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MINES BRANCH INVESTIGATION REPORT IR 65-86

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

by

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SUMMARY OF RESULTS

This investigation report is a 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.

Laboratory investigations carried out on $3\frac{1}{2}$ x 4 x $15\frac{1}{4}$ in. beams showed that non-air-entrained concrete specimens made with the two types of cement had very little frost resistance. The concrete test beams made with both Type I and modified Type II cements had been very severely damaged after exposure to less than 55 cycles of repeated freezing and thawing. In almost all cases no ultrasonic pulse velocity or transverse frequency readings were possible after exposure to freeze-thaw cycling; the residual flexural strength of the test beams varied from zero to 11.8 per cent.

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Rapport d'investigation de la Direction des mines IR 65-86

DURABILITÉ DES BÉTONS SANS AIR OCCLUS ET PRÉPARÉS AVEC LES CIMENTS DE TYPE I ET DE TYPE MODIFIÉ II

par

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

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RÉSUMÉ

Ce rapport d'investigation fait partie d'une étude à long terme sur la durabilité des bétons préparés avec les ciments du type I et du type modifié II en liaison avec le projet hydro-électrique de la Manicouagan de l'Hydro-Québec.

Les essais de laboratoire effectués sur les éprouvettes de 3½ sur 4 sur 15¼ pouces, ont montré que les échantillons de béton sans air occlus, faits des deux types de ciments, avaient une très faible résistance au gel. Les éprouvettes d'essai en béton, préparées avec les ciments type I et type modifié II, avaient été très sérieusement endommagées après exposition à moins de 55 cycles de gel et de dégel. Dans presque tous les cas, après l'exposition aux cycles de gel et de dégel, les lectures de la vitesse de pulsations ultrasoniques et de la fréquence transversale, n'étaient plus possibles; la résistance résiduelle à la flexion des éprouvettes variait entre zéro et 11.8 p. 100.

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INTRODUCTION

In the construction of concrete dams of the multi-million dollar Manicouagan-Outardes Hydro-Electric Project in Northern Quebec, the Quebec Hydro-Electric Commission (Hydro-Quebec), Montreal, 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) as compared to normal Portland cement (70 to 76 cal/g in 7 days).

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).

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

SCOPE OF INVESTIGATION

In order to study the durability of concrete made with Type I and modified Type II cements, the concrete mixes were divided into the following two series:

Series A - Medium Strength Mixes

A water/cement ratio of 0.64 was used for the four mixes made in this series; two mixes each were made with blended Type I and Type II cements. Six $3\frac{1}{2}$ x 4 x $15\frac{1}{4}$ in. beams were cast from each mix for durability studies; in addition six 6 x 12 in. cylinders were cast for compressive strength determinations.

Series B - Low Strength Mixes

A water/cement ratio of 0.86 was used for the four mixes made in this series; two mixes each were made with blended Type I and Type II cements. Six $3\frac{1}{2}$ x 4 x $15\frac{1}{4}$ in. beams were cast from each mix for durability studies; in addition fine 6 x 12 cylinders were cast for compressive strength determinations.

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 July 22 and July 29, 1965.

The details of the materials used, mix 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

Three brands of each cement 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 blended 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	21.30	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_3S	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 used was obtained from a coarse grained pink granite from the bedrock near the Manicouagan-2 dam site. The crushed 3/4 and 1½ 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.

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 1½ in. to 3/4 in. coarse aggregate was combined in 2:1 proportion by weight.

