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DURABILITY OF NON-AIR-ENTRAINED AND AIR-ENTRAINED CONCRETES MADE WITH TYPE I AND MODIFIED TYPE II CEMENTS

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by

V. M. MALHOTRA AND N. G. ZOLDNERS

MINERAL PROCESSING DIVISION

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DURABILITY OF NON-AIR-ENTRAINED AND AIR-ENTRAINED CONCRETES MADE WITH TYPE I AND MODIFIED TYPE II CEMENTS

by

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

SUMMARY OF RESULTS

This report covers part of long term studies on the durability of concrete made with Type I and modified Type II cements in connection with the Manicouagan hydro-electric project of Hydro-Quebec.

Tests carried out on 3 1/2 x 4 x 15 in. beams showed that non-air-entrained specimens made with both types of cement had very little resistance to accelerated cycles of freezing and thawing. The specimens had been very severely damaged after exposure to less than 56 cycles. In almost all cases no ultrasonic pulse velocity or transverse frequency readings were possible after exposure to freeze-thaw cycling; the residual flexural strengths of the beams varied from zero to 40.2 per cent.

Air-entrained concrete specimens were in excellent condition after exposure to more than 1000 repeated cycles of freezing and thawing. Changes in weight, length, ultrasonic pulse velocity and transverse frequency were negligible after the freeze-thaw exposure; the residual flexural strengths of the beams were more than 80.5 per cent.

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Rapport d'investigation IR 67-29 de la Direction des Mines

DURABILITÉ DES BÉTONS AÉRÉS ET NON AÉRÉS FABRIQUÉS À L'AIDE DE CIMENTS DE TYPE I ET DE TYPE II MODIFIÉ

par

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

RÉSUMÉ DES RÉSULTATS

Le présent rapport fait partie d'une étude à long terme entreprise pour déterminer la durabilité de bétons fabriqués à l'aide de ciments de type I et de type II modifié, en vue de l'aménagement hydro-électrique de l'Hydro-Québec sur la rivière Manicouagan.

Des essais effectués sur des poutres en béton mesurant 3 1/2 sur 4 sur 15 pouces ont révélé que les éprouvettes non aérées, fabriquées à l'aide des deux genres de ciment, résistent très peu à des cycles accélérés de gel et de dégel. Après avoir été exposées à moins de 56 cycles, les éprouvettes étaient fortement endommagées. Dans presque tous les cas, il était impossible d'y enregistrer la vitesse des ondes ultra-sonores ou la fréquence transversale après leur exposition au cycle de gel-dégel; la résistance résiduelle des poutres aux efforts de flexion allait de zéro à 40.2 p. 100.

Les éprouvettes en béton aéré étaient en excellent état après avoir été exposées à plus de 1,000 cycles de gel-dégel. Les changements de poids, de longueur, de vitesse des ondes ultra-sonores et de fréquence transversale étaient négligeables après l'exposition au gel-dégel, et la résistance résiduelle des poutres aux efforts de flexion était de plus de 80.5 p. 100.

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INTRODUCTION

The Quebec Hydro-Electric Commission (Hydro-Quebec), Montreal, started building in 1962 in northern Quebec a two-billion dollar Manicouagan-Outardes hydro-electric project. In constructing concrete dams, power houses, and tunnels of this vast complex, Hydro-Quebec is using a modified Type II cement. The principal feature of this cement is its low heat of hydration (60 to 63 cal/g in 7 days) compared with that of normal portland cement* (70 to 76 cal/g).

Since 1963, the Mineral Processing Division of the Mines Branch has been carrying out for Hydro-Quebec durability studies on concrete made with modified Type II cement. Results of these studies have been reported in Mines Branch Investigation Reports (1, 2, 3, 4).

The present report gives the results of an investigation on durability of non-air-entrained and air-entrained concretes made with Type I and modified Type II cements.

SCOPE OF INVESTIGATION

For this investigation, the concrete mixes were divided into the following two series:

Series A. Non-Air-Entrained Concrete Mixes

A total of four non-air-entrained concrete mixes was made in this series; two mixes were designed for medium strength (W/C** = 0.64), and the remaining two for low strength (W/C = 0.86). In each strength group, one mix was made using blended Type I cement whereas the other mix was made with blended Type II cement. From each mix in this series, six 3 1/2 x 4 x 15 in. beams were cast for durability studies; in addition, five 6 x 12 in. cylinders were cast for strength determination.

