsperre. — Historia simplificada del aumento medio de temperatura en el hormigón de una presa de tamaño ordinario.

Here again the solid lines show the comparison for an exposure of 3 days from the surface of the lift, and the dotted lines for an exposure of 10 days. It is also assumed that the upstream and downstream faces are continuously exposed to the initial temperature subsequent to the time of placement.

Selected Bibliography of United States Publications Relating to Special Cements

1. S. B. Biddle, Jr., and Alexander Klein. *A Hydrometer Method for Determining the Fineness of Portland-Pozzolan Cements.* Proc. Am. Soc. Test. Mat. 1936, preprinted.

   The theoretical considerations in particle-size determination by hydrometer are reviewed, the procedure of testing and calculating is described, and typical results are presented and compared with those obtained by independent methods. The concordance of test results indicates that the assumptions are reasonable and that the degree of reproducibility is satisfactory for practical purposes. A sample of cement is uniformly dispersed in a suitable liquid medium and simultaneous observations of elapsed time and of specific gravity (as measured by hydrometer) are made as the particles settle, and the particle-size distribution and the surface area of the sample may then be calculated.
2. Engineering News Record. *Slag-Cement Blend Concrete Tried at Norris Dam.* Eng. News Rec., Vol. 115, Dec. 19, 1935, p. 861.

   Results of Tennessee Valley Authority tests to determine whether 25 percent admixture of slag cement to ordinary cement in mass-concrete structures is advantageous in respect to temperature rise, volume constancy, workability, and durability. Tests showed that slag-cement blend gives slower strength gain than straight cement, but reaches normal at 28 days; temperature rise of blended cement was same as that of straight cement.
3. National Bureau of Standards. *Heat of Hydration of Partially Prehydrated Cement.* Nat. Bur. Stnds. Tech. News Bul., Nov. 1935, p. 114.

   Found that prehydration with 3 percent water reduced average heat of hydration of standard portland cements cured at 70° F. by 14, 12, and 6 percent for ages of 7 and 28 days and 1 year, respectively. Prehydration with 5 percent water reduced average heat of hydration of the same cements cured at the same temperature by 28, 27, and 16 percent, respectively, for ages of 7 and 28 days and 1 year. Under conditions of simulated adiabatic storage (150° after initial 24 hours) the same order of decrease in the heat of hydration was effected by the two respective prehydrations as was found at 70 F. storage.

4. E. W. Scripture. *The Possibilities of Pozzolanas in Mortars and Concrete.* Eng. News Rec., Vol. 115, Oct. 24, 1935, p. 563.

   Pozzolanas becoming more important. They are material of natural, treated, or artificial origin, possessing constituents which combine with lime at ordinary temperatures in the presence of moisture to form insoluble cementious compounds. Are used as an addition to cement to react with lime originally in the cement and that produced by hydration. Their use reduces the solubility of cement and thereby the susceptibility to corrosion and weather. In certain cases workability may be maintained at reduced water-cement ratio. Pozzolanic materials of varying activity may be used for different types of construction.

5. G. Rupert Gause. *A Study for the Preparation of a Specification for High-Early-Strength Portland Cement.* Nat. Bur. Stnds. Res. Pap., 839, Vol. 15, Oct. 1935.

   This paper reports test results to be used as a basis for the preparation of a Federal specification for high-early-strength cement. Investigation was made of samples of 28 commercial cements representing a wide spread in compound composition, fineness, and physical properties. Tests and test methods are described. The requirements for a specification for high-early-strength cement are discussed and recommendations made for tests to be incorporated in such a specification.

6. Raymond E. Davis, J. W. Kelly, G. E. Troxell, and Harmer E. Davis. *Properties of Mortars and Concretes Containing Portland-Pozzolan Cements.* Jour. Am. Conc. Inst., Vol. 7, Sept.–Oct., 1935, p. 80.

   Results are presented of a study of pozzolanic cement to determine its effect on the characteristics of concrete. Results show that the pozzolan cements are more grindable, produce more plastic concrete exhibiting less water gain, generate less heat of hydration and produce more impermeable concrete. On the other hand they require more water to yield mortars and concretes of a given consistency, and mortars containing them shrink more on drying. Data and results of other tests to show the characteristics of pozzolan cement are given and interpreted.

7. R. H. Bogue. *Compounds in Portland Cement.* Ind. and Eng. Chem., Vol. 27, Sept. 1935, p. 1312.

   This paper deals with the development of cement chemistry and describes methods employed in the identification of most of the compounds of portland cement. The establishment of the parts which the various compounds play in affecting the properties of portland cement are discussed.

8. S. L. Meyers. *Volume Changes in Cement, Mortar and Concrete.* Concrete, Aug. 1935, p. 16.

   The thermal expansion coefficient of concrete increases with increase in richness of mix, and is affected by the type of aggregate and by the method of curing. The coefficient varies with chemical composition in neat cements and is reduced by steam treatment. The coefficient usually decreases with increase in water-cement ratio.

9. United States Bureau of Reclamation. *Portland Cement and Portland Cement Clinker for Grand Coulee Dam.* U. S. Bur. Reclamation Spec. No. 641.

   Purchase specifications for modified portland cement and modified portland cement clinker for Grand Coulee Dam, Columbia Basin project. Limits tricalcium silicate to not less than 35 nor more than 55 percent, and the tricalcium aluminate to not more than 7 percent. Specifies that the specific surface of the cement shall be not less than 1,800 sq. cm. per gm.

10. J. Arthur Swenson, Lacey A. Wagner, and George L. Pigman. *Effect of the Granulometric Composition of Cement on the Properties of Pastes, Mortars, and Concretes.* Nat. Bur. Stands. Research Paper 777, Vol. 14, Apr. 1935, p. 419.

    Data obtained in studies of five laboratory-ground and one commercial cement are presented. Each of the ground clinkers was separated into the groups 0–7, 7–22, 22–35, 35–55, and greater than 55 microns. The commercial cement was separated into only the first four groups. Various tests were made. It was found that the 0–7 micron size is valuable because of the plastic quality it confers upon the concrete mix and because of the high contribution it makes to early strength. Other test results are reported.

11. P. H. Bates. *Trends in the Production and Use of Various Types of Hydraulic Cement.* Proc. Am. Conc. Inst., Vol. 31, 1935. (Jan.–Feb. 1935), p. 225.
    Various types of cement distinguished (1) ordinary portland cement attaining its full strength at a moderate rate; (2) low-heat cement, where the shrinkage is low on account both of the slow and diminished total evolution of heat; (3) cements which are especially resistant to sulphate attack, of low alumina and/or high iron oxide content; (4) rapid hardening cement.
12. R. E. Glover. *Flow of Heat in Dams.* Proc. Am. Conc. Inst., Vol. 31, 1935. (Nov.–Dec. 1934), p. 113.
    Formulas and tables for estimating magnitude of temperature changes likely to occur in concrete during construction of Boulder Dam, as well as those produced by external temperature variations.
13. R. F. Blanks. *Boulder Dam Cement and Concrete Studies.* Eng. News Rec., Vol. 113, Nov. 22, 1934, p. 648.
    From the mass of data accumulated in three years of intensive cement and concrete investigations by the Bureau of Reclamation, the basic information on characteristics and properties is outlined. Properties of low-heat cement; specific heat and conductivity, aggregate and cylinder size, cement efficiency, effect of wet screening, placing temperatures.
14. Wm. Lerch. *Heat of Hydration of Cement by Simple Apparatus.* Eng. News Rec., Vol. 113, Oct. 25, 1934, p. 523.
    Inexpensive method for heat-of-solution determination using hydrofluoric acid; comparative data indicate reproductibility of results and agreement with isothermal calorimeter in order of 1 cal. per gm; comparative values of heat of hydration obtained with Bureau of Standard calorimeter and with thermos-bottle calorimeter.
15. R. H. Bogue and Wm. Lerch. *Hydration of Portland Cement Compounds.* Ind. and Eng. Chem., Vol. 26, Aug. 1934, p. 837.
    Procedures and results of an extensive investigation of reactions taking place when the compounds of cement, individually and collectively, are gaged with water in proportions similar to those used with cements in concrete. Studies made of chemical nature of the reactions of hydrolyses and hydration, the rate of reaction, the nature of reaction products, the physical characteristics of the hardened specimen and the compressive strengths and other physical characteristics of the materials.
16. R. W. Stenzel and S. B. Miller. *Heat of Solution Method in the Calorimetry of Portland Cement.* Ind. and Eng. Chem., July 15, 1934, p. 246.
    Study of the thermochemistry of cement has recently been given considerable impetus by such practical application as specification of heat evolution limits during hardening for cement used in construction of Boulder Dam. Method specially designed for measuring heat of hydration at various ages. Zinc oxide suggested as suitable secondary standard for heat capacity determinations.
17. T. J. Noland. *Heat of Hydration of Cements for Boulder Dam.* Civil Eng., July 1934, p. 365.
    Report of work done by the U. S. Bureau of Reclamation at the University of California for the Boulder Dam project. The three calorimeter methods used are described; the adiabatic method, the high-insulation method, and the heat of solution method. The effect of composition of cement, fineness of cement, and water-cement ratio of mix on the heat of hydration are reported.
18. A. S. T. M. Cement Committee. *Cements for Low Heat of Hardening and Resistance to Sulphates.* Concrete, Vol. 42, July 1934, p. 15.
    Report of Cement Committee presented to annual meeting of A. S. T. M.; low-heat cement not a cure-all; subject needs more study.
19. Raymond E. Davis, R. W. Carlson, G. E. Troxell, and J. W. Kelly. *Cement Investigations for Boulder Dam With Results up to the Age of 1 Year.* Proc. Am. Conc. Inst., Vol. 30, 1934 (May–June 1934), p. 485.
    Some principal conclusions are: Heat liberated is decreased at 1 year about 3 cal. per gm. for each 1 percent increase of ignition loss. An increase of 100 sq. cm per gm. increases 28-day heat of hydration about 2 cal. per gm.; 1-year heat about 1 cal. per gm. The strength-heat ratio is greater the higher the fineness, the lower the $3CaO.Al_2O_3$ content, and (at late ages) the higher the $2CaO.SiO_2$ content.

20. Raymond E. Davis, R. W. Carlson, J. W. Kelly, and G. E. Troxell. *Properties of Mortars and Concretes Containing High-Silica Cement.* Proc. Am. Conc. Inst., Vol. 30 (Mar.–Apr. 1934), p. 369 and Vol. 31, 1935 (Sept.–Oct. 1934), p. 33.

Types of high-silica cements; historical notes; interpretation of past experience and research; research program at University of California; discussion of test results.

21. United States Bureau of Reclamation. *Portland Cement for Boulder Dam.* U. S. Bur. Reclamation Spec. No. 566.

Purchase specifications for low-heat cement for Boulder Dam. Following limits placed on computed compounds:

Tricalcium silicate	Not more than 40 percent.
Dicalcium silicate	Not more than 65 percent.
Tricalcium aluminate	Not more than 7 percent.
Tetracalcium alumoferrite	Not more than 20 percent.

The specific surface must be not less than 1,700 nor more than 2,300 cm^2 per gm. The cumulative heat of hydration is limited to not more than 65 calories per gram at the age of 7 days and to not more than 75 calories per gram at the age of 28 days. Test methods are described.

22. R. A. Kinzie. *Perfection of High-Silica Cement by the Santa Cruz Portland Cement Co.* Min. and Met., Feb. 1934.

This cement is manufactured by grinding, with portland cement clinker, properly calcined mixture of siliceous material and lime; flow sheet as of Aug. 1933; test data on physical characteristics of high-silica cement; has utility of portland cement, together with increased resistance to destructive action of many aggresive solutions.

23. S. C. Pierce and H. McC. Lamour. *Simple Apparatus for Testing Cement Characteristics.* Eng. News Rec., Vol. 112, Jan. 25, 1934, p. 114.

Description of inexpensive testing device developed at Yosemite Portland Cement Co., Merced, Calif., for making heat of hydration and volume change determinations; tests indicate wide range of characteristics in commercial cements.

24. R. W. Carlson. *The Vane Calorimeter.* Proc. Am. Soc. Test. Mat.; Vol. 34, Part 2, 1934, p. 322.

A type of calorimeter which can be used for measuring heat of hydration of neat-cement pastes while curing at substantially constant temperature. Comparison of results from this calorimeter and from the heat of solution calorimeter indicate that satisfactory accuracy is obtained using the Vane calorimeter. It consists essentially of a metal cup connected by radial metal veins to a surrounding copper shell. The rate of heat generation of the hydrating cement in the metal cup is determined as a function of the temperature differential between the specimen and the surrounding surface, which is maintained at constant temperature.

25. Wm. Lerch and R. H. Bogue. *Heat of Hydration of Portland Cement Pastes.* Bur. Stds. Jour. Research Paper 684, Vol. 12, 1934, p. 645.

Two methods of obtaining heat of hydration determined for four major compounds of cement; computing total heat liberated at any age; apparatus and experimental procedure; heat evolved on complete hydration; determination of rate of heat evolution and effect of surface area on this rate.

26. B. W. Steele. *Mass Concrete for Boulder Dam—Its Development and Characteristics.* Eng. News Rec., Vol. 111, Dec. 21, 1933, p. 737.

Size and construction speed dictate new provisions to control heat and shrinkage cracks; properties of the aggregate and mix and advantages of the special low-heat cement. Problems of placing and cooling the concrete.

27. S. B. Morris. *Special Low-Heat Cement for Mass Concrete.* Jour. Am. Water Works Assn., Vol. 25, Oct. 1933, p. 1350.

Specifications for low-heat value cement in Pine Canyon Dam, discussion by T. Merriman.

28. C. S. Rippon and L. J. Snyder. *Thermal Properties of Mass Concrete.* Proc. Am. Conc. Inst., Vol. 30, 1934 (Sept.–Oct. 1933), p. 35.

Thermal properties requisite to intelligent prediction of internal temperature conditions and to rational design and operation of adequate and economical cooling system for Boulder Dam.

29. H. S. Meissner. *Development of Large Calorimeter Rooms and Automatic Temperature Controls for Adiabatic Curing of Mass Concrete.* Proc. Am. Conc. Inst., Vol. 30, 1934 (Sept.-Oct. 1933), p. 21.

Adiabatic curing of concrete test specimens to determine heat generation, volume change, and other characteristics under conditions simulating those within a mass studied at Denver in connection with Boulder Dam.

30. R. F. Blanks. *Comparison of Selected Portland Cements in Mass Concrete Tests.* Proc. Am. Conc. Inst., Vol. 30, 1934 (Sept.-Oct. 1933), p. 9.

Heats of hydration of cements determined and contribution of each cement compound computed at ages to 90 days.

31. Raymond E. Davis, R. W. Carlson, G. E. Troxell, and J. W. Kelly. *Cement Investigations for Hoover Dam.* Proc. Am. Conc. Inst., Vol. 29, 1933 (June 1933), p. 413.

Program of investigation, testing apparatus and methods, heat of hydration of cement and relation to compressive strength of mortar; effect of variations in curing temperature on heat of hydration and strength, water-cement ratio of concrete of fixed consistency, and measurement of cement fineness.

32. Hubert Woods, Harold H. Steinour and Howard R. Starke. *Heat Evolved by Cement in Relation to Strength.* Eng. News Rec., Vol. 110, Apr. 6, 1933, p. 431.

One-year records of heat evolution and strength development and equations for computing their values; choice of cements for mass concrete.

33. B. W. Steele. *Mass Concrete Research for Hoover Dam.* Proc. Am. Conc. Inst., Vol. 29 (Mar.-Apr. 1933), p. 305.

Results of experimental research of concrete containing aggregates up to cobble size; volume change; foundation and contraction joint grouting; mass cncrete strength and mix proportions; permeability.

34. Rock Products. *Pozzolanic Materials and Blended Cements.* Rock Prod., Feb. 25, 1933, p. 31.

Pozzolanic materials have real value, especially where they can be kept wet for a long time and where concrete is likely to be attacked by sea water or ground water; their effect is due to active silica combining with lime that is free in cement or liberated in setting process.

35. P. H. Bates. *Status of Specifications for Hydraulic Cements in the United States.* Proc. Am. Soc. Test. Mat., Vol. 33, Part II, 1933, p. 462.

Uses of hydraulic cements and service conditions they must meet. Possibility of one type of cement being able to meet adequately the various demands. Properties of various types of cement and their adaptability to various services. Various requirements of present portland cement standards of A. S. T. M. need for several kinds of cement for various uses.

36. R. W. Carlson and G. E. Troxell. *Effect of Adding a Siliceous Material to Portland Cements Upon Volume Changes, Compressive Strength, and Heat Generation.* Proc. Am. Soc. Test. Mat., Vol. 33, Part 2, 1933, p. 484.

Advantages to be derived from blending of siliceous materials with portland cements, particularly with reference to mass concrete construction. Results of a series of tests to determine volume changes, compressive strength, and heat of hydration. The variables in these tests are calcination temperature of the silica, chemical composition of the cement with which the silica is blended, curing condition, method of blending and proportions of silica and cement. These variables determine whether blending leads to favorable or unfavorable properties. Further study warranted by results.

37. S. B. Biddle, Jr., and J. W. Kelly. *Calorimeter Installation for Studies of Heat Generation in Mass Concrete.* Proc. Am. Soc. Test. Mat., Vol. 33, Part 2, 1933, p. 571.

System of calorimeters and curing chambers employed for Boulder Dam investigations of heat generated by 96 cements, during hydration and curing of specimens for strength and volume-change tests, under variable temperature conditions corresponding to those in mass concrete.

38. J. L. Savage. *Hoover Dam Cement Specifications Tentatively Formulated.* Eng. News Rec., Vol. 109, Nov. 10, 1932, p. 558.

Reclamation Bureau engineers and consulting boards decide to call for two cements of low and moderate heat evolution, fineness to be rated by surface area; briquet replaced by crushing test on cylinder.

39. Hubert Woods, Harold H. Steinour, and Harold R. Starke. *Effect of Composition of Portland Cement on Heat Evolved During Hardening.* Ind. and Eng. Chem., Vol. 24, Nov. 1932, p. 1207.

Theory of heat evolution, calorimeter design, preparation of clinker, storage of cement pastes, experimental data, method of mathematical analysis, application of results to commercial cements and practice.

40. R. W. Carlson. *Development of Low-Heat Cement for Mass Concrete.* Eng. News Rec., Vol. 109, Oct. 20, 1932, p. 461.

Size of modern concrete dams and construction speed intensify problems of cracking. Present cements generate high heat during hydration. Modification of chemical composition retards and reduces heat rise.

41. Hubert Woods, Howard R. Starke, and Harold H. Steinour. *Effect of Cement Composition on Mortar Strength.* Eng. News Rec., Vol. 109, Oct. 13, 1932, p. 435.

Summary of second phase of studies on composition of portland cement conducted by research department of Riverside Cement Co. of California; high tricalcium silicate gives early strength in standard sand mortars and high dicalcium silicate gives increased strength after first month.

42. Hubert Woods, Howard R. Starke, and Harold H. Steinour. *The Heat Evolved by Cement During Hardening.* Eng. News Rec., Vol. 109, Oct. 6, 1932, p. 404.

Tests of cements determine influence of composition on heat evolved during hardening. Tables and figures. Portland cements evolve heat during hardening for long periods of time. The compounds ranked in order of descent in heat evolution during the first 3 days are tricalcium aluminate, tricalcium silicate, tetracalcium alumoferrite, and beta-dicalcium silicate.

43. Engineering News Record. *Special Low-Heat Cement for Pine Canyon Dam.* Eng. News Rec., Vol. 109, Oct. 6, 1932, p. 404.

Requirements include: (1) cumulative heat of hydration must not exceed 65 cal. per gm. cement at 7 days, and 80 cal. at 28 days; (2) tricalcium aluminate must not exceed 6 percent by weight; and (3) fineness to be 85 and 98 percent on 200-mesh sieve. Standard mortar compression specimen to show 2,000 lb. at 28 days, but 28-day strength to be at least 35 percent higher than 7-day strength.

44. S. L. Meyers. *Heat Developed by Cement While Setting and Hardening.* Rock Products, Vol. 35, Sept. 24, 1932, p. 22.

Sources of heat generated, rate of heat generation by hydration, hydration of $4 CaO.Al_2O_3.Fe_2O_3$; effect of surface variation and prehydration on heat generation, condition of grouts after 3 days, determination of specific heat, calculated heat generated in a dam. Particle size and prehydration affect rate of heat liberated and, therefore, its time temperature relation.

45. Thaddeus Merriman. *Durability of Portland Cement.* Eng. News Rec., Vol. 104, Jan. 9, 1930, p. 62. Discussions; E. N. R., July 23, Aug. 20, 1931.

New method of sugar solubility test used. Instead of evaluating cements on basis of their solubility in sugar solutions, the difference in titratable alkalinity of each solution when the titration is made with two different indicators: phenolphthalein and methyl orange. The differences are then compared with the conditions of test briquets after storage in sulphate solution. Author concludes that the concordance "is so striking as to leave practically no room for doubt as to value of this indicator as a measure of durability." Relationship occurs between index values and Al_2O_3 content. He suggests limiting index value to 5.8 and alumina to 5.7.

46. Raymond E. Davis and G. E. Troxell. *Temperatures Developed in Mass Concrete and Their Effect Upon the Compressive Strength.* Proc. Am. Soc. Test. Mat., Vol. 31, Part 2, 1931, p. 576.

Results of field observations made by various investigators upon mass-concrete structures to determine temperatures developed during hardening period, and laboratory tests made under direction of authors to determine compressive strengths of concrete cured under conditions duplicating those found.

47. Raymond E. Davis and G. E. Troxell. *Properties of Mass Concrete.* Proc. Am. Conc. Inst., Vol. 27, 1931 (Dec. 1930), p. 385. Discussion Proc. A. C. I., Vol. 27, 1931 (May 1931) p. 1165.

Report Committee 108: Summary of existing data with suggested program of research. Tests at Boonton Dam, Panama Canal Locks, Des Moines Arch Bridge, Arrowrock, Ashokan, Reservoir Bridge, Kensiro Dam, East Canyon Creek Dam, tests at University of Illinois, Emigrant Creek Dam, Calderwood and Wilson Dams, Stevenson Creek, Minneapolis Bridge, Pardee Dam, Putnam Co. Arch Bridge, Chute a Caron, University of California.

48. AM. CONC. INST., REPORT COM. 202, P. H. BATES, Chairman. *Variations in Standard Portland Cement.* Proc. Am. Conc. Inst., Vol. 26, 1930 (Nov. 1929), p. 107. Discussion: Proc. A. C. I., Vol. 26, 1930 (March 1930), p. 597.

No such thing as standard portland cement; variations in early strength, late strength, permeability, shrinkage and plastic yield; chemical heat of setting in large masses; internal stresses in concrete dams are due to heat evolution during setting and resulting shrinkage during cooling; reactions to curing conditions.

49. AM. CONC. INST., REPORT OF COMITTEE 102, R. E. DAVIS, Chairman. *A Summary of the Results of Investigations Having to Do With Volumetric Changes in Cement, Mortars and Concretes, Due to Causes Other Than Stress.* Proc. Am. Conc. Inst., Vol. 26, 1930, p. 407.

Summary has been prepared with view of bringing together results of what are considered to be some more important investigations in this field; changes due to variations in temperature; volume changes as affected by moisture conditions.

50. J. B. LIPPINCOTT. *Blending Fresno Pumicite With Cement.* West. Constr. News, May 1929, p. 243.

Analysis of Fresno pumicite; tests of setting time; tensile strength; compression strength; sieve analysis of pumicite; Fresno pumicite is unique on account of its extreme fineness and uniformity, which should give to it greater cementaceous properties than coarser materials of same chemical properties.

51. A. H. WHITE. *Volume Change of Portland Cement as Affected by Chemical Composition and Ageing.* Proc. Am. Soc. Test. Mat., Vol. 28, Part II, 1928, p. 398.

Summary of results of tests on volume change of cement which have been conducted over a period of 26 years; it shows graphically volume changes of 12 bars of neat cement representing 6 brands of commercial cement and 34 expansion bars prepared from 16 cements burned in laboratory covering very wide range in composition; cements relatively low in alumina and high in iron oxide show lowest volume changes with variations in moisture.

52. WM. LERCH and R. H. BOGUE. *Studies of the Hydrolysis of Compounds Which May Occur in Portland Cement.* Jour. of Phys. Chem., Vol. 31, Nov. 1927, p. 1627.

Hydrolysis of several compounds which may occur in portland-cement clinker have been investigated under various conditions.

53. J. R. BAYLIS. *Relation Between the Characteristics of Portland Cement and the Deterioration of Concrete.* Concrete, Vol. 31, July, Aug., Sept., Oct., Nov., 1927.

Discussion of some characteristics of portland cement and concrete for purpose of arriving at clear understanding of why some concrete remains good and why some disintegrates; some suggestions for improving durability of concrete. July: Characteristics of portland cement. Aug.: Compounds in solution during setting of cement. Sept.: Corrosion of concrete. Oct.: Reaction of high calcium cement compounds with other widely distributed compounds. Nov.: Improving durability of cement.

SUMMARY

This paper is a brief summary of a comprehensive treatise on the subject of special cements for mass concrete, which was prepared for the Second Congress on Large Dams and published by the United States Bureau of Reclamation.

One of the most serious mass concrete problems is the control of volume changes due to temperature variations during and subsequent to construction. Observations at Boulder Dam indicate that the placing temperature may have a more important bearing on the temperature drop and consequent shrinkage of the concrete than any reduction based on the heat-generating characteristics of the cement. Volume changes may be due also to climatic conditions, the character of the foundation, the methods and rate of construction, and the thermal, elastic and plastic properties of the concrete.

The effect of the type of cement upon the durability of a mass concrete dam is much less than that of the other ingredients or the construction methods employed. The cement influences resistance of the concrete to weathering and aggressive waters and dissolution by percolation. Use of the proper type of cement may materially reduce the initial cost or improve the quality so as to minimize maintenance costs.

For smaller dimensions, such as might be found in thin arch dams, the average maximum temperature attained by the concrete might be reduced as much as 10° to 15° F. by the use of low-heat cement.

Low-heat portland cement was used in the construction of the Morris Dam in California and, in conjunction with artificial cooling, in the building of Boulder Dam. Both of these have developed unusually little cracking. Low-heat cement was used to advantage also in the slab-and-buttress type Rodriquez Dam in Mexico.

Normal portland cement used at Owyhee Dam showed extensive cracks due to weather and other conditions as well as the type of cement.

At Norris Dam, where a modified cement containing a lower percentage of tricalcium aluminate was used with no artificial cooling, surface cracks developed.

The use of sulphate-resistant portland cement in the massive concrete piers and anchorages of the San Francisco-Oakland Bay Bridge and the Golden Gate Bridge gives promise of much greater resistance to the corrosive effects of exposure to sea water than if normal portland cement had been used. "High-silica," a portland-pozzolana cement, was also used in parts of these structures. Time will determine which of these two cements has a greater resistance to sea water.

Bonneville Dam in Oregon is being built with portland-pozzolana cement in combination with a rather lean mix, low placing temperatures and a modified rate of construction. It is still too early to warrant conclusions, but there has been very little cracking so far.

Recent laboratory investigations conducted in the United States have resulted in much new information concerning the chemical and physical properties of cements. The National Bureau of Standards tested 51 commercial cements, and at the University of California some 50 special cements were manufactured, burned and ground in the laboratory to provide a wide range of variable compositions for the tests.

It was shown that tricalcium silicate and dicalcium silicate are the chief strength-giving compounds in portland cement. Finer grinding also improves the strength. High initial temperature of mass curing is detrimental to ultimate compressive strength.

Different types of cement exhibit marked differences in heat of hydration, in resistance to freezing, thawing, and the aggressive action of sulphate waters, in workability, tensile strength, extensibility, permeability, and other properties.

The author discusses the mathematical analysis of temperature movements in mass concrete. The mathematical approach to the thermal history is an important step in evaluating the contribution of special cements to the thermal control of concrete. It is possible to determine mathematically the loss of heat at any point in a structure or the temperature distribution through the mass at any time.

RESUME

Ce rapport est le résumé sommaire d'un traité très étendu sur les ciments spéciaux pour les bétons massifs, traité préparé pour le Deuxième Congrès des Grands Barrages et publié par le "Bureau of Reclamation" des États-Unis.

Un des problèmes les plus importants que présente le béton massif est celui du contrôle des changements de volume dus aux variations de température pendant et après la construction. Des observations effectuées au Barrage Boulder indiquent que la température de mise peut exercer, sur la baisse de la température et sur le retrait conséquent du béton, une influence plus importante que toute réduction basée sur les caractéristiques de dégagement de chaleur du béton. Les changements de volume peuvent être également dus aux conditions climatiques, au caractère des fondations, aux méthodes et à la rapidité de construction, et aux propriétés thermiques, élastiques et plastiques du béton.

L'effet du type de ciment sur la durabilité d'un barrage en béton massif est beaucoup moins important que celui des autres ingrédients ou des méthodes de construction employées. Le ciment influence la résistance du béton à l'intempérie, aux eaux aggressives, et à la dissolution par percolation. L'emploi d'un type convenable de ciment peut réduire sensiblement les premiers frais et améliorer la qualité du béton, de sorte que les frais d'entretien seront réduits.

Pour les barrages de dimensions plus petites, comme par exemple les barrages voûtes minces, la température maxima moyenne atteint par le béton pourrait être réduite autant que 10° ou 15° F. par l'emploi d'un ciment à température basse.

Le ciment portland basse-température a été employé pour la construction du Barrage Morris en Californie et du Barrage Boulder, dans ce dernier conjointement avec le refroidissement artificiel. Il ne s'est produit, dans l'un et l'autre, que très peu de fissures. Le ciment basse-température a également été employé au Mexique, pour le Barrage Rodriquez, du type à dallage et contreforts, et a donné satisfaction.

Le ciment portland ordinaire utilisé pour le Barrage d'Owyhee a révélé des fissures importantes dues aux conditions atmosphériques et à d'autres raisons aussi bien qu'au type de ciment.

Au Barrage Norris, où l'on a employé un ciment modifié contenant un pourcentage plus bas d'aluminate de tricalcium, sans refroidissement artificiel, des fissures se sont produites à la surface.

L'emploi de ciment portland résistant au sulphate, pour les piles et ancrages massifs de béton du pont de San Francisco-Oakland et du pont de la Golden Gate, permet d'escompter une résistance beaucoup plus grande à l'action corrosive de l'eau de mer que si l'on avait employé du portland ordinaire. Un ciment portland-pozzolane, dit "high-silica," a été également utilisé pour certaines parties de ces constructions. L'avenir déterminera lequel de ces deux ciments offre la plus grande résistance à l'eau de mer.

Le Barrage de Bonneville, en Oregon, est en cours de construction au moyen d'un ciment portland-pozzolane, combiné dans un béton assez maigre. Les températures de mise sont basses, et le taux de construction est modéré. Il est encore trop tôt pour tirer des conclusions définitives, mais jusqu'à présent il ne s'est produit que très peu de fissures.

De récentes récherches de laboratoire effectuées aux États-Unis ont amené la découverte de nombreuses nouvelles données relatives aux propriétés physiques et chimiques du ciment. Le "National Bureau of Standards" a soumis à des essais cinquante-et-un types commerciaux de ciment; et, à l'Université de Californie, environ cinquante ciments spéciaux ont été fabriqués, brûlés, et pulverisés au laboratoire, pour assurer une échelle très variée de compositions diverses, destinées aux essais.

Il a été démontré que le silicate de tricalcium et le silicate de dicalcium sont les principaux composés qui assurent au ciment portland sa résistance. Une pulvérisation plus fine améliore également la résistance. Une haute température initiale est nuisible à la résistance à la rupture par compression.

Différents types de ciment montrent des différences notables sous les rapports de la chaleur d'hydration, de la résistance au gel et au dégel et à l'action corrosive des eaux sulphatées, aussi en ce qui concerne la maniabilité, la résistance à la traction, l'extensibilité, la perméabilité, et autres caractéristiques.

Le rédacteur étudie l'analyse mathématique des mouvements de température dans les bétons massifs. L'étude du point de vue mathématique de l'histoire calorifique constitue un progrès sensible dans l'évaluation de la contribution des ciments spéciaux au contrôle thermique du béton. Il est possible de déterminer mathématiquement la déperdition de chaleur en n'importe quel point de la construction, ou la distribution de la température dans l'ensemble de la masse à n'importe quel moment.

ZUSAMMENFASSUNG

Dieser Bericht ist eine kurze Zusammenfassung einer umfangreichen Abhandlung über Spezialzemente für Betonmassen, die für den Zweiten Talsperrenkongress vorbereitet und von dem "United States Bureau of Reclamation" veröffentlicht wurde.

Eines der grössten Probleme bei Betonmassen ist die Kontrolle der infolge Temperaturschwankungen während und nach der Konstruktion auftretenden Volumenänderungen. Beobachtungen am "Boulder Dam" zeigen, dass die Einführungstemperatur einen grösseren Einfluss auf den Temperaturrückgang und auf die darauf folgende Schrumpfung haben kann, als die wärmeerzeugenden Eigenschaften des Betons. Volumenänderungen können auch von klimatischen Verhältnissen, Beschaffenheit des Fundamentes, Baumethoden und Baugeschwindigkeit, sowie von den thermischen, elastischen und plastischen Eigenschaften des Betons herrühren.

Der Einfluss der Zementart auf die Dauerhaftigkeit einer Betonsperre ist viel geringer als der anderer Bestandteile und der angewandten Baumethoden. Der Zement beeinflusst die Widerstandsfähigkeit von Beton gegen Verwitterung und aggressive Wässer, sowie gegan Auflösung durch Sickerung. Die Verwendung der richtigen Zementart kann die Baukosten erheblich verringern oder die Qualität verbessern und auf diese Weise die Unterhaltungskosten vermindern.

Bei kleineren Ausmassen, wie sie bei dünnen Bogenstaumauern anzutreffen sind, kann die von dem Beton erreichte durchschnittliche Höchsttemperatur durch Verwendung von Zement mit niedriger Hydrationswärme um 10 bis 15° F reduziert werden.

Bei dem Bau des "Morris Dam" in Kalifornien wurde Portlandzement mit niedriger Hydrationswärme verwandt; ebenso bei dem "Boulder Dam" in Verbindung mit künstlicher Kühlung. Beide zeigen eine ungewöhnlich geringe Rissbildung. Zement mit niedriger Hydrationswärme wurde auch vorteilhaft bie der im "Platten- und Bogentyp" (slab-and-buttress type) erbauten Rodriquez-Staumauer in Mexiko verwandt.

Bei dem "Owyhee Dam" verwandter, gewöhnlicher Portlandzement zeigte infolge Wettereinwirkungen und anderer Verhältnisse, sowie auch wegen der Zementart, ausgedehnte Risse.

Bei dem "Norris Dam", wo ein besonderer Zement mit einem niedrigen Gehalt von Trikalzium-Aluminat und ohne künstliche Kühlung verwandt wurde, entstanden Risse an der Oberfläche.

Der bei den massiven Betonpfeilern und Fundamenten der San Francisco Oakland Bay Brücke und bei der Golden Gate Brücke verwandte sulfatfeste Portlandzement verspricht weit grösseren Widerstand gegen die ätzenden Wirkungen der Berührung mit dem Meerwasser, als wenn gewöhnlicher Portlandzement verwandt worden wäre. In Teilen der beiden Konstruktionen wurde auch ein Portland-Puzzolan-Zement "High-silica" verwandt. Die Zeit wird zeigen, welcher der beiden Zemente dem Meerwasser am besten Widerstand bietet.

Der "Bonneville Dam" in Oregon wird mit Portland-Puzzolan-Zement in Verbindung mit einer ziemlich mageren Mischung, einer niedrigen Einbringungstemperatur und einer bestimmten Baugeschwindigkeit errichtet. Es ist noch zu früh, Schlüsse zu ziehen; es haben sich aber indessen bis jetzt nur sehr wenige Risse gebildet.

Kürzlich in den Vereinigten Staaten durchgeführte Laboratoriums-Untersuchungen brachten als Ergebnis viele neue Aufschlüsse über die chemischen und physikalischen Eigenschaften von Zementen. Das "National Bureau of Standards" untersuchte 51 gewerbliche Zementarten, und an der Universität von Kalifornien wurden im Laboratorium ungefähr 50 Spezialzemente hergestellt, gebrannt und gemahlen, um eine grosse Anzahl von veränderlichen Zusammensetzungen für die Untersuchungen zur Verfügung zu haben.

Es zeigte sich, dass Trikalzium-Silikat und Dikalzium-Silikat die haupt stärkenden Bestandteile in Portlandzement sind. Auch feineres Mahlen verhöht die Festigkeit. Hohe Anfangstemperatur bei dem chemischen Prozess in der Betonmasse ist schädlich für die endgültige Druckstärke.

Verschiedene Zementarten zeigen deutliche Unterschiede in Hydrationswärme, Widerstand gegen Frost, Tauwetter und die aggressive Wirkung von Sulfat-Wässern, in Verarbeitbarkeit, Spannstärke, Dehnbarkeit, Durchlässigkeit und anderen Eigenschaften.

Der Verfasser behandelt auch die mathematische Analyse von Temperatur-Bewegungen in der Betonmasse. Die mathematische Annäherung an die thermischen Vorgänge ist ein wichtiger Schritt zur Bewertung der Bedeutung von Spezialzementen für die thermische Kontrolle von Beton. Es ist möglich, den Wärmeverlust an irgend einem Punkte des Bauwerkes oder die Temperatur-Verteilung durch die Betonmasse zu irdend einer Zeit mathematisch zu bestimmen.

RESUMEN

Esta memoria es un resumen de un extenso tratado sobre cementos especiales para hormigón de masa, que fué preparado para el Segundo Congreso de Grandes Presas y publicado por el "Bureau of Reclamation" de los Estados Unidos.

Uno de los problemas más importantes que presenta el hormigón de masa es el control de los cambios de volumen causados por las variaciones atmosféricas durante y despúes de la construcción. Las observaciones hechas en la Presa Boulder indican que la temperatura durante la colocación puede ejercer en el descenso de temperatura y en la consiguiente retracción del hormigón una influencia mucho mayor que ninguna otra reducción basada en las características de producir calor propias del cemento. Las variaciones de volumen también pueden ser causadas por las condiciones climáticas, el carácter de la fundación, los métodos y la duración de la obra, y por las propiedades térmicas, elásticas y plásticas del hormigón.

El efecto de la clase de cemento en la durabilidad de una presa de hormigón de masa es de menor importancia que los otros ingredientes o los otros métodos de construcción empleados. El cemento influye la resitsencia del hormigón contra los cambios atmosféricos y la acción de las aguas, y contra la disolución causada por la infiltración. El empleo del tipo de cemento adecuado puede reducir grandemente el costo inicial o mejorar la calidad, de forma que se reduzca al mínimo el costo de mantenimiento.

Para dimensiones más pequeñas, tales como las que peuden hallarse en las presas bóvedas delgadas, el promedio de temperatura máxima alcanzado por el hormigón puede llegar a reducirse de 10° a 15° F. usando cemento que produzca poco calor.

Esta clase de cemento portland se empleó en la construcción de la Presa Morris de California y, al mismo tiempo que la refrigeración artificial, en la construcción de la Presa Boulder. En ambos casos se han producido muy pocas grietas. También se empleó cemento que produce poco calor, con buenos resultados, en la Presa Rodríguez de Méjico.

El cemento Portland normal empleado en la Presa Owyhee presenta grandes grietas debidas al tiempo y a otras condiciones así como también al tipo de cemento.

En la Presa Norris, donde se empleó un cemento modificado que contenía una baja proporción de aluminato de tricalcio sin refrigeración artificial, aparecieron grietas en la superficie.

El empleo de cemento Portland resistente al sulfato en los pilares y anclajes de hormigón del Puente de San Francisco-Oakland Bay y del Puente Golden Gate promete una resistencia mucho mayor a los efectos corrosivos del contacto con el agua de mar que si se hubiera empleado cemento portland normal. Un cemento portland-puzolana, llamado "high-silica," también se usó en algunas partes de estas estructuras. El tiempo determinará cual de estos dos cementos ofrece mayor resistencia al agua de mar.

La Presa Bonneville, en Oregón, está siendo construída con cemento portland-puzolana, combinado con una mezcla bastante pobre, y colocado a bajas temperaturas y una duración de construcción modificada. Todavía es demasiado pronto para sacar conclusiones, pero hasta la fecha se ha notado muy poco agrientamiento.

Recientes estudios de laboratorio hechos en los Estados Unidos han suministrado mucha información nueva sobre las propiedades químicas y físicas de los cementos. El "National Bureau of Standards" hizo ensayos con cincuenta y un cementos comerciales, y en la Universidad de California se fabricaron unos cincuenta cementos especiales, se quemaron y molieron en el laboratorio a fin de obtener una gran diversidad de composiciones variables para los ensayos.

Se encontró que el silicato de tricalcio y el silicato de dicalcio son los principales compuestos para dar resistencia al cemento portland. Una pulverización más fina también mejora la resistencia. Una elevada temperatura inicial en el fraguado de la masa es perjudicial a la fuerza de compresión definitiva.

Diferentes clases de cemento presentan marcadas diferencias en el calor de hidratación, en la resistencia a las heladas, al deshielo y a la acción agresiva de las aguas que contienen sulfato, así como también en cuanto se refiere a la trabajabilidad, la resistencia de tensión, la extensibilidad, la permeabilidad y otras propiedades.

El autor discute el análisis matemático de los movimientos de temperatura en el hormigón de masa. El estudio matemático de la historia térmica es un paso importante para evaluar le contribución de los cementos especiales al control térmico del hormigón. Se puede determinar matemáticamente la pérdida de calor en cualquier punto de una estructura o la distribución de temperatura por toda la masa en cualquier momento.

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

ARBEITEN DES LABORATORIUMS FUER WASSERBAUSTOFFE DES WISSENSCHAFTLICHEN FORSCHUNGSINSTITUTS FUER HYDROTECHNIK (LENINGRAD) AUF DEM GEBIET DER UNTERSUCHUNG SPEZIELLER ZEMENTE DES WASSERBAUES*

Professor Dr. W. A. Kind
U. S. S. R.

Teil I

Im Wasserbau finden folgende Bindemittel Verwendung:

(1) Portlandzement.

(2) Hochofenzement mit grösserem oder kleinerem Gehalt von gekörnter basischer Hochofenschlacke.

(3) Tonerdezement.

(4) Romanzement.

(5) Hydraulischer Kalk.

(6) Kalk-Puzzolanzemente, welche Erzeugnisse einer fabrikmässig erhaltenen innigen Mischung pulverartigen Löschkalks mit dem vor-

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* *Research Work by the Hydrotechnical Laboratory of the Scientific Research Institute of Hydrotechnics in Leningrad on special cements for water-work constructions.*

Travaux du Laboratoire des Matériaux de Constructions Hydrauliques, de l'Institut Soviétique des Recherches Scientifiques d'Hydrotechnique, concernant l'étude des propriétés des ciments spéciaux pour constructions hydrauliques.

Trabajos del Laboratorio de Materiales de Construcciones Hidráulicas, del Instituto Soviético de Investigaciones Cientificas de Hidrotecnia, referentes al estudio de las propiedades de los cementos especiales para construcciones hidráulicas.

her in feines Pulver vermahlenen sauren hydraulischen Zusatz darstellen.

(7) Kalk-Schlackenzemente, welche Erzeugnisse einer fabrikmässig erhaltenen innigen Mischung pulverartigen Löschkalks mit der vorher in feines Pulver vermahlenen gekörnten basischen Hochofenschlacke darstellen.

Ausser den obengenannten Bindemitteln, fand in der U.d.S.S.R. während der letzten zwei Jahrzehnte der sogenannte Puzzolan-Portlandzement eine weite Verbreitung. Letzterer ist ein Erzeugnis, das beim Mahlen des Portlandzement-Klinkers zusammen mit sauren hydraulischen Zuschlägen (Puzzolanen), wie z.B. Trass, Diatomeenerde, Si-Stoff, geglühter Ton u.s.w. erhalten wird.

Die letzte Art des Bindemittels in der U.d.S.S.R. wird ausschliesslich fabrikmässig hergestellt, wobei die Zusatzmenge im fertigen Produkt, in Abhängigkeit von den Zusatzeigenschaften, in den Grenzen von 30 bis 50% (vom Gewicht des fertigen Produktes) schwankt. Zur Zeit haben folgende Zemente die grösste Verbreitung in der U.d.S.S.R. gefunden: (1) Puzzolan-Portlandzement mit Trass (50% Portlandzement 50% Trass) und (2) Puzzolan-Portlandzement mit Trepel oder Diatomeenerde (70% Portlandzement 30% Diatomeenerde).

Von allen obengenannten Bindemitteln können Betone genügender Festigkeit für den Bau verantwortlicher hydrotechnischer Bauwerke (zu denen vor allem hohe Wehre zugezählt werden müssen) nur bei Verwendung folgender vier Zementarten erhalten werden:

(1) Portlandzement.
(2) Hochofenzement.
(3) Tonerdezement.
(4) Puzzolan-Portlandzement.

Was jedoch die übrigen hydraulischen Bindemittel anbetrifft, so werden sie wegen ihrer verhältnismässig geringen Festigkeit und bedeutend langsameren Erhärtens nur für den Bau hydrotechnischer Bauwerke mit weniger hohen Anforderungen an den Beton verwendet; für den Bau hoher Wehre können sie selbstverständlich nicht angewendet werden.

Man muss annehmen, dass auch Tonerdezement, obwohl er auch Betone überaus hoher Eigenschaft erzeugt, in den nächsten Jahren für den Bau massiver hydrotechnischer Bauwerke keine Verwendung finden wird, weil er erstens ein sehr teueres Bindemittel ist und zweitens in kleinen Mengen wegen begrenzter Tonerdevorräte, die zudem als Rohstoff für die Gewinnung des Metall-Aluminiums dienen, hergestellt wird.

Demgemäss können als Bindemittel beim Bau hoher Wehre praktisch bloss drei Zementarten benutzt werden: (1) Portlandzement, (2) Hochofenzement, und (3) Puzzolan-Portlandzement.

Es sei hierbei bemerkt, dass beinahe bis zur allerletzten Zeit der Bau hoher Wehre hauptsächlich auf der Verwendung von Portlandzement gegründet wurde. Die zwei anderen Bindemittel wurden jedoch für diesen Zweck beinahe garnicht verwendet, obwohl sie nach ihren Eigenschaften, wie es weiter ausführlich erörtert wird, sich bedeutend mehr für die Herstellung hydrotechnischen Betons eignen. Die Vorzüge des Hochofenzementes und namentlich des Puzzolan-Portlandzementes vor dem Portlandzement ohne hydraulische

Zuschläge sind in den Betrielsverhältnissen der hydrotechnischen Bauwerke so gross, dass diese Zemente mit vollem Recht zu den speziellen Zementen für die Herstellung des wasserdichten hydrotechnischen Betons gezählt werden können.

In ihren Untersuchungen, deren Hauptzweck die Ermittelung neuer wasserbeständiger Zemente und Betone ist, hat das Laboratorium der Hydrobaustoffe des Wissenschaftlichen Forschungsinstituts für Hydrotechnik eine besondere Aufmerksamkeit der Vergleichs-Untersuchung der Eigenschaften obenerwähnter drei Arten von Bindemitteln, in bezug auf die an den Beton in hydrotechnischen Bauwerken gestellten Anforderungen gewidmet.

Wie bekannt, werden an den hydrotechnischen Beton, ausser den Anforderungen hinsichtlich Festigkeit, noch hohe Anforderungen in bezug auf die *Wasserbeständigkeit* im vollen Sinne dieses Wortes gestellt.

Ungenügende Wasserbeständigkeit des Betons in hydrotechnischen Bauwerken ruft eine Reihe von Erscheinungen hervor: (1) die Auflösung (Auslaugung) des freien Kalkes aus den Portlandzement-Betonen, (2) die Einwirkung der sich im Wasser befindlichen Salze auf den Beton, (3) die Entstehung von Rissen im Beton infolge des Schwindens, der Wärmeprozesse u.s.w.

All die obenerwähnten Erscheinungen können auf folgende drei Arten bekämpft werden:

(1) durch die Wahl und Verwendung von Bindemitteln und Zuschlagstoffen erhöhter Wasserbeständigkeit,

(2) durch die Wahl der Betonzusammensetzung, ausgehend aus den Verhältnissen seiner grösseren Festigkeit und folglich kleineren Wasserdurchlässigkeit,

(3) durch Einhaltung einer Reihe von Massnahmen für richtiges Betonieren und estsprechende Nachbehandlung des erhärtenden Betons.

Im Zusammenhang mit den obenangeführten Bestimmungen betreffs der Verfahren zur Erhöhung der Wasserbeständigkeit des Betons, hat das Laboratorium der Hydrobaustoffe des Wissenschaftlichen Forschungsinstituts für Hydrotechnik ihre Untersuchungsarbeiten zur Ermittelung effektiver Massnahmen zur Bekämpfung der zerstörenden Einwirkung verschiedener Wässer auf hydrotechnische Betone ausgeführt.

Im Folgenden werden bloss diejenige von den bei diesen Untersuchungen erhaltenen Ergebnissen beschrieben, welche den Einfluss der Bindemitteleigenschaften auf die Wasserbeständigkeit des hydrotechnischen Betons charakterisieren. Diese Untersuchungen wurden von den wissenschaftlichen Arbeitern: Dipl. Ing. P. I. Gluschge, W. W. Kind, S. D. Okorokow und I. D. Saporoshetz unter der wissenschaftlichen Hauptleitung des Professor-Doktors W. A. Kind ausgeführt.

Bei der Erforschung des Einflusses der Eigenschaften spezieller Zemente auf die Wasserbeständigkeit des Betons wurden folgende vier Richtungen eingehalten:

(1) Einfluss auf die Wasserdurchlässigkeit des Betons,

(2) Einfluss auf die Auslaugung des Kalkes aus dem Beton bei Durchsickerung des Wassers,

(3) Einfluss auf das Verhalten des Betons in Mineralwässern, und
(4) Einfluss des Bindemittels auf das Schwinden des Betons.

TEIL II

Die Wasserdurchlässigkeit der Baumörtel und Betone aus verschiedenen Zementen wurde mit Hilfe des Gerätes der Schweizerfirma Amsler festgestellt. Vorversuche mit verschiedenen speziellen Zementen wurden durch Prüfung der selben in Mörtelmischungen: 1:2, 1:3 und 1:4 mit Zusatz ein und desselben Sandes ausgeführt. Die Mörtelversuchsprobekörper hatten die Form eines abgestumpften Kegels von 2 cm Höhe, mit einem Durchmesser der oberen Fläche von 5 cm und der unteren von 6 cm. Beim Versuch ging das Wasser durch eine Kreisflache von 5 cm Durchmesser.

Für die Charakteristik der Wasserdurchlässigkeit der Mörtel wurde derjenige Druck ermittelt, bei welchem die Probekörper bei gewissen (für alle Proben gleichen) Prüfungsverhältnissen anfingen das Wasser durchzulassen. Für diesen Zweck wurden alle Versuchsproben im Gerät einem allmählich sich erhöhenden Druck unterworfen, wobei derselbe nach gewissen Zeitabschnitten in vorher festgesetzten Stufen geändert wurde.

Die Ergebnisse dieser Versuche werden in der Tabelle 1 für Mörtel im Alter von 28 Tagen und in der Tabelle 2 für Mörtel im Alter von 14 Tagen bis 4 Monaten widergegeben.

Die in der Tabelle 1 bezeichneten Ergebnisse ermöglichen den vom Standpunkt der Wasserdurchlässigkeit relativen Wert verschiedener Bindemittel festzustellen. Aus 16 geprüften Zementen, wie aus der Tabelle 1 ersichtlich, besitzt der Puzzolan-Portlandzement mit 40% Si-Stoffgehalt die kleinste Wasserdurchlässigkeit. Ein Vergleich der zu den Puzzolan-Portlandzementen und Hochofenzementen bezüglichen Angaben mit den Ergebnissen der Versuche der Mörtel aus reinem Portlandzement ohne Zuschläge gestattet folgende Schlüsse zu ziehen:

TABELLE 1.—*Abhängigkeit der Wasserdurchlässigkeit der Baumörtel von der Art des Bindemittels (Probekorper von 2 cm Dicke; Alter der Probekorper, 28 Tage)*

Nr.	Bindemittel	Druck in Atmosphären, bei dem die Proben anfangen das Wasser durchzulassen; Mörtelzusammensetzung nach Gewicht:		
		1:9	1:3	1:4
1	Portlandzement	>10, 0	5, 0	2, 0
	Puzzolan-Portlandzement:			
2	mit 20% Gehalt von Brjansky Diatomeenerde	>10, 0	10, 0	2, 0
3	mit 30% Gehalt von Brjansky Diatomeenerde	>10, 0	10, 0	3, 5
4	mit 40% Gehalt von Brjansky Diatomeenerde	>10, 0	10, 0	2, 0
5	mit 20% Si-Stoff	>10, 0	5, 0	2, 0
6	mit 30% Si-Stoff	>10, 0	10, 0	5, 0
7	mit 40% Si-Stoff	>10, 0	>10, 0	5, 0
8	mit 20% Naltschik-Asche	>10, 0	3, 5	1, 0

TABELLE 1.—*Abhängigkeit der Wasserdurchlässigkeit der Baumörtel von der Art des Bindemittels (Probekörper von 2 cm Dicke; Alter der Probekörper, 28 Tage)*—Fortsetzung

Nr.	Bindemittel	Druck in Atmosphären, bei dem die Proben anfangen das Wasser durchzulassen; Mörtelzusammensetzung nach Gewicht:		
		1:9	1:3	1:4
	Puzzolan-Portlandzement—Fortsetzung.			
9	mit 30% Naltschik-Asche	10, 0	2, 0	0, 5
10	mit 40% Naltschik-Asche	10, 0	2, 0	0, 5
11	mit 40% Karadagsky Trass	>10, 0	3, 5	1, 0
12	mit 50% Karadagsky Trass	10, 0	2, 0	1, 0
13	mit 60% Karadagsky Trass	5, 0	1, 0	0, 5
	Hochofenzement:			
14	mit 30% Hochofenschlacke	10, 0	10, 0	2, 0
15	mit 50% Schlacke	>10, 0	5, 0	1, 0
16	mit 70% Schlacke	10, 0	2, 0	1, 0

TABELLE 2.—*Abhängigkeit der Wasserdurchlässigkeit der Baumörtel von der Erhärtungsdauer*

Nr.	Bindemittel	Mörtel 1:3.—Druck in Atmosphären, bei dem die Probekörper anfangen das Wasser durchzulassen (Erhärtungsdauer)				Mörtel 1:4.—Druck in Atmosphären, bei dem die Probekörper anfangen das Wasser durchzulassen (Erhärtungsdauer)			
		14 Tage	28 Tage	2 Monate	4 Monate	14 Tage	28 Tage	2 Monate	4 Monate
1	Portlandzement	2, 0	5, 0	5, 0	10, 0	0, 5	2, 0	3, 5	7, 5
	Puzzolan-Portlandzement:								
2	mit 30% Diatomeenerde	2, 0	10, 0	>10, 0	>10, 0	0, 5	3, 5	10, 0	10, 0
3	mit 30% Si-Stoff	2, 0	10, 0	>10, 0	>10, 0	0, 5	5, 0	5, 0	7, 5
4	mit 40% Trass	2, 0	3, 5	10, 0	10, 0	0, 5	1, 0	5, 0	10, 0
5	Hochofenzement mit 50% Schlacke	1, 0	5, 0	5, 0	10, 0	1, 0	1, 0	3, 5	7, 5

1. Die Beimengung solcher sauren hydraulischen Zuschläge, wie Diatomeenerde und besonders Si-Stoff, übt einen sehr grossen Einfluss auf die Wasserdurchlässigkeit der Betonmörtal aus.

