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INVESTIGATION OF DURABILITY OF CONCRETE FOR MANICOUAGAN-5 PROJECT

by

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MINERAL PROCESSING DIVISION

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SUMMARY OF RESULTS

Durability studies were carried out on the first series of 18x18x58 in. concrete prisms to evaluate the relative performance of the two admixtures, Pozzolith No. 8 and Cerygel, to be used in concrete for the Manicouagan-5 project.

Visual examination showed no damage of concrete test specimens after 513 cycles of freezing and thawing.

Periodic pulse velocity measurements indicated that, of the two otherwise identical concretes, the one made with Cerygel showed slightly better durability than that made with Pozzolith No. 8.

The control test specimen incorporating Pozzolith showed better flexural and compressive strength than that made with Cerygel.

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Rapport industriel confidentiel

Direction des mines

Rapport d'Investigation IR 63-84

ÉTUDE DE LA DURABILITÉ DU BÉTON DESTINÉ À L'ENTREPRISE Nº 5 DE LA MANICOUAGAN

par

N.G. Zoldners*

APERÇU DES RÉSULTATS

Des études de la durabilité ont été menées à l'aide de la première série de prismes de béton de 18 pouces sur 18 pouces sur 58 aux fins de déterminer le comportement relatif des deux agents d'addition (Pozzolithe nº 8 et Cérygel) destinés à servir à la préparation du béton de l'entreprise nº 5 de la Manicouagan.

L'examen visuel n'a pas permis de déceler de dommage sur les échantillons de béton soumis à 513 cycles de gel et de dégel.

Les mesures de la vitesse des pulsations périodiques ont indiqué que, des deux bétons, qui sont par ailleurs identiques, celui qui est préparé à l'aide de Cérygel a fait preuve d'une durabilité légèrement supérieure à celle du béton préparé à l'aide de la Pozzolithe nº 8.

L'échantillon expérimental de vérification qui contenait de la Pozzolithe a démontré une résistance à la flexion et à la compression légèrement supérieure à celle du béton qui contenait du Cérygel.

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INTRODUCTION

The Quebec Hydro-Electric Commission (Hydro-Quebec) has started the development of a huge hydro-electric power project in northern Quebec. The project consists of three dams and related power generating stations on the Manicouagan River and two dams on the Outardes River.

The main feature of the entire project is the Manic-5 dam, about 135 miles north of Baie Comeau, a town on the north shore of the St. Lawrence River. The dam was designed by the late André Coyne, the famous French dam-builder, as a multiple arch dam, and probably will be the largest one of its kind in the world. A total of 2.8 million cu yd of high-strength concrete is required for the dam which will be 4000 ft long and 720 ft high.

Arrangements were made by the Power Development Division of Hydro-Quebec with the Mineral Processing Division of the Mines Branch to make, periodically, non-destructive tests of large concrete test prisms exposed to freezing and thawing, using the Mines Branch ultrasonic concrete tester.

PURPOSE AND SCOPE OF THE INVESTIGATION

The purpose of this investigation was to determine the durability of concrete test prisms exposed to slow freezing and thawing cycles.

Two 18x18x58 in. concrete prism specimens were prepared from each of the two identical mixes A and B, using two different water-reducing and air-entraining admixtures. One prism of each mix was tested for durability in a specially designed, automatically controlled, large freeze-thaw unit of the Ecole Polytechnique, University of Montreal. The test specimens were exposed to slow freezing in air and thawing in water, with the unit performing two full cycles per day.

Ultrasonic pulse measurements were made on the two test prisms in thawed condition after 161, 246, 360 and 513 cycles. No measurements were made at zero cycles due to delayed participation of the Mines Branch in this investigation programme.

The two companion prisms were kept as reference test specimens and tested for flexural and compressive strength.

CONCRETE MIXES

Test mixes were designed and test specimens prepared at the Ecole Polytechnique, Montreal, by the Industrial and Commercial Laboratories Limited.

The details of the materials used, mix proportions, and characteristics of fresh concrete were supplied by the above laboratory (1), and are given below.

Materials Used

Cement and concrete aggregates for the test mixes were supplied by Hydro-Quebec from the Manic-5 job-site and are being used for producing concrete for construction of the dam.

Cement

Modified type II cement, used in the preparation of concrete mixes, was specially manufactured to the specifications of the Hydro-Quebec by St. Lawrence Cement Company Ltd., at the Villeneuve plant at Quebec City.

Aggregates

The rock for coarse aggregate was grey granite gneiss, containing an appreciable amount of biotite. The rock was crushed and graded to a maximum size of 6 inches.

