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INVESTIGATION OF DURABILITY OF CONCRETE FOR MANICOUAGAN-2 PROJECT

by

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MINERAL PROCESSING DIVISION

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SUMMARY OF RESULTS

Freeze-thaw durability studies were carried out on eight concrete test series to evaluate the relative performance of different admixtures to be used in concrete for the Manicouagan-2 project.

The investigation showed that the concrete test specimens suffered no significant damage at the completion of 1,000 freeze-thaw cycles.

The residual flexural strengths of the test series at the completion of 1,000 freeze-thaw cycles were between 83.5 and 108.9 per cent except for series 580 containing Cyrigel and series 644 containing Darex, for which the corresponding strengths were 70.1 and 59.7 per cent, respectively.

The relative dynamic moduli of elasticity of the test specimens from the different series were greater than 96 per cent, indicating excellent durability of concrete.

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Rapport industriel et confidentiel

Rapport d'investigation IR 63-38

RECHERCHES SUR LA DURABILITÉ DU BÉTON DESTINÉ À L'ENTREPRISE MANICOUAGAN 2

par

V.M. Malhotra* et N.G. Zoldners**

RÉSUMÉ DES RÉSULTATS

Les auteurs ont étudié la durabilité du béton, dans des conditions de gel-dégel, au cours de 8 séries d'essais faits pour juger du comportement relatif de différents mélanges à béton pour l'entreprise Manicouagan 2.

Ils ont constaté qu'après avoir subi 1,000 cycles de gel-dégel, les échantillons d'essai de béton n'ont pas été gravement endommagés.

A la fin de ces expériences, les résistances résiduelles à la flexion de ces échantillons variaient de 83.5 à 108.9 p. 100, sauf ceux de la série 580 qui contenaient du Cyrigel (70.1 p. 100) et de la série 644 qui contenaient du Darex (59.7 p. 100).

Les modules (coefficients) d'élasticité dynamiques relatifs des échantillons d'essai des différentes séries, avaient un taux supérieur à 96 p. 100. C'est là l'indice de l'excellente durabilité du béton.

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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, about 200 miles northeast of Quebec City. The project consists of 3 dams and related power generating stations on the Manicouagan River and 2 dams on the Outardes River.

The Concrete Laboratory Inc., Montreal, has been retained by the Commission to carry out investigations on concrete mix design and concrete materials to be used in the construction of Manicouagan-2 dam of the above project. The main structure of this part of the project is a concrete gravity dam of a hollow-joint type. This will probably be the largest void structure of its kind in the world. A total of 1.5 million cu yd of concrete are required for the dam, which will be 2300 ft long and 240 ft high.

Arrangements were made with the Mineral Processing Division of the Mines Branch to conduct freezing and thawing tests on concrete beam specimens prepared by the above laboratory.

The purpose of this investigation was to study the relative durability of concrete test beams prepared from eight identical mixes using different air-entraining and water-reducing admixtures.

CONCRETE MIXES

A series of eight concrete mixes were designed and prepared, and test specimens were moulded by the Concrete Laboratory Inc., Montreal.

The details as regards the materials used, mix design data, and the test results on fresh concrete were supplied by the above laboratory, and these are given below.

Materials Used

Cement

Modified type II cement, specially manufactured to the specifications of the Hydro-Electric Commission of Quebec by St. Lawrence Cement Company Ltd.,(Villeneuve plant, Quebec City), was used in the preparation of concrete mixes. The chemical composition and the calculated potential compound composition of the cement are given in Table 1.

TABLE 1

Chemical Analysis and Compound Composition of Cement

Cement Constituents	%	Compound Composition*	%
SiO_2	22.50		
Al_2O_3	5.28	C_3S	28.0
Fe_2O_3	4.85	C_2S	44.0
CaO, free	0.34	C_3A	5.8
CaO, total	60.35	C_4AF	14.7
MgO	2.88	Others	7.5
SO_3	2.10	Total	100.0
Ignition Loss	0.58		
Insoluble Residue	0.28		
Total	99.16		

Aggregates

The coarse aggregate used was a coarse-grained pink granite from a quarry near the dam site.

Fine aggregate consisted of a blend of two grades of natural sand, a medium sand from region "A" (70 per cent) and a fine sand from region "B" (30 per cent).

The gradings of the coarse aggregate and blended fine aggregate are given in Table 2.

