CANMET

Canada Centre for Mineral and Energy Technology

Centre canadien de la technologie des minéraux et de l'énergie

REPORT 80-18E

DURABILITY OF CONCRETE CONTAINING GRANULATED BLAST FURNACE SLAG OR FLY ASH OR BOTH IN MARINE ENVIRONMENT

V.M. MALHOTRA, G.G. CARETTE AND T.W. BREMNER

MINERALS RESEARCH PROGRAM
MINERAL SCIENCES LABORATORIES

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

JUNE 1980

Available in Canada through

Authorized Bookstore Agents
and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Hull, Quebec, Canada K1A 0S9

CANMET
Energy, Mines and Resources Canada,
555 Booth St.,
Ottawa, Canada K1A 0G1

or through your bookseller

Catalogue No. M38–13/80–18E   Canada: $2.00
ISBN 0-660-10701-5   Other Countries: $2.40

Price subject to change without notice.

En vente au Canada par l'entremise de nos

agents libraires agréés
et autres librairies

ou par la poste au:

Centre d'édition du gouvernement du Canada
Approvisionnements et Services Canada
Hull, Québec, Canada K1A 0S9

CANMET
Énergie, Mines et Resources Canada,
555, rue Booth
Ottawa, Canada K1A 0G1

ou chez votre libraire.

N° de catalogue   Canada:
ISBN   Hors Canada:

Prix sujet à changement sans avis préalable.

ERRATA FOR CANMET REPORT 80-18E

DURABILITY OF CONCRETE CONTAINING GRANULATED BLAST FURNACE SLAG OR FLY ASH OR BOTH IN MARINE ENVIRONMENT

ABSTRACT

This progress report describes the CANMET research project to assess the durability of portland cement/granulated blast-furnace slag/fly ash concretes in marine environments. The project was divided into three phases - laboratory work associated with Phases I and II was completed and that for Phase III will commence in July, 1980.

DURABILITY OF CONCRETE CONTAINING GRANULATED BLAST FURNACE SLAG OR FLY ASH OR BOTH IN MARINE ENVIRONMENT

by

V.M. Malhotra*, G.G. Carette** and T.W. Bremner***

ABSTRACT

This progress report describes the CANMET research project to assess the durability of portland cement/granulated blast-furnace slag/fly ash concretes in marine environments. The project was divided into three phases laboratory work associated with Phases I and II was completed and that for Phase III will commence in July, 1980.

The work entails making 0.1-m^3 concrete mixes with water to cementitious material ratios ranging from 0.40 to 0.60. The cementitious materials consisted of various replacements of portland cement by fly ash and granulated blast furnace slag. The prisms and cylinders made with these mixes are installed at a natural weathering station at Treat Island, Maine, where they are exposed to the effects of the alternating conditions of immersion in sea water and exposure to cold air for more than 100 cycles of freezing and thawing each winter. The test specimens at Treat Island are being monitored at yearly intervals for visual deterioration, and measurements are being taken to determine changes in pulse velocity and fundamental resonant frequency.

The specimens from Phase I have now been exposed for one year. The results of first yearly inspection indicated no significant deterioration of any specimen except for some surface scaling on those made with high water:cement ratios incorporating high percentages of slag.

*Head and **Materials engineer, Construction Materials Section, Mineral Sciences Laboratories, CANMET, Department of Energy, Mines and Resources Ottawa, Canada. ***Professor, Department of Civil Engineering, University of N.B., Fredericton, New Brunswick.

LA DURABILITE DU BETON CONTENANT DES SCORIES GRANULEUSES DE HAUT-FOURNEAU OU DE LA CENDRE VOLANTE OU LES DEUX EN MILIEU MARIN

par

V.M. Malhotra*, G.G. Carette** et T.W. Bremner***

RESUME

Le présent rapport décrit un projet de recherche effectué au CANMET pour évaluer la durabilité des bétons de ciment portland/scories granuleuses de haut-fourneau/cendre volante en milieu marin. Le projet est divisé en trois phases - la recherche en laboratoire pour les phases I et II est déjà terminée et celle de la phase III commencera en juillet 1980.

Les travaux consistent de mélanger 0,1 m^3 de béton ayant un rapport de l'eau aux matières cimenteuses de 0,40 à 0,60. Les matières cimenteuses sont formées en remplaçant différentes portions du ciment portland par de la cendre volante et des scories granuleuses de haut-fourneau. Les prismes et les cylindres fabriqués à partir de ces mélanges sont installés dans la station atmosphérique naturelle de Treat Island (Maine) où ils sont exposés à des conditions successives d'immersion dans l'eau salée et d'exposition à l'air froid et à plus de 100 cycles de gel et de dégel à chaque hiver. Les échantillons d'essais de treat Island sont examinés à tous les ans pour déceler la détérioration visuelle et on prend des mesures pour déterminer les modifications de la vélocité d'impulsion et la fréquence résonante fondamentale.

Les échantillons de la phase I ont été exposés pendant une période d'un an. Les résultats des premières observations n'indiquent aucune détérioration apparente sur aucun des échantillons sauf un léger écaillement à la surface des échantillons ayant un rapport élevé d'eau à ciment et une grande teneur de scories.

*Chef et **Ingénieur des matériaux, Section de matériaux de construction, Laboratoires des sciences minérales, CANMET, Energie, Mines et Ressources Canada, Ottawa. ***Professeur, Département de Génie civil, Université du N.-B., Frédéricton, Nouveau-Brunswick.

CONTENTS

TABLES

FIGURES

INTRODUCTION

In recent years the performance of concrete in a marine environment has assumed added interest because of the offshore gas and oil exploration activity in various countries. The Maritime provinces of Canada are no exceptions and the discoveries of oil and gas in sizable amounts will lead inevitably to increased construction activity and greater demand for durable concrete. In addition, the renewed interest in the Bay of Fundy tidal project requires long-term studies on the performance of concrete in marine environments using local materials. This is not to imply that concrete has not performed well in sea water applications on Canada's coasts. On the contrary, some harbour works and docks in St. John, Halifax and other cities are a monument to a long history of successful use of concrete. However, the very high energy cost associated with the production of cement in the Maritime provinces demand that less energy intensive materials should be investigated for making concrete. The performance of this concrete under severe marine exposure must also be assured so that long-term service life of structures can be guaranteed. Of all the concrete-making materials, cement is the most energy intensive, requiring 6570 MJ/tonne of product representing 42% of the total plant production cost (1). Thus, any attempt to reduce the amount of cement in concrete can offer considerable energy savings. Fly ash and granulated blast furnace slag are two such materials which are less energy intensive and can be used to replace cement. Some European data are avilable on the performance of concrete incorporating granulated blast furnace slags and fly ash (1,2). As all granulated blast furnace slags and fly ashes are different and have unique properties depending on the raw materials it is therefore imperative to develop performance data for their use in Canada. At present fly ash and granulated blast furnace slags are not available in the Maritime provinces in significant amounts. However, commencing in 1981, the Lingan plant of Nova Scotia Power Commission will be producing about 100,000 tonnes of fly ash per year as a byproduct and the availability of granulated blast furnace slag from the SYSCO plant at Sydney, Nova Scotia, is a distinct possibility in the not so distant future.

The present investigation was therefore undertaken to determine the performance of portland cement concrete incorporating blast furnace slag and fly ash in the marine environment of Eastern Canada. These products were obtained from the southern Ontario and Detroit areas but the investigations will be extended to incorporate fly ash and granulated blast furnace slag from sources in Nova Scotia as they become available.