The fine aggregate was washed natural sand graded in minus 3/8 in. sizes. The gradings of the coarse and fine aggregate used in test mixes are shown in Table 1.

TABLE 1

Grading of Aggregates

Coarse Aggregate			Fine Aggregate		
Size Fractions	lb	%	Size Fractions	lb	%
6 in. to 3 in.	891	35.4	3/8 in. to No. 4	70	8.0
3 in. to 1½ in.	698	27.7	No. 4 to No. 16	227	26.0
1½ in. to ¾ in.	570	22.6	No. 16 to No. 50	419	48.0
3/4 in. to 3/8 in.	461	14.3	Minus No. 50	157	18.0

The proportion of coarse to fine aggregate used in test mixes was, in per cent by weight, CA:FA = 75:25.

Admixtures

Water-reducing and air-entraining admixtures were added to concrete mixtures in amounts, per bag of cement, as follows:

Mix A Pozzolith No. 8 - 1/4 lb
MBVR - $1\frac{1}{2}$ oz
(Both admixtures are products of Master Builders Co., a Division of American Marietta Company, Cleveland 3, Ohio, U.S.A.)

Mix B Cerygel - 1 oz
(Manufactured by the Les Industries Chimiques de Voreppe, France)

Properties of Fresh Concrete

Both test mixes were prepared on April 2, 1962. Pertinent mix data and characteristics of the fresh concrete wet screened through a 2 in. sieve are given in Table 2.

TABLE 2

Mix Data

	Mix A (Pozzolith)	Mix B (Cerygel)
Cement, lb/cu yd	438	438
Aggregate, "	3493	3493
Water "	188	183
Total	4119	4114
W/C ratio	0.43	0.42
Slump, in.	3/8	1/4
Air Content, %	6.0	6.0
Unit Wt., lb/cu ft	152.3	152.9

TEST SPECIMENS

From each of the test mixes, two 18x18x58 in. prisms were moulded. The steel moulds were collapsable and lined with plastic sheet to prevent adhesion of concrete. The dry mixture, of a consistency of less than 1/2 in. slump, was consolidated by a 2-in. immersion vibrator, leaving some honeycombs on the surface of the prisms.

One prism of each pair was moist cured for about 6 months and then subjected to freeze-thaw cycling. The other prism served as a control test specimen and was broken in flexure after more than 8 months of moist curing.

From the broken prism ends 9x18 in. cores were drilled for testing in compression.

CONCRETE DURABILITY STUDIES

Although the durability of concrete cannot be measured directly, prolonged exposure to repeated cycles of freezing and thawing produces measurable changes in its physical properties. These changes may indicate deterioration of concrete. Measurements, made by non-destructive methods, after freeze-thaw cycling of the test specimens, provide data which can be used for evaluating the relative frost resistance or durability of concrete.

Ultrasonic Concrete Tester

To determine the resistance of concrete to alternate freezing and thawing, periodic determinations of ultrasonic pulse velocity in the test specimens were made using an ultrasonic concrete tester*. This apparatus (Type UCT 30) operates at 100 Kc frequency with a 0.1 microsecond sensitivity. However, this accuracy was rarely achieved in this project due to the large size of test specimens, and the readings were obtained with an accuracy of one microsecond. Whenever the measurements were to be made, the equipment was taken in a departmental station wagon to Montreal. The apparatus was left overnight in the concrete laboratory of the École Polytechnique to adjust it to the laboratory temperature before being used for testing.

Pulse Velocity Determination

The end faces of the test prisms were divided into a 3-in. grid pattern, as shown in Figure 1.

The method (2) consists essentially of measuring the time of propagation of a pulse of longitudinal vibration between two piezoelectric transducers placed in contact with opposite end faces of the prism. The 2-in. diameter barium-titanate transducers in brass housings were pressed in turn at all corresponding grid points of every grid line from 1A to 5E. To ensure maximum accuracy three readings were taken at each grid point.

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*Manufactured by Cawkell Research & Electronics Limited, Scotts Road, Southall, Middlesex, England.