Series B. Air-Entrained Concrete Mixes

A total of four air-entrained concrete mixes was made in this series; two mixes were designed for medium strength (W/C = 0.62), and the remaining two for low strength (W/C = 0.82). In each strength range, one mix was

*Equivalent to ASTM Type I and is designated as such.
**W/C = Water-Cement ratio, by weight.

made using blended Type I cement whereas the other mix was made using blended Type II cement. From each mix in this series, six 3 1/2 x 4 x 15 in. beams were cast for durability studies; in addition five 6 x 12 in. cylinders were cast for strength determination.

CONCRETE MIXES

The two series of concrete mixes were designed and prepared, and test specimens were cast in the Mines Branch laboratory at Ottawa between August 30 and September 13, 1965. The details of the materials used, design data and the test results on fresh and hardened concrete are described below:

Materials Used

Cement

Three brands of both normal Portland cement, Type I, and low-heat, modified cement Type II, (two bags of each brand, each type) were supplied by the Concrete Laboratory Inc., Montreal. These cements were produced by the following cement companies.

(a) Canada Cement Company, Limited,
Montreal East, P.Q. .... Types I and II

(b) Miron Company Ltd.,
City of St. Michel, P.Q. .... Types I and II

(c) St. Lawrence Cement Co.,
Villeneuve, P.Q. .... Types I and II

The three brands of each type were blended before use. The blended cement was prepared by placing two bags of each brand and each type in a Taylor tube mill and mixing dry for 30 minutes.

The chemical analyses and the calculated compound composition of each blend type of cement are given in Table 1.

TABLE 1

Chemical Analyses and Compound Composition of Cements

Chemical Constituents, per cent			Compound Composition, per cent		
	Blended Type I	Blended Type II		Blended Type I	Blended Type II
SiO_2	22.30	22.02	C_3S	46.0	37.9
Al_2O_3	5.63	4.91	C_2S	26.3	34.5
Fe_2O_3	2.57	4.08	C_3A	10.6	6.1
CaO, Total	63.05	61.63	C_4AF	7.8	12.4
MgO	3.17	2.68	Others	9.3	9.1
SO_3	2.52	2.35	Total	100.0	100.0
Ignition Loss	1.17	1.10			
Insoluble Residue	0.36	0.31			
Total	99.77	99.08			

Aggregates

The coarse aggregate was obtained from a coarse-grained pink granite from the bedrock near the Manicouagan-2 dam site. The crushed 3/4 and 1 1/2 in. nominal size aggregate was shipped in wooden boxes by the Concrete Laboratory Inc., from Baie Comeau, P.Q. to the Mines Branch concrete laboratory in Ottawa. The 1 1/2 in. and the 3/4 in. aggregates were combined in 2:1 proportion by weight.

Local "Ottawa Valley" natural sand was used as fine aggregate. To keep the grading uniform for each mix, the sand was first separated in 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

Combined Coarse Aggregate		Fine Aggregate	
Sieve Size	Per Cent Passing	Sieve Size	Per Cent Passing
2 in.	100.0	No. 4	100.0
1 1/2 in.	98.5	No. 8	90.0
1 in.	75.9	No. 16	67.5
3/4 in.	56.4	No. 30	42.5
1/2 in.	21.4	No. 50	20.0
3/8 in.	9.0	No. 100	6.0
Pan	-	Pan	0

TABLE 3

Physical Properties of Coarse and Fine Aggregates

	Crushed Stone	Natural Sand
Specific Gravity	2.63	2.70
Absorption	0.37	0.70

Mix Design Data

Detailed mix design data for the concrete mixes of Series A and B are given in Table 4.