SCOPE

This investigation has been divided into three phases. The laboratory experimental work associated with Phases I and II has been completed and the experimental work for Phase III is planned for July, 1980. The test specimens from the first two phases have been installed at a natural weathering station at Treat Island, Maine, U.S.A. to determine the effects of the alternating conditions of immersion in sea water and exposure to cold air for more than 100 cycles of freezing and thawing each winter.

PHASE I

In this phase, 51 concrete mixes were made with water to cement plus slag ratios ranging from 0.40 to 0.60. For each water to cement plus slag ratio, the percentage replacement of cement by slag varied from 0 to 65%. Normal portland cement, ASTM Type I*, was used throughout, except for two additional mixes using ASTM type V** for each water to cement plus slag ratio. All mixes were air-entrained. In addition, a series of six mixes, four of which incorporated superplasticizers, was made. A total of 36 prisms, 305 x 305 x 915 mm in size, and 363 cylinders 152 x 305 mm in size, were cast for long-term field exposure and laboratory studies. Specimens at Treat Island are being monitored at yearly in-

---

*CSA Type 10

**CSA Type 50

tervals to visually determine deterioration and to measure changes in pulse velocity and fundamental resonant frequency.

PHASE II

In this phase 51 concrete mixes were made with water to cement plus fly ash plus slag ratios ranging from 0.40 to 0.60. For each ratio, the percentage of cement replacement by fly ash and slag varied from 0 to 80%. Normal portland cement (ASTM Type I) was used throughout except for each water to cement plus slag plus fly ash ratio, two mixes each being made with ASTM Type II*** and Type V cements. All mixes were air-entrained.

A total of 33 prisms, 305 x 305 x 915 mm in size and 420 cylinders, 152 x 305 mm in size, were cast for long-term field exposure and laboratory studies. Specimens at Treat Island will be monitored at yearly intervals to visually determine deterioration and to measure changes in pulse velocity and fundamental resonant frequency.

PHASE III

This phase will be identical to Phase I, except that instead of normal weight aggregate as used in Phase I, lightweight aggregate will be used as the coarse aggregate. A total of 45 concrete mixes will be made and prism and cylinder specimens will be cast for laboratory studies and field exposure.

EXPOSURE OF TEST SPECIMENS AT TREAT ISLAND, MAINE FOR LONG-TERM DURABILITY

EXPOSURE STATION, TREAT ISLAND, MAINE

The natural weathering exposure station at Treat Island, Maine located in Cobscook Bay near Eastport, has been in use by the U.S. Corps of Engineers since 1936 (3). This exposure site was selected because of its proximity to the Maritimes about 30 km from St. Stephen, N.B., and because it offers exposure conditions which are typical of the Bay of Fundy basin area and consist of twice daily tide reversals, together with severe winters.

CRITERIA OF FAILURE OF SPECIMENS

The criteria of specimen failure will be the same as those adopted by the U.S. Corps of Engineers (3). These are:

(i) exposed specimens will be considered as having failed when they separate into pieces;

(ii) when the relative dynamic modulus is 50% or less, or

(iii) when deterioration has progressed to such a point that reliable measurement of fundamental transverse frequency and pulse velocity cannot be made.

MONITORING OF TEST SPECIMENS

The test specimens exposed at the station are to be inspected visually each year. At the time of inspection, pulse velocity measurements (ASTM Designation C597) are made and photographs taken of each specimen.

In addition to the monitoring by CANMET personnel, an inspection team of Corps of Engineers also inspects these specimens as a part of its program and the test data are included in its annual report. In addition to the visual inspection and pulse velocity measurements, personnel from the Corps of Engineers also determine fundamental transverse frequency of test specimens (ASTM Designation C215).

PHASE I INVESTIGATIONS

CONCRETE MIXES

The concrete mixes were made in the Civil Engineering Laboratory of the University of New Brunswick, at Fredericton, during July and August 1978.

Material

Cement

Portland cements, ASTM Types I and V, were used. The physical properties and chemical analyses of the cements are given in Table 1.

***CSA Type 20.

Table 1 - Physical properties and chemical analyses of cement and slag - Phase I

Description of tests	Portland cement* ASTM Type I	Portland cement* ASTM Type V	Slag
Physical tests - general			
Fineness - passing 74 µm %	90.7	92.0	92.7
- passing 74 µm %	77.6	85.0	84.2
- blaine, m^2/kg	339	323	466
Normal consistency, %	22.7	23.5	--
Setting time, min.	120	330	--
Autoclave expansion %	0.00	-0.02	--
Physical tests - mortar strength			
Water content, %	48.5	46.0	--
Flow, %	115	114	--
Compressive strength, MPa			
3-d	22.4	14.4	3.1
7-d	27.2	20.1	8.6
28-d	32.4	31.4	18.0
Chemical analyses			
SiO_2, %	20.56	24.04	36.84
CaO, %	63.07	64.19	36.92
CaO (free), %	0.53	0.53	--
Insoluble, %	0.47	0.23	--
Loss on ignition, %	1.27	0.74	0.23**
Al_2O_3, %	5.59	3.21	9.53
Fe_2O_3, %	1.99	3.85	1.11
SO_3, %	4.63	1.94	0.10
MgO, %	1.44	1.29	11.07
Na_2O, %	0.08	0.13	0.28
K_2O, %	1.27	0.62	0.36
Alkalies (as Na_2O), %	0.92	0.54	0.52
$CaSO_4$, %	6.79	3.3	--
C_3A, %	11.4	2.0	--

*Manufacturer's data

**Determined at 120°C and indicates moisture loss on drying

Granulated blast furnace slag

Granulated blast furnace slag from a plant in southern Ontario was used as a partial replacement for cement. The physical properties and chemical analysis of the slag are given in Table 1.

Aggregates

Minus 37.5-mm crushed gravel from the Blagdon pit, 80 km south east of Fredericton was used for both the fine and coarse aggregates. The aggregates were obtained in three sizes, the sieve analyses for which are given in Table 2. Mineralogically the gravel aggregate consisted primarily of a mixture of dense, fine- to medium-grained volcanic rocks, coarse-grained granite and impure, medium-grained sandstone.

Air-entraining agent

A sulphonated hydrocarbon type air-entraining agent was used in all the mixes.

Superplasticizers

The following two types of superplasticizers were used in four mixes of one series.

Sulphonated melamine formaldehyde condensate

It is of German origin and is a 20% aqueous solution with a density of 1100 kg/m^3 and is limpid to slightly turbid or milky in appearance. The chloride content is 0.005%.

Sulphonated naphthalene formaldehyde condensate

It is of Japanese origin and is a 42% aqueous solution with a density of 1200 kg/m^3 and is dark brown in colour. The chloride content is negligible.

Mix Proportioning

The non-superplasticized mixes were proportioned to have water to cement plus slag ratios of 0.40, 0.50 and 0.60. At each ratio, 15 0.1-m^3 batches were made with each batch proportioned to have a slump of 75 ± 25 mm and an air content of 6 ± 1%. Thirteen batches were made using ASTM Type I cement and two batches were made using Type V. In concrete batches made with Type I, up to 65% of the cement was replaced by blast-furnace slag. The concrete mix series incorporating superplasticizers consisted of 6 batches; each batch was made using ASTM Type I cement and had a water to cement ratio of 0.5. The detailed mix proportions are given in Table 3.

