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TESTING OF LOW-STRENGTH CONCRETE AFTER STANDARD AND ACCELERATED CURING

by

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SUMMARY OF RESULTS

This report concerns an investigation of the compressive strength of low-strength concrete after standard and accelerated curing in connection with the Outardes-3 project of the Quebec Hydro-Electric Commission, Montreal, Quebec.

The 23-hour compressive strength of standard-cured, 6 x 12-in. concrete test cylinders made with low-heat portland cement varies from 130 psi to 230 psi. Even at such low strengths, no damage to the specimens appears to have been caused by handling and capping.

The compressive strength of accelerated-cured, 6 x 12-in. cylinders varies from a low of 380 psi to a high of 610 psi for low-heat portland cement concrete. These values are about twice the compressive strength of companion 6 x 12-in. cylinders tested after $28\frac{1}{2}$ hours of standard moist-curing.

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ESSAIS SUR LE BETON DE FAIBLE RESISTANCE UTILISANT LA PRISE STANDARD OU ACCÉLÉRÉE

par

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RÉSUMÉ DES RESULTATS

Ce rapport concerne une recherche sur la résistance à la compression d'un béton de faible résistance en utilisant la prise standard ou accélérée, ceci en liaison avec le projet "Outardes-3" de la Commission Hydro-électrique du Québec, Montréal, Québec.

La résistance à la compression du béton de prise standard des cylindres d'essais 6 x 12 pouces, avec le ciment portland de basse température, varie entre 120 et 230 lb au pouce carré. Même à des si faibles résistances, il n'y a pas d'apparition de dégats aux spécimens par manipulation et par démoulage.

La résistance à la compression du béton de prise accélérée, des cylindres 6 x 12 pouces varie depuis un minimum de 380 lb au pouce carré jusqu'un maximum de 610 lb au pouce carré pour un béton au ciment portland de basse température. Ces valeurs sont environ doubles de la résistance à la compression des cylindres temoins 6 x 12 pouces, cylindres essayés après 28 1/2 heures de prise standard dans l'atmosphère humide.

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INTRODUCTION

Since 1963 the Construction Materials Section of the Mineral Processing Division has been engaged in the development of an accelerated test method for estimating the potential strength of concrete. The findings of this research work have been reported in departmental publications (1-3).

Briefly, the accelerated test method consists of curing 6 x 12-in. test cylinders for 24 hours under standard* conditions, followed by boiling in water for 3½ hours and measuring compressive strength one hour later.

The Quebec Hydro-Electric Commission, Montreal, has adopted this method as one of the routine control methods of estimating strength of concrete at the Outardes-3 project. This project involves the construction of a 270-ft-high concrete gravity dam located about 70 miles north of Baie Comeau, P.Q. Before the above method could be used on the job, however, additional information was needed on:

(a) Compressive strength of 6 x 12-in. test cylinders after 23 hours of standard moist-curing, to see if test cylinders can be handled at low strengths without damage.

(b) Percentage gain in compressive strength of 6 x 12-in. test cylinders, after accelerated curing, to justify the use of this test procedure.

This investigation was, therefore, undertaken to supply the required information. It was carried out at the request of Mr. René Bauset, Supervisor, Concrete Quality Control, Project Management Division, Quebec Hydro-Electric Commission, Montreal.

SCOPE OF INVESTIGATION

In order to obtain the required information, a series of nine 2-cu-ft concrete mixes were made at a constant water/cement ratio (by weight) of 0.78 ± 0.01 and a constant aggregate/cement ratio (by weight) of 9.96 ± 0.07. Nine 6 x 12-in. test cylinders were cast from each of the six concrete mixes made with low-heat portland cement, and three 6 x 12-in. cylinders were cast from each of the three concrete mixes made with normal portland cement. All specimens were tested for compressive strength after standard and/or accelerated curing.

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* 73.2 ± 3°F and 100 per cent relative humidity.

