Ontario

Ministry of Transportation and Communications
Minister : James Snow

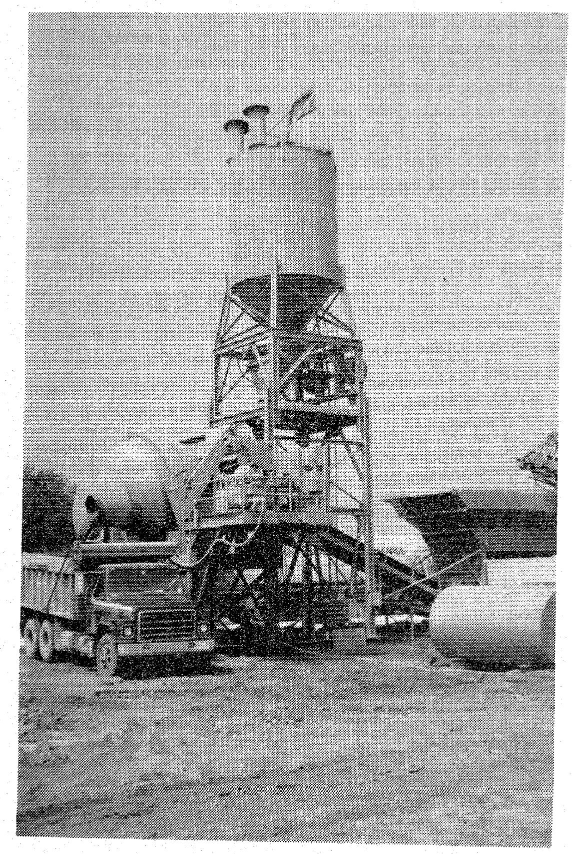
Highway Engineering Division

Engineering Materials Office

EM - 60

Provincial Highways

Lean Concrete for Pavement Base



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June 1982

SUMMARY

Since the new Ministry standards for concrete pavement and composite pavement utilize a lean concrete base, it is necessary to develop a material specification for the lean concrete.

London area aggregates were used in the laboratory test program since the initial contracts in the lean concrete base were scheduled for Southwestern Region.

A series of mixes were made with four Granular "A" aggregates and tested for workability, strength and freeze-thaw durability.The cement content varied from 120 to 310 kg/m^3, some mixes contained 25% and 50% of a cementitious hydraulic slag by mass of the total cementitious materials.

Specification requirements for the lean concrete have been developed and are recommended for use by this Ministry.

INTRODUCTION

The escalating cost of asphalt cement in recent years has made concrete pavements more competitive with bituminous pavements in terms of initial cost.

The new Ministry standards for the rigid pavements contain a number of features not previously used in Ontario, principly the use of a lean concrete base placed directly on the earth grade. The base is intended to provide a sufficiently strong, durable platform for the overlying pavement layers preventing subgrade pumping and resultant faulting at joints and cracks. Lean concrete is made with a relatively low cement content and aggregates that do not necessarily meet conventional requirements for concrete aggregates. The lean concrete base is air entrained to provide adequate freeze-thaw durability in the pressence of deicing salts.

The laboratory investigation described in this report was carried out between April 1980 and November 1981 to provide the specification requirements for the first contract using lean concrete base (Hwy.402, London). The intention was to use local Granular A aggregate complying with MTC Form 1010 requirements and it was envisaged that the lean concrete base would be placed with a slip form paver (slump 20-80 mm).

This report recommends material specification requirements for lean concrete bases.

GRANULAR "A" AGGREGATES

Samples of Granular A aggregates were obtained from four sources (pits) in the London area. Table A shows the properties of each of the four materials. There were no significant differences between them with the exception of the differences in the amounts of the pass 75 um material and the amount of crushed particles. The aggregate from Huron Construction Ltd.'s pit contained the lowest amount (5.4%) of pass 75 um material while the aggregate from Marshall and Sons Ltd.'s pit contained the highest amount (9.2%).

Each sample was dried and separated into retained 26.5, 19.0, 13.2, 9.5, 4.75 mm and pass 4.75 mm sieve fractions. The pass 4.75 mm fraction was placed on a clean concrete floor, mixed thoroughly with a shovel and placed in bags. Each of the coarse fractions was also placed in bags. The bagged material was stored until the day before making the mixes. The day before making the mixes, it was recombined to produce the gradation shown in Table A and the amount needed for the batch.

Some bags were checked for the pass 75 μm material content to ensure that there were no significant changes from the amounts shown in Table A.

CONCRETE INGREDIENTS

The cement was Type 10 complying with the requirements of MTC Form 1301. Table B shows its properties (4 batches were used in the tests).

Cementitious hydraulic slag was used in some mixes. Its properties are shown in Table B.

The chemical admixture (Porzite L70, Lab. No. 744/79) was a WN type and the air entraining admixture (Lab. No. 696/79) was a neutralized vinsol resin type complying with the requirements of MTC Form 1303.

The mixing water was City of North York tap water.

TEST PROGRAM

Three Type 10 cement mixes and four Type 10-slag cement mixes were made with each Granular A aggregate for compressive strength tests. The mix proportions and the tests results are shown in Tables C, D, E, F and G, and Fig. 1 to 4. All tests on fresh and hardened concretes were carried out in accordance with the current CSA A23.2 test methods. The compressive strength specimens were the standard 150x300 mm cylinders.

Four Type 10 cement and four Type 10 - slag cement mixes were made with two of the four Granular A aggregates for the durability tests. The mix proportions and the fresh concrete test results are shown in Tables H and I. Two durability tests were carried out; one was the standard ASTM C666-77 freezing and thawing in water test and the other the salt scaling test described in MTC Form 1351. In addition, two 100x200 mm cylinders from each mix were tested in accordance with ASTM D 560-57. Freezing and Thawing Tests of Compacted Soil-Cement Mixtures.