2. Der Ersatz eines Teiles des Portlandzementes durch vulkanische Asche und Trass erhöht ein wenig die Wasserdurchlässigkeit der Mörtel im 28-tägigen Alter. Es sei jedoch bemerkt, dass für die letzteren zwei Zuschläge das Obengesagte bloss für kurze Erhärtungsdauer gilt; mit fortschreitendem Alter (schon ca. nach 2–3 Monaten) holen die Puzzolan-Portlandzemente mit solchen Zuschlägen den Portlandzement in bezug auf die Wasserdichtigkeit ein und überholen ihn sogar. (Siehe Tabelle 2—Wasserdurchlässigkeit der Mörtel verschiedenen Alters.)

3. Die gekörnte basische Hochofenschlacke kann die Wasserdurchlässigkeit des Mörtels erhöhen und auch erniedrigen, in Abhängigkeit davon, in welcher Menge sie zum Zement zugesetzt ist. Aus den in der Tabelle 1 angeführten Ergebnissen zur Ermittelung der Wasser-

durchlässigkeit der drei Hochofenzemente ist es ersichtlich, dass bei 30% Schlacke im fertigen Produkt der Hochofenzement in der Wasserdichtigkeit den Portlandszement übersteigt, bei 50% — in der Wasserdichtigkeit ihm gleich ist, und bei 70% — dem Portlandzement nachsteht. Es sei hierbei bemerkt, dass von den drei untersuchten Hochofenzementen der Zement mit 30% Schlackengehalt die grösste Festigkeit besass.

Diejenige Bindemittel, mit welchen günstige Ergebnisse in Mörtelmischungen erzielt wurden, also Puzzolan-Portlandzement und Hochofenzement, wurden zur Ergänzung noch in Betonmischungen auf Wasserdurchlässigkeit geprüft.

Die Betonprobekörper wurden gleich den Mörtelprobekörpern mit Hilfe des Amsler-Gerätes geprüft; sie besassen die Form eines abgestumpften Kegels von 15 cm Höhe mit 15 cm Durchmesser der oberen Fläche und 19 cm — der unteren.

Der Wasserdruck wurde alle 12 Stunden in folgenden Stufen geändert: 2, 5, 10, 20, 35, and 50 Atmosphären. Die Wasserdurchlässigkeit der Probekörper bei diesen Prüfungsverhältnissen kann am leichtesten durch die durchgesickerte Wassermenge charakterisiert werden.

Aus einer grossen Anzahl der im Laboratorium ausgeführten Versuche werden als Beispiel in der Tabelle 3 bloss einige Ergebnisse angeführt.

TABELLE 3.—*Abhängigkeit der Wasserdurchlässigkeit des Betons von der Art des Bindemittels*

BETONZUSAMMENSETZUNG 1:6 NACH RAUMTEILEN

[1:7,46 nach Gewichtsteilen]

Alter.	Druck in Atmosphären	Zeit in Stunden	Wassermenge in cm,³ die durch den ganzen Probekörper vom Versuchsbeginn an durchgesickert ist			
			Novorossiisky Portlandzemente	Hochofenzement mit 60% Schlacke	Puzzolan-Portlandzement mit 40% Brjansky Diatomeenerde	Puzzolan-Portlandzement mit 30% Si-Stoff
1	2	3	4	5	6	7
7 Tage	2	8	32	15	13	2
	5	12	330	107	143	30
	10	12	1, 073	380	370	100
	20	12	1, 985	750	845	219
	35	12	3, 837	1, 610	2, 025	436
	50	12	--------	--------	--------	--------
28 Tage	2	8	3	0	0	0
	5	12	41	3	0	0
	10	12	159	38	2	0, 5
	20	12	389	116	38	1, 0
	35	12	854	405	134	2, 5
	50	12	--------	--------	--------	--------
3 Monate	2	8	0	0	0	0
	5	12	18	2	0	0
	10	12	111	5	2	0
	20	12	276	45	4	0
	35	12	--------	150	22	0
	50	12	--------	--------	51	0

TABELLE 3.—*Abhängigkeit der Wasserdurchlässigkeit des Betons von der Art des Bindemittels*—Fortsetzung

BETONZUSAMMENSETZUNG 1:7 NACH RAUMTEILEN

[1:8,62 nach Gewichtsteilen]

Alter.	Druck in Atmosphären	Zeit in Stunden	Wassermenge in cm,^{3} die durch den ganzen Probekörper vom Versuchsbeginn an durchgesickert ist			
			Novorossiisky Portlandzemente	Hochofenzement mit 60% Schlacke	Puzzolan-Portlandzement mit 40% Brjansky Diatomeenerde	Puzzolan-Portlandzement mit 30% Si-Stoff
1	2	3	4	5	6	7
7 Tage	2	8	162	90	25	1
	5	12	807	451	341	39
	10	12	2, 275	1, 419	981	145
	20	12	4, 678	3, 164	2, 081	328
	35	12	8, 660	6, 552	3, 833	743
	50	12	--------	--------	--------	--------
28 Tage	2	8	7	8	2	0
	5	12	124	58	12	1
	10	12	549	231	86	10
	20	12	1, 492	534	236	37
	35	12	2, 896	1, 175	436	161
	50	12	--------	--------	--------	--------
3 Monate	2	8	0	0	0	0
	5	12	10	5	0	0
	10	12	121	42	0	0
	20	12	267	120	7	1
	35	12	427	292	54	2
	50	12	573	535	156	81
6 Monate	2	8	0	0	0	0
	5	12	1	0	1	0
	10	12	10	0	1	0
	20	12	51	9	2	0
	35	12	155	43	5	0
	50	12	343	156	6	0

BETONZUSAMMENSETZUNG 1:8 NACH RAUMTEILEN

[1:9,94 nach Gewichtsteilen]

7 Tage	2	8	1, 081	--------	--------	38
	5	12	5, 922	--------	--------	433
	10	12	17, 408	--------	--------	2, 905
	20	12	32, 266	--------	--------	4, 213
28 Tage	2	8	191	41	1	2
	5	12	772	194	26	2
	10	12	1, 473	566	221	35
	20	12	5, 199	833	699	119
3 Monate	2	8	1	--------	--------	1
	5	12	141	--------	--------	1
	10	12	701	--------	--------	22
	20	12	2, 005	--------	--------	112

Die im Laboratorium erhaltenen Angaben über die Wasserdurchlässigkeit des Betons aus verschiedenartigen Zementen gestatten annähernd dieselben Schlussfolgerungen zu machen, welche auf Grund provisorischer Mörtelversuche erreicht wurden. So z.B. ist aus der Tabelle 3 zu ersehen, dass von den geprüften vier Zementarten der reine Portlandzement ohne Zuschläge die grösste Wasserdurchlässigkeit in den Betonen verschiedener Zusammensetzung besitzt; der Hochofenzement erscheint schon als weniger durchlässig; mit einer noch geringeren Wasserdurchlässigkeit werden Puzzolan-Portlandzemente charakterisiert, wobei von den letzteren die kleinste Wasserdurchlässigkeit der Puzzolan-Portlandzement mit Si-Stoff aufweist. Demzufolge kann man hinsichtlich der Abnahme der Wasserdurchlässigkeit der Betone für die geprüften Zemente eine folgende Ordnungsreihe feststellen: (1) Portlandzement ohne Zuschläge, (2) Hochofenzement, (3) Puzzolan-Portlandzement mit Diatomeenerde, und (4) Puzzolan-Portlandzement mit Si-Stoff. Es sei dabei bemerkt, dass der Unterschied des Grades der Wasserdurchlässigkeit der Betone aus verschiedenen Zementen in der ersten Erhärtungszeit (7 Tage) weniger stark ausgedrückt ist, und dagegen bei dauerndem Zeitabschnitt (3 und 6 Monaten) sehr schroff hervortritt.

Die durch den Ersatz im Beton des reinen Portlandzementes (ohne Zuschläge) mit Puzzolan-Portlandzementen hervorgerufene Abnahme der Wasserdurchlässigkeit ist so bedeutend, dass sie bei Verwendung letzterer Zemente in hydrotechnischen Bauwerken eine sehr bemerkbare Verringerung der Zementmenge auf 1 m^3 Beton ermöglicht. So, z.B. wenn man die Wasserdurchlässigkeit der Betone verschiedner Zusammensetzungen und aus verschiedenen Zementen im Alter von 28 Tagen (Tabelle 3) vergleicht, wird man gewahr, dass der Beton in Mischung 1:7 (Zementverbrauch 211 kg/m^3) bei Puzzolan-Portlandzement mit Diatomeenerde eine geringere Wasserdurchlässigkeit besitzt, als der Beton in Mischung 1:6 (Zementverbrauch 256 kg/cm^3) mit Portlandzement ohne Zuschläge. Einen noch grösseren Effekt erhält man bei Verwendung des Puzzolan-Portlandzementes mit Si-Stoff: ein Beton von Zusammensetzung 1:8 (Zementverbrauch 188 kg/m^3) aus letzterem Zement erwies sich als weniger durchlässig, als der reine Portlandzementbeton von Mischung 1:6 (Zementverbrauch 256 kg/m^3).

TEIL III

Zur Zeit kann man als eine bestimmt festgesetzte Tatsache annehmen, dass ein beliebiger Zementbeton oder Mörtel, aus welchem Bindenmittel er auch hergestellt sei, in sich einige, verhältnismässig leicht im Wasser lösbare Bestandteile enthält. In einer in dieser Hinsicht besonders unvorteilhaften Lage befinden sich Portlandzementbetone und Mörtel, da sie eine beträchtliche Menge leicht lösbaren Kalziumhydroxyds, das sich beim Erhärten des Portlandzementes bildet, enthalten. Was jedoch die Puzzolan-Portlandzemente anbetrifft, so müssen sie, nach allgemein angenommenen theoretischen Anschauungen, eine bedeutend grössere Widerstandsfühigkeit gegen die auslaugende Wirkung des Wassers haben, da die aktive Kieselsäure des hydraulischen Zuschlages den sich bei der Hydratation des Portlandzementes bildenden freien Kalk bindet.

Die Richtigkeit dieser theoretischen Voraussetzungen war einer Versuchsprüfung im Laboratorium zwecks Ermittelung der Auslaugung des Kalks aus den aus verschiedenen Zementen bestehenden Mörteln unterworfen.

Zwecks quantitativer Charakteristik der Widerstandsfähigkeit verschiedener Zemente gegen Auslaugung, wurden (in der Ordnungsfolge der Ausarbeitung der Untersuchungsmethodik) folgende Verfahren nachgeprüft:

(1) Verfahren, die auf der Absonderung des Kalkes ins Wasser bei der Zementhydratation gegründet waren;

(2) Verfahren, die auf der Auslaungung des Kalks beim Rütteln des erhärteten Zementpulvers mit Wasser gegründet waren;

(3) Verfahren, welche auf der Feststellung der Kalkdiffusion aus den ins Wasser versenkten Zementmörtelproben basiert waren (insbesondere bei erhöhter Temperatur);

(4) Verfahren, welche auf der Ermittelung der ausgelaugten Kalkmenge beim Wasserdurchgang durch Mörtelproben aus verschiedenen Zementen basiert waren.

Die letzte Gruppe der Verfahren gab die zuverlässigsten Ergebnisse, weshalb die weitere Erforschung der Auslaugfähigkeit nach diesem Verfahren ausgeführt wurde. Die bezeichnete Methode stellt in der Art ihrer Ausarbeitung und Anwendung im Laboratorium folgendes dar:

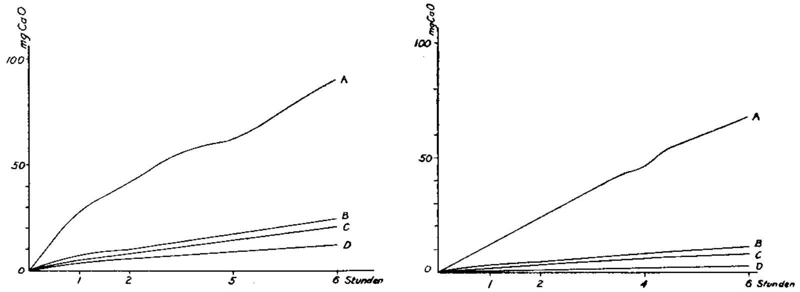

Abbildung 1.—**7 Tage alt.** — 7 days old. — de 7 jours. — de 7 días.

Abbildung 2.—**3 Monate alt.** — 3 months old. — de 3 mois. — de 3 meses.

Kurven der Kalkauslaugung von Mörteln aus verschiedenen Zementen.
Curves of lime-leaching of mortar of different cements.
Courbes de lessivage de la chaux de differents ciments.
Curvas de lixiviación de la cal del mortero de diferentes cementos.

A. **Portlandzement.** — Portland Cement.
B. **Zement mit Trass.** — Cement with trass.
C. **Zement mit Si-Stoff.** — Cement with silicate.
D. **Zement mit Diatomeenerde.** — Cement with diatomaceous earth.

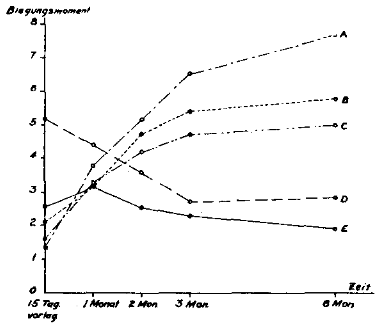

ABBILDUNG 3.—**Kalziumsulfat.**— Calcium sulphate.—De sulphate de calcium.—De sulfato de calcio.

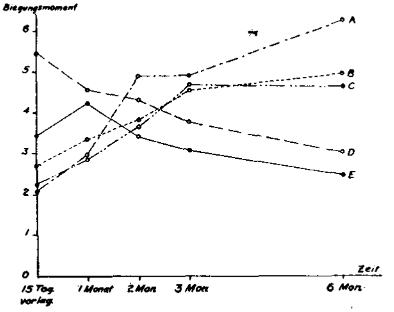

ABBILDUNG 4.—**Natriumsulfat.**— Sodium sulphate.—De sulphate de soude.—De sulfato de sodio.

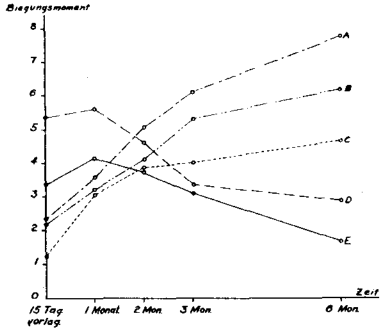

ABBILDUNG 5.—**Magnesiumsulfat.**— Magnesium sulphate.—De sulphate de magnesium.—De sulfato de magnesio.

Festigkeitsveränderungskurven der Probekörper von Mörteln aus verschiedenen Zementen, die in verschiedenen Lösungen (Konzentration 0,2%) gelagert wurden.

Curves of stability variations on test bodies of mortar of different cements which have been submitted to various solutions (concentration 0.2 percent).

Courbes des variations de la stabilité d'éprouvettes de mortier de differents ciments, ayant été traitées avec de differentes solutions (concentration 0,2%).

Curvas de las variaciones de la estabilidad de muestras de mortero de diferentes cementos que han sido sometidas a diferentes soluciones (concentración 0,2%).

A. **60% Portlandzement I. 40% Diatomeenerde.**—60 percent Portland Cement. 40 percent Diatomaceous earth.

B. **25% Portlandzement I. 75% Schlacke.**— 25 percent Portland Cement. 75 percent slag.

C. **50% Portlandzement I. 50% Trass.**—50 percent Portland Cement. 50 percent trass.

D. **Portlandzement II.**

E. **Portlandzement I.**

Aus den der Prüfung zu unterwerfenden Zementen wurden Versuchsproben aus Mörtel 1:4 und 1:5 in der Form von kleinen in Messinghülsen eingeschlossenen zylindrischen Körpern angefertigt. Nach Verlauf eines gewissen Erhärtungszeitraums wurden die Hülsen mit den sich in ihnen befindlichen Proben mit dem Gerät vereinigt, worauf die Proben während einer halben Stunde einem für alle Proben gleichen Druck destillierten Wassers mit entzogener CO_2 unterworfen wurden. Die durch die Probekörper durchgegangene Flüssigkeit wurde hernach hinsichtlich ihres Kalkgehalts analysiert. Die Prüfung der Proben im Gerät wurde im Laufe von 3 Tagen vollzogen, wobei jeden Tag zu je vier Auslaugungen mit halbstündigen Zwischenräumen ausgeführt wurden. Auf solche Weise wurde jede Probe insgesamt 12 Auslaugungen ausgesetzt. Die dabei erhaltenen Ergebnisse wurden in Kurven der Abhängigkeit der ausgelaugten Kalkmenge von der Wasserdurchgangsdauer dargestellt, welche auch zur guten Charakteristik der Wasserbeständigkeit der Zemente dienten.

Ueber die relative Wasserbeständigkeit der geprüften Zemente kann man nach Abbildung 1 und 2 urteilen. Wie aus diesen Abbildungen zu ersehen ist, geschieht die Auslaugung des Kalkes aus den Portlandzementmörteln bedeutend schneller als aus den Mörteln mit Puzzolan-Portlandzementen, wobei mit der Zunahme des Alters der Versuchsproben dieser Unterschied immer deutlicher wird. Letzterer Umstand wird gut durch die Angeban in der Tabelle 4 veranschaulicht.

Es sei hierbei bemerkt, dass bei allen im Laboratorium durchgeführten Versuchen der Charakter der Lage der Auslaugungskurven für die untersuchten Zemente ein und derselbe blieb (nämlich entsprechend den Abb. 4 und 5), unabhängig vom Alter des Mörtels, seiner Zusammensetzung, der Erhärtungsverhältnisse u.s.w.

Eine bedeutend geringere Auslaugungsfähigkeit des Kalks aus den Mörteln aus Puzzolan-Portlandzementen, die in den obengenannten Versuchen beobachtet wurde, bestätigt die Richtigkeit der Meinung, dass in den Mörteln und Betonen aus solchen Zementen Kalk in freiem Zustande (in der Form von $Ca(OH)_2$) fehlt.

Spezielle Versuche, welche im Laboratorium in den Jahren 1934–35 ausgeführt wurden, zeigten, dass schon ungefähr nach 1–2 Monaten der Erhärtung der freie Kalk in den Puzzolan-Portlandzementen von der aktiven Kieselsäure des Zuschlags gebunden ist (natürlich bei genügender Menge des letzteren). Solches wurde durch unmittelbare analytische Ermittelungen des freien Kalkes in den erhärteten Puzzolan-Portlandzementen sowohl als auch mittels thermischer Analyse bewiesen. Die mit Hilfe des Gerätes des Akademikers N. S. Kurnakow erhaltenen thermischen Kurven hatten keine der Auflösung des Kalziumoxydhydrats entsprechenden Punkte.

Das Fehlen des freien Kalks in den erhärteten Puzzolan-Portlandzementen ist gerade die Grundsache ihrer höheren Wasserbeständigkeit.

TABELLE 4.—*Kalkmenge (mgr. CaO), die aus den Proben von 1:5 Mischung während einer 6-stündigen Wasserdurchsickerung ausgelaugt wurde (12 Auslaugungen)*

Nr.	Zemente.	Alter der Proben:			
		7 Tage	28 Tage	3 Monate	6 Monate
1	Portlandzement	91, 4	59, 3	38, 1	35, 8
	Puzzolan-Portlandzement:				
2	mit Si-Stoff	21, 9	12, 4	43, 4	26, 6
3	mit Diatomeenerde	13, 9	75, 9	12, 9	--------
4	mit Trass	31, 0	25, 9	63, 3	68, 5

TEIL IV

Die Untersuchung der Vergleichsbeständigkeit verschiedener Zemente im Laboratorium der Hydrobaustoffe des Wissenschaftlichen Forschungsinstituts für Hydrotechnik wurde nicht nur in bezug auf süsses Wasser, sondern auch in bezug auf Mineralwässer ausgeführt.

Zur schnellen Schätzung der Vergleichsbeständigkeit verschiedener Zemente in Mineralwässern wurde provisorisch eine beschleunigte Methode ausgearbeitet, welche es ermöglicht bestimmte Ergebnisse schon im Laufe von 3–6 Monaten zu erhalten. Diese Methode setzt eine Prüfung der Zement-Versuchsproben in stark verdünnten Lösungen oder direkt in natürlichen Mineralwässern mit einem Salzgehalt von ca. 0,1–0,2% und höher voraus (bei geringerem Salzgehalt werden für die Prüfungen 8–12 Monate benötigt), was in einem hohen Grade die Prüfungsverhältnisse zu den natürlichen Verhältnissen des Betonbetriebes in hydrotechnischen Bauwerken annähert.

Bei der Ausarbeitung der Methodik wurde eine Beschleunigung des Prozesses der Zementzerstörung durch maximale Erniedrigung ihrer Dichtigkeit erreicht. Bei der Feststellung der Widerstandsfähigkeit der Zemente ist eine Erhöhung der Salzkonzentration in der Lösung sowie eine Temperaturerhöhung der letzteren unzulässig.

Die ausgearbeitete Methode setzt eine Prüfung der Zemente in Form von kleinen Probekörpern (Prismen von 1 x 1 x 3 cm und Würfeln von 1,41 x 1,41 x 1,41 cm) voraus, welche mit Hilfe der Apparatur des Prof. H. Kühl hergestellt werden. Die Versuchsproben werden aus Mörtel in Mischung 1 : 35 mit speziellen Sande zubereitet, dessen Kornzusammensetzung eine geringe Dichtigkeit der Versuchsproben sichert. Nach gewissen Zeiträumen der Probenlagerung im aggressiven Wasser werden die Versuchskörper auf Festigkeit geprüft.

Die Schätzung der relativen Zementwiderstandsfähigkeit wird auf Grund des Charakters der Kurven für Festigkeitsänderung der in der entsprechenden Lösung gelagerten Proben gemacht und auch mit Hilfe des Kurvenvergleiches für verschiedene Zemente untereinander und mit den Kurven, welche die Festigkeitsänderung der im süssen (reinen) Wasser gelagerten Proben bezeichnen, festgesetzt.

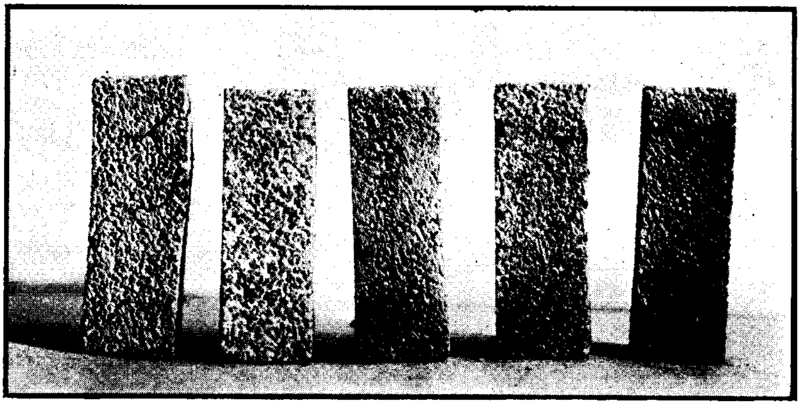

ABBILDUNG 6.—**Natriumsulfat.** — Sodium sulphate. — de sulphate de soude. — de sulfato de sodio.

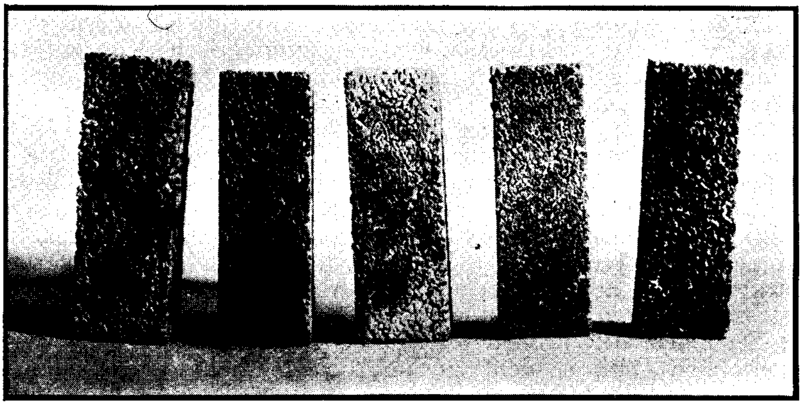

ABBILDUNG 7.—**Magnesiumsulfat.** — Magnesium sulphate. — de sulphate de magnesium. — de sulfato de magnesio.

Ansicht von Prismen aus Mörtel 1:3,5 nach 7-monatiger Lagerung in verschiedenen Losungen (Konzentration 0, 2%). Von links nach rechts: (1) Portlandzement, (2) Puzzolan-Portlandzement mit Trass, (3) Puzzolan-Portlandzement mit Diatomeenerde, (4) Puzzolan-Portlandzement mit Si-Stoff, (5) Hochofenzement.

Elevations of prisms of mortar 1:3:5 after having been submitted to various solutions (concentration 0.2%) for 7 months. From left to right: (1) portland cement, (2) pozzolan portland cement with trass, (3) pozzolan portland cement with diatomaceous earth, (4) pozzolan portland cement with silicious content, (5) slag cement.

Vue laterale de prismes de mortier 1:3:5 après traitement par de differentes solutions (concentration 0, 2%) pendant 7 mois. De gauche à droit: (1) ciment Portland, (2) ciment Portland de puzzolan avec trass, (3) ciment Portland de puzzolan avec terre à diatomée, (4) ciment Portland de puzzolan contenant de la silice, (5) ciment de laitier.

Vista lateral de los prismas de mortero 1:3:5 después de haber sido sometidos a diferentes soluciones (concentración 0,2%) durante 7 meses. De izquierda a derecha: (1) cemento portland, (2) cemento portland de puzolana con trass, (3) cemento portland de puzolana con tierra de diatomea, (4) cemento portland de puzolana conteniendo sílice, (5) cemento de escoria.

Die Vergleichsuntersuchung der Widerstandsfähigkeit verschiedener Zemente wurde in Bezug auf eine sehr grosse Zahl von Lösungen verschiedener Salze ausgeführt. Von den erhaltenen Ergebnissen sind solche von den Prüfungen der Zementproben, die in den Kalzium, Natrium und Magnesiumsulfatlösungen gelagert wurden, die charakteristischesten; diese Ergebnisse werden auch in Flogender beschrieben.

Für die Untersuchung wurden folgende Zemente verwendet:

(1) Puzzolan-Portlandzement mit Trass,
(2) Puzzolan-Portlandzement mit Diatomeenerde,
(3) Puzzolan-Portlandzement mit Si-Stoff,
(4) Hochofenzement,
(5) Portlandzement I (gewöhnlicher),
(6) Portlandzement II (hochwertiger).

Proben aus diesen Zementen wurden in Lösungen folgender Zusammensetzungen gelagert:

(1) $CaSO_4$, (2) Na_2SO_4, (3) $MgSO_4$, (4) $CaSO_4+Na_2SO_4$, (5) $CaSO_4+MgSO_4$ (6) $Na_2SO_4+MgSO_4$, und (7) $CaSO_4+Na_2SO_4+MgSO_4$.

Die Konzentration dieser Lösungen war 0, 03 N, was für die genannten Salze annähernd 2 Gr per Liter ausmachte (für Lösungen, welche zwei oder drei Sal ze enthalten, wird eine summarische Konzentration vorausgesetzt, die Konzentration jedoch jedes Salzes war entsprechend zwei oder dreimal kleiner).

Die Erforschungsergebnisse zeigten, dass alle drei Salze, wie einzeln so auch in gemischten Lösungen beinahe gleichen Einfluss auf die Zemente ausüben. In schwachen Lösungen dieser Salze werden Portlandzemente verhältnismässig schnell zerstört, was, anscheinend, eine Folge des Entstehens in ihnen von Kalziumsulfoaluminat ist. Die geprüften Puzzolan-Portlandzemente zeigten dagegen garkeine Markmale der Zerstörung; die auf Abbildungen 3, 4 und 5 dargestellten Kurven der Festigkeitsänderung weisen darauf hin, dass die Festigkeit der Proben aus diesen Zementen im Laufe der 6-monatlichen Prüfung sich ununterbrochen erhöhte.[1] Dasselbe gilt auch für den Hochofenzement, der sich als vollständig widerstandsfähig bewährte. Das Aussehen der Proben nach ihrer 7-monatlichen Lagerung in den 0,03 N Lösungen des Natrium- und Magnesiumsulfats ist auf den Abb. 6 und 7 gezeigt.

Ausser den obenbezeichneten Untersuchungen wurde die relative Beständigkeit der obengenannten Zemente gegenüber Meerwasser und mineralischer Bodenwässer verschiedener Zusammensetzungen (hauptsächlich enthaltend Sulfate) nachgeprüft. In diesem Falle wurde die Zementwiderstandsfähigkeit mittels Lagerung der Probekörper entweder unmittelbar in Naturwasser oder in künstlich zubereiteten, nach Zusammensetzung und Konzentration den Naturwässern analogen, synthetischen Lösungen festgestellt. Bei all diesen Versuchen war die verhältnismässige Widerstandsfähigkeit des Zementes beinahe gleich der, die bei schwachen Lösungen der Sulfate erhalten wurde. In allen Fällen erwiesen sich die Puzzolan-Portlandzemente und Hochofenzemente als vollständig widerstandsfähig, während Portlandzemente mehr oder weniger schnell zerstört wurden.

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[1] *Auf den Diagrammen ist die Festigkeit der Prismen durch den ide Probenzerstörung hervorrufenden Biegungsmoment ausgedrückt.*

Aus dem Gesagten kann man schliessen, dass Puzzolan-Portlandzemente und Hochofenzemente überaus beständig gegen die Einwirkung von Mineralwässern mit Sulfatgehalt sind; in dieser Hinsicht stehen sie dem Tonerdezement nicht nach.

Auf die Widerstandsfähigkeit der Puzzolan-Portlandzemente kann man, nach den Laboratoriumversuchen, nur in dem Falle nicht rechnen, wenn das Wasser eine sehr beträchtliche Menge der Magnesiasalze (Chlormagnesium und namentlich Magnesiumsulfat) enthält, mehr als 10 Gr per Liter, oder wenn in Wasser bedeutende Mengen aggressiver Kohlensäure enthalten sind. In solchen Fällen ist die Zerstörung der Portlandzemente ähnlich der der Portlandzemente.

TEIL V

Eine Vergleichs-Untersuchung der linearen Formänderungen, welche bei der Erhärtung der Mörtel mit Betonen aus verschiedenen Zementen stattfinden, wurde im Laboratorium der Hydrobaustoffe des Wissenschaftlichen Forschungsinstituts für Hydrotechnik mit Hilfe des Amsler Geräts mit Betonprismen von 10 x 10 x 50 cm Grösse ausgeführt.

Der Prüfung wurden Betone zweier Zusammensetzungen nach Raumteilen: 1:4 und 1:6 und zweier Konsistenzen: plastischer und giessfähiger unterworfen. Die Versuchsproben wurden auf folgende Weise gelagert: (1) an der Luft, (2) in feuchten Sägespänen und (3) bwechselnd 6 Tage in feuchten Sägespänen und 12 Tage an der Luft.

TABELLEN 5 UND 6.—*Durchschnittsangaben für Schwinden für zwei Konsistenzen und zwei Zusammensetzungen*

(Die Zahlen sind in Zehntausendsteln v. H. angegeben. Das Zeichen — (Minus) bezeichnet eine Längenabnahme — (Schwinden)) und das Zeichen+(Plus) bezeichnet eine Längenzunahme (Quellen)]

Lagerungsart	An der Luft												
Erhärtungsdauer in Tagen Zement	30	60	90	120	150	180	210	240	270	300	330	360	450
1. Portlandzement, hochwertiger	−177	−295	−370	−416	−460	−435	−396	−386	−450	−486	−495	−503	−481
2. Portlandzement, gewöhnlicher	−182	−281	−359	−426	−455	−450	−425	−436	−501	−531	−540	−538	−516
3. 60% hochwertigen Portlandzementes+40% Diatomeenerde	−413	−508	−556	−622	−601	−591	−583	−635	−648	−678	−699	−719	−605
4. 50% hochwertigen Portlandzementes+50% Trass	−110	−402	−404	−419	−398	−360	−386	−449	−467	−495	−511	−535	−495
5. 30% hochwertigen Portlandzementes+70% Hochofenschlacke	−201	−330	−334	−326	−336	−366	−400	−435	−475	−478	−467	−454	−413
6. Tonerdezement	−93	−165	−198	−184	−176	−178	−194	−218	−267	−289	−279	−295	−228

Lagerungsart	In feuchten Säge spänen												
Erhärtungsdauer in Tagen Zement	30	60	90	120	150	180	210	240	270	300	330	360	450
1. Portlandzement, hochwertiger	+102	+125	+139	+149	+163	+199	+215	+220	+210	+215	+209	+200	+220
2. Portlandzement, gewöhnlicher	+33	+68	+69	+79	+87	+104	+121	+126	+116	+118	+111	+98	+149
3. 60% hochwertigen Portlandzementes+40% Diatomeenerde	+34	+47	+63	+84	+102	+124	+123	+113	+103	+89	+79	+64	+102
4. 50% hochwertigen Portlandzementes+50% Trass	+58	+80	+91	+122	+139	+158	+146	+150	+139	+128	+110	+95	+139
5. 30% hochwertigen Portlandzementes+70% Hochofenschlacke	+19	+20	+53	+71	+91	+62	+59	+53	+47	+42	+44	+54	+70
6. Tonerdezement	−23	−28	−44	−41	−36	−45	−40	−40	−44	−77	−87	−89	−59

Zum Moment der Zusammenfassung des gegenwärtigen Berichtes erreichte die Erhärtungsdauer der Versuchsproben 450 Tage. Die in diesem Zeitabschnitt erhaltenen Ergebnisse der Messungen linearer Formänderungen sind in den Tabellen 5 und 6 angeführt; die Zahlen dieser Tabellen sind Durchschnittsangaben für Betone zweier Zusammensetzungen und zweier Konsistenzen. Graphisch sind diese Angaben auf Abbildung 8 angegeben.

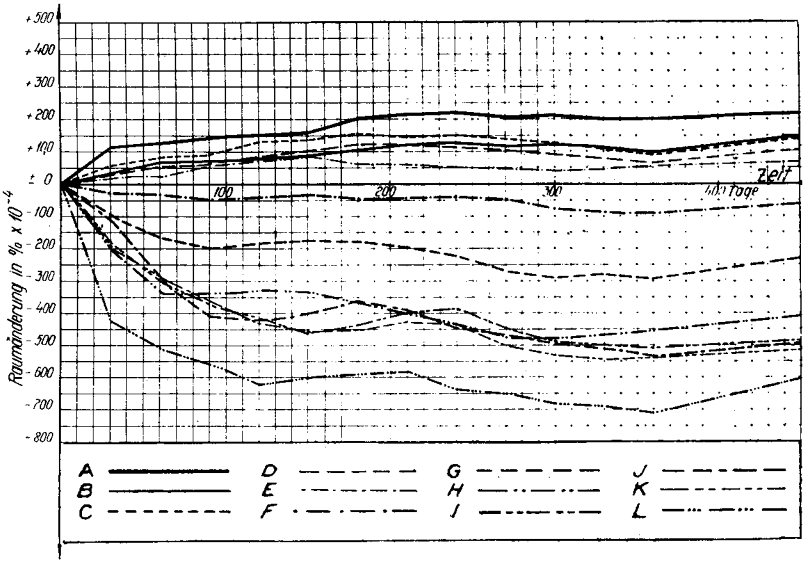

Abbildung 8. Mittlere Schwindkurven für Betons mit verschiedenen Zementen
Average shrinkage curves for concrete of different cements.
Courbes des moyennes du retrait de béton de ciments differents.
Curvas de los promedios de la retracción del hormigón de diferentes cementos.

A. Hochwertiger Portlandzement.
B. Gewöhnlicher Portlandzement.
C. Portlandzement mit Trass.
D. Portlandzement mit Diatomeerde.
E. Hochofenzement.
F. Tonerdezement.
G. Tonerdezement.
H. Hochefenzement.
I. Hochwertiger Portlandzement.
J. Portlandzement mit Trass.
K. Gewöhnlicher Portlandzement.
L. Portlandzement mit Diatomeenerde.

Aus dem beigelegten Diagramm ist zu ersehen, dass die Kurven linearer Formänderung für alle Zemente (mit Ausnahme von Tonerdezement) zwei Kurvenscharen bilden. Die obere Kurvenschar entspricht dem Quellen der Proben, das bei Lagerung letzterer in feuchten Sägespänen beobachtet wird; die untere Kurvenschar charakterisiert das Schwinden bei Lagerung der Versuchsproben an der Luft. Tonerdezement weist kein Quellen auf; bei beiden Lagerungsarten gibt er ein Schwinden.[2]

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[2] *Eine Analyse der Ursachen, welche ein verschiedenes Verhalten einzelner Zementarten und ihr Schwinden hervorrufen, wird hier nicht gemacht. Diese Fragen werden in einer besonderen Arbeit, die zur Zeit noch nicht beendigt ist, erörtert werden.*

Bei wechselnder Lagerung haben die Deformationskurven eine Zickzackform, sie sind auf dem Diagramm nicht angegeben.

Aus diesen Diagrammen kann man den Schluss ziehen, dass bei allen geprüften Zementen, mit Ausnahme des einen, die Lagerungsverhältnisse den Charakter der Formänderungen bestimmen, indem sie dieselben in Abhängigkeit vom Feuchtigkeitsgrade, entweder zum Quellen oder zum Schwinden bringen. Letztere Abhängigkeit wird auch vom Charakter der Schwindungskurven bei Lagerung der Proben an der Luft bestätigt: diese Kurven haben an einigen Stellen Wendepunkte, welche der relativen Zunahme der Probenlänge entsprechen. Der Versuch zeigt, dass die bezeichneten Wendepunkte mit der Aenderung der relativen Luft-euchtigkeit übereinstimmen, und zwar entsprechend ihrer Zunahme.

Die auf Abb. 8 angegebenen Kurven, ebenso wie auch die Angaben auf den Tabellen 5 und 6, zeigen, dass die intensivste Längenänderung der Versuchsproben im Laufe der ersten 3 Monate stattfindet; eine weitere Zunahme der Formänderung ist weniger bedeutend und nach einem Jahr des Erhärtens beträgt sie ca. 29% der Deformationsgrösse im Alter von 3 Monaten.[3]

Der Vergleich der Formänderungen beim Quellen und Schwinden zeigt, dass die Schwindungsdeformationen bedeutend grösser sind als die Quellungsdeformationen (im Mittel für alle Zemente um 3,85 mal).

Ueber den Einfluss der Art des Bindemittels auf die Deformationsgrösse, kann man nach den Angaben der Gesamttabelle 7 urteilen, wo die maximalen Formänderungen bei verschiedenen Erhärtungsverhältnissen für eine Lagerungsdauer bis 360 Tage angegeben sind.

Ausser den Grössen maximaler Formänderungen, welche in Prozenten der ursprünglichen Probenlänge ausgedrückt ist, werden in der Tabelle 7 gleichfalls die Schwindungsfaktoren angeführt, welche Quotiente der Division der Formänderungen verschiedenartiger Zemente durch die Formänderung hochwertigen Portlandzementes, welche forlglich für „Eins'' gehalten wird, darstellen.

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[3] *Diese Zahl entspricht den Angaben des Prof. Ros, welcher die Schwindungszunahme in 360 Tagen im Verhältnis zu solcher in 90 Tagen mit 25% feststellt.*

TABELLE 7.—*Maximale Schwindungsdeformationen in Prozenten und Schwindungsfaktoren in bezug auf das Schwinden des hochwertigen Portlandzementes, das für „Eins" gehalten wird*

Lagerungsart Zement	An der Luft		In feuchten Sägespänen		Wechsellagerung	
	Maximale Formänderung	Schwindungsfaktor	Maximale Formänderung	Schwindungsfaktor	Maximale Formänderung	Schwindungsfaktor
1. Portlandzement, hochwertiger	−0, 0505	1, 00	+0, 0220	1, 00	−0, 0220	1, 00
2. Portlandzement, gewöhnlicher	−0, 0540	1, 06	+0, 0130	0, 59	−0, 0200	0, 91
3. 60% hochwertigen Portlandzementes + 40% Diatomeenerde	−0, 0720	1, 43	+0, 0125	0, 57	−0, 0130	0, 59
4. 50% hochwertigen Portlandzementes + 50% Trass	−0, 0535	1, 06	+0, 0160	0, 73	−0, 0075	0, 34
5. 30% hochwertigen Portlandzementes + 70% Hochofenschlacke	−0, 0480	0, 95	+0, 0090	0, 41	−0, 0100	0, 46
6. Toneredezement	−0, 0290	0, 58	−0, 0090	(1)	−0, 0220	1, 00

[1] Ausgeschlossen, als unvergleichbar.

Der Vergleich der Schwindungsfaktoren verschiedener Zemente unter einander gestattet folgende Schlussfolgerungen zu machen:

1. Bei Lagerung an der Luft gibt Puzzolan-Portland-zement mit Diatomeenerde die grössten Formänderungen; Tonerdezement dagegen die kleinsten.

2. Bei Lagerung in feuchten Sägespänen gibt hochwertiger Portlandzement die grössten Formänderungen und Hochofenzement — die kleinsten.

3. Bei wechselnder Lagerung erhielt man die grössten Formänderungen bei hochwertigem Portlandzement und Tonerdezement, die übrigen Zemente gaben kleinere Längenänderungen.

4. Beim Vergleich maximaler Formänderungen bei Luftund Wechsellagerung kann man feststellen, dass im zweiten Falle die Schwindungserscheinungen bedeutend niedriger sind (im Mittel für alle Zemente — um 3 mal).

Alles Obengesagte zusammenfassend, kann man zur Schlussfolgerung kommen, dass nur in einem Fall (bei Puzzolan-Portlandzement mit Zusatz von 40% Diatomeenerde und bei Luftlagerung) eine bedeutende Erhöhung der Schwindungsdeformationen im Vergleich zum hochwertigen Portlandzement beobachtet wird; alle übrigen Zemente geben praktisch gleiche und kleinere Längenänderungen.

Demzufolge werden, vom Standpunkt der Schwindungsdeformationen (namentlich bei Lagerung des Betons in feuchten Sägespänen oder bei Wechsellagerung), Puzzolan-Portlandzemente und Hochofenzemente für den Wasserbau als vollständig anwendbar gekennzeichnet.

TEIL VI

In speziellen Zementen, welche für den Bau hoher Wehre verwendet werden, können ausser den oben angeführten Anforderungen der Wasserbeständigkeit (im weiten Sinn dieses Wortes) gleichfalls hohe Anforderungen in bezug auf Festigkeit und geringe Wärmeabsonderung beim Erhärten des Zementes gestellt werden.

Die Praxis der Fabrikherstellung von Puzzolan-Portlandzementen und Hochofenzementen in U.d.S.S.R. weist darauf hin, dass bei entsprechend organisiertem technologischen Vorgang diese Zemente mit einer Festigkeit hergestellt werden können, welche der Festigkeit hoher (sich den hochwertigen nahender) Portlanzementsorten nicht nachstehen. Daher fallen alle Zweifel der Verwendungsmöglichkeit der Puzzolan,Portlandzemente in hydrotechnischen Betonen hoher Festigkeit ab.

Die Wärmeabsonderung beim Erhärten der Puzzolan-Portlandzemente und Hochofenzemente ist vorläufig experimentell noch nicht ermittelt worden [4] nichtsdestoweniger kann man auf Grund theoretischer Voraussetaungen bei Verwendung dieser Zemente einen um 20–30% kleineren Wärmeeffekt als bei der Verwendung von Portlandzementen erwarten.

TEIL VII

Die oben erörterten Arbeiten des Laboratoriums für Hydrobaustoffe des Wissenschaftlichen Forschungsinstituts für Hydrotechnik auf dem Gebiete der Erforschung der Eigenschaften der Puzzolan-Portlandzemente und Hochofenzemente beweisen überzeugend die grossen Vorzüge dieser Zemente im Vergleich zum Portlandzement. Da Puzzolan-Portlandzemente und Hochofenzemente viel festere und wasserdichte Betone geben, guten Widerstand der Einwirkung des süssen sowohl als Mineralwassers leisten und praktisch in den Schwindungs-deformationen dem Portlandzement nicht nachstehen, müssen sie (namentlich Puzzolan-Portlandzemente) beim Bau hoher Wehre sowohl als anderer hydrotechnischer Bauwerke beliebigen Portlandzementsorten vorgezogen werden.

ZUSAMMENFASSUNG

1. Im Wasserbau mit seinen hohen Anforderungen an den Beton, können zu Zeit anstatt Portlandzement spezielle Zemente, wie Hochofenzement und Puzzolan-Portlandzemente mit sauren hydrulischen Zuschlägen, als Zemente höherer Wasserbeständigkeit empfohlen werden.

2. Beton, welche aus Hochofenzement und Puzzolan-Portlandzement hergestellt werden, haben eine höhere Wasserundurchlässigkeit im Vergleich zu den Beton aus Portlandzement. Um beim Ersatz des Portlandzementes durch Puzzolan-Portlandzement einen Beton gleicher Wasserdichtigkeit zu erhalten, kann die Zementmenge auf 1 m³ Beton stark erniedrigt werden. Z.B., für Zement mit Diatomeenerde um 40–50 kgr/m³ und für Zement mit Si-Stoff um 60–70 kgr/m³.

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[4] *Das Laboratorium der Hydrobaustoffe des Wissenschaftlichen Forschungsinstituts für Hydrotechnik hat diese Arbeit bloss im Jahre 1935 begonnen.*

3. Bei der Durchsickerung des Wassers durch die mit Puzzolan-Portlandzement hergestellten Beton geht die Auslaugung bedeutend langsamer vor sich, als bei Portlandzementbeton. Es ist dies dadurch zu erklären, dass sich in den ersteren der ganze Kalk in einem chemisch gebundenen Zustande, in Form von Hydro-Kalzium-Silikat befindet.

4. Wenn hydrotechnische Bauwerke der Einwirkung der Mineralwässer ausgesetzt sind, bleibt der Beton aus Puzzolan-Portlandzementen praktisch unzerstört, wogegen beim Portlandzement-Beton die Festigkeit mit des Zeit abnimmt.

5. Die linearen Formänderungen beim Erhärten der Beton aus verschiedenen Zementen (Quellen im Wasser und Schwinden in der Luft) erwiesen sich für die Puzzolan-Portlandzemente und für den Portlandzement als praktisch gleichartig. Eine gewisse Ausnahme bildet der Puzzolan-Portlandzement mit Zusatz von Diatomeenerde. Der mit diesem Zusatze herge-stellte Beton weist beim Erhärten in der Luft, im Vergleich zu anderen untersuchten Zementen, etwas erhöhte Werte der Schwindungsformänderungen auf.

SUMMARY

For the erection of hydraulic structures, with high requirements for the quality of concrete, special cements, such as slag portland cement and pozzolanic portland cement with acid hydraulic admixtures, may be recommended for the present, as desirable cements of a higher degree of watertightness.

Compared with those prepared with ordinary portland cement, concretes produced from slag and pozzolanic portland cements possess a higher degree of watertightness. In order to obtain a concrete of equal watertightness of pozzolanic portland cement as substitute for portland cement, the quantity of cement used per 1 m^3 concrete may be considerably decreased, i. e. by 40–50 kg/m^3 for cement containing diatomaceous earth, and by 60–70 kg/m^3 for cement with silicious content.

The lime-leaching process is much slower when water is percolating through a concrete made with pozzolanic portland cement than with portland cement. This may be explained by the fact that all the lime contained in pozzolanic portland cement is chemically bound and appears in the form of hydrocalcium silicate.

Whenever hydraulic constructions are subjected to the action of mineral waters, the concrete produced from pozzolanic portland cement remains practically undestroyed, whereas the strength of portland cement concrete decreases with time.

The linear deformations which occur during the setting of the concrete made with different cements (swelling in water and shrinking in air) prove to be practically the same both for pozzolanic portland cement and for portland cement. Only the pozzolanic portland cement, with an admixture of diatomaceous earth, is an exception. The concrete produced with this admixture shows after setting in air, compared with other tested cements, slightly increased values of shrinkage deformations.

RESUME

Pour les constructions hydrauliques pour lesquelles on imposent des spécifications de béton sévères, on peut recommander les ciments Portland de haut fourneau et les ciments Portland de pouzzolane avec additions hydrauliques acides; ces ciments possèdent des qualités d'étanchéité supérieures à celles du ciment Portland ordinaire.

Les bétons fabriqués avec ces ciments Portland de haut fourneau ou de pouzzolane possèdent, par comparaison avec les bétons de ciment Portland, une plus grande imperméabilité. Pour obtenir avec du ciment Portland de pouzzolane un béton de même imperméabilité que le béton de ciment Portland ordinaire, on peut diminuer fortement la quantité de ciment employée par mètre cube de béton, savoir: de 40 à 50 Kgs/m^3 si l'on emploie un ciment à terre à diatomées, de 60 à 70 Kgs/m^3 si l'on emploie du ciment contenant des matières siliceuses.

Le délavage de la chaux dû aux infiltrations d'eau à travers le béton, fait avec du ciment Portland de pouzzolane, progresse bien plus lentement que pour du béton de ciment Portland ordinaire, parce que, dans le premier cas, toute la chaux se trouve chimiquement combinée sous forme d'hydrosilicate de calcium.

Dans le cas où la construction hydraulique est soumise à l'action d'eaux minérales, le béton de ciment de pouzzolane ne subit pratiquement aucune désintégration, tandis que pour le béton de ciment ordinaire, toutes choses égales l'ailleurs, la résistance diminue avec le temps.

Les déformations linéaires (gonflement dans l'eau et retrait à l'air) observées au cours de la prise de bétons faits avec différents ciments sont pratiquement les mêmes dans les ciments Portland de pouzzolane et les ciments Portland ordinaires. Le ciment Portland de pouzzolane avec addition de terre à diatomées peut être considéré comme une exception: en effet, le béton ainsi fait subit, au cours de la prise, des retraits légèrement supérieurs à ceux des autres ciments actuellement connus.

RESUMEN

Para las construcciones hidráulicas en que se dan rígidas especificaciones para el hormigón, se pueden recomendar los cementos portland de altos hornos y los cementos portland de puzolana con adiciones hidráulicas ácidas; estos cementos poseen cualidades de impermeabilidad superiores a las del cemento portland ordinario.

Los hormigones fabricados con los cementos portland de altos hornos o de puzolana poseen, en comparación con los hormigones de cemento portland ordinario, una impermeabilidad mucho mayor. Para obtener con el cemento portland de puzolana un hormigón de la misma impermeabilidad que la del hormigón de cemento portland ordinario, se puede disminuir considerablemente la cantidad de cemento empleada por metro cúbico de hormigón, a saber: de 40 a 50 kgs/m^3, si se emplea un cemento de tierra de diatomea, y de 60 a 70 kgs/m^3, si se emplea cemento que contenga materias silíceas.

La lixiviación de la cal, debida a las infiltraciones de agua a través del hormigón hecho con cemento portland de puzolana, progresa mucho más lentamente que en el hormigón de cemento portland ordinario, porque, en el primer caso, toda la cal se encuentra químicamanta combinada bajo la forma de hidrosilicato do calcio.

Cuando la construcción hidráulica se somete a la acción de aguas minerales, el hormigón de cemento de puzolana no sufre casi ninguna desintegración, mientras que la resistencia del hormigón de cemento portland ordinario disminuye con el tiempo.

Las deformaciones lineales (hinchamiento en el agua y retracción en el aire) son casi las mismas en el cemento portland de puzolana y en el cemento portland ordinario. El cemento portland con adición de tierra de diatomea puede considerarse como una excepción: en efecto, el hormigón hecho con este cemento sufre, durante el endurecimiento, retracciones ligeramente superiores a las de los otros cementos actualmente conocidos.

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QUESTION III
SUBCOMMITTEE ON
SPECIAL CEMENTS

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

INTERIM REPORT ON METHODS OF TESTING CEMENT IN REGARD TO HEAT OF HYDRATION, ACTION ON CEMENT BY WATER PERCOLATING THROUGH CONCRETE, SHRINKAGE, PERMEABILITY AND WORKABILITY*

SUBMITTED BY THE INTERNATIONAL SUBCOMMITTEE ON
SPECIAL CEMENTS FOR LARGE DAMS
APRIL 1936

I. INTRODUCTION

The cracking and deterioration of concrete dams and other water-retaining structures has become a serious problem of recent years. The fact that the problem has only recently become of importance is due partly to the high speed of construction with modern plant, as a result of which the internal heat of the concrete has little chance of escaping, partly to the fact that deterioration takes some time and has made itself felt in recent years only. In addition, evidence has accumulated regarding the gradual attack on concrete by certain types of impounded water. The deterioration that has occurred within a relatively short period of years in some dams has been such as to necessitate the expenditure of large sums of money on repairs.

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* *Rapport intérimaire sur les méthodes d'essai des ciments en ce qui concerne la chaleur d'hydration, l'action sur le ciment des eaux d'infiltration dans le béton, le retrait, la perméabiltté et la maniabilité.*

Zwischenbericht über die Prüfungsmethoden von Zementen auf Hydrationswärme, auf die Wirkung des Wassers auf Zement beim Durchgang durch Beton, auf Schwindung, auf Durchlässigkeit und Verarbeitbarkeit.

Informe interino sobre los métodos de ensayos de los cementos en lo que concierne al calor de hidratación, la acción sobre el cemento de las aguas que se infiltran en el hormigón, la retracción, la permeabilidad y la trabajabilidad.

Shrinkage cracks may be due to two causes: The attainment of a high temperature during the hardening process and the subsequent cooling and thermal contraction, and such change of volume as is due to setting and drying out of the concrete. In structures subjected to unilateral water pressure, the deterioration is due mainly to the dissolution and leaching of lime from the cement by very pure or slightly acid waters continuously percolating through the concrete. The rate of deterioration depends largely upon the permeability of the concrete, whereby the attack of the corrosive waters is not confined to the surface of the dam. The interrelated questions of the water-cement ratio and the factors governing the workability of a concrete during deposition are also of importance.