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* The abbreviations used are:

C_3S = Tricalcium silicate
C_2S = Dicalcium silicate
C_3A = Tricalcium aluminate
C_4AF = Tetracalcium alumina-ferrite

TABLE 2

Grading of Aggregates

Coarse Aggregate		Fine Aggregate	
Sieve Size	Per cent Passing	Sieve Size	Per cent Passing
$1\frac{1}{2}$ in.	99.6	No. 4 mesh	96.9
1 in.	60.4	No. 8 mesh	90.6
$\frac{3}{4}$ in.	41.0	No. 16 mesh	78.9
$\frac{1}{2}$ in.	23.8	No. 30 mesh	51.7
3/8 in.	13.3	No. 50 mesh	20.4
No. 4 mesh	1.9	No. 100 mesh	4.6
		No. 200 mesh	0.7

Some physical properties of both the crushed coarse aggregate and blended natural sand are given in Table 3.

TABLE 3

Physical Properties of Coarse and Fine Aggregates

	Crushed Granite	Natural Sand
Specific Gravity	2.72	2.63
Unit Weight, lb/cu ft	93.0	108.0
Mix Proportions by Weight, %	60	40

Admixtures

Seven of the eight concrete mixes contained a combination of an air-entraining and a water-reducing admixture produced by different manufacturers as listed below. The eighth mix contained no admixture.

1. DAREX AEA - Air-entraining agent
   WRDA - Water-reducing dispersing agent
   Manufactured by Dewey and Almy Chemical, a division of W. R. Grace & Co., Montreal 32, Canada.

2. PROTEX AEA - Air-entraining agent
   PDA-IX - Protex dispersing agent
   Manufactured by Autolene Lubricants Company, Denver 9, Colorado, U.S.A.

3. VINSOL NVX - Neutralized vinsol resin air-entraining agent
   MARACON MC - Maracon water-reducing agent
   Manufactured by Marathon Corp., a division of American Can Company, Menasha, Wisconsin, U.S.A.

4. MBVR - Master Builders vinsol resin air-entraining agent
   POZZOLITH - Master Builders dispersing agent
   Manufactured by the Master Builders Company, a division of American-Marietta Company; Cleveland 3, Ohio, U.S.A.

5. PX A2 - Modification of N.V.R., Sternson air-entraining agent
   PORZITE 73 - Sternson water-reducing additive
   Manufactured by G. F. Sterne & Sons Limited, Brantford, Ontario, Canada.

6. CYRIGEL - Air-entraining and water-reducing agent
   Manufactured by Les Industries Chimiques de Voreppe, France.

7. DAREX - Air-entraining agent
   Manufactured by Dewey and Almy Chemicals, a division of W. R. Grace & Co., Montreal 32, Canada.

Mix Design Data

The same mix design was used for all the test mixes. Design data for a typical mix are given in Table 4.

TABLE 4

Design Data of a Typical Concrete Mix

Mix Proportions per cu yd				
Cement, lb	Aggregates, lb		Water, lb	W/C Ratio (by weight)
	Coarse	Fine		
405	2025	1345	220	0.54

Properties of Fresh Concrete

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

TABLE 5

Properties of Fresh Concrete

Series No.	Admixtures	Properties of Fresh Concrete		
		Slump, in.	Unit-weight, lb/cu ft	Air content, %
B 280	Darex AEA, WRDA			4.3
B 316	Protex, PDA IX	Slump	Was	4.8
B 402	Vinsol NVX, Maracon MC	varied		4.6
B 430	MBVR, Pozzolith	from	not	4.0
B 491	PX A2, Porzite 73	0		4.7
B 580	Cyrigel	to	recorded	4.0
B 612	None	3/8 in.		3.0
B 644	Darex AEA			3.8

CONCRETE TEST SPECIMENS

From each of the eight test mixes, six 3 x 4 x 15 in. beams were prepared for durability studies. After initial moist-curing for 14 to 21 days, all test beams, packed in moist sand boxes, were delivered to the Mines Branch laboratories in Ottawa where they were further moist-cured until the test specimens reached 28 days of age.

Every test beam was provided with stainless steel reference inserts embedded in each end for length measurements.

All beams were received in good, undamaged condition and were provided with fresh markings and serial numbers.

CONCRETE DURABILITY STUDIES

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

Freezing and Thawing Procedure

In this investigation, test specimens were exposed to rapidly repeated cycles of freezing in air and thawing in water according to the ASTM Test Method C 291-61T.

However, the standard procedure for this work has been altered at the request of the Hydro-Quebec by extending the period of initial moist-curing from 14 to 28 days.

The automatic freeze-thaw unit* used in this investigation performs 8 cycles per day. One complete cycle, from 40 ± 3°F to 0 ± 3°F and back to 40 ± 3°F, requires about 3 hours.