TABLE 4

Mix Design Data

Series	Mix No.	Mix Proportions, lb/cu yd Water, lb	Cement, lb	Coarse	Fine	Water/Cement, Ratio (By Weight)
A. Non-Air-Entrained						
Medium	1	267	436	1810	1454	0.64
Strength	2	286	449	1864	1425	0.64
Low	3	296	342	1777	1537	0.86
Strength	4	298	344	1786	1545	0.86
B. Air-Entrained						
Medium	5	249	401	1823	1383	0.62
Strength	6	246	394	1792	1360	0.62
Low	7	330	269	1711	1479	0.82
Strength	8	322	264	1671	1446	0.82

Properties of Fresh Concrete

The properties of the fresh concrete, i.e., temperature, slump, unit weight and air content for mixes of Series A and B are given in Table 5.

PREPARATION OF TEST SPECIMENS

The 3 1/2 x 4 x 15 in. test beams were cast in heavy brass moulds with 3/8 in. side plates and 1/2 in. end plates. Stainless steel reference plugs were cast at each end of the beam specimens for length measurements. The beams were moulded by placing concrete in the moulds in two approximately equal layers and vibrating these on a vibrating table for 10 and 20 sec for the bottom and top layers, respectively.

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 by a single insertion of approximately 4 to 6 seconds.

TABLE 5

Properties of Fresh Concrete

Series	Mix No.	Type of Cement	Properties of Fresh Concrete: Temperature, °F	Slump, in.	Unit Weight, lb/cu ft	Air Content, per cent
A. Non-Air-Entrained						
Medium Strength	1	I	66	2	148.0	1.5
	2	II	67	2 3/4	148.8	1.4
Low Strength	3	I	68	2	146.4	1.6
	4	II	67	3	147.2	1.3
B. Air-Entrained						
Medium Strength	5	I	72	1 1/4	142.8	5.1
	6	II	73	2 1/2	140.0	6.0
Low Strength	7	I	73	2	140.4	5.4
	8	II	73	3	137.2	6.5

The moulded test specimens, covered with glass plates and water-saturated burlap were left in the casting room for 24 hr.

At the end of this period the test specimens were removed from the moulds and transferred immediately to a moist-curing room maintained under standard curing conditions.

COMPRESSION AND FLEXURE TESTS

Concrete test cylinders were tested for compressive strength at 90-days in accordance with ASTM standard method of test C39-64. The corresponding beams were tested for flexural strength at 90-days using the third-point loading method (ASTM Standard C78-64). The test results for both cylinders and beams are given in Table 6. Also included in this table is the 90-day density of hardened concrete cylinders in the saturated, surface-dry condition.

TABLE 6

Properties of Hardened Concrete
(All specimens standard moist cured)

Series	Mix No.	Type of Cement	W/C Ratio	Density of Concrete lb/cu ft	Flexural Strength, psi 3 1/2x4x15 in. beams, at 90 days (average of 2)	Compressive Strength, psi, (6 x 12 in. cylinders) 90 days (average of 3)	97 days (average of 2)	525 days (Average of 2)
A. Non-Air-Entrained								
Medium	1	I	0.64		805	5060	5090	-
Strength	2	II	0.64		800	5070	5070	-
Low	3	I	0.86		535	2870	2710	-
Strength	4	II	0.86		570	2510	2560	-
B. Air-Entrained								
Medium	5	I	0.62		725	4290	-	4850
Strength	6	II	0.62		685	4110	-	4820
Low	7	I	0.82		565	2810	-	3025
Strength	8	II	0.82		550	2540	-	2920

CONCRETE DURABILITY STUDIES

Although durability of concrete cannot be measured directly, prolonged exposure of concrete to accelerated cycles of freezing and thawing produces measurable changes in the test specimens, and these changes can be used for evaluating the relative frost resistance or durability of the concrete.

Two test beams from each mix were subjected to the freezing and thawing tests; the two companion test beams from each mix were kept in moist-curing room as references, until the end of the freeze-thaw cycling.

Freezing and Thawing Procedure

After 90-days of initial moist-curing, the freeze-thaw test specimens were exposed to repeated cycles of freezing in air and thawing in water according to ASTM test method C291-61T.

The automatic freeze-thaw unit* used performs 8 cycles per day. One complete cycle, from 40 $\pm$ 3°F to 0 $\pm$ 3°F and back to 40 $\pm$ 3°F, requires about three hours.