MATERIALS USED

Cements

Five brands of low-heat portland cement and one brand of normal portland cement were used. Low-heat portland cements were supplied in two-bag lots by the following cement companies:

1. Canada Cement Company Limited, Montreal East, P.Q.
2. Canada Cement Company Limited, Hull, P.Q.
3. Lafarge Cement Quebec Ltd., St. Constant, P.Q.
4. Miron Company Ltd., St. Michel, P.Q.
5. St. Lawrence Cement Company, Villeneuve, P.Q.

Normal portland cement was supplied by Canada Cement Company Limited, Hull, P.Q.

One bag of each of the five brands of low-heat portland cement was blended before use by dry mixing for 30 minutes in a Taylor tube mill.

The chemical analyses of each brand of low-heat portland cement and normal portland cement are given in Table 1. No chemical analyses were carried out on the blended low-heat portland cement.

TABLE 1

Chemical Analyses of Normal and Low-Heat Portland Cements*

	Low-heat Portland Cement					Normal Portland Cement
	Canada Cement, Montreal	Canada Cement, Hull	Lafarge Cement	Miron Cement	St. Lawrence Cement	
Chemical Analyses						
Insoluble Residue, %	0.30	0.06	0.15	0.30	0.02	0.09
Silicon Dioxide, SiO_2%	22.64	23.8	22.96	23.00	22.32	21.0
Aluminum Oxide, Al_2O_3%	4.65	4.3	4.02	4.50	4.94	5.8
Ferric Oxide, Fe_2O_3%	4.75	3.1	3.98	4.10	4.91	2.5
Calcium Oxide, CaO%	61.67	63.0	62.11	63.0	60.79	63.9
Magnesium Oxide, MgO%	2.64	2.5	2.96	2.90	3.02	2.9
Sulphur Trioxide, SO_3%	2.14	2.0	2.30	1.50	2.26	2.3
Loss on Ignition, %	0.68	0.52	0.70	0.70	0.54	0.09
Compound Composition						
Tricalcium Silicate, C_3S%	34.9	36.6	36.9	41.2	31.2	51.4
Dicalcium Silicate, C_2S%	38.6	40.6	38.2	34.9	40.5	21.4
Tricalcium Aluminate, C_3A%	4.3	6.1	3.9	4.9	4.8	11.1
Tetracalcium alumina-ferrite, C_4AF%	14.4	9.4	12.1	12.5	14.9	7.6

* Test data supplied by the cement companies concerned.

Aggregates

The coarse aggregate used was crushed limestone having a maximum size of one inch.

Local natural sand was used as fine aggregate. To keep the grading uniform for each mix, the sand was separated into different size fractions and then recombined to a specific grading.

The gradings and physical properties of both coarse and fine aggregates are given in Tables 2 and 3.

TABLE 2

Grading of Aggregates

Coarse Aggregate		Fine Aggregate	
Sieve Size	Cumulative percentage retained	Sieve Size	Cumulative percentage retained
		No. 4	0
3/4 in.	33.3	No. 8	10.0
3/8 in.	66.6	No. 16	32.5
No. 4	100.0	No. 30	57.5
		No. 50	80.0
		No. 100	94.0
		Pan	100.0

TABLE 3

Physical Properties of Coarse and Fine Aggregates

	Crushed Limestone	Natural Sand
Specific Gravity	2.68	2.70
Absorption (%)	0.4	0.5

MIX DESIGN DATA

Mix-design data for the concrete mixes are given in Table 4. Darex air-entraining agent was used; in some mixes a de-air-entraining agent had to be used to control the correct amount of air in the mixes.

The graded, room-dry coarse and fine aggregates were weighed and immersed in water for 24 hours before use. At the end of soaking period, the excess water was decanted and the amount of water held by the wet aggregate was determined by weighing.