Mixing Procedure

A laboratory counter-current mixer was used throughout. The mixer was started and all ingredients were added simultaneously over a two-minute period following which mixing was continued for another five minutes. In superplasticized concrete batches, the required dose of a superplasticizer was added after a mixing time of seven minutes, following this, mixing was continued for a further five minutes.

Table 2 - Grading of aggregates - Phase I

Sieve size, mm	Coarse aggregate: Cumulative % retained		Fine aggregate: Sieve size, mm	Fine aggregate: Cumulative % retained
38	0		4.75	1.6
25	59.7		2.36	15.7
19	92.1	0	1.18	27.0
12.5	100.0	41.0	600 µm	56.4
9.5		82.6	300 µm	79.4
4.75		99.6	150 µm	92.9
2.36		100.0	pan	100.0

Table 3 - Mix proportions - Phase I

Mix series	Cement type and batch No.	W:(C+S) ratio	A:(C+S) ratio	Water, kg/m^3	Cement, kg/m^3	Cement replacement by slag mass %	A.E.A., mL/m^3
A	Type I, 1	0.40	4.51	158	396	0	360
	2		4.50	160	292	25	580
	3		3.99	178	318	25	480
	4		3.98	181	316	25	440
	5		3.83	176	444	0	430
	6		3.83	176	243	45	870
	7		3.83	175	243	45	860
	8		3.83	176	243	45	870
	9		3.83	177	445	0	370
	10		3.83	176	154	65	1130
	11		3.74	179	155	65	1120
	12		3.75	180	156	65	1120
	Type V, 13		4.58	157	392	0	490
	14		4.58	158	395	0	500
	Type I, 15		3.84	179	446	0	390
B	Type I, 1	0.50	5.50	161	329	0	280
	2		5.50	161	244	25	380
	3		5.51	161	247	25	340
	4		6.03	151	231	25	320
	5		5.92	161	320	0	260
	6		5.43	166	183	45	450
	7		5.44	166	183	45	450
	8		5.43	167	183	45	460
	9		5.49	167	335	0	350
	10		5.45	166	116	65	590
	11		5.40	167	117	65	540
	12		5.45	168	118	65	540
	Type V, 13		5.92	157	314	0	350
	14		5.92	157	313	0	350
	Type I, 15		5.49	166	331	0	370
C	Type I, 1	0.60	6.76	170	282	0	270
	2		6.74	167	209	25	320
	3		6.75	168	209	25	300
	4		7.27	159	199	25	300
	5		7.11	160	267	0	260
	6		7.10	160	147	45	390
	7		7.11	158	145	45	440
	8		7.11	158	145	45	410
	9		7.11	160	266	0	260
	10		7.06	160	94	65	380
	11		7.06	160	93	65	380
	12		7.07	161	94	65	390
	Type V, 13		7.11	163	272	0	260
	14		7.11	163	272	0	260
	Type I, 15		7.10	161	268	0	260
S	Type I, 1		5.50	167	334	0	280
	2*		5.49	166	332	0	280
	3*		5.50	174	348	0	0
	4		5.49	174	349	0	0
	5**		5.50	165	330	0	280
	6**		5.49	172	345	0	0

*Naphthalene-based superplasticizer used to obtain collapse slump

**Melamine-based superplasticizer used to obtain collapse slump

Properties of Fresh Concrete

The temperature, slump, unit mass and air content of the fresh concrete were determined after mixing (Table 4). In the case of the superplasticized batches, the slump was taken after mixing and again after addition of the superplasticizer and further mixing for five minutes.

Some slump loss was noted in concrete batches which had high replacement of cement with slag; also in these batches, there was a tendency for the concrete to stick to the sides of the slump cone.

Casting of Test Specimens

A total of 399 specimens were cast in this phase. These consisted of 305 x 305 x 915-mm prisms and 152 x 305-mm cylinders. As far as possible, all specimens were cast in accordance with standard ASTM procedures. The details of specimens cast are given in Table 5.

All prisms were cast by filling wooden moulds in two layers of equal depth with each layer being vibrated with an internal vibrator. After the vibration of each layer, the sides and ends of the moulds were hammered with a rubber mallet to eliminate any surface air pockets. Upon completion of vibration, the concrete was struck off with a wooden straight-edge. As soon as the bleed water had evaporated, the concrete was floated with a wooden trowel and the prism was covered with a sheet of plastic.

For concrete batches A01 to A12, the 152 x 305-mm cylinders were cast by filling heavy-duty plastic moulds in three equal layers and each layer was rodded 25 times. The cyclinders from subsequent batches were consolidated using an internal vibrator. All cylinder surfaces were struck off with a wooden trowel and covered with a metal sheet.

All the moulded specimens were covered and left in the casting room at about 24°C and 50% relative humidity for 24 hours following which they were demoulded. After determining density of the cylinders they were then transferred to the moist-curing room. The prisms were left in the casting room for an additional two days during which they were kept covered with wet burlap and plastic sheets to prevent moisture loss. Following this, they were transferred to the moist-curing room.

TESTING OF SPECIMENS

At 28 d, two cylinders from each batch were removed from the moist-curing room, and were capped and tested in compression. For batch No. A04, A08, A12, A14, B04, B12, B13, B14, C04, C08, C12 and C14, two additional cylinders were tested at 28 d for the determination of modulus of elasticity. The testing schedule is shown in Table 5 and the test results in Tables 6 and 9.

TRANSFER OF TEST SPECIMENS TO TREAT ISLAND, MAINE

On October 12, 1978, after 28 d of moist curing and a minimum of 30 d of curing at 70°F and 50% relative humidity, the large prisms and two companion cylinders were transferred to Treat Island, Maine for long-term durability studies (Fig. 1). After a short period of immersion of the specimens at Treat Island, pulse velocity measurements were taken on each (Table 10).

INSPECTION OF TEST SPECIMENS AT ONE YEAR

The results of pulse velocity measurements taken after one year of exposure are shown in Table 10. The pulse velocity changes over the one-year period were relatively small, indicating no major deterioration of the specimens. All prisms, except one, showed some slight increase in pulse velocity whereas the cylinders, in general, showed no consistent change. Test specimens with high water to cement ratio and high cement replacement by slag were found to exhibit some surface scaling (Fig. 2).

PHASE II INVESTIGATIONS

CONCRETE MIXES

The concrete mixes were made in the Civil Engineering laboratories at the University of New Brunswick during June-July 1979. The mixing equipment and procedure were identical to those used in Phase I.