Before the freezing and thawing test was commenced, the temperatures of the four test beams from each test mix was reduced to a uniform 40 + 3°F by holding the test specimens in the freeze-thaw cabinet at the thawing phase of the cycle for one hr. Initial and all subsequent measurements on the freeze-thaw and reference specimens were made at this temperature. After the initial measurements had been taken, two beams were placed back in the freeze-thaw cabinet and the two companion beams were placed in the moist-curing room.

Test Methods

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

1. Weight determinations;
2. Length determinations;
3. Pulse velocity determinations;

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

4. Resonant frequency determinations;
5. Flexural strength determinations of
   a) Test beams after freeze-thaw cycling;
   b) Reference beams after standard curing.
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 both the beginning and end of the freeze-thaw cycling. At completion of the test, both freeze-thaw and reference beams were broken in flexure in accordance with the ASTM Standard Method C78-64, using a simple beam with third-point loading. Frequent visual inspections of the test specimens were made while the test was in progress.

Test specimens were weighed with a probable accuracy of ± 0.005 lb.

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

Test Results

Table 7 shows weight, pulse velocity and transverse frequency values determined at the start and at the end of the test. Also included in this table are the flexural strengths and the visual observations of the freeze-thaw beams at the end of cycling.

The weight loss and length changes in per cent are shown in Table 8. A gauge length of 13.6 in. has been used for calculations of the length changes. The changes in ultrasonic pulse velocity and resonant frequency are shown in Table 9.

The flexural strength test results for both the reference and freeze-thaw test beams are summarized in Table 10. 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 the test by those of the reference beams at the corresponding curing age and expressing the results as a percentage.

The relative dynamic modulus of elasticity, for the purpose of discussion, was calculated from the following equation, given in ASTM Standard method C291-61T.

$$Pc = \frac{N_i^2}{N^2} \times 100 \text{ per cent,}$$

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

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

Photographs of the beams at the completion of the freeze-thaw test are shown in Figures 1 to 4. Also included in the photographs are the reference beams for comparative purposes.

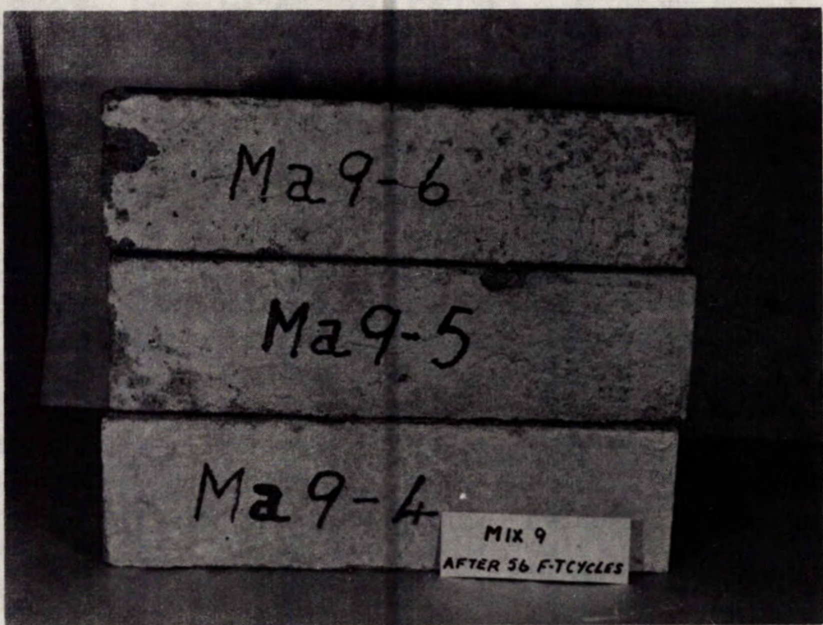

Figure 1. Series A, Mix 1: Medium Strength Concrete Beams Made With Type I Cement (Non-Air-Entrained).