The freeze-thaw specimens were 75x75x400 mm prisms; three specimens were made and tested for each mix. They were cured for 1 day in their moulds and immediately after demoulding for 13 days in lime saturated water. They were placed in the freeze-thaw cabinet at an age of 14 days for exposure to 300 cycles. The change in mass of Marshall Granular A specimens is shown in Fig. 5 and their appearance after termination of the exposure in Fig. 6 and 7. The test results and the appearance of the Huron Granular A specimens are shown in Fig. 8 to 10. Fig. 11 illustrates the effect of cement and slag contents on the freeze-thaw resistance (mass loss).

Two salt scaling specimens were made for each variable. Each specimen was a 300x300x75 mm slab; it was cured for 14 days in a standard moisture room and then stored for 14 days in normal laboratory air conditions before starting the exposure. Table J and Fig. 12 to 16 show the test results for the Marshall Granular A mixes while Table K and Fig. 17 to 22 show the test results for the Huron Granular A mixes.

Fig. 23 shows the appearance of the lowest, and the highest cement content cylinders tested in accordance with ASTM D 560-57 together with soil-cement specimens for comparison purposes.

TEST RESULTS

All mixes made with each of the four Granular "A" aggregates were cohesive and had good workability. They did not differ much from conventional concrete mixes except that their colour was brownish grey. They required a large amount of air entraining admixture (Table C to F) to entrain the desired amount of air (8 ± 1.5%). The amount of the admixture increased with the amount of the pass 75 um sieve material content in the aggregate and the cement content. There was a significant difference between the amounts of NVR used in the compressive strength mix series (Table C) and the durability mix series (Table H) with the Marshall aggregate. There was no apparent reason for this difference; the only known change was that different batches of cement from the same source were used in the two series. The laboratory mixes indicate that lean concrete may require 2-6 times the amount of neutralized vinsol resin that conventional concrete requires to entrain the same amount of air.

The setting times shown in Table G were determined on the compressive strength mixes. Considering the precision of this test, the differences between the Type 10 cement mixes are insignificant but, as expected, the blended cement mixes reached their time of initial and final setting on the average approximately 50 min and 90 min later, respectively.

There were no significant differences in the compressive strengths of the mixes of the same cement contents and different aggregates (Table C to F, Fig. 1 to 4). However, the strengths of the mixes with blended cement were considerably lower at the early ages than those of the mixes with Type 10 cement. These differences were considerably reduced at 28 days and in some cases (cementitious materials content 240 kg/m^3) the blended cement mixes produced somewhat higher strength at this age than the Type 10 cement mixes. Because of this relatively low early strength, blended cement lean concrete would require a longer curing period than Type 10 cement lean concrete before construction traffic could be allowed on the base. All the mixes tested, including those with the slag, developed good strength (10.8--27.5 mPa) and there would be no problem, even for the mix with a cement content of 160 kg/m^3, to comply with the generally suggested minimum 28 day strength requirement of 5 to 10 MPa (2,3.4).

The characteristics of the Marshall aggregate mixes tested for freeze-thaw resistance (ASTM C666, Method A) are shown in Table H, the test results in Fig. 5 and the appearance of the test prisms after termination of the exposure in Fig. 6 and 7. The data for the Huron aggregate mixes are shown in Table I, and Fig. 8 to 10. Fig. 11 summarizes the test results for both the Marshall and Huron aggregate concretes. It is evident from Fig. 11 that the freeze-thaw performance of the Marshall aggregate concretes was somewhat inferior when compared to that of the Huron aggregate concrete. There is no clear reason for the difference. Generally, the Marshall aggregate concretes had a slightly higher water-cement ratio than their corresponding Huron aggregate concretes. Where the air void system was determined, the spacing factor of the air voids was well within the generally accepted maximum of 0.20 mm for good frost resistance with the exception of the control mix (Table H) made with the concrete laboratory standard aggregates. The latter had an air void spacing factor of 0.234 mm. The performance of each series depended on the cement content (water-cement ratio); the higher the cement content, the better the freeze-thaw resistance. The concretes containing the slag showed lower freeze-thaw resistance to the exposure than those without the slag.

The salt scaling test results are shown in Table J and Fig. 12 to 16 for the Marshall aggregate mixes and in Table K and Fig. 17 to 22 for the Huron aggregate mixes. As in the freeze-thaw test, the salt scaling resistance of the Marshall aggregate concretes was inferior to that of the Huron aggregates concretes. The performance of each series generally depended on the cement content and the mixes with the slag did not perform as well as those without the slag. The scaling increased with the increase in slag content from 25% to 50%.

Table L shows the results of the freeze-thaw test carried out in accordance with ASTM D560-77. The appearance of the 120 and 310 kg/m^3 cement content specimens, after the exposure, is shown in Fig. 23. All the lean concrete specimens had excellent resistance to this exposure and there was little difference between the appearance of the low cement content lean concrete and the conventional concrete specimens (cement content 310 kg/m^3). Fig. 23 also shows typical soil-cement specimens after the exposure. The Ministry accepted soil-cement mixes with the freeze-thaw mass loss up to 14%. The lean concrete specimens with the cement content of 120 kg/m^3 had a mass loss of max. 1.58%, far less than would be expected from high cement content soil-cement specimens.

MATERIAL SPECIFICATION REQUIREMENTS

There are a number of properties that should be specified to ensure adequate performance of a lean concrete base. Basically, the properties workability, strength and durability. All the three properties were determined for each mix included in this investigation. Findings of other agencies (1,2,3,4) were also reviewed.

Lean concrete is usually placed by slipforming requiring concrete of good workability and a slump of 20 to 80 mm. Workability depends on the aggregate characteristics, air content, cement content, addition of water reducing admixture and the combination of all these. Trial mixes must be made in the laboratory using representative samples of the job aggregate to establish mix proportions which will ensure adequate workability.