At the end of the initial moist-curing period, the temperature of each set of 3 test beams was reduced to a uniform 40 ± 3°F by placing the beams in the freeze-thaw cabinet at the thawing phase of the cycle for one hour. The initial and all subsequent measurements of the freeze-thaw and the reference test specimens were made at this temperature.

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*Manufactured by the Canadian Ice Machine Company, Ltd., Toronto, Ont.

After initial measurements of the test beams were taken, three beams were placed in the freeze-thaw cabinet and the three companion beams were kept in the moist-curing room for reference purposes.

The tests were started on September 7, 1962, and were terminated on February 5, 1963, at the completion of 1000 ± 8 freeze-thaw cycles.

Tests

The following tests were made to evaluate the resistance of concrete test beams to accelerated freezing and thawing:

1. Weight determinations
2. Length measurements
3. Pulse velocity determinations
4. Resonant frequency determinations
5. Determination of flexural strength
6. Visual examination of test specimens

The freeze-thaw test specimens were weighed, measured and tested by ultrasonic pulse velocity and resonant frequency methods at regular intervals of about 100 cycles.

At the completion of 1000 cycles, both freeze-thaw and reference beams were measured, tested and broken for flexural strength determination.

Test Methods

Test specimens were weighed with a probable accuracy of ± 0.001 lb.

Length measurements were made on an Ames comparator, having a dial reading of 0.0001 in.

Ultrasonic pulse velocity was determined by a UCT electronic concrete tester*. This instrument operates at 100 kc with 0.1 microsecond sensitivity.

Transverse frequency was determined by Electro Sonometer**, using ASTM Standard Method C 215-60+. This instrument operates on 50/60 cps with 20 cps dial reading accuracy.

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*Manufactured by A. E. Cawkell Electronic Engineers, 6-7 Victory Arcade, The Broadway, Southall, Middx., England.

**Manufactured by Electro Products Laboratories, Chicago 40, Illinois, U.S.A.

+Standard Method of Test for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens (C 215-60), 1961 ASTM Book of Standards, Part 4, p. 771.

Concrete flexural strength was determined by testing 3 x 4 x 15 in. beams according to ASTM Standard Method C 78-59+ , using the third point loading system. The beams were tested in a manually operated, lever type Tinius Olsen testing machine, the accuracy of which in the 10,000 lb range is 1 lb.

In addition to the above tests, visual inspection of the specimens was carried out after every 100 cycles of freezing and thawing. Photographs of the freeze-thaw test beams and of the companion reference beams were taken at the completion of 1000 cycles to show the scaling and deterioration effects.

Test Results

The results of various tests are shown in Tables 6 to 8.

Table 6 shows weight, length, pulse velocity, and transverse resonant frequency results at zero and at completion of 400 and 1000 freeze-thaw cycles. Also included in this Table are the results of flexural strengths and visual observations of the test beams.

The relative weight loss and length changes, in per cent, are shown in Table 7. A gauge length of 13.6 in. has been taken for calculation of the changes in length.

In Table 8 are given the per cent relative losses in pulse velocity and transverse frequency. These have been calculated as the difference between the percentage gains in the results of the reference and freeze-thaw test specimens at completion of 1000 freeze-thaw cycles. (The 1000 freeze-thaw cycles correspond to a total curing period of 148 days for the reference specimens).

The relative dynamic modulus of elasticity, for the purpose of discussion, was calculated from the following equation, as given in the ASTM Standard Method C 291-61T.

$$P_c = \frac{N_1^2}{N^2} \times 100 \text{ per cent,}$$

where: N = fundamental transverse frequency at 0 cycles of freezing and thawing,

N_1 = fundamental transverse frequency after c cycles of freezing and thawing.

+Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (C 78-59), 1961, ASTM Book of Standards, Part 4, p. 734.