To overcome the difficulties referred to, it would be of great assistance to obtain a cement, or cements, specially suitable for structures subjected to unilateral water pressure. The use of a special cement, no matter how good, will, however, in no way obviate the necessity of taking every precaution to obtain sound concrete of a high class. This is, and always will be, of fundamental importance for all concrete structures and particularly for large dams.

One of the main tasks of the International Subcommittee on Special Cements for Large Dams is to make suggestions as to standard methods of testing normal and special cements in regard to such properties as are of importance for dams and other water-retaining structures and for which few or no methods of testing are known. The subcommittee has arranged with the National Committees on Large Dams (or National Subcommittees on Special Cements) to carry out experiments necessary for this purpose. The present report deals exclusively with such testing methods. Complicated and expensive methods have been excluded, and the aim has been to find simple, inexpensive methods for common use in laboratories as well as at the works.

The investigations carried out by the subcommittee have so far been confined to the properties of cement and concrete mentioned below. The content of this interim report may be summarized as follows:

Heat of hydration.—A tentative standard specification of testing the heat of hydration of cement based on the adiabatic principle is suggested, the details, however, being subject to further investigations now in progress.

An investigation of determining the heat of hydration by observing the temperature rise of cement mortar in thermos flasks has been carried out, and a description of these experiments is given.

Action on cement of water percolating through concrete.—Experiments of testing the action on cement by water percolating through cement-mortar plaques have been made and compared with an extraction method of determining the solubility of hydrated, pulverized cement shaken with water, and also with a method of determining the action on cement-mortar plaques subjected to a jet of water. An account of this investigation is given and a tentative standard specification submitted.

Shrinkage.—Details are given of a German standard specification for testing shrinkage.

Permeability.—Tentative recommendations for testing permeability are submitted.

Workability.—Investigations of testing workability according to two different new methods have been carried out, and accounts of these experiments are given.

As the work of the subcommittee is not yet concluded and investigations are still in progress, it has been possible to submit tentative specifications or recommendations as to heat of hydration, action on cement of water percolating through concrete, and permeability only. The specification for testing shrinkage has been prepared in Germany. As the subcommittee has not been in a position to study the results obtained by this method, the specification is attached for information only.

It is hoped that the present findings of the subcommittee will be placed before the members of the International Commission on Large Dams for their scrutiny and criticism.

II. HEAT OF HYDRATION

During recent years a number of different methods have been developed in various countries to test the heat of hydration of cement when setting and hardening. The more important of these methods may be classified as (1) indirect methods and (2) direct methods. The latter comprise—

(*a*) Apparatus in which the heat accumulates and the dissipation of heat is reduced to a minimum;

(*b*) Apparatus in which the heat dissipates and the accumulation of heat is reduced to a minimum; and

(*c*) Apparatus in which part of the heat accumulates and part dissipates.

In case 2 (*a*) the main object is to determine the accumulation of heat and corrections may or may not be introduced for the dissipation of heat, while in case 2 (*b*) the dissipation of heat is accounted for and corrections may or may not be introduced for the accumulation of heat.

In case 2 (*c*) both the accumulation and dissipation of heat are of importance and must be taken into account.

Certain methods are simple but inaccurate, while others are more accurate but complicated and expensive, and the subcommittee has not found any of the existing methods entirely satisfactory as an inexpensive routine method.

The indirect method, generally referred to as the heat-of-solution method, has been frequently used in certain countries as a routine method for very large dams, but the test must be carried out by an experienced chemical tester, who may not easily be available, or who can hardly be afforded for dams of moderate size.

It has been considered that a full adiabatic method, which comes under 2 (*a*), giving the thermal history of concrete actually used in the field would be preferable, but the existing accurate methods were found too complicated. Of the methods under 2 (*c*), the thermos-flask method, by which the temperature rise of cement mortar in insulated flasks is measured, is simple, but the way in which this method has been used so far has given inaccurate results.

The subcommittee has tried to find a simple, inexpensive, fully adiabatic routine method, and it is hoped that the method described in appendices 1 and 2 will be found satisfactory. This method has been worked out by the Building Research Station in Great Britain for the British Committee on Special Cements.[1]

The investigation carried out in Great Britain is referred to in part I of appendix 1 and comprises comparative tests by means of an existing, accurate standard calorimeter, the simplified adiabatic calorimeter, and the heat-of-solution method.

The main results of these comparative tests are as follows:

(*a*) The temperature-rise values for the two types of adiabatic calorimeter are practically the same, and it is concluded that the values obtained with the simplified adiabatic calorimeter are sufficient for practical purposes.

(*b*) For cements which evolve heat rapidly, the values obtained by the heat-of-solution and adiabatic methods may not differ very considerably.

(*c*) For cements which evolve heat slowly, the heat-of-solution method may be expected to give much higher results than the adiabatic method.

(*d*) The equipment for the simplified adiabatic method can be used for one sample of concrete only at the time. On the other hand, the cost of the apparatus, which is easily made, is estimated at £10 to £15 only.

After the method had been developed and tried at the Building Research Station, six apparatus were built at the Cement Laboratory at Stockholm and experiments with these calorimeters have been carried out for the Swedish Committee on Large Dams. These investigations are still in progress. They have, on the whole, confirmed the tests carried out by the Building Research Station in Great Britain but may result in minor modifications of the method and of the apparatus.

Duplicate tests made with the calorimeters built in Sweden showed a difference between each other of about 10 percent. The values of heat of hydration when the simplified adiabatic calorimeter was used were found to agree fairly well with those obtained by the thermos-flask method as described in appendix 3, but were considerably lower than those obtained by the heat-of-solution method. An account of the Swedish investigation is given in part II of appendix 1.

In the opinion of the subcommittee, the simplified adiabatic method of testing the heat of hydration described in appendix 2 appears suitable as a routine testing method, although further tests may result in the suggestion of certain minor modifications.

The subcommittee has also considered the thermos-flask method. A description of an improved application of this method is referred to below and is fully described in appendix 3. This method has been evolved for the Swedish Committee on Large Dams by Dr. A. Frey Samsioe of Vattenbyggnadsbyrån (VBB), consulting engineers, Stockholm, in conjunction with the cement laboratory of the Royal Swedish Institute for Engineering Research, Stockholm.

According to this method, the temperature rise is observe in cement mortar filled in ordinary commercial thermos flasks plac in a bath of water of constant temperature. The thermos flasks are

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[1] *The British Committee on Special Cements is a joint committee of the Institution of Civil Engineers and the British Committee on Large Dams.*

calibrated by filling the flasks with hot water of about 50° C., the temperature of the water bath being 30° C. The temperature of the water in the flasks, as well as of the water bath, is measured by ordinary thermometers (accuracy 0.1° C.) 3 and 44 hours after the beginning of the tests, the individual heat-transmission constants being determined on the basis of these readings. The flasks are then filled with cement mortar (1 part cement to 4.5 parts of standard sand by weight, water-cement ratio 0.60) and placed in the water bath, and the temperature of the cement mortar is read very frequently during the first day and night, and afterwards at longer intervals. The heat of hydration during a certain time is the sum of the heat accumulated in the flask and the heat dissipated during the same time. The accumulation of heat is the product of the rise in temperature and the heat capacity of the mortar and the flask, and the heat dissipated is calculated by measuring, on a diagram, the area between the temperature curve for the mortar and the constant temperature of the water bath, applying for each flask the heat-transmission constant previously found.

From the tests, the following conclusions can be drawn:

(*a*) The thermos-flask method of measuring heat evolution of cement, as outlined above, is fairly accurate. As shown in appendix 3, a definite amount of heat, electrically supplied to a thermos flask, is accounted for by calculations, according to the method given, with an accuracy within a few percent. Duplicate measurements on cement differ from one another by amounts up to 2 calories per gram of cement.

(*b*) In comparison with the heat-of-solution method, the values obtained with the thermos-flask method for three cements tested are on an average 9 calories per gram lower. Of these 9 calories, about 3 are due to the heat of wetting, which is not accounted for in the latter method. As stated in part I of appendix 1, tests performed in Great Britain show similar or still greater differences between values obtained with the heat-of-solution method and the adiabatic method.

(*c*) Values obtained with the thermos-flask method agree fairly well with those of the simplified adiabatic method. The accuracy of the thermos-flask method may be considered satisfactory as a routine method.

(*d*) The measurements according to the thermos-flask method are not very complicated. The calculation of the results requires some care, but ought not to give any great trouble. When a large number of tests are to be made, the labor involved is much reduced. The method is, therefore, fairly simple and in cases when several tests are performed at the same time to be considered as satisfactory.

(*e*) The cost of the apparatus is low and decreases rapidly with an increasing number of tests.

(*f*) The fragility of the thermos flasks is an inconvenience of the method.

Although the subcommittee considers the thermos-flask method well worth consideration as a standard method of testing, the subcommittee desires to defer expressing an opinion on this subject until the method has been tried in more than one laboratory and found satisfactory. The subcommittee trusts, however, that the publication of the experiments, given in appendix 3, will induce other research laboratories to give the method a further trial and to communicate the results to the subcommittee.

To judge from experiments carried out in Great Britain and in Sweden, it appears that the heat-of-solution method gives higher values of heat of hydration than the adiabatic and the thermos-flask methods.

III. Determination of Action on Cement of Water Percolating Through Concrete

Various methods have been used for determining the action on cement of water percolating through concrete. Due to difficulties in obtaining satisfactory accuracy and reproducibility when measuring the dissolution of cement in concrete or cement mortar subjected to percolating water, other methods have been resorted to.

In Sweden the following two extraction methods have been used: (*a*) Water is led over pulverized, hydrated cement, and (*b*) pulverized, hydrated cement is repeatedly shaken with water. In both cases the water is analyzed and the dissolved material determined. In this report method (*b*) has been referred to as the extraction method.

In France a method has been developed by Mr. E. Rengade by which cement-mortar plaques are subjected to the action of a jet of water impinging their surfaces. The amount of errosive wear is determined by ocular observation.

Objections have been raised to the Swedish methods on the ground that hydrated cement in the form of a powder exposes a much larger surface area of the cement to attack than occurs in a concrete specimen, and also that the grinding of the cement tends to expose unhydrated portions to water action.

To obviate these objections, the United States Bureau of Reclamation carried out a series of tests by which the dissolution curves were obtained by the analyses of water forced through concrete cylinders, the concrete being comparable to that used in existing structures. However, for such concrete the quantity of water passing through the specimen, even at a very great pressure, is so small that years would be required to bring about a break-down of the cement. In order to produce an accelerated test in which enough water could be put through the specimen to effect reasonably rapid break-down, tests were made with lean concrete. It was found that the dissolution curve obtained by these tests was very similar in shape to corresponding curves obtained according to the Swedish methods. As the two widely different test methods showed a qualitative agreement, it was considered that, for porous concrete through which a substantial flow of water takes place, the crushed mortar extraction tests would give reliable indications of what might be expected in the structure itself. An account of the tests carried out in the United States is given in part II of appendix 4.

Objections to Rengade's method were raised on account of the influence of the mechanical erosive factor in addition to the solvent action of water, and also to the fact that ocular observation only was resorted to.

Encouraged by the experiments carried out in the United States, the subcommittee found it desirable to investigate further the different methods mentioned, and a description of this investigation is given in part I of appendix 4. These experiments have been carried out by the Building Research Station in Great Britain for the British Committee on Special Cements. The following conclusions have been reached:

(*i*) The reproducibility of the percolation method is unsatisfactory, and it does not seem practicable to adopt this method as a standard routine method.

(*ii*) A single set of specimens was tested according to Rengade's method and confirmation of these tests are required before any definite conclusions can be drawn.

(*iii*) The Swedish extraction method mentioned above under (*b*) is rapid and gives a good reproducibility.

The tests referred to in part I of appendix 4 were all carried out with distilled water or rain water, and no hard water was used for a comparison between the methods.

Previous to the experiments described in parts I and II of appendix 4, experiments were made in Sweden to determine the action on normal portland cement of soft and hard water according to the Swedish extraction method. When soft water was used, the results of 100 extractions were found throughout to follow the trend given for portland cement in table 9 of appendix 4, while the effect of hard water was quite different. At first a positive dissolution was obtained, reaching a maximum at about 10 extractions, after which a marked negative dissolution took place. At about 50 extractions the lime content was the same as in the original sample, and hardly any variation of the lime content occurred up to 100 extractions. An account of some of the tests made in Sweden is given in part III of appendix 4.

The subcommittee, at the present time, is unable to reach a definite conclusion as to a suitable method which can be recommended for testing the action on cement of water percolating through concrete, but the extraction method, by which pulverized, hydrated cement is repeatedly shaken with water, appears to be a suitable routine method. A tentative standard specification for this method is given in appendix 5. This method may not be applicable to aluminous cement.

IV. SHRINKAGE

Shrinkage of cement, cement mortar, and concrete has been extent sively studied all over the world by means of many different methods, but no international routine method of testing has yet been agreed upon. So far as the subcommittee is concerned, the object has mainly been to find a simple method to determine the effect of different cements on the shrinkage of concrete. In this connection it was considered that tests on hydrated cement would give values of shrinkage of another magnitude than tests on concrete, while, on the other hand, tests on concrete are slower and more cumbersome and would be difficult to standardize. The subcommittee has, therefore, considered that tests on cement mortar would provide the most practical means of testing shrinkage. To decide whether tests on cement mortar can be accepted, it is, however, indispensable to investigate the shrinkage of cement mortar and of concrete made of the same cements, one of the main objects of the comparison being to find out whether tests on cement mortar would place the cements in the same order of shrinkage as tests on concrete.

In the early stages of the proceedings of the subcommittee, the German subcommittee on special cements undertook to carry out experiments for the purpose of drawing up a specification of routine tests of shrinkage. As this investigation is not yet concluded, the subcommittee is unable to submit a tentative standard specification. In the opinion of the subcommittee, however, and subject to further investigation, the test method suggested by the German subcommittee appears worth consideration, and a description of this method of testing is attached for information, appendix 6.

V. Permeability

The subcommittee has examined various methods used for testing the permeability of cement mortar and concrete, and has come to the conclusion that for the present it appears inadvisable to standardize a definite, detailed method of testing permeability. The subcommittee has, therefore, limited the scope of its activities in this respect to submitting certain tentative recommendations which should be applicable to any test method that may be preferred. These recommendations are contained in appendix 7 and have been compiled after the problem has been studied on behalf of the subcommittee by Mr. M. Mary (France). The subcommittee, being concerned with the influence on permeability of different cements, has confined its considerations to this aspect of the problem.

In concrete structure great care and supervision is needed to prevent the formation of cracks, which often are responsible for permeable concrete. Cracks are sometimes caused by structural defects, and these do not fall under the investigation undertaken by the subcommittee under the strict definition of permeability. No attempts have accordingly been made to analyze structural defects, and it cannot be too often repeated that it is of little use devoting attention to the actual permeability if, in design and during construction, consideration of the structure itself is neglected.

The subcommittee considers that a comparison of different cements should be determined by tests on concrete and not on cement mortar.

When studying permeability, it is of fundamental importance to note that, for any given concrete, permeability is a continually varying property, since it is intimately connected with the condition of the cement. For this reason the curing conditions and the length of time during which the test specimen is subjected to water pressure during the tests are of great importance. Apart from the amount of cement used per unit volume of finished concrete, the grading of the material has a great influence on permeability. Also the method of making the test specimen must be carefully considered.

In conducting experiments on permeability, great care is always necessary to ensure uniformity in the fabrication and curing of the specimens. The results from neglect in this respect are much more remarked in the effect on permeability than on strength. In order to obtain consistent figures, the mixing conditions, water content, ramming, and curing must all be controlled within very narrow limits. So sensitive is the concrete that even the slightest variation of conditions on successive days is liable to lead to discordant permeability results.

The testing equipments used in various laboratories may conveniently be classified as follows:

1. Apparatus providing for a test specimen of two free surfaces, one for the entrance and one for the escape of the water. The total quantity of water penetrating the specimen enters through one surface and escapes through the other.

2. Apparatus providing for a test specimen of which all surfaces are free, but a limited area of one surface is reserved for the entrance of the water and a limited area of another surface for its escape.

The subcommittee believes that it would be most suitable to use testing equipment under class 1. It is desirable to make such arrangements that the amount of water penetrating through the specimen can be collected and measured with minimum loss due to evaporation, and it is also preferable that the testing equipment should be such that the percolating water can be measured at every moment.

To compare the effect of different cements, permeability can in principle be tested according to two different methods.

Method A.—The determination of the minimum amount of cement per unit volume of finished concrete which, under fixed test conditions, gives impermeable concrete; and

Method B.—The determination of the permeability of concrete of different cements by using test specimens of the same amount of cement per unit volume of finished concrete.

The comparison of the different cements according to method A is obtained on the basis of the minimum amount of cement required to obtain impermeable concrete, while according to method B the basis of comparison is the amount of percolating water.

Although the first method is somewhat more expensive than the second, it seems preferable to use this method whenever possible.

With reference to the grading of the fine aggregate, it should be noted that the amount of very fine particles (smaller than 0.30 mm) has a marked influence on the permeability of the concrete, and that when tests are carried out according to method B, excessive amount of very fine particles should be avoided so as to obtain permeable concrete. For this purpose the test specimens for method B should be made of comparatively lean concrete containing about 200 kilograms of cement per cubic meter of finished concrete for specimens to be tested under a water pressure of 10 kilograms per square centimeter.

When considering the method and time of curing, the subcommittee has taken into account the possibility of certain special cements having a slow rate of hardening and has, therefore, found it desirable to allow ample time for curing so as to obtain a fair comparison between different cements. For this reason the subcommittee recommends a comparatively long time of curing in water (25 to 53 days) and a subsequent curing in moist air (at least 14 days). As the recommendations refer to tests to compare different cements in regard to permeability and not to routine tests at the works, of which quick results are required, the fairly long time of curing does not seem to be of any great disadvantage.

VI. WORKABILITY

It appears that no satisfactory and recognized method of testing the workability of concrete has yet been evolved, and a suitable method of determining the influence on workability of different cements seems also to be lacking. Even finding a definite and clear definition of workability has, for obvious reasons, met with difficulties. As previously generally understood, workability is that property which is indicated by the effort required to place concrete to obtain a uniform and homogeneous finished product. In any case, workability is not a simple physical property but the resultant of several properties of the ingredients, and according to the present conception the workability is closely connected with the following two properties of the concrete mix:

(*a*) Mobility (also referred to as plasticity or the ease with which the concrete can be placed in the molds); and

(*b*) Cohesion or nonsegregation.

Experience has shown that the cement has a certain influence on the workability of concrete. Although the aim of the subcommittee is to determine this influence, no satisfactory testing method has yet been developed.

Many of the methods of testing workability, so far published, have in reality resulted in testing consistence rather than workability. Such methods are, for instance, the slump, flow, and penetration tests, the spout test, and the ball-plasticimeter method. As other methods have also been found unsuitable, the subcommittee has considered it advisable to start the study of the problem in question by investigating the workability of concrete generally.

During the proceedings of the subcommittee, the Swedish Committee on Large Dams offered to carry out certain investigations in this respect, which offer was gratefully accepted by the subcommittee. These investigations were made by Mr. G. S. Lalin (Sweden) and Dr. A. Frey Samsioe (Sweden), and are attached to this report as appendices 8 and 9, respectively. A summary is given below.

Mr. Lalin is considering different degrees of workability between the following limits:

Lower limit.—Heavy and firm concrete giving a nonworkable mix, and

Upper limit.—Signs of segregation, and complete segregation.

Between these limits the following properties of a workable concrete mix are considered: Mobility, cohesiveness, smoothness, flow, and water separation in the mixer. A great number of different mixes were studied, and in each case the workability was estimated with reference to an arbitrary scale from 0 (corresponding to a nonworkable mix) to 20 (corresponding to the highest degree of workability) according to the experience and the individual judgment of the investigator. Through consideration of the various factors influencing workability, previously mentioned, an empiric formula expressing the workability is evolved. This formula contains a constant, the value of which was determined by the degree of workability estimated by the individual judgment of the investigator. This constant is the same for all mixes. The formula is proved by comparing the degree of workability calculated from the formula with the degree of workability estimated by the subjective method.

Dr. Samsioe defines workability as the facility with which the concrete mix, by the aid of certain tools, may be worked into certain molds so as to obtain a mass free from cavities. It is considered that, at least for the present, it is of importance to determine the interval rather than the degree of workability. The lower limit, at which the concrete mix becomes barely workable, is called the point of workability, and the upper limit, at which segregation occurs, is called the point of segregation. Workable concrete lies between these two limits, and as in actual practice it is necessary to allow certain variations in the composition of the mixes it is of importance that the interval of workability should be as great as possible.

It is suggested to determine the quality of workable mixes by testing the compactibility; i. e., the volume of solid material in ratio to the total volume. This is done by weighing a sample of the concrete mix before the concrete has set and hardened. The method is proved by tests on hardened concrete in respect to strength and watertightness.

Dr. Samsioe also deals with the question whether there is a relation between the results obtained in the laboratory and those experienced with the same concrete mix in the field. The author recommends that further investigations of the influence of different cements on workability should include the following tests:

1. The determination of the difference of the water content between (*a*) mixes at the point of workability and at the point of segregation, respectively, by different methods of placing in the field, and (*b*) a mix of the same ingredients at maximum compactibility and at the point of segregation, by a fixed laboratory method of placing.
2. The determination of the compactibility of concrete mixes at the point of workability and at the point of segregation, as well as within the interval of workability, when the concrete is placed by the laboratory method.
3. Observations of the adherence of the cement to the tools and the mixer.

In the opinion of the subcommittee, further investigations are necessary before it is possible to reach any definite conclusion as to the best method of testing workability to compare different cements. The subcommittee trusts that the experiments carried out by Mr. Lalin and Dr. Samsioe will be of assistance in a further study of this problem.

Brussels, March 30, 1936.

For and on behalf of the International Subcommittee on Special Cements for Large Dams.

Bo Hellström,
Chairman.

A. Genthial,
Secretary-General of the International Committee on Large Dams.

RAPPORT INTERIMAIRE SUR LES METHODES D'ESSAI DES CIMENTS EN CE QUI CONCERNE LA CHALEUR D'HYDRATATION, L'ACTION SUR LE CIMENT DES EAUX D'INFILTRATION DANS LE BETON, LE RETRAIT, LA PERMEABILITE ET LA MANIABILITE

(TRADUCTION)

I. INTRODUCTION

La question de la fissuration et de la détérioration des barrages en béton et autres ouvrages de retenue de l'eau est devenue dans les dernières années un problème sérieux: Pourquoi? parce que, d'une part, les méthodes modernes de construction rapide ne laissent pas à la chaleur de prise le temps de se dégager, que, d'autre part, la détérioration ne se manifeste qu'au bout de quelque temps et que, par conséquent, on ne s'en est rendu compte que récemment; en outre, l'attaque progressive du béton par certaines eaux pures s'est de plus en plus confirmée. La détérioration survenue dans certains barrages au bout d'une période relativement courte a nécessité des frais de réparation importants.

Les fissures de retrait peuvent avoir deux causes: la température élevée atteinte pendant le durcissement et le refroidissement consécutif, et la variation de volume due à la prise et au séchage du béton. Dans les constructions soumises à la pression de l'eau d'un seul côté, la détérioration est due principalement à la dissolution et à l'entraînement de la chaux du ciment par des eaux très pures ou légèrement acides s'infiltrant continuellement dans le béton. La vitesse de progression de la détérioration dépend dans une large mesure de la perméabilité du béton: c'est ce qui explique que l'action des eaux corrosives n'est pas limitée à la surface du barrage. Les questions connexes du rapport eau-ciment et des facteurs influant sur la maniabilité d'un béton pendant sa mise en œuvre ont aussi leur importance.

Pour surmonter les difficultés résultant de ces phénomènes, il serait d'une grande utilité d'avoir un ciment ou des ciments convenant plus particulièrement aux ouvrages soumis à la pression unilatérale de l'eau. L'emploi d'un ciment spécial, pour si bonne que soit sa qualité, ne supprime cependant en rien la nécessité de prendre toutes précautions pour obtenir un bon béton de tout premier ordre. Ce point est et sera toujours d'une importance fondamentale pour toutes les constructions en béton et particulièrement pour les grands barrages.

Une des tâches principales de la Sous-Commission Internationale des Ciments Spéciaux pour grands barrages est d'établir des propositions concernant des méthodes standard d'essai des ciments normaux et spéciaux au point de vue des propriétés ayant de l'importance pour les barrages et autres ouvrages de retenue d'eau, et pour lesquelles il n'existe pas ou il n'existe que peu de méthodes d'essai connues. La sous-commission s'est entendue avec les Comités Nationaux des Grands Barrages (ou les sous-comités des ciments spéciaux) pour exécuter les expériences nécessaires dans ce but. Le présent rapport traite exclusivement de ces méthodes d'essai: on a délibérément écarté les méthodes compliquées et coûteuses, l'objectif étant de trouver des méthodes simples et bon marché pouvant servir à la fois en laboratoire et sur chantier.

Les recherches exécutées par la sous-commission ont été limitées aux propriétés du ciment et du béton mentionnées ci-après. Le contenu de ce Rapport Provisoire peut se résumer comme il suit:

Chaleur d'hydratation.—Il est proposé une spécification standard d'essai de la chaleur d'hydratation du ciment, basée sur le principe adiabatique; cependant, les détails sont encore soumis à de nouvelles recherches actuellement en cours.

On a exécuté des recherches pour déterminer la chaleur d'hydratation en observant l'élévation de température du mortier de ciment dans les bouteilles thermos; on donne une description de ces expériences.

Action sur le ciment de l'eau filtrant à travers le béton.—On a exécuté des expériences sur cette action en utilisant des plaques de mortier de ciment; on a comparé ces essais avec une méthode d'extraction consistant à déterminer la solubilité du ciment pulvérisé et hydraté, agité avec de l'eau, ainsi qu'avec une méthode de détermination de l'action sur des plaques de mortier de ciment soumises à un jet d'eau. On donne un compte rendu de ces recherches, et on présente une spécification standard d'essai.

Retrait.—On donne les détails d'une spécification standard allemande pour essayer le retrait.

Perméabilite.—Le rapport présente des recommandations concernant les essais de perméabilité.

"Workability" (maniabilité).—On a executé des recherches d'essais de "workability" d'après deux méthodes nouvelles: compte rendu de ces experiénces est donné.

Comme le travail de la sous-commission n'est pas encore terminé et que les recherches sont encore en cours, on n'a pu proposer des spécifications provisoires ou des recommandations que pour la chaleur d'hydratation, l'action sur le ciment de l'eau de filtration à travers le béton, et la perméabilité. La spécification concernant les essais de retrait a été préparée en Allemagne: comme la sous-commission n'a pas été en mesure d'étudier les résultats obtenus par cette méthode, la spécification est donnée ici à titre de renseignement seulement.

On espère que les résultats des recherches de la sous-commission seront présentés aux membres de la Commission Internationale des Grand Barrages, en vue d'obtenir leur avis et leurs critiques.

II. CHALEUR D'HYDRATATION

Au cours des dernières années, un certain nombre de méthodes diverses ont été appliquées dans différents pays pour déterminer la chaleur d'hydratation du ciment pendant la prise et le durcissement. Les plus importantes de ces méthodes peuvent être classées en: (1) méthodes indirectes, (2) méthodes directes. Ces dernières comprennent:

(*a*) des appareils dans lesquels la chaleur s'accumule, la dissipation de chaleur étant réduite au minimum;

(*b*) des appareils dans lesquels la chaleur se dissipe, l'accumulation de chaleur étant réduite au minimum;

(*c*) des appareils où une partie de la chaleur s'accumule et une partie se dissipe.

Dans le cas 2 (*a*), le but principal est de déterminer l'accumulation de chaleur, et on introduit ou non des corrections pour la dissipation de chaleur, tandis que dans le cas 2 (*b*), on tient compte de la dissipation de chaleur et on introduit ou non des corrections pour l'accumulation de chaleur. Dans le cas 2 (*c*) on tient compte à la fois de l'accumulation et de la dissipation, qui ont toutes les deux de l'importance.

Certaines méthodes sont simples mais sans précision, tandis que d'autres, plus précises, sont plus compliquées et coûteuses; la sous-commission n'a trouvé aucune des méthodes existantes entièrement satisfaisante pour servir de méthode courante bon marché.

Dans certains pays on a souvent employé, comme méthode courante pour de très grands barrages, la méthode indirecte, qui est généralement une méthode de dissolution; mais les essais doivent être exécutés par un chimiste éprouvé qui peut ne pas être facile à trouver ou qu'on ne peut guère employer pour des barrages de dimensions modestes.

On a estimé que la méthode à préférer serait une méthode entièrement adiabatique (catégorie 2 *a*), donnant l'histoire thermique du béton réellement employé sur le chantier, mais les méthodes précises existantes ont été jugées trop compliquées. Parmi les méthodes de la catégorie 2 (*c*), la méthode de la bouteille thermos, où l'on mesure l'élévation de température du mortier de ciment dans des bouteilles isolées, est simple; mais le mode d'application de cette méthode employé jusqu'ici a donné des résultats inexacts.

La sous-commission a essayé de trouver une méthode pratique, simple, bon marché, entièrement adiabatique, et elle espère que la méthode décrite aux appendices 1 et 2 sera jugée satisfaisante. Cette méthode a été établie par la "Building Research Station" de Grande-Bretagne, pour le Sous-Comité Britannique des ciments spéciaux.[1]

Les recherches effectuées en Angleterre sont décrites à la 1ère partie de l'appendice 1 et comprennent des essais comparatifs au moyen d'un calorimètre standard déjà existant, précis, du calorimètre adiabatique simplifié et de la méthode de chaleur de dissolution.

Les principaux résultats de ces essais comparatifs sont les suivants:

(*a*) Les valeurs d'élévation de température sont pratiquement les mêmes pour les deux types de calorimètre adiabatique: on en conclut

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[1] *Le Comité Britannique des Ciments Spéciaux est une Commission mixte dépendant à la fois de l' "Institution of Civil Engineers" et du Comité Britannique des Grands Barrages.*

que les valeurs obtenues avec le calorimètre adiabatique simplifié sont suffisantes pour les buts pratiques poursuivis.

(*b*) Pour les ciments à dégagement rapide de chaleur, les valeurs obtenues par les méthodes adiabatique et de chaleur de dissolution ne peuvent pas différer notablement.

(*c*) Pour les ciments à dégagement lent de chaleur, il faut s'attendre à ce que la méthode de chaleur de dissolution donne des valeurs plus élevées que la méthode adiabatique.

(*d*) L'équipement pour la méthode adiabatique simplifiée ne peut être employé que sur un seul échantillon à la fois. D'autre part, le prix de l'appareil, facile à fabriquer, est évalué à 10–15 livres seulement.

Une fois que cette méthode eut été essayée à la "Building Research Station", 6 appareils ont été construits au Laboratoire du Ciment à Stockholm et on a exécuté avec ces calorimètres, pour le Comité Suédois des Grands Barrages, des expériences qui sont encore en cours. On peut dire que, dans l'ensemble, elles ont confirmé les résultats obtenus à la "Building Research Station" en Angleterre; il peut se faire cependant qu'il y ait de légères différences dans la méthode et l'appareil.

Des essais en double, exécutés avec des calorimètres fabriqués en Suède, ont montré, entre eux, des différences d'environ 10%. Avec le calorimètre adiabatique simplifié, on a trouvé que les valeurs de la chaleur d'hydratation concordaient bien avec celles obtenues par la méthode de la bouteille thermos, comme indiqué à l'appendice 3, mais étaient considérablement plus basses que celles obtenues par la méthode de la chaleur de dissolution; un exposé de la recherche suédoise est donné à la 2$^{\text{ème}}$ partie de l'appendice 1.

De l'avis de la sous-commission, la méthode adiabatique simplifiée pour mesurer la chaleur d'hydratation, décrite à l'appendice 2, paraît convenable comme méthode d'essai pratique, bien que des essais ultérieurs puissent peut-être démontrer l'utilité de certaines légères modifications.

La sous-commission a aussi étudié la méthode de la bouteille thermos: il est donné ci-après un court aperçu de cette méthode, complètement décrite à l'appendice 3. Cette méthode a été étudiée, pour le Comité Suédois des Grands Barrages, par le Dr. A. Frey Samsioe, de la Société Vattenbyggnadsbyran (VBB), Ingénieurs Conseil, Stockholm, en collaboration avec le Laboratoire du Ciment de l'Institut Royal Suédois pour les Recherches de Génie Civil à Stockholm.

D'après cette méthode, on observe l'élévation de température dans du mortier de ciment dont on a rempli une bouteille thermos du type commercial ordinaire, la bouteille étant plongée dans un bain d'eau à température constante. Les bouteilles thermos sont étalonnées en les remplissant d'eau chaude à environ 50° C, la température du bain étant de 30° C. On mesure la température de l'eau des bouteilles ainsi que de l'eau du bain au moyen de thermomètres ordinaires (précision 0,1° C), trois heures et quarante-quatre heures après le début des essais, et on détermine d'après ces lectures les constantes individuelles de transmission de chaleur. Ceci fait, on remplit les bouteilles de mortier de ciment (1 part de ciment pour 4,5 parts de sable standard, en poids, rapport eau-ciment 0,60), et on les plonge dans le bain d'eau: on lit la température, très fréquement pendant le premier jour et la première nuit, et ensuite à plus longs intervalles. La chaleur d'hydratation pendant un temps donné est la somme de la chaleur accumulée dans la bouteille et de la chaleur dissipeé pendant le même temps. L'accumulation de chaleur est le produit de l'élévation de température par la chaleur spécifique du mortier et de la bouteille; quant à la chaleur dissipée, on la calcule en mesurant, sur un diagramme, l'aire comprise entre la courbe de température du mortier et la température constante du bain d'eau, en appliquant à chaque bouteille la constante de transmission de chaleur préalablement trouvée.

Des essais exécutés on peut tirer les conclusions suivantes:

(*a*) La méthode de la bouteille thermos pour mesurer l'évolution thermique du ciment, telle qu'elle est décrite ci-dessus, est assez précise. Comme on le voit à l'appendice 3, on tient compte dans les calculs, d'après la méthode en question, d'une quantité déterminée de chaleur fournie électriquement à une bouteille thermos, avec une précision d'un petit nombre de centièmes. Des mesures doubles exécutées sur le ciment ne diffèrent l'une de l'autre que de 2 calories au plus par gramme de ciment.

(*b*) Par comparaison avec la méthode de chaleur de dissolution, les valeurs obtenues par la méthode de la bouteille thermos, pour trois essais de ciment, sont, en moyenne, inférieures de 9 calories par gramme. De ces 9 calories, 3 sont dues à la chaleur de mouillage, dont il n'est pas tenu compte dans la deuxième méthode. Comme on le voit à l'appendice 1, 1ère partie, les essais exécutés en Grande-Bretagne donnent des différences analogues, ou même supérieures, entre les valeurs obtenues par la méthode de la chaleur de dissolution et la méthode adiabatique.

(*c*) Les valeurs obtenues par la méthode de la bouteille thermos concordent assez bien avec celles de la méthode adiabatique simplifiée: On peut considérer la précision de la méthode de la bouteille thermos comme satisfaisante, en tant que méthode pratique de chantier.

(*d*) Les opérations de mesure prévues par la méthode de la bouteille thermos ne sont pas très compliquées. Le calcul des résultats exige un peu de soin, mais sans exagération. Le travail se trouve réduit de beaucoup lorsqu'il s'agit d'un grand nombre d'essais. Par conséquent, la méthode est assez simple et elle peut être considérée comme satisfaisante lorsqu'on exécute plusieurs essais en même temps.

(*e*) Le prix de l'appareil est peu élevé et diminue rapidement au fur et à mesure que le nombre des essais exécutés est plus grand.

(*f*) La fragilité des bouteilles thermos est un inconvénient de la méthode.

Bien que la sous-commission juge la méthode de la bouteille thermos comme fort digne de considération, elle désire différer l'émission de son opinion sur cette question jusqu'a ce que cette méthode ait été essayée dans plus d'un laboratoire et jugée partout satisfaisante. Le sous-commission espère que la publication des expériences, à l'appendice 3 ci-après, incitera d'autres laboratoires à exécuter d'autres essais et à en communiquer les résultats à la sous-commission.

A en juger par les expériences exécutées en Grande-Bretagne et en Suède, il semble que, du moins pour certains ciments, la méthode de la chaleur de dissolution donne pour la chaleur d'hydratation des valeurs plus élevées que la méthode adiabatique et que celle de la bouteille thermos.

III. DÉTERMINATION DE L'ACTION SUR LE CIMENT DE L'EAU FILTRANT À TRAVERS LE BÉTON

Diverses méthodes ont été employées pour déterminer l'action sur le ciment de l'eau filtrant à travers le béton. En raison des difficultés pour obtenir une précision et une reproductibilité satisfaisantes lorsqu'on mesure la dissolution du ciment d'un béton ou d'un mortier soumis à une filtration d'eau, on a essayé d'autres méthodes.

En Suède, on a employé les deux méthodes d'extraction suivantes: (*a*) l'eau est versée sur du ciment pulvérisé et hydraté; (*b*) le ciment pulvérisé et hydraté est agité à plusieurs reprises avec de l'eau. Dans les deux cas on analyse l'eau et on détermine la quantité de matières dissoutes.

En France, M. Rengade a imaginé une méthode d'après laquelle des plaques de mortier de ciment sont soumises à l'action d'un jet d'eau qui frappe leur surface: l'importance de l'usure par érosion est déterminée par l'observation oculaire.

On a fait deux objections à la méthode suédoise: le ciment hydraté, sous forme de poudre, présente à l'attaque de l'eau une aire supérieure à celle que présente un échantillon de béton: le broyage du ciment tend à exposer à l'action de l'eau des portions non hydratées.

Pour répondre à ces objections, le "Bureau of Reclamation" des États-Unis a exécuté une série d'expériences dans lesquelles les courbes de dissolution ont été obtenues par l'analyse de l'eau qui a passé sous pression à travers des cylindres de béton, ce béton étant comparable à celui employé dans les constructions existantes. Mais avec un béton de ce genre, la quantité d'eau passant à travers l'éprouvette, même sous une pression très forte, est si faible qu'il faudrait des années pour produire une désagrégation du ciment. Afin de réaliser un essai accéléré dans lequel on pourrait faire passer assez d'eau à travers l'éprouvette pour obtenir une désagrégation suffisamment rapide, on a exécuté des essais avec du béton maigre. On a constaté que les courbes de dissolution obtenues avec ces essais avaient une forme très semblable à celle de la courbe obtenue par les méthodes suédoises. Comme les deux méthodes d'essai, largement différentes, donnaient, qualitativement, des résultats concordants en général, on a estimé que pour du béton poreux à travers lequel se produit une infiltration substantielle, les essais d'extraction sur du mortier écrasé donneraient des indications sûres concernant ce qu'il y a lieu d'attendre dans la construction réelle. Un exposé des essais exécutés aux États-Unis est donné à l'appendice 4, 2ème partie.

On a fait à la méthode Rengade l'objection que l'influence du facteur d'érosion mécanique vient s'ajouter à l'action dissolvante de l'eau, et aussi qu'on n'avait recours qu'à l'observation oculaire pour évaluer cette influence.

Encouragée par les expériences exécutées aux États-Unis, la sous-commission a jugé bon d'étudier de plus près les diverses méthodes mentionnées; un exposé détaillé de ces recherches est donné à l'appendice 4, 1ère partie. Ces expériences ont été exécutées par la

"Building Research Station", pour le Comité Britannique des Ciments Spéciaux. En voici les conclusions:

(1) La méthode de filtration ne permet pas une reproduction satisfaisante; cette méthode ne parait pas pouvoir constituer une méthode standard courante.

(2) On n'a appliqué la méthode Rengade qu'à un seul échantillon. Il est nécessaire que ces essais soient confirmés avant que l'on puisse en tirer des conclusions définitives.

(3) La méthode suédoise d'extraction mentionnée à l'alinéa (*b*) ci-dessus est rapide et est facile à reproduire dans des conditions identiques.

Les essais visés à l'appendice 4, 1ère partie, ont été tous exécutés avec de l'eau distillée ou de l'eau de pluie; on n'a pas employé d'eau dure pour la comparaison de ces diverses méthodes.

Avant les expériences décrites à l'appendice 4, 1ère et 2ème parties, on a exécuté en Suède des expériences pour déterminer l'action, sur le ciment Portland normal, de l'eau douce et de l'eau dure, d'après la méthode d'extraction suédoise. Avec l'eau douce, on a trouvé que les résultats de 100 extractions ont l'allure indiquée pour le ciment Portland à la table 9 de l'appendice 4; par contre, l'effet de l'eau dure était entièrement différent. Au début, on obtenait avec une dissolution positive, atteignant un maximum au bout d'environ 10 extractions, ensuite une dissolution nettement négative. Vers 50 extractions, la proportion de chaux était la même que dans l'échantillon initial, et c'est à peine si l'on constatait quelque variation du contenu en chaux jusqu'à la centième extraction. Un exposé de quelques-uns des essais exécutés en Suède est donné à l'appendice 4, 3ème partie.

Actuellement, la sous-commission n'est pas en mesure d'émettre une conclusion définitive sur la méthode à recommander pour essayer l'action sur le ciment de l'eau filtrant à travers le béton; mais la méthode d'extraction, dans laquelle le ciment hydraté, pulverisé, est agité à plusieurs reprises avec l'eau, parait être une méthode pratique convenable. Une spécification standard provisoire basée sur cette méthode est donée à l'appendice 5. Cette méthode peut ne pas s'appliquer au ciment alumineux.

IV. RETRAIT

Le retrait du ciment, du mortier de ciment et du béton a été largement étudié dans le monde entier au moyen de différentes méthodes, mais on ne s'est pas encore mis d'accord sur quelque méthode pratique internationale. En ce qui concerne la sous-commission, elle s'est proposée de trouver une méthode simple pour déterminer l'effet des différents ciments sur le retrait du béton. Dans cet ordre d'idées, on a pensé que les essais sur le ciment hydraté donneraient des valeurs de retrait différentes de celles obtenues par les essais sur le béton, et que, d'autre part, les essais sur le béton, plus lents et plus compliqués, seraient difficiles à standardiser. En conséquence, la sous-commission a jugé que l'essai sur le mortier de ciment serait préférable, comme fournissant le moyen le plus pratique d'évaluer le retrait. Cependant, pour décider si l'on peut accepter les essais sur le mortier de ciment, il est indispensable d'étudier le retrait d'un mortier de ciment et de béton faits du même ciment, puisque l'un des principaux objets de comparaison est de trouver si les essais sur le mortier de ciment classent les ciments, au point de vue de retrait, dans le même ordre que les essais sur le béton.

Dans les débuts de l'activité de la sous-commission, le sous-comité allemand des ciments spéciaux a entrepris des expériences en vue de mettre sur pied une spécification d'essais pratiques de retrait. Comme ces recherches ne sont pas encore terminées, la sous-commission n'est pas en mesure de présenter une spécification standard. Cependant, et sous réserve de recherches ultérieures, la méthode d'essais suggérée par la sous-commission allemande parait digne de considération et un exposé de cette méthode est donné pour information (appendice 6).

V. PERMÉABILITÉ

La sous-commission a examiné les diverses méthodes qui ont été suivies pour étudier la perméabilité du mortier de ciment et du béton, et elle a conclu, qu'actuellement, il lui paraissait peu sage de fixer une méthode standard définie et détaillée pour servir aux essais de perméabilité. C'est pourquoi la sous-commission s'est bornée, en ce qui concerne cette question, à soumettre certaines recommandations expérimentales qui pourraient être adoptées pour n'importe quelle méthode d'essai choisie. On trouvera ces recommandations à l'appendice 7, elles ont été arrêtées après que le problème eut été étudié, pour la sous-commission, par M. Mary (France). La sous-commission ayant à s'occuper de l'influence de divers ciments sur la perméabilité a limité son étude à cet aspect du problème.

Dans les structures en béton il faut beaucoup de précautions et de surveillance pour éviter la formation de fissures, qui sont souvent la cause de la perméabilité du béton. Les fissures sont quelquefois provoquées par des défauts de structure, et ces défauts ne concernent pas les recherches qui ont été entreprises par la sous-commission à propos de la stricte définition de la perméabilité. En conséquence, on n'a pas cherché à étudier les défauts de structure, et on ne peut jamais trop répéter qu'il est inutile de concentrer l'attention sur la perméabilité réelle si dans l'établissement des projets et au cours de la construction on néglige les problèmes de structure.

La sous-commission considère qu'une comparaison entre les différents ciments doit être faite au moyen d'essais sur le béton et non sur le mortier de ciment.

Quand on étudie la perméabilité, il est d'importance primordiale de noter que la perméabilité est, pour n'importe quel béton, une propriété qui varie continuellement car elle est intimement liée à l'état du ciment. Pour cette raison, les conditions de conservation et le temps pendant lequel l'éprouvette d'essai est soumise à la pression de l'eau au cours de l'essai ont une grande importance. La quantité de ciment utilisée par unité de volume de béton mis en œuvre étant mise à part, la granulométrie du matériau a une grande influence sur la perméabilité. Aussi, la méthode suivie pour fabriquer l'éprouvette d'essai doit être examinée avec soin.

En procédant aux essais de perméabilité, il faut toujours avoir soin de s'assurer qu'une méthode uniforme a été suivie pour la fabrication et la conservation de l'éprouvette. Des négligences à cet égard auraient plus d'importance pour la perméabilité que pour la résistance. Pour obtenir des résultats cohérents, il faut surveiller très étroitement les conditions de mélange, le dosage en eau, le damage, et la conservation. Le béton est si sensible que même les plus légères variations de condition au cours des jours qui se succèdent peuvent provoquer des résultats de perméabilité discordants.

Le matériel d'essai utilisé dans divers laboratoires peut, pour la commodité, être classé comme suit:

1. Appareils conçus pour des éprouvettes d'essai ayant deux surfaces libres, l'une pour l'entrée et l'autre pour la sortie de l'eau. La quantité totale d'eau traversant l'éprouvette entre par une surface et s'échappe par l'autre.
2. Appareils conçus pour une éprouvette d'essai dont toutes les surfaces sont libres, mais une certaine partie de l'une des surfaces est réservée pour l'entrée de l'eau, et une certaine partie d'une autre surface est réservée pour la sortie de l'eau.

La sous-commission croit qu'il vaudrait mieux utiliser le matériel d'essai n° 1. Il faudrait prendre des dispositions pour que la quantité d'eau traversant l'éprouvette puisse être recueillie et mesurée avec le minimum de perte d'évaporation, et il serait également désirable que le matériel d'essai soit muni d'un dispositif tel que l'eau filtrée puisse être mesurée à tout instant.

Pour étudier l'action des différents ciments, les essais de perméabilité peuvent, en principe, être faits suivant deux méthodes différentes:

Méthode A.—Détermination, par unité de volume de béton mis en œuvre, de la quantité minimum de ciment, qui, dans certaines conditions d'essai, donne un béton imperméable.

Méthode B.—Détermination de la perméabilité du béton fait avec différents ciments en utilisant des éprouvettes d'essai fabriquées avec la même quantité de ciment par unité de volume de béton mis en œuvre.

La comparaison des différents ciments suivant la méthode A est établie sur la base de la quantité minimum de ciment nécessaire pour obtenir un béton imperméable, tandis qu'avec la méthode B la base de comparaison est la quantité d'eau filtrée.

Bien que la première méthode soit un peu plus coûteuse que la seconde, il parait préférable de l'adopter toutes les fois que cela sera possible.

En ce qui concerne la granulométrie des fins agrégats, il faut noter que la quantité des éléments très fins (au-dessous de 0,30%) a une influence notable sur la perméabilité du béton, et que lorsqu'on adopte pour les essais la méthode B, il faut éviter d'avoir une quantité excessive d'éléments très fins pour obtenir du béton perméable. Dans ce but, les éprouvettes d'essai employées par la méthode B devront être faites avec du béton relativement maigre contenant environ 200 kg de ciment par m^3 de béton mis en œuvre pour les éprouvettes qui devront être soumises aux essais sous une pression d'eau de 10 kg par cm^2.

Lorsqu'elle a examiné la méthode et la durée de la conservation, la sous-commission a aussi arrêté son attention sur le fait que certains ciments spéciaux durcissent lentement, et elle a trouvé qu'il serait désirable que la durée de la conservation soit longue afin de permettre d'établir une comparaison équitable entre les divers ciments. C'est pour cette raison que la sous-commission recommande une période de conservation relativement longue dans l'eau (25 ou 53 jours), suivie d'une période de conservation dans l'air humide (au moins 14 jours). Comme ces recommandations concernent les essais faits en vue de comparer différents ciments au point de vue de leur perméabilité, et non les essais pratiques effectués sur le chantier, et dont on attend des résultats rapides, il ne semble pas que cette longue période de conservation puisse avoir de gros inconvénients.

VI. WORKABILITY (MANIABILITÉ)

Il semble que l'on n'a pas encore trouvé de méthode satisfaisante, universellement reconnue, d'essai de la "workability" du béton, en sorte que l'on paraît aussi manquer de méthode convenable pour déterminer l'influence des divers ciments sur cette propriété. On s'est même heurté, pour des raisons aisées à comprendre, à des difficultés pour définir d'une manière nette et précise le terme "workability". En général, on entend par là la propriété indiquée par l'effort exigé pour mettre en place le béton en vue d'obtenir un produit fini, uniforme et homogène. Quoi qu'il en soit, la "workability" n'est pas une simple propriété physique: c'est le résultat de plusieurs propriétés des éléments constituants, et, d'après l'opinion actuellement admise, cette propriété est étroitement liée aux deux propriétés suivantes du béton:

(*a*) mobilité (qui concerne la plasticité ou la facilité avec laquelle le béton peut être mis dans des moules);

(*b*) cohésion ou non ségrégation.

L'expérience a montré que le ciment a une certaine influence sur la maniabilité du béton. Bien que le but poursuivi par la sous-commission soit de déterminer cette influence, on n'a pas encore trouvé de méthode d'essai satisfaisante.

Maintes méthodes d'essai de cette propriété, tout au moins celles qui ont été publiées, se sont, en réalité, appliquées à la consistance plutôt qu'à la "workability": tels sont, par exemple, les essais d'affaissement, d'étalement, de pénétration, d'écoulement sur goulotte, et la méthode du plasticimètre à bille. Comme les autres méthodes n'ont pas non plus été jugées acceptables, la sous-commission a décidé d'entreprendre l'étude du problème en question en étudiant la "workability" du béton en général.

Au cours des opérations de la sous-commission, le Comité Suédois des Grands Barrages s'est offert pour exécuter certaines recherches à ce sujet, et la sous-commission a accepté cette offre avec reconnaissance. Ces recherches ont été exécutées par M. G. S. Lalin (Suède) et M. le Dr. A. Frey Samsioe (Suède): elles sont exposées aux appendices 8 et 9 respectivement: en voici un aperçu:

M. Lalin considère différents degrés de maniabilité compris entre les limites suivantes:

Limite inférieure.—Béton lourd et ferme donnant un mélange non maniable;

Limite supérieure.—Signes de ségrégation et ségrégation complète.

Entre ces deux limites, on considère les propriétés suivantes d'un béton maniable: mobilité, cohésion, onctuosité, écoulement, séparation de l'eau dans le malaxeur. On a étudié un grand nombre de mélanges divers, et dans chaque cas on a évalué la "workability" par rapport à une échelle arbitraire allant de 0 (qui correspond à un mélange non maniable) à 20 (le degré le plus élevé de "workability"), d'après l'expérience et le jugement individuel de l'expérimentateur.

En considérant les divers facteurs ci-dessus mentionnés, qui influencent la "workability", on a établi une formule empirique exprimant cette propriété: cette formule contient une constante dont la valeur a été déterminée par le degré de "workability" résultant du jugement individuel de l'expérimentateur dont il vient d'être question; cette constante est la même pour tous les mélanges. Ladite formule se vérifie en comparant le degré de "workability" calculé grâce à elle au degré de "workability" évalué par la méthode subjective.

Le Dr. Samsioe définit la "workability" comme la facilité avec laquelle le béton peut, à l'aide de certains outils, être introduit dans certains moules, de manière à obtenir une masse exempte de cavités. On estime que, du moins pour le moment, il est plus important de déterminer l'intervalle dans lequel le béton est maniable que le degré de "workability." La limite inférieure, celle à laquelle le béton commence à devenir tout juste maniable, est appelée "point de maniabilite"; la limite supérieure, celle à laquelle se produit la ségrégation, s'appelle "point de ségrégation." Le béton maniable se trouve placé entre ces deux limites et comme, dans la pratique actuelle, il est nécessaire de tolérer certaines variations dans la composition des mélanges, il est important que l'intervalle en question soit le plus grand possible.

On a suggéré de mesurer la maniabilité des mélanges en mesurant leur compacité, c'est-à-dire le rapport entre le volume du matériau solide et le volume total. Ce qu'on obtient en pesant un échantillon du béton frais avant que le béton ait fait prise et soit durci. La méthode est vérifiée par des essais sur béton durci en ce qui concerne la résistance et l'étanchéité.

Le Dr. Samsioe traite aussi la question de savoir si, pour un même béton, il y a une relation entre les résultats en laboratoire et ceux de chantier. L'auteur recommande que les nouvelles recherches qui seront faites sur l'influence des différents ciments sur la maniabilité comprennent les essais suivants:

1. Détermination de la différence de la teneur en eau entre: (*a*) les mélanges au point de "workability" et au point de ségrégation, respectivement, selon les diverses méthodes de mise en œuvre du béton sur le chantier; (*b*) un mélange des mêmes matériaux au point de compacité maximum et au point de ségrégation, au moyen d'une méthode de laboratoire de mise en œuvre.
2. Détermination de la compacité des mélanges de béton au point de "workability" et au point de ségrégation, aussi bien que dans l'intervalle de maniabilité, lorsque le bétonnage se fait d'après la méthode de laboratoire.
3. Examen de l'adhérence du ciment aux outils et à la malaxeuse.

La sous-commission est d'avis que des recherches utlérieures sont nécessaires avant de pouvoir arriver à une conclusion nette sur la meilleure méthode d'essai de la "workability" permettant de comparer différents ciments entre eux. La sous-commission est convaincue que les expériences exécutées par Mr. Lalin et le Dr. Samsioe contribueront puissament à aider à découvrir une nouvelle méthode de résolution de ces problèmes.

Bruxelles, le 30 mars 1936,

Pour et au nom de la Sous-Commission Internationale du Ciment Spécial pour Grand Barrages.

(Signé) Bo HELLSTRÖM,
President.