The gradation of this Ministry's Granular A (Form 1010) is similar to the typical gradations specified by others (4) but it allows smaller amounts retained on the coarse sieves and it limits the amount of pass 75 μm sieve material to maximum 8.0% for gravel and maximum 10.0% for crushed rock. Since considerably less cement is used in lean concrete than in conventional concrete and the fines enhance the workability, it would be advantageous for the lean concrete to allow up to 12.0% pass 75 um sieve material regardless of the aggregate type.

The use of a Type WN or SN (MTC Form 1303) chemical admixture will also have a positive effect on the workability of the concrete. Since the admixture will decrease the water-cement ratio, it will increase the strength and freeze-thaw durability. Air entrainment will also be beneficial to both the workability and durability. It was found by others and confirmed by this laboratory investigation that an air content of 8.0 ± 2.0% will adequately enhance these two properties without significantly affecting other properties.

It has been determined by others (1,2,3,4) that a compressive strength of at least 5.0 MPa at 28 days is adequate for lean concrete base. The mixes with a cement content of 160 kg/m^3 (Table C to F) developed a strength of at least 6.9 MPa at 3 days, 9.8 MPa at 7 days and 13.2 MPa at 28 days, the mixes with a cement content of 200 kg/m^3 were at least 25% stronger. A strength of 10.0 MPa is considered adequate for allowing construction traffic on the base thus the concrete should have a strength of at least 10.0 MPa at 28 days and the traffic should be allowed when the concrete has developed this strength.

Since lean concrete base constitues the lower course in a composite or concrete pavement, aggregate properties such as polishing, resistance to abrasion and popouts are unimportant. However, in Ontario climate, it is important that the concrete be resistant to freeze-thaw action. The exposure of the lean concrete base is not as severe as that of the pavement surface and the requirements of Form 1010 for Granular A (Petrographic Number) should be adequate provided that the paste is freeze-thaw resistant. Air entrained lean concrete has been tested by others (1,4) for resistance to 300 freeze-thaw cycles following the ASTM Method C666, Procedure B (freezing in air, thawing in water). The investigators found that an air content of at least 7% was required for good resistance to the test conditions (durability factor approximately 100). The Ministry laboratory was not equipped to test the resistance to freezing in air and thawing in water. Instead, the more severe ASTM C666, Method A (freezing and thawing in water) was used to test the lean concretes and, also, as the apparatus for the measurement of fundamental transverse frequency was unavailable, only the change in mass of the freeze-thaw prisms was monitored during the exposure. The concretes scaled at the surface and there was a significant loss in mass in most cases but the core of each prism was sound and the durability factor would be high. Since the lean concrete will not be exposed to deicing salt, except at leaking joints and cracks, and at the edges of the pavement, it does not have to possess high salt scaling resistance. The concrete, regardless of its cement factor has a significantly greater freeze-thaw durability than a cement treated granular base (CTB) layer previously used. Since the latter was generally satisfactory from the freeze-thaw durability point of view (except where it was exposed to deicing salt), lean concrete will provide more than adequate freeze-thaw resistance. Air content of 8 ± 2% and cement content of minimum 175 kg/m^3 will ensure satisfactory freeze-thaw durability.

Another aspect of durability is the expansion of concrete caused by alkali-aggregate reactivity. Both the silica and carbonate reactions are experienced in Ontario. As the concrete will be in moist condition most of the time, reactive aggregates will cause its expansion and restrictions are necessary on the use of such aggregates. The Ministry's current restrictions on the use of carbonate aggregates in conventional concrete should also apply to lean concrete (Form 1002.04.04. [3]). Silicious aggregate should be evaluated using the standard ASTM C227 method.

Generally, the concretes containing the slag were inferior in the freeze-thaw performance as compared to the concretes without the slag. However, their freeze-thaw performance may be adequate for the exposure. The suitability of lean concrete base mixes with slag as a partial replacement for Portland cement should be investigated further.

CONCLUSIONS

i) Air entrained lean concrete of good workability was made with Granular A aggregate from the London area, with a water reducing admixture and cement content varying from 120 to 240 kg/m^3.

ii) Compressive strength of air entrained lean concrete, made with any of the four Granular A aggregates and a Type WN water reducing admixture and having a slump of 50-65 mm and an air content of 7-9%, was at least 13.2 MPa, 18.5 MPa and 23.2 MPa at 28 days for Type 10 cement contents of 160, 200 and 240 kg/m^3, respectively. The 3 day and 7 day strengths were at least 55 and 76% of the 28 day strength, respectively.

iii) Compressive strength of lean concrete as in ii) above but with a total Type 10 cement plus a slag content of 160 and 240 kg/m^3, was at least 10.8 MPa (50% slag) and 24.2 MPa (25% slag) at 28 days, respectively. The 3 day and 7 day strengths as a percentage of the 28 day strength increased with the increase in the total cementitious materials content and decreased with an increase in the slag content. The lowest 3 day strength (approximately 20% of the 28 day strength) produced the mix containing a total cementitious material content of 160 kg/m^3, and a slag content to 50%. Its 7 day strength was approximately 40% of the 28 day strength.

iv) The freeze-thaw durability (ASTM C666, Procedure A) varied generally with the cement content. The durability, as measured by the change in mass, decreased significantly with a decrease in cement content below approximately 175 kg/m^3. However, the core of the test prisms remained sound regardless of the cement content. The concretes containing slag had, generally, a higher mass loss than the concretes without slag and the mass loss increased with the increase in the slag content. The performance of Marshall Granular A concretes was inferior to that of Huron Granular A concretes. The magnitude of the mass loss is summarized in Fig. 11.

v) The salt scaling resistance of the concretes generally decreased with decreasing cement contents and the Marshall Granular A concretes had a significantly lower salt scaling resistance than the Huron Granular A concretes. None of the Huron Granular A, Type 10 cement concretes had a mass loss higher than 3.12 kg/m^2 at 50 cycles while the mass loss of the Marshall Granular A concretes was at least 3.17 kg/m^3 at 50 cycles (the concrete with a cement content of 120 kg/m^3 had a mass loss of 9.66 kg/m^3 at 35 cycles). The concrete containing slag had a much higher mass loss than the concrete without the slag and the mass loss increased with the increase in the slag content from 25 to 50% of the total cementitious material content.