TABLE 6

Test Results on Beams Subject to Freeze-Thaw Cycles

Test Series No.	Admixtures	No. of freeze-thaw cycles	Test Results*					Description of test beams after exposure to 1000 cycles of freezing and thawing
			Weight, lb	Length,** in.	Transverse Frequency, cps	Pulse Velocity, fps	Flexural Strength, psi	
B-280	Darex AEA, WRDA	0	15.726	0.0910	2010	13,880	-	Slight surface scaling
		400	15.754	0.0913	2025	14,350	-	
		1002	15.707	0.0934	2000	14,450	525	
B-316	Protex, PDA 1X	0	16.062	0.0723	2030	14,650	-	Slight surface scaling
		400	16.026	0.0729	2010	14,580	-	
		1002	15.996	0.0750	2000	14,720	690	
B-402	Vinsol NVX, Maracon MC	0	15.911	0.0723	2040	14,410	-	No visible signs of deterioration
		400	15.871	0.0738	2025	14,310	-	
		1001	15.846	0.0745	2010	14,400	675	
B-430	MBVR, Pozzolith	0	16.108	0.0992	2030	14,410	-	Slight surface scaling
		400	16.096	0.0978	2025	14,510	-	
		1001	16.079	0.1012	2025	14,660	640	
B-491	PX A2, Porzite 73	0	16.099	0.0888	2050	14,730	-	Slight surface scaling
		400	16.115	0.0639	2000	14,990	-	
		1000	16.112	0.0905	2010	14,810	635	
B-580	Cyrigel	0	16.376	0.1117	2010	14,690	-	No visible signs of deterioration
		400	16.548	0.1140	2000	14,690	-	
		1001	16.043	0.1165	2010	14,850	495	
B-612	None	0	16.683	0.0712	2000	14,920	-	Slight surface scaling
		400	16.282	0.0730	2000	14,890	-	
		1002	16.270	0.0719	2000	15,000	670	
B-644	Darex AEA	0	15.982	0.0971	2000	14,820	-	Some damage at the edges of one beam
		400	15.989	0.1030	1995	14,920	-	
		992	15.970	0.1074	2010	15,120+	465	

*Each result is a mean of tests on three beams except for series 612, for which only two beams were tested.

**gauge length = 13.6 in.

+The individual pulse velocities were 15,600, 15,350 and 14,410 fps respectively.

TABLE 7

Per Cent Relative Weight and Length Changes*

Test Series No.	Admixtures	Weight of Beams, lb: Reference W_{28} +	Reference W_{148} +	Reference Per Cent Gain	Freeze-Thaw W_0 ++	Freeze-Thaw W_{1000} ++	Freeze-Thaw Per Cent Loss	Relative Loss, Per Cent	Length of Beams**, in.: Reference L_{28} +	Reference L_{148} +	Reference Per Cent Change	Freeze-Thaw L_0 ++	Freeze-Thaw L_{1000} ++	Freeze-Thaw Per Cent Expansion	Relative Change, Per Cent
B-280	Darex AEA, WRDA	15.855	15.953	0.61	15.726	15.707	0.12	0.73	0.1130	0.1156	0.0190	0.0910	0.0934	0.0175	-0.0015
B-316	Protex, PDA IX	16.176	16.340	1.01	16.062	15.996	0.41	1.42	0.0886	0.0913	0.0197	0.0723	0.0750	0.0198	+0.0001
B-402	Vinsol NVX, Maracon MC	15.736	15.803	0.43	15.911	15.846	0.41	0.84	0.1353	0.1366	0.0094	0.0723	0.0745	0.0161	+0.0167
B-430	MBVR, Pozzolith	16.167	16.217	0.31	16.108	16.079	0.18	0.49	0.0484	0.0497	0.0095	0.0992	0.1012	0.0146	+0.0051
B-491	PX A2, Porzite 73	16.116	16.181	0.40	16.099	16.112	0.08	0.48	0.1060	0.1062	0.0014	0.0888	0.0905	0.0124	+0.0110
B-580	Cyrigel	16.287	16.337	0.38	16.376	16.043	2.04	2.42	0.1171	0.1175	0.0029	0.1117	0.1165	0.0350	+0.0321
B-612	None	16.251	16.306	0.34	16.683	16.270	2.48	2.82	0.0702	0.0719	0.0124	0.0712	0.0719	0.0051	-0.0073
B-644	Darex AEA	15.960	15.981	0.13	15.982	15.970	0.07	0.20	0.1098	0.1113	0.0109	0.0971	0.1074	0.0754	+0.0645

*Each result is a mean of tests on three beams except for series 612, for which only two beams were tested.

**Gauge length = 13.6 in.

+Weight and Length of beams at 28 and 148 days.

++Weight and Length of beams after 0 and 1000 cycles of freezing and thawing.