A. GENTHIAL,
Secrétaire Général de la
Commission Internationale des Grand Barrages.

ZWISCHENBERICHT UEBER DIE PRUEFUNGSMETHODEN VON ZEMENTEN AUF HYDRATIONSWAERME, AUF DIE WIRKUNG DES WASSERS AUF ZEMENT BEIM DURCHGANG DURCH BETON, AUF SCHWINDUNG, AUF DURCHLAESSIGKEIT UND VERARBEITBARKEIT

(ÜBERTRAGUNG INS DEUTSCHE)

I. Einleitung

Die Rißbildung und der Zerfall von Beton-Staumauern und anderer Wasserbauten ist zu einem ernsten Problem der letzten Jahre geworden. Die Tatsache, daß dieses Problem erst seit kurzem Bedeutung erlangt hat, rührt teilweise von der hohen Geschwindigkeit des Baues mit modernen Fabrikationsmethoden her, als Folge deren die innere Wärme der Betonmasse nur schlecht entweichen kann, teils aber auch von dem Umstand, daß die Korrosion eine gewisse Zeit beansprucht und erst in den letzten Jahren sich bemerkbar machte. Ferner haben sich die Beweise dafür gehäuft, daß durch bestimmte Typen des Wassers in den Talsperrenbecken der Beton allmählich angegriffen wird. Die Korrosion, die bei einigen Sperren schon in einer relativ kurzen Reihe von Jahren sich eingestellt hat, machte die Aufbringung erheblicher Summen für Reparaturen notwendig.

Schwindungsrisse können zweierlei Ursachen haben: die Erreichung einer hohen Temperatur bei dem Erhärtungsprozeß, worauf Abkühlung und thermische Zusammenziehung erfolgte, and dann Volumenänderung beim Abbinden und Austrocknen des Betons. In Bauten, welche einseitigem Wasserdruck ausgesetzt sind, ist die Zerstörung hauptsächlich eine Folge der Auflösung und Auslaugung von Kalk aus dem Zement, besonders durch sehr reines oder schwach saures Wasser, welches fortwährend durch den Beton dringt. Die Geschwindigkeit der Zerstörung hängt großenteils von der Durchlässigkeit des Betons ab, so daß der Angriff der korrosiven Wässer nicht auf die Oberfläche der Staumauer beschränkt ist. Auch die damit verknüpften Fragen des Wasser-Zement-Verhältnisses und der Einflüsse, welche die Verarbeitbarkeit eines Betons bei der Herstellung der Mauer bestimmen, sind von Wichtigkeit.

Um die erwähnten Schwierigkeiten zu überwinden, wäre es eine große Hilfe, einen Zement oder Zemente zu erhalten, die speziell für Bauten geeignet sind, welche einseitigem Wasserdruck unterliegen. Der Gebrauch eines Spezialzementes, so gut er auch sei, wird indessen nicht die Notwendigkeit entbehrlich machen, daß auf jeden Fall alle Maßregeln ergriffen werden, um einen vorzüglichen und einwand-freien Beton herzustellen. Dies ist und wird immer von grundlegender Wichtigkeit für alle Betonbauwerke sein, vor allen Dingen für Talsperren.

Eine der Hauptaufgaben der Internationalen Unterkommission für Spezialzemente für Talsperren ist es, Vorschläge zu machen bezüglich der Prüfungsmethoden für normale und Spezialzemente in bezug auf diejenigen Eigenschaften, welche für Staumauern und andere wasserdichte Bauwerke von Wichtigkeit sind, besonders wenn für diese nur wenige oder gar keine Prüfungsverfahren bekannt sind. Die Unterkommission hat gemeinsam mit den Nationalen Talsperren-Kommissionen (oder den Nationalen Unterkommissionen für Spezialzemente) es unternommen, zu diesem Zweck Untersuchungen anzustellen. Der vorliegende Bericht behandelt ausschließlich solche Prüfverfahren. Von komplizierten und kostspieligen Verfahren wurde abgesehen, vielmehr war das Ziel, einfache billige Methoden zum allgemeinen Gebrauch sowohl in den Laboratorien wie auch in den Werken zu finden.

Die von der Unterkommission durchgeführten Untersuchungen sind bisher auf die Eigenschaften von Zement und Beton nach den unten ausgeführten Gesichtspunkten beschränkt worden. Der Inhalt des vorliegenden vorläufigen Berichtes kann demnach in Folgendem zusammengefaßt werden:

Hydratationswärme.—Eine probeweise Prüfungsvorschrift für die Bestimmung der Hydratationswärme des Zementes auf Grund des adiabatischen Prinzips wird vorgeschlagen; die Einzelheiten des Verfahrens sind jedoch noch Gegenstand weiterer fortschreitender Untersuchungen.

Eine Untersuchung über die Bestimmung der Hydratationswärme durch Beobachtung des Temperaturanstiegs in Zementmörtel, der sich in Isoliergefäßen (Thermosflaschen) befindet, wurde durchgeführt, und eine Beschreibung dieser Versuche wird gegeben.

Wirkung des Wassers auf Zement beim Durchgang durch Beton.—Es wurden Versuche über die Wirkung des Wassers auf Zement beim Durchgang durch Platten von Zementmörtel angestellt, und diese mit einer Extraktionsmethode verglichen, bei welcher die Löslichkeit hydratatisierten Zementpulvers beim Schütteln mit Wasser bestimmt wird, ferner mit einer Methode, bei der ein Wasserstrahl auf Platten aus Zementmörtel einwirkt. Es wird ein Bericht über diese Untersuchung gegeben und vorläufige Versuchsregeln vorgeschlagen.

Schwindung.—Es werden die Einzelheiten eines deutschen Untersuchungsverfahrens über die Bestimmung der Schwindung gegeben.

Durchlässigkeit.—Vorläufige Empfehlungen zur Prüfung der Durchlässigkeit werden vorgelegt.

Verarbeitbarkeit.—Es wurden Untersuchungen zur Prüfung der Verarbeitbarkeit nach zwei verschiedenen neuartigen Verfahren durchgeführt, über diese Versuche wird berichtet.

Da die Arbeit der Unterkommission noch nicht abgeschlossen ist und noch weiterhin Untersuchungen im Gange sind, konnten nur vorläufige Arbeitsvorschriften oder Empfehlungen bezüglich der Hydratationswärme, der Einwirkung des Sickerwassers in Beton auf den Zement, und der Durchlässigkeit vorgelegt werden. Die Arbeitsvorschrift zur Prüfung der Schwindung wurde in Deutschland ausgearbeitet. Da die Unterkommission noch nicht in der Lage war, die Ergebnisse dieser Methode eingehend zu untersuchen, ist die Arbeitsvorschrift zunächst nur zur Kenntnisnahme beigefügt.

Es wird der Hoffnung Ausdruck gegeben, daß die gegenwärtigen Feststellungen der Unterkommission den Mitgliedern der Internationalen Talsperrenkommission zur eingehenden Prüfung und kritischen Stellungnahme vorgelegt werden.

Bemerkung.—Nach Ansicht der Schwedischen Talsperren-Kommission ist die Extraktionsmethode gegenwärtig die bestgeeignete vorliegende Methode zum Vergleich von Zementen bezüglich der Einwirkung des Wassers auf Zement beim Durchgang durch Beton; die Schwedische Kommission regt an, daß diese Methode in den Bericht als eine probeweise Prüfungsmethode aufgenommen werde. Wenn dieser Anregung entsprochen wird, ist auf Seite 6 des Übermittlungsschreibens und des vorliegenden Berichtes der Wortlaut noch entsprechend zu ändern. Eine probeweise Arbeitsvorschrift müßte dann auch dem vorliegenden Bericht als Beilage angefügt werden.

II. HYDRATATIONSWÄRME

Während der letzten Jahre wurde in verschiedenen Ländern eine Reihe verschiedener Methoden entwickelt, um die Hydratationswärme des Zementes beim Abbinden und Erhärten zu bestimmen. Die wichtigeren dieser Verfahren können eingeteilt werden (1) in indirekte Verfahren und (2) direkte Methoden. Die letzteren umfassen

(*a*) Vorrichtungen, in welchen die Wärme sich ansammelt und die Wärmeabgabe nach außen auf ein Minimum beschränkt wird;

(*b*) Apparate, in welchen die Wärme nach außen abgegeben wird und die Ansammlung der Wärme auf ein Minimum beschränkt wird;

(*c*) Apparate, in welchen ein Teil der Wärme sich ansammelt, ein Teil nach außen abzieht.

Im Fall 2(*a*) ist es die Hauptsache, die Ansammlung der Wärme zu bestimmen, es können dann, wenn erforderlich, Korrekturen für die Abgabe von Wärme nach außen angebracht werden; demgegenüber wird in Fall 2 (*b*) die Wärmeabgabe berechnet, und erforderlichenfalls werden Korrekturen für die Wärmeansammlung angebracht.

Im Fall 2 (*c*) ist sowohl die Wärmeansammlung wie die Wärmeabgabe von Wichtigkeit und müssen in Rechnung gebracht werden.

Gewisse Methoden sind einfach aber ungenau, während andere genauer arbeiten, aber kompliziert und kostspielig sind; die Unterkomission hat keine der vorhandenen Methoden völlig zufriedenstellend befunden, um eine billige Gebrauchsmethode abzugeben.

Das indirekte Verfahren, welches allgemein als die Methode der Lösungswärme bezeichnet wird, wurde in gewissen Ländern häufig als Gebrauchsmethode für sehr große Talsperrenbauten angewandt, die Prüfungen müssen aber von einem erfahrenen Chemiker durchgeführt werden, der nicht leicht allenthalben zu bekommen ist, oder sie können kaum bei Dammbauten beschränkten Umfangs in Betracht kommen.

Es wurde erwogen, daß eine ganz adiabatisch arbeitende Methode entsprechend 2 (*a*), welche die gesamte Wärmegeschichte des Betons, wie er wirklich auf der Baustelle Verwendung findet, wiedergibt, vorzuziehen wäre, aber die vorhandenen genauen Methoden wurden doch als zu kompliziert betrachtet. Von den Methoden unter 2 (*c*) ist die Thermosflaschen-Methode, bei welcher der Temperaturansteig in Zementmörtel in Isolierflaschen (Dewar-Gefäßen) gemessen wird sehr einfach, aber die Art, wie diese Methode angewandt wurde, hat nur ungenaue Resultate ergeben.

Die Unterkommission versuchte eine einfache und billige, ganz adiabatisch arbeitende Gebrauchsmethode zu finden; es ist zu hoffen, daß die in den Beilagen 1 und 2 beschriebene Methode befriedigen wird. Diese Methode wurde von der "Building Research Station" von Großbritannien für die Britische Unterkommission für Spezialzemente[1]

Die in Großbritannien durchgeführte Untersuchung, welche in Beilage 1, Teil I beschrieben ist, umfaßt vergleichende Prüfungen mittels eines vorhandenen genauen Standard-Kalorimeters, dem vereinfachten adiabatischen Kalorimeter und der Methode der Lösungswärmen.

Die Hauptergebnisse dieser Vergleichsprüfungen sind die folgenden:

(a) Die Werte für den Temperaturanstieg in den beiden Typen adiabatischer Kalorimeter sind praktisch die gleichen; es wird daraus geschlossen, daß die mit dem vereinfachten adiabatischen Kalorimeter erhaltenen Werte für praktische Zwecke ausreichen.

(b) Für Zemente, die rasch Wärme entwickeln, mögen die durch Lösungswärme oder adiabatische Methoden erhaltenen Werte nicht sehr erheblich voneinander abweichen.

(c) Für Zemente, die langsam Wärme entwickeln, ist zu erwarten, daß die Methode der Lösungswärme viel höhere Werte gibt, als die adiabatische Methode.

(d) Die Vorrichtung für die vereinfachte adiabatische Methode kann nur immer für eine Betonprobe angewandt werden. Andererseits betragen die Kosten für den leicht herzustellenden Apparat schätzungsweise nur 10 bis 15 englische Pfund.

Nachdem die Methode auf der "Building Research Station" entwickelt und erprobt worden war, wurden sechs Apparate dieser Art im Zementlaboratorium zu Stockholm gebaut, und mit diesen Kalorimetern wurden für den Schwedischen Talsperrenausschuss Versuche angestellt, die noch im Fortgang sind. Im großen und ganzen bestätigen sie die Prüfung der "Building Research Station" in Großbritannien, aber kleinere Abänderungen der Methode und des Apparates mögen sie noch zur Folge haben.

Wiederholte Versuche mit den in Schweden gebauten Kalorimetern zeigten untereinander Differenzen von etwa 10 v.H. Die Werte für die Hydratationswärme bei Anwendung des vereinfachten adiabatischen Kalorimeters ergaben sich in guter Übereinstimmung mit denen nach der Thermosflaschen-Methode (siehe Beilage 3) waren aber beträchtlich niedriger, als nach der Methode der Lösungswärme.

Nach Ansicht der Unterkommission scheint die vereinfachte adiabatische Methode zur Bestimmung der Hydratationswärme, die in Beilage 2 beschrieben ist, als eine Prüfungsmethode für den Werkgebrauch gangbar zu sein, obwohl weitere Prüfungen gewisse kleine Abänderungen zur Folge haben dürften.

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[1] *Die Britische Unterkommission für Spezialzemente wurde gemeinsam durch die "Institution of Civil Engineers" und den Britischen Talsperrenausschuss gebildet.*

Die Unterkommission hat auch die Thermosflaschen-Methode erwogen. Eine Beschreibung einer verbesserten Anwendung dieser Methode wird weiter unten erwähnt und ist in Beilage 3 ausführlich beschrieben. Diese Methode wurde von Dr. A. Frey Samsjö von dem Vattenbyggnadsbyran, Ingenieurbüro in Stockholm entwickelt für den Schwedischen Talsperrenausschuss, in Zusammenarbeit mit dem Zementlaboratorium des Königlichen Schwedischen Instituts für Industrielle Forschung in Stockholm.

Nach dieser Methode wird der Temperaturanstieg in Zementmörtel beobachtet, der in gewöhnliche, im Handel erhältliche Thermosflaschen gefüllt ist; die Flaschen werden in ein Wasserbad von konstante Temperatur eingesetzt. Die Thermosflaschen werden geeicht, indem man sie mit Wasser von etwa 50° C füllt, die Temperatur des Wasserbades ist 30° C. Die Temperatur des Wassers in den Flaschen, wie auch im Wasserbad, wird mit gewöhnlichen Thermometern (auf 0,1° C genau) 3 und 44 Stunden nach Versuchsbeginn gemessen, die einzelnen Konstanten für den Wärmeübergang werden dann auf Grund dieser Ablesungen bestimmt. Die Flaschen werden dann mit Zementmörtel (1 Gew.-Teil Zement auf 4,5 Gew.-Teile Normensand, Wasser-Zement-Faktor 0,60) gefüllt, in das Wasserbad gebracht, und die Temperatur des Zementmörtels während der ersten 24 Stunden sehr häufig abgelesen, später in längeren Zeiträumen. Die Hydratationswärme während einer gewissen Zeit ist die Summe der in der Flasche angesammelten und der in der gleichen Zeit nach außen abgegebenen Wärme. Die Wärmeanhäufung ist das Produkt aus Temperaturanstieg und Wärmekapazität des Mörtels und der Flasche; die nach außen abgegebene Wärme wird dadurch berechnet, daß in einem Diagramm die Fläche zwischen der Temperaturkurve des Mörtels und der konstanten Temperatur des Wasserbades ausgemessen wird, wobei für jede Flasche die vorher bestimmte Konstante des Wärmeübergangs angesetzt wird.

Aus den Bestimmungen können folgende Schlüsse gezogen werden:

(*a*) Die Thermosflaschen-Methode zur Messung der Wärmeentwicklung des Zements, wie oben umrissen, ist ziemlich genau. Wie in Beilage 3 gezeigt, wird eine bestimmte Wärmemenge, die in einer Thermosflasche auf elektrischem Wege eingeführt wird, nach den Rechnungen gemäß der gegebenen Methode mit einer Genauigkeit innerhalb einiger Prozente wiedergegeben. Wiederholte Messungen am Zement weichen untereinander bis zu etwa 2 Kalorien pro Gramm Zement ab.

(*b*) Im Vergleich zur Methode der Lösungswärme sind die mit der Thermosflaschen-Methode für drei Portlandzemente erhaltenen Werte im Durchschnitt 9 Kalorien pro Gramm niedriger. Von diesen 9 Kalorien entsprechen 3 der Benetzungswärme, welche bei letzterer Methode nicht besonders angeführt wird. Wie in Beilage 1, Teil I gezeigt wird, ergeben sich bei den Prüfungen in Großbritannien ähnliche oder noch größere Differenzen zwischen den Werten nach der Methode der Lösungswärme und der abiabatischen Methode.

(*c*) Die mit der Thermosflaschen-Methode erhaltenen Werte stimmen ziemlich gut mit denen der vereinfachten adiabatischen Methode überein. Die Genauigkeit des Thermosflaschen-Verfahrens kann als hinreichend für eine Gebrauchsmethode betrachtet werden.

(*d*) Die Messungen nach dem Thermosflaschen-Verfahren sind nicht sehr kompliziert. Die Berechnung der Resultate verlangt einige Sorgfalt, dürfte aber keine großen Schwierigkeiten machen. Wenn eine große Zahl von Prüfungen auszuführen ist, reduziert sich die aufzubringende Arbeit sehr. Die Methode ist daher ziemlich einfach und kann in den Fällen, wenn verschiedene Prüfungen zu gleicher Zeit durchgeführt werden, als zufriedenstellend gelten.

(*e*) Die Kosten für den Apparat sind niedrig und nehmen mit zunehmender Zahl der Prüfungen rasch ab.

(*f*) Die Zerbrechlichkeit der Thermosflaschen ist eine Unbequemlichkeit der Methode.

Obwohl die Unterkommission glaubt, daß die Thermosflaschen-Methode als Hauptprüfungsmethode wohl erwogen werden kann, wünscht sie dennoch ihre Entscheidung über diesen Gegenstand zu verschieben, bis die Methode in mehreren Laboratorien versucht und zufriedenstellend befunden worden ist. Die Unterkommission glaubt jedoch, daß die Bekanntgabe der in Beilage 3 gegebenen Versuche auch andere Forschungslaboratorien veranlassen wird, um die Methode noch weiterhin zu erproben, und das Ergebnis der Unterkommission mitzuteilen.

Nach Versuchen, die in Großbritannien und in Schweden ausgeführt worden sind, zu urteilen, wird offenbar, daß die Methode der Lösungswärme höhere Werte für die Hydratationswärme ergibt als sowohl das adiabatische Verfahren wie die Thermosflaschen-Methode.

III. Bestimmung der Einwirkung des Sickerwassers im Beton auf den Zement

Verschiedene Methoden sind gebraucht worden, um die Wirkung des Wassers auf den Zement zu bestimmen, welches durch den Beton sickert. Infolge der Schwierigkeiten, eine genügende Genauigkeit und Reproduzierbarkeit bei der Messung der Auflösung des Zementes im Beton oder Zementmörtel bei der Einwirkung des Sickerwassers zu erhalten, wurde zu anderen Methoden Zuflucht genommen.

In Schweden wurden folgende beiden Extraktionsmethoden angewandt:

(*a*) Wasser wird über pulverisierten hydratisierten Zement geleitet.

(*b*) Pulverisierter hydratisierter Zement wird wiederholt mit Wasser geschüttelt. In beiden Fällen wird das Wasser analysiert und die aufgelöste Substanz bestimmt.

In Frankreich wurde von Herrn E. Rengade eine Methode entwickelt, bei welcher Platten aus Zementmörtel der Einwirkung eines Wasserstrahles ausgesetzt werden, der gegen ihre Oberfläche trifft. Der Betrag der Abnutzung durch Auflösung wird durch den Augenschein bestimmt.

Gegen die schwedischen Methoden sind Einwände erhoben worden, weil hydratisierter Zement in Pulverform eine sehr viel größere Zementoberfläche dem Angriff darbietet als in einem Betonkörper vorkommt, ferner daß das Mahlen des Zementes unhydratisierte Teile für die Einwirkung des Wassers freilegt.

Um diesen Einwänden zu begegnen, führte das U. S. Bureau of Reclamation eine Reihe von Versuchen aus, bei welchen die Auflösungskurven sich aus Analysen des Wassers ergab, welches durch Betonzylinder hindurchgepreßt wurde; der Beton war dabei vergleichbar mit dem in den vorhandenen Bauwerken. Jedoch ist bei einem solchen Beton die durch den Probekörper hindurchtretende Wassermenge selbst bei sehr hohem Druck nur so gering, daß man Jahre dazu brauchte, um einen Zerfall des Zementes zu erreichen. Für eine beschleunigte Prüfung, bei welcher genug Wasser durch den Probekörper getrieben werden konnte, um einen genügend schnellen Zerfall herbeizuführen, wurden Versuche mit magerem Beton angesetzt. Es wurde gefunden, daß die so erhaltenen Auflösungskurven in ihrem Verlauf sehr ähnlich den Kurven nach den schwedischen Methoden waren. Da die beiden so weit verschiedenen Prüfungsverfahren im allgemeinen qualitative Übereinstimmung zeigten, wurde erwogen, daß für einen porösen Beton, durch welchen ein wesentlicher Durchgang des Wassers stattfindet, die Extraktionsversuche an Mörtelgries verläßliche Anhaltspunkte dafür geben, was am Bauwerk selbst zu erwarten ist. Die in den Vereinigten Staaten ausgeführten Versuche sind in Beilage 4, Teil II, beschrieben.

Gegen die Methode von Rengade wurden Einwände erhoben bezüglich des Einflusses mechanischer Erosion zusätzlich zu der auflösenden Wirkung des Wassers, ferner gegen den Umstand, daß nur eine augenscheinliche Beobachtung in Betracht kommt.

Die Unterkommission hielt es nach den ermutigenden Versuchen, die in den Vereinigten Staaten ausgeführt worden waren, für wünschenswert, weiterhin die erwähnten verschiedenen Methoden zu untersuchen, eine ausführliche Beschreibung dieser Untersuchung ist in Beilage 4, Teil I, gegeben. Diese Arbeiten wurden von der Building Research Station in Großbritannien für die Britische Unterkommission für Spezialzement durchgeführt. Man gelangte zu folgenden Schlüssen:

I. Die Reproduzierbarkeit der Methode des Sickerwassers ist unbefriedigend, und es scheint nicht gangbar, diese Methode als eine grundlegende Gebrauchsmethode aufzunehmen.

II. Eine einzige Serie von Probekörpern wurde nach der Methode von Rengade geprüft, und es ist notwendig, diese Prüfung bestätigt zu sehen, bevor endgültige Schlüsse gezogen werden können.

III. Die unter (*b*) genannte schwedische Extraktionsmethode ist schnell und gibt eine gute Reproduzierbarkeit.

Die in Beilage 4, Teil I, ausgeführten Prüfungen wurden alle mit destilliertem oder Regenwasser ausgeführt, zum Vergleich der Methoden wurde kein hartes Wasser gebraucht.

Vor den in Beilage 4, Teil I und II, beschriebenen Versuchen in Schweden Untersuchungen angestellt wurden, um die Einwirkung weichen und harten Wassers nach der schwedischen Extraktionsmethode auf normalen Portlandzement zu bestimmen. Bei Anwendung weichen Wassers wurde gefunden, daß die Ergebnisse von 100 Extraktionen durchaus den für Portlandzement in Tabelle 2 von Beilage 4 gegebenen Verlauf befolgten, während das Ergebnis von hartem Wasser völlig verschieden war. Zuerst erhielt man eine positive Auflösung, welche nach etwa 10 Extraktionen ein Maximum erreichte, danach aber setzte eine ausgeprägte negative Auflösung ein. Bei etwa 50 Extraktionen war der Kalkgehalt der gleiche wie in der ursprünglichen Probe, und bis zu 100 Extraktionen fand kaum noch eine Änderung des Kalkgehaltes statt. Einige der in Schweden ausgeführten Versuche sind in Beilage 4, Teil 9, beschrieben.

Vorläufig kann die Unterkommission keinen endgültigen Beschluß bezüglich einer gangbaren Methode fassen, die zur Prüfung der Einwirkung von Sickerwasser im Beton auf den Zement dient; aber die Extraktionsmethode, bei welcher pulverisierter hydratisierter Zement wiederholt mit Wasser geschüttelt wird, erscheint als eine schon gegenwärtig gangbare Gebrauchsmethode. Eine vorläufige Arbeitsvorschrift für dieses Verfahren ist in Beilage 9 gegeben. Die Methode ist nicht anwendbar zur Prüfung von Tonerdezementen.

IV. Schwindung

Die Schwindung von Zement, Mörtel und Beton wurde in allen Ländern sehr eingehend mit vielen verschiedenen Methoden untersucht, aber noch keine international gültige Gebrauchsmethode für die Prüfung konnte bis jetzt Beifall finden. Soweit es die Unterkommission betrifft, kam es vor allen Dingen darauf an, eine einfache Methode zur Bestimmung des Einflusses verschiedener Zemente auf das Schwinden des Betons zu finden. In dieser Beziehung wurde erwogen, daß Prüfungen an dem hydratisierten Zement Werte für die Schwindung von einer anderen Größe ergeben, als Prüfungen am Beton, und daß andererseits Prüfungen am Beton sehr viel langsamer verlaufen und viel beschwerlicher sind, auch schwierig genau vorzuschreiben sind. Deshalb kam die Unterkommission zu der Ansicht, daß eine Prüfung am Zementmörtel vorzuziehen sei, weil sie auf die praktischste Weise eine Schwindprüfung ermöglicht. Um zu entscheiden, ob Prüfungen an Zementmörtel angenommen werden können, ist es indessen unumgänglich, die Schwindung des Zementmörtels und des Betons, mit den gleichen Zementen angesetzt, zu erforschen, wobei bei diesem Vergleich hauptsächlich herausgefunden werden muß, ob die Prüfungen am Mörtel die Zemente auch in der gleichen Reihenfolge der Schwindungsgrößen ergeben als Prüfungen am Beton.

Schon bei Beginn der Arbeiten der Unterkommission unternahm die Deutsche Unterkommission für Spezialzemente Versuche zum Zweck der Aufstellung einer Arbeitsvorschrift für Gebrauchsmethoden bei der Schwindungsprüfung. Da jedoch die Arbeiten noch nicht abgeschlossen sind, kann die Unterkommission noch nicht eine Standard-Arbeitsvorschrift vorlegen. Nach Ansicht der Unterkommission ist indessen die von der Deutschen Unterkommission angeregte Methode vorbehaltlich weiterer Forschungsarbeit sehr wohl der Erwägung wert; eine Beschreibung dieser Prüfungsmethode ist zur Kenntnisnahme im Anhang 6 beigegeben.

V. Durchlässigkeit

Die Unterkommission hat verschiedene Methoden eingehend geprüft, die zur Bestimmung der Durchlässigkeit von Zementmörtel und Beton gebraucht wurden und kam zu dem Schluß, daß es gegenwärtig noch nicht ratsam erscheint, eine endgültige, ins einzelne gehende Methode zur Bestimmung der Durchlässigkeit festzusetzen. Die

Unterkommission beschränkte daher ihre diesbezügliche Tätigkeit darauf, gewisse probeweise Empfehlungen vorzulegen, welche auf jede Prüfungsweise nach Belieben angewandt werden können. Diese Empfehlungen sind in Beilage 7 enthalten und wurden nach eingehenden Studien zu Nutzen der Unterkommission von Herrn M. Mary (Frankreich) zusammengestellt. Die Unterkommission, welche der Einfluß verschiedener Zementarten auf die Durchlässigkeit betrifft, beschränkte ihre Erwägungen auf diese Seite des Problems.

In einem Betonbauwerk muß große Sorgfalt und Umsicht zur Verhütung der Rißbildung angewandt werden, welche oft die Ursache für undichten Beton ist. Manchmal bilden sich Risse durch Gefügefehler, diese fallen naturgemäß nicht unter die von der Unterkommission gepflogene Untersuchung einer strengen Definition der Durchlässigkeit. Demgemäß wurde auch nicht versucht, Gefügefehler näher zu betrachten, und es kann nicht oft genug wiederholt werden, daß es nur wenig Sinn hätte, auf die wirkliche Wasserdurchlässigkeit besondere Aufmerksamkeit zu richten, wenn im Planentwurf und während des Baues die Berücksichtigung des Gefüges nicht gebührend beachtet wurde.

Die Unterkommission glaubt, einen Vergleich verschiedener Zemente aufstellen zu sollen durch Prüfung an Betonkörpern und nicht an Zementmörtel.

Beim Studium der Durchlässigkeit ist es von grundlegender Wichtigkeit zu bemerken, daß für einen gegebenen Beton die Durchlässigkeit eine kontinuierlich sich ändernde Eigenschaft darstellt, da sie sehr eng mit der Beschaffenheit des Zementes zusammenhängt. Aus diesem Grunde sind die Bedingungen der Lagerung und die Dauer der Einwirkung des Wasserdruckes auf den Versuchskörper während der Untersuchung von großer Wichtigkeit. Abgesehen von der Menge des Zementes pro Volumeneinheit des fertigen Betons hat die Kornabstufung der Zuschläge einen großen Einfluß auf die Durchlässigkeit. Auch die Art der Herstellung der Probekörper muß sorgfältig berücksichtigt werden.

Bei der Durchführung von Versuchen über Durchlässigkeit ist stets große Sorgfalt nötig, um Gleichmäßigkeit der Herstellung und Lagerung der Proben sicherzustellen. Die Folgen einer Nachlässigkeit in dieser Beziehung sind sehr viel ausgeprägter in ihrer Auswirkung auf die Durchlässigkeit als auf die Festigkeit. Um maßgebliche Zahlen zu erhalten, müssen die Bedingungen beim Mischen, der Wassergehalt, das Stampfen und die Lagerung, alle innerhalb sehr enger Grenzen gehalten werden. Der Beton ist so empfindlich, daß sogar die geringfügigsten Änderungen der Bedingungen an aufeinander folgenden Tagen leicht zu einander widersprechenden Ergebnissen der Durchlässigkeit führen.

Die in verschiedenen Laboratorien angewandten Prüfungsgeräte können zweckmäßig folgendermaßen eingeteilt werden:

1. Apparate für Prüfungskörper mit zwei freien Oberflächen, eine für den Eintritt und eine für den Austritt des Wassers. Die gesamte Wassermenge, die durch die Probe geht, tritt durch die eine Oberfläche ein und durch die andere aus.

2. Apparate für Prüfungskörper mit allseitig freien Oberflächen, bei der aber ein bestimmter Bezirk auf einer Oberfläche für den Einlaß des Wassers dient und ein beschränkter Bezirk einer anderen Oberfläche für seinen Austritt.

Die Unterkommission glaubt, daß eine Prüfungsanordnung der ersten Klasse am zweckmäßigsten wäre. Es ist wünschenswert, die Anordnung so zu treffen, daß die durch die Probe gehende Wassermenge gesammelt und unter minimalem Verdunstungsverlust gemessen werden kann; es ist auch vorzuziehen, wenn die Prüfungsanordnung die Messung des hindurchtretenden Wassers zu jedem Zeitpunkt zuläßt.

Um die Wirkung verschiedener Zemente zu vergleichen, kann die Durchlässigkeit im Prinzip nach zwei verschiedenen Methoden bestimmt werden:

Methode A.—Die Bestimmung des minimalen Zementgehalts auf die Volumeneinheit fertigen Betons, welche unter genau bestimmten Prüfungsbedingungen einen vollkommen wasserdichten Beton ergibt, und

Methode B.—Bestimmung der Durchlässigkeit von Beton aus verschiedenen Zementen bei Anwendung von Probekörpern aus der gleichen Menge Zement auf die Volumeneinheit des fertigen Betons.

Der Vergleich der verschiedenen Zemente nach Methode A ergibt sich auf Grund des zur Erlangung eines völlig dichten Betons erforderlichen Zementmenge, während nach Methode B die Menge des durchlaufenden Wassers die Vergleichsbasis ergibt.

Obgleich die erste Methode kostspieliger als die zweite ist, scheint es doch besser, wenn irgend möglich, diese Methode zu gebrauchen.

Mit Bezug auf die Korngröße der feinen Zuschläge muß bemerkt werden, daß die Menge der feinsten Zuschlagstoffe (kleiner als 0,30 mm) einen deutlichen Einfluß auf die Durchlässigkeit des Betons hat, ferner, daß bei Untersuchungen nach Methode B ein Überschuß an den feinsten Zuschlägen vermieden werden muß, um einen durchlässigen Beton zu erhalten. Zu diesem Zweck sollten die Probekörper für Methode B aus einem verhältnismäßig mageren Beton hergestellt werden mit ungefähr 200 Kilogramm Zement im Kubikmeter, wenn die Prüfungen unter einem Wasserdruck von 10 kg/cm^2 stattfinden sollen.

Bei Überlegung der Methode und der Lagerungsdauer berücksichtigte die Unterkommission auch die Möglichkeit, daß gewisse Spezialzemente mit geringer Erhärtungsgeschwindigkeit vorkommen können; sie hielt es daher für wünschenswert, daß zur Lagerung reichlich Zeit bemessen wird, damit eine zuverlässige Vergleichung zwischen verschiedenen Zementen erhalten werden kann. Aus diesem Grunde empfiehlt die Unterkommission eine verhältnismäßig lange Zeit der Wasserlagerung (25 oder 53 Tage) und nachfolgende Lagerung in feuchter Luft (mindestens noch 14 Tage). Da die Empfehlungen Prüfungen zum Vergleich verschiedener Zemente bezüglich Durchlässigkeit betreffen und nicht Gebrauchsmethoden auf den Werken, bei welchen schnelle Ergebnisse gefordert werden, scheint die recht lange Lagerungszeit keinesfalls einen großen Nachteil mit sich zu bringen.

Offenbar ist noch keine befriedigende und anerkannte Methode zur Prüfung der Verarbeitbarkeit von Beton entwickelt worden, und es scheint auch eine zweckmäßige Methode zur Bestimmung des Einflusses verschiedener Zemente auf die Verarbeitbarkeit völlig zu fehlen. Sogar die Aufstellung einer endgültigen und klaren Definition der Verarbeitbarkeit begegnete aus einleuchtenden Gründen rechten Schwierigkeiten. Wie schon früher allgemein üblich ist die Verarbeitbarkeit diejenige Eigenschaft, welche durch den Arbeitsaufwand aufgewiesen wird, um einen Beton in einheitliche homogene endgültige Form zu bringen. Keinesfalls ist die Verarbeitbarkeit eine einfache physikalische Eigenschaft, vielmehr die Resultierende aus verschiedenen Eigenschaften der Bestandteile, und nach der gegenwärtigen Auffassung ist die Verarbeitbarkeit eng verbunden mit folgenden beiden Eigenschaften des Betongemisches:

(*a*) Beweglichkeit (auch als Plastizität bezeichnet oder als die Fähigkeit, einen Beton in den Formen einzubringen);

(*b*) Kohäsion oder Nicht-Entmischung.

Die Erfahrung hat gezeigt, daß der Zement auf die Verarbeitbarkeit von Beton einen bestimmten Einfluß hat. Obwohl die Unterkommission diesen Einfluß bestimmen möchte, ist bis jetzt noch keine befriedigende Methode dafür entwickelt.

Viele der bis jetzt veröffentlichten Methoden zur Prüfung der Verarbeitbarkeit haben in Wirklichkeit Konsistenzprüfungen gezeitigt, weniger die Verarbeitbarkeit erfaßt. Solche Methoden sind z.B. die "Plumpsprobe", das Ausbreit- und das Eindring-Maß (the slump, flow and penetration tests), die Rinnenprüfung (the spout test) und die Kugel-Plasticimeter-Methode. Da auch andere Methoden nicht zweckmäßig erscheinen, hielt es die Unterkommission für ratsam, das fragliche Problem durch Untersuchung der Verarbeitbarkeit von Beton im Allgemeinen in Angriff zu nehmen.

Während der Arbeiten der Unterkommission erbot sich das Schwedische Talsperren-Komitee zur Ausführung bestimmter diesbezüglicher Untersuchungen, was von der Unterkommission dankend angenommen wurde. Diese Untersuchungen wurden von den Herren G. S. Lalin (Schweden) und Dr. A. Frey Samsjö (Schweden) durchgeführt und sind diesem Bericht als Beilagen 8 bzw. 9 beigegeben. Eine Zusammenfassung ist weiter unter gegeben.

Herr Lalin betrachtet verschiedene Grade der Verarbeitbarkeit zwischen folgenden Grenzen:

Untere Grenze.—Dichter, fester Beton, der eine nicht mehr verarbeitbare Mischung ergibt;

Obere Grenze.—Anzeichen der Entmischung, völlige Entmischung.

Zwischen diesen Grenzen werden folgende Eigenschaften eines verarbeitbaren Betongemisches betrachtet: Beweglichkeit, Zusammenhalt (cohesiveness), Geschmeidigkeit, Fließen und Wasserabgabe im Mischer. Es wurde eine große Zahl verschiedener Mischungen untersucht, und in jedem Einzelfall wurde die Verarbeitbarkeit nach einer willkürlichen Stufenfolge von 0 (entsprechend einem nicht mehr verarbeitbaren Gemisch) bis zu 20 (entsprechend dem höchsten Grad der Verarbeitbarkeit) nach Erfahrung und individuellem Urteil des Untersuchenden geschätzt. Durch Berücksichtigung der verschiedenen Faktoren, welche in erwähnter Weise die Verarbeitbarkeit beeinflussen, wurde eine empirische Formel zum Ausdruck dieser Eigenschaft abgeleitet. Diese Formel enthält eine Konstante, deren Wert durch den Verarbeitungsgrad nach Schätzung des Untersuchenden bestimmt wurde. Diese Konstante ist für alle Mischungen die gleiche. Die Formel wurde geprüft durch den Vergleich des Grades der Verarbeitbarkeit, berechnet aus der Gleichung, mit dem Verarbeitungsgrad nach der subjektiven Schätzung.

Dr. Samsjö definiert die Verarbeitbarkeit als die Fähigkeit, mit welcher die Betonmischung mittels gewisser Werkzeuge in bestimmte Formen eingebracht werden kann, um eine von Hohlräumen freie Masse zu erhalten. Wenigstens vorläufig scheint es von besonderer Wichtigkeit, mehr das Intervall als den Grad der Verarbeitbarkeit zu bestimmen. Die untere Grenze, bei welcher die Betonmischung schwer verarbeitbar wird, soll die "Verarbeitbarkeitsgrenze" (workability point) genannt werden, die obere Grenze, bei der Entmischung einsetzt, heißt der "Entmischungspunkt". Verarbeitbarer Beton liegt zwischen diesen beiden Grenzen, und wie in der wirklichen Praxis gewisse Abänderungen in der Zusammensetzung der Mischungen zugelassen werden müssen, ist es üblich, daß das Verarbeitbarkeits-Intervall so groß wie möglich sein sollte.

Es wird angeregt, die Qualität der verarbeitbaren Mischungen durch Bestimmung des "Grad der Verdichtungsmöglichkeit" (compactibility) zu bestimmen, d.h. durch das Volumen der festen Bestandteile im Verhältnis zum Gesamtvolumen. Dies erfolgt durch Abwiegen einer Probe der Betonmischung, bevor der Beton abgebunden und erhärtet ist. Die Methode wird durch Prüfungen an erhärtetem Beton bezüglich Festigkeit und Wasserdichtigkeit ergänzt.

Dr. Samsjö behandelt auch die Frage, ob eine Beziehung zwischen den Ergebnissen im Laboratorium und denen mit der gleichen Betonmischung auf der Baustelle besteht. Er empfiehlt, daß fernerhin Untersuchungen über den Einfluß verschiedener Zemente auf die Verarbeitbarkeit auch folgende Prüfungen umfassen sollten:

1. Die Bestimmung der Differenz des Wassergehaltes zwischen (*a*) Gemischen an der Grenze der Verarbeitbarkeit bzw. am Entmischungspunkt, durch verschiedene Methoden de Einbringung des Betons auf der Baustelle, und (*b*) einer Mischung derselben Bestandteile bei maximalem Verdichtungsgrad und am Entmischungspunkt durch eine bestimmte Laboratoriumsmethode der Einbringung.

2. Bestimmung der Verdichtungsmöglichkeit von Betonmischungen an der Grenze der Verarbeitbarkeit und am Entmischungspunkt gleichermaßen wie im Verarbeitbarkeitsgebiet, wenn der Beton nach der Laboratoriumsmethode eingebracht wird.

3. Beobachtungen über das Haften des Zementes an den Werkzeugen und am Mischer.

Nach Ansicht der Unterkommission sind weitere Untersuchungen nötig, bevor eine endgültige Beschlußfassung über die beste Methode zur Bestimmung der Verarbeitbarkeit beim Vergleich verschiedener Zemente getroffen werden kann. Die Unterkommission ist der Überzeugung, daß die Versuche der Herren Lalin und Dr. Samsjö bei dem weiteren Studium dieses Problems von großem Wert sein werden.

Brüssel, 30. März 1936.

Für die Internationale Unterkommission für Spezialzemente für Talsperren.

Im Auftrag.

Bo Hellström,
Vorsitzender.
A. Genthial,
Generalsekretär.

APPENDIX 1

Determination of Heat of Hydration of Cement by a Simple Adiabatic Calorimeter Method

PART I. INVESTIGATION CARRIED OUT IN GREAT BRITAIN

A comparison has been made of the heat evolution of cements as measured with the standard adiabatic calorimeter in use at the Building Research Station, the simplified adiabatic calorimeter described in appendix 2, and the heat-of-solution method. The results of this work are described in the report of the British subcommittee by W. T. Halcrow and F. M. Lea, which is presented as a separate paper to the congress in the United States, 1936. Only a brief summary will, therefore, be given here.

In the two methods using the standard and simplified adiabatic calorimeters, tests were made on a 1:2:4 cement:sand:gravel mix by weight of water-cement ratio 0.60 (by weight) as specified in appendix 2. The tests by the heat-of-solution method were carried out on neat cement gaged with 40 percent water and stored 1 day at 22° C. and thereafter at 38° C.

The comparative results obtained by the three methods for three normal portland cements, two portland blast-furnace cements, and a pozzolanic cement specially made to give a low heat evolution, are shown in table 1.

The agreement between the recorded values for the standard and simplified adiabatic calorimeters is satisfactory. It is concluded that the values obtained with the simplified adiabatic calorimeter are sufficiently accurate for practical purposes. The heat-of-solution method gives higher values than the adiabatic methods. This is most marked in the cement of lowest heat evolution (no. 220) for which the temperature rise of the concrete under adiabatic conditions reached only 20° C., and the actual temperature of the concrete 38° C. after 7 days. In the heat-of-solution method, the cement is maintained at 38° C. after the first 24 hours, and it is to this higher average temperature of storage over the period involved that the much higher value given for heat evolution is to be attributed.

TABLE No. 1.—*Comparison of heat evolution of cements by different methods*

Cement no.	Type	Heat evolution—Calories per gram cement						Heat-of-solution method	
		B. R. S. standard adiabatic calorimeter			B. R. S. simplified adiabatic calorimeter				
		1 day	3 days	7 days	1 day	3 days	7 days	7 days	28 days
207	Portland	47. 4	76. 0	88. 1	50. 0	76. 6	86. 4	95. 9	99. 7
208	do	31. 9	57. 0	67. 4	34. 8	53. 8	66. 5	72. 0	113. 9
210	do	38. 6	62. 3	74. 3	43. 7	63. 2	74. 3	79. 4	94. 4
220	Experimental	21. 2	32. 9	37. 7	20. 1	34. 4	42. 4	65. 2	79. 7
209	Portland blast furnace	22. 8	50. 2	63. 2	24. 1	54. 0	66. 5	68. 9	102. 4
212	do	25. 9	48. 7	58. 9	26. 6	49. 6	62. 3	62. 1	87. 5

PART II. INVESTIGATION CARRIED OUT IN SWEDEN

For the tests carried out in Sweden, three different cements were used. The chemical analyses of these are given in table 8 of appendix 3.

The simplified adiabatic calorimeter, of which type six apparatus were built, deviated from the British calorimeter in certain details. Some of these deviations should be improvements and have been included in the description of the apparatus given in appendix 2. Photographs of the calorimeter are shown in figure 1 and 2.

In addition to test according to the simplified adiabatic calorimeter method, the Swedish investigation comprised the determination of heat by hydration by the heat-of-solution method and the thermos-flask method, as described in appendix 3.

The results of the tests are given in table 2.

TABLE No. 2.—*Heat of hydration in calories per gram of cement measured according to different methods*

Type	Method	Heat in calories			
		3 days	7 days	14 days	28 days
Limhamn A cement.	Heat of solution	92–91	97–97	98–97	103–103
	Thermos flask	80–78	92–90		
	Simplified adiabatic calorimeter.	80–75	91–82		
Limhamn silicate cement.	Heat of solution	54–54	62–60	70–69	79–79
	Thermos flask	45–44	53–52	59	
	Simplified adiabatic calorimeter.	43–37	55–46		
Hellekis A cement	Heat of solution	99–99	107–106	105–104	110–109
	Thermos flask	87	97	101	
	Simplified adiabatic calorimeter.	85–83	92–91		

From table 2 it will be seen that the values obtained in accordance with the thermos-flask method and the simplified adiabatic calorimeter method are in fairly close agreement, while according to the heat-of-solution method the values are considerably higher. The first two methods do not include the heat of wetting, which may be estimated at some three calories per gram for portland cement and slow-hardening cements.

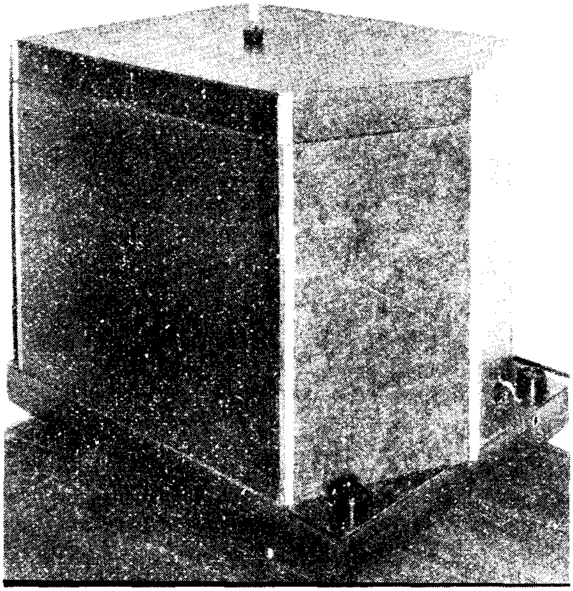

FIGURE 1.—External view of the simplified adiabatic calorimeter.

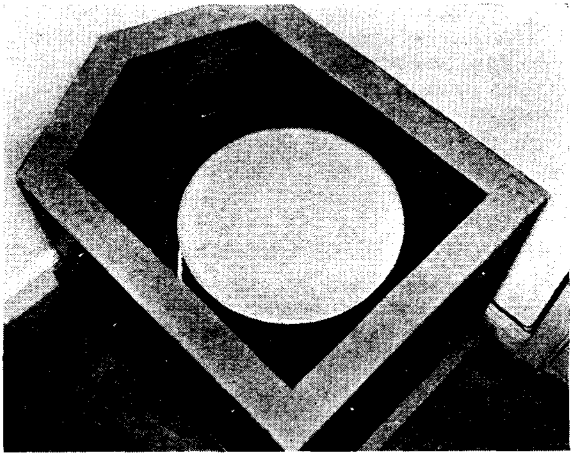

FIGURE 2.—The simplified adiabatic calorimeter with the lid taken off.

APPENDIX 2

TENTATIVE STANDARD SPECIFICATION FOR TESTING HEAT OF HYDRATION OF CEMENT BY AN ADIABATIC CALORIMETRIC METHOD

PART I

The determination of the heat of hydration of a sample of concrete shall be made in an approved form of adiabatic calorimeter.[1] The weight of the sample of concrete to be tested shall not be less than 1,000 g. The proportion of mix, by weight, shall be one part of cement to six parts of quartz aggregate. The grading [2] of the aggregate is not critical, but should be such as to give a workable mix with the specified water-cement ratio.

Sufficient of the dry materials shall be weighed on scales in which the tolerance shall not exceed 0.1 percent to produce a sample of concrete not less than 50 percent greater in weight than is actually required. The materials shall be placed upon a smooth, nonabsorbent surface, thoroughly mixed dry, and a crater formed in the center, into which the proper percentage of clean water shall be poured. The material on the outer edge shall be turned into the crater by the aid of a trowel within 30 seconds of adding the water, and then mixed continuously for a further 2 minutes.

The temperature of the room and dry materials shall be maintained at 64° F. (18° C.).[3] In tropical countries this temperature may be modified.

The concrete shall then be filled into the container in which it is to be stored, in layers not exceeding 3 in. in depth, each layer being well compacted with a blunt-nosed rod not less than ½ in. in diameter. The container shall be capable of holding not less than 1000 g of concrete. At the completion of the filling operation, which shall occur not more than 15 minutes after the commencement of mixing, the temperature at the center of the sample shall be measured and recorded with a thermometer which shall be accurate to 0.1° C. Any heat evolved before this measurement is made is, of course, lost. If it is desired to allow for this, the initial temperature measurement should be made on the constituent materials before mixing and their

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[1] *A simple form of calorimeter is described in pt. II, but this specification does not exclude the use of other approved fully adiabatic calorimeters.*

[2] *A suitable grading, by weight, which can be modified if necessary, is one part of material 3/16 inch (0.48 cm) down, and 2 parts of material between ⅜ inch (0.95 cm) and 3/16 inch.*

[3] *The heat is evolved by the cement at a much higher rate in the early stages when concrete is placed at temperatures higher than 64° F. (18° C.), and at a much lower rate when placed at temperatures below 64° F. (18° C.). At the end of 7 days there is, however, little difference in the values of the temperature rise obtained. If the heat of hydration of cements is to be compared at shorter ages (1 or 3 days), it is important that the placing temperature should be the same.*

mean temperature obtained. The subsequent rise in temperature shall be measured from this temperature and, from the rise in temperature so observed, the heat of hydration shall be computed.

The container shall then be placed in the calorimeter and all necessary adjustments completed within 30 minutes of the commencement of mixing.

The heat of hydration expressed in calories per gram of cement shall be obtained by multiplying the observed temperature rise in °C. by 1.9.[4]

PART II. A SIMPLE FORM OF ADIABATIC CALORIMETER

(a) Description of Apparatus.

The calorimeter consists of an outer box *A*, as shown in figure 3, constructed of cork slabs 3 inches thick, with a lid of the same material. The interior dimensions of the box so formed are approximately 24×24×24 inches, but one side is extended outward to provide accommodation for a small electric fan *B*.

The sample of concrete under test is contained in a tin *C* 6 inches in diameter and 10 inches high fitted with a press-on lid. The tin is mounted on a tripod support *D* and is held centrally thereon by three setscrews *E* carried by three ebonite supports *F*. The tin *C* is screened by an inverted sheet-metal container *G;* an additional outer metal screen *H* is also provided. Between this outer screen *H* and the cork walls of the box the small electric fan *B* is situated. A 50-candlepower carbon-filament lamp *K* is wired in parallel with the motor operating the fan. The direct radiation of heat from the lamp and electric fan across to the screen *H* is prevented by an asbestos screen, which is also connected to another asbestos sheet in which the fan is placed in a cylindrical housing. If necessary, especially when testing cements which generate a large amount of heat, auxiliary lamps connected in

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[4] *The heat of hydration is computed from the following formula:*

$$H=t\,(s_c\cdot c+s_a\cdot a+w)$$

where H = *calories per g;*
t = *observed temperature rise in ° C.;*
s_c = *specific heat of cement;*
s_a = *specific heat of aggregate.*

c, a, *and* w *are proportions of cement, aggregate, and water expressed in terms of cement as unity.*

The specific heat of cement may be taken as 0.22.

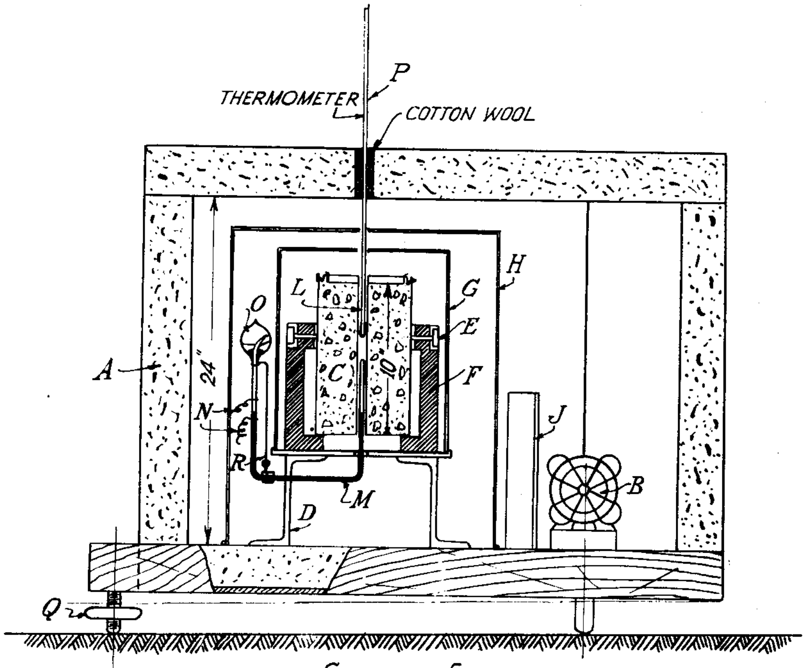
Recent tests have shown that, with a quartz aggregate, an over-all value of 0.25 as the specific heat of the 1:6 mix by weight with 60 percent mixing water may be taken as sufficiently accurate, in which case

$$\begin{aligned}H&=t\cdot 0.25\cdot 7.6\\&=1.9\,t\end{aligned}$$

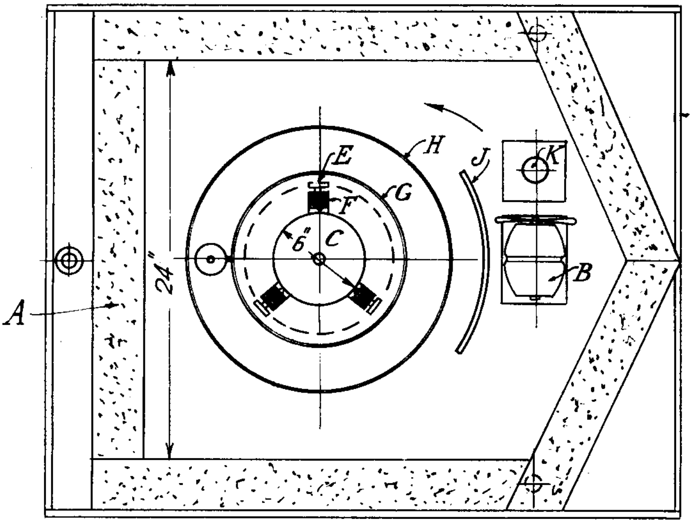
It should be borne in mind that, if any thermometer tubes or fitments of any kind are embedded in the concrete, the heat capacity of such should strictly be taken into account and a correction applied. In this case

$$H=t\,(s_c\cdot c+s_a\cdot a+w+s_x\cdot x),$$

where s_x *is the specific heat of material used for the fitments, and* x *is the weight of the fitments relative to the weight of cement. Normally, however, where the sample of concrete tested is relatively large, the correction is almost negligible. In the apparatus described in appendix 1, the correction is of the order of 1 to 2 percent and may be neglected.*



SECTIONAL ELEVATION.



PLAN.

FIGURE 3.—Adiabatic calorimeter.