vi) The air void system of each of the hardened lean concrete durability mixes, regardless of the cement plus slag contents, had satisfactory air contents, specific surface and spacing factor of the air voids. These were 5.1 - 9.7%, 22.9 - 35 mm^{-1} and 0.082 - 0.167 mm, respectively.

vii) All the lean concretes tested performed considerably better in the standard freeze-thaw test for soil-cement mixtures (ASTM D560) than a typical soil-cement mixture. The highest mass loss was 1.58%.

viii) All the lean concretes tested had a considerably lower salt scaling resistance than the control mixes. Their freeze-thaw resistance was, generally also considerably lower than that of the control concretes.

RECOMMENDATIONS

The following material specification requirements are recommended for lean concrete bases:

i) The aggregate to be Granular A complying with MTC Form 1010 requirements except that its pass 75 um sieve material content shall be increased to a maximum of 12.0%. Carbonate Granular A shall comply with the requirements of MTC Form1002.04.04(3). Silicious Granular A, when tested in accordance with ASTM C227, shall not show excessive alkali-aggregate reactivity.

ii) Type 10 cement complying with MTC Form 1301 shall be used. The concrete shall have a cement content of at least 175 kg/m^3.

iii) The concrete shall be air entrained, the air content shall be 8.0 ± 2.0%. The air entraining admixture shall comply with the requirements of Form 1303.

iv) A Type WN or SN water reducing admixture complying with MTC Form 1303 shall be used to reduce water-cement ratio and im prove workability.

v) The compressive strength shall be at least 10.0 MPa at 28 days and construction traffic shall not be allowed on the base until the concrete develops this strength.

Performance of the first lean concrete base, expecially at cracks and joints, shall be monitored to ensure that the concrete is adequate for Ontario climate.

Because of the inferior performance of the Type 10-slag cement mixes, cementitious hydraulic slag is not recommended for lean concrete bases at this time.

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3. "Lean Concrete (Econocrete) Base for Pavements: Current Articles", Concrete Information IS 205.01P, Portland Cement Association, Skokie, Ilinois, 1980.

4. "Econocrete Pavements - Current Practices", by W. A. Yrjanson, American Concrete Pavement Association and R. G. Packard, Portland Cement Association, A Paper Prepared for Presentation at the 59th Annual Meeting of the Transportation Research Board, January 1980.

TABLE A. Physical Properties of Aggregates

Property	Sieve Size	Aggregate Source				MTC Form 1010 Requirements for Granular A
		Marshall L07-149 79-B-60393	T.C.G. S09-060 79-B-60390	Huron S09-159 79-B-60391	Yundt L07-002 79-B-60392	
Gradation, % passing	37.5 mm	-	-	-	-	100.0
	26.5	-	-	-	-	-
	22.4	100.0	100.0	100.0	100.0	-
	19.0	99.4	98.9	99.3	97.6	-
	16.0	95.7	95.7	94.9	92.4	62-100
	13.2	87.8	87.4	86.7	84.5	-
	9.5	74.4	73.2	73.6	73.9	48-73
	6.7	63.4	63.6	63.0	64.8	-
	4.75	54.0	55.0	54.0	55.0	33-55
	2.36	41.2	42.8	44.5	36.6	-
	1.18	30.2	28.6	36.8	20.8	15-45
	600 um	20.0	18.2	27.3	13.3	-
	300	13.1	12.1	15.2	10.0	5-22
	150	10.6	9.1	7.7	8.4	-
	75	9.2	7.0	5.4	7.3	0-8
Los Angeles Abrasion, Loss % (Grade B)		21.1	21.1	25.2	22.8	60
Petrographic Number (Granular)		108.7	106.1	118.1	107.1	200
MTC Magnesium Sulphate Soundness, Loss % (Grade B & C)		3.1	4.1	6.7	2.3	-
Crushed Particles,% (ret.4.75 mm sieve)		61.3	70.7	45.5	77.9	50
Relative density pass 4.75 mm sieve -bulk (dry)		2.638	2.647	2.643	2.627	-
-apparent		2.730	2.732	2.723	2.726	-
Relative density, ret.4.75 mm sieve -bulk (dry		2.634	2.652	2.605	2.647	-
-apparent		2.725	2.738	2.722	2.726	-
Absorption, % -pass 75 um sieve		1.270	1.180	1.110	1.370	-
-ret. 75 um sieve		1.240	1.175	1.645	1.080	-

All tests carried out in accordance with the current MTC test procedures (LS-600 to 609).

TABLE B. Physical and Chemical Properties of Cement

Property		Cement, Type 10				Slag
		Batch No.				
		79-L-18 183	80-L-04 190	80-L-05 191	80-L-09 195	
Physical Properties						
Fineness - pass 75 um sieve, % - Blaine, m^2/kg		96.6 344.2	94.8 349.1	97.0 359.5	96.0 349.4	90.2 422.8
Normal consistency,%		22.3	22.3	23.1	22.3	-
Setting time, min		95	85	100	75	-
Soundness, exp., %		0.066	-	-	0.140	-
False set,penetr.,mm at 11 min/after remixing		50/50	50/50	50/50	50/50	-
Air content, %		8.5	-	-	5.6	-
Compressive strength	3d	23.1	21.6	21.9	19.5	4.3
	7d	27.4	26.5 (at 8d)	26.0	24.4	9.9
MPa	28d	34.5	33.7	35.0	32.6	15.8
Chemical Properties						
Loss on ignition, %		0.69	0.76	1.37	1.23	0.98
Insoluble Residue, %		0.11	0.06	0.08	0.15	-
C_3A, %		4.69	6.33	8.04	5.91	-
SO_3, %		2.80	3.03	3.02	2.94	0.12
MgO, %		3.40	3.28	3.27	3.48	12.10
Al_2O_3, %		3.61	3.81	4.43	3.90	7.04
Fe_2O_3, %		2.89	2.23	2.19	2.62	1.40
CaO, %		64.10	63.89	63.59	63.51	37.92
SiO_2, %		21.52	22.01	21.26	21.38	38.94
Na_2O, %		0.47	0.51	0.42	0.50	0.25
K_2O, %		0.47	0.48	0.45	0.44	0.33
Alkali content, %		0.78	0.83	0.72	0.79	0.47
Oxides ratio		$\frac{CaO+MgO+Al_2O_3}{Si\ O_2}$				1.465