Table 4 - Properties of fresh concrete - Phase I

Mix series	Batch No.	Properties of fresh concrete			
		Temperature °C	Slump, mm	Unit mass, kg/m3	Air content, %
A	1	26.5	70	2342	5.6
(W:C+S = 0.40)	2	26.5	55	2304	7.0
	3	26.5	90	2294	6.6
	4	26.5	90	2281	6.8
	5	27.5	90	2325	6.5
	6	26.5	75	2316	6.8
	7	26.5	55	2310	6.4
	8	27.0	60	2315	6.5
	9	22.0	90	2328	5.8
	10	24.0	55	2308	6.0
	11	24.5	75	2254	6.4
	12	24.5	75	2260	6.4
	13	25.0	70	2347	6.2
	14	25.0	65	2361	5.6
	15	25.5	75	2337	5.5
B	1	26.0	90	2302	6.5
(W:C+S = 0.50)	2	26.0	100	2288	6.7
	3	26.0	90	2310	5.9
	4	26.0	85	2323	5.5
	5	26.0	85	2374	5.5
	6	25.0	75	2308	6.4
	7	25.0	70	2305	6.8
	8	25.5	75	2312	6.2
	9	26.5	75	2344	6.5
	10	25.0	75	2305	7.0
	11	25.0	65	2325	5.6
	12	25.5	75	2344	5.5
	13	24.5	85	2334	6.2
	14	25.0	90	2325	6.5
	15	25.0	85	2316	6.5
C	1	24.5	90	2363	5.8
(W:C+S = 0.60)	2	24.5	100	2331	6.4
	3	25.0	100	2334	5.5
	4	25.0	90	2360	5.9
	5	24.0	75	2325	5.7
	6	23.0	75	2328	5.2
	7	23.0	90	2294	6.5
	8	23.0	95	2297	6.2
	9	24.0	90	2316	5.4
	10	23.5	90	2316	5.5
	11	23.5	90	2310	6.2
	12	24.0	90	2336	5.2
	13	24.0	100	2368	5.4
	14	24.0	100	2374	5.3
	15	24.5	100	2334	6.0
S	1	26.0	80	2339	5.6
(W:C = 0.50	2	26.0	collapse*	2320	6.3
	3	26.5	collapse*	2438	0.9**
	4	25.0	60	2440	1.5**
	5	26.5	collapse*	2313	6.2
	6	26.5	collapse*	2411	0.3**

*Slump about 75 mm before addition of superplasticizers

**Non-air-entrained mixed

Table 5 - Type and number of specimens cast and testing schedule - Phase I

Mix Series	Batch No.	Type and number of specimens cast		Total number of specimens cast		Testing of specimens			
		305x305x915-mm prisms	152x305-mm cylinders	305x305x915-mm prisms	152x305-mm cylinders	305x305x915-mm prisms	152x305-mm cylinders		
							1	2	3
A	A01,A02,A03, A05,A06,A07 A09,A10,A11, A13	One prism cast from each batch	Four cylinders cast from each batch	10	40	Prisms installed at Treat Island for long-term durability studies	Two cylinders from each batch tested in compression at 28 d	Two cylinders from each batch installed at Treat Island for long-term durability studies	---
	A04,A08,A12, A14,A15	---	Sixteen cylinders cast from each batch except A15 when nine cylinders were cast	-	73	---	Four cylinders from each batch except A15 tested in compression and for modulus of elasticity at 28 d	Two cylinders from each batch installed at Treat Island for long-term durability studies	Ten cylinders from each batch (seven from A15) stored in moist-curing room for long-term strength testing
B	B01,B02,B03, B05,B06,B07 B09,B10,B11 B13	One prism cast from each batch	Four cylinders cast from each batch	10	40	Prisms installed at Treat Island for long-term durability studies	Two cylinders from each batch tested in compression at 28 d	Two cylinders from each batch installed at Treat Island for long-term durability studies	---
	B04,B08,B12, B14,B15	---	Sixteen cylinders cast from each batch except B15 when nine cylinders were cast	-	73	---	Four cylinders from each batch except B15 tested in compression and for modulus of elasticity at 28 d	Two cylinders from each batch installed at Treat Island for long-term durability studies	Ten cylinders from each batch (seven from B15) stored in moist-curing room for long-term strength testing
C	C01,C02,C03, C05,C06,C07 C09,C10,C11, C13	One prism cast from each batch	Four cylinders cast from each batch	10	40	Prisms installed at Treat Island for long-term durability studies	Two cylinders from each batch tested in compression at 28 d	Two cylinders from each batch installed at Treat Island for long-term durability studies	---
	C04,C08,C12, C14,C15	---	Sixteen cylinders cast from each batch except C15 when nine cylinders were cast	-	73	---	Four cylinders from each batch except C15 tested in compression and for modulus of elasticity at 28 d	Two cylinders from each batch installed at Treat Island for long-term durability studies	Ten cylinders from each batch (seven from C15) stored in moist-curing room for long-term strength testing
S	S01,S02,S03, S04,S05,S06	One prism cast from each batch	Four cylinders cast from each batch	6	24	Prisms installed at Treat Island for long-term durability studies	Two cylinders from each batch tested in compression and for modulus of elasticity at 28 d	Two cylinders from each batch installed at Treat Island for long-term durability studies	---
			Grand Total	36	363				

Table 6 - Summary of density and mechanical properties of test cylinders - Series A - Phase I

W : (C+S) ratio	Cement type and batch No.	Relative proportions of cement and slag, %		Density at one day, kg/m^3	Compressive strength* at 28 d, MPa	Young's modulus of elasticity** and compressive strength at 28 d	
		Cement	Slag			E, MPa x 10^4	Strength, MPa
0.40	Type I, 1	100	0	2364	32.0	--	--
	2	75	25	2312	29.8	--	--
	3	75	25	2316	29.3	--	--
	4	75	25	2305	26.8	2.61***	26.9***
	5	100	0	2318	29.0	--	--
	6	55	45	2300	28.6	--	--
	7	55	45	2320	30.5	--	--
	8	55	45	2324	26.6	2.85***	28.2***
	9	100	0	2329	30.3	--	--
	10	35	65	2312	29.5	--	--
	11	35	65	2292	27.2	--	--
	12	35	65	2300	27.2	2.79***	27.0***
	Type V, 13	100	0	2344	33.6	--	--
	14	100	0	2387	38.9	3.10	38.5
	Type I, 15	100	0	2336	--	--	--

* Each result is average of two values

** After determination of Young's modulus of elasticity, the test cylinders were broken in compression. Each value is average of two test results

***Determined at 35 d

Table 7 - Summary of density and mechanical properties of test cylinders - Series B - Phase I

W: (C+S) ratio	Cement type and batch No.	Relative proportions of cement and slag, %		Density at one day, kg/m³	Compressive strength* at 28 d, MPa	Young's modulus of elasticity** and compressive strength at 28 d	
		Cement	Slag			E, MPa x 10^4	Strength, MPa
0.50	Type I, 1	100	0	2323	27.2	--	--
	2	75	25	2299	27.1	--	--
	3	75	25	2302	27.9	--	--
	4	75	25	2313	26.8	2.48	25.3
	5	100	0	2334	26.5	--	--
	6	55	45	2297	25.6	--	--
	7	55	45	2323	28.1	--	--
	8	55	45	2313	27.4	--	28.3
	9	100	0	2360	27.1	--	--
	10	35	65	2278	22.7	--	--
	11	35	65	2305	23.5	--	--
	12	35	65	2331	24.4	2.72***	24.7***
	Type V, 13	100	0	2345	32.0	--	--
	14	100	0	2366	32.2	2.80	31.4
	Type I, 15	100	0	2304	--	--	--

* Each result is the average of two values

** After determination of Young's modulus of elasticity, the test cylinders were broken in compression. Each value is average of two test results

***Determined at 30 d

Table 8 - Summary of density and mechanical properties of test cylinders - Series C - Phase I