A, cork box; *B*, electric fan; *C*, concrete sample; *D*, tripod; *E*, setscrews; *F*, ebonite supports; *G*, inverted copper can; *H*, metal screen; *J*, asbestos screen; *K*, lamp; *L*, copper-foil tube; *M*, thermoregulator; *N*, mercury contacts; *O*, mercury reservoir; *P*, thermometer; *Q*, leveling screw; *R*, plummet and scale.

parallel or a lamp of higher wattage may be used. Through the center of the concrete sample is a tube *L* made of copper foil, which is sealed in the bottom of the container *C* to prevent leakage of water from the concrete. Up this tube passes one arm of a glass thermoregulator *M*, which is shown in more detail in figure 4. The outer

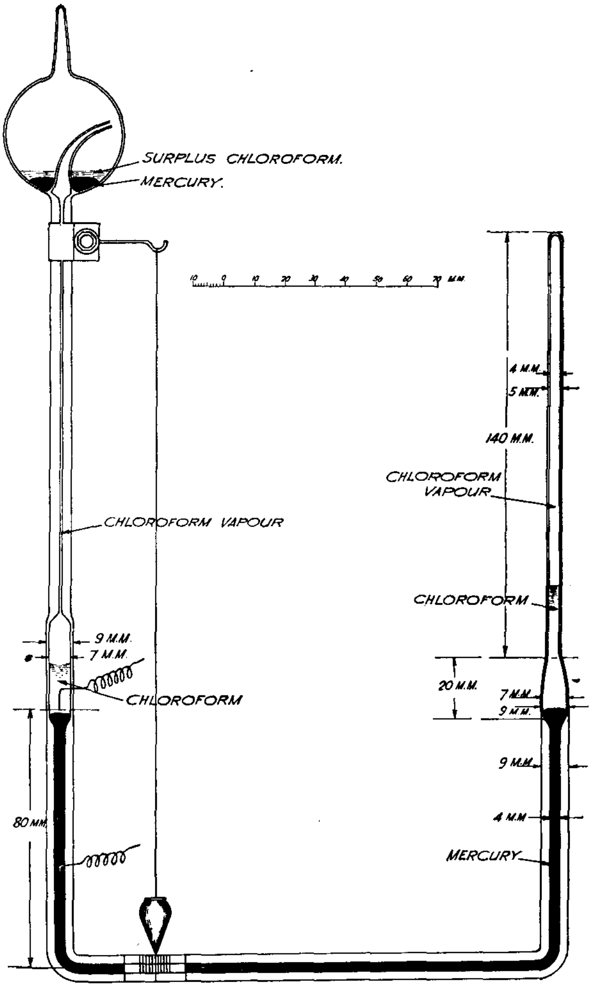


FIGURE 4.—Chloroform-vapor thermoregulator.

arm of the regulator is situated between the screens *G* and *H*. The thermoregulator is essentially a sealed glass U-tube partially filled with mercury. The remainder of the space is filled with chloroform and vapor. When the temperature of one arm differs slightly from that of the other arm, the vapor pressure of the chloroform changes, and the mercury is forced one way or another in such a manner that it makes or breaks contact across the platinum wires *N*, which are sealed in the walls of the regulator. The regulator is constructed with a bulb *O*, which serves as a reservoir for excess mercury, and also allows adjustments to be made in the mercury level. The regulator may, if desired, be sealed off below bulb *O* after the mercury level has been adjusted. This procedure has the advantage of preventing any distillation of chloroform from the bulb down the side arm. The wires *N* are connected to a simple 4- or 6-volt relay, operated by a battery, and this in turn controls the fan and the lamp.

A thermometer *P* passes through the lid of the box to the inside of the tube *L*. As the concrete sets, its temperature rises, the vapor pressure of the chloroform increases and forces the mercury round in the U-tube. The mercury makes contact with the wires *N* and the fan and lamp are switched on. The air heated by the lamp is blown round the chamber by the fan and the outer screen *H* is warmed. When the cavity between *G* and *H* attains the same temperature as *C*, the circuit is broken and the fan and lamp are switched off.

In order to set the regulator so that the concrete can be controlled adiabatically, *C* is filled with hot water of a temperature of about 45° C., or with other material, and the regulator tilted so that the temperature can be maintained constant over a period of at least 24 hours. The tilting of this regulator is best achieved by means of an external leveling screw *Q*. The regulator is fitted with a small plummet *R* and scale, upon which the correct setting can be noted. Once this setting has been determined, and is adhered to, no further adjustments are necessary, and the apparatus can be run indefinitely unless the setting is disturbed.

(*b*) *Procedure.*

The container *C*, with the tube *L* in the center, is filled in the prescribed manner with the concrete sample prepared as described in the draft specification. After the container has been filled, a thermometer is pushed into the center of the concrete and the temperature read. This is recorded as the initial temperature of the concrete. The tripod *D* is removed from the apparatus and placed on a bench, and the container *C*, already filled with the concrete, is placed on it. The thermoregulator *M*, which has been previously smeared with a trace of vaseline, is pushed up the center tube *L*, in which it is held in position by a small rubber sleeve round the stem of the regulator and fitting into the bottom of the tube *L*. The whole is then placed in the cork box *A*, and a rubber pad (not shown on the diagram) is placed under the base of the regulator to support it. The inverted sheet-metal container *G* is next placed in position and the necessary electrical connections made. The apparatus is then leveled so that the plummet *R* on the thermoregulator is in line with the calibration mark, thus giving the correct setting The metal screen *H* is placed over the top of the container *G* and regulator, and finally the box is closed by placing the cork lid in position. A thermometer *P* is inserted so that the bulb is well within the top of the tube *L* in the container *C*. Cotton wool is placed round the thermometer where it passes through the cork lid.

The electrical power is then switched on and readings taken on the thermometer at the required intervals of time.

(c) *Initial Adjustment of Regulator.*

The level of the mercury in the arms of the regulator is adjusted by tilting the regulator on to one side so that the small outlet tube in the bulb *O* (figure 4) comes below the level of the surface of the mercury in the bulb. The bulb *O* or the opposite arm may then be warmed with the hand, causing the mercury to move in or out of the arms. The level of the mercury in the arms should be so adjusted that, when the regulator is stood upright, and left in a bath of water to attain a uniform temperature throughout, the level in the left arm is just below the upper contact *N*.

The final adjustment is made by use of the leveling screw *Q* by the method previously described. After the final adjustment has been made, and the setting of the plummet *R* on the scale noted, the regulator must at no time be laid on the side so that the mercury escapes from or enters the arms. If this occurs, it will be necessary to reset the regulator.

APPENDIX 3

DETERMINATION OF HEAT OF HYDRATION OF CEMENT BY THERMOS-FLASK METHOD

A. DESCRIPTION OF METHOD

The thermos-flask method is based on the principle of measuring the heat evolved as a sum of the heat accumulated in the specimen and the heat dissipated from the specimen, steps being taken to secure that the last-mentioned be the greater. In order to bring this about, the test specimens are stored in thermos flasks submerged in water.

The heat accumulated is calculated as the product of temperature rise and heat capacity of the specimen and respective parts of the apparatus. This amount of heat being the smaller part, no great accuracy is needed in the determination of the heat capacity or the temperature rise. The latter is easily measured with an ordinary mercury thermometer. It is then sufficient to calculate the heat capacity as the sum of the heat capacity of the individual parts, using common values for the specific heat. Here an error is knowingly made in assuming the specific heat of, particularly, the water as a constant throughout the test. However, in the test procedure worked out, the greater part of the temperature rise playing a role in this calculation is the rise from room temperature to the bath temperature of the specimen, which takes place during the first few hours, when only small changes occur in the specific heat of the water. If it is desired, and if sufficient tests are available, a suitable correction for the changes in the specific heat values may, of course, be made.

The heat dissipated is calculated as the product of the leakage constant of the thermos flask in question and the planimetered surface between the temperature curve of the specimen and that of the bath temperature, both being plotted in a diagram as functions of time. The surface is measured from time zero to time x, for which the corresponding caloric value is sought. As the temperature of the specimen at the beginning of the test is lower than the bath temperature, the curves mentioned intersect. The part of the surface measured which lies below the bath temperature in the diagram is then to be reckoned with negative sign and thus subtracted from the rest of the surface.

To calculate the heat dissipated, it is necessary to know the leakage constant of the flask and the temperature curves mentioned. The latter are obtained when the cement in question is tested. To find the former, a special calibration test is necessary. The leakage constant and the temperature curves must be known with fairly great accuracy.

B. DESCRIPTION OF APPARATUS

A schematic drawing of the apparatus is given in figure 5. Figure 6 shows a set of six thermos flasks, mounted in a bath in complete condition ready for measurements. Figure 7 shows two thermos flasks with appurtenant thermometers.

The apparatus (fig. 5) consists of the water bath and the thermos flasks. The water bath A is provided with arrangements for securing a constant temperature B, for a constant water level C, for stirring D, and for temperature readings E. The apparatus may be constructed for any number of flasks.

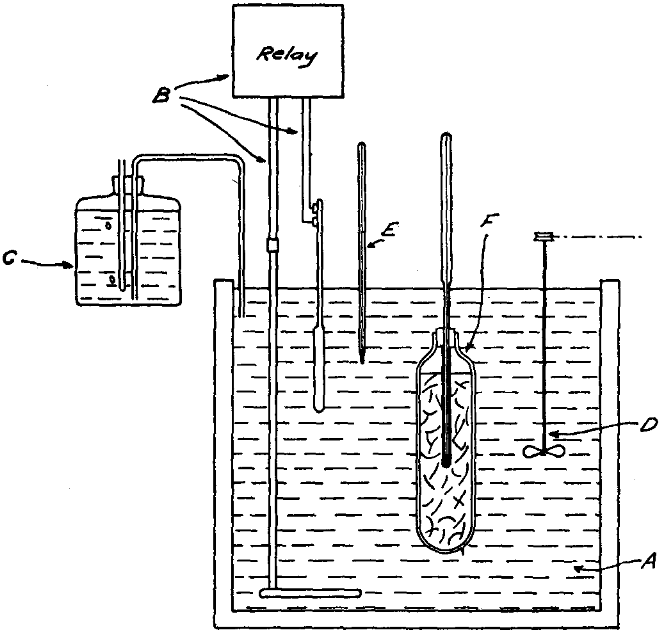


FIGURE 5.—Schematic drawing of apparatus for thermos-flask method.

The constancy of the temperature may be secured in any convenient way, provided the device works automatically and with satisfactory accuracy. Deviations of more than some hundredths of a degree centigrade should, as a rule, not be tolerated. In the apparatus illustrated, the temperature is maintained constant by means of a mercury regulator, operating an electric heater over an electromagnetic relay, the whole being run on the standard 220-volt circuit. For long periods of time this arrangement did not, however, work quite satisfactorily, owing to the dirt deposit formed on the mercury in the regulator, and it was, therefore, supplemented with a vacuum-valve relay, coupled between the mercury regulator and the electromagnetic relay. With this addition, the regulation of the bath temperature functioned perfectly.

The constancy of the water level is most simply maintained by means of a Mariotte flask.

The stirring, as shown in figure 6, is effected with a number of screws mounted on vertical shafts turned by a joint electric motor. A better effect is obtained if the screws work in tubes open at both ends. The number of screws may in this case be substantially decreased.

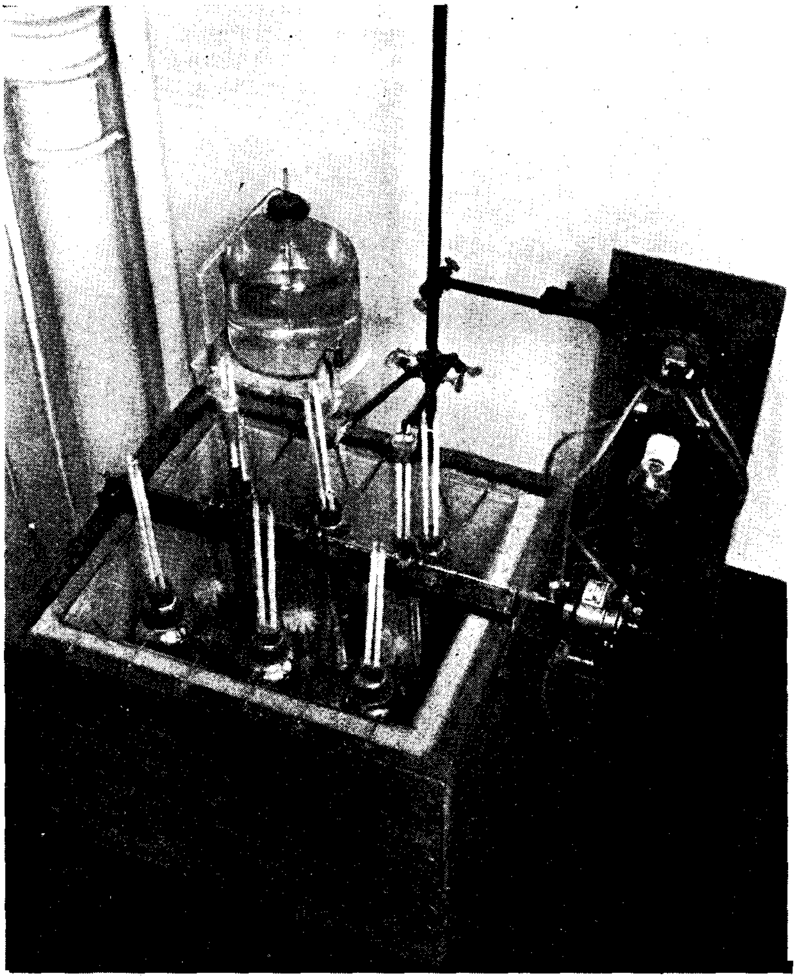


Figure 6.—Complete apparatus used for measurements of heat evolution of cements according to the thermos-flask method.

For the temperature readings, a mercury thermometer graded in tenths of a degree centigrade, and duly calibrated, is quite sufficient.

The thermos flasks are commercial glasses of ½-liter capacity, tested to be of about the same quality as regards insulation power. They are mounted with rubber stoppers and thermometers. The thermometers are graded in ⅕ of a degree centigrade and have exceptionally long necks. The parts of the thermometers extending into the flasks are covered with rubber tubing to facilitate the extraction of the thermometers after the completed tests. The bulbs are placed well in the middle of the flasks. These thermometers, of course, have to be calibrated.

C. DESCRIPTION OF TEST PROCEDURE

Before the commencement of the actual tests, determinations have to be made of the heat capacity of the interior parts of the individual thermos flasks, as well as of the leakage constants of these flasks.

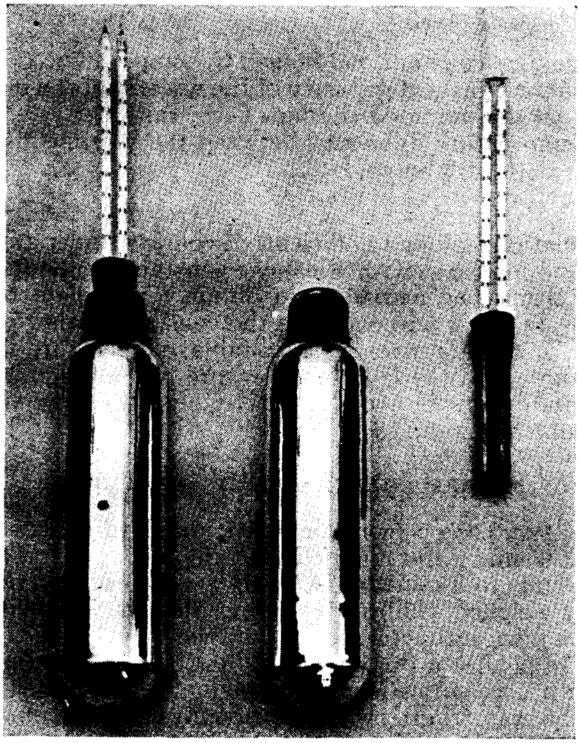


FIGURE 7.—Thermos flasks for heat-evolution measurements.

The heat capacity of a mounted thermos flask is obtained by weighing the empty flask, the rubber stopper and tubing, and by determining the volume of the thermometer bulb. The computation is made from the following formula:

$$C_f=\frac{f}{2}\cdot 0.20+\left(\frac{s}{2}+h\right)\cdot 0.34+b\cdot 0.47$$

where C_f=heat capacity of the mounted thermos flask in cal/° C.:
f=weight in g of the empty thermos flask;
s=weight in g of the rubber stopper;
h=weight in g of the rubber tubing;
b=volume in cm^3 of the bulb of the mercury thermometer.

The leakage constant of a thermos flask is calculated from a calibration test performed in the same way as an actual test with cement, but using hot water instead of cement.

The mounted flask is weighed empty and filled with hot water at a temperature of 45°–50° C. The flask is then placed in the water bath, which is kept at a constant temperature of 30.0° C. The temperature of the flask is read at 3 and 44 hours after the beginning of the test, and the leakage constant is then calculated from the following formula:

$$K = C_{f+w} \cdot \frac{{}^{e}\log t_3 - {}^{e}\log t_{44}}{44-3}$$

where K=leakage constant, cal/hour/° C. temp. diff.;

C_{f+w}=sum of the heat capacity of the water and the interior parts of the mounted thermos flask, cal/° C.;

t_3=temperature difference between the thermos flask and the bath at 3 hours, ° C.;

t_{44}=the same at 44 hours, ° C.

This calculation is found sufficiently accurate under the condition mentioned and for flasks with a leakage constant of about 15–20. In other cases it may be necessary to obtain a complete temperature curve for several days and compute the constant, either on the basis of planimetering the surface in a suitable temperature interval between this curve and the bath temperature plotted against time in a linear diagram, or on the basis of determining the slope of the curve in a logarithmic diagram.

D. PERFORMANCE OF TESTS ON CEMENT

For such a test 220 g cement and 990 g standard quartz sand is well mixed dry, 132 cm^3 water is added, and the whole mixed thoroughly. This corresponds to a mortar 1:4.5 and a water-cement ratio of 0.60. A previously weighed, calibrated thermos flask is filled with the mortar, leaving a few centimeters free below the mouth, the thermometer is inserted (to facilitate this, a hole is first bored in the mortar), and the flask with accessories is weighed again. The flask is then submerged in the water bath, the temperature of which must be maintained at 30.0° C. throughout the test. At short intervals readings are made of the temperature of the flask and of the bath, so that a complete temperature curve is obtained. The readings must be done very often the first day and night but can then be done at increasingly longer intervals. Figures 8 and 9 show temperature curves obtained in this way with a normal but fairly rapid portland cement and with a low-heat portland cement.

E. CALCULATION OF TEST RESULTS

The calculation is made according to the following formula:

$$H_x = C_{f+m} \cdot [(30 - t_o) + (t_x - 30)] + S_{o-x} \cdot K$$

where H_x=heat developed up to the time x, cal.;

C_{f+m}=sum of the heat capacity of the interior parts of the mounted thermos flask and of the mortar, cal/°C.;

t_o=temperature (°C.) of the flask filled with mortar[1] but before being placed in the bath;

t_x=temperature (°C.) of the flask at the time x;

S_{o-x}=planimetered surface in the interval of time $o-x$ between the temperature curve of the flask and the temperature of the bath plotted against time in a linear diagram, Σ°C. diff. per hour (the surface below the bath temperature is given a negative sign and thus subtracted from the rest of the surface).

K=leakage constant of the thermos flask, cal/°C./ hour.

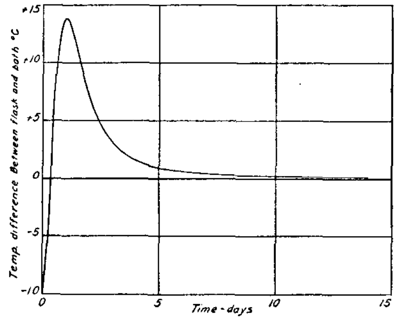


FIGURE 8.—Temperature curve from actual test on a standard portland cement. Thermos-flask method.

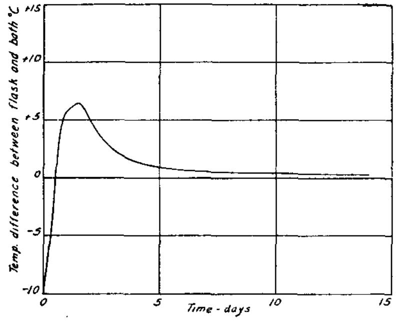


FIGURE 9.—Temperature curve from actual test on a low-heat portland cement. Thermos-flask method.

The heat capacity of the mortar is computed from the following formula:

$$C_m=0.186\cdot \text{weight of cement}+0.189\cdot \text{weight of sand}+0.998\cdot \text{weight of water.}$$

F. DETAILS SPECIALLY INVESTIGATED

(1) The temperature decrease in a thermos flask filled with hot water, or a mixture of sand and water, and kept in a water bath of constant temperature follows Newton's law for cooling quite well in the temperature interval necessary for the measurements. The logarithm for the difference between the temperature of the flask and of the bath will, therefore, be a nearly straight line, when plotted against the time in a diagram. See figure 11.

(2) The leakage constant may be calculated from the logarithmic diagram mentioned. The constant is proportional to the angle between the tangent to the line and the abscissa. As the line is not quite straight, however, the angle and the constant vary a little according to the point at the line (height of temperature) where the tangent is drawn. An average for a given temperature interval is obtained when using the line connecting the time-temperature end points of the interval, instead of the tangent. Owing to the logarith-

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[1] *Any heat evolved before this measurement of temperature is made on the mortar is, of course, lost. If it is desired to allow for this, the initial temperature measurements should be made on the constituent materials before mixing and their mean temperature obtained.*

mic scale, this average will not correspond to the arithmetic. The best way of obtaining the average constant is to calculate it on the basis of planimetering the corresponding linear diagram (fig. 10). The variation of the constant thus calculated with the height of the temperature difference between the flask and the bath is illustrated by figures from an actual test in table 3.

TABLE No. 3.—*Variations of leakage constant with temperature*

(Temperature of bath 30° C. Thermos flask filled with water)

Temperature interval	Average temperature difference between flask and bath	Leakage constant
19.7° to 15.0°	17. 3°	19. 03
15.0° to 10.0°	12. 5°	18. 23
10.0° to 5.5°	7. 7°	17. 23
5.5° to 1.7°	3. 6°	16. 90

As the measurements of the heat evolution of cements, according to the method worked out, include temperature differences seldom exceeding an interval average of 8° C., it will be seen that the variation of the constant in such a test will be of the order of a few units percent. If the constant is chosen to suit the average temperature difference during the first few days, when the dissipation of heat is greatest, the value for these days will be correctly calculated and only quite small error introduced into the values for later periods.

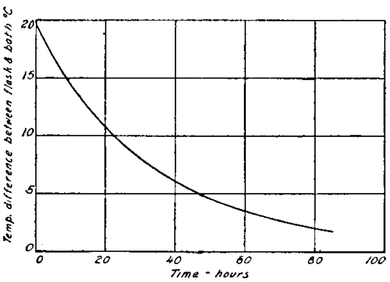

FIGURE 10.—Temperature decrease of a thermos flask. Linear scale.

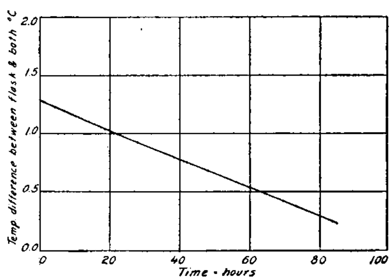

FIGURE 11.—Temperature decrease of a thermos flask. Logarithmic scale.

(3) In order to simplify the calibration procedure, it was investigated whether the leakage constant could be satisfactorily calculated in an easier way than by using the above-mentioned laborious, long-time test and planimeter calculation. It was then found that about the same constant will be obtained when measuring the temperature of the flask filled with hot water at two different times suitably chosen (3 and 44 hours in our tests) and calculating the constant by the use of the following formula:

$$K = C_{f+w} \cdot \frac{{}^{e}\log t_3 - \log t_{44}}{44-3}$$

The degree of accuracy thus obtained will be seen from table 4.

TABLE NO. 4.—*Comparison of different ways of obtaining leakage constants*

No.	Constant calculated on planimetering	Constant calculated on only 2 temperature readings
1	15. 01	15. 18
2	21. 06	21. 00
3	17. 88	17. 86
4	14. 39	14. 45
5	16. 91	16. 89
6	13. 57	13. 68

(4) The determination of the leakage constant for thermos flasks has been carried out on flasks filled (a) with hot water, (b) with a mixture of hot water and standard sand, and (c) with a mixture of hot water, filler, and standard sand. All three methods give very similar results, as illustrated in table 5. On this basis, it is concluded that determination of the leakage constant may be made with the convenient method of using hot water.

TABLE NO. 5.—*Leakage constants obtained of flasks with different contents*

Flask no.	Calibration no.	Contents of the flask	Leakage constant	Difference percent for the same flasks
2	V	Water plus filler plus sand	20. 61	2. 5
2	VI	do	21. 13	
3	V	do	20. 76	2
3	VI	do	21. 16	
5	III	Water	22. 68	. 5
5	III	Water plus sand	22. 80	
6	III	Water	26. 12	1. 5
6	III	Water plus sand	26. 51	
6	VI	Water plus filler plus sand	26. 33	

(5) The reproducibility of the calibrations will also be seen from table 5. The values obtained are considered satisfactory.

(6) In some tests thermoelements have been used to ascertain whether any great temperature difference may occur within a slowly cooling thermos flask filled with hot water and in one filled with hot water and sand. The results indicated that only slight temperature differences were displayed within the flasks filled with hot water, but that differences of a magnitude up to 2°–3° C. could occur in the flasks filled with hot water and sand. In part, these differences were caused by the thermometers and wires to the thermoelements and electric heaters mounted in the flasks. However, it was considered necessary for future tests to place the bulb of mercury thermometers well in the middle of the flasks, in order to obtain the average temperature. When the contents of the flasks were heated electrically,

as mentioned in the following point, it was found that very great temperature differences between different horizontal layers occurred in the water flasks. These great differences leveled out, after some time, leaving only the slight ones mentioned above. In the sand-and-water flasks this phenomenon did not occur, about the same relative temperature being maintained throughout the test. The different behavior of the water flasks and the sand-and-water flasks in this case may be explained as a result of currents in the water in the former flasks, together with the difference in thermal conductivity between sand and water.

(7) Some tests have been made in order to show whether a known amount of heat delivered electrically to a mixture of sand and water in a thermos flask could, on the cooling down of the flask, be recalculated, using a leakage constant calculated as mentioned above. It was found that this could be done with a fair degree of accuracy if the constant was calculated on the basis of the average temperature of the flask and of the planimetered linear diagram. Some figures showing this are given in table 6.

TABLE No. 6.—*Comparison between heat introduced and heat calculated*

Heat electrically introduced (cal.)	Heat calculated as the sum of dissipated heat and accumulated heat (cal.)	Percent of difference
10. 180	10. 370	+1. 9
10. 080	10. 170	+0. 9
12. 150	11. 860	−2. 4
12. 040	11. 600	−3. 7

G. ACTUAL TESTS ON CEMENT AND COMPARISON WITH THE HEAT-OF-SOLUTION METHOD

During the work, some tests were made with less accurate thermometers and with varying bath temperatures, which tests, however, are of interest only for the development of the method, therefore they are not described here.

In the following table 7, values for heat evolution of three cements are given. These values were obtained by the thermos-flask method in its last form, as described in the present report, and by the heat-of-solution method as developed in the United States. (A. S. T. M. Proc. *1933*, II, 575).

The conditions were the following:

	Thermos-flask method	Heat-of-solution method
Proportion cement: sand	1:4.5	1:0.
Water-cement ratio	0. 60	0. 40.
Curing temperature	Depending on the rate of heat evolution.	The first day 21° C.; then 38° C.

Two of the temperature curves obtained by these thermos-flask tests are given in figures 8 and 9.

TABLE No. 7.—*Actual tests on cement*

Type of cement	Age in days	Calories per gram						
		Heat-of-solution method A			Thermos-flask method B			Difference A–B
Limhamn silicate cement (low-heat portland).	3	54	54	*54*	45	44	*45*	9
	7	60	62	*61*	53	52	*53*	8
	14	69	70	*69*	(1)	59		10
	28	79	79	*79*				
Limhamn A-cement (standard portland).	3	92	91	*92*	78	80	*79*	13
	7	97	97	*97*	90	92	*91*	6
	14	98	97	*97*	(1)	(1)		
	28	103	103	*103*				
Hellekis A-cement (standard portland).	3	99	99	*99*	(1)	87		12
	7	107	106	*107*		97		10
	14	104	105	*105*		101		4
	28	110	109	*110*				
Average								9

(1) The thermos flask cracked.

TABLE No. 8.—*Analyses of cements*

	Limhamn A-cement (standard portland)	Limhamn silicate cement (low-heat portland)	Hellekis A-cement (standard portland)
SiO_2	21. 46	25. 09	20. 58
CaO	64. 84	62. 46	64. 42
Al_2O_3	5. 51	3. 92	6. 47
Fe_2O_3	3. 05	2. 66	3. 62
MgO	1. 31	1. 39	1. 36
K_2O+Na_2O	1. 60	1. 48	1. 62
SO_3	1. 89	2. 21	1. 75
Loss on ignition (electric furnace 700°–800° C.)	0. 72	0. 84	0. 91
"Insoluble"	0. 24	0. 24	0. 15

H. CONCLUSIONS

The thermos-flask method of measuring heat evolution of cement, as outlined above, is fairly accurate. As is shown under "Details specially investigated", a known amount of heat electrically supplied to a thermos flask is accounted for by calculations according to the method with an accuracy within a few units percent. Duplicate measurements on cement, as shown under "Actual tests on cement and comparison with the heat-of-solution method", differ from one another by up to 2 calories per gram of cement. In comparison with the heat-of-solution method, the values obtained with the thermos-flask method for three cements tested are on an average 9 calories per gram lower. Of these 9 calories, about 3 are due to the heat of wetting, which is not accounted for in the latter method. As is shown in appendix 2, tests performed in Great Britain show similar or still greater differences in the same direction between values obtained with the heat-of-solution method and the adiabatic method. Tests performed later by the Cement Laboratory show that the results of the thermos-flask method agree fairly well with those of the simplified adiabatic method. The accuracy of the thermos-flask method may thus be considered satisfactory as a routine method.

The measurements according to the thermos-flask method are not very complicated. Special precision is required only for the readings of the thermometers, but even these readings ought to be satisfactorily made by an average assistant. The calculation of the results requires some care, especially the planimeter measurements, but ought not to give any great trouble. The chief remark in this connection is that the method is somewhat laborious, e. g. compared with the simplified adiabatic method. When many tests are to be made, the labor is, however, much reduced, and such complications as thermometer readings during the night are then less important. The simplicity of the method is, therefore, fairly good and, in cases when several tests are performed at the same time, is to be considered as satisfactory.

The last remark applies also to the cost of the apparatus. The essential expense is involved by the water bath and appurtenant devices for maintaining constancy of temperature, etc. An extension of the bath to take more flasks affects the cost very little. The flasks themselves are cheap and therefore, though a flask is consumed for every test, do not contribute much to the cost. The cost of the apparatus thus decreases rapidly with an increasing number of parallel tests and is quite low when this number is fairly great.

The fragility of the thermos flasks deserves a special remark. There is a tendency for the thermos flasks, especially the very light ones, to crack during the tests, owing to expansion of the mortars, etc., thus ruining the test. Different brands of flasks behave differently, however, and with a suitable choice of flasks, this risk can be considerably reduced. Nevertheless, this at present represents an inconvenience of the method.

APPENDIX 4

DETERMINATION OF ACTION ON CEMENT OF WATER PERCOLATING THROUGH CONCRETE

PART I. INVESTIGATION CARRIED OUT IN GREAT BRITAIN

A comparison has been made of the solubility of cements as measured by the Swedish extraction method, Rengade's method, and a percolation method. The results of this work are described in the report of the British subcommittee by W. T. Halcrow and F. M. Lea, which is presented as a separate paper to the Congress of the United States of America, 1936. Only a brief summary will, therefore, be given here.

The Swedish method used was that described by Werner [1] and differs in detail, but not in principle, from that given in the tentative standard specification for testing the action on cement of water percolating through concrete by an extraction method, appendix 5.

In Rengade's method,[2] mortar specimens are subjected to the action of a jet of water impinging on their surface, and the extent of wear or erosion is used as a measure of the relative solubility of cements. The percolation tests were carried out on lean (1:8) mortar plaques. The water flowing through was collected and its lime content determined. Distilled water or rain water was used in all the tests.

The Swedish extraction method was found simple to carry out and showed a satisfactory reproducibility. When 1:8 mortars were tested by Rengade's method, results could be obtained within one month, but with 1:3 mortars, as used by Rengade, the rate of attack was much slower and the test period correspondingly prolonged. Insufficient data are at present available to determine the degree of reproducibility of the method. Tests by the percolation method showed considerable variations between triplicate specimens, and the reproducibility of the results was not satisfactory. Tests were made on both standard sand and graded sand mortars.

The comparative results obtained by the three test methods applied to six cements are shown in table 9. For each test the average value for the six cements is equated to 100 and the results for the individual cements recalculated to this basis in order to facilitate a comparison between the relative order in which the cements are placed by the various methods. The tests by Rengade's method refer only to a single set of specimens, but all other results are the means of triplicate determinations.

All the methods agree in showing that cement no. 220 has the greatest resistance to attack, but the order in which the other cements

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[1] *D. Werner, Zement 1931, 20, 626.*

[2] *E. Rengade, Rev. Mat. Constr. 1932, 276, 365; 14th Congress Industrial Chemistry, Paris, 1934, "Action des eaux pures sur les mortiers ou bétons."*

are placed differs with the various methods. The Swedish extraction method offers many advantages from the experimental standpoint, but it is still uncertain whether it differentiates correctly in all cases between different cements. Further investigations are being made.

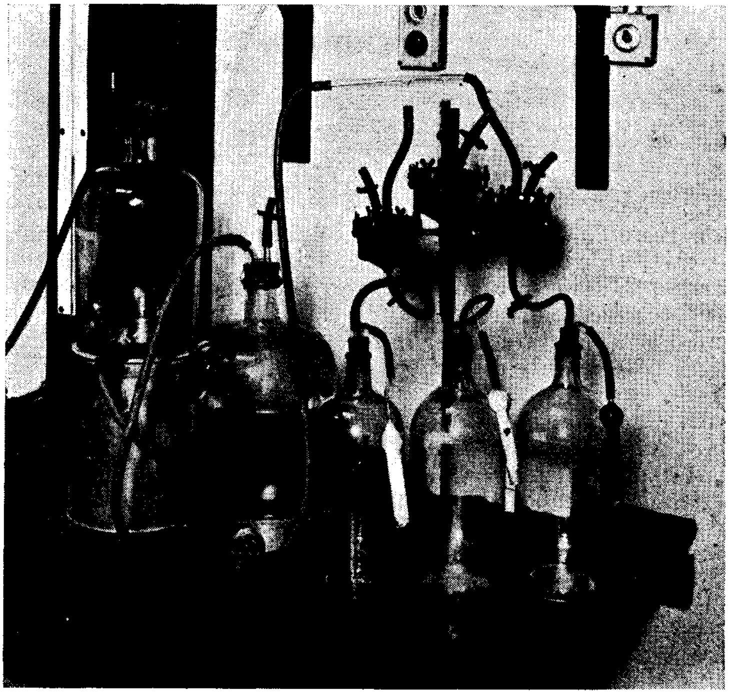

FIGURE 12.—Apparatus for determining the action on cement of water percolating through cement-mortar plaques.

TABLE 9.—*Comparison of different methods of measuring solubility of cements*

[Results expressed as percentage of the average value for the 6 cements in each type of test]

Cement		Extraction tests on neat cement		Percolation tests on 1:8 mortar (age, 1 month)			Rengade's method, 1:8 standard sand mortar (age, 1 month)
Type	No.	Age, 1 month	Age, 3 months	Standard sand mortar controlled flow rate [1]	Graded sand mortar controlled flow rate [1]	Graded sand mortar free flow [2]	
Portland	207	124	131	100	113	109	94
	210	131	121	78	145	112	105
	208	112	114	104	125	109	97
Portland blast furnace	209	119	130	99	141	102	143
	212	73	66	119	64	70	107
Experimental pozzolanic	220	42	37	------	12	------	53

[1] Flow rate maintained at 30 to 50 cm^2 per hour through specimens 3 inches in diameter. Results calculated from amount of lime extracted by a given volume of water passed.

[2] Free flow under pressure of 10 pounds per square inch. Results calculated from amount of lime extracted by a given volume of water passed.

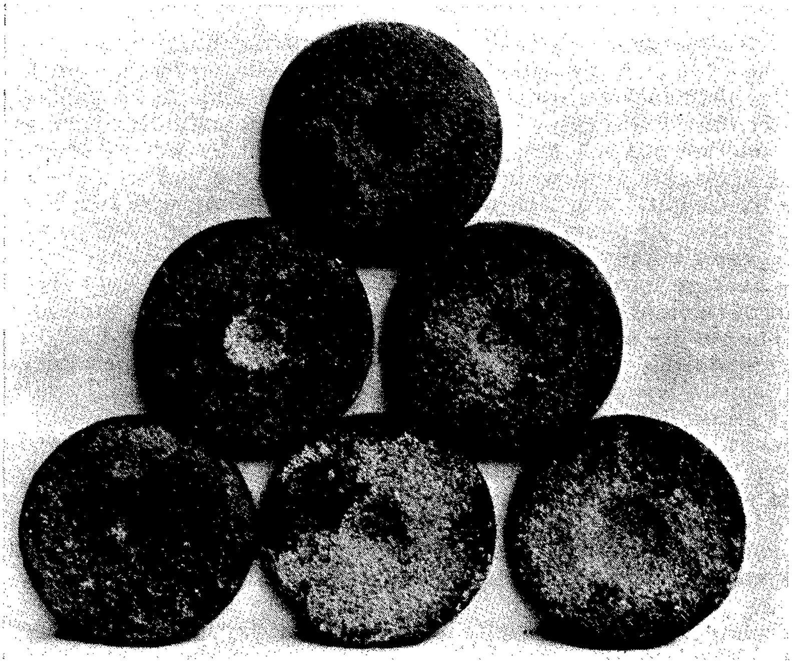

FIGURE 13.—Cement-mortar plaques, mix 1:8, tested according to Rengade's method for one month.

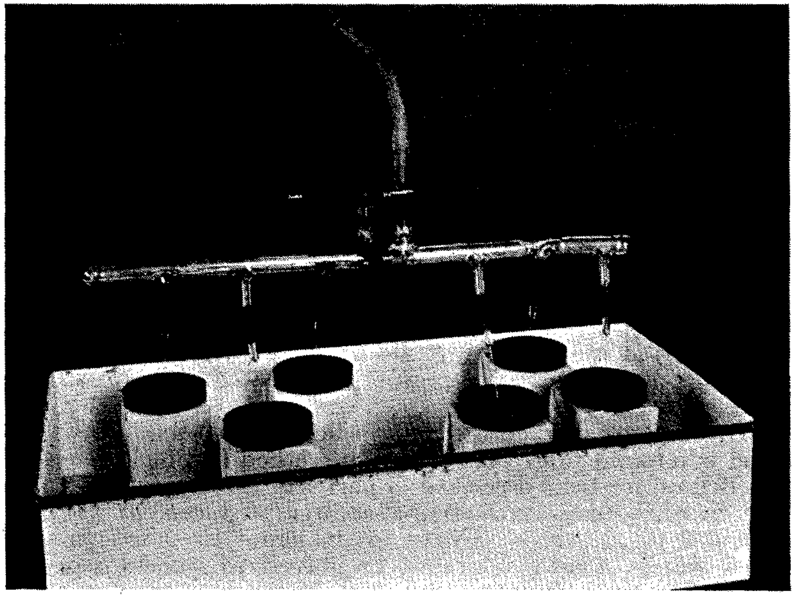

FIGURE 14.—Apparatus for the determination of the action on cement of water percolating through concrete according to Rengade's method.

PART II. INVESTIGATION CARRIED OUT IN THE UNITED STATES

In conjunction with certain concrete-permeability investigations in the United States, some tests on the dissolution of the cement by water percolating through concrete have been made by analysis of water forced through concrete cylinders. The cylinders were made of concrete mixes 1:8.5, 1:17, 1:19, and 1:29 by weight of cement and aggregate, the water-cement ratio varying between 0.66 and 2.0 by weight. For rich mixes the water pressure was 400, and for lean mixes 50 pounds per square inch. The water used was from the water supply of the city of Denver. The pH value was 7.7, the average hardness in $CaCO_3$, 125 parts per million, and the content of calcium oxide, counted as calcium, 16.1 parts per million.

The results are shown by curves (*a*) and (*b*) in figure 15. In the period during which up to about 50 liters of water per kilogram of cement has passed through the specimen, the solubility is high and presumably the lime hydrate produced by the hydration of the cement forms the bulk of extracted material. In the range from about 50 to about 500 liters of water per kilogram of cement, the rate of solubility falls rapidly, and by the end of the period all the free lime has been removed. From then on, the attack of the water is concentrated on the more stable silicates and the rate of solution decreases slowly. Although the test specimens were of various mixes and of lengths up to 24 inches and were tested at nominal percolation velocities of 0.03 to 150 feet per day, the solution curves were found to be very similar. Evidently, at these velocities, the percolating water becomes saturated with respect to the particular compounds involved.

PART III. INVESTIGATION CARRIED OUT IN SWEDEN

In Sweden several indirect methods have been used to determine the action on cement of water percolating through concrete. In principle these methods may be classified as follows:

(*a*) Hardened, hydrated cement is pulverized and material of a certain grading selected and placed in a glass tube. Water is conducted through the cement at a certain velocity and the extract analyzed.

(*b*) Hardened, hydrated cement is pulverized and material of a certain grading selected and placed in a glass bottle or crucible. A fixed amount of water is added and the mixture agitated for a certain time. The water is drawn off and analyzed. Fresh water of the same amount is added, the mixture agitated for a certain time, and the extract analyzed. This process is repeated as many times as desired.

The results of method (*b*) only will be discussed below. This method is referred to as the extraction method and has been used in Great Britain for tests described in part I of this Appendix.

The Swedish tests have comprised hydrated cement varying in age from 7 to 112 days. Curve (*d*) in figure 15 shows results for distilled water. Curve (*c*) refers to pulverized cement mortar for Stockholm water. This has a content of calcium oxide of 34 parts per million, a pH value of 7.4, and contains 4 parts per million of

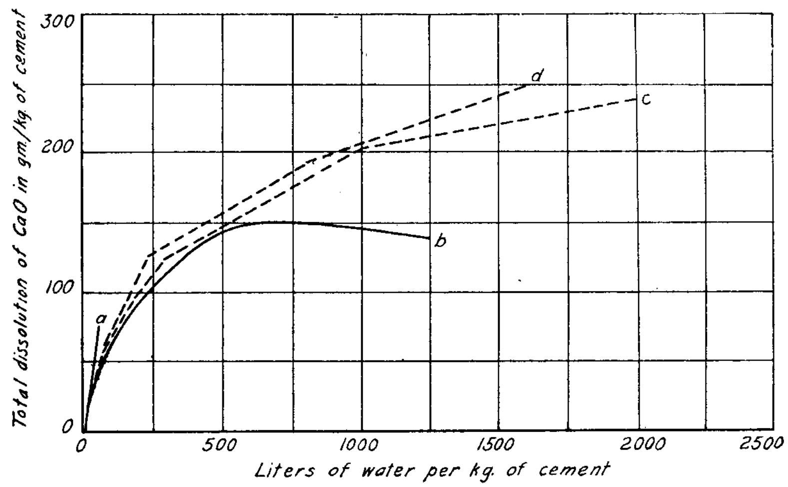

FIGURE 15.—Results of percolation tests.

Curve *a*.—Average values of United States Bureau of Reclamation percolation tests on concrete 1:8.5–1:17, Denver water.

Curve *b*.—United States Bureau of Reclamation percolation tests on concrete 1:19–1:29, Denver water.

Curve *c*.—Swedish extraction tests, pulverized cement mortar 1:1, Stockholm water.

Curve *d*.—Swedish extraction tests, pulverized hydrated cement, distilled water.

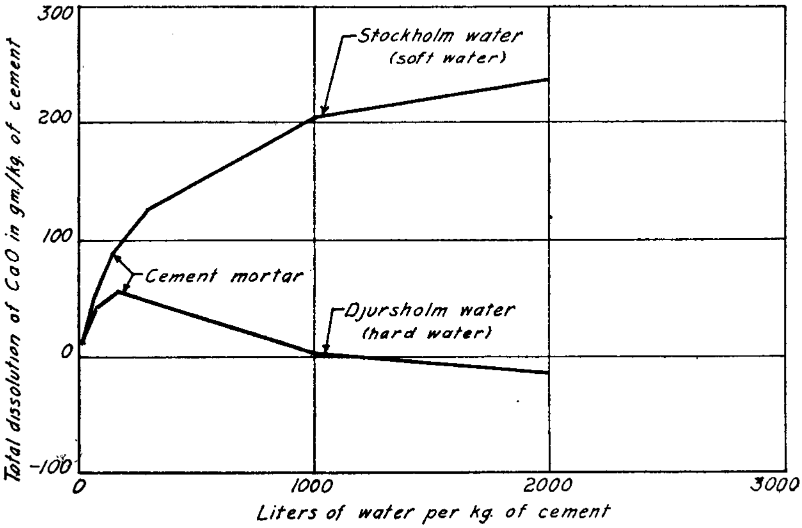

FIGURE 16.—Results of percolation tests.

aggressive carbon dioxide. From figure 15 it will be seen that the extraction method gives results very similar to those of the United States Bureau of Reclamation tests.

According to practical experience, deterioration takes place if pure or slightly acid water percolates through the concrete, while no appreciable effect has been found for hard water. To determine whether the extraction method would show this very marked difference, tests were carried out with soft (Stockholm) and hard (Djursholm) water. The latter has a content of calcium oxide of 116 parts per million, a pH value of 7.5, and contains no aggressive carbon dioxide. The tests were made on crushed cement mortar 1:1, and the results are shown in figure 16. For soft water calcium oxide is successively dissolved, first at a greater rate and then more slowly. When hard water is used, the dissolution obtains a maximum for a certain amount of water per kilogram of cement and is then reduced, showing that a negative dissolution takes place.

The first part of the curve for hard water corresponds to the stage when the whole content of bicarbonate of the water is precipitated and lime goes into the solution, so that the water is saturated with lime. As the cement is deprived of lime, its capacity to give up lime is reduced and successively lower and lower concentrations of lime are obtained in the water. When the incoming and outgoing water have the same lime content, no dissolution of lime takes place. This corresponds to the point of maximum of the curve. When the outgoing water has a lower lime content than the incoming water, a negative dissolution is obtained. This corresponds to the falling part of the curve. The greatest negative value is obtained when the quantity of lime given up by the cement is just sufficient (or able) to liberate the bicarbonate content of the water but not to allow any lime to go into solution. If the lime given up is still less, part of the bicarbonate in the water is not liberated, and the negative rate of dissolution is reduced. This corresponds to the last part of the curve.

From the tests referred to, it will be seen that the extraction method shows a marked differentiation between soft and hard water.

APPENDIX 5

TENTATIVE STANDARD SPECIFICATION FOR TESTING ACTION ON CEMENT OF WATER PERCOLATING THROUGH CONCRETE BY AN EXTRACTION METHOD

PART I

The determination of the action on cement of water percolating through concrete shall be made by the extraction method described below and by means of an apparatus a description of which is given in Part II.

The test specimen shall be made in the following way: 100 g of cement and 40 g of distilled water are mixed and placed in a tin about 65 mm in diameter and 20 mm in height, which is closed and sealed with paraffin. The specimen shall be aged for 28 days at 20° ± 2° C. The set cement shall then be taken out and crushed to a fine powder, which shall rapidly be sieved through a sieve with free openings of 0.088 mm. The material which has passed the sieve shall be analyzed as to its content of lime, and as much of the material selected as corresponds to 0.500 g of dry, nonhydrated cement.

This amount of material shall be mixed with 250 cm^3 of distilled water, free from carbon dioxide, and shall be introduced into the extraction bottle, the rubber stopper of which shall be inserted with all tubes closed. The bottle shall be shaken violently by hand before being placed in the shaking apparatus. In this apparatus the bottle shall be shaken for 15 minutes, counted from the time of addition of water, and then taken out. The filter tube shall then be connected to a glass container and to a vacuum pump. The water in the extraction bottle shall then be sucked, as completely as possible, from the bottle to the container by evacuation. Towards the end of this procedure the glass filter shall be pressed against the bottom of the bottle, and finally the bottle shall be turned upside down to empty the filter tube. The air which, during the evacuation process, is sucked into the bottle shall pass through an absorption tube filled with a mixture of asbestos and sodium hydroxide ("ascarite") and connected to one of the glass tubes in the stopper. When the evacuation is finished, 250 cm^3 of distilled water, free from carbon dioxide shall be introduced into the extraction bottle and the whole procedure repeated. At least five extractions shall be made. Each of the extracts is analyzed for its content of lime and, if required, also for other substances.

The main parts of the extraction apparatus are the extraction bottle and the shaking apparatus. The extraction bottle is of glass with a content of about 500 cm^3. It is furnished with a rubber stopper with three holes for (*a*) a glass filter tube for inverse filtration, (*b*) a glass tube which, during the filtration, is connected to a tube for absorption of carbon dioxide, and (*c*) a glass tube for the supply of water. The filter tube is provided with a stem, which passes through the hole in the rubber stopper. This stem is cut in the middle and the parts joined together with rubber pressure tubing. This facilitates the pressing of the filter tube against the bottom of the bottle as specified in part I. Arrangements shall be provided for allowing the tubes through the rubber stopper to be closed. The shaking apparatus shall rotate at a speed of about 35 revolutions per minute and be designed so as to allow the extraction bottle to be strapped on and rotated round an axis perpendicular to the direction of the length of the bottle. The extraction apparatus and its arrangement for the test is shown in figure 17.

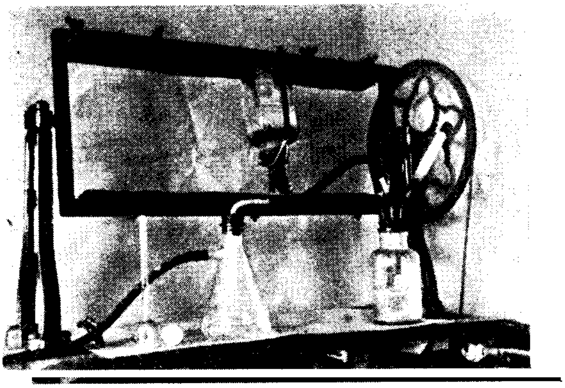

FIGURE 17.—Apparatus for the determination of the action on cement of water percolating through concrete by the extraction method.

APPENDIX 6

A GERMAN STANDARD SPECIFICATION FOR TESTING SHRINKAGE OF CEMENT MORTAR

PART I

(1) *Tests and Testing Equipment.*

The measurements shall comprise the determination of the length and the weight of test specimens made of cement mortar.

The determination of length shall be made with an accuracy of 0.01 mm in the apparatus, described in part II.

The determination of weight shall be made with an accuracy of 0.1 g.

The average value of three test specimens shall be considered.

(2) *Composition of Cement Mortar.*

The cement mortar shall be made of 1 part of cement and 3 parts of dry sand by weight.

The sand shall be made up of 2 parts of dry standard sand and 1 part of dry fine sand, by weight. The fine sand shall have the following grading:

About 12 percent of particles of about 0–0.30μ;
68 percent ±10 percent of particles retained on a sieve of 4,900 mesh per square centimeter; and
about 5 percent of particles retained on a sieve of 900 mesh per square centimeter.

The consistency of the cement mortar shall be such so as to give a flow of 17 to 19 cm as measured on the flow table, described in part II.[1] The cement mortar shall be placed on the flow table in a cone having an upper diameter of 70 mm, a lower diameter of 100 mm, and a height of 60 mm. The flow shall be measured after 15 bumps.

The cement and the fine sand shall be mixed dry by hand until the mix obtains an even color. The standard sand shall be added and the dry materials mixed by hand for 1 minute. The water shall then be added and the mortar shall be mixed by hand for 1 minute, whereupon it shall be mixed in a Steinbrück-Schmelzer mixer during the time required for at least 20 revolutions.[2]

(3) *Test Specimen*

The size of the specimen shall be 40 mm by 40 mm by 160 mm.

The molds shall be of steel as described in part II. The underside of the mold shall be coated with a thin layer of grease, and the inside of the mold shall be slightly oiled. The joint between the base and

---

[1] *As a rule, 15 percent water by weight of the dry materials of the cement mortar is required, which corresponds to a water-cement ratio of 0.60.*

[2] *The amount of material required for 3 test specimens is 450 g of cement, 450 g of fine sand, 900 g of standard sand, and 270 g of water.*

the mold shall be made watertight on the outer side by a mixture of 3 parts of paraffin wax and 1 part of colophony applied hot by a brush.

The specimen shall be fitted with two pins of stainless steel, as described in part II, one at each end. For this purpose the mold shall be provided with two holes, one at each end. The holes shall be filled with plasticine into which the pins shall be pressed at right angles to the end faces of the mold. The pins shall reach 8.5 mm into the mold. Any plasticine protruding into the mold shall be removed.

Before the cement mortar is put in, an auxiliary mold, as described in part II, shall be placed on top of the mold proper to facilitate the depositing of the mortar.

The mortar shall be deposited in two layers, each containing about 310 g of mortar. . The first layer shall be placed so that the steel pins will be well surrounded by mortar.

The consolidation of the mortar shall be made by a wooden tamper, as described in part II.

The mortar shall be consolidated by 20 movements of the tamper, for each layer, the movements alternately starting from one or the other end of the mold.

The mortar at the ends of the mold at the steel pins shall not be consolidated by the tamper.

When the consolidation of the second layer is completed, the auxiliary mold shall be removed and the surface of the mortar made even. Two hours later, excessive mortar, if any, shall be removed and the top surface of the mortar smoothed.

(4) *Curing.*

The molds containing the test specimens shall be stored for 2 days in containers with moist air of a temperature of 17° to 20° C., after which time specimens shall be removed from the molds.

The test specimens having been removed from the molds, they shall be cured in water of a temperature of 17° to 20° C. during 5 days for normal-hardening cements and during 26 days for slow-hardening cements.

After the curing in water, the specimens shall be placed in containers and cured in air of a temperature of 17° to 20° C. and of a constant relative humidity of about 50 percent.

The containers shall be airtight, and a relative humidity of 50 percent shall be maintained by sulphuric acid of a specific gravity of 1.33, or a constant humidity may be maintained by a saturated solution of potash.[3]

Every time the container is opened, the sulphuric acid or salt solution shall be renewed.