All tests were in accordance with CSA Standard CAN3-A5-M77 with the exception of Blaine fineness, air content, false set, and some chemical properties (CaO, SiO_2, Na_2O, K_2O) which were in accordance with ASTM C204-79, C185-75, C359-75 and C114-75, respectively.

TABLE C. Mix Proportions, Fresh Concrete and Compressive Strength Test Results. MARSHALL AGGREGATE

		Nominal Cementitious Materials Content, kg/m³													
		160		200		240		160		160		240		240	
		Mix No.													
		735/80	736/80	737/80	738/80	739/80	740/80	741/80	742/80	745/80	746/80	747/80	748/80	749/80	750/80
Batch Proportions															
Cement, kg		6.4		8.0		9.6		4.8		3.2		7.2		4.8	
Slag, kg		-		-		-		1.6		3.2		2.4		4.8	
Aggregate (dry),kg		76.1		74.9		73.7		76.0		75.9		72.6		72.5	
Water (total), kg		7.0		7.2		7.3		6.8		7.0		7.2		7.1	
Porzite L70, mL		25.6		32.0		38.4		25.6		25.6		38.4		38.4	
NVR, mL		9.5		11.3		12.8		9.6		10.0		15.1		13.5	
Test Results, Fresh Concrete															
Slump, mm		60	55	50	55	60	60	60	60	60	55	55	60	50	60
Air Content, %		7.9	7.8	7.1	7.7	7.6	9.0	7.4	7.8	7.2	7.1	8.0	8.0	7.4	7.6
Density, kg/m³		2245	2248	2259	2248	2248	2237	2255	2241	2255	2262	2245	2252	2266	2255
Yield, L		39.8	38.1	39.9	40.1	40.3	40.6	39.6	39.8	39.6	39.5	39.8	39.7	39.4	39.6
Cement factor, kg/m³		160.5	160.8	200.6	200.0	238.2	236.3	161.8	160.8	161.6	162.1	241.0	241.8	243.8	242.7
Eff. w/c		0.953	0.953	0.788	0.788	0.667	0.667	0.922	0.922	0.953	0.953	0.656	0.656	0.646	0.646
Test Results, Hardened Concrete															
Compressive strength, MPa	3d	8.2	8.3	12.0	12.8	14.4	15.8	4.9	4.8	2.6	2.7	11.1	11.2	6.8	7.3
		8.3		12.4		15.1		4.9		2.7		11.2		7.1	
	7d	10.9	10.9	15.6	16.7	19.9	20.5	7.8	7.9	5.3	5.9	15.6	16.1	12.1	12.8
		10.9		16.2		20.2		7.9		5.6		15.9		12.5	
	28d	14.1	14.4	19.9	19.9	24.1	24.7	13.6	13.6	12.4	14.3	23.6	24.8	26.6	27.3
		14.3		19.9		24.4		13.6		13.4		24.2		27.0	

TABLE D. Mix Proportions, Fresh Concrete and Compressive Strength Test Results. HURON AGGREGATE

	Nominal Cementitious Materials Content, kg/m^3													
	160		200		240		160		160		240		240	
Mix No.	752/80	753/80	754/80	755/80	756/80	757/80	758/80	759/80	760/80	761/80	762/80	763/80	764/80	765/80
Batch Proportions														
Cement, kg	6.4		8.0		9.6		4.8		3.2		7.2		4.8	
Slag, kg	-		-		-		1.6		3.2		2.4		4.8	
Aggregate (dry), kg	75.6		73.8		72.5		75.8		75.2		72.0		71.9	
Water (total), kg	7.1		7.1		7.2		7.1		7.0		7.2		7.1	
Porzite L70, mL	25.6		32.0		38.4		25.6		25.6		38.4		38.4	
NVR, mL	5.5		7.5		7.5		5.5		5.5		7.5		7.5	
Test Results, Fresh Concrete														
Slump, mm	55	60	60	55	60	55	55	60	60	60	60	50	60	60
Air Content, %	7.6	7.8	7.4	7.8	8.1	7.6	8.2	8.1	8.3	8.0	8.3	7.5	7.8	7.6
Density, kg/m^3	2255	2255	2270	2252	2255	2255	2248	2238	2227	2230	2241	2262	2270	2270
Yield, L	39.5	39.5	39.2	39.5	39.6	39.6	39.7	39.9	39.8	39.7	39.6	39.3	39.1	39.0
Cement factor, kg/m^3	162.0	162.0	204.2	202.6	242.4	242.4	161.3	160.5	160.8	161.1	242.2	244.6	245.9	245.9
Eff. w/c	0.938	0.938	0.763	0.763	0.646	0.646	0.938	0.938	0.922	0.922	0.656	0.656	0.646	0.646
Test Results, Hardened Concrete														
Compressive strength, MPa — 3d	6.5	7.2	10.6	10.6	13.4	14.9	4.6	4.4	2.2	2.2	9.2	10.7	6.2	6.6
	6.9		10.6		14.2		4.5		2.2		10.0		6.4	
7d	9.3	10.3	14.8	14.2	17.4	19.0	7.6	7.3	4.2	3.7	14.4	15.7	12.6	13.2
	9.8		14.5		18.2		7.5		4.0		15.1		12.9	
28d	12.8	13.5	18.4	18.5	22.1	24.3	13.7	12.4	10.4	11.2	23.6	25.9	24.2	26.2
	13.2		18.5		23.2		13.1		10.8		24.8		25.2	

TABLE E. Mix Proportions, Fresh Concrete and Compressive Strength Test Results. T.C.G. AGGREGATE.