Top two beams : after 56 freeze-thaw cycles
Bottom beam : reference specimen

Figure 2. Series A, Mix 2: Medium Strength Concrete Beams Made With Type II Cement (Non-Air-Entrained).
Top two beams : after 56 freeze-thaw cycles
Bottom beam : reference specimen

Figure 3. Series A, Mix 3: Low Strength Concrete Beams Made With Type I Cement (Non-Air Entrained).
Top two beams : after 40 freeze-thaw cycles
Bottom beam : reference specimen

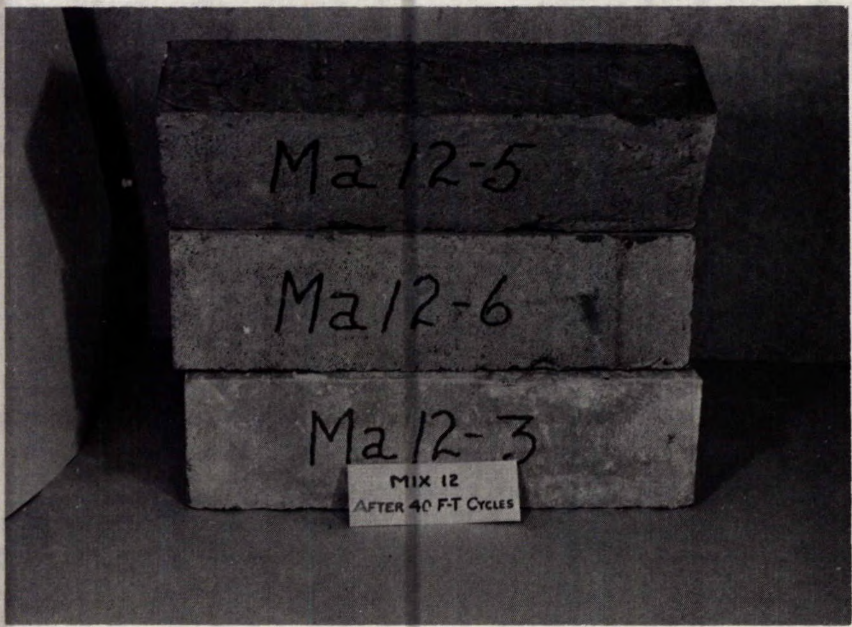

Figure 4. Series A, Mix 4: Low Strength Concrete Beams Made With Type II Cement (Non-Air Entrained).
Top two beams : after 40 freeze-thaw cycles
Bottom beam : reference specimen

TABLE 7

Test Results on Beams Subjected to Freezing and Thawing Cycles

Series No.	Type of Cement	Number of Freeze-Thaw Cycles	Test Results[1] Weight, lb	Length, in.	Transverse Resonant Frequency, cps	Ultrasonic Pulse Velocity fps	Flexural Strength psi	Description of Test Beams at the End of Freeze-Thaw Cycling
A. Non-Air-Entrained								
Medium Strength 1	I	0	19.120	0.0463	2045	15,776	-	Both beams severely damaged
		56	19.598	*	1600	**	280	
Medium Strength 2	II	0	19.336	0.0633	2245	15.875	-	Both beams severely damaged
		56	19.635	*	1485	**	340	
Low Strength 3	I	0	19.113	0.0155	2040	15,469	-	Both beams in state of disintegration
		40	16.674	*	**	**	**	
Low Strength 4	II	0	19.304	0.0144[2]	2075	15,047	-	Both beams very severely damaged
		40	19.530	0.0874	**	**	50	
B. Air-Entrained								
Medium Strength 5	I	0	19.076	0.0566	2045	15,602	-	Both beams in excellent condition
		1092	19.010	0.0586	2045	15,545	665	
Medium Strength 6	II	0	18.830	0.0586	2025	15,583	-	Both beams in excellent condition
		1092	18.767	0.0609	2045	15,564	700	
Low Strength 7	I	0	18.589	0.0458	2055	15,137	-	Both beams in excellent condition
		1050	18.520	0.0477	2045	14,959	490	
Low Strength 8	II	0	18.067	0.0227	2015	14,941	-	Both beams in excellent condition
		1050	18.012	0.0280	2015	14,733	495	