(5) *Measurements.*

The determination of the length and the weight of the specimens shall be made at the end of the water curing; i. e., at an age of the specimens of 7 days for normal-hardening cement and of 28 days for slow-hardening cement. Subsequent measurements shall be made at an age of the specimens of 28 days for normal-hardening cement,

---

[3] *The size of the container taking three test specimens shall be 19 by 24 by 11.5 cm^3. The amount of sulphuric acid for each container shall be 500 cm^3, and the free surface of the acid shall be 15 by 21 cm^2. The lid of the container is tightened by adhesive insulation ribbons.*

and for any cement at an age of 56 and 90 days, and after such longer time as may be required.

PART II

(1) *Apparatus for Measurement of Length.*

The determination of the length of the test specimen shall be made in the apparatus shown in figures 18 and 19. It consists of a base of steel (1, figure 19) with a seat for carrying the test specimen, which is placed in a vertical position in a steel frame (2). The vertical bars of the frame are made of Indilatan invar steel. The frame rests on the upper pin (3) of the specimen, and a micrometer dial gage is connected to the lower pin (4). The load on the upper pin is the weight of the frame and the gage (about 1.1 kg), and the load on the lower pin is the pressure from the gage (about 0.1 kg).

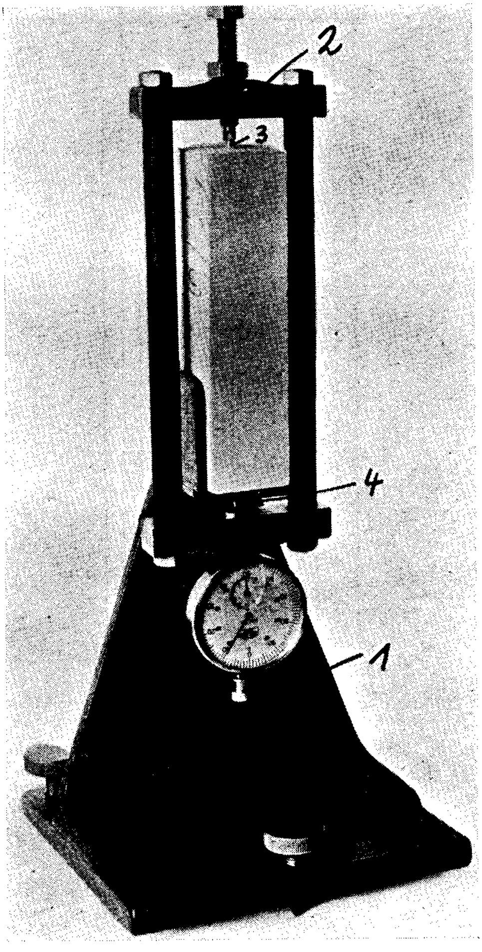

FIGURE 18.—Apparatus for determination of shrinkage.

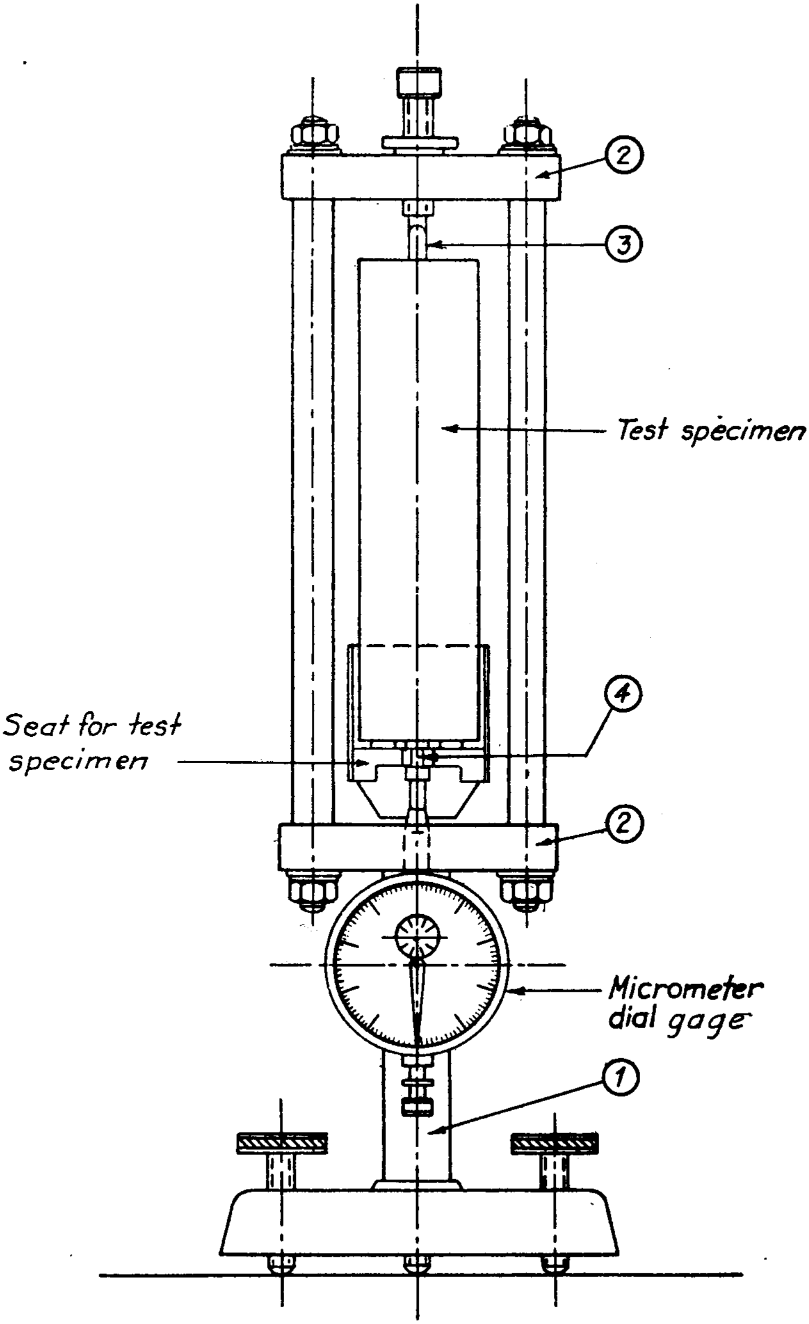

FIGURE 19.—Diagram of apparatus for determination of shrinkage.

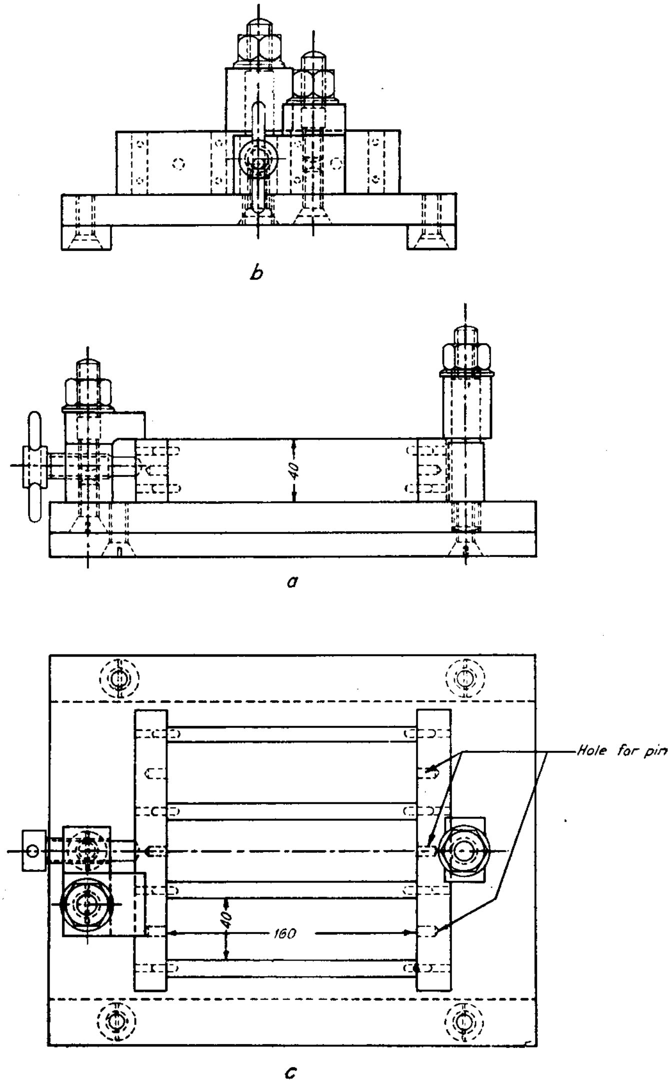

FIGURE 20.—Steel mold.

A control piece for checking the apparatus is made of ordinary steel of the same size as the test specimen, including the pins.

(2) *Molds and Containers.*

The mold is made of steel and provides for three test specimens, as shown in figure 20, *a*, *b*, and *c*. Each part has a length of 160 mm, a width of 40 mm, and a height of 40 mm. At the ends it is provided with two holes for the pins, the diameter of the holes being 6.5 mm.

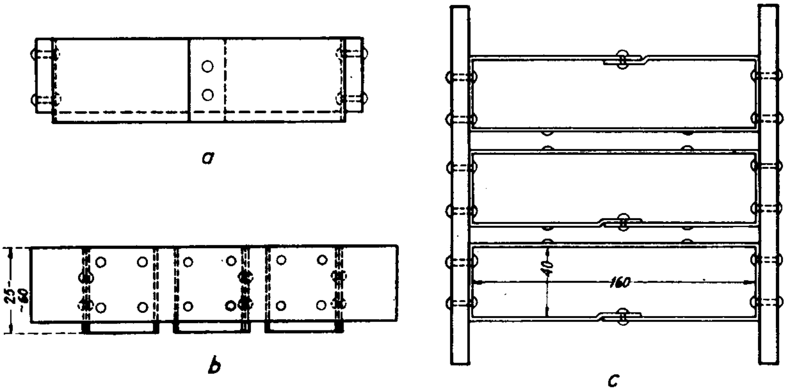

FIGURE 21.—Auxiliary steel mold. Figures in milimeters.

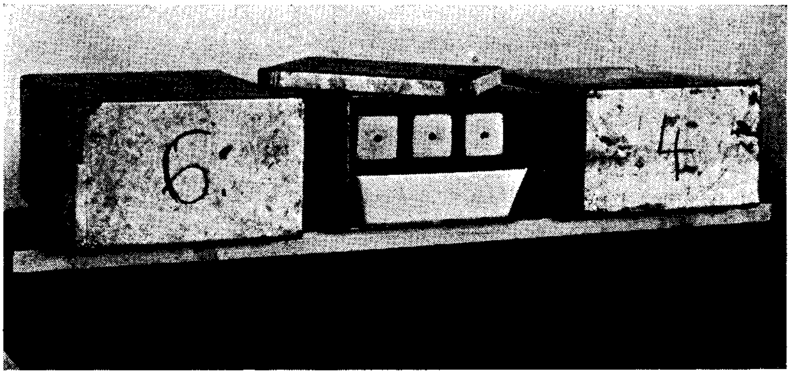

FIGURE 22.—Curing containers.

The auxiliary mold is shown in figure 21, *a*, *b*, and *c*, and is of the same size except that the height may be anything between 25 mm and 60 mm, and it has no holes at the ends.

A photograph of the curing containers is shown in figure 22.

(3) *Pins.*

The pins are made of stainless steel as shown in figure 23. The total length of the pin is about 18 mm, and the diameter of the head is 4.5 mm.

(4) *Tamper.*

The tamper is made of wood as shown in figure 24. It has a weight of 500 g and a tamping area of 11 by 2 cm². The under side of the tamper is provided with a shoe of thin steel plating.

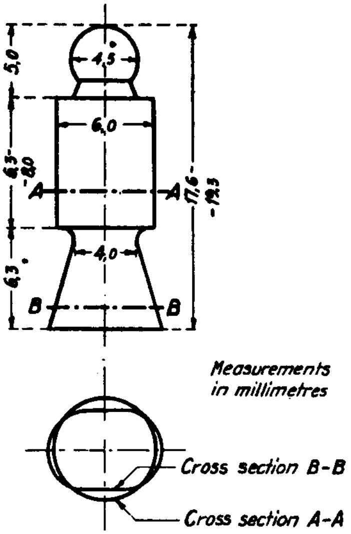

FIGURE 23.—Pin of stainless steel. Measurements in millimeters.

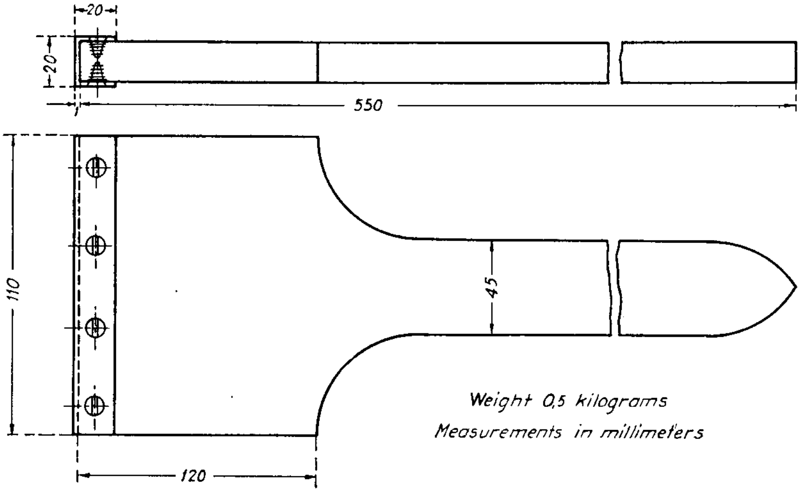

FIGURE 24.—Wooden tamper.

(5) *Flow Table.*

The flow table is of the Haegermann type. It has a height of falling of 10 mm, and the weight of the table is 3.30 km. The flow table is described in "Zement" 1935.

APPENDIX 7

TENTATIVE RECOMMENDATIONS FOR TESTING PERMEABILITY OF CONCRETE TO COMPARE DIFFERENT CEMENTS

I. *Testing Equipment.*

Any suitable approved testing equipment may be used.

II. *Methods of Testing.*

The tests shall be made on concrete.

Any of the following methods of testing may be used:

Method A.—The minimum amount of cement per unit volume of finished concrete shall be determined which, under fixed test conditions gives impermeable concrete, and the different cements shall be compared on the basis of the minimum amount of cement required for this purpose.

Method B.—The permeability of concrete of different cements shall be determined by using test specimens containing the same amount of cement per unit volume of finished concrete, and the different cements shall be compared on the basis of the amount of percolating water.

In case of Method A, a series of specimens of each cement shall be tested, and the difference of cement content of the series may be about 25 kg of cement per cubic meter of finished concrete.

In case of Method B, comparatively lean concrete shall be used so as to obtain permeable concrete for all cements to be tested.

III. *Composition of the Concrete.*

In tests for actual works, the grading of the fine and coarse aggregate shall, so far as possible, be the same as the grading of the aggregates used in the works.

For laboratory tests any suitable grading of the aggregates may be used.

No modification of the grading shall be made for the same series of tests.

The material of fine and coarse aggregate shall be impervious.

The method of placing the concrete shall be the same for all cements tested in the same series and, so far as possible, the same as the method used in the works. The utmost care shall be taken in preparing the test specimens so as to ensure uniform results.

The water-cement ratio shall be chosen with regard to the method of placing the concrete. For comparison between different cements, placed in the same manner, the concrete shall have the same flow measured on the flow table or, for stiffer consistencies, the same slump.

IV. *Curing.*

When the test specimens have been prepared, the molds shall be kept in moist air or covered with suitable material, which shall be kept moist. The specimens shall be removed from the molds 3 days after the specimens are made. After they have been removed from the molds they shall be placed in water of constant temperature for 25 or 53 days, and then be kept in moist air of constant temperature and humidity for 14 days, or for such longer time as may be considered necessary.

V. *Water.*

In case of method A, clean or distilled water and, in case of method B, distilled water shall be used. If the water pressure is obtained by compressed gas, it shall not contain carbon dioxide.

VI. *Number of Test Specimens.*

At least four test specimens of each cement shall be tested, and the average result shall be considered.

APPENDIX 8

WORKABILITY OF CONCRETE

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The term "workable concrete" was first used during investigations into the influence of various factors upon the quality of the hardened concrete. It served to denote the limits of water content or consistency within which a certain transport and a certain method of work were applicable. As practically all concrete was poured concrete, the expression was used to signify the limit of water content within which concrete could be poured.

A water content which gave about 20-mm slump or a flow-table value of about 30 to 40 percent constituted one limit, and the utmost quantity of water that would have to be added to reach segregation point, the other. Evidently, there was no thought of classifying concrete in respect of its greater or lesser degree of workability.

With increased knowledge of the influence of various factors upon the ability to obtain a workable concrete, there came the demand for the gradation of this property, and the term "workability" was introduced.

It is clear that the mobility of the particles in the concrete is an important factor of its workability, but another factor, less evident and more difficult to define, must be included. In practice it is not sufficient for concrete to retain its homogeneity during mixing. It must do so during conveyance to the molds and during the subsequent handling; otherwise it cannot be considered as workable.

The term "workability" must therefore embrace facility of manipulation, as well as resistance to segregation during handling in the molds. These two properties, which could for the sake of convenience be called "mobility" and "durable homogeneity", are the most important factors relating to the workability of concrete. A third property, namely, "smoothness", has often been mentioned in this connection, but whether it should also be included in the term "workability" is doubtful. Increased smoothness carries with it lessened mobility, but reduces liability to segregation.

The experiments with cast concrete hereafter described have made it clear that there are still other factors influencing the workability of concrete, but these can be traced to the factors directly influencing one or both of the properties above named. Therefore no further partition of the meaning of the term "workability" appears to be required. Presumably, however, it will undergo modification if and when new methods of work, such as that of vibration, are introduced.

In actual construction work there is generally no great difficulty in gaging concrete fairly accurately, when the aim is to obtain a comparison between different mixtures having the same consistency (determined by slump, flow table, etc.) for which the same method of handling and means of transport are to be employed. Very much more difficult is the problem of forming an accurate judgment of the workability of concrete when it is a question of general consideration of different kinds of cement and ingredients. Up to the present, no exact theoretical definition of the workability of concrete exists. It is only by methodical research that the influence of the different factors can be ascertained, and, when the results can be made clear by expression in some empirical formula, it may be possible to profit by these results in a practical manner. It must be understood from the beginning that such a formula is not to have a theoretical basis and that it must be wholly dependent upon its agreement with the subjective estimate of workability obtained in the laboratory.

The measure of workability could be taken as a positive number varying between low values at each of the limits for workable concrete, i. e., with a consistency of 30 to 40 percent measured on the flow table, as well as with water content where segregation begins. Each experiment to determine workability must therefore comprise a series of observations on the same mix with the addition of various proportions of water between these limits.

The series of experiments that has been carried out comprises:

Cement.

A. Low-heat portland cement.
B. High-heat portland cement.
C. Low-heat portland cement with powdered admixture.
D. Normal portland cement with powdered admixture.

Chemical analysis

	Percent			
	A	B	C	D
SiO_2	26. 1	20. 7	27. 7	30. 9
CaO	62. 0	64. 6	58. 9	52. 1
Al_2O_3	4. 2	5. 4	4. 2	6. 1
Fe_2O_3	2. 9	3. 1	2. 8	2. 6
MgO	2. 2	2. 2	1. 7	1. 6
SO_3	1. 3	2. 4	1. 8	1. 9
Loss on ignition (el. furnace, 700° to 800° C.)	. 8	. 6	2. 1	4. 1

Fineness

	A	B	C	D
Residue on 900-mesh sieve (0.20 mm openings)	0. 1	0. 05	0. 2	0. 1
Residue on 4,900-mesh sieve (0.088 mm openings)	7. 2	2. 0	4. 6	5. 8

Setting time

	A	B	C	D
Temperature of the air	17° C.	18° C.	17° C.	17° C.
Amount of water needed to obtain normal consistency of cement paste, percent by weight of cement	25. 3	26. 3	28. 0	29. 5
Initial setting time	$4^h\ 35^m$	$1^h\ 55^m$	$4^h\ 0^m$	$2^h\ 15^m$

Sand.

The two most extreme kinds of sand allowed by Swedish specifications: Fine sand, fineness modulus 2.1, coarse sand, fineness modulus 4.4.

Coarse Aggregates.

Gravel, graded from 7 to 30 mm.
Gravel, graded from 7 to 70 mm.
Crushed stone, graded from 7 to 33 mm.
Crushed stone, graded from 7 to 70 mm.

Proportions of Ingredients.

Cement contents 400, 350, 300, 250, and 200 kg per m^3 concrete.

$$\frac{\text{Sand}}{\text{Coarse aggregates}}=1{:}1 \text{ and } 1{:}1.5$$

The above schedule comprises 320 different mixtures, about half of which did not yield workable concrete and, therefore, had to be excluded. This was mostly the case with combinations of low cement content and coarse sand.

To avoid the escape of water during the process of mixing (as well as to make the mixing at all possible at the high-water percentage where segregation begins), a specially constructed mixer was employed, consisting of a watertight steel cylinder, capable of rotating simultaneously round its axis and round a line of 45° drawn through its center. This holder enabled a perfect mixing to be obtained without the use of wings, which was particularly desirable in this case in view of the necessity of measuring the volume of the concrete and of cleaning the mixer.

The consistency of the concrete was determined partly by its spread over the flow table after 15 jolts of one-half inch drop, and partly by the angle of incline at which the concrete began to move by its own weight. For the latter, an iron chute was used, the cross section of which was a semicircle of 30 cm diameter. The second method was used as a check on the first, and also to determine the consistency of the wettest mixtures, for which purpose the flow table was impracticable.

The entire series of experiments was carried out in a laboratory having an atmospheric temperature of 15° C. The temperature of the concrete was practically 14° C. for all the mixtures. The dry ingredients were mixed together for 3 minutes; then the whole of the water content required for the first workability limit was added (flow table 30 to 40 percent) and the concrete again mixed for 3 minutes After each addition of water, the 3-minute mixing was repeated.

In order to find out whether successive increases in the duration of mixing could exercise any noticeable influence on the workability of the concrete, experiments were made with exactly similar mixtures and water percentages, but with mixing periods varying from 3 to 15 minutes. No apparent difference was observed, a result which may possibly be attributed to the use of a tightly closed mixer, which prevented evaporation.

The subjective estimate of the workability of concrete has been arrived at partly by direct judgment and partly by listing the properties of concrete, in accordance with the following:

Properties observed in concrete:

T. Heavy and firm. Not workable in the ordinary sense. Impracticable for cast concrete.

E. Approximate consistency limit for workable cast concrete.

L. Mobile.

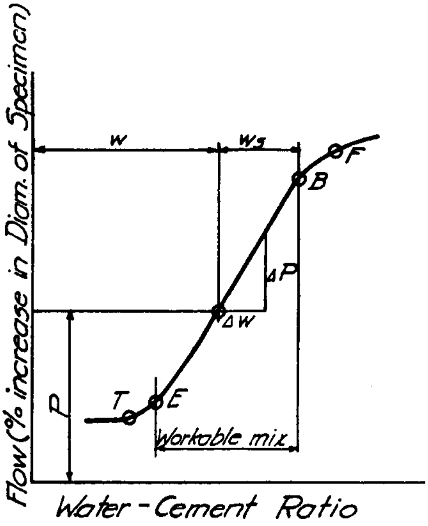

FIGURE 25.—Water-cement-flow relation.

G. Cohesive.

S. Smooth.

K. Ring of stone on the flow table.

A. Water is separated in the mixer.

B. Apparent signs of segregation. In the case of certain mixtures the water begins to run off, and in others the coarse aggregates sink to the bottom.

F. Complete segregation.

The properties noted under T, E, B, and F are inserted in the diagram of figure 25, the coördinates of which bear upon the water ratio and consistency.

It would appear from this experiment that the factors that influence the mobility of concrete are the cement content and consistency. The latter does so partly directly and partly indirectly through certain momentary changes due to increase in water-cement ratio.

The mobility of the concrete was therefore expressed by the formula:

$$L=cP^2\frac{\Delta P}{\Delta w}$$

where c=kilograms of cement per m^3 of concrete;
P=consistency (percent increase) measured on the flow table;
$\frac{\Delta P}{\Delta w}$=slope of the curve in figure 25.

At an early stage of the experiments it was evident that the durable homogeneity of the concrete depends not only upon the relative quantity of water that can be added before segregation begins—that is to say, $\frac{w_s}{w}$ in figure 25—but also upon the capacity of the mixture to retain water. The finer the grading of the cement and sand, the more water can be absorbed. The same applies to powdered admixtures. In order to determine this factor, the following method was used:

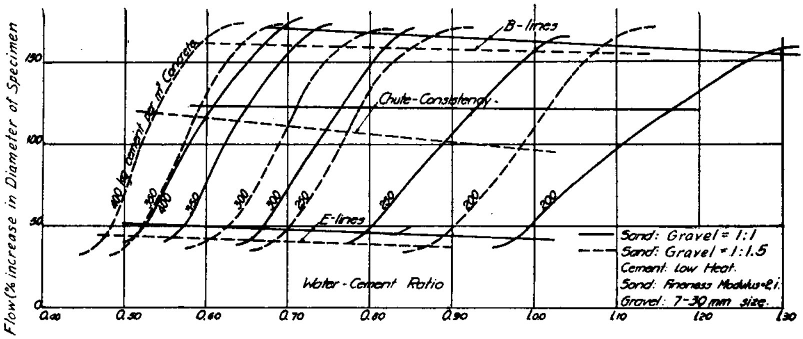

FIGURE 26.—Water-cement-flow relation.

A cylindrical-shaped jug of 16 cm inner diameter and 50 cm height was filled with concrete of chute consistency and jolted 15 times on the flow table. The surface water was decanted in three stages—namely, after 30, 60, and 90 minutes. Its total volume v, expressed in cm^3, according to the experiment is related to the resistance to segregation of the concrete approximately in accordance with the empirical expression:

$$y=\frac{1}{1+10_{\log}(1+v)}$$

That property appertaining to concrete which has in the foregoing been called "durable homogeneity" is, therefore, expressed by

$$Q=\frac{w_s}{w}y$$

As workability should be directly proportional to both L and Q, it has finally been expressed by

$$A=RLQ$$

where R is a constant ($R=5.10^{-8}$) for the whole of the series of experiments, adapted so that the values for workability A are numbers between 0 and 20.

Table 10 gives the data of two of the 22 series of the experiments, including the subjective estimate of the workability. The same data are traced in figures 26 and 27.

With the exception of value y, which was determined by direct measurement of the water decanted and may be found on table 11 and figure 32, all the values included in the foregoing formulas have been extracted from these curves. Figures 28–31 contain the complete results.

The object of the above-described investigation, and the empirical method drawn up from it, was to arrive at a suitable estimate of the workability of concrete, as applied to varying materials, means of transport, and methods of work. The strength of concrete increases or decreases gradually, consequent upon changes in the influencing factors, but the allowable stresses are in general low in relation to the required strength. A slight variation in the composition of the concrete is not, as a rule, of any great importance for the strength of the structure.

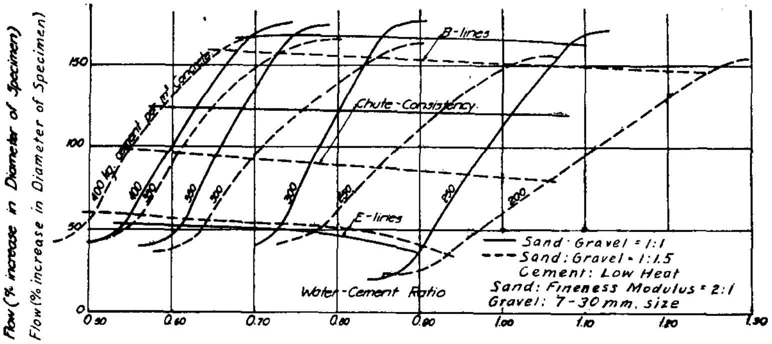

FIGURE 27.—Water-cement-flow relation.

In the case of hydraulic concrete structures, however, defective homogeneity can have very unfortunate consequences, because, at the slightest leakage, dissolution of the cement would immediately set in. As, therefore, impermeability in every detail of the structure is an indispensable condition for such concrete, it is of great importance that as complete homogeneity as possible should be attained. The more workability possessed by the concrete, the more homogeneity it will attain when completed.

With respect to investigations to ascertain the suitability of available materials for concrete, as well as the proportions giving the required workability of the mass, and the required compressive strength and impermeability in the hardened concrete, it is of great assistance to be able to foresee to what extent these requirements could be satisfied by the employment of a certain means of transport. The proposed workability determination provides useful guidance in such cases.

TABLE No. 10.—*Data for low-heat cement and fine sand FM=2.1*

Cement content kg per m^3 concrete	Gravel graded 7 to 30 mm											
	$\frac{\text{Sand}}{\text{Gravel}}=1:1$						$\frac{\text{Sand}}{\text{Gravel}}=1:1.5$					
	Water-cement ratio	Chute (α)	Flow (percent)	Property of mix	Estimated workability	Formula values	Water-cement ratio	Chute (α)	Flow (percent)	Property of mix	Estimated workability	Formula values
400	0.50	0.58	------	T G	------	------	0.45	0.51	17	T	------	------
	.53	.53	53	T S	4	------	.49	.50	57	T G	6	------
	.595	.49	97	E G	8	10	.525	.43	104	T S	12	13
	.61	.38	127	L	10	9	.56	.30	140	E G	8	9
	.65	.28	147	L	4	6	.60	.23	------	L B	------	------
	.69	.20	------	B	------	------	.64	.13	------	L B	------	------
	.725	.13	------	F	------	------	.675	------	------	B	------	------
350	.61	.50	87	E G	6	8	.51	.53	40	T G	2	------
	.66	.36	137	L	8	6	.56	.48	87	T S	8	9
	.70	.27	160	L	4	2	.60	.31	130	E G	10	9
	.74	.17	------	B	------	------	.64	.25	167	B	2	0
	.785	------	------	F	------	------	.69	.18	------	B	------	------
300	.58	.62	------	T	------	------	.60	.53	43	T G	------	------
	.67	.51	50	T G	------	------	.65	.52	60	T G	4	------
	.72	.49	87	E G	6	5	.70	.35	110	E	6	8
	.77	.33	120	L	6	5	.75	.28	154	L	4	2
	.82	.26	167	L B	2	0	.80	.19	------	B	------	------
	.87	.18	------	B	------	------	.85	------	------	B	------	------
	.92	------	------	F	------	------	.90	------	------	F	------	------
250	.80	.57	53	T G	2	------	.72	.51	67	T	2	------
	.86	.49	70	E G	4	------	.78	.38	114	E G	4	5
	.92	.42	117	L	4	3	.84	.23	154	L	2	1
	.98	.27	167	L B	2	0	.90	.18	------	L B	------	------
	1.04	.22	------	B	------	------	.96	------	------	B	------	------
	1.10	.16	------	F	------	------	1.02	------	------	F	------	------
200	.75	.57	------	T	------	------	.90	.53	50	E G	------	------
	.875	.55	------	T	------	------	.975	.40	90	L	------	2.5
	1.00	.52	60	E G	2	------	1.05	.22	------	L	------	------
	1.08	.50	63	L	2	------	1.125	.16	------	L B	------	------
	1.15	.43	120	L V	2	1.5	1.20	------	------	B	------	------
	1.23	.32	140	B	------	1	1.27	------	------	F	------	------
	1.30	.20	------	F	------	------	------	------	------	------	------	------
	1.38	.16	------	F	------	------	------	------	------	------	------	------

TABLE NO. 10—*Data for low-heat cement and fine sand FM=2.1*—Continued

Cement content kg per m^3 concrete	Crushed stone graded 7 to 30 mm											
	$\frac{\text{Sand}}{\text{Crushed stone}}=1{:}1$						$\frac{\text{Sand}}{\text{Crushed stone}}=1{:}1.5$					
	Water-cement ratio	Chute (*a*)	Flow (percent)	Property of mix	Estimated workability	Formula values	Water-cement ratio	Chute (α)	Flow (percent)	Property of mix	Estimated workability	Formula values
400	0.56	0.53	60	E G	6		0.49	0.57	30	T		
	.60	.48	110	G	8	7	.525	.41	52	E	2	
	.64	.37	124	L	6	7	.56	.35	100	E G	8	8
	.675	.28	160	L B	2	1	.60	.28	130	L	6	5
	.71	.22		B			.64	.24	154	L	2	0
	.75			F			.675	.23	160	B		
							.71			F		
350	.64	.51	83	E G	6	4.5						
	.69	.31	137	L	6	3						
	.73	.23	167	L B	2	0						
	.77			B								
	.815			F								
300	.77	.34	97	L	6	4.5	.60	.56	23	T		
	.80	.29	150	L V	4	2	.65	.47	53	E	4	3
	.85						.70	.38	100	L G	6	4.5
	.90						.75	.31	104	L G	4	4.5
							.80	.24	117	L	2	4
							.85	.22	134	B		
							.90			F		
250	.84	.49	10	T V								
	.90	.53	33	T V								
	.96	.43	87	E V	2	2						
	1.02	.38	130	L	4	2						
	1.08	.25	164	B	2	0						
	1.14			F								
200							.90	.52	33	T		
							.975	.43	47	E K	2	1
							1.05	.36	67	E K V	2	1
							1.125	.26	97	L V	2	1
							1.20	.23	130	L V		
							1.275			B		
							1.35			F		

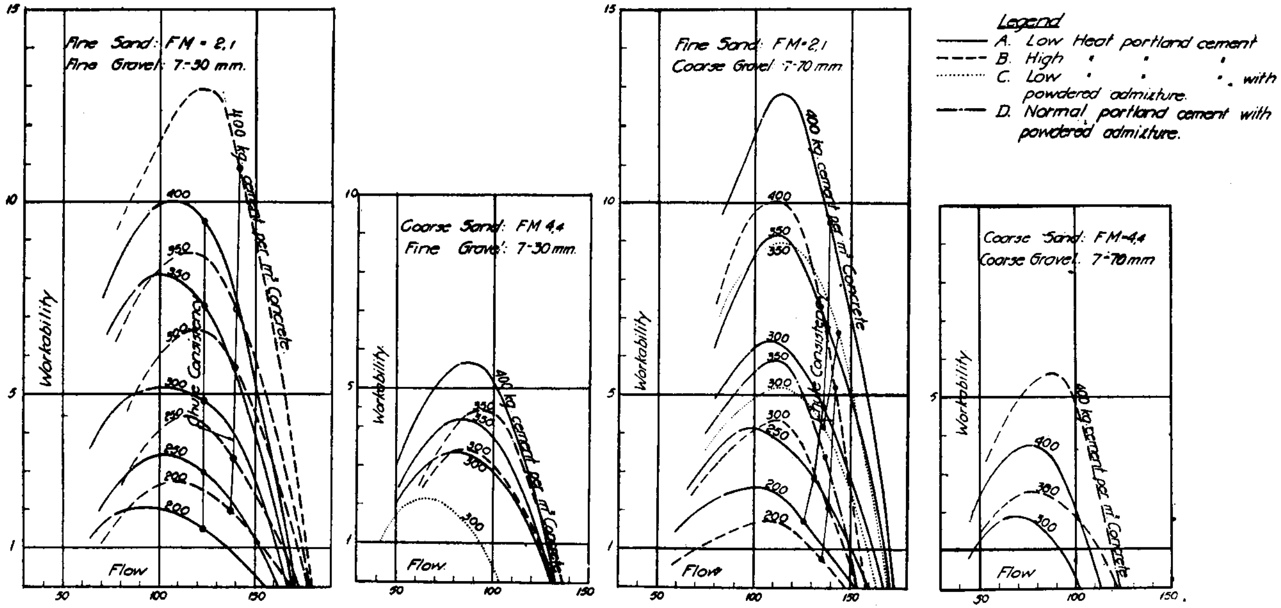

FIGURE 28.—Workability-flow relation. Sand:gravel = 1:1

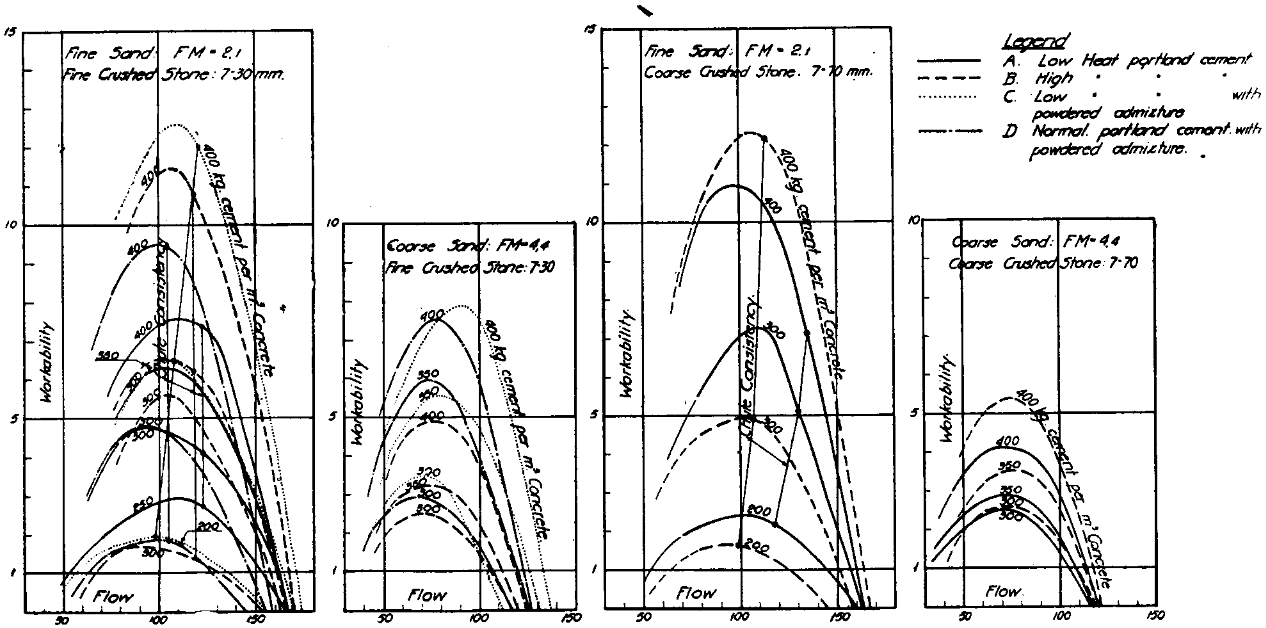

FIGURE 29.—Workability-flow relation. Sand:crushed stone = 1:1

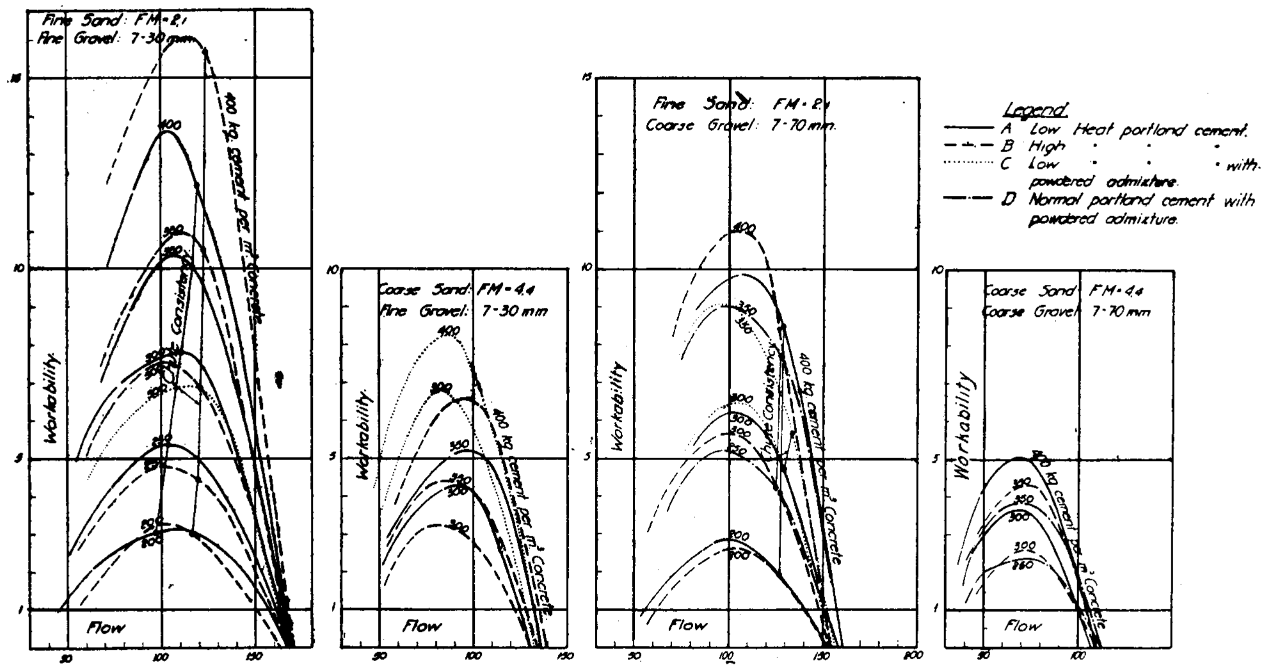

FIGURE 30.—Workability-flow relation. Sand:gravel=1:1.5.

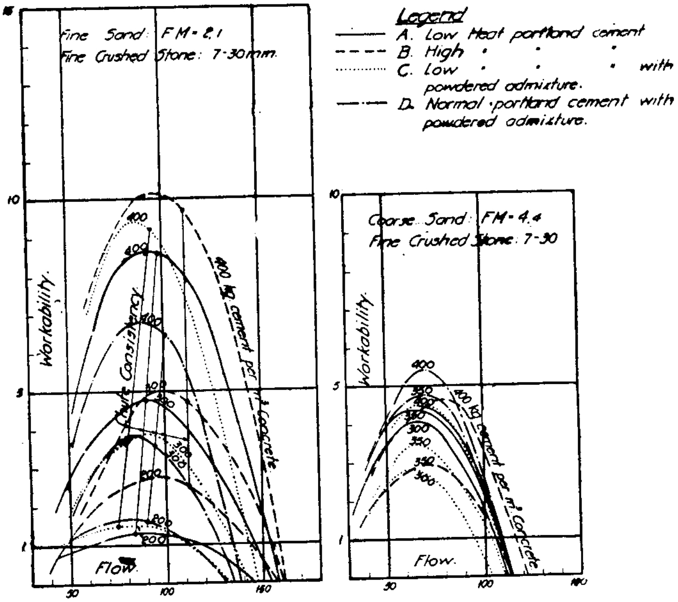

FIGURE 31.—Workability-flow relation. Sand: crushed stone=1:1.5.

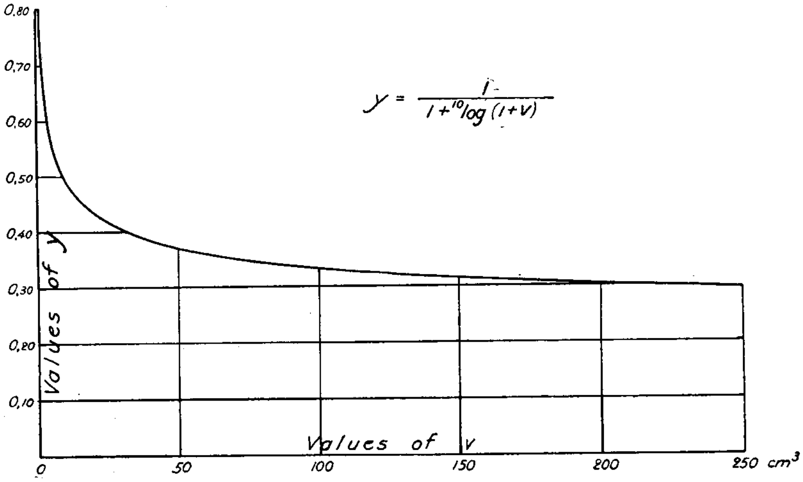

FIGURE 32.—Determination of values of y.

TABLE NO. 11.—*Amount of decanted water v, expressed in cm³*

[Figures in heavy-line frames refer to the two series of experiments given in table 10 and figs. 26 and 27]

Ratio sand: coarse aggregate	Coarse aggregate	Cement content kg/m³	Cement							
			A		B		C		D	
			Fine sand	Coarse sand	Fine sand	Coarse sand	Fine sand	Coarse sand	Fine sand	Coarse sand
1:1	Gravel 7–30	400	120	70	25	----	----	----	----	----
		350	110	50	45	40	65	35	45	----
		300	105	40	60	50	85	10	----	----
		250	100	35	85	90	----	----	----	----
		200	100	35	130	----	----	----	----	----
	Gravel 7–70	400	80	55	25	15	----	----	----	----
		350	75	----	----	----	40	----	25	10
		300	70	35	45	65	60	----	----	----
		250	65	----	----	----	----	----	----	----
		200	65	25	112	150	----	----	----	----
	Crushed stone 7–30	400	255	150	30	55	35	30	30	12
		350	240	----	55	60	----	----	----	15
		300	230	90	70	75	80	30	40	20
		250	220	----	----	----	----	----	----	----
		200	215	75	170	----	120	10	70	----
	Crushed stone 7–70	400	155	120	30	20	----	----	----	----
		350	----	85	----	50	----	----	----	----
		300	150	80	50	70	----	----	----	----
		250	----	----	----	----	----	----	----	----
		200	145	----	160	----	----	----	----	----
1:1.5	Gravel 7–30	400	90	30	30	50	----	30	----	----
		350	85	6	70	35	50	25	----	----
		300	80	5	100	25	60	5	----	----
		250	75	4	105	20	----	----	----	----
		200	75	3	105	----	----	----	----	----
	Gravel 7–70	400	60	40	30	20	----	----	----	----
		350	----	----	----	----	25	----	20	8
		300	55	10	75	50	40	----	----	----
		250	----	----	----	----	----	----	35	8
		200	50	5	80	60	----	----	----	----
	Crushed stone 7–30	400	180	60	35	65	35	25	25	11
		350	----	----	----	40	----	25	----	8
		300	170	5	120	----	55	5	30	----
		250	----	----	----	----	----	----	----	----
		200	165	----	120	----	85	----	50	----

APPENDIX 9

NOTE ON THE WORKABILITY OF CONCRETE

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In reference to concrete, the term "workability" in its literal sense, and as generally understood, may be defined as the facility with which the concrete mixture, by the aid of certain tools, may be worked into certain molds so as to obtain a mass free from cavities. Thus the workability may be considered as a function of two factors, viz. the properties of the concrete mixture and the method of working this mixture into the mold. The workability of a concrete mixture is not the same when it is to be worked into the form by hand labor in the usual way as when it is to be worked by vibrators or by some other mechanical means.

As for the present, the conception of different degrees of workability to a great extent is subject to individual judgment, and as it appears very difficult to find a method by means of which the degree of workability could be determined in an objective way, it seems appropriate, before trying to surmount these difficulties, to consider whether in reality the conception of different degrees of workability serves any useful purpose.

It is generally recognized that, with given materials, the density of the concrete may be taken as a criterion of its quality. As, however, the specific gravity of the different ingredients plays a negligible part in regard to the quality of the concrete, it may be assumed that a more adequate expression for the rule would be obtained by substituting the density by the volume of solid material in percent of the volume of the concrete.

This rule is of little use as applied to hardened concrete, for in this case its quality can be found by other tests. The rule would, however, be of great value if it could be established that the quality of the hardened concrete can be prejudged, at the placing of the concrete, by determining at this moment the volume of solid material in percent of the concrete mixture as placed in the forms.

In an attempt to ascertain whether such a prejudgment is possible along the line indicated, a series of laboratory experiments have been carried out at the Swedish Government Testing Institute. Although these tests, an account of which is given below, so far cover a very limited field, they give certain indications of the direction which may be expected.

To determine the volume of solid material per unit volume of concrete mixture, the freshly mixed concrete was packed into a cast-iron box 20 × 20 × 20 cm, as shown in figure 33. In order to imitate a reinforcement, the box is provided with half-round steel bars fitted to its sides as shown. The sides of the box are detachable so as to facilitate the cleaning out, and steering pins fitted with care and screws are provided to obtain exactness of the volume of the box when erected.

The concrete was placed approximately according to the A. S. T. M. standard method in three layers, each about 7 cm high, and each layer packed by 25 strokes of a round steel rod 20 mm in diameter and 50 cm long, the end of which is shaped to a conical blunt point. At the packing of the first layer, the steel rod did not penetrate practically to the bottom of the box; and at the packing of the subsequent layers, the strokes were just hard enough to make the rod penetrate into the underlying layer. When the box had been filled, the surplus material was scraped off by means of a steel rule, care being taken not to effect any additional packing of the concrete mass. The box with its content was then weighed.

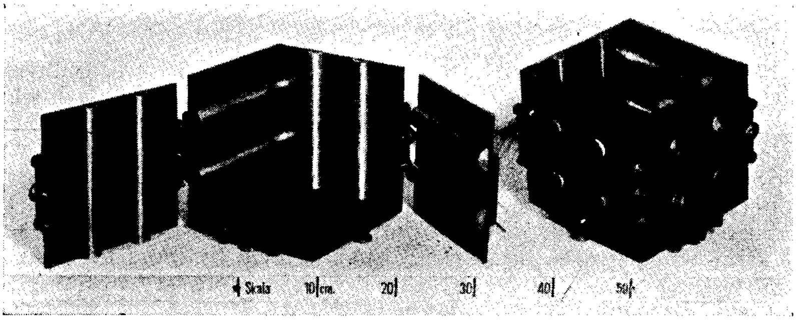


FIGURE 33.—Cast-iron box used in the experiment.

Since the weight of the empty box, its volume, the proportions of the mixture and its water content, as well as the specific gravity of the ingredients, are known, the volume of solid material in percent of the volume of the packed mixture can be computed.

Cement.

Two brands of cement were used, supplied by "Cementa", the largest cement manufacturers in Sweden, viz, Limhamn A cement, in the following called A. C., and Limhamn Pansar cement, in the following called P. C. When tested according to the Swedish Standard Specification for Portland Cement, these brands were found to have the following properties:

Chemical analysis

	Percents	
	A. C.	P. C.
SiO_2	22. 2	23. 0
CaO	65. 1	55. 7
Al_2O_3	5. 0	5. 1
Fe_2O_3	2. 9	2. 8
MgO	1. 5	1. 4
K_2O+Na_2O	1. 6	1. 4
SO_3	1. 3	1. 8
Loss on ignition (el. furnace, 700–800° C.)	0. 7	2. 6
Insoluble	0. 2	7. 1

Fineness

Residue on 900-mesh sieve (0.20 mm openings)	0. 2	0. 2
Residue on 4,900-mesh sieve (0.088 mm openings)	8. 5	5. 6

Fineness according to sedimentation analysis (Andreasen's method)

Percent of material with a calculated cube-edge length of less than—

A. C.		P. C.	
Length (mm)	Percent	Length (mm)	Percent
0. 051	82	0. 047	82
0. 030	62	0. 032	62
0. 017	44	0. 018	49
0. 009	25	0. 011	33
0. 005	10	0. 006	11

Setting time

	A. C.	P. C.
Temperature of the air	18° C.	18° C.
Temperature of the water	18° C.	18° C.
Amount of water needed to obtain normal consistency of cement paste, percent by weight of cement	26	30. 5
Initial setting time	2h 25′	1h 0′

Crushing strength of cement mortar

[Cubes 50 cm^2 side, 1:3 "Normal Sand", Boeme-Marten Hammer apparatus]

	A. C.	P. C.
Water-cement ratio by weight	0. 348	0. 408
Crushing strength in kg/cm^2:		
1 day in moist atmosphere	363	308
6 days in water		
1 day in moist atmosphere	573	545
6 days in water		
21 days in air		
1 day in moist atmosphere	535	553
27 days in water		
1 day in moist atmosphere	535	532
6 days in water		
83 days in air		
1 day in moist atmosphere	632	667
89 days in water		

Specific gravity of cement

	A. C.	P. C.
In g/cm^3	3. 16	2. 88

Sand.

The sand used for the concrete tests was a natural, clean sand with the following grading:

Passing sieve U. S. no.—	Retained on sieve U. S. no.—	Percent
3½ (opening 5.6 mm)	4	4. 4
4 (opening 4.7 mm)	8	19. 2
8 (opening 2.4 mm)	16	28. 4
16 (opening 1.2 mm)	30	23. 5
30 (opening 0.6 mm)	50	16. 7
50 (opening 0.3 mm)	100	5. 4
100 (opening 0.15 mm)	--------	2. 4

The specific gravity of the sand was 2.65 g/cm^3.

Coarse Aggregate.

The coarse aggregate used was a mixture of previously screened shingle and had the following grading:

Passing sieve with free opening (mm)	Retained on sieve with free opening (mm)	Percent
53. 9	45. 3	5
45. 3	38. 1	9
38. 1	32. 0	9
32. 0	22. 6	18
22. 6	16. 0	16
16. 0	11. 3	14
11. 3	8. 0	12
8. 0	5. 6	17
		100

The specific gravity of the coarse aggregate was 2.64 g/cm^3.

Proportions of Ingredients.

The ratio between cement, sand, and coarse aggregate was 1:3.00:3.27 by weight throughout.

The water-cement ratio varied and was given the value 0.49, 0.54, 0.59, 0.64, and 0.69 by weight for different gagings.

Mixing.

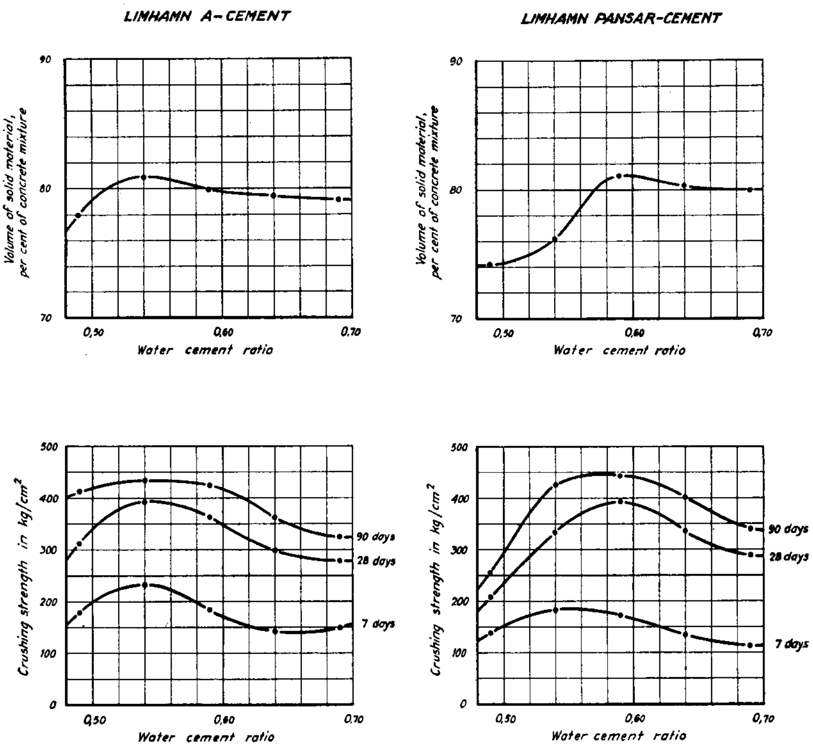
The concrete was hand-mixed.