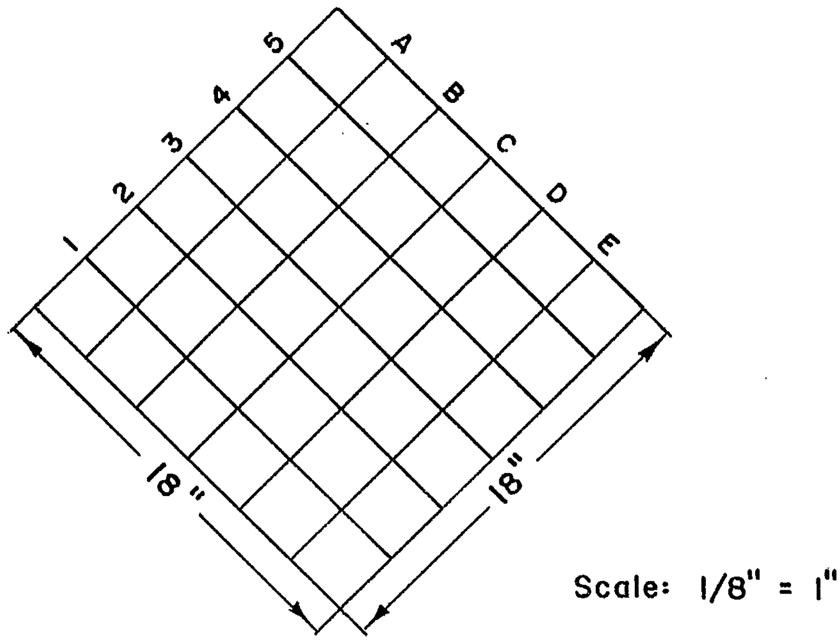

Figure I. End View of a Prism
Showing Grid Layout

Test Results

The reading obtained by the ultrasonic concrete tester is the actual pulse transmission time and is measured in microseconds. All the test readings for prisms A and B are compiled in Tables 3 and 4. Each result is the mean of three readings. Also shown are the average of the five points on each grid line. These values have been converted into pulse velocities, by dividing the pulse path length (i.e., prism length - 4.83 ft) into pulse transmission time (i.e., microseconds) readings, and are shown in Tables 5 and 6.

The companion control prisms were tested for flexural and compressive strength in the concrete laboratory of Ecole Polytechnique. The test results were reported by Prof. J. Houde(3) and are shown in Table 7.

TABLE 3

Pulse Transmission Time - Prism A (Pozzolith)

Date of Test	Number of Fr -Th Cycles	Line 1		Line 2		Line 3		Line 4		Line 5	
		Point	Time, μsec	Point	Time, μsec	Point	Time, μsec	Point	Time, μsec	Point	Time, μsec
Jan.8, 1963	161	1-A	340	2-A	340	3-A	336	4-A	340	5-A	336
		1-B	340	2-B	340	3-B	340	4-B	343	5-B	340
		1-C	336	2-C	350	3-C	346	4-C	340	5-C	340
		1-D	336	2-D	346	3-D	336	4-D	340	5-D	333
		1-E	333	2-E	340	3-E	340	4-E	340	5-E	343
		Average	337	Average	343	Average	340	Average	341	Average	338
Feb.27, 1963	246	1-A	340	2-A	340	3-A	340	4-A	340	5-A	337
		1-B	330	2-B	340	3-B	340	4-B	347	5-B	340
		1-C	337	2-C	350	3-C	347	4-C	340	5-C	333
		1-D	330	2-D	343	3-D	340	4-D	337	5-D	323
		1-E	340	2-E	337	3-E	337	4-E	340	5-E	337
		Average	335	Average	342	Average	341	Average	341	Average	334
Apr.26, 1963	360	1-A	344	2-A	342	3-A	340	4-A	340	5-A	341
		1-B	348	2-B	342	3-B	341	4-B	341	5-B	341
		1-C	352	2-C	355	3-C	354	4-C	350	5-C	341
		1-D	348	2-D	349	3-D	349	4-D	342	5-D	341
		1-E	344	2-E	342	3-E	340	4-E	334	5-E	340
		Average	347	Average	346	Average	345	Average	342	Average	341
July 17, 1963	513	1-A	352	2-A	350	3-A	352	4-A	351	5-A	351
		1-B	348	2-B	355	3-B	356	4-B	353	5-B	350
		1-C	349	2-C	352	3-C	354	4-C	350	5-C	350
		1-D	341	2-D	350	3-D	351	4-D	341	5-D	350
		1-E	344	2-E	350	3-E	350	4-E	340	5-E	350
		Average	345	Average	351	Average	353	Average	347	Average	350

TABLE 4

Pulse Transmission Time - Prism B (Cerygel)