CONCRETE MIXES

A series of nine 2-cu-ft concrete mixes were prepared and test specimens cast in the Mines Branch laboratory at Ottawa on August 24, 29 and 31, 1967. On each of these three days, three mixes were made, two with low-heat portland cement and one with normal portland cement. A laboratory counter-current concrete mixer was used for preparing the concrete batches.

Properties of Fresh Concrete

The properties of the fresh concretes, i.e. temperature, slump, unit weight and air content are given in Table 5.

Preparation and Testing of Test Specimens

Nine 6 x 12-in. test cylinders were cast from concrete mixes made with low-heat portland cement, and three 6 x 12-in. cylinders were cast from mixes made with normal portland cement. The test cylinders were prepared by filling 6 x 12-in. steel moulds in two approximately equal layers. Each layer was compacted with a 1 1/8-in.-diameter internal vibrator, inserted once for approximately 4 to 6 seconds.

For concrete mixes, made with low-heat portland cement, three of the moulded specimens selected at random were fitted with machined steel caps; the remaining six sylinders were covered only with glass plates. Following this, all the moulded specimens were covered with water-saturated burlap and left in the casting room for 22 hours. At the end of this period, the nine test specimens cast from each of the mixes made with low-heat portland cement were disposed of as follows:

Two of the specimens were removed from the moulds, capped and tested at the age of 23 hours.

Two of the specimens were removed from the moulds and transferred immediately to a moist-curing room, maintained at 73.2 $\pm$ 3°F and 100 per cent relative humidity, for testing at 28 days.

TABLE 4

Mix Design Data

Mix No	Type of Cement	Date of Mixing	W/C* Ratio	Mix Proportions, lb/cu yd				A/C* Ratio
				Free Water	Cement	Aggregate, SSD**		
						Fine Aggregate	Coarse Aggregate	
1	Low-heat, Lafarge	August 24/67	0.78	258	331	1602	1688	9.9
2	Low-heat, St. Lawrence	"	0.78	257	330	1597	1683	9.9
3	Normal portland,	"	0.78	256	329	1586	1672	9.9
4	Low-heat, Miron	August 29/67	0.78	256	329	1591	1676	9.9
5	Low-heat, Canada Cement, Hull	"	0.78	261	337	1629	1715	9.9
6	Normal portland	"	0.78	262	338	1627	1715	9.9
7	Low-heat, Canada Cement, Montreal	August 31/67	0.78	252	325	1571	1654	10.0
8	Low-heat, Blended	"	0.78	255	329	1589	1674	9.9
9	Normal portland	"	0.77	253	329	1585	1668	9.9

* W/C: Water-cement ratio by weight of free water to cement; A/C: aggregate-cement ratio by weight.

** SSD: aggregate in a saturated, surface-dry condition.

TABLE 5

Properties of Fresh Concrete

Mix No	Type of Cement	Date of Mixing	Properties of Fresh Concrete			
			Temp, °F	Slump, in.	Unit Weight, lb/cu ft	Air Content, per cent
1	Low-heat, Lafarge	Aug.24/67	66	1 1/4	144.0	3.5
2	Low-heat, St. Lawrence	"	68	2 1/4	143.2	5.2
3	Normal portland	"	69	1 1/2	142.4	5.4
4	Low-heat, Miron	Aug.29/67	70	2 1/2	142.8	6.2
5	Low-heat, Canada Cement, Hull	"	70	2.0	146.0	5.2
6	Normal portland	"	71	2 1/4	146.0	4.0
7	Low-heat, Canada Cement, Montreal	Aug.31/67	71	1 3/4	140.8	6.2
8	Blended low-heat	"	70	3 1/4	142.4	4.0
9	Normal portland	"	69	1 1/2	142.0	4.2

Two of the specimens were removed from the moulds and kept under wet burlap for $5\frac{1}{2}$ hours, after which they were capped and tested in compression at $28\frac{1}{2}$ hours.