TABLE 8

Per Cent Relative Loss of Pulse Velocity and Transverse Frequency*

Test Series No.	Admixtures	Ultrasonic Pulse Velocity, V, fps							Fundamental Transverse Frequency, N, cps						
		Reference Beams			Freeze-Thaw Beams			Relative Loss, Per Cent	Reference Beams			Freeze-Thaw Beams			Relative Loss, Per Cent
		V_{28} +	V_{148} +	Per Cent Gain	V_0 ++	V_{1000} ++	Per Cent Gain		N_{28} +	N_{148} +	Per cent Gain	N_0 ++	N_{1000} ++	Per Cent Change	
B-280	Darex AEA, WRDA	14,230	15,700	10.30	13,880	14,450	+4.10	6.20	2010	2455	22.0	2010	2000	-0.5	22.5
B-316	Protex, PDA IX	14,880	16,300	9.50	14,650	14,720	+0.47	9.03	1980	2460	24.2	2030	2000	-1.5	25.7
B-402	Vinsol NVX, Maracon MC	14,620	15,800	8.10	14,410	14,400	0.0	8.10	2040	2455	20.4	2040	2010	-1.5	21.9
B-430	MBVR, Pozzolith	14,600	16,000	9.60	14,410	14,660	+1.73	7.87	2000	2450	22.5	2030	2025	-0.3	22.8
B-491	PX A2, Porzite 73	14,990	15,990	6.70	14,730	14,810	+0.54	6.16	2040	2460	20.6	2050	2010	-1.9	22.5
B-580	Cyrigel	14,850	15,750	6.10	14,690	14,850	+1.09	5.01	2010	2450	21.9	2010	2010	0.0	21.9
B-612	None	14,990	16,200	8.10	14,920	15,000	+0.53	7.57	2040	2460	20.6	2000	2000	0.0	20.6
B-644	Darex AEA	15,030	16,100	7.10	14,820	15,120	+2.02	5.08	2000	2450	22.5	2000	2010	+0.5	22.0

*Each result is a mean of tests on three beams except for series 612, for which only two beams were tested.

\+ Pulse velocity and transverse frequency at 28 and 148 days.

++ Pulse velocity and transverse frequency at 0 and 1000 cycles of freezing and thawing.

The flexural strength test results for the reference as well as the freeze-thaw test beams are summarized in Table 9. Also included in the table are the residual strengths which have been calculated by dividing the flexural strength of the freeze-thaw beams at completion of 1000 cycles by those of the reference beams at the corresponding curing age, and expressing it as a percentage.

TABLE 9

Summary of Flexural Strength Test Results

Batch No.	Admixtures	Flexural Strength of Beams*		
		Reference	After 1000 freeze-thaw cycles	Residual Strength, Per cent
B-280	Darex, WRDA	630	525	83.5
B-316	Protex, PDA IX	635	690	108.9
B-402	Vinsol NVX, Maracon MC	730	675	92.5
B-430	MBVR, Pozzolith	710	640	90.1
B-491	PxA2, Porzite 73	690	635	92.1
B-580	Cyrigel	705	495	70.1
B-612	None	720	670	93.0
B-644	Darex AEA	780	465	59.7**

*Each result is a mean of 3 test beams, except for series B-612, for which only 2 reference beams were tested.

**Low residual strength is due to a very low strength of one beam, the individual beam strengths being 435, 650 and 310 psi, respectively.

Photographs of the beams at the completion of 1000 cycles of freezing and thawing are shown in Figures 1 to 8. Also included are the photographs of the reference beams for series B-612 and B-644 for comparison purposes.

Figure 1. Series B-280 containing Darex and WRDA; concrete specimens show slight surface scaling after 1002 freeze-thaw cycles.

Figure 2. Series B-316 containing Protex and PDA IX; concrete specimens show slight surface scaling after 1002 freeze-thaw cycles.