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 mesh	100.0
1½ in.	98.5	No. 8 mesh	90.0
1 in.	75.9	No. 16 mesh	67.5
3/4 in.	56.4	No. 30 mesh	42.5
1/2 in.	21.4	No. 50 mesh	20.0
3/8 in.	9.0	No. 100 mesh	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 No.	Mix Proportions, lb/cu yd				Water/Cement Ratio (By Weight)
	Cement, lb	Water, lb	Aggregates, lb		
			Coarse	Fine	
A	418	266	1898	1427	0.64
B	326	281	1812	1567	0.86

Properties of Fresh Concrete

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

TABLE 5

Properties of Fresh Concrete

Series No.	Type of Cement	Properties of Fresh Concrete			
		Temperature, °F	Slump, in.	Unit Weight, lb/cu ft	Entrapped Air Content, per cent
A					
1	I	74	1-3/4	149.4	1.7
2	II	72	2-1/2	149.6	2.5
3	I	72	2	148.0	2.0
4	II	71	2-1/2	148.4	1.7
B					
5	I	75	2	147.2	2.0
6	II	74	2-1/4	146.8	1.8
7	I	68	2-1/4	146.4	2.0
8	II	70	2-3/4	147.2	1.7

PREPARATION OF TEST SPECIMENS

The $3\frac{1}{2}$ x 4 x $15\frac{1}{4}$ in. test beams were cast in heavy brass moulds with 3/8 in. side plates and $\frac{1}{2}$ 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 bottom and top layer.

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.

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 14 and 28 days in accordance with the ASTM standard method of test C39-64. The corresponding beams were tested for flexural strength at 14 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 14-day density of hardened concrete cylinders in the saturated, surface-dry condition.

TABLE 6

Properties of Hardened Concrete

Series No.	Type of Cement	Density of Concrete, lb/cu ft	Flexural Strength* of $3\frac{1}{2}$ x 4 x $15\frac{1}{4}$ in. beams at 14 days, psi	Compressive Strength*, psi	
				14-day	28-day
Series A					
1	I	150.3	670	3285	3820
2	II	151.1	470	2495	3225
3	I	151.8	660	3250	3730
4	II	152.1	520	2645	3535
Series B					
5	I	149.6	485	2050	2590
6	II	150.6	300	1195	1645
7	I	150.0	430	1770	-
8	II	150.7	320	1240	-

*Each test result is average of tests on two specimens.

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 four companion test beams from each mix were kept in moist-curing: two for the 14-day flexural strength and two, as reference, until the end of the freeze-thaw cycling.

Freezing and Thawing Procedure

After 14 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 ± 3° F to 0 ± 3° F and back to 40 ± 3° F, requires about three hours.

Before the freezing and thawing test was commenced, the temperatures of all six 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. The 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 four companion beams were placed in the moist-curing room. The freezing and thawing cycling was started on August 5, 1965, and was terminated on August 16, 1965.

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;
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.

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

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.

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

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

Flexural strength tests were made, as mentioned earlier, in accordance with the ASTM Standard Method C78-64, using a simple beam with third-point loading.

Test Results

Table 7 shows weight, pulse velocity and transverse frequency values as 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 the reference as well as the 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, as given in the ASTM Standard method C291-61T.

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

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

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

Photographs of the beams at the completion of the freeze-thaw test are shown in Figures 1 to 3. Also included in the photographs are the reference beams for comparison purposes.

TABLE 7

Test Results on Beams Subjected to Freezing and Thawing

Series No.	Type of Cement	Number of Freeze-thaw cycles	Test Results: Weight, lb	Length, in.	Transverse Resonant Frequency, cyc/sec	Ultrasonic Pulse Velocity, ft/sec	Flexural Strength, psi	Description of Test Beams at the End of Freeze-Thaw Cycling
Series A								
1	I	0 32	19.351 19.433	0.0126 0.0827	2085 1145	16,015 –	85	Both beams severely damaged.
2	II	0 32	19.235 19.275	0.0246 –	2040 1125	15,935 –	25	Both beams very severely damaged.
3	I	0 52	19.015 19.127	0.0350 0.1029	2060 1115	15,935 –	65	Both beams severely damaged.
4	II	0 52	19.383 19.577	0.0169 0.1499	2085 1105	15,815 –	25	Both beams very severely damaged.
Series B								
5	I	0 38	19.110 19.168	0.0235 –	2050 –	15,735 –	25	Test result on one beam only; other beam disintegrated during handling.
6	II	0 38	19.131 –	0.0209 –	2065 –	14,905 –	0	Both beams disintegrated during handling.
7	I	0 29	19.140 19.414	0.0164 –	2045 –	15,470 –	10	Test results on one beam only; other beam disintegrated during handling.
8	II	0 29	19.071 19.008	0.0218 –	2015 –	14,125 –	0	Both beams disintegraded during handling.