The remaining three specimens were left in their moulds for another two hours, then they were placed, together with their moulds and caps, in an accelerated-curing tank maintained at 210°F, for $3\frac{1}{2}$ hours. At the end of this period they were removed from the tank, demoulded, cooled, capped and tested in compression at an age of $28\frac{1}{2}$ hours.

For each of the mixes made with normal portland cement, two specimens were tested in compression after 23 hours of moist curing and one after 28 days of moist curing.

All testing was carried out in accordance with the ASTM Standard Method of test C 39-64, in a 600,000-lb-capacity Amsler testing machine. The test results are shown in Table 6.

TABLE 6

Compressive Strength Test Results

Mix No	Type of Cement	Strength, psi			
		Accelerated[1] Cured $28\frac{1}{2}$ hours	Standard Moist-Cured		
			23 hours[2]	$28\frac{1}{2}$ hours[2]	28-days[2]
1	Low-heat, Lafarge	580	230	280	1860
2	Low-heat, St. Lawrence	380	130	180	1475
3	Normal portland	-	220	-	2105[3]
4	Low-heat, Miron	610	220	280	1600
5	Low-heat, Canada Cement, Hull	500	195	240	1440
6	Normal portland	-	325	-	2330[3]
7	Low-heat, Canada Cement, Montreal	465	160	215	1310
8	Blended low-heat	495	165	200	1550
9	Normal portland	-	205	-	2210[3]

1. Average of three test results
2. Average of two test results
3. Only one 6 x 12-in. cylinder tested.

DISCUSSION

The 23-hour compressive strength of the standard moist-cured 6 x 12-in. cylinders made with low-heat portland cement concrete varies from 130 psi to 230 psi. Demoulding, handling and capping of the specimens appeared to cause no damage to the specimens. Therefore, it is believed that the handling of 23-hour-old test specimens cast from low-heat portland cement concrete should not pose any special problems in the field. However, unnecessary handling of test specimens must be avoided.

Time-of-set determinations using penetration needles were carried out on concrete mixes made with low-heat portland cement (Canada Cement Company Limited, Montreal) and blended low-heat portland cement. In each case, the final time-of-set was $13\frac{1}{2}$-14 hours. Thus there was a time interval of about 10 hours between the final set of concrete and the handling of test specimens which was considered adequate.

The compressive strength of 6 x 12-in. cylinders after accelerated curing varies from 380 psi for concrete made with St. Lawrence low-heat portland cement to 610 psi for concrete made with Miron low-heat portland cement. These values are about twice the compressive strength of companion 6 x 12-in. cylinders tested at $28\frac{1}{2}$ hours after standard moist-curing.

In general, the compressive strengths of 6 x 12-in. cylinders after accelerated curing are about 30 per cent of the compressive strength of companion cylinders at 28 days after standard moist-curing. This level of strength, although low, can be used to accurately predict the potential strengths of concrete at later age (1).

Notwithstanding the constant water/cement ratio and constant aggregate/cement ratio of the concrete mixes, there is a wide spread in the compressive strengths of test specimens after both accelerated and standard moist-curing. It is believed that this large spread is primarily due to the differences in the compound composition of the cements being used.

It should be noted that the compressive strength of test cylinders (Lafarge low-heat portland cement concrete) at the age of 23 hours is about the same as that obtained for test cylinders cast from concrete made with normal portland cement (Mix No. 3).

This investigation was not designed to compare the strength characteristics of different brands of low-heat portland cements, and therefore these data should not be used to compare the relative superiority of the cements under study.

CONCLUSIONS

1. Test specimens cast from low-heat portland cement concrete with a cement content of 335 $\pm$ 6 lb/cu yd can be demoulded, handled and capped as early as 23 hours after casting without causing any apparent damage to the specimens.

2. The compressive strengths of 6 x 12-in. cylinders after accelerated curing are about 30 per cent of the 28-day compressive strengths of companion 6 x 12-in. moist-cured cylinders. This ratio can be used to predict, with an acceptable degree of accuracy, the later-age compressive strength of concrete.

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