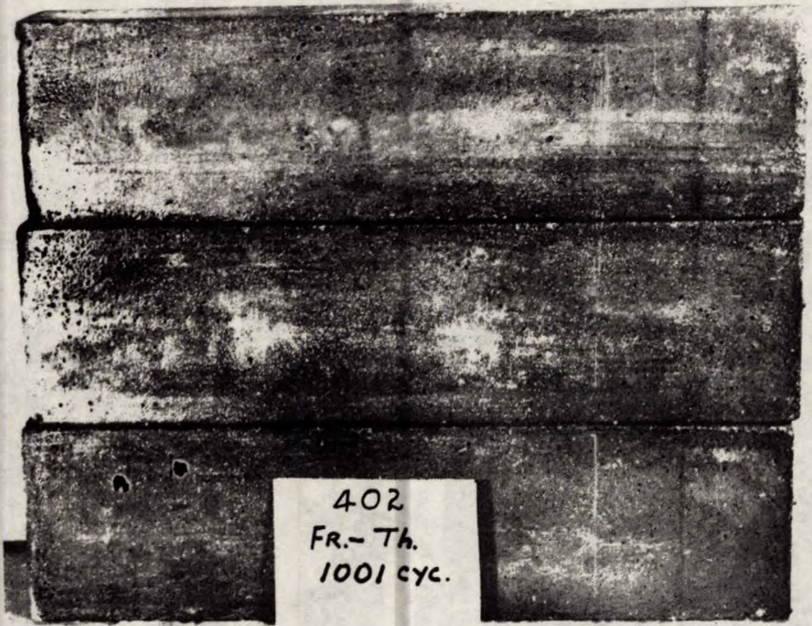

Figure 3. Series B-402 containing Vinsol NVX and Maracon MC, shows no signs of deterioration after 1001 freeze-thaw cycles.

Figure 4. Series B-430 containing MBVR and Pozzolith shows slight surface scaling after 1001 freeze-thaw cycles.

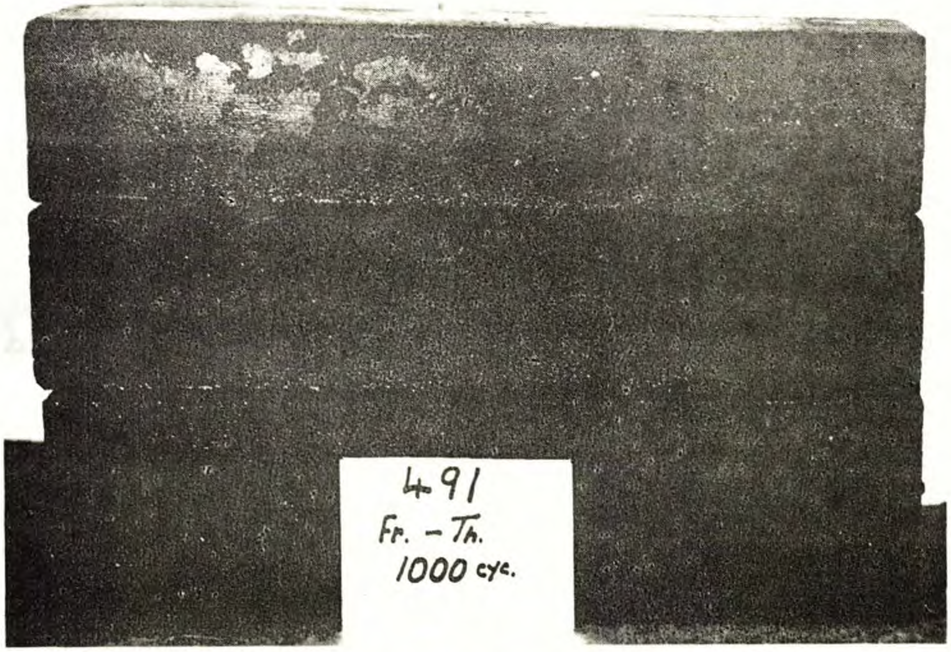

Figure 5. Series B-491 containing PX A2 and Porzite 73, shows slight surface scaling after 1000 freeze-thaw cycles.

Figure 6. Series B-580 containing Cyrigel shows no signs of deterioration after 1001 freeze-thaw cycles.