Determination of Solid Material.

The determination of the volume of solid material in percent of the volume of concrete packed in the special box as described above gave the result shown in table 12.

TABLE NO. 12.—*Solid material in certain concretes*

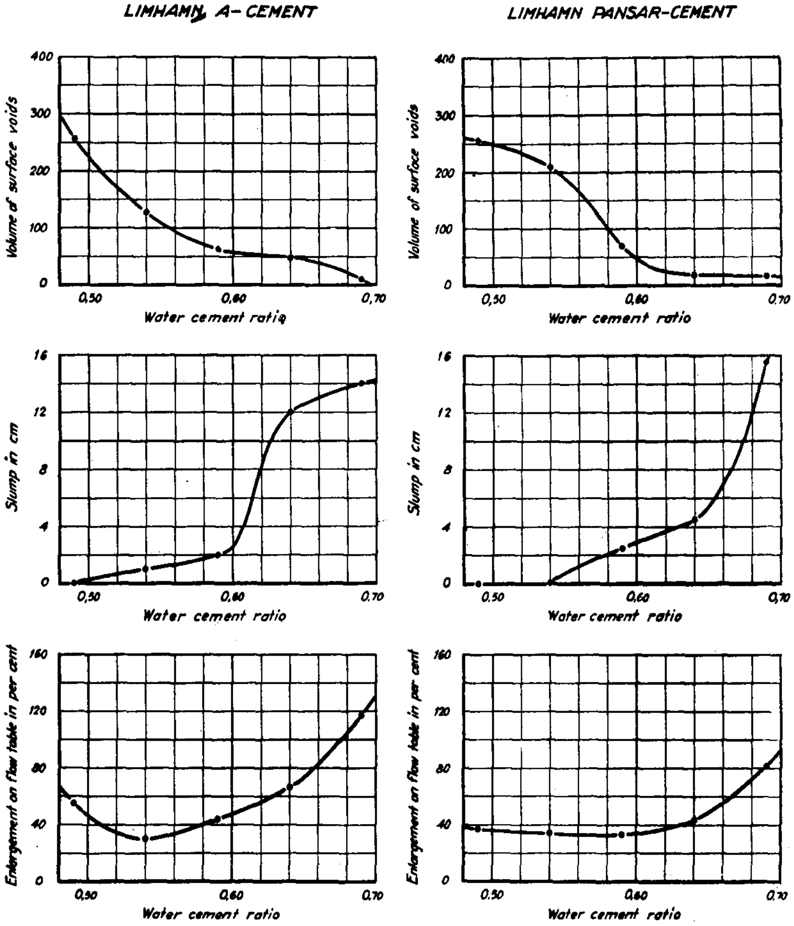
Brand of cement	W/C ratio	Volume of solid material, percent of concrete mixture		
		Box 1	Box 2	Average
A. C	0. 49	77. 99	77. 80	77. 90
A. C	0. 54	80. 82	80. 88	80. 85
A. C	0. 59	80. 11	79. 75	79. 93
A. C	0. 64	79. 36	79. 44	79. 40
A. C	0. 69	78. 49	79. 64	79. 06
P. C	0. 49	73. 92	74. 41	74. 16
P. C	0. 54	76. 05	76. 27	76. 16
P. C	0. 59	81. 06	81. 06	81. 06
P. C	0. 64	80. 19	80. 30	80. 25
P. C	0. 69	79. 54	80. 20	79. 87


LIMHAMN A-CEMENT

LIMHAMN PANSAR-CEMENT

FIGURE 34.—Volume of solid material in certain concretes.

The average values are plotted on figure 34, which shows that the maximum solid material per unit of the mixture is obtained at a water-cement ratio of 0.54 for the A. C. concrete and 0.59 for the P . C. concrete. Both these batches are, however, very stiff and have a very small slump.


LIMHAMN A-CEMENT

LIMHAMN PANSAR-CEMENT

FIGURE 35.—Results of slump and flow-table tests plotted against water-cement ratio.

Slump and flow-table tests.

In fact, slump tests (diameter of cone, bottom 20 cm, top 10 cm, height of cone, 30 cm; concrete packed into cone as for the box described above) and flow-table test (15 strokes; 12.5 mm drop; diameter of cone, bottom 30 cm, top 20 cm; height of cone, 15 cm; concrete packed into cone as for the box described above), performed on the freshly mixed concrete, gave the result shown in table 13.

Table No. 13.—*Results of slump and flow-table tests*

Brand of cement	W/C ratio	Slump in cm	Enlargement on flow table in percent
A. C	0. 49	0	55
A. C	0. 54	1	30
A. C	0. 59	2	44
A. C	0. 64	12	66
A. C	0. 69	14	117
P. C	0. 49	0	37
P. C	0. 54	0	34
P. C	0. 59	2. 5	33
P. C	0. 64	4. 5	43
P. C	0. 69	15. 5	81

These values are plotted against the water-cement ratio on figure 35.

In both cases a water-cement ratio of 0.64 was required to obtain a mixture which could flow, due to its own weight, in a half-circle steel chute, diameter 30 cm and slope 1:2.5.

Segregation.

When packed into the box, water containing cement particles was found to separate from the A. C. concrete at a water-cement ratio of 0.63 or more; for P. C. concrete, such separation occurred at a water-cement ratio at 0.66 or more.

Table No. 14.—*Results of certain tests of crushing strengths*

[In kg/cm²]

Brand of cement	W/C ratio	7 days		28 days		90 days	
		Individual values	Average	Individual values	Average	Individual values	Average
A. C	0. 49	181 175	178	320 302	311	424 401	413
A. C	. 54	220 242	231	395 390	393	445 418	432
A. C	. 59	176 189	183	361 365	363	421 428	425
A. C	. 64	142 141	142	304 294	299	350 373	362
A. C	. 69	148 149	149	277 280	278	318 330	324
P. C	. 49	144 134	139	211 201	206	259 248	254
P. C	. 54	194 172	183	334 332	333	393 459	426
P. C	. 59	176 173	174	391 393	392	451 431	441
P. C	. 64	136 133	134	329 340	335	429 372	401
P. C	. 69	111 115	113	289 286	288	352 335	343

Crushing Strength.

In order to test the crushing strength of the concrete in the different batches, 20-cm cubes were made in wooden molds. The concrete was placed in the mold in the same manner as described above for the box test. These cubes were cured the first 7 days under wet sacks, and later in air. The forms were detached on the fourth day. Of each batch six cubes were made, of which two were crushed after 7 days, two after 28 days, and two after 90 days. The result, expressed in kg/cm^2, is shown in table 14.

Watertightness.

In order to test the watertightness of the concrete, two test pipes were made from each batch in wooden molds as shown in figure 36.

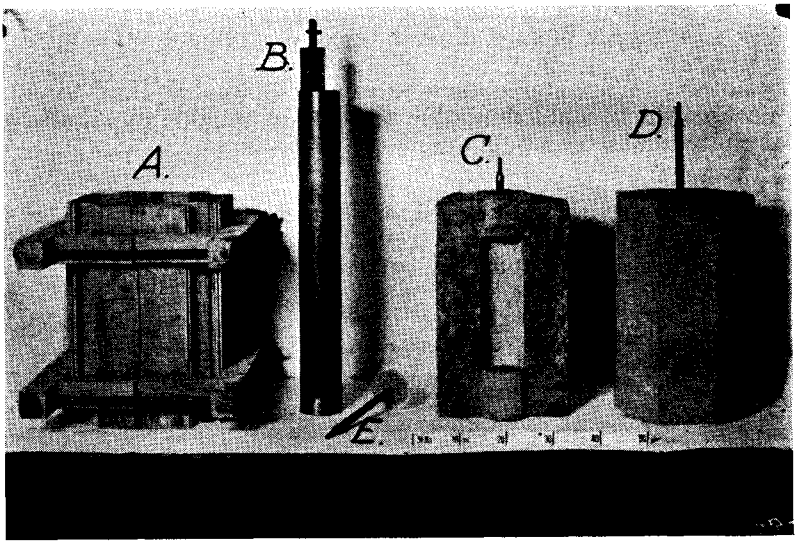


FIGURE 36.—*A* and *B*, wooden mold and steel plate core; *C*, broken test specimen with watertight end plugs; *D*, test specimen ready for testing of permeability; *E*, inlet pipe in one end fitted with rubber hose, and in the other a bottom plate for the upper watertight plug.

The concrete was placed in seven layers, each about 8 cm high, and each layer was packed by 40 strokes of a flat steel bar 13 mm × 26 mm and 1 m long. In the packing, the strokes were just hard enough to make the steel bar penetrate the latest layer only. The test specimens were cured 7 days under wet sacks and the remaining time in air. The forms were detached on the fourth day, and then the specimens were cured in air.

The test pipes were subjected to internal water pressure at an age of 7–11, 28–32, and 90–94 days. During the first 2 days of each period of testing, the water pressure was 1.5 atm, and during the last two days of each period, 4 atm.

The results of the tests are shown in table 15.

TABLE No. 15.—*Results of certain tests for watertightness*

Brand of cement	W/C ratio	Age in days	Specimen	1.5 atm water pressure		4 atm water pressure	
				Appearance of outside surface	Leakage	Appearance of outside surface	Leakage
A. C.	0.49	7-11	I-II	Whole surface wet.	Very great		
		28-32	I-II	do	do		
		90-94	I-II	do	do		
A. C.	0.54	7-11	I-II	Dry	None	Dry	None.
		28-32	I-II	do	do	do	Do.
		90-94	I-II	do	do	do	Do.
A. C.	0.59	7-11	I-II	do	do	do	Do.
		28-32	I-II	do	do	do	Do.
		90-94	I-II	do	do	do	Do.
A. C.	0.64	7-11	I-II	Major part of surface wet.	Inconsiderable.	Major part of surface wet.	Inconsiderable.
		28-32	I-II	Dry	None	A 5-cm^2 moist spot on each specimen, the remaining part dry.	None.
		90-94	I	do	do	A 80-cm^3 moist spot, remaining part dry.	Do.
			II	do	do	A 130-cm^2 moist spot, remaining part dry.	Do.
A. C.	0.69	7-11	I	Whole surface wet.	4 g/h	Whole surface wet	28 g/h.
			II	do	3 g/h	do	9 g/h.
		28-32	I	Dry	None	A 10-cm^2 moist spot, remaining part dry.	None.
			II	do	do	Dry	Do.
		90-94	I	do	do	A small moist spot, remaining part dry.	Do.
			II	do	do	Dry	Do.
P. C.	0.49	7-11	I-II	Whole surface wet.	Very great		
		28-32	I-II	do	do		
		90-94	I-II	do	do		
P. C.	0.54	7-11	I	do	do		
			II	Detached wet spots on whole surface.	50 g/h	Detached wet spots on whole surface.	50 g/h.
		28-32	I	Whole surface wet.	6,000 g/h		
			II	Dry	None	A small wet spot	None.
		90-94	I	Whole surface wet.	Very great		
			II	Dry	None	Dry	Do.
P. C.	0.59	7-11	I-II	do	do	"Sweating" on half of the surface.	Do.
		28-32	I-II	do	do	Dry	Do.
		90-94	I-II	do	do	do	Do.
P. C.	0.64	7-11	I-II	Whole surface wet.	4 g/h	Whole surface wet	3 g/h.
		28-32	I-II	Dry	None	Dry	None.
		90-94	I-II	do	do	do	Do.
P. C.	0.69	7-11	I	Whole surface wet.	12 g/h	"Sweating" on whole surface.	3 g/h.
			II	do	do	Minor part of surface "sweating", the remaining part damp.	Do.
		28-32	I-II	Dry	None	Dry	None.
		90-94	I-II	do	do	do	Do.

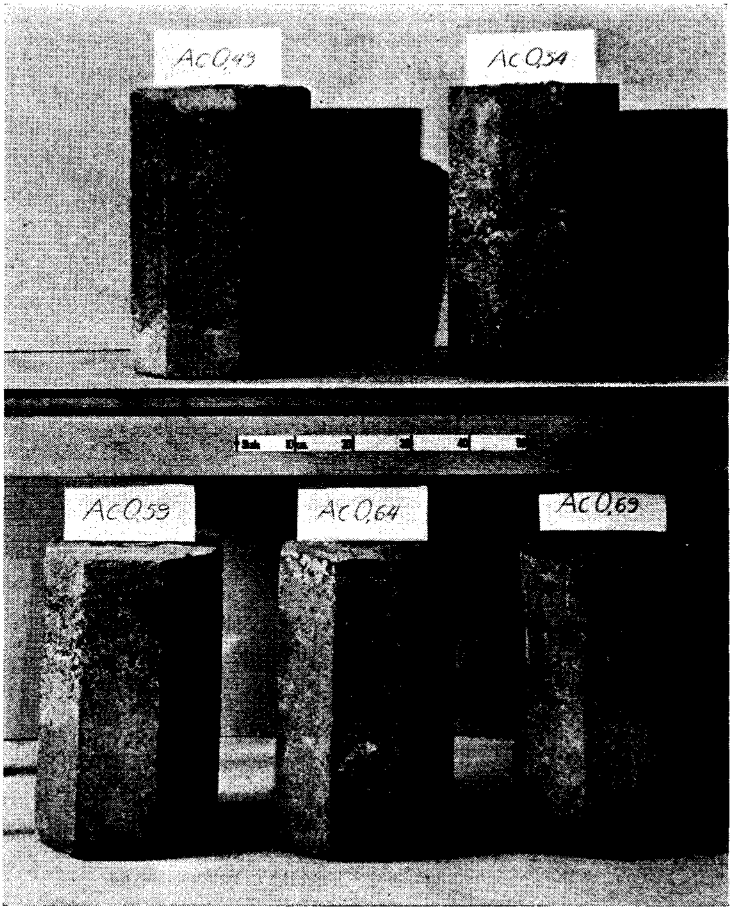


FIGURE 37a.—Specimens for the watertightness test.

Surface.

In order to be able to compare the aptitude of the different batches of concrete to fill out against the mold so as to obtain a surface free from voids and agglomerations of coarse aggregate, the different test specimens were inspected when taken out of the molds. As can be seen in the photographs of figure 37, the specimens for the watertightness tests show a surface improving with increasing water-cement ratio, although when surpassing the water-cement ratio 0.59 this improvement is very slight.

In order to obtain, in figures, an expression for the roughness of the surface, the concrete of the different batches was allowed to set in the cast-iron box molds described above, and the volume of the surface voids was later on measured by the amount of grease necessary to fill all the surface voids of these specimens. The volume of the surface voids is shown in table 16.

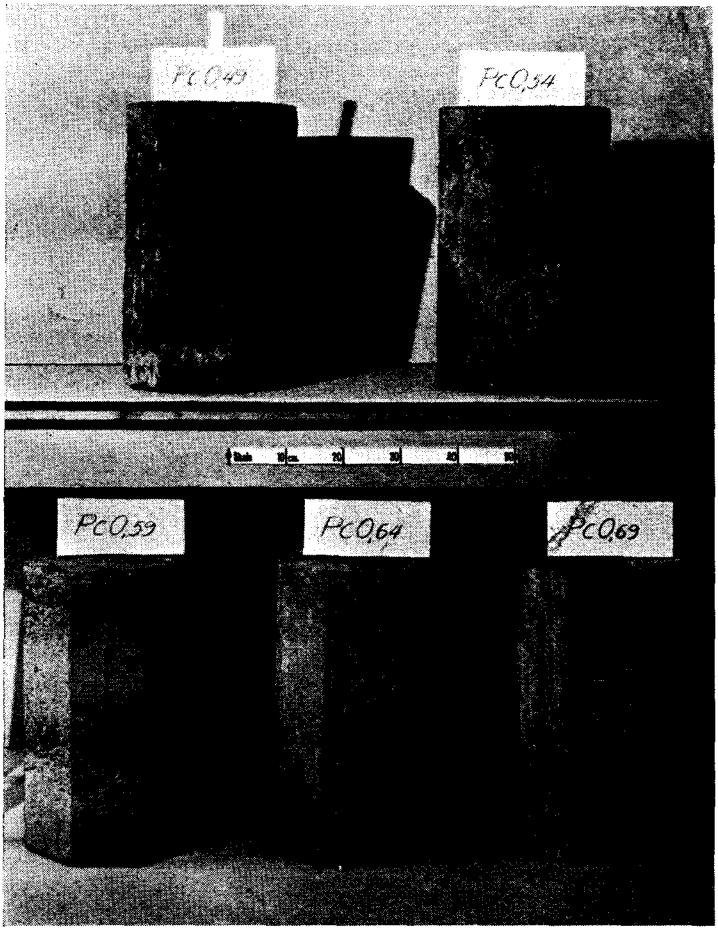
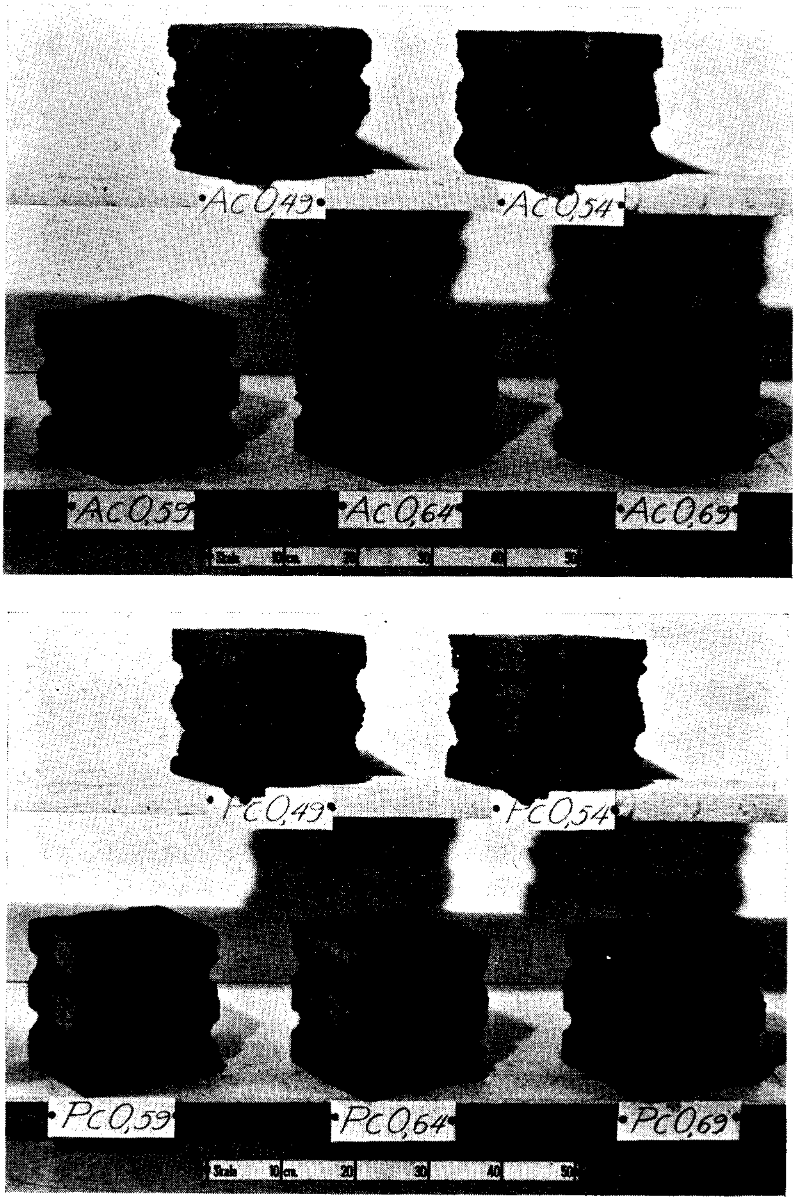


FIGURE 37b.—Specimens for the watertightness test.

TABLE No. 16.—*Volume of surface voids on certain concrete specimens.*

Brand of cement	W/C ratio	Surface voids in cm³		
		Specimen I	Specimen II	Average
A. C	0. 49	266	251	259
A. C	. 54	139	114	127
A. C	. 59	77	48	63
A. C	. 64	59	32	46
A. C	. 69	12	9	10
P. C	. 49	260	249	255
P. C	. 54	210	209	210
P. C	. 59	82	56	69
P. C	. 64	18	15	17
P. C	. 69	23	6	15



FIGURES 38a and 38b.—Specimens after a test for watertightness.

On figure 35 the volume of the surface voids is plotted against the water-cement ratio. By a comparison of the figures given above with the actual appearance of the specimens shown on figure 38, it seems that a volume of surface voids of about 50 cm^3 for the size of specimen used may be considered as satisfactory. This result is obtained at a water-cement ratio of about 0.60 or more.

Considering the crushing strength, the watertightness, and the appearance of the surface of the different batches of concrete, it appears that the quality of the hardened concrete is closely related to the volume of solid material per unit volume of concrete mixture. In fact, the best quality of the hardened concrete was obtained at a water-cement ratio between 0.54 and 0.59 for A. C. concrete and between 0.59 and 0.64 for P. C. concrete. At these water-cement ratios the volume of solid material per unit is also the biggest.

For ordinary concrete mixtures the figure for the volume of solid material in percent of the concrete mixture varies within a very small range and, therefore, the quality of the concrete does not vary in direct proportion to this figure. As a criterion of the quality, it seems more advantageous to use this percentage *less a constant*. The difference thus obtained varies practically in direct proportion to the quality for the mixtures tested if the constant is taken at about 75.

It seems appropriate to introduce a certain name for this criterion. It may suitably be called the compactness, and may be expressed by the figure for the solid material in percent of the concrete mixture, when placed, *less* 75. The property of the concrete mixture that represents its aptitude of being worked to a compactness by a given method of placing may suitably be termed its compactibility at this method of placing and may be expressed by the figure for compactness (as defined above) of the concrete mass obtained when placed according to the method considered.

In the tests described, the best quality and compactness were obtained for relatively dry mixtures. This result is in conformity with the usual experience that the best results in the laboratory are obtained for much drier mixtures than those which can be handled and used in the field. The explanation can be but one. The careful laboratory method used for placing (the A. S. T. M. standard method), does not correspond to the usual hand-labor method of placing in the field. It could be said in conformity with the usual conception of the term workability that certain concrete mixtures which are workable by the laboratory method of placing are not workable by the usual hand-placing method in the field.

At a given method of placing, we may thus distinguish between a concrete mixture that is workable and one that is not workable. In conformity with the definition given in the beginning of these notes, a workable mixture would be such as can be worked into the mold, by the method of placing (and amount of labor) considered, so as to obtain a mass free from cavities; and a nonworkable mixture would be such as does not fulfill these requirements.

Whether a concrete is workable or not in the field may also depend on the training of the men who work it. A gang of well-trained workmen will work satisfactorily into the forms a stiff concrete mixture which a gang of men not so well trained could not handle in a satisfactory manner.

Now the laboratory tests indicate that, all other things being equal, the driest mixture is the best, provided that it is workable. The experience from the field underlines these last five words but gives the word "workable" a slightly different meaning, viz, workable by the field method. The aim of the engineer must, therefore, be to supply to the forms the driest possible mixture which, under the given conditions, is still workable.

What we aim at is, therefore, not a high degree of workability but a low one, not a mixture which can be worked into the mold with great facility so as to obtain a mass free from macroscopic voids, but one which only with certain difficulty and care can be worked thus into the mold.

It serves, therefore, no practical purpose to distinguish between different degrees of workability. It is sufficient to distinguish only between mixtures which are workable and such as are not workable under the given conditions.

The state at which the concrete mixture under the given conditions becomes barely workable is of practical interest. This state may be termed "the point of workability." Thus the aim of the engineer should be to supply a concrete mixture which is as close as possible, on the wet side, to the point of workability.

There is another interesting state of a concrete mixture, and that is the state when the concrete segregates. By segregation is generally understood the separation of the ingredients of the concrete mixture. The first sign of segregation is that water which contains a great amount of suspended particles of the finest fractions of the cement and very small air bubbles separates from the mixture. If this suspended matter is allowed to settle, it forms the well-known skin of laitance on the surface of the placed concrete. All other things being equal, segregation may be attributed to too great a wetness of the mixture.

Segregation may occur either during transport or during the process of working the concrete into the forms, and whether segregation will occur or not is dependent on the methods used for transportation and placing. A wet concrete which does not segregate when worked by the usual hand-labor method may segregate if worked by vibrators or other mechanical means. Thus the segregation may be considered as due to two factors, viz the properties of the concrete mixture and the method of transportation and of handling and working this mixture into the mold.

As in the case of workability, it serves no practical purpose to distinguish between *different degrees* of segregation; it is sufficient to distinguish between concrete mixtures which do not segregate to a perceptible degree and those which segregate when handled and placed by the methods considered. The state of wetness in which segregation just starts to be perceptible will be denominated as the "point of segregation."

Usually there is a fair interval of wetness between the point of workability and the point of segregation; this interval may be called the "interval of workability." It may, however, occur that no such interval exists; the concrete mixture segregates before it becomes sufficiently wet to be workable. This defect is usually due to an unsuitable (too coarse) grading of the sand, but may also be due to the brand of cement used. The defect can usually be remedied by adding fine inert material (fine sand or "filler") to the mixture.

It would involve no great difficulties to determine these two interesting points in the laboratory by the laboratory method (the A. S. T. M. standard method) of placing. The point of workability can be considered to coincide with the wetness for maximum compactability, and the point of segregation is the wetness at which water starts to separate from the mixture when rodded in the prescribed manner.

The question now arises: Is there a relation between the results obtained in this way in the laboratory and those which will be obtained with the same concrete mixture in the field? At present there are no data available to determine such a relation. One knows that the point of workability in the field corresponds to a greater wetness than in the laboratory, but whether this difference in water-cement ratio is a constant, or a constant fraction of the water-cement ratio, or depends on other things, we do not know. The case is much the same with the point of segregation. It appers necessary to find out this relation before the questions related to workability can be analyzed in a scientific way.

One of the aims of the International Cement Commission is to recommend methods for determining the influence of different brands of cement on the workability of the concrete mixture. We will try to elucidate in what way such an influence may have a practical importance.

First of all, the different brands of cement may influence the wetness i. e., the water-cement ratio, at the point of workability. Such was the case with the two brands of cement tested, when worked into the mold by the laboratory method (for A. C. concrete, w/c was 0.54, and for P. C. concrete, w/c was 0.59 at the point of workability). This effect on the water-cement ratio was, however, of no importance as the compactibility of both mixtures at the point of workability was the same. We conclude that an influence of the brand of cement on the water-cement ratio at the point of workability is of importance only if it influences the compactibility at this point.

Further, the different brands of cement may influence the water-cement ratio at the point of segregation. Such was the case with the two brands of cement tested (for A. C. concrete, w/c was 0.63, and for P. C. concrete, w/c was 0.66 at the point of segregation). This is, however, of no importance in itself but becomes important only insofar as it influences the interval of workability.

In the field it is not possible to have the concrete at the very point of workability. It is necessary to be somewhat on the wet side, i. e., to have a certain margin in order to be sure that no batch, due to involuntary variations, comes on the dry side of this point—in other words, becomes not workable. For given arrangements for measuring the ingredients on the site, this margin can be considered to be a fixed quantity of water per batch or per unit volume of concrete mixture. This means that the water-cement ratio has to be increased by a fixed amount for a given ratio between cement and aggregate.

Just as involuntary variations from the water-cement ratio specified can be foreseen to occur towards the dry side, such variations may occur also towards the wet side, and these variations may be of the same magnitude as the former. In this latter case the mixture may pass the point of segregation and thus pass out of the interval of workability. It is, therefore, necessary that there should be a fair interval of workability, and if a brand of cement decreases this interval as compared with another brand, it must be considered to be to the disadvantage of the former.

The margin between the decided wetness and the point of workability entails a decrease of compactness of the concrete actually placed as compared with concrete placed at its point of workability. The magnitude of this decrease depends not only on the magnitude of the margin but also on the rate of decrease in compactibility due to an increase of the water-cement ratio; therefore, this rate is of importance.

Another thing which is of practical importance is the adherence of the mixture to the machinery and tools by which it is to be mixed and handled. Such an adherence has, in actual practice, been found a drawback in respect to the mixers, which have to be cleaned out more often when using certain brands of cement than when using other brands.

In view of the above, the author would recommend that a comparison between different brands of cement as to workability include the following points:

(1) The determination of the difference of the water content between (*a*) mixtures at the point of workability and the point of segregation, respectively, by different methods of placing in the field, and (*b*) a mixture of the same ingredients at maximum compactibility and the point of segregation, by a definite laboratory method of placing (for instance the A. S. T. M. standard method).

(2) Determination of the compactibility of concrete mixtures at the point of workability and at the point of segregation, as well as within the interval of workability, when the concrete is placed by the laboratory method.

(3) Observations regarding adherence to the tools and the mixers.

Lacking the determinations mentioned under point 1 above, no true comparison can be made between the two brands of cement tested. Judging from the laboratory tests carried out and referred to under point 2, the following preliminary statement could be made as regards workability.

(1) The compactibility at the point of workability is practically the same. In this respect the two brands are equal.

(2) The compactibility at the point of segregation is slightly higher for P. C. than for A. C. This is to the advantage of P. C.

(3) The interval of workability is practically the same. In this respect they are equal.

(4) The rate of decrease of the compactibility due to increasing water-cement ratio is practically the same. In this respect they are equal.

(5) According to actual experience from the field P. C. sticks more to the mixers than A. C. This is to the disadvantage of P. C.

APPENDIX 10

List of Unpublished Reports Submitted to International Subcommittee on Special Cements for Large Dams up to March 30, 1936

Copies of the following reports are deposited in the library of the central office of the International Commission on Large Dams, at Paris, and have also been submitted to the members of the subcommittee.

No.	Author	Title	Date	Number of pages
1	R. Feret (France)	Contribution à la documentation française sur les ciments speciaux pour grands barrages.	Aug. 6, 1934	5
2	E. Rengade (France)	Recherches ou travaux personelles de la société des Chaux et Ciments de Lafarage du Teil concernant les questions mises à l'ordre du jour par la sous-commission du ciment spécial.	October 1934	4
3	do	Note sur l'attaque des mortiers par les eaux pures.	do	7
4	W. Eitel (Germany)	Bericht über Forschungsarbeiten auf dem Gebiet der Spezial-Zemente für Talsperren und Wasserbauten.	do	12
5	British subcommittee on special cements.	Methods employed in Great Britain for testing special properties of cements of importance for large dams.	do	5
6	F. Vogt (Norway)	Report on calorimeter for routine tests on the heat evolution of cement.	Oct. 5, 1934	5
7	A. Frey Samsioe (Sweden)	Heat of hydration of cement	September 1934	4
8	D. Werner and S. Giertz-Hedström (Sweden).	Method for the determination of heat development according to the heat-of-solution method.	do	2
9	do	Method for the determination of heat development according to the method given in the Swiss standard specification of 1932.	do	1
10	do	Method for the determination of solubility—shaking of crushed specimens.	do	5
11	P. S. Håkansson (Sweden)	Method for the determination of solubility—a method for the determination of lime that can be extracted from cement.	do	3
12	D. Werner and S. Giertz-Hedström (Sweden).	Method for the determination of shrinkage—measurement of the longitudinal contraction of L-shaped rods of hardened cement.	do	3
13	do	Method for the determination of shrinkage—measurements according to the Swiss standard specification of 1932.	do	1

No.	Author	Title	Date	Number of pages
14	D. Werner and S. Giertz. Hedström (Sweden)	Method for the determination of shrinkage—measurement of the number of cracks due to drying out of reinforced test rods of hardened cement.	September 1934	3
15	do	Method for the determination of watertightness—tests on concrete cylinders with a core of porous brick.	do	5
16	G. S. Lalin (Sweden)	Method for the determination of watertightness.	do	3
17	do	Method for the determination of workability.	do	2
18	The cement laboratory of the Royal Swedish Institute for Engineering Research.	Preliminary survey based on the reports of the national committees of methods for measuring certain properties of cement.	Sept. 26, 1934	18
19	J. L. Savage (U. S. A.)	Compilation of data on special cements for dams, and apparatus for evolution of heat, solubility, shrinkage, watertightness, and workability.	Aug. 31, 1934	330
20	Raymond E. Davis (U. S. A.)	Cement investigations for Boulder Dam (in 2 parts).	June 21, 1934	385
21	R. F. Blanks, E. N. Vidal, and H. S. Meissner (U. S. A.).	Progress report of Boulder Dam concrete research.	Apr. 5, 1934	157
22	J. L. Savage (U. S. A.)	Compilation of miscellaneous supplementary data.	Sept. 22, 1934	337
23	R. Schlyter (Sweden)	Report on various properties of cement.	Oct. 5, 1934	3
24	A. F. Roscher-Lund (Norway)	Bautechnische Bedürfnisse für Schwindquellenversuche. Die Grundzüge eines Verfahrens für externe Änderungen der Zementmörtel.	Oct. 6, 1934	41
25	British subcommittee on special cements.	Interim report on a simplified adiabatic calorimeter and solubility of cements.	May 1935	19
26	F. Vogt (Norway)	Report on investigation of calorimeters.	June 6, 1935	6
27	D. Werner and S. Giertz-Hedström (Sweden).	Communication on the work on heat evolution by means of thermos flasks carried out for the Swedish National Committee for Large Dams.	May 29, 1935	3
28	do	Comparison of the results of the Swedish dissolution tests of cement.	Mar. 27, 1935	11
29	A. Ekwall (Sweden)	Interim report on workability	June 15, 1935	4
30	M. Mary (France)	Rapport sur la perméabilité	June 1935	8
31	D. de Langavant (France)	Mesure de la chaleur d'hydration	do	8
32	C. de Langavant (France)	Mesure du retrait des ciments	do	7
33	do	Mesure de la solubilité des ciments	do	6
34	do	Mesure de la perméabilité des ciments.	do	2
35	do	Mesure des chaleurs d'hydration du ciment par la méthode de la bouteille thermos.	do	11
36	do	Discussion de la valeur de l'essai par bouteille thermos. Évaluation de l'erreur commise.	do	4
37	do	Discussion de la formule de correction de M. Marcotte.	do	7
38	do	Mesure de la chaleur d'hydration par la méthode de la bouteille thermos. Exposé détaillé de la méthode d'essai.	do	8
39	do	Fabrication en France du ciment spécial pour grands barrages.	do	4

No.	Author	Title	Date	Number of pages
[1] 40	British subcommittee on special cements.	The measurement of heat of evolution of cements including a draft specification for an adiabatic calorimeter method.	September 1935	15
41	M. Mary (France)	Note relative aux expériences de perméability de béton.	do	5
42	Bureau of Reclamation (U. S. A.).	Suggested method for computing heat of hydration from the compound composition of portland cement.	Aug. 30, 1935	13
43	S. Giertz-Hedström (Sweden)	Measuring heat evolution of cement by means of thermos flasks.	Oct. 9, 1935	20
44	E. Rengade (France)	Nouveaux essais sur l'attaque des mortiers par les eaux pures.	October 1935	18
45	R. Schlyter (Sweden)	Methods of testing the permeability of concrete and mortar.	Oct. 11, 1935	9
46	Deutsche Unterkommission für Spezialzemente.	Entwurf einer Arbeitsvorschrift für die Bestimmung des Schwindvermögens der Zemente.	October 1935	7
47	M. Mary (France)	Rapport sur la perméabilité	September 1935	12
[2] 48	G. S. Lalin (Sweden)	The workability of concrete	Oct. 1, 1935	11
[2] 49	A. Frey Samsioe (Sweden)	Notes regarding workability	do	21
[3] 50	British subcommittee on special cements.	Report on solubility of cements	February 1936	11
51	German author	Bericht über den Schwindung von Talsperren-Zementen.	do	12
[2] 52	Deutsche Unterkommission für Special-Zemente.	Arbeitsvorschrift für die Bestimmung des Schwindvermögens der Zemente.	do	7
[2] 53	M. Mary (France)	Projet de standardisation des méthodes d'essais pour la comparaison des ciments: perméabilité.	December 1935	6
54	do	Projet de standardisation des méthodes d'essais pour la comparaison des ciments: perméabilité et action sur le ciment de l'eau de filtration.	do	3
[2] 55	S. Giertz-Hedström (Sweden)	Experiences with the simplified adiabatic calorimeter developed by the Building Research Station.	Mar. 11, 1936	4
56	do	Separation of water from a cement paste.	March 1936	3
[2] 57	Swedish Committee on Large Dams.	Tentative standard specification for the determination of action on cement of water percolating through concrete.	Mar. 21, 1936	4
58	H. E. Schwiete (Germany)	Schwindung nach Messungen im Kaiser Wilhelm-Institut für Silikatforschung 1935–36.	Mar. 27 ,1936	3

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[1] Published partly in a report on special cement by W. T. Halcrow and F. M. Lea submitted by the British Committee on Special Cements to the Congress in the United States, 1936, partly in the interim report attached.

[2] Published in the interim report attached.

[3] Published in a report on special cements by W. T. Halcrow and F. M. Lea submitted by the British Committee on Special Cements to the Congress in the United States, 1936.

LETTER OF TRANSMITTAL

The PRESIDENT,
The International Commission on Large Dams of the World Power Conference,
5, Avenue de Friedland, Paris.

SIR: At the first Congress of the International Commission on Large Dams held in Sweden 1933, one of the main subjects referred to in the papers and discussions was the suitability of obtaining and using for large dams and other structures subject to unilateral water pressure a cement specially suitable for such works. After the Congress, a proposal was made that an international committee be formed to study this subject. Subsequently you appointed a provisional international subcommittee to prepare for the work of the definite subcommittee to be nominated later on. This provisional subcommittee met in Paris on the 26th June 1934, and in London on the 16th October 1934, at which meetings representatives of Belgium, France, Germany, Great Britain, India, Norway, and Sweden were present.

At the executive meeting of the International Commission on Large Dams held in London on the 17th October 1934, the definite International Subcommittee on Special Cements was formed and the following members appointed:

Belgium.—F. A. A. Campus, professor, and L. Van Wetter, chief engineer.

France.—A. Coyne, chief engineer, and E. Rengade, chemist.

Germany.—W. Eitel, professor and doctor, and E. Link, doctor of engineering.

Great Britain.—W. T. Halcrow, consulting engineer, and B. Hellström, consulting engineer.

India.—C. B. Pooley, civil engineer.

Norway.—K. Baalsrud, chief engineer, and F. Vogt, professor.

Sweden.—A. Ekwall, chief engineer, and L. Forsen, doctor of engineering.

U. S. A.—J. L. Savage, chief engineer.

The International Subcommittee on Special Cements having been authorized to co-opt further members, the following gentlemen were elected by the subcommittee at the meeting at The Hague on June 17, 1935:

Czechoslovakia.—O. Kallauner, professor, doctor of engineering, and J. Kobza, chief engineer.

Japan.—M. Fujii, chemist, and E. Ishii, civil engineer.

Switzerland.—A. Kaech, doctor of civil engineering, and E. Martz, doctor of chemistry.

The chairman of the subcommittee has been Mr. B. Hellström, and the secretarial work has been carried out by the central office of the International Commission on Large Dams, in Paris.

Great interest has been taken by nonmembers in the proceedings of the subcommittee, and the following gentlemen have assisted at some or all of the meetings:

Belgium.—P. De Rudder, and F. Van Ortroy.

France.—R. Feret, R. Lahaye, W. Duffaut, C. De Langavant, and M. Mary.

Germany.—G. De Thierry, O. Graf, G. Haegerman, R. Kneisel, A. Müller, and H. E. Schwiete.

Great Britain.—F. M. Lea, S. G. S. Panisset, H. Stanger, and H. Woodcock.

Norway.—B. A. Loe, and K. Friis.

Sweden.—S. Giertz-Hedström, P. S. Håkanson, and D. Werner.

Switzerland.—H. E. Gruner, W. Humm, W. Jeannim, and P. Schläpfer.

The subcommittee desires to place on record the valuable assistance rendered by these nonmembers of the subcommittee.

At present the subcommittee consists of 20 members representing 11 countries, 12 members being civil engineers and 8 members chemists.

The subcommittee has held the following meetings: In London October 18, 1934; in The Hague June 17, 1935; in Berlin October 29 and 30, 1935; and in Brussels March 30, 1936.

At the first meeting of the subcommittee the following working program was unanimously adopted:

I. To explore the possibility of obtaining a cement or cements suitable for use in large dams, and, if possible, to make recommendations thereon; also to take steps to increase the interest in obtaining and using special cement for dams and mass concrete works.

II. To make suggestions as to routine methods to be used for the testing of special cements, and to arrange with the national committees on large dams (or national subcommittees on special cements) to carry out experiments necessary for this purpose.

III. To make suggestions in regard to the reports on special cements to be submitted by the National Committees on Large Dams to the next Congress of the International Commission on Large Dams as to the lines on which the reports should be drawn up and the most important points they should cover, in order to facilitate comparison.

IV. To issue at intervals (through the permanent bureau) lists of literature on special cements which have come to the notice of the subcommittee.

With reference to the first point, it is not proposed that the subcommittee should evolve a special cement with low heat of hydration and high resistance to attack, but rather that it should enunciate and specify the special properties desired in cements for large dams which are not covered by the usual cement specifications.

Steps to increase interest in obtaining and using special cements for dams and mass concrete works have been taken by members of the subcommittee, and several national subcommittees on special cements have been formed. A number of articles in technical journals in different countries have also appeared which have stressed the importance of using special cements for large dams.

Contact has been established with the cement industries in various countries, partly through members of the subcommittee belonging to these industries, and members of the subcommittee have followed the use of special cements in actual practice.

The subcommittee has also made suggestions in regard to the content of the reports on special cements to be submitted by national committees on large dams to the next Congress of the International Commission, which is to be held in the United States in 1936.

On behalf of the subcommittee, the Permanent Bureau of the Commission has issued at intervals lists of literature on special cements.

Up to the present time, the main deliberations of the subcommittee have been concerned with investigations of routine methods to be used for testing cements for large dams with reference to heat of hydration, action on cement of water percolating through concrete, shrinkage, permeability, and workability, and the subcommittee has now prepared its first report, dealing with this question. The preparatory work within the subcommittee has consisted in considering—

(*a*) Reports describing methods of testing used for the present in different countries;

(*b*) Reports on various questions in connection with the problems discussed; and

(*c*) Reports on experimental work carried out on the initiative of the subcommittee in certain countries. Particularly in Great Britain, Norway, and Sweden, funds were raised within the countries to cover the cost of extensive laboratory tests.

Copies of the reports, which have not been published, are deposited at the central office at Paris and have been distributed among the members. A list of the reports is appended.

At all meetings detailed minutes of the discussions were prepared.

During recent years considerable experience has been gained in the United States with reference to the use of low-heat cements. Although the American delegate of the subcommittee has submitted extensive and valuable reports on questions under discussion, it is felt that the subcommittee has not been able to take full advantage of American experience, and the subcommittee has, for obvious reasons, dealt mainly with European practice. It will, therefore, be of great advantage to study special cements and methods of testing at the forthcoming Congress in the United States.

The subcommittee regrets that, in the short time available, it has been impossible to reach definite conclusions on the questions dealt with; but it is felt that it might be of greater advantage to report before the Congress is held in the United States on the work carried out so far, rather than to postpone the issue of a report until the work is concluded, which by necessity will be after the Congress.

The subcommittee begs to submit an account of the work carried out, as follows:

(1) A report entitled "Interim report on methods of testing cement in regard to heat of hydration, action on cement by water percolating through concrete, shrinkage, permeability, and workability."

(2) Copies of reports submitted to the subcommittee from various countries on questions under consideration.[1]

(3) Minutes from the meetings.[1]

The content of the interim report mentioned under (1) may be summarised as follows:

Heat of hydration.—A tentative standard specification for testing the heat of hydration of cement based on the adiabatic principle is suggested, the details, however, being subject to further investigations now in progress.

An investigation of testing the heat of hydration by observing the temperature rise of cement mortar in thermos flasks has been carried out, and a description of these experiments is given.

Action on cement of water percolating through concrete.—Experiments of testing the action on cement of water percolating through cement-mortar plaques have been made and compared with an extraction method of determining the solubility of hydrated, pulverised cement shaken with water, and also with a method of determining the action on cement-mortar plaques of a jet of water. An account of this investigation is given and a tentative standard specification submitted.

Shrinkage.—Details are given of a German standard specification for testing shrinkage of cement mortar.

Permeability.—Certain recommendations for testing permeability are submitted.

Workability.—Investigations of testing according to two different new methods have been carried out, and, on account of these experiments, is given.

RECOMMENDATIONS

The subcommittee wishes to make the following recommendations:

1. That the subcommittee's interim report, including this letter of transmission, be submitted to, and discussed at, the next Congress of the International Commission on Large Dams, printed in the transactions, and reprints made available to the public.
2. That the subcommittee be instructed to proceed with the work as outlined in the working program.

Brussels, March 30, 1936.

For and on behalf of the International Subcommittee on Special Cements for Large Dams.

Bo Hellström,
Chairman.
A. Genthial,
Secretary General of the International Commission on Large Dams.

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[1] *Not published.*

CONTENTS

APPENDICES

QUESTION III

SWEDISH and NORWEGIAN SUBCOMMITTEES

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

A SURVEY OF RECENT SCANDINAVIAN LITERATURE ON SPECIAL CEMENTS FOR DAMS AND WATER-RETAINING STRUCTURES*

By the Swedish and the Norwegian Subcommittees on Large Dams

A. Literature Published in Sweden

1. *Deterioration of concrete caused by dissolution or position of cement, and means of protection* (*Skador hos betong genom cementets utlösning eller sönderdelning och skyddsmedel härför*). Schlyter, R.: Betong, *1926*, 61.—Introduction to a discussion on practical experience of deterioration of concrete and means of protection. The author gives a brief survey of cases of concrete failures, i. e., of concrete pipes, quay walls, bridges, dams, etc., and describes causes and suitable means for preventing failures. In the discussion the importance of the density of the concrete is stressed, the use of a number of special admixtures is described and the quality of the cement considered.

2. *The cement injection method* (*Cementinpressningsmetoden*). Westerberg, G.: Tekn. Medd. fr. K. Vattenfallsstyrelsen, Ser. B., (7), *1926*.—Description of the use of the method for reinforcing rocks and repairing deteriorated concrete.

3. *On the heat evolution of cements during setting and hardening* (*Om värmeutvecklingen vid cementets bindning*). Samsioe, A F.: Tekn. Tidskr. *1927*, V. o. V., 25.—Description of an apparatus (insulated thermos flasks) for the measurement of the heat evolution of cement. A theory for the calculation of the heat evolved on the

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**Revue de la bibliographie récente scandinave des ciments spéciaux pour barrages et ouvrages de retenue des eaux.*

Eine Übersicht über die jüngste skandinavische Literatur über Spezial-Zemente und Wasserstauwerke.

Estudio bibliográfico de trabajos escandinavos recientes sobre cementos especiales para presas y estructuras de retención de aguas.

basis of calibrations of the flasks is given. Values of heat evolution are given for five cements.

4. *Investigation on the heat evolution of different cements during hardening* (*Undersökning av värmeutvecklingen hos olika cementsorter under hårdnandet*). Frost, R. V.: Betong, *1927*, 77.—With the same apparatus as is described above by Samsioe (3) the author has carried out a number of measurements the results of which are communicated.

5. *The use of Swedish blast furnace slag for the manufacture of cement* (*Svensk masugnsslaggs anvandning vid cementtillverkning*). Grün, R.: Tekn. Tidskr. *1928*, 436.—The possibilities for the utilisation of Swedish blast furnace slags for the manufacture of cements of the type "iron portland cement" and "blast furnace cement" is detailed. Ground slag may also be used as a kind of pozzolana for modifying the properties of portland cement.

6. *Causes of deterioration of concrete in dams* (*Orsaker till betongorstorelser i dammbyggnader*). Ekwall, A.: Tekn. Tidskr. *1929*, V. o. V. 64, 69.—Lecture giving a review of cases of deterioration of concrete and their causes. Failures have been observed for more than 10 years in Sweden. They have occurred in structures subjected to unilateral water pressure only. They have not appeared in modern dams of reinforced concrete whilst they are frequent in gravity dams, where the concrete has been made according to the practice usual some 20 years ago. A short report is given of the research work carried out during the last 5 years by a committee appointed for this purpose. (Cfr. a publication by K. Vattenfallsstyrelsen mentioned below under 7.) In addition lectures are referred to by N. Sundius (Cfr. below under 7) on The Constitution and Hydration of Cement and by A. F. Samsioe on Suitable Proportioning of Concrete (Betongmaterialernas lämpliga sammansättning). In the following discussion the design and construction of dams, causes of failure, and possible means of prevention were detailed. It was decided to request the cement manufacturers to produce a cement having a complete resistance to the action of water and as low heat evolution as possible.

7. *An account of investigations concerning the causes of deterioration of concrete in hydraulic structures* (*Redogörelse för undersökningar angående orsakerna till förstörelse av betong i vattenbyggnader*). Tekn. Medd. fr. K. Vattenfallsstyrelsen, Ser. B. (16), *1929*.—A short review of the problem concerning failures of concrete in hydraulic structures and a detailed description of research work carried out in this connection. Special attention has been given to the importance of humic acid in sand used for concrete, the influence of various factors on the watertightness of concrete, the composition of the water in rivers where failures have occurred, the dissolving action of water on cement, and the effect of admixtures on the dissolution of cement. Further, the constitution and hydration of portland cement is described and an account given of an investigation carried out on this subject. Concerning the different methods of investigations and the individual test results, the original and extensive report should be consulted. As a conclusion it is stated, that sand containing humus should be avoided; that a definite watertightness when using pure materials and a good cement can be obtained with a mixture of 1:4, 5 and suitable consistency; and that of the admixtures tested

slaked lime considerably improved the watertightness. Further, it is stressed that the failures observed cannot be ascribed to an unsatisfactory quality of the cement or a specially high aggressiveness of the water.

8. *On the change in chemical resistance of portland cement against the action of water by means of different admixtures* (*Om förändring av portlandcementets kemiska motståndsförmåga mot vatten genom inblandning av olika tillsatsmedel.* Sundius, N. and Assarsson, G.: Tekn. Tidskr. *1930*, V. o. V. 101.—The continuation of tests referred to under 7 concerning the solubility of cements in pure water is described. The effect of addition of burnt slate, trass, blast furnace slag, "cementit" "Sika," diatomaceous earth, arsenious acid, oxalic acid, and silicious acid is investigated, showing that only the four last-mentioned additions have appreciably increased the resistance of the cement against the action of percolating water.

9. *On the constitution of hydrated portland cement.* Assarsson, G. and Sundius, N.: Sveriges Geol. Unders. Arsbok, *1929* (2).—A determination of the amount of free lime in set cement shows that the approximate composition of the hydro-silicate in the cement is $2\ CaO \cdot SiO^2 \cdot aq$.

10. *The resistance of concrete, particularly in concrete pipes, against water* (*Betongs och speciellt betongrörs beständighet mot vatten*). Frost, R. and Virgin, E.—Betong, *1929*, 100.—A number of failures observed on concrete and concrete pipes led to this investigation. The report contains a detailed review of the literature on the subject, a report on observed failures in Sweden and an account of investigations on especially manufactured pipes as to their resistance against ordinary water (from a town supply) and water containing carbon dioxide. For the manufacture of the pipes various machines, cements, aggregates and proportions were used. The behaviour of some protective coatings was also studied. Further, percolation tests were made on crushed and hardened cement using different kinds of water and carbonated as well as noncarbonated specimens. The investigation stresses the importance of the watertightness of concrete pipes and shows that attack on concrete pipes by ground water containing carbon dioxide is liable to occur in Sweden. It also gives a qualitative analysis of factors influencing the durability.

11. Facts concerning the solubility of cement (*Löslighetsförhållanden hos cement*). Werner, D.: Tekn. Tidskr. 1930, K. 57, 68.—Review of earlier works. Description of a method for the determination of the solubility of hardened cement by means of shaking crushed specimens with water. The results of such measurements made on portland cement, aluminous cement, and cement with acid admixtures are given. It is confirmed, that the dissolution of lime in cement takes place in two stages, of which one may be eliminated by means of a suitable acid admixture.

12. *Differentiation of the properties of cement* (*Differentiering av cementets egenskaper*). Giertz-Hedström, S. and Werner, D.: Tekn. Tidskr. *1930*, 197.—It is suggested that cement is too much standardised, although cement is used in many different kinds of work. Consequently a rational specialisation must be considered. The possibilities for this are discussed, the different properties of cement being

classified as desirable and undesirable. It is stressed that a simultaneous improvement of all properties is impossible, and that a differentiation is necessary. In the first instance two special cements are anticipated, one for use in hydraulic structures and mass concrete and one for ordinary building structures and for very wet concrete mixes.

13. *On the effect on concrete of water containing carbon dioxide* (*Till frågan om kolsyrehaltigt vattens inverkan på betong.*) Sundius, N.: Betong, *1930*, 41.—A theoretical analysis of process and rate of the dissolution of lime is given and also calculations of the duration of the concrete under certain assumed conditions.

14. *The effect of portland cement on aluminous cement* (*Inverkan av portlandcement på aluminatcement*). Lalin, G. S.: Tekn. Tidskr. *1931*, 189.—Mixtures of aluminous and portland cement containing a small amount of portland cement only set very rapidly and harden fairly slowly. They are well suited for rendering concrete that will resist high water pressure.

15. *Methods of investigation for ascertaining the condition of concrete in hydraulic structures* (*Undersökningsmetoder för konstaterande av betongens beskaffenhet i vattenbyggnader*). Westerberg, G.: Sv. Vattenkraftfören. Publ. (256), *1933:* 1.—Review of suitable methods for establishing existing failures and their distribution in the concrete. The content of lime in water leaking through concrete gives information about this. When one-third of the lime in the cement is dissolved the concrete may be considered as destroyed. The author finds that concrete mixes which have been placed as a very wet mixture or by tamping have shown the greatest deterioration.

16. *On the heat evolution in concrete during hardening* (*Om värmentvecklingen i betong under hårdnandet*). Werner, D.: Betong, *1933*, 1.—American investigations are referred to, on the basis of which a table is drawn up showing the heat evolution of portland cements of known chemical composition. A diagram is then given from which the maximum temperature rise in a concrete of a given mix and of a cement of given composition can be calculated. A comparison is made between the calculated and the observed temperature in a certain case.

17. *On the formation of cracks in concrete* (*Om sprickbildning i betong*). Werner, D.: IVA, *1933*, 27.—Description of a method using a thread steel rod for measuring the formation of cracks in hardened cement due to drying. Test results are communicated.

18. *Repair of concrete by means of quick-setting mortars* (*Betongreparationer med hastigt bindande bruk*). Lalin, G. S.: Tekn. Tidskr. *1933*, V. o. V. 37.—A rapid-setting mixture of portland cement and aluminous cement can be sprayed against water pressure, and leaks in concrete structures may be successfully stopped. A suitable execution of the method is detailed.

19. *Concrete in large structures* (*Betong i grova konstruktioner*). Werner, D.: Betong, *1933*, 64.—A comparison is made between the last American specifications for low-heat cements for dams and the properties of a Swedish cement for hydraulic structures.