TABLE 8

Weight and Length Changes of Beams*

Mix Series	Weight of Beams, lb						Length of Beams**, in.					
	Reference			Freeze-Thaw			Reference			Freeze-Thaw		
	W_{14}^{a}	W_{x}^{b}	Per Cent Change	W_{o}^{c}	W_{x}^{d}	Per Cent Change	L_{14}^{a}	L_{x}^{b}	Per Cent Change	L_{o}^{c}	L_{x}^{d}	Per Cent Change
Series A												
1	19.085	19.098	+0.07	19.351	19.433	+0.4	0.0293	0.0329	+0.026	0.0126	0.0827	0.514
2	19.315	19.304	-0.05	19.235	19.275	+0.2	0.0240	0.0262	+0.016	0.0246	-	-
3	19.277	19.262	-0.08	19.015	19.127	+0.6	0.0328	0.0352	+0.018	0.0350	0.1029 (f)	0.497
4	19.134	19.127	-0.04	19.383	19.577	+1.0	0.0356	0.0380	+0.018	0.0169	0.1499	0.975
Series B												
5	19.258	19.247	-0.05	19.110	19.168	+0.3	0.0164	0.0200	+0.026	0.0235	-	-
6	19.120	19.115	-0.002	19.131	- (e)	-	0.0170	0.0199	+0.021	0.0209	-	-
7	19.304	19.297	-0.04	19.140	19.414 (f)	+1.4	0.0403	0.0403	No change	0.0164	-	-
8	19.024	19.014	-0.05	19.071	19.008 (f)	+0.3	0.0253	0.0218	-0.026	0.0218	-	-

*Each result is a mean of tests on two beams.
**Gauge length 13.6 in.
(a) Weight and length of beams after 14 days standard moist curing.
(b) Weight and length of beams at the end of 20 ± 1 days of moist curing for Series A, and 19 ± 1 days of moist curing for Series B.
(c) Weight and length of beams at zero cycles of freezing and thawing.
(d) Weight and length of beams at the end of 32 and 52 cycles of freezing and thawing for mixes 1 and 2, and 3 and 4 of Series A respectively; at the end of 38 and 39 cycles of freezing and thawing for mixes 5 and 6, and 7 and 8 of Series B respectively.
(e) Both beams disintegrated during handling.
(f) Only one beam was used, the other disintegrated during handling.

TABLE 9

Ultrasonic Pulse Velocities and Transverse Frequencies of Beams*

Mix Series	Ultrasonic Pulse Velocity, ft/sec						Transverse Resonant Frequency, cycles/sec					
	Reference			Freeze-Thaw				Reference		Freeze-Thaw		
	V_{14}[a]	V_x[b]	Per Cent Change	V_o[c]	V_x[d]	Per Cent Change	f_{14}[a]	f_x[b]	Per Cent Change	f_{14}[c]	f_x[d]	Per Cent Change
Series A												
1	15,935	16,015	+0.5	16,015	-	-	2075	2070	-0.2	2085	1145	45.1
2	15,915	16,075	+1.0	15,935	-	-	2050	2120	+3.4	2040	1125	44.8
3	15,995	16,260	+1.7	15,935	-	-	2050	2155	+5.1	2060	1115	45.9
4	15,700	15,915	+1.4	15,815	-	-	2060	2115	+2.7	2085	1105	47.0
Series B												
5	15,545	15,735	+1.2	15,735	-	-	2040	2135	+4.6	2050	-	-
6	14,615	15,010	+2.7	14,905	-	-	2040	2110	+3.4	2065	-	-
7	15,640	15,620	-0.1	15,470	-	-	2050	2075	+1.2	2045	1050	48.6
8	14,595	14,800	+1.4	14,995	-	-	2025	2055	+1.5	2015	-	-

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

a Ultrasonic pulse velocity and transverse frequency of beams after 14 days of moist-curing.

b Ultrasonic pulse velocity and transverse frequency of beams at the end of 20 ± 1 days of moist curing for Series A and 19 ± 1 days of moist curing for Series B 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 at the end of 32 and 52 cycles of freezing and thawing for mixes 1 and 2, and 3 and 4 of Series A respectively; at the end of 38 and 29 cycles of freezing and thawing for mixes 5 and 6, and 7 and 8 of Series B respectively.