		Nominal Cementitious Materials Content, kg/m³													
		160		200		240		160		160		240		240	
		Mix No.													
		768/80	769/80	770/80	771/80	772/80	773/80	774/80	775/80	776/80	777/80	778/80	779/80	780/80	781/80
Batch Proportions															
Cement, kg		6.4		8.0		9.6		4.8		3.2		7.2		4.8	
Slag, kg		-		-		-		1.6		3.2		2.4		4.8	
Aggregate (dry),kg		76.1		74.3		73.0		76.1		75.7		72.5		72.5	
Water (total), kg		6.8		7.0		7.0		6.7		6.9		6.7		6.7	
Porzite L70, mL		25.6		32.0		38.4		25.6		25.6		38.4		38.4	
NVR, mL		7.5		8.8		10.5		7.5		7.5		11.2		11.2	
Test Results, Fresh Concrete															
Slump, mm		55	60	60	60	60	55	55	60	65	60	65	65	60	60
Air Content, %		8.0	8.6	8.6	8.0	7.1	7.2	7.7	8.4	8.4	8.7	7.7	9.0	7.0	7.0
Density, kg/m³		2255	2248	2248	2262	2277	2280	2255	2252	2248	2241	2262	2245	2277	2277
Yield, L		39.6	39.7	39.7	39.5	39.4	39.3	39.5	39.6	39.6	39.6	39.3	39.6	39.0	39.0
Cement factor, kg/m³		161.7	161.2	201.4	202.7	243.9	244.3	161.9	161.7	161.7	161.2	244.6	242.7	246.1	246.1
Eff. w/c		0.914	0.914	0.763	0.763	0.635	0.635	0.898	0.898	0.930	0.930	0.604	0.604	0.604	0.604
Test Results, Hardened Concrete															
Compressive strength, MPa	3d	8.1	8.1	11.4	11.7	15.1	16.0	4.4	5.1	2.7	2.5	11.2	12.2	6.6	7.0
		8.1		11.6		15.6		4.8		2.6		11.7		6.8	
	7d	11.4	11.2	15.3	15.2	20.7	19.9	7.2	8.2	5.0	5.3	16.3	17.8	13.0	13.3
		11.3		15.3		20.3		7.7		5.2		17.1		13.2	
	28d	14.9	14.8	18.8	20.1	25.9	25.9	13.2	14.5	13.0	12.5	24.9	26.9	27.5	27.5
		14.9		19.5		25.9		13.9		12.8		25.9		27.5	

TABLE F. Mix Proportions, Fresh Concrete and Compressive Strength Test Results. YUNDT AGGREGATE.

		Nominal Cementitious Materials Content, kg/m³													
		160		200		240		160		160		240		240	
		Mix No.													
		789/80	790/80	791/80	792/80	793/80	794/80	795/80	796/80	800/80	801/80	802/80	803/80	804/80	805/80
Batch Proportions															
Cement, kg		6.4		8.0		9.6		4.8		3.2		7.2		4.8	
Slag, kg		-		-		-		1.6		3.2		2.4		4.8	
Aggregate (dry),kg		75.9		74.1		72.7		75.8		75.4		72.2		72.2	
Water (total), kg		6.8		7.0		6.9		6.7		6.8		7.1		7.1	
Porzite L70, mL		25.6		32.0		38.4		25.6		25.6		38.4		38.4	
NVR, mL		7.5		8.8		11.2		7.5		7.5		11.2		11.2	
Test Results, Fresh Concrete															
Slump, mm		55	55	60	55	55	60	55	55	65	65	65	60	65	60
Air Content,* %		7.5	8.9	9.0	7.5	7.6	8.6	8.6	8.5	7.7	8.2	8.4	7.0	8.2	8.1
Density, kg/m³		2269	2241	2234	2266	2284	2248	2252	2248	2234	2223	2216	2262	2220	2223
Yield, L		39.3	39.8	39.9	39.3	39.1	39.7	39.5	39.5	39.6	39.8	40.1	39.3	40.1	40.0
Cement factor, kg/m³		163.0	161.0	200.6	203.5	245.8	241.9	162.1	161.9	161.5	160.7	239.4	244.3	239.7	240.1
Eff. w/c		0.906	0.906	0.750	0.750	0.625	0.625	0.891	0.891	0.898	0.898	0.646	0.646	0.646	0.646
Test Results, Hardened Concrete															
Compressive strength, MPa	3d	8.5	8.4	10.6	11.6	17.5	14.4	5.8	5.4	2.6	2.6	8.6	11.7	5.4	6.9
		8.5		11.1		16.0		5.6		2.6		10.2		6.2	
	7d	11.5	11.6	13.5	15.2	20.8	18.9	8.9	8.6	5.7	5.4	13.3	17.4	8.3	13.2
		11.6		14.4		19.9		8.8		5.6		15.4		10.8	
	28d	15.3	14.9	18.5	19.7	24.1	24.9	14.9	13.9	12.7	12.4	20.9	27.6	22.6	26.4
		15.1		19.1		24.5		14.4		12.6		24.3		24.5	