1 All test results are the average of readings on two beams unless otherwise stated.

2 Test results on one beam only

* Beams were too long to be measured

**Beams were too much damaged for readings to be taken.

TABLE 8

Weight and Length Changes of Beams*

Series	Mix No.	Weight of Beams, lb						Length of Beams**, in.					
		Reference			Freeze-Thaw			Reference			Freeze-Thaw		
		W_{90} (a)	W_x (b)	Per Cent Change	W_o (c)	W_x (d)	Per Cent Change	L_{90} (a)	L_x (b)	Per Cent Change	L_o (c)	L_x (d)	Per Cent Change
A. Non-Air-Entrained													
Medium	1	19.379	19.390	+0.057	19.120	19.598	+ 2.50	0.0402	0.0398	-0.0029	0.0463	— (f)	—
Strength	2	19.529	19.526	-0.015	19.336	19.635	+ 1.55	0.0330(e)	0.0321(e)	-0.0066	0.0633	— (f)	—
Low	3	19.244	19.249	+0.026	19.113	16.674	-12.76	0.0200	0.0200	Nil	0.0115	—	—
Strength	4	19.370	19.380	+0.052	19.304	19.530	+ 1.17	0.0345	— (h)	—	0.0144	0.0874(g)	+0.54
B. Air-Entrained													
Medium	5	18.855	18.900	+0.24	19.076	19.010	- 0.35	0.0318	0.0331	+0.009	0.0566	0.0586	+0.014
Strength	6	18.696	18.717	+0.11	18.830	18.767	- 0.33	0.0515	0.0524	+0.006	0.0563	0.0609	+0.034
Low	7	18.566	18.579	+0.70	18.589	18.520	- 0.37	0.0547	0.0553	+0.004	0.0458	0.0477	+0.014
Strength	8	18.364	18.409	+0.24	18.067	18.012	- 0.30	0.0488	0.0456	-0.023	0.0227	0.0280	+0.039

*Each result is a mean of tests on two beams.
**Gauge length 13.6 in.
(a) Weight and length of beams after 90 days of standard moist curing.
(b) Weight and length of beams after 98 and 97 days of moist curing for mixes (1, 2) and (3, 4); after 234 and 227 days of moist curing for mixes (5, 6) and (7, 8), respecitvely.
(c) Weight and length of beams at zero cycles of freezing and thawing.
(d) Weight and length of beams after 56 and 40 cycles of freezing and thawing for mixes (1, 2) and (3, 4); after 1092 and 1050 cycles of freezing and thawing for mixes (5, 6) and (7, 8), respectively.
(e) Readings may be doubtful because gauge studs had to be re-adjusted.
(f) Beams expanded beyond the range of the comparator.
(g) Test results on one beam only.
(h) No measurements were recorded.

TABLE 9

Ultrasonic Pulse Velocity and Transverse Frequencies of Beams*

Series	Mix No.	Ultrasonic Pulse Velocity, fps**						Transverse Resonant Frequency, cps					
		Reference			Freeze-Thaw			Reference			Freeze-Thaw		
		V_{90} (a)	V_x (d)	Per Cent Change	V_o (c)	V_x (d)	Per Cent Change	f_{90} (a)	f_x (b)	Per Cent Change	f_{90}	f_x (d)	Per Cent Change
A. Non-Air-Entrained													
Medium	1	15679	16015	+2.14	15776	—(e)	—	2034	2035	Nil	2045	1600	-21.8
Strength	2	15885	16147	+1.65	15875	—(e)	—	2050	2050	Nil	2245	1485	-33.8
Low	3	15564	15611	+0.30	15469	—(e)	—	2075	2065	-0.48	2040	—(e)	—
Strength	4	15246	15516	+1.77	15047	—(e)	—	2075	2075	Nil	2075	—(e)	—
B. Air-Entrained													
Medium	5	15640	15995	+2.27	15602	15545	-0.36	2035	2035	Nil	2045	2045	Nil
Strength	6	15621	16178	+3.57	15583	15564	-0.11	2035	2055	+0.98	2025	2045	+ 0.99
Low	7	15347	15478	+0.85	15137	14959	-1.10	2045	2055	+0.99	2055	2045	- 0.49
Strength	8	15128	15375	+1.63	14941	14733	-1.32	2040	2080	+1.96	2015	2015	Nil

*Each result is a mean of tests on two beams.

**Length used for pulse velocity calculations = 15.25 in.

(a) Ultrasonic pjlse velocity and transverse frequency of beams after 90 days of moist curing.

(b) Ultrasonic pulse velocity and transverse frequency of beams after 98 and 97 days of moist curing for Mixes (1,2) and (3,4); after 324 and 3227 days of moist curing for mixes (5,6) and (7,8), respectively.