W: (C+S) ratio	Cement type and batch No.	Relative proportions of cement and slag, %		Density at one day, kg/m^3	Compressive strength* at 28 d, MPa	Young's modulus of elasticity** and compressive strength at 28 d	
		Cement	Slag			E, MPa x 10^4	Strength, MPa
0.60	Type I, 1	100	0	2334	24.0	--	--
	2	75	25	2329	25.7	--	--
	3	75	25	2321	24.8	--	--
	4	75	25	2353	23.3	2.73	23.8
	5	100	0	2350	26.5	--	--
	6	55	45	2345	26.2	--	--
	7	55	45	2328	25.5	--	--
	8	55	45	2323	24.7	2.55	23.8
	9	100	0	2320	22.7	--	--
	10	35	65	2318	19.5	--	--
	11	35	65	2308	19.8	--	--
	12	35	65	2336	18.1	2.65	18.5
	Type V, 13	100	0	2310	25.4	--	--
	14	100	0	2382	27.9	2.79	28.2
	Type I, 15	100	0	2315	--	--	--

* Each result is the average of two values

** After determination of Young's modulus of elasticity, the test cylinders were broken in compression. Each value is average of two test results

Table 9 - Summary of density and mechanical properties of test cylinders - Series S - Phase I

W : C ratio (by mass)	Cement type and batch No.	Density at one day, kg/m^3	Young's modulus of elasticity** and compressive strength at 28 d	
			E, MPa x 10^4	Strength, MPa
0.50	Type I, 1	2366	2.88	28.0
	2	2307	2.78	24.2
	3	2433	3.23	34.9
	4	2441	3.12	34.7
	5	2368	2.70	29.4
	6	2454	3.24	33.7

* Note: Series S refers to concrete mixes using superplasticizers

** After determination of Young's modulus of elasticity, the test cylinders were broken in compression. Each value is average of two test results

Fig. 1 - A view of the concrete specimens installed at Treat Island - Phase I

Table 10 - Pulse velocity measurements on specimens installed at Treat Island - Phase I

Mix series	Batch No.	Ultrasonic pulse velocity, m/s			
		305 x 305 x 915-mm prisms		152 x 305-mm cylinders	
		Initial	At 365 d	Initial	At 365 d
A	1	4400	4470	4470	4430
(W:C+S = 0.40)	2	4260	4320	4400	4310
	3	4230	4300	4390	4350
	4	--	--	4370	4260
	5	4350	4420	4350	4310
	6	4320	4350	4310	4230
	7	4260	4300	4330	4310
	8	--	--	4270	3970
	9	4360	4410	4390	4320
	10	4300	4340	4370	4270
	11	4250	4260	4240	4270
	12	--	--	4250	4220
	13	4420	4480	4410	4480
	14	--	--	4440	4420
	15	--	--	4400	4410
B	1	4300	4320	4340	4290
(W:C+S = 0.50)	2	4240	4280	4260	4210
	3	4290	4330	4310	4180
	4	--	--	4410	4350
	5	4300	4360	4360	4290
	6	4250	4300	4350	4390
	7	4280	4320	4260	4380
	8	--	--	4380	4430
	9	4220	4280	4370	4360
	10	4170	4240	4260	4290
	11	4200	4300	4250	4320
	12	--	--	4260	4240
	13	4330	4410	4380	4340
	14	--	--	4400	4350
	15	--	--	4370	4270
C	1	4290	4300	4360	4320
(W:C+S = 0.60)	2	4260	4310	4300	4320
	3	4250	4300	4260	4300
	4	--	--	4360	4330
	5	4290	4300	4330	4240
	6	4260	4290	4290	4270
	7	4190	4250	4230	4260
	8	--	--	4300	4410
	9	4280	4300	4350	4260
	10	4160	4240	4220	4080
	11	4143	3940	4190	4240
	12	--	--	4240	4230
	13	4310	4370	4240	4270
	14	--	--	4380	4410
	15	--	--	4380	4270
S	1	4280	4330	4340	4070
(W:C = 0.50)	2	4220	4270	4220	4130
	3	4460	4480	4310	4180
	4	4460	4540	4520	4460
	5	4300	4350	4260	4140
	6	4460	4460	4450	4290

*Each value is average of three measurements on a single specimen (path length = 915 mm)

**Each value is average of measurements on two specimen (path length = 305 mm)

(a)

(b)

Fig. 2 - Concrete prisms (W:C+S = 0.60 and 65% slag) after 1-year exposure at Treat Island, showing surface scaling; (a) general view, (b) close-up view.

Materials

Cement

Three types of portland cement (ASTM Type I, II and V) were used in this investigation. The physical properties and chemical analyses are given in Table 11.

Granulated blast furnace slag

The granulated blast furnace slag was from the same batch as in Phase I. Its physical and chemical properties already given in Table 1 are reproduced in Table 2 for convenience.

Table 11 - Physical properties and chemical analyses of cements, fly ash and slag - Phase II

Description of tests	Portland cements*			Fly ash	Slag
	ASTM Type I	ASTM Type II	ASTM Type III		
Physical tests - general					
Fineness - passing 74 µm %	94.8	97.2	94.8	--	92.7
- passing 74 µm %	81.2	91.2	86.8	88.1	84.2
- blaine, m^2/kg	382	354	320	295	466
Normal consistency, %	24.0	23.7	23.1	--	--
Setting time, min.	145	150	285	--	--
Autoclave expansion %	0.03	0.01	-0.04	--	--
Physical tests - mortar strength					
Water content, %	48.5	47.3	45.9	--	--
Flow, %	108	111	111	--	--
Compressive strength, MPa					
3-d	25.3	20.0	18.0	--	3.1
7-d	29.4	27.2	22.5	--	8.6
28-d	35.0	35.6	35.0	--	18.0
Chemical analysis					
SiO_2, %	20.71	21.18	23.54	52.68	36.84
CaO, %	63.04	62.62	64.24	1.02	36.92
CaO (free), %	0.56	0.81	0.52	--	--
Insoluble, %	0.53	0.11	0.24	--	--
Loss on ignition, %	1.64	0.68	0.74	3.45**	0.23***
Al_2O_3, %	5.75	4.36	3.28	29.36	9.53
Fe_2O_3, %	2.03	3.86	3.76	9.14	1.11
SO_3, %	4.03	2.99	2.25	0.39	0.10
MgO, %	1.38	2.26	1.01	1.35	11.07
Na_2O, %	0.11	0.27	0.15	0.32	0.28
K_2O, %	1.37	0.95	0.68	2.57	0.36
Alkalies (as Na_2O), %	1.01	0.90	0.60	2.02	0.52
$CaSO_4$, %	6.9	5.1	3.8	--	--
C_3A, %	11.8	5.0	2.3	--	--

*Manufacturer's data

**Determined at 1050°C

***Determined at 120°C and indicates moisture loss or drying

Fly ash

The fly ash was obtained from a plant in the Detroit area. Its physical properties and chemical analysis are given in Table 11.

Aggregates

Coarse and fine aggregates were identical to the ones used in Phase I except that 37.5 - 19 mm fraction was sieved over 37.5 screen and the oversize was discarded. The gradings of the aggregate are given in Table 12.

Air-entraining agent

A sulphonate hydro-carbon type air-entraining agent was used in all mixes.

Mix Proportioning

The mixes were proportioned to have a water to cement plus fly ash plus slag ratios of 0.40, 0.50 and 0.60. At each ratio, 17 concrete batches were made. Thirteen batches were made using ASTM Type I cement and two batches each using ASTM Type II and V. In batches made with Type I, up to 80% (by mass) was replaced by fly ash and blast furnace (B.F.) slag or by fly ash alone; the batches made with Type II and V cements were used for direct comparison with those made with Type I. The detailed mix proportions are given in Table 13.