TABLE G. Setting Time Test Results

Cementitious Materials Content, kg/m^3	Setting Time	
	Initial h:min	Final h:min
Marshall Aggregate		
160	6:50	9:35
200	7:30	9:30
240	7:25	9:40
120 + 40	7:35	10:15
80 + 80	7:55	>12
180 + 60	6:50	9:05
120 + 120	7:35	10:35
Huron Aggregate		
160	7:05	10:20
200	7:25	9:10
240	7:20	9:20
120 + 40	8:20	10:40
80 + 80	9:25	13:30
180 + 60	8:30	10:40
120 + 120	8:30	11:00
TCG Aggregate		
160	6:40	9:40
200	6:45	8:45
240	7:05	9:00
120 + 40	7:50	10:50
80 + 80	7:45	8:50
180 + 60	6:45	8:55
120 + 120	7:00	9:55
YUNDT Aggregate		
160	6:45	9:14
200	6:25	8:40
240	6:20	8:20
120 + 40	7:40	10:40
80 + 80	8:50	>13
180 + 60	7:35	10:10
120 + 120	8:50	13:10
The test procedure was in accordance with ASTM C403-77		

TABLE H. Mix Proportions, Fresh Concrete and Air Void System Test Results. DURABILITY MIXES-MARSHALL AGGREGATE

	Nominal Cementitious Materials Content, kg/m^3								
	120	160	200	240	160	160	240	240	310
	Mix No.								
	816/80	817/80	818/80	819/80	820/80	821/80	824/80	825/80	826/80*
Batch Proportions									
Cement, kg	4.8	6.4	8.0	9.6	4.8	3.2	7.2	4.8	12.4
Slag, kg	-	-	-	-	1.6	3.2	2.4	4.8	-
Aggregate (dry),kg	77.3	76.1	74.9	73.7	76.0	75.9	72.6	72.5	74.3
Water (total), kg	6.9	7.0	7.2	7.3	6.8	7.0	7.2	7.1	6.4
Porzite L70, mL	19.2	25.6	32.0	38.4	25.6	25.6	38.4	38.4	49.6
NVR, mL	19.5	16.0	20.0	24.0	20.0	20.0	24.0	24.0	3.8
Test Results, Fresh Concrete									
Slump, mm	70	65	55	65	55	65	60	65	60
Air content, %	8.6	7.0	6.8	6.9	6.8	7.5	7.8	6.9	6.9
Density, kg/m^3	2196	2262	2259	2255	2248	2220	2227	2230	2330
Yield, L	40.5	39.6	39.9	40.2	39.7	40.2	40.1	40.0	40.0
Cement factor, kg/m^3	118.4	161.8	200.6	239.0	161.3	159.1	239.2	240.1	310.3
Eff. w/c	1.250	0.953	0.788	0.667	0.922	0.953	0.656	0.646	0.452
Air Void System									
Air content, %	9.1	6.8	6.2	6.0	5.5	9.2	5.1	7.0	5.7
Specific surface, mm^{-1}	24.8	25.4	25.1	29.5	25.5	25.3	34.1	35.0	17.9
Spacing factor, mm	0.082	0.118	0.144	0.132	0.143	0.091	0.131	0.094	0.234

*Control mix, laboratory standard fine and coarse aggregates.

TABLE I. Mix Proportions, Fresh Concrete and Air Void System Test Results.
DURABILITY MIXES-HURON AGGREGATE

	Nominal Cementitious Materials Content, kg/m^3								
	120	160	200	240	160	160	240	240	310
	Mix No.								
	870/80	868/80	869/80	871/80	872/80	704/80	705/80	706/80	707/80*
Batch Proportions									
Cement, kg	4.8	6.4	8.0	9.6	4.8	3.2	7.2	4.8	12.4
Slag, kg	-	-	-	-	1.6	3.2	2.4	4.8	-
Aggregate (dry),kg	77.3	75.6	73.8	72.5	75.8	75.2	72.0	71.9	74.3
Water (total), kg	7.0	7.1	7.1	7.2	7.1	6.9	7.0	7.0	6.5
Porzite L70, mL	19.2	25.6	32.0	38.4	25.6	25.6	38.4	38.4	49.6
NVR, mL	4.5	6.0	7.5	7.5	5.0	5.5	7.5	9.0	3.8
Test Results, Fresh Concrete									
Slump, mm	65	60	55	65	65	55	55	60	60
Air Content, %	8.5	8.3	8.5	7.6	8.6	7.2	7.3	7.0	6.6
Density, kg/m^3	2206	2213	2223	2241	2202	2248	2259	2266	2355
Yield, L	40.4	40.3	40.0	39.9	40.5	39.4	39.2	39.0	39.6
Cement factor, kg/m^3	118.8	158.9	200.1	240.9	158.0	162.6	244.9	246.0	313.3
Eff. w/c	1.229	0.938	0.763	0.646	0.938	0.906	0.630	0.630	0.460
Air Void System									
Air content, %		8.0			9.7		5.6		4.3
Specific surface, mm^{-1}		25.5			22.9		25.5		26.0
Spacing factor, mm		0.105			0.093		0.167		0.188

*Control mix, laboratory standard fine and coarse aggregates.