Table 10

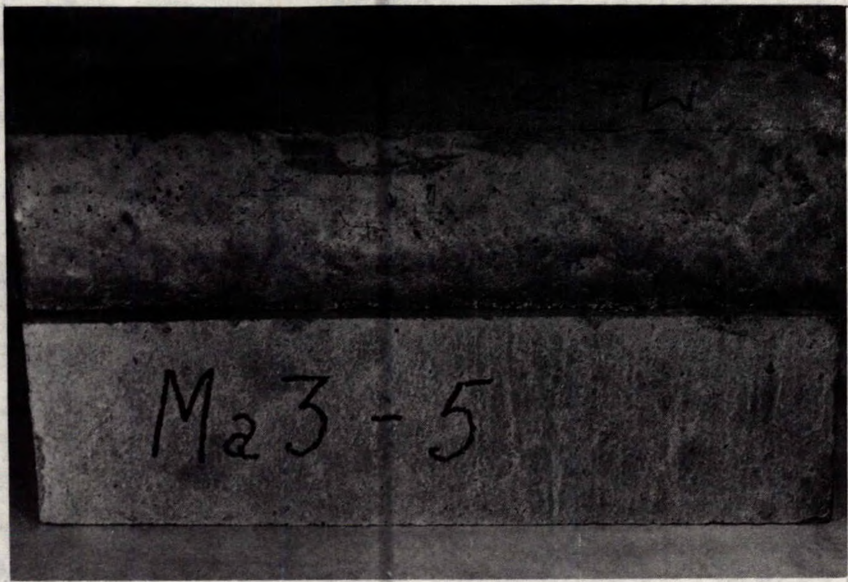
Summary of Flexural Strength Test Results*

Series No.	Type of Cement	Reference Beams** Age, days	Reference Beams** Strength, psi	Freeze-Thaw Beams Number of Freeze-thaw cycles	Freeze-Thaw Beams Strength, psi	Freeze-Thaw Beams Residual Strength, per cent
A						
1	I	19	720	32	85	11.8
2	II	19	615	32	25	4.1
3	I	21	720	52	65	9.0
4	II	21	645	52	25	3.9
B						
5	I	20	525	38	25+	4.8
6	II	20	395	38	Beams disintegraded during handling	-
7	I	18	490	29	10+	2.0
8	II	18	372	29	Beams disintegraded during handling	-

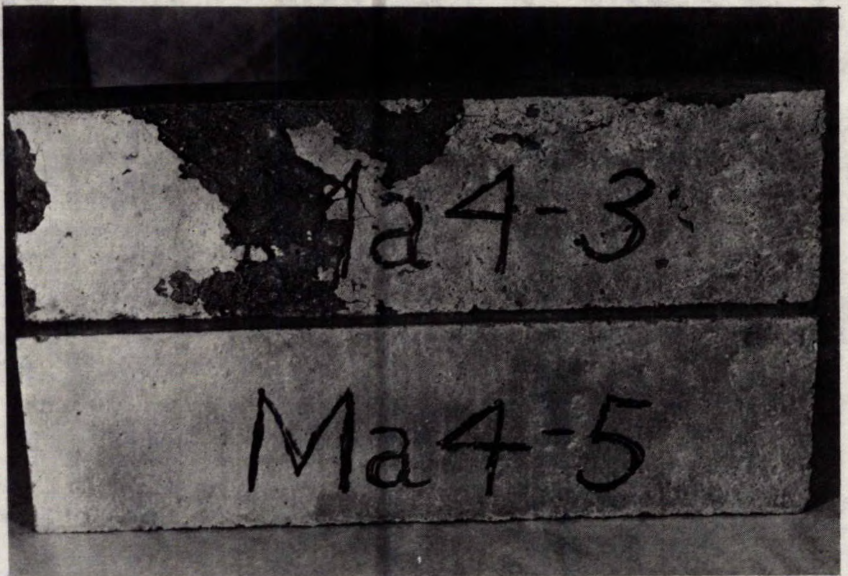
*Each result is a mean of tests on two beams unless otherwise stated.
**These beams were standard moist-cured.
+Strength of one beam only; other beam disintegrated during handling.