Properties of Fresh Concrete

The temperature, slump, unit mass and air content of fresh concrete were determined immediately after mixing and are shown in Table 14. Concrete mixes incorporating fly ash alone or fly ash and slag, exhibited improved workability compared with mixes of Phase I when cement was partially relaced by slag only.

Casting of Test Specimens

A total of 453 specimens were cast in this phase. These consisted of 305 x 305 x 915-mm prisms and 152 x 305-mm cylinders; details are given in Table 15. The procedure for casting and curing of the test specimens was identical to the one used in Phase I of the investigation, except that moist curing was extended to a minimum of 100 d before the test specimens were transferred to Treat Island, Maine.

TESTING OF SPECIMENS

At 28 d, two cylinders from each batch of each of the three water to cement plus fly ash plus slag ratios were removed from the moist curing room, and were capped and tested in compression. In addition, for cylinders from batches D04, D08, D12, D14, D15, D17, E04, E08, E12, E14, E15, E17 and F04, F08, F12, F14, F15 and F17, the following additional testing was done:

Table 12 - Grading of aggregates - Phase II

Coarse aggregate			Fine aggregate	
Sieve size, mm	Cumulative % retained		Sieve size, mm	Cumulative % retained
38	0		4.75	1.3
25	39.8	0	2.36	14.2
19	82.3	4.3	1.18	30.8
12.5	--	39.9	600 μm	54.0
9.5	96.0	63.7	300 μm	81.5
4.75	100.0	95.1	150 μm	94.9
2.36		100.0	Pan	100.0

Table 13 - Mix proportions - Phase II

Mix series	Cement type and batch No.	W : (C+F+S) ratio	A : (C+F+S) ratio	Water, kg/m^3	Cement, kg/m^3	Cement replacement by mass, %		A.E.A., mL/m^3
						fly ash	slag	
D	Type I 1	0.40	4.73	158	395	--	--	390
	2		4.74	150	281	25	--	960
	3		4.73	150	281	25	--	960
	4		4.73	149	279	25	--	950
	5		4.34	164	411	--	--	370
	6		4.27	160	161	20	40	1290
	7		4.27	160	161	20	40	1290
	8		4.27	161	162	20	40	1460
	9		4.33	164	411	--	--	420
	10		4.19	165	83	20	60	2130
	11		4.03	168	84	20	60	1910
	12		4.03	168	84	20	60	2070
	Type V 13		4.67	153	384	--	--	310
	14		4.84	151	379	--	--	280
	Type I 15		4.32	165	412	--	--	300
	Type II 16		4.99	148	370	--	--	270
	17		5.33	141	355	--	--	260
E	Type I 1	0.50	5.84	160	320	--	--	160
	2		5.86	160	240	25	--	590
	3		6.01	154	231	25	--	640
	4		6.21	151	227	25	--	570
	5		6.44	149	298	--	--	150
	6		5.77	160	128	20	40	640
	7		6.05	152	122	20	40	610
	8		6.04	154	123	20	40	580
	9		6.43	148	297	--	--	180
	10		6.49	143	57	20	60	770
	11		6.36	147	59	20	60	680
	12		6.37	148	59	20	60	680
	Type V 13		6.30	152	304	--	--	290
	14		7.05	138	275	--	--	240
	Type I 15		6.44	147	293	--	--	190
	Type II 16		6.26	149	297	--	--	320
	17		7.35	133	264	--	--	260
F	Type I 1	0.60	8.02	148	246	--	--	140
	2		8.02	145	182	25	--	440
	3		8.29	139	174	25	--	490
	4		8.27	141	175	25	--	460
	5		8.27	139	233	--	--	210
	6		7.86	146	97	20	40	540
	7		7.79	145	98	20	40	490
	8		8.12	142	96	20	40	480
	9		8.47	137	226	--	--	190
	10		8.47	138	46	20	60	540
	11		8.46	136	46	20	60	500
	12		8.37	140	46	20	60	510
	Type V 13		8.79	135	225	--	--	170
	14		8.79	135	224	--	--	170
	Type I 15		8.28	143	237	--	--	150
	Type II 16		9.22	126	209	--	--	200
	17		9.09	129	216	--	--	170

Table 14 - Properties of fresh concrete - Phase II

Mix series	Batch No.	Properties of fresh concrete			
		Temperature, °C	Slump, mm	Unit mass, kg/m^3	Air content, %
D (W : C+F+S=0.40)	1	27.5	55	2419	6.0
	2	26.0	75	2291	6.2
	3	27.0	60	2291	6.4
	4	26.0	70	2275	6.9
	5	28.5	55	2355	5.3
	6	30.0	50	2275	6.4
	7	26.0	65	2275	5.8
	8	27.0	60	2291	5.5
	9	24.0	80	2355	5.7
	10	24.0	55	2307	6.2
	11	22.5	60	2275	5.5
	12	24.0	50	2275	6.6
	13	24.5	100	2339	6.6
	14	24.5	80	2355	6.0
	15	26.0	90	2355	6.0
	16	25.5	85	2371	5.4
	17	26.0	65	2387	5.1
E (W : C+F+S=0.50)	1	24.5	100	2355	5.2
	2	24.5	95	2339	5.2
	3	24.0	100	2307	6.6
	4	24.0	95	2339	6.2
	5	22.0	100	2371	5.0
	6	21.5	85	2323	6.9
	7	22.5	100	2291	6.3
	8	22.0	100	2323	5.7
	9	24.5	85	2355	5.6
	10	23.5	95	2291	6.9
	11	23.5	85	2307	6.2
	12	23.5	85	2323	5.8
	13	26.0	50	2371	5.5
	14	26.0	60	2355	5.5
	15	26.0	60	2323	5.9
	16	27.0	55	2307	6.8
	17	26.5	50	2339	6.5
F (W : C+F+S=0.60)	1	23.0	80	2371	5.3
	2	22.5	100	2339	5.2
	3	23.0	90	2291	6.7
	4	22.0	85	2307	6.5
	5	25.5	60	2307	6.5
	6	25.0	95	2307	6.5
	7	24.0	100	2291	6.5
	8	25.0	65	2323	5.5
	9	26.0	75	2275	6.5
	10	25.0	85	2307	6.4
	11	25.0	75	2291	6.5
	12	25.0	70	2307	5.5
	13	25.0	60	2339	6.0
	14	25.0	70	2323	5.8
	15	26.0	60	2339	5.0
	16	24.5	75	2275	6.9
	17	25.0	70	2307	6.4