(c) Ultrasonic pulse velocity and transverse frequency of beams at zero cycles of freezing and thawing.

(d) Ultrasonic pulse velocity and transverse frequency of beams after 56 and 40 cycles of freezing and thawing for mixes (1,2) and (3,4); after 1092 and 1050 cycles of freezing and thawing for mixes (5,6) and (7,8), respectively.

(e) Beams too extensively damaged for readings to be taken.

TABLE 10

Summary of Flexural Strength Test Results

Series	Mix No.	Type of Cement	Reference Beams		Freeze-Thaw Beams		
			Age, days	Strength, psi	Number of Freeze-Thaw cycles	Strength, psi	Residual Strength, per cent
A. Non-Air-Entrained							
Medium Strength	1	I	98	805	56	280	34.8
	2	II	98	845	56	340	40.2
Low Strength	3	I	97	585	40	**	-
	4	II	97	590	40	50	8.5
B. Air-Entrained							
Medium Strength	5	I	234	720	1092	665	92.4
	6	II	234	750	1092	700	93.4
Low Strength	7	I	227	560	1050	490	87.5
	8	II	227	615	1050	495	80.5

**Beams too extensively damaged to be tested.

DISCUSSION OF TEST RESULTS

Non-Air-Entrained Concrete

Test beams made from non-air-entrained concrete mixes were subjected to freeze-thaw cycling after 90 days of initial moist curing. This procedure was adopted so that the test specimens made with blended Type I and blended Type II cements were of approximately equal strength at the commencement of the freeze-thaw test. In spite of this procedure, the test results in Tables 7 to 10, and Figures 1 to 4 show that the non-air-entrained concrete beams for both types of cements had been extensively damaged after exposure to less than 56 cycles of freezing and thawing. Residual flexural strengths of medium strength concrete test beams made with blended Type I and blended Type II cements were 34.8 and 40.2 per cent, respectively, the corresponding values for the low strength beams were zero and 8.5 per cent.

Due to the extremely deteriorated condition of the beams after freeze-thaw exposure, no ultrasonic pulse velocity readings were possible for either medium or los strength concrete specimens. The relative dynamic modulus of elasticity for medium strength concrete test beams made with blended Type I and blended Type II cements were 61.2 and 43.7 per cent respectively; no corresponding values could be computed for the low strength concrete beams because no measurements of transverse frequency readings were possible.

No length change readings were possible for the beams in this group because generally the expansion had exceeded the measuring capacity of 0.5 in. of the comparator. The only exception was one test beam of low strength concrete made with blended Type II cement where the expansion had reached 0.54 per cent.

The weight changes shown in Table 8 do not truly reflect the deteriorated condition of the beams. Strictly, all the loose material should have been removed from the beams with a wire brush before weighing; however this was not done because of the danger that the beams might completely disintegrate. Therefore, the weight changes shown in Table 8 are only indicative of early absorption.

The test results given in Tables 7 to 10 and discussed above do not indicate that non-air-entrained concrete made with blended Type II cement was of superior durability to concrete made with blended Type I cement.

Air-Entrained Concrete

Test beams made from air-entrained concrete were also subjected to freeze-thaw cycling after 90 days of initial moist curing. The test results (Tables 7 to 10) and visual inspection of the beams show that the concrete was in excellent condition after exposure to more than 1000 cycles of freezing and thawing. The residual flexural strength for both medium and low strength concrete specimens were more than 80.5 per cent. The changes in weight, length, ultrasonic pulse velocity and transverse frequency readings were negligible. Once again the test results failed to reveal any differences in the durability of concrete made with blended Type I and blended Type II Cements.

CONCLUSIONS

The durability tests carried out on concrete prism specimens show that:

1. The medium and low strength non-air-entrained concrete specimens made with both blended Type I and Type II cements have very little resistance to accelerated cycles of freezing and thawing; however both medium and low strength air-entrained concrete specimens made with the above types of cements have excellent durability characteristics.

2. This investigation did not reveal any superior durability of concrete made with blended Type II cement to that made with blended Type I cement. This was true for non-air-entrained as well as air-entrained concrete specimens.

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