Date of Test	Number of Fr -Th Cycles	Line 1		Line 2		Line 3		Line 4		Line 5	
		Point	Time, μsec	Point	Time, μsec	Point	Time, μsec	Point	Time, μsec	Point	Time, μsec
Jan.8, 1963	161	1-A	347	2-A	350	3-A	353	4-A	350	5-A	343
		1-B	350	2-B	353	3-B	356	4-B	353	5-B	347
		1-C	350	2-C	357	3-C	360	4-C	356	5-C	350
		1-D	347	2-D	343	3-D	356	4-D	353	5-D	350
		1-E	353	2-E	343	3-E	353	4-E	343	5-E	340
		Average	349	Average	349	Average	356	Average	351	Average	346
Feb.27, 1963	246	1-A	343	2-A	340	3-A	337	4-A	340	5-A	320
		1-B	340	2-B	330	3-B	347	4-B	337	5-B	330
		1-C	333	2-C	340	3-C	350	4-C	340	5-C	337
		1-D	340	2-D	340	3-D	343	4-D	343	5-D	330
		1-E	340	2-E	340	3-E	340	4-E	330	5-E	320
		Average	339	Average	338	Average	343	Average	338	Average	327
Apr.26, 1963	360	1-A	340	2-A	340	3-A	340	4-A	340	5-A	-
		1-B	-	2-B	347	3-B	340	4-B	341	5-B	-
		1-C	-	2-C	346	3-C	351	4-C	-	5-C	340
		1-D	-	2-D	345	3-D	350	4-D	340	5-D	340
		1-E	345	2-E	340	3-E	-	4-E	342	5-E	339
		Average	343	Average	344	Average	345	Average	341	Average	340
July 17, 1963	513	1-A	350	2-A	350	3-A	350	4-A	350	5-A	350
		1-B	350	2-B	350	3-B	350	4-B	350	5-B	351
		1-C	-	2-C	350	3-C	357	4-C	350	5-C	350
		1-D	-	2-D	350	3-D	350	4-D	350	5-D	350
		1-E	350	2-E	343	3-E	350	4-E	350	5-E	344
		Average	350	Average	349	Average	352	Average	350	Average	349

TABLE 5

Ultrasonic Pulse Velocities - Prism A (Pozzolith)
(fps)

Number of Fr -Th Cycles	Line 1	Line 2	Line 3	Line 4	Line 5	Average
161	14,310	14,090	14,210	14,150	14,250	14,202
246	14,400	14,100	14,150	14,150	14,450	14,250
360	14,010	14,080	14,200	14,450	14,200	14,188
513	14,000	13,750	13,690	14,150	13,790	13,876

TABLE 6

Ultrasonic Pulse Velocities - Prism B (Cerygel)
(fps)

Number of Fr -Th Cycles	Line 1	Line 2	Line 3	Line 4	Line 5	Average
161	13,820	13,820	13,550	13,750	13,980	13,784
246	14,220	14,280	14,090	14,280	14,780	14,330
360	14,080	14,020	13,990	14,150	14,210	14,090
513	13,800	13,810	13,700	13,790	13,850	13,790

TABLE 7

Test Results of Control Prisms (3)

Test	Test Specimen	A (Pozzolith)	B (Cerygel)
Flexural Strength, psi -	18x18x58 in. prism	591	356
Compressive Strength, psi -	9 x 18 in. drill core	6000 6700	5360 5250

DISCUSSION

Tables 5 and 6 show that the average pulse velocity determined at the beginning of the measurements was 14,202 fps for prism A and 13,784 fps for prism B, indicating the good quality of both test specimens (2). Although the 3 per cent lead in pulse velocity of prism A over that of B is small, it is significant. The higher strength of prism A was substantiated by flexural and compressive strength results of companion control test prisms as shown in Table 7.

The average results in Tables 5 and 6 show that the pulse velocity, after a slight increase at 246 cycles, decreased with the increasing number of freeze-thaw cycles. The total decrease after 513 cycles was 2.3 per cent for prism A, but showed a slight increase for prism B.

These results, as well as visual examination of the freeze-thaw test prisms after 513 cycles, showing no surface deterioration, are an indication of good frost-resisting qualities of both prisms, with concrete in prism B being superior in durability to concrete in prism A.

CONCLUSIONS

1. Concrete used in both prisms A and B was in good condition after completion of 513 cycles of freezing and thawing.

2. Of the two otherwise identical concretes, that made with Pozzolith No. 8 and MBVR showed higher flexural and compressive strength than that made with Cerygel.

3. Of the two otherwise identical concrete specimens subjected to freezing and thawing, that incorporating Cerygel showed slightly better durability, as measured by pulse velocity, than that made with Pozzolith No. 8 and MBVR.

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