Table 15 - Type and number of specimens cast, and testing schedule - Phase II

Mix Series	Batch No.	Type and number of specimens cast: 305x305x915-mm prisms	Type and number of specimens cast: 152x305-mm cylinders	Total number of specimens cast: 305x305x915-mm prisms	Total number of specimens cast: 152x305-mm cylinders	Testing of specimens: 305x305x915-mm prisms	Testing of specimens: 152x305-mm cylinders, 28 day	Testing of specimens: 152x305-mm cylinders, 120 day	Testing of specimens: 152x305-mm cylinders, Remarks
D	D01,D02,D03, D05,D06,D07, D09,D10,D11, D13,D16	One prism cast from each batch	Four cylinders cast from each batch	11	44	Prisms installed at Treat Island for long-term durability studies	Two cylinders from each batch tested in compression	--	Two cylinders from each batch installed at Treat Island for long-term durability studies
	D04,D08,D12, D14,D15,D17	--	16 cylinders cast from each batch	--	96	--	Two cylinders from each batch tested in compression. Two cylinders from each batch tested for modulus of elasticity	Two cylinders from each batch tested in compression	Ten cylinders stored in moist-curing room for long-term strength testing
E	E01,E02,E03, E05,E06,E07, E09,E10,E11, E13,E16	One prism cast from each batch	Four cylinders cast from each batch	11	44	Prisms installed at Treat Island for long-term durability studies	Two cylinders from each batch tested in compression	--	Two cylinders from each batch installed at Treat Island for long-term durability studies
	E04,E08,E12 E14,E15,E17	--	16 cylinders cast from each batch	--	96	--	Two cylinders from each batch tested in compression. Two cylinders from each batch tested for modulus of elasticity	Two cylinders from each batch tested in compression	Ten cylinders stored in moist-curing room for long-term strength testing.
F	F01,F02,F03, F05,F06,F07, F09,F10,F11, F13,F16	One prism cast from each batch	Four cylinders cast from each batch	11	44	Prisms installed at Treat Island for long-term durability studies	Two cylinders from each batch tested in compression	--	Two cylinders from each batch installed at Treat Island for long-term durability studies
	F04,F08,F12, F14,F15,F17	--	16 cylinders cast from each batch	--	96		Two cylinders from each batch tested in compression. Two cylinders from each batch tested for modulus of elasticity	Two cylinders from each batch tested in compression	Ten cylinders stored in moist-curing room for long-term strength testing
			Grand Total	33	420				

(a) At 28 d, two cylinders from each batch were removed from the moist-curing room, capped and tested for the determination of Young's modulus of elasticity and subsequent compressive strength;

(b) At 120 d, two cylinders from each batch were removed from the moist-curing room, capped and tested in compression.

As far as possible, all testing was done in accordance with ASTM standards. The compressive strength and modulus of elasticity data are shown in Tables 16, 17 and 18.

TRANSFER OF TEST SPECIMENS TO TREAT ISLAND, MAINE

On November 5, 1979 after a minimum of 100 d of moist-curing, all large prisms and two companion cylinders were transferred to Treat Island exposure station for long-term durability cylinders testing. The balance of the cylinders, ten cylinders from each of the batches D04, D08, D12, D14, D15, D17, E04, E08, E12, E14, E17 and F04, F08, F12, F14, F14 and F17, were shipped to CANMET for long-term testing. Before shipping the specimens to Treat Island, Maine, ultrasonic pulse velocity measurements were taken on each of the prisms and cylinders, and these are shown in Tables 16, 17 and 18.

LONG-TERM DURABILITY STUDIES

The concrete prisms and cylinders at Treat Island will be monitored at yearly intervals consisting of visual inspection, pulse velocity measurements and a photographic record.

PHASE III INVESTIGATIONS

Concrete mixes for Phase III will be made in July 1980. Essentially these will be identical to Phase I except that instead of river gravel, manufactured expanded shale aggregates will be used as the coarse aggregate. A total of 45 concrete mixes will be made with cement contents ranging from 235 to 475 kg/m^3 and about 30 prisms and three hundred 152 x 305-mm cylinder specimen will be cast for long-term exposure at Treat Island.

CONCLUSIONS

CANMET research, which commenced in 1978, is being continued to determine the performance of portland cement concrete incorporating less energy intensive materials under severe marine exposure.

To date, no definite trends or conclusions can be drawn from the first yearly inspection of test specimens installed at the natural weathering station. However, there are indications of some scaling on prisms incorporating 65% granulated blast furnace slag.

It is expected that the data which will become available over the next few years will establish the relative performance of portland cement concrete and portland cement concrete incorporating granulated blast furnace slag and fly ash. This data should be useful to those engaged in the design and construction of offshore concrete stuctures.

Table 16 - Summary of density, compressive strength, modulus of elasticity and pulse velocity test results - Series D - Phase II

W : C+F+S ratio	Cement type and batch No.	Relative proportions of cement, fly ash and slag, %			Density of test cylinders at one day, kg/m^3	Compressive strength* of 152x305-mm cylinders, MPa		Young's modulus of elasticity* of 152x305-mm cylinders at 28 d, MPa x 10^4	Ultrasonic pulse velocity** before exposure at Treat Island, m/s	
		cement	fly ash	slag		28 d	120 d		152x305-mm clyinders (path length = 305 mm)	305x305x915-mm prisms (path length = 915-mm)
0.40	Type I, 1	100	--	--	2378	33.0	--	--	4340	4320
	2	75	25	--	2312	24.0	--	--	4270	4230
	3	75	25	--	2290	26.0	--	--	4250	4290
	4	75	25	--	2278	26.3	30.6	2.53	4210	--
	5	100	--	--	2395	33.7	--	--	4420	4390
	6	40	20	40	2301	26.4	--	--	4160	4240
	7	40	20	40	2268	24.3	--	--	4180	4230
	8	40	20	40	2309	25.3	31.2	2.97	4240	--
	9	100	--	--	2357	29.2	--	--	4390	4370
	10	20	20	60	2278	18.6	--	--	4140	4070
	11	20	20	60	2291	19.1	--	--	4120	4090
	12	20	20	60	2273	18.3	22.5	2.36***	4070	--
	Type V, 13	100	--	--	2333	32.3	--	--	4420	4310
	14	100	--	--	2360	33.4	40.1	3.02	4430	--
	Type I, 15	100	--	--	2335	28.4	37.3	2.84	4400	--
	Type II, 16	100	--	--	2347	29.9	--	--	4400	4400
	17	100	--	--	2380	29.5	36.7	3.03	4390	--

* Each test result is average of two values

** For cylinders, each value is average of measurements on two specimens; for prisms, each value is average of three measurements on a single specimen

***Determined at 31 d

Table 17 - Summary of density, compressive strength, modulus of elasticity and pulse velocity test results - Series E - Phase II

W : (C+F+S) ratio	Cement type and batch No.	Relative proportions of cement, fly ash and slag, %			Density of test cylinders at one day, kg/m^3	Compressive strength* of 152x305-mm cylinders, MPa		Young's modulus of elasticity* of 152x305-mm cylinders at 28 d, MPa x 10^4	Ultrasonic pulse velocity** before exposure at Treat Island, m/s	
		cement	fly ash	slag		28 d	120 d		305x305x915-mm prisms (path length = 915-mm)	152x305-mm clyinders (path length = 305 mm)
0.50	Type I, 1	100	--	--	2367	29.7	--	--	4430	4340
	2	75	25	--	2345	24.0	--	--	4360	4260
	3	75	25	--	2296	20.1	--	--	4380	4130
	4	75	25	--	2326	21.9	28.8	2.46	4270	--
	5	100	--	--	2364	27.3	--	--	4380	4260
	6	40	20	40	2300	22.2	--	--	4250	4100
	7	40	20	40	2311	22.0	--	--	4210	4160
	8	40	20	40	2317	21.9	25.9	2.52	4220	--
	9	100	--	--	2349	26.6	--	--	4360	4260
	10	20	20	60	2282	16.2	--	--	4210	4010
	11	20	20	60	2301	17.3	--	--	4130	4090
	12	20	20	60	2321	16.5	20.9	2.38	4120	--
	Type V, 13	100	--	--	2344	28.3	--	--	4340	4350
	14	100	--	--	2349	28.6	35.0	2.80	4380	--
	Type I, 15	100	--	--	2344	26.9	29.8	2.80	4380	--
	Type II, 16	100	--	--	2326	24.5	--	--	4410	4260
	17	100	--	--	2327	24.4	28.7	2.67	4360	--