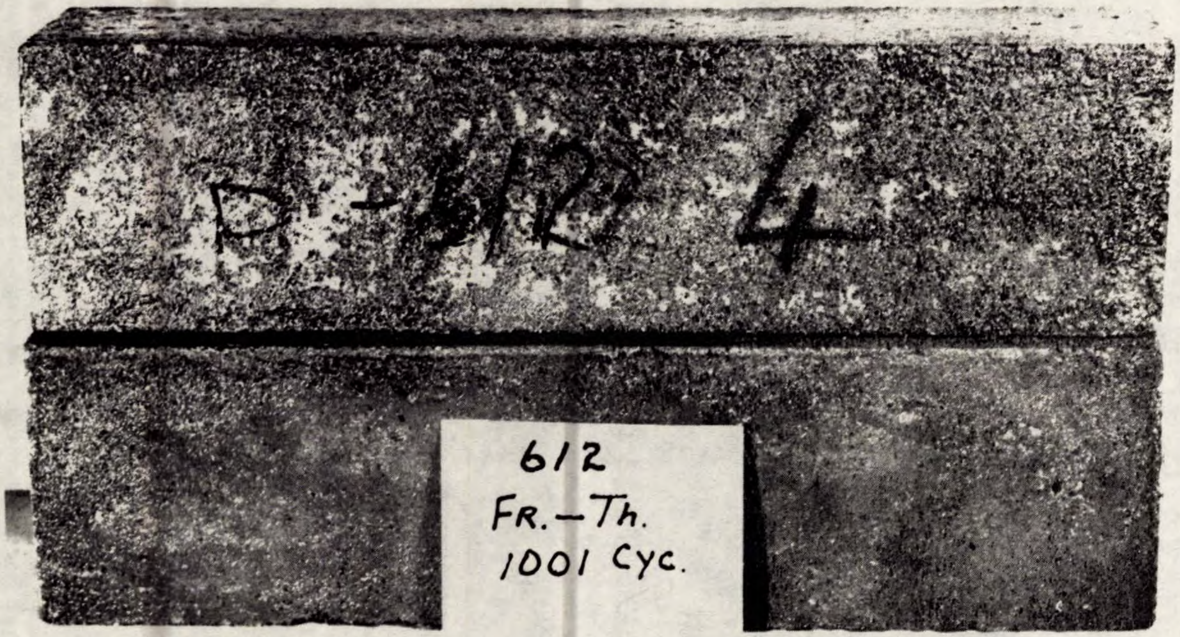

Figure 7a. Series B-612 without any admixture, shows signs of surface scaling after 1001 freeze-thaw cycles.

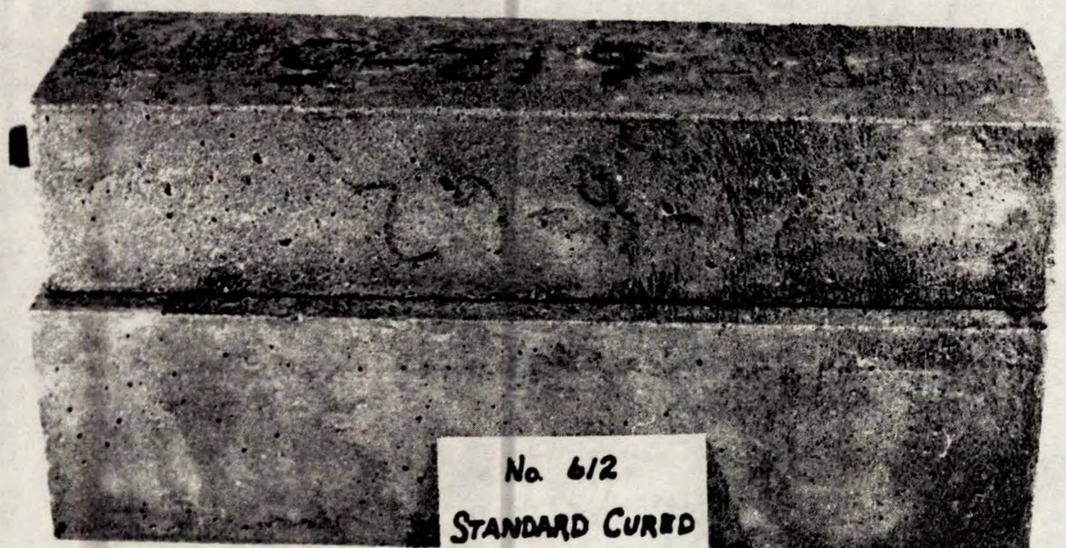

Figure 7b. Series B-612 without any admixture; reference test specimens.