20. *The twenty-fourth annual meeting of the Swedish Water Power Association the 27th of April 1933* (*Svenska Vattenkraftföreningens tjugufjärde ordinarie årsmöte den 27 april 1933*). Sv. Vattenkraftfören.

Publ. (260), *1933:5*.—Among other subjects at the meeting the question of "Methods for the repair of deteriorated concrete in hydraulic structures" was treated. Two lectures of introduction were given, the first by G. Westerberg, who stressed the importance of the position of the "front of dampness" in concrete dams and the advantages of keeping the downstream side of the dam dry. He also described how to repair deteriorated concrete by means of spraying quick-setting mortar and gave details of the method of "grouting behind shield." The second lecturer, C. Matton, described cement injections as a method of repair and gave statistics on the use of the method. In the discussion the manner of construction of dams was mentioned as well as the possible advantages of injections according to Joosten, of the use of special cements, e. g. silicate cements and pozzolana cements, and hydraulic admixtures.

21. *Watertightness of concrete* (*Vattentäthet hos betong*). Lalin, G. S.: Betong, *1933*, 138.—The difficulties to obtain conformity between laboratory tests and practical results as to watertightness of concrete are referred to. The workability is a fundamental property and must be considered also in the laboratory. The method for measuring permeability used by the Royal Waterfall Board is described. Data are given on tests performed, especially concerning silicate cement with 3 percent admixture of diatomaceous earth.

22. *Investigation on the suitability of concrete pipes for the use as road culverts* (*Utredning angående lämpligheten av betongrör till vägtrummor*). Granholm, Hj., Werner, D. and Giertz-Hedström, S.: Betong, *1934*, 1.—The report contains inter alia, a review of the experiences with concrete pipes used as road culverts, a report on field studies, a review of literature on the durability of concrete, results of chemical analysis of water and concrete from the field, results of laboratory investigations of the aggressive action of different types of water on concrete pipes of various kinds as well as of the resistance of different protective coatings against aggressive water and wear. A classification according to aggressiveness is given of different types of water containing carbon dioxide. Specifications are proposed for concrete pipes for road culverts.

23. *Watertight concrete* (*Vattentät betong.*) Hellström, B.: Betong, *1934*, 99.—The author reports on experiences of concrete as to watertightness and recommends the use of sand containing a great amount of fine particles. Methods of testing watertightness are described and results obtained therewith reported.

24. *On differentiation of cement* (*Om cementspecialisering*). Forsén, L.: Betong, *1934*, 221.—The author refers to requests as to special cements and reviews in detail the series of mainly Swedish investigations having resulted in special cements called "silicate cements", and Pansar (pozzolana) cements. These cements as well as Swedish normal and rapid hardening portland cements are described with reference to time of setting, mechanical resistance, shrinkage, heat evolution, workability, solubility, and watertightness. Reference is made to the constitution of portland cement clinker and the properties of the clinker minerals. Starting from the properties of the cements the author gives a table for the suitable range of use of the different cements.

25. *The proportioning of concrete to obtain watertightness* (*Proportionering av betong med särskild hänsyn till tätheten*). Bährner, V.: Byggmästaren, *1930*, 9, *1933*, 129, *1934*, 41.—Rules are given for the proportioning of concrete mixtures in order to obtain watertightness. Convenient diagrams for the calculation are shown.

26. *The manufacture of cement—A review of modern methods with special regard to Swedish conditions* (*Om cementtillverkning—En översikt av modernare metoder med särskild hänsyn till svenska förhållanden*). Danielsen, N.: Tekn. Tidskr. *1935*, K 57, 68.—The types of standard and special cements manufactured in Sweden are mentioned and briefly characterized. A detailed description is given of the technical arrangements for the manufacture of cements.

27. *On the chemistry of portland cement and on different types of cement* (*Om portlandcementets kemi och om olika cementsorter*). Forsén, L.: Tekn. Tidskr. *1935*, K. 65.—A summary of the author's views on the constitution of cement clinker and the procedure of burning cement. The influence of the various clinker minerals on the properties of the cement is briefly described.

28. *Measurements of the heat of hydration of cement according to the heat-of-solution method* (*Mätning av cementets hydratationsvärme enligt lösningsvärmeprincipen*). Giertz-Hedstöm, S.: IVA, *1934*, 67, *1935*, 75.—Description of an apparatus of the American type for the determination of heat of hydration. Some test data are given, showing inter alia the effect on the heat evolution of pozzolana admixtures.

29. *Methods for testing the watertightness of concrete and mortar* (*Metoder för provning av betongs respektive cementbruks vattentäthet*). Schlyter, R.: Tekn. Tidskr. *1935*, V. o. V. 137.—A description is given of test methods used at the Government Testing Institute in Sweden and details accounted for.

30. *Separation of water from a cement paste* (*Vattenavskiljning hos cement*). Giertz-Hedström, S.: IVA, *1935*, 65.—The degree of separation of water from a cement paste has been studied for a number of different cements. The importance of this property for the resistance, watertightness, and durability of the concrete is briefly considered and references in this connection are made to American investigations. The separation of water is as a rule an undesirable property which seems to bear a simple relation to the workability of the concrete.

B. Literature Published in Norway

1. *Investigation on failures of our concrete and masonry dams, causes and remedies* (*Undersøkelse av skader på våre betongdammer og bruddstensdammer i mørtel, årsak og botemidler*). Den Norske Ingeniørforenings Betongkomité: Meddelelse Nr. 1, Oslo, *1930*.—A detailed account of the making of concrete and of the present conditions of the concrete in a number of Norwegian dams. Review of the causes for the failures occurred and description of dissolution tests, results of borings in the concrete, etc., made in connection therewith. Different cures are discussed, as for instance the use of more resistant cements, better methods of concreting, protecting materials, etc. Methods of repair are described, such as injection of cement, the use of insulating materials and building of a protective wall of reinforced concrete on the upstream side of the dam.

2. *Shrinkage and cracks in concrete of dams.* Vogt, F.: Kgl. Norske Vidensk. Selskabs Skrifter, *1930*, (4).—A thorough investigation of the problem of volume changes causing cracks in mass concrete. The temperature distribution in dams is mathematically treated and its dependence on the variations of temperature of the atmosphere is shown. The relation between opening up of contraction joints and shrinkage is elucidated. A great number of dams are described and discussed in detail.

3. *Manufacture of concrete (Betongfremstilling).* Den Norske Ingeniørforenings Betongkomité: Meddelelse Nr. 2, Oslo, *1932*.—As a continuation of the work described under 1, rules are given for the manufacture of concrete. The materials, the proportioning, and the control of the product are detailed.

4. *On the construction of the Grønvollfossen power plant and the manufacture of cement in connection therewith (Fra Grønvollfossens utbygning og cementfabrikasjon).* Rolfsen, O.: Teknisk Ukeblad, *1933*, 18, 32, 102, 151, 288.—The author describes the selection of blast furnace slag cement for the building of the Grønvollfossen power plant. German authorities were consulted and a mill specially procured in which a cement consisting of 30–40 percent portland-cement clinker and 60–70 percent blast-furnace slag was ground. The aim was to get a reduced heat evolution and an increased resistance against the action of water. Data are given of the heat evolution and the dissolution of lime of the cement. An extensive discussion of the subject is given.

5. *Analysis of rise in temperature during hardening of concrete.* Vogt, F.: Kgl. Norske Vidensk. Selskabs Skrifter, *1933*, (3).—Calculation of the temperature in concrete during hardening. The influence of the pouring rate and the thickness of poured layers on the temperature rise is mathematically treated in detail. Numerical examples are given.

C. LITERATURE PUBLISHED IN DENMARK

1. *Watertightness of concrete pipes (Cementrørs Vandtaethed).* Suenson, E.: Ingeniørvidenskabelige Skrifter, B–3, *1930*.—Account of an investigation of factors governing the watertightness of concrete pipes. Tests were made with different kinds of pipes and water.

2. *The density and durability of mortar in water (Mørtels taethed og holdbarhed i vand).* Poulsen, A.: Ingeniøren, *1931*, 470.—Review of a paper presented to the Fifteenth International Congress of Navigation. The author compares different pozzolanas and judges their value from their content of silica and alumina soluble in alkali. The amount of pozzolana to be added to a concrete mix should be estimated on basis of the lime-containing capacity of the pozzolana and the quantity of lime liberated by the cement. It is recommended to use pozzolanas in concrete for hydraulic structures.

3. *Tests on the permeability of mortar of portland cement and "moler" cement (Nogle forsøg vedrørende vandgennemtraengelighed af mørtler af portlandcement og molercement).* Löventhal, Y.: Beretpnig Statsprøveanstaltens Virksomhed *1931–32*, 14.—A comparison is made between mortars made of portland cement and of "moler" cement as to the watertightness under various conditions.

4. *"Moler"-cement mortar* (*Molercementmørtel*). Suenson, E.: Ingeniøren, *1932*, 430.—The mechanical properties, resistance against frost, shrinkage, permeability, and resistance against sulphate water of the "moler" cement mortar are determined and compared with those of portland cement mortar. A discussion follows.

5. *On mortars of portland cement and "moler" cement* (*Om mørtler af portlandcement og molercement*). Löventhal, Y.: Beretning Statsprøveanstaltens Virksomhed *1932–33*, 13.—The mechanical properties and the resistance against water containing sulphates of the mortars are described.

6. *The durability of concrete pipes in acid water* (*Cementrørs syrefasthed*). Suenson, E.: Ingeniørvidenskabelige Skrifter, B–15, *1935*.—A review is given of failures on concrete pipes observed in Denmark. Extensive tests have been made of the resistance of concrete pipes against water containing carbon dioxide, the pipes being manufactured under various conditions and some of them provided with protective coatings. The resistance of prisms of mortar against water containing carbon dioxide and lactic acid is also investigated. The tests are described in detail. It is concluded that pipes resisting water containing carbon dioxide may very well be made from concrete. The different cements tested showed no appreciable difference in regard to the resistance of the concrete pipes.

D. LITERATURE PUBLISHED IN FINLAND

1. *Specialisation of cement* (*Erikossementeistä*). Forsén, L.: Teknillinen Aikakauslehti, *1935*, (1).—Cfr. the publication in Swedish referred to above under A 24 by the same author.

DISCUSSION—QUESTION III

SECOND CONGRESS
ON LARGE DAMS
WASHINGTON, D. C., 1936

SESSION OFFICERS

Service de la Séance—Sitzungspräsidium—Personal Directivo de la Sesión

MR. BO HELLSTRÖM, Consulting Engineer, Vattenbyggnadsbyrån; Chairman, International Subcommittee on Special Cements, Stockholm, Sweden, *Chairman.*

MR. JAMES W. RICKEY, Chief Hydraulic Engineer, Aluminum Company of America, Pittsburgh, United States, *Associate Chairman.*

MR. J. L. SAVAGE, Chief Designing Engineer, U. S. Bureau of Reclamation, Denver, United States, represented by Mr. R. F. Blanks, U. S. Bureau of Reclamation, Denver, *General Reporter.*

SPEAKERS

Orateurs—Redner—Horadores

MR. BO HELLSTRÖM, Consulting Engineer, Stockholm	SWEDEN
MR. JAMES W. RICKEY, Chief Hydraulic Engineer, Aluminum Co. of America, Pittsburgh	UNITED STATES
MR. N. G. GEDYE, Consulting Civil Engineer, London	GREAT BRITAIN
MR. P. H. BATES, Chief, Clay and Silicate Products Division, U. S. Bureau of Standards, Washington	UNITED STATES
PROF. OTTO GRAF, Techn. Hochschule, Stuttgart	GERMANY
THE RIGHT HONOURABLE VISCOUNT FALMOUTH, Vice President, Conjoint Conference of Public Utility Associations, London	GREAT BRITAIN
MR. ARTHUR RUETTGERS, U. S. Bureau of Reclamation, Denver	UNITED STATES
DR. ING. LENNART FORSÉN, Chief Chemist, Skånska, Malmö	SWEDEN
LT. COL. AXEL EKWALL, Engineer in Chief, Royal Board of Waterfalls, Stockholm	SWEDEN

Sir Harold Hartley, C. B. E., Vice President and Director of Research, London, Midland and Scottish Railway; Chairman, International Executive Council, World Power Conference, London	Great Britain
M. Marcel Mary, Ingénieur des Ponts et Chaussées, Paris	France
Dr. F. M. Lea, Research Chemist, Department of Scientific and Industrial Research, Garston Watford, Herts	Great Britain
Mr. Kristen Friis, Civil Engineer; Secretary, Norwegian Committee of Large Dams, World Power Conference, Oslo	Norway
Mr. J. H. A. Brahtz, Engineer, U. S. Bureau of Reclamation, Denver	United States
Mr. Stig Giertz-Hedström, Laboratory Director, the Cement Laboratory of the Royal Swedish Institute for Engineering Research, Djursholm	Sweden
Dr. Ing. Erich J. M. Honigmann, Leiter und Stellvertreter an den Versuchs-Anstalten für Maschinenmaterial und für Baustoffe, Wien	Austria

HELLSTRÖM
Sweden

The question of concrete structures has become a serious problem in recent years. This is due in part to the high speed of modern construction with consequent lack of opportunity for escape of the internal heat and in part to the fact that deterioration takes considerable time and has made itself felt in recent years only. To overcome these difficulties, therefore, it is of great assistance to use cements especially suitable for structures subjected to unilateral water pressures. I lay particular stress on the word "assistance," because the use of a special cement, no matter how good it may be, will not obviate the necessity of taking every precaution to obtain sound concrete by looking after the grading of materials, the mixing and transport of the concrete, and its handling in the forms, etc. Subject to this general reservation, the choice of a suitable cement is of primary importance.

Among a number of very interesting reports from different countries you will find one from the International Subcommittee on Special Cements dealing with methods of testing of certain cements. There is also available an American report on special cements for mass concrete which has been prepared by the engineers and chemists of the United States Bureau of Reclamation. The subjects dealt with in the several reports can be divided into two groups: First, the special cements used in different countries and experience gained thereon; and, second, methods of testing. With respect to the latter, the International Subcommittee on Special Cements has suggested a tentative technique which is submitted for discussion and trial.

RICKEY
United States

The company with which I am connected built between 1914 and 1931 seven major dams containing well over 2 million cubic yards of concrete and nearly 2½ million barrels of cement. We paid no particular attention to the cement, merely bought the best obtainable in the market, and no engineer would be ashamed of the work. We could proceed similarly in the future and use standard brands of cement, but considerable change in engineering attitude has taken place in recent years. We are not satisfied even with the best which the manufacturer offers us, we have developed a critical attitude, we scrutinize the materials, and we force the manufacturer to give us new and more suitable materials, even though they are more expensive. Research is going on in many countries. In the United States it became a very real problem to find the best possible cement for Boulder Dam; for its unprecedented size exaggerated all the problems and questions which could be passed by lightly in smaller dams. One of the problems was to cool the structure to its normal service temperature within a short time and without detrimental effects. The special cements which are now being developed, and which will unquestionably continue to be developed in the future, will be much superior for the purposes we have in mind, namely the safe and economical construction of large dams.

GEDYE *Great Britain* I wish to express, on behalf of the British National Committee, appreciation of the valuable work done during the past 2 years by the International Subcommittee on Special Cements under the chairmanship of Mr. Hellström—a work which is yet far from completed and which, I understand, will be continued on the lines of the program adopted in October 1934.

The Subcommittee does not propose to set up standard specifications for one or more special cements. It has dealt so far with selected problems and has made tentative suggestions for further investigation and discussion of certain chemical and physical properties which are not adequately covered by the ordinary specifications in general use in Europe and America, but which are essential factors in any cement intended for use in large monolithic concrete masses. The aim of the Subcommittee is to formulate methods and standards of testing which can be used in whole or in part, and if desirable modified, in national specifications, and which will cover the essential qualities desired in a special cement for dam construction. I suggest that it is of the utmost importance that the work of this Subcommittee be international in character and not merely the work of a few European countries. The work done in the United States by the engineers and chemists of the Bureau of Reclamation, and other authorities, on certain cements is so important, and the experience of these experts in recent years has been so varied and complete, that it is highly desirable that full use should be made of that work and experience by the International Subcommittee.

There is nothing antagonistic or contradictory between the work of the Americans and that of the International Committee; each supports the other. Taken together, they mark a definite advance towards the solution of the problem of an entirely suitable cement for mass concrete construction in dams. The American report prepared at the end of 5 years of scientific investigation and construction work on a gigantic scale is an essential document. We hope that active and more direct participation by our American colleagues may be possible in the future. If the United States of America will contribute their share in the work of the Subcommittee on Special Cements, I venture the prophecy that the influence of that committee's work and recommendations will be apparent in the near future in many national specifications, and will encourage manufacturers both in Europe and America to produce on a large scale a cement or cements complying with all the essential requirements which may be recommended by this Subcommittee.

BATES *United States* I have always been an advocate of the necessity of studying the type of cement required for any particular use, but I must confess that I have been astounded by the avalanche of special cements which are appearing on the market. It would seem that there is no end to the types of cement which may be demanded of manufacturers under present conditions. I am particularly pleased to note that in the interim report of the Subcommittee the composition of cement has been left in the background. It seems to me that if we must tell a manufacturer that to get a certain physical result he must turn out a cement of a certain composition we are still back in the primitive ages of cement development. If we cannot develop tests which will indicate to the manufacturers the physical quality of the cement, I fear we are not making much progress.

Among matters dealt with in the interim report, the methods of heat of hydration are of particular interest to me in view of the fact that at the Bureau of Standards we have been using very largely the heat-of-solution method. While that method has been legitimately criticized, the lack of reproducibility of results is not a question of precision of the equipment but of the inability to hydrate identical samples of cement identically. The equipment used to determine the heat is, in fact, too precise for the work in hand. In employing the method of solubility, so far as the composition of the cement is in question, at least solubility in different waters, the Swedish method is of interest because it was used for some time at the Bureau of Standards. I would suggest to the Subcommittee that the Swedish tests be extended to follow the volume changes taking place in waters and concretes during hardening, and not to wait until the hardening is over before starting the test. Greater volume change takes place during the setting and hardening within the first 24 hours. The changes thereafter are invariably much smaller; but bear in mind that while cracks may not develop during this first 24 hours, strain has developed and there is stress in the concrete.

It is particularly interesting also to note the emphasis placed on workability. In view of the advocacy of certain types of cements because they are more workable it would seem that we should do far more than we have done to develop tests to measure that quality. I would also like to see carried out in all of your work more correlation with actual concrete. The papers presented are too much confined to the test method and I find such statements as that both the bending and the compressive test methods are particularly improved by the use of a plastic mortar instead of an earth-moist one, but on reading the paper I find nothing to show that those improved test methods indicate in any better way a better cement in the concrete. True it is a better test method, but what of that? What we need to know are the merits of the cement in the concrete.

GRAF *Germany* Wir sind in neuerer Zeit in Deutschland an das Problem der Spezialzemente in etwas anderer Weise herangetreten, als dies in den Vereinigten Staaten geschehen ist. Wir denken nicht daran, nun ausschliesslich Zemente mit niedriger Wärmeentwicklung herzustellen. Es ist mehr unsere Absicht, Zemente in grösserer Zahl zu schaffen, die ausgezeichnete Eigenschaften für ein weiteres Verwendungsgebiet haben; Zemente mit hoher Biegefestigkeit, mit geringem Schwindvermögen, vor allem aber mit möglichst wenig ausgeprägter Eigenschaft des Zurücksinkens der Festigkeit beim Austrocknen. Wir haben Zemente mit besonders ausgeprägten guten Eigenschaften für den Ingenieurbau, Brücken, Betonstrassen und auf der anderen Seite den gewöhnlichen Zement für den Hochbau usw. Bei diesem Problem hat es sich nun in ganz besonderem Masse gezeigt, dass es nötig ist, die Prüfmethoden, wie sie heute meist noch üblich sind, von Kurzprüfungen gewöhnlichster Art zu Prüfmethoden zu entwickeln, welche uns die Eigenschaften der Zemente so angeben, dass wir sicher sind, dass draussen im Beton das entsteht, was wir erwarten. Wir sind deshalb in Deutschland im Begriff, die Zugprüfung abzuschaffen und vor allem die Biegeprüfung einzuführen, weil die Biegeprüfung dem näher liegt, was in der Praxis verkommt. Die Zugfestigkeit wird nie oder sehr selten angewandt, währand die Biegefestigkeit sehr oft verlangt wird. Wir haben weiterhin versucht, Zemente mit geringem Schwindvermögen zu entwickeln und haben dabei eine Methode benützt, um eine gewisse Statistik aufzustellen über die Zusammenhänge zwischen Schwinden und Zusammensetzung, zwischen physikalischen und chemischen Eigenschaften. Wir haben dabei unter anderem auch gefunden, dass die Schwindemessung allein nicht ausreicht. Es gibt Zemente, die in nassem Zustand eine grössere Festigkeit haben, und während des Austrocknens im allgemeinen an Festigkeit verlieren; ein Umstand, der sich namentlich bei Betonanlegen, Betonstrassen und dergleichen, auswirken wird.

Wir haben weiterhin die Notwendigkeit empfunden, zu untersuchen, wie die Festigkeit des Zements sich mit zunehmenden Alter entwickelt. Für Talsperren suchen wir einen Zemente herzustellen, der allen Witterungseinflüssen zu widerstehen vermag. Damit ergibt sich die Notwendigkeit der Umstellung unserer Prüfmethoden, dass sie sich den modernen Verhältnissen anpassen und die Eigenschaften des Zements angeben, die in der Praxis wirklich entscheidend sind. Meiner Ansicht nach sind die gegenwärtigen Prüfmethoden veraltet.

Es sollten ferner Methoden entwickelt werden zur Prüfung der Ergebnisse der Beinmischung von Materialien wir Trass und Hochofenschlacke zu Normenmörtel.

FALMOUTH
Great Britain
In view of the excellent work which has been done both by your International Subcommittee and by the one working under Mr. Savage's direction, I feel that it would be of great help if the two subcommittees could get more closely together in order to introduce what I might call universal specifications in connection with the manufacture of these special cements. We haven't much opportunity for large dams in Great Britain; but outside, in the British Empire, as well of course as in other European countries, there is a very large field for cements. Speaking for the interest of the manufacturer, I am certain that such universal specifications would be of the very greatest assistance. It is very difficult also for engineers building dams in various parts of the world to choose between different specifications drawn up by the different parties. But an international specification, I am quite certain, would be of overwhelming benefit to the engineers, to the manufacturers, and, incidentally, to the public at large.

RUETTGERS
United States

During the past decade portland cement has been the subject of critical examination in this country in the hope of finding a product ideally suited to concrete dam construction. It was natural that attention should be focused on the cement, for builders were still troubled with extensive cracking and some deterioration of concrete in massive structures. But it became increasingly evident through endeavors to control the quality of concrete with strength as the yardstick that it was a mistake to regard portland cement as a standard commodity. When the early results of the first extensive cement investigation exposed large variations in the properties of existing cements and showed definite promise of effecting substantial improvements, there was an overenthusiasm which manifested itself in a tendency to look upon newly developed special cements as a possible cure-all. However, this tendency gave way to more sober judgment, additional test data became available, and more study was given to the causes of cracking and other concrete ills, so that now we appear to have reached or are approaching the stage where the cement factor is being properly evaluated and its limitations recognized.

Notwithstanding these recognized limitations there are certain valuable outgrowths of the recent cement investigation which have combined to raise the standard of quality of all cements. The first is the control of the properties of the finished concrete by control of the compound composition of the cement. I wish to emphasize the value of such compound composition as a working tool for the engineer—a tool so simple that with little study and without knowing even the physical make-up of the compounds or how they are formed the engineer is enabled to select or to specify the cement best adapted to his needs. He soon learns that C_3A is the undesirable compound, that C_3S and C_2S contribute respectively to early and late strength development or heat evolution, and that increased resistance to sulphate action is accomplished by reducing the C_3A content preferably without going too high in the C_4AF. Compound compositions further provide the common medium of thought and expression for engineers and concrete technicians, inspectors, and cement chemists. As a by-product of studies for determining the unit contributions of the principal compounds to heat of hydration we have the development of the heat-of-solution apparatus, the Bain calorimeter, various types of calorimeter apparatus, and the more simple thermos glass calorimeter.

A second principal outgrowth of recent cement investigations is the recognized importance of fineness of cement. It is now apparent that finer grinding increases the efficiency of cement by putting more of it to work. Furthermore, increased fineness improves the workability of concrete, permits improved placement with the use of less cement, less heat evolution, and less volume change. With increased fineness, particularly within a certain range, there is lowering of the water-cement ratio for concrete of the same mix proportions and consistency and a marked decrease in permeability.

A third outgrowth of the recent cement investigations is the progress, the organized activity, and the cement consciousness directly traceable to these investigations. Special cements are not a passing fancy, but are well intrenched. Investigational activities have spread into various government organizations, cement companies, educational institutions, and commercial testing laboratories. The cement industry itself is generally alive to the situation, and without its helpful attitude and cooperation the special cements of today could not have been produced.

FORSÉN *Sweden* I wish to suggest that the excellent report of the Bureau of Reclamation on special cements for mass concrete be discussed at the meetings of the International Subcommittee, and that it would be particularly valuable if our American colleagues in the future would cooperate by correspondence and, whenever circumstances permit, by visits to our meetings in Europe. From the technical point of view I would like to say a few words on one question only.

In the general report Mr. Savage refers to high fineness of cement as one of the properties to be required. I do not agree with this. In my opinion specifications should cover only such properties of cement as strength, heat of hydration, water-cement ratio, etc. It should be left to the cement maker to decide what means he will use to obtain the properties specified by the engineer. Chemical composition, fineness, etc., should therefore not be specified. My reason for leaving the question of fineness to be decided upon by the cement maker is that only by coarse grinding could we produce the low-heat cement specified by the Royal Board of Waterfalls in Sweden, namely a cement with long time of setting and small water-cement ratio. High workability may be obtained by means other than high fineness; and the strength and watertightness of this coarsely ground cement have been quite satisfactory.

EKWALL *Sweden* The Swedish Board of Waterfalls started 5 years ago to build a new power station on the Göta River. The head was only 11 feet. Economic considerations required the use of turbines of a diameter of 27 feet, the largest ever built, and the elimination of gates on the upstream side of the turbines. When the air is evacuated the water flows into the intake of the turbine, thus raising the water level about 7 feet on the upstream side of the turbine, and causing the turbine to run as if in a giant syphon. The concrete structures are, therefore, very large and had to be built not only without cracks but absolutely water and air tight. We did this by using low-heat cement with a large amount of silicate. When the workability of the silicate-cement concrete was not sufficient we added a small quantity of diatomaceous earth which made it satisfactory. This water-power plant, constructed in 1933, has been very successful because the concrete is absolutely tight and without any cracks.

HARTLEY *Great Britain* The manufacture of cement and the setting of concrete present a series of very complex chemical problems on which much work is still required. The fundamental researches of Rankin and Wright of the Geophysical Laboratory in Washington have established the conditions under which various crystalline solids are formed from mixtures of lime, alumina, and silica. We know, therefore, the limits within which cements are formed by banning mixtures of lime and clay containing these constituents. The further problem of the chemical and thermal volume changes which take place when concrete sets, has not yet yielded to investigation. Certain cement constituents are called hybrids, but whether the strength of the concrete depends on an interlacing network of crystals like the strength of an alloy or on a jelled structure we do not know. Here is a case where practice is far ahead of theory, and practice is so efficient that you may ask whether theory is worth while. My answer is that control is always found to pay eventually. I, too, would like to make a plea for the closest cooperation between those in various countries who are engaged in the work of research, and especially between American workers and those in Europe.

MARY *France* Je voudrais dire quelques mots sur les essais de perméabilité du béton que j'effectue au laboratoire des Ponts et Chaussées et qui entrent dans le cadre des recherches de la Sous-Commission du Ciment Spécial. L'étanchéité est une des qualités essentielles d'un bon béton. Sans doute, les filtrations qu'on observe à travers de gros massifs viennent rarement de la perméabilité proprement dite du béton, mais presque toujours de mauvaises reprises, de fissures ou d'imperfections dans la mise en oeuvre. Mais la perméabilité du béton, qui est d'importance secondaire quant aux fuites d'un ouvrage, prend une importance primordiale en ce qui concerne la dissolution du béton par les eaux pures ou la décomposition par les eaux agressives. Elle a également une importance considérable pour la perméabilité des ouvrages minces.

Nos essais, qui sont en cours depuis plusieurs années, ont porté pour la plupart sur des bétons au dosage de 200 à 250 kg de ciment par unité cube. Les éprouvettes, de forme tronçonique, sont placées dans des pots en acier et soumises à une pression de 10 kg/cm². L'un des résultats les plus intéressants que nous ayons obtenus est la différence considérable de perméabilité que l'on obtient en changeant uniquement le ciment, toutes les autres conditions étant les mêmes. Nous avons essayé depuis quelques mois des bétons confectionnés avec des ciments de provenances très diverses (français, américains, belges). Certains d'entre eux nous ont donné des filtrations s'élevant de 4 à 5 litres par heure, d'autres donnent seulement quelques centimètres cubes. Il y a là un domaine de recherche qui nous semble de la plus haute importance.

Il est certain, comme le disait tout à l'heure M. Ruettgers, que la finesse du ciment exerce une influence considérable sur la perméabilité. A cet égard une expérience a été faite tout récemment dans notre laboratoire. Un ciment de même provenance a été brisé à trois finesses différentes:

1. à 58 pour-cent de grains inférieurs à 30 microns, la perméabilité a été de 1,6 litres par heure (1.600 cm^3 par heure);
2. à 66 pour-cent, 11 cm^3 par heure; et
3. à 79 pour-cent, 7 cm^3 par heure.

Les dimensions des grains intéressantes pour conférer à un ciment l'imperméabilité paraissent d'ailleurs être de quelques microns seulement. Il y a là un ensemble de recherches qui ne paraissent pas avoir été l'objet jusqu'à présent d'essais systématiques, mais qui sont du plus haut intérêt.

LEA *Great Britain* In the addendum to the General Report the comment is made that the adiabatic method of measuring heat of hydration of cement seems satisfactory, provided values can be obtained up to 28 days with reasonable accuracy. I would like to ask whether American engineers do consider a 28-day value essential, and whether, in fact, a 7-day value may not be sufficient. I ask this question because a colleague of mine has analyzed the temperature data obtained in three dams going up in Scotland, and has been able, for given rates of placing of concrete, to correlate them very well with the temperature rises occurring in 7 days, as determined by adiabatic methods in the laboratory.

Perhaps the main point of the addendum to Mr. Savage's report is the comment there made that fineness and chemical composition may be more important than any of the properties with which the International Subcommittee has dealt. Chemical composition is obviously very important when we are concerned with the *study* of cements, but whether chemical composition is important when we come to *specification* of cements is a matter on which there are obviously very divergent views. I must say that I have viewed the growing use of calculated compound contents in specifications with a feeling that we are putting in certain mathematical figures which, while they look very well and have an air of authority, are actually serving only to cloak to some extent our ignorance of what we actually have. While it may appear to the engineer that the compound content is a very simple tool, the chemist is likely to feel that it is too simple and can be very misleading. We use chemical compositions in our specifications only because we do not feel sufficient faith in the physical tests which we likewise put into those specifications. If we had complete faith in the latter, we would not be disposed to bother about the former. They are an intermediate stage, shall I say, in our attainment of our real aim, which is a sufficiently complete knowledge to base specifications wholly on physical tests.

FRIIS
Norway

A Norwegian committee some years ago made a detailed study of all of the concrete dams in the country. It found that dams which had been built 10 or 15 years ago showed signs of deterioration due, first of all, to bad concrete—that is, to too lean mixes and poor workmanship; and secondly and foremost, to inadequate treatment of construction joints. Deterioration in all cases began in these joints, but the concrete between the joints is still entirely satisfactory.

Most of the great dams in Norway are situated in the mountains around 1,000 meters above sea level, where water is very acid, with pH value going down to 5.7 and with an alkalinity of only 7 milligrams per liter. It seems to me that this question of special cement for dam construction must be viewed from the standpoint of the alkalinity of the water. If the water contains lime, I see no necessity for using anything other than an ordinary brand of good portland cement of which we know the qualities, the chemical composition, and the behavior. But where the water is acid and, as in Norway, very cold, and where the water is pure, it is best to have a special cement. Nevertheless, the point to be observed is the one too often forgotten, that even with a special cement surface cracks cannot be entirely avoided.

We have another problem in Norway and that is concrete in sea water, about which we have just completed some investigation. We should like to have the Subcommittee give consideration to the possibility of making two things in one, and give us a special cement which stands up both in acid water and in sea water.

BRAHTZ
United States

The problem of stresses in dams caused by volume changes of the material is a very difficult one, and a complete solution is possible only when sufficient data are available on the time behavior of concrete due to natural shrinkage and to temperature variations. In the past certain simple temperature distributions have been assumed, such as uniform shrinkage relative to the foundation or to a linear gradient from the upstream to the downstream face, etc. Few attempts, if any, have been made to analyze the time effect of the heat generated by the cement in connection with the time order of placing the concrete. With the development of special low-heat cements it is possible in many cases of large dams to save the cost of the block system of pouring and do away with the cost of refrigeration.

Temperature stresses may be divided into two groups; those due to uniform and those due to nonuniform temperature changes. In order to minimize the former, it is necessary to have a low-heat cement, whereas it is desirable to have a high-heat cement in order to avoid tensile stresses during construction. Thus, there is an optimum which is determined by the climatic conditions in conjunction with the program of pouring.

In gravity dams the principal danger is formation of nearly vertical cracks propagated upwards from the foundation. Imagine a layer of, say, 2 meters thickness placed on an elastic foundation. When the concrete hardens heat is generated, the temperature rises, and the restraining base sets up a compression. But if the concrete is allowed to cool long enough the stress is reversed into a tension which will ultimately crack the layer. Hence the next layer must be placed before this happens. Guided by the time temperature and by stress behavior data, such a special cement may be specified that the initial compression will remain throughout. Later on the dam as a whole will shrink relative to the foundation, but the stresses set up will be much less per degree of temperature change than during construction.

The work already done on special cements and that now in progress is of immense importance for the prevention of cracks. It is very desirable, therefore, that this question be continued on the program of the Congress on Large Dams. While the analysis of the stresses in the dam during construction is greatly facilitated by the photoelastic experiments on bakelite models in conjunction with mathematical analysis, the most important part of the problem is the time behavior of the cement, for without it no analysis is possible.

GIERTZ-HEDSTRÖM
Sweden

I would like to speak briefly about the method for measuring solubility of cement which has been recommended by a Swedish committee. This method is mentioned in the report of the International Subcommittee on Special Cements but the latter has not yet found it possible to adopt the recommendations as a standard specification. Research work on its adaptability is, however, still going on in the leading research station in London.

In Sweden much research has been carried on and many tests have been made on methods of measuring cement solubility and its leaching with water, for such leaching has been responsible for many failures of dams and other structures. Furthermore, several questions might be raised as to the parallelism between the test method mentioned in the report and actual conditions in dams. It is the experience of Sweden that the tests recommended by its committee are of great value in judging the solubility of cement in water-retaining structures. It is believed, therefore, that this method should definitely be included in specifications for such a cement.

In response to the remarks of Mr. Bates I would state that we in Europe are much interested in pozzolana cements and are inclined, therefore, to use the adiabatic method of measuring the heat of hydration, since the usual method cannot generally be used with such cements. Similar considerations apply, in some degree, to the value of chemical composition and fineness, since they cannot be regarded as technical indications of the properties of a cement. I agree with Mr. Bates about the measurement of volume changes within 24 hours from pouring. We have found in Sweden that in some cases, and with some kinds of cement, we get fine cracks on the fresh concrete even before the 24 hours have passed.

HONIGMANN *Austria* Die Frage der Temperaturerschienungen im Innern erhärtender Betonmassen und die der Prüfungsmethoden ist noch lange nicht gelöst. Ich erlaube mir daher, die nochmalige Aufstellung eines eigenen Punktes für die nächste Tagung vorzuschlagen: "Abbindewärme von Zement und Beton, ihre Bestimmung und ihr Zusammenhang mit anderen charakteristischen Eigenschaften des erhärtenden Zements und Beton." Ich habe in meinem Bericht [1] die Wege aufgezeigt, die uns in der Versuchsanstalt für Baustoffe am Technologischen Gewerbemuseum im Wien zur Klärung des ganzen Fragenkomplexes vorschweben, und habe dort auch den von uns entwickelten Apparat zur Bestimmung der Abbindewärme beschrieben und seine Verwendung zur Bestimmung der Druckfestigkeit im Innern grosser Betonmassen.

Es ist heute absolut möglich, die im Innern grosser Betonmassen beim Erhärten auftretende Temperatur genau vorauszurechnen und die jeweilige Druckfestigkeit des Betons messtechnisch zu verfolgen. Voraussetzung ist die Kenntnis des Arbeitsvorganges, des Betonierungsplanes und der entsprecheden thermodynamischen Beziehungen (dem es handelt ja um rein thermodynamische Probleme), die Kenntnis der Regeln der Wärmespeicherung und des Wärmedurchganges, ferner der Wärmetönnung des Zements und Betons und ihrer spezifischen Wärme. Die letzten zwei Grössen, also die Hydratationswärme und die spezifische Wärme, sind heute in ihrer vielfachen Abhängigkeit meist nicht vollständig, wenn überhaupt bekannt.

Bezüglich der Frage der Bestimmungsmethoden der Wärmetönnung bietet der Zwischenbericht des Internationalen Subkomitees ausserordentlich wertvolle Anhaltspunkte. Da ich mich seit Jahren mit diesen Problemen befasst habe, gestatten Sie mir bitte, kurz auf das Prinzipielle der einzelnen Methoden einzugehen. Die chemische Methode bietet nur einen Summeneffekt und erfordert ausserordentlich zahlreiche und besonders sorgfältige Versuchsreihen, um die Abhängigkeit der Wärmetönnung von anderen Faktoren zu erfassen. Die Bestimmung der Wärmetönnung kann direkt nach einer isothermen Methode vorgenommen werden, wie sie die Thermosflaschen-Methode von Dr. Frey Samsioe und in variierter Form das Verfahren von Dr. Sandri näherungsweise darstellen. Näherungsweise deshalb, weil in beiden Fällen der zu prüfende Inhalt keine über sein Inneres

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[1] *D 26.*

konstante Temperatur haben kann, was erst durch Korrektur zu berücksichtigen ist.

Die rein adiabatische Methode verzichtet auf eine direkte Bestimmung der Wärmetönnung und umhüllt das Prüfgut so, das keine von diesem entwickelte Wärme abfliessen kann, sonderen zur Erhöhung von dessen Temperatur dient. Wäre die spezifische Wärme des Prüfgutes und ihre Abhängigkeit von den anderen Einflussfaktoren bekannt, so könnte aus dieser Temperaturerhöhung die Wärmentwicklung des Prüfgutes berechnet werden. Die adiabatische Methode gibt also die oberste Temperaturgrenze an, die im Innern einer unendlich grossen Betonmasse ohne Wärmeabgabe erreicht werden könnte. Die isotherme Methode zeigt uns die Wärmeabgabe einer kleinen oder unendlich dünnen Betonmasse ohne Temperaturerhöhung an. Es ergeben sich also mit diesen beiden Methoden die mathematischen Grenzwerte für die Temperaturerhöhung einerseits und die Wärmeabgabe andererseits, zwischen denen die Wirklichkeit je nach den Umständen näher dem einen oder dem anderen Extrem liegen wird. Die von mir entwickelte Methode arbeitet, möglichst der Wirklichkeit nahekommend, zwischen der adiabatischen und isothermen Methode.

Um die Hydratationswärme richtig in Rechnung stellen zu können, brauchen wir ihre Abbängigkeit von Temperatur, Zeit, eventuell Druck, Wasserzugabe und Zuschlagsstoffart. Die Wärmeabgabe des Betons ist eine Funktion der Temperatur. Je niedriger die Temperatur, desto langsamer treten die Wärmeentwicklung und das Abbinden ein, bei konstantem Wasser-Zement-Faktor, bei konstantem Druck und bei gleicher Zuschlagsstoffart. Die Wärmeabgabe des Betons ist also eine Funktion von wenigstens drei, vermutlich aber von vier oder fünf Variablen. Ob diese Zusammenhänge nun nach der einen oder anderen Methode in ihrer Gesamtheit bestimmt werden ist keine prinzipielle Frage, sondern nur eine Frage der versuchstechnisch praktischsten und exaktesten Durchführung. Alle Wege müssen, wenn sie exakt arbeiten, zu dem gleichen Ergebnis führen.

SUMMARY OF DISCUSSION

Mr. Hellström (Sweden) states that while special cements are of much assistance, their use does not obviate the necessity of looking after the grading of materials and the mixing, transport, and handling of the concrete.

Mr. Rickey (United States) points out that engineers are no longer satisfied with standard cements, but have developed a critical attitude and are forcing manufacturers to give them new and more suitable materials.

Mr. Gedye (Great Britain) explained the work of the International Subcommittee on Special Cements, and its relation to similar work done by the United States Bureau of Reclamation.

Mr. Bates (United States) discusses certain test methods, and criticizes the practice of requiring of manufacturers a specific composition of the cement instead of developing tests capable of determining the physical qualities desired.

Herr Graf discusses the practice followed in Germany of developing cements having physical qualities suitable for the specific conditions met in various types of construction.

Viscount Falmouth (Great Britain) suggests that the International Subcommittee and the United States Bureau of Reclamation collaborate in the preparation of universal specifications for the manufacture of special cements.

Mr. Ruettgers (United States) strongly advocates compound composition as a tool for determining quality of cement, and stresses the importance of fine grinding for improving the efficiency of cements.

Mr. Forsén (Sweden) does not believe that fine grinding should be required, but would limit specifications to such properties as strength, heat of hydration, and water-cement ratio.

Mr. Ekwall (Sweden) gives reasons for the use of low-heat high-silicate cement in the new power station on the Göta River.

Sir Harold Hartley (Great Britain) discusses the complex chemical problems presented by the manufacture of cement and the setting of concrete, and asks for cooperation between research workers of America and of Europe.

M. Mary (France) describes cement tests made in the Ponts et Chaussées Laboratory, and discusses the relation of fineness to permeability and of permeability to dissolution of cement.

Mr. Lea (Great Britain) questions the necessity of determining heat of hydration during a period as long as 28 days; and, while asserting the importance of chemical composition in a study of cements, expresses much doubt of its value as a specification for cement.

Mr. Friis (Norway) said that, in general, he saw no necessity for using other than ordinary brands of cement; but that when, as in Norway, the water is acid, it is better to use a special cement.

Dr. Brahtz (United States) discusses the importance of time behavior of cement; the kind of cement required to resist uniform and non-uniform temperature stresses, respectively; and the procedure to be followed for avoiding cracks in dams.

Mr. Giertz-Hedström (Sweden) discusses the measurement of solubility of cement and its leaching with water; and states that European engineers are much interested in pozzolanic cements and hence largely employ the adiabatic method of measuring heat of hydration.

Herr Honigmann (Austria) discusses the several methods for determining heat of hydration, and the factors upon which its accurate determination depend; and suggests that the questions involved be placed upon the program of the next Congress on Large Dams.

RESUME DE LA DISCUSSION

M. Hellström (Suède) déclare que, quoique des ciments spéciaux constituent un précieux avantage, leur emploi n'obvie pas à la nécessité de veiller à la qualité des matériaux, ainsi qu'au mélange, au transport et à la manipulation du béton.

M. Rickey (États-Unis) fait remarquer que les ingénieurs ne sont plus satisfaits des ciments "standard," mais sont devenus plus exigeants, et obligent les fabricants à leur fournir des matériaux de plus en plus adaptés aux travaux.

M. Gedye (Grande-Bretagne) explique les travaux de la Sous-Commission Internationale des Ciments Spéciaux, et leurs rapports avec les travaux identiques effectués par le Bureau of Reclamation des États-Unis.

M. Bates (États-Unis) discute certaines méthodes d'essais, et critique la pratique d'imposer aux fabricants une composition spécifique du ciment au lieu de créer des essais susceptibles de déterminer les propriétés physiques désirées.

M. Graf examine la pratique suivie en Allemagne, de créer des ciments présentant des propriétés physiques convenant aux conditions spécifiques rencontrées dans les divers types de construction.

Le *Vicomte Falmouth* (Grande-Bretagne) suggère que la Sous-Commission Internationale et le "Bureau of Reclamation" des États-Unis collaborent à la préparation de spécifications universellement reconnues pour la fabrication des ciments spéciaux.

M. Ruettgers (États-Unis) préconise fortement la composition composée comme moyen de déterminer la qualité du ciment, et insiste sur l'importance d'une pulvérisation fine pour augmenter le rendement des ciments.

M. Forsén (Suède) n'estime pas que la pulvérisation fine soit indispensable, mais les spécifications devrait se borner, selon lui, à des propriétés telles que la résistance, la chaleur d'hydratation, et le rapport eau-ciment.

M. Ekwall (Suède) expose les raisons de l'emploi du ciment basse-chaleur fort en silice dans la nouvelle usine hydraulique sur le fleuve Göta.

Sir Harold Hartley (Grande-Bretagne) examine les problèmes chimiques complexes soulevés par la fabrication du ciment et la prise du béton; il demande une collaboration étroite entre les investigateurs d'Amérique et d'Europe.

M. Mary (France) décrit les essais de ciment effectués au Laboratoire des Ponts et Chaussées et discute les rapports entre la finesse et la perméabilité, et entre la perméabilité et la dissolution du ciment.

M. Lea (Grande-Bretagne) n'est pas convaincu de la nécessité de déterminer la chaleur d'hydratation pendant une période allant jusqu'à 28 jours, et, tout en affirmant l'importance de la composition chimique dans une étude des ciments, doute fortement de sa valeur en qualité de spécification pour le ciment.

M. Friis (Norvège) déclare qu'en général il ne voit pas la nécessité d'employer des ciments autres que ceux des types ordinaires, mais que lorsque l'eau est acidule, comme en Norvège, il est préférable d'employer un ciment spécial.

Le *Dr. Brahtz* (États-Unis) discute l'importance du rapport entre les activités du ciment et l'écoulement du temps; la sorte de ciment voulue pour résister aux efforts thermiques uniformes et non-uniformes, respectivement; et enfin les mesures à prendre pour empêcher la fissuration des barrages.

M. Giertz-Hedström (Suède) étudie la manière de mesurer la solubilité du ciment et son entraînement avec de l'eau, et déclare que les ingénieurs européens s'intéressent beaucoup aux ciments pouzzolanes, et emploient largement, par suite, la méthode adiabatique pour mesurer la chaleur d'hydratation.

M. Honigmann (Autriche) discute les diverses méthodes pour déterminer la chaleur d'hydratation, et les facteurs desquels sa détermination exacte depend; il suggère que les questions ainsi soulevées soient inscrites au programme du prochain Congrès des Grands Barrages.

ZUSAMMENFASSUNG DER DISKUSSION

Herr Hellström (Schweden) führt an, dass trotz der grossen Vorteile von Spezialzementen, deren Verwendung die Notwendigkeit grösster Sorgfalt bei der Zusammenenstellung der Materialien, bei der Mischung, beim Transport und bei der Behandlung von Beton nicht erübrigt.

Mr. Rickey (Vereinigte Staaten) weist darauf hin, dass die Ingenieure nicht mehr mit Standard-Zementen zufrieden sind, sondern eine kritische Haltung einnehmen und die Hersteller zur Lieferung von neuen und besser geeigneten Materialien zwingen.

Mr. Gedye (Grossbritannien) gibt Erklärungen über die Arbeit des Internationalen Unterkommission für Spezialzemente und seiner Beziehung zu ähnlichen Arbeiten des "U. S. Bureau of Reclamation."

Mr. Bates (Vereinigte Staaten) behandelt verschiedene Prüfungsmethoden und wendet sich gegen die Gewohnheit, von Herstellern eine besondere Zusammensetzung des Zements zu verlangen, anstatt Prüfungsmethoden auszuarbeiten, mit denen sich die gewünschten physikalischen Eigenschaften bestimmen lassen.

Herr Graf spricht über die in Deutschland bestehende Gepflogenheit, Zemente herzustellen mit physikalischen Eigenschaften, die für die bei den verschiedenen Konstruktionsarten auftretenden besonderen Verhältnisse geeignet sind.

Viscount Falmouth (Grossbritannien) empfiehlt eine Zusammenarbeit des Internationalen Unterkommission mit dem "U. S. Bureau of Reclamation" in der 'Aufstellung von universellen Spezifikationen für die Herstellung von Spezialzementen.

Mr. Ruettgers (Vereinigte Staaten) ist sehr für eine gemischte Zusammensetzung als Mittel zur Bestimmung der Qualität von Zement und betont die Bedeutung einer feiner Körnung zur Erhöhung der Festigkeit von Zementen.

Herr Forsén (Schweden) hält feine Körnung nicht für unbedingt erforderlich, sondern beschränkte seine Spezifikationen auf Eigenschaften wie Festigkeit, Hydratationswärme und Wasser-Zement-Faktor.

Herr Ekwall (Schweden) gibt Gründe für die Verwendung von Hochsilikatzement]mit niedriger Temperatur bei der neuen Kraftstation im Götafluss.

Sir Harold Hartley (Grossbritannien) behandelt diemit der Zementherstellung und mit dem Abbinden von Beton zusammenhängenden schwierigen chemischen Probleme und empfiehlt eine Zusammenarbeit zwischen amerikanschen und europäischen Forschern.

M. Mary (Frankreich) beschreibt die in dem Ponts et Chaussées-Laboratorium durchgeführten Untersuchungen und spricht über die Beziehungen zwischen Feinheit und Durchlässigkeit, und zwischen Durchlässigkeit und Auflösung von Zement.

Mr. Lea (Grossbritannien) lässt es fraglich erscheinen, ob die Bestimmung der Hydratationswäre für eine Zeit von 28 Tagen erforderlich ist, und trotz seiner Hervorhebung der Wichtigkeit der chemischen Zusammensetzung bei einer Untersuchung von Zementen, hegt er doch Zweifel über deren Wert als Specifikation für Zement.

Herr Friis (Norwegen) bringt zum Ausdruck, dass er im allgemeinen keine Notwendigkeit für die Verwendung anderer als gewöhnlicher Zemente sieht, dass jedoch bei säurehaltigem Wasser, wie in Norwegen, die Verwendung von Spezialzementen vorzuziehen ist.

Dr. Brahtz (Vereinigte Staaten) behandelt die Bedeutung des Verhaltens von Zement nach verschiedenen Zeitabschnitten und die bei einheitlichen, beziehungsweise nicht einheitlichen, Temperaturbeanspruchungen erforderlichen Zementarten; ferner spricht er über das zur Verhütung von Rissbildung in Talsperren anzuwendende Verfahren.

Herr Giertz-Hedström (Schweden) befasst sich mit der Messung der Löslichkeit von Zement und dessen Laugen mit Wasser und führt an, dass europäische Ingenieure Puzzolanzementen grosses Interesse entgegenbringen und daher in weitem Masse die adiabatische Methode zur Messung der Hydratationswärme anwenden.

Herr Honigmann (Österreich) behandelt die verschiedenen Methoden zur Bestimmung der Hydratationswärme und die für deren genaue Festellung entscheidenden Faktoren; er empfiehlt eine Aufnahme der damit zusammenhängenden Fragen in das Programm des nächsten Talsperren-Kongresses.

RESUMEN DE LA DISCUSION

El *Sr. Hellström* (Suecia) manifiesta que aun cuando los cementos especiales son de gran ayuda, su empleo no debe evitar la necesidad de tener cuidado con la calidad de los materiales y las mezclas, el transporte y la manipulación del hormigón.

El *Sr. Rickey* (Estados Unidos) indica que a los ingenieros ya no les satisfacen los cementos "standard", sino que son más exigentes y están obligando a los fabricantes a suministrarles materiales nuevos y más apropiados.

El *Sr. Gedye* (Gran Bretaña) explica el trabajo del Subcomisión Internacional de Cementos Especiales, y su relación con el trabajo similar realizado por el "Bureau of Reclamation" de los Estados Unidos.

El *Sr. Bates* (Estados Unidos) discute ciertos métodos de ensayo, y critica la práctica de exigir a los fabricantes una composición específica del cemento en vez de conseguir ensayos capaces de determinar las propiedades físicas deseadas.

El *Sr. Graf* discute la práctica seguida en Alemania de conseguir cementos que tengan las propiedades físicas apropiadas a las condiciones específicas que aparecen en los diversos tipos de construcción.

El *Vizconde Falmouth* (Gran Bretaña) sugiere que el Subcomisión Internacional y el "Bureau of Reclamation" de los Estados Unidos colaboren en la preparación de especificaciones universales para la fabricación de cementos especiales.

El *Sr. Ruettgers* (Estados Unidos) defiende calurosamente la composición compuesta como medio para determinar la calidad del cemento, y recalca la importancia de una pulverización fina para mejorar el rendimiento de los cementos.

El *Sr. Forsén* (Suecia) no cree que sea indispensable la pulverización fina, sino que deben limitarse las especificaciones a tales propiedades como la resistencia, el calor de hidratación y la relación agua-cemento.

El *Sr. Ekwall* (Suecia) expresa las razones para el empleo de cemento de bajo calor rico en silicato en la nueva central hidráulica situada en el río Göta.

Sir Harold Hartley (Gran Bretaña) discute los complejos problemas químicos que presenta la fabricación del cemento y el fraguado del hormigón, y pide una estrecha colaboración entre los investigadores de América y los de Europa.

El *Sr. Mary* (Francia) describe los ensayos de cementos hechos en el laboratorio de "Ponts et Chaussées", y discute la relación de la fineza con la permeabilidad y de la permeabilidad con la disolución del cemento.

El *Sr. Lea* (Gran Bretaña) pone en duda la necesidad de determinar el calor de hidratación durante un período tan largo como 28 días; y aunque sostiene la importancia de la composición química en el estudio de los cementos, pone muy en duda su valor como especificación para el cemento.

El *Sr. Friis* (Noruega) manifiesta que, en general, no ve la necesidad de emplear otros tipos de cementos que no sean los ordinarios; pero que cuando el agua es ácida, como sucede en Noruega, es preferible emplear un cemento especial.

El *Dr. Brahtz* (Estados Unidos) discute la importancia del comportamiento del cemento con relación al tiempo; la clase de cenento que se necesita para resistir los esfuerzos térmicos uniformes y no uniformes, respectivamente; y las medidas que deben tomarse para evitar las grietas en las presas.

El *Sr. Giertz-Hedström* (Suecia) estudia la manera de medir la solubilidad del cemento y su disolución por el agua; y manifiesta que los ingenieros europeos están muy interesados en los cementos puzolánicos y por este motivo emplean principalmente el método adiabático para medir el calor de hidratación.

El *Sr. Honigmann* (Austria) discute los diferentes métodos para determinar el calor de hidratación, y los factores de que depende su determinación exacta; y sugiere que estas cuestiones se incluyan en el programa del próximo Congreso de Grandes Presas.

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