Figure 1 - Series A: Medium Strength Concrete Mixes 1 and 2
After 32 Freeze-Thaw Cycles

Top Beam: Type I cement concrete after flexural test.
Bottom Beam: Type II cement concrete.



(a)



(b)

Figure 2 - Series A: Medium Strength Concrete Mixes 3 and 4 After 52 Freeze-Thaw Cycles

(a) Type I cement concrete reference (bottom) and freeze-thaw (top) beams.

(b) Type II cement concrete reference (bottom) and freeze-thaw (top) beams.

(a)

(b)

Figure 3 - Series B: Low Strength Concrete Mixes 5 and 8
After freeze-thaw cycling

(a) Type I cement concrete reference (bottom) and freeze-thaw (top) beams after 38 cycles.

(b) Type II cement concrete reference (bottom) and freeze-thaw (top) beams after 29 cycles. Note the disintegrated condition of the top beam.

DISCUSSION OF TEST RESULTS

The test results in Tables 7 to 9 and photographs 1 to 3 show that the test beams for both Series A and B had been extensively damaged after exposure to less than 55 cycles of freezing and thawing. Test beams made with blended Type II cement had shown greater deterioration than those made with blended Type I cement. This was true for both low and medium strength mixes. However this should not be taken to mean that concrete made using Type I cement has relatively superior durability compared to that made using Type II cement. This is because the hydration characteristics of Type II cement are such that concrete made using this cement is slow to gain strength at early ages compared to concrete made with Type I cement. The 14-day compressive and flexural strengths given in Table 6 effectively demonstrate this; however at later ages of 90 days and 1-year the strength of Type II cement concrete is higher than that of Type I cement(3). Therefore if it is desired to compare the relative durability of concretes made with the two types of cement, it is most essential that the test beams should be put in the freezing and thawing cabinet not at the end of any fixed number of days of standard moist-curing but at the end of a period at which test beams made with both types of cement have reached approximately equal strength.

The weight changes shown in Table 8 do not truly reflect the deteriorated condition of the beam. 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.

In most cases, due to the extremely deteriorated condition of the beams, no ultrasonic pulse velocity and transverse frequency readings were possible after exposure to 25 cycles of freezing and thawing. Where transverse frequency readings were possible, the relative dynamic modulus of elasticity was less than 26.4 per cent.

The residual flexural strength of the test beams exposed to freezing and thawing varied from zero to a maximum of 11.8 per cent.

CONCLUSIONS

The durability studies made on the test beams show that:

1. The non-air-entrained concretes specimens made with both blended Type I and Type II cements have very little resistance to accelerated cycles of freezing and thawing. This is in line with the published data for non-air-entrained concretes.

2. No conclusions can be drawn as to the relative durability of concrete made with the two types of cement, because the investigation was not designed for that purpose.

REFERENCES

1. V.M. Malhotra and N.G. Zoldners, "Investigation of Durability of Concrete for Manicouagan-2 Project" Mines Branch Investigation Report IR 63-38 (March, 1963).

2. V.M. Malhotra and N.G. Zoldners, "Durability Studies of Concrete For Manicouagan-2 Project" Mines Branch Investigation Report IR 64-69 (July 24, 1964).

3. V.M. Malhotra and N.G. Zoldners, "Strength and Durability of Concrete Made with Type II Cement" Mines Branch Investigation Report IR 65-27 (March 24, 1965).

VMM/NGZ/Jg