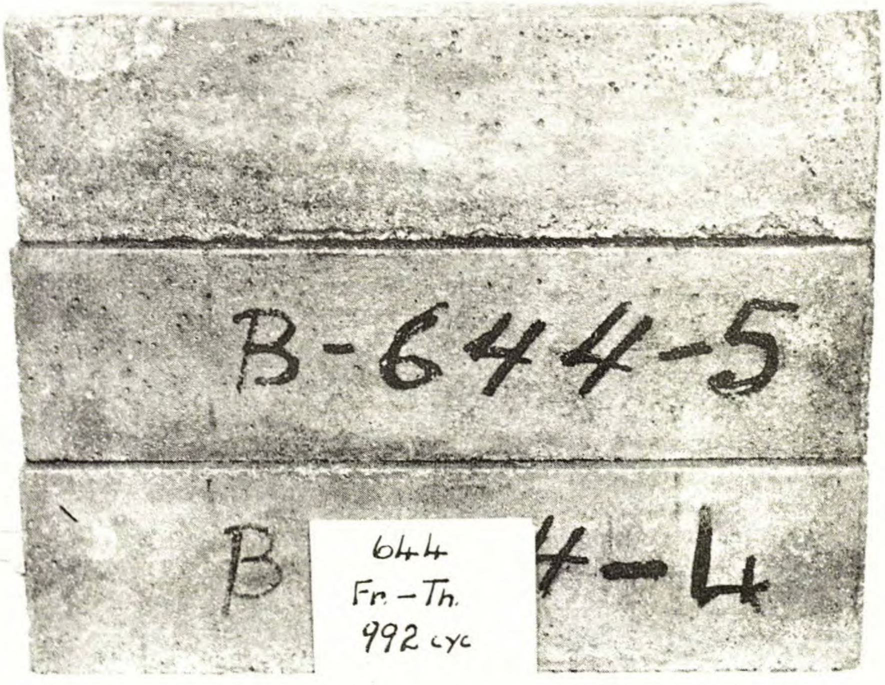

Figure 8a. Series B-644 containing Darex AEA, shows signs of damage at edges of the upper beam after 992 freeze-thaw cycles.

Figure 8b. Series B-644 containing Darex AEA; reference test specimens.

Discussion of Results

The results compiled in Table 6 and photographs in Figures 1 to 8, show that none of the test beams under test suffered serious damage at the completion of 1000 cycles of freezing and thawing.

The results in Table 7 show that the moist-cured reference beams gained 0.13 to 1.01 per cent in weight, whereas the freeze-thaw test specimens suffered a loss ranging from 0.07 to 2.48 per cent, giving a relative loss in weight from 0.2 to 2.82 per cent, which is rather small considering that the beams had been subjected to 1000 cycles of freezing and thawing.

The reference beams after 148 days of moist storage showed a maximum expansion of about 0.02% (Series B-316), whereas the maximum expansions at 400 and 1000 cycles of freeze-thaw were 0.04 and 0.08 per cent respectively. Thus, the expansion of the beams is well within the limit of 0.07 per cent set by Paul Klieger(1) for durable concrete after 300 cycles of freezing and thawing.

The relative dynamic moduli of elasticity for the test beams are greater than 96 per cent, indicating an excellent durability of concrete. This high durability was confirmed also by the ultrasonic pulse velocity measurements, which showed a gain for all the test beams after 1000 cycles of freezing and thawing.

Table 8 indicates that at completion of 1000 cycles of freeze-thaw, the specimens did not show significant changes from the conditions at zero cycles. However, the beams have actually deteriorated to some extent as compared to the reference specimens, which increased in strength during the curing period.

The residual flexural strengths as given in Table 9, vary from 59.7 to 108.9 per cent of the reference beam strengths. The lowest strength was obtained for Series B-644 specimens, one beam of which was the most affected by freeze-thaw cycling. The ultrasonic pulse velocity of this particular beam was 1065 fps lower than the average of the two companion beams of the same series.

It is interesting to note that the beams of Series B-612 (without any admixture) had suffered no damage after 1000 freeze-thaw cycles. This is probably because the sand used in the mixes occludes air into the mixture (air content of Series B-612 = 3.0 per cent), which may account for the excellent performance of this series when subjected to freeze-thaw cycling. Whether concrete made with the sand from this source would perform equally well in the field is open to question because it has been shown(2) that the accidental air entrapped by sand from a single source varies from day to day and with different conditions of storage and exposure. This could well mean very strict field quality control if the sand from this source has to be used for the dam concrete.

The visual appraisal of the test beams after exposure to 1000 cycles of freeze-thaw has been recorded by photographs shown in Figures 1-8. The photographs show the beams to be in excellent condition in spite of the large number of freeze-thaw cycles to which they have been subjected.

CONCLUSIONS

1. The durability studies show that all concrete test specimens, with or without admixtures, performed excellently at completion of 400 freeze-thaw cycles. At the end of 1000 cycles, concrete specimens containing Cyrigel and Darex as admixtures, showed relatively more deterioration than the other concrete specimens, including the test beams containing no admixtures.

2. In evaluating the relative performance of admixtures in concrete series under test, it is suggested that the results of this investigation should be interpreted in conjunction with the findings of other tests on the same concrete, as outlined in ASTM Specification C 233-60T, "Methods of Tests for Air-Entraining Admixtures for Concrete".

REFERENCES

1. P. Klieger, "Studies of the Effect of Entrained Air on the Strength and Durability of Concretes Made with Various Maximum Sizes of Aggregate", Proceedings, Highway Research Board, Vol. 31, p. 177, Table 15 (1952).

2. F. M. Macnaughton and John B. Herbich, "Accidental Air in Concrete", AC1 Journal, Proceedings, V. 51-13, p. November 1954.

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