TABLE J. Salt Scaling Test Results. MARSHALL AGGREGATE

Number of Freeze-Thaw Cycles	Cement Content, kg/m³								
	Portland Type 10					Portland, Type 10:Slag			
	310	120	160	200	240	120:40	80:80	180:60	120:120
	Mix No.								
	826/80*	816/80	817/80	818/80	819/80	820/80	821/80	824/80	825/80
	Mass loss, kg/m²								
5	0.41 0.60 0.51	3.88 4.28 4.08	2.84 2.20 2.52	2.98 2.08 2.53	0.67 2.05 1.36	4.09 4.06 4.08	7.30 7.24 7.27	1.42 1.28 1.35	4.14 3.15 3.64
10	0.46 0.63 0.54	4.63 5.55 5.09	3.62 2.75 3.18	3.77 3.15 3.46	0.83 2.64 1.74	5.95 5.46 5.70	11.74 10.24 10.99	1.66 1.47 1.56	5.03 3.71 4.37
15	0.52 0.65 0.58	5.63 6.56 6.10	4.24 3.13 3.68	4.08 3.33 3.71	0.91 2.77 1.84	7.03 6.76 6.90	14.57 11.95 13.26	1.76 1.57 1.66	5.66 4.14 4.90
20	0.55 0.66 0.60	6.35 7.46 6.91	4.96 3.76 4.36	4.63 3.84 4.23	0.97 3.03 2.00	7.73 7.76 7.75	16.19 13.37 14.78	1.79 1.59 1.69	6.17 4.36 5.27
25	0.55 0.67 0.61	7.28 8.82 8.05	5.61 4.14 4.87	4.97 4.18 4.58	0.99 3.14 2.07	9.11 8.76 8.94	16.45 15.12 15.79	1.80 1.59 1.70	6.49 4.64 5.56
30	0.56 0.69 0.63	7.90 9.27 8.58	5.89 4.24 5.06	5.38 4.40 4.90	1.12 3.27 2.19	9.50 9.50 9.50	17.52 16.21 16.87	1.83 1.63 1.73	6.87 4.97 5.92
35	1.10 0.80 0.95	9.00 10.33 9.66	6.67 4.71 5.69	5.92 4.86 5.39	1.19 3.53 2.36	Tests Discontinued after 30 cycles		2.18 2.19 2.18	7.38 5.59 6.49
40	1.13 0.83 0.98	Tests discon- tinued after 35 cycles	6.97 4.94 5.96	6.82 5.58 6.20	1.49 4.14 2.82			2.27 2.25 2.26	7.89 5.96 6.93
45	1.15 0.87 1.01		8.27 5.86 7.07	7.62 6.14 6.88	1.52 4.37 2.95			2.35 2.31 2.33	8.41 6.42 7.42
50	1.16 0.89 1.02		9.45 6.59 8.02	8.38 6.91 7.64	1.56 4.78 3.17			2.43 2.39 2.41	8.82 6.73 7.78

* Control mix, laboratory standard fine and coarse aggregates.

TABLE K. Salt Scaling Test Results. HURON AGGREGATE

Number of Freeze-Thaw Cycles	Cement Content, kg/m³								
	Portland Type 10					Portland, Type 10:Slag			
	310	120	160	200	240	120:40	80:80	180:60	120:120
	Mix No.								
	L707/80*	L870/80	L868/80	L869/80	L871/80	L872/80	L704/81	L705/81	L706/81
	Mass loss, kg/m²								
5	0.31 0.30 0.30	1.41 1.50 1.45	0.46 0.67 0.57	1.12 0.51 0.81	0.30 0.52 0.41	1.31 1.58 1.45	4.02 4.39 4.20	2.45 2.63 2.54	3.51 2.45 2.98
10	0.40 0.34 0.37	1.67 1.72 1.70	0.58 0.89 0.73	1.25 0.60 0.93	0.51 0.76 0.64	1.98 2.24 2.11	6.53 6.91 6.72	3.88 4.33 4.10	5.15 3.64 4.40
15	0.44 0.37 0.40	1.78 2.18 1.98	0.90 1.16 1.03	1.68 0.89 1.28	0.76 1.08 0.92	2.93 2.87 2.90	7.64 8.00 7.82	4.42 4.92 4.67	5.89 4.21 5.05
20	0.47 0.38 0.42	1.99 2.44 2.22	1.20 1.57 1.39	1.92 1.23 1.57	0.97 1.16 1.06	3.60 3.45 3.52	Test discontinued after 15 cycles		
25	0.48 0.39 0.44	2.17 2.68 2.42	1.27 1.66 1.47	2.13 1.56 1.84	1.05 1.20 1.12	4.04 3.84 3.94			
30	0.50 0.41 0.45	2.22 2.74 2.48	1.35 1.73 1.54	2.33 1.76 2.05	1.08 1.22 1.15	4.56 4.06 4.31			
35	0.51 0.43 0.47	2.44 3.00 2.72	1.51 1.83 1.67	2.41 1.80 2.11	1.11 1.36 1.24	4.74 5.66 5.20			
40	0.52 0.44 0.48	2.48 3.07 2.78	1.58 1.88 1.73	2.44 1.82 2.13	1.15 1.38 1.26	4.81 5.70 5.26			
45	0.53 0.45 0.49	2.55 3.15 2.85	1.68 1.91 1.79	2.50 1.87 2.18	1.17 1.41 1.29	5.09 5.92 5.50			
50	0.54 0.47 0.50	2.84 3.39 3.12	1.73 1.92 1.83	2.56 1.93 2.24	1.18 1.44 1.31	5.30 6.04 5.67			

* Control mix, laboratory standard fine and coarse aggregates.

TABLE L. Freeze-Thaw Test Results.
ASTM D560-77 (Freezing and Thawing Test of compacted Soil-Cement Mixtures).

Aggregate	Cementitious Materials Content, kg/m³								
	120	160	200	240	120+40	80+80	180+60	120+120	310*
	Mass loss, %								
	Mix No.								
	816/80	817/80	818/80	819/80	820/80	821/80	824/80	825/80	826/80
Marshall	0.76 0.76 0.76	0.33 0.21 0.27	0.40 0.35 0.37	0.45 0.42 0.43	0.17 0.31 0.24	0.25 0.19 0.22	0.30 0.17 0.24	0.24 0.06 0.15	0.29 0.25 0.27
	Mix No.								
	870/80	868/80	869/80	871/80	872/80	704/81	705/81	706/81	707/81
Huron	1.95 1.21 1.58	0.69 0.73 0.71	0.73 0.84 0.79	0.59 0.64 0.61	1.25 1.28 1.27	0.67 0.66 0.66	0.37 0.28 0.33	0.42 0.39 0.40	0.13 0.20 0.16

Test carried out in accordance with ASTM D560-77. Mass loss shown was calculated as shown below.

$$\text{Mass loss, \%} = \frac{A-B}{A} \times 100$$

where A = sat, surf. dry mass after 7d curing
B = sat, surf. dry mass after 12 freeze-thaw cycles.

* Control mix, laboratory standard fine and coarse aggregates.