* Each test result is average of two values

**For cylinders, each value is average of measurements on two speciments; for prisms, each value is average of three measurements on a single specimen

Table 18 - Summary of density, compressive strength, modulus of elasticity and pulse velocity test results - Series F - Phase II

W : C+F+S ratio	Cement type and batch No.	Relative proportions of cement, fly ash and slag, %			Density of test cylinders at one day, kg/m³	Compressive strength* of 152x305-mm cylinders, MPa		Young's modulus of elasticity* of 152x305-mm cylinders at 28 d, MPa x 10⁴	Ultrasonic pulse velocity** before exposure at Treat Island, m/s	
		cement	fly ash	slag		28 d	120 d		152x305-mm clyinders (path length = 305 mm)	305x305x915-mm prisms (path length = 915-mm)
0.60	Type I, 1	100	--	--	2351	23.2	--	--	4330	4240
	2	75	25	--	2345	18.9	--	--	4330	4160
	3	75	25	--	2280	15.7	--	--	4250	4070
	4	75	25	--	2314	17.6	23.0	2.25	4370	--
	5	100	--	--	2290	19.3	--	--	4230	4120
	6	40	20	40	2295	16.6	--	--	4300	4050
	7	40	20	40	2323	17.0	--	--	4320	4070
	8	40	20	40	2335	18.0	24.7	2.62	4280	--
	9	100	--	--	2288	17.9	--	--	4260	4050
	10	20	20	60	2291	12.6	--	--	4090	3920
	11	20	20	60	2302	12.7	--	--	4070	3960
	12	20	20	60	2316	12.9	15.5	2.23	4090	--
	Type V, 13	100	--	--	2335	20.3	--	--	4280	4240
	14	100	--	--	2334	19.8	27.6	2.54	4280	--
	Type I, 15	100	--	--	2343	23.3	26.1	2.65	4340	--
	Type II, 16	100	--	--	2318	19.6	--	--	4300	4040
	17	100	--	--	2304	19.5	21.7	2.35	4250	--

* Each test result is average of two values

**For cylinders, each value is average of measurements on two specimens; for prisms, each value is the average of three measurements on a single specimen

ACKNOWLEDGEMENTS

Grateful acknowledgement is made to the following:

1. Corps of Engineers, U.S.A. (R.E. Philleo and Bryant Mather) for allowing the use of the Treat Island Natural Weathering Exposure Station.
2. Canadian Çement Lafarge Ltd., Montreal (W.S. Weaver and H.S. Isabelle) for providing cement and helpful suggestions during initial planning of the research program.
3. Standard Slag Cement Company, Fruitland, Ontario (W. Berry) for providing granulated blast-furnace slag.

REFERENCES

1. Malhotra, V.M., Berry, E.E. and Wheat, T.A. (Editors), Proceedings, Seminar on energy and resource conservation in the cement and concrete industry; CANMET, Energy, Mines and Resources, Ottawa, Canada; 1976.

2. Lea, F.M. "The chemistry of cement and concrete"; (Third Edition), Chemical Publishing Co. Inc., New York; 1971.

3. Thornton, Jr. H.J. "Natural weathering exposure station for concrete and concrete materials - Treat Island, Maine"; U.S. Corps of Engineers, Vicksburg, Mississippi, U.S.A.; 1980.

OPINION POLL

The opinion of concerned readers may influence the direction of future CANMET research.

We invite your assessment of this report - No.__________

Is it useful?	Yes______	No______
Is it pertinent to an industry problem?	Yes______	No______
Is the subject of high priority?	Yes______	No______

Comments____

Please mail to: CANMET Editor, EMR, 555 Booth Street,
Ottawa, Ontario, K1A 0G1

A complimentary copy of the CANMET REVIEW describing CANMET research activity will be sent on request.

CANMET REPORTS

Recent CANMET reports presently available or soon to be released through Printing and Publishing, Supply and Services, Canada (addresses on inside front cover), or from CANMET Publications Office, 555 Booth Street, Ottawa, Ontario, K1A 0G1:

Les récents rapports de CANMET, qui sont présentement disponibles ou qui le seront bientôt peuvent être obtenus de la direction de l'Imprimerie et de l'Edition, Approvisionnements et Services Canada (adresses au verso de la page couverture), ou du Bureau de vente et distribution de CANMET, 555, rue Booth, Ottawa, Ontario, K1A 0G1:

79-23 Selection of ternary fused chlorides for the electrowinning of lead and zinc based on calculated thermodynamic properties; C.W. Bale, A.D. Pelton, W.J. Thompson and J.M. Skeaff;
Cat. No. M38-13/79-23, ISBN 0-660-10667-1; Price: $3.25 Canada, $3.90 other countries.

79-34 Recycling of steel plant waste oxides - A review; C.J. Adams;
Cat. No. M38-13/79-34, ISBN 0-660-10552-7; Price: $1.50 Canada, $1.80 other countries.

79-35 Reference materials - Rock samples SY-2, SY-3 and MRG-1; Sydney Abbey;
Cat. No. M38-13/79-35, ISBN 0-660-10611-6; Price: $4.00 Canada, $4.80 other countries.

79-38 Strength and freeze-thaw characteristics of concrete incorporating granulated blast furnace slag; V.M. Malhotra;
Cat. No. M38-13/79-38, ISBN 0-660-10577-2; Price: $2.25 Canada, $2.70 other countries.

79-39 Fluidized-bed combustion - An emerging technology; F.O. Friedrich;
Cat. No. M38-13/79-39, ISBN 0-660-10578-0; Price: $2.00 Canada, $2.40 other countries.

79-40 Comparisons of coke produced in different CANMET coke ovens - Part 2; J.T. Price and R. Leeder;
Cat. No. M38-13/79-40, ISBN 0-660-10590-X; Price: $2.00 Canada, $2.40 other countries.

79-41 Catalogue of CANMET publications 1978-79/Catalogue des publications de CANMET 1978-79;
Cat. No. M38-13/79-41, ISBN 0-660-50636-X; Price: $18.50 Canada, $22.20 other countries.

80-1E Sodium beta- and beta"-alumina ceramics: Powder preparation; D.J. Green and T.A. Wheat;
Cat. No. M38-13/80-1E, ISBN 0-660-10655-8; Price: $2.95 Canada, $3.55 other countries.

80-3E Petrography in the evaluation of aggregates and concretes; J.A. Soles;
Cat. No. M38-13/80-3E, ISBN 0-660-10591-8; Price: $2.00 Canada, $2.40 other countries.

80-4E Cokemaking with Canadian medium- and high-volatile commercial coking coals; J.F. Gransden, J.T. Price and W.R. Leeder;
Cat. No. M38-13/80-4E, ISBN 0-660-10571-3; Price: $2.25 Canada, $2.70 other countries.

80-5E Assessment of an expanded clay lightweight aggregate in structural concrete; H.S. Wilson;
Cat. No. M38-13/80-5E, ISBN 0-660-10612-4; Price: $1.50 Canada, $1.80 other countries.

80-6E Certified reference materials; H.F. Steger;
Cat. No. M38-13/80-6E, ISBN 0-660-10579-9; Price: $2.25 Canada, $2.70 other countries.

80-8 Metals terminology/La terminologie des metaux; André Blouin;
Cat. No. M38-13/80-8, ISBN 0-660-50586-X; Price: $24.95 Canada, $29.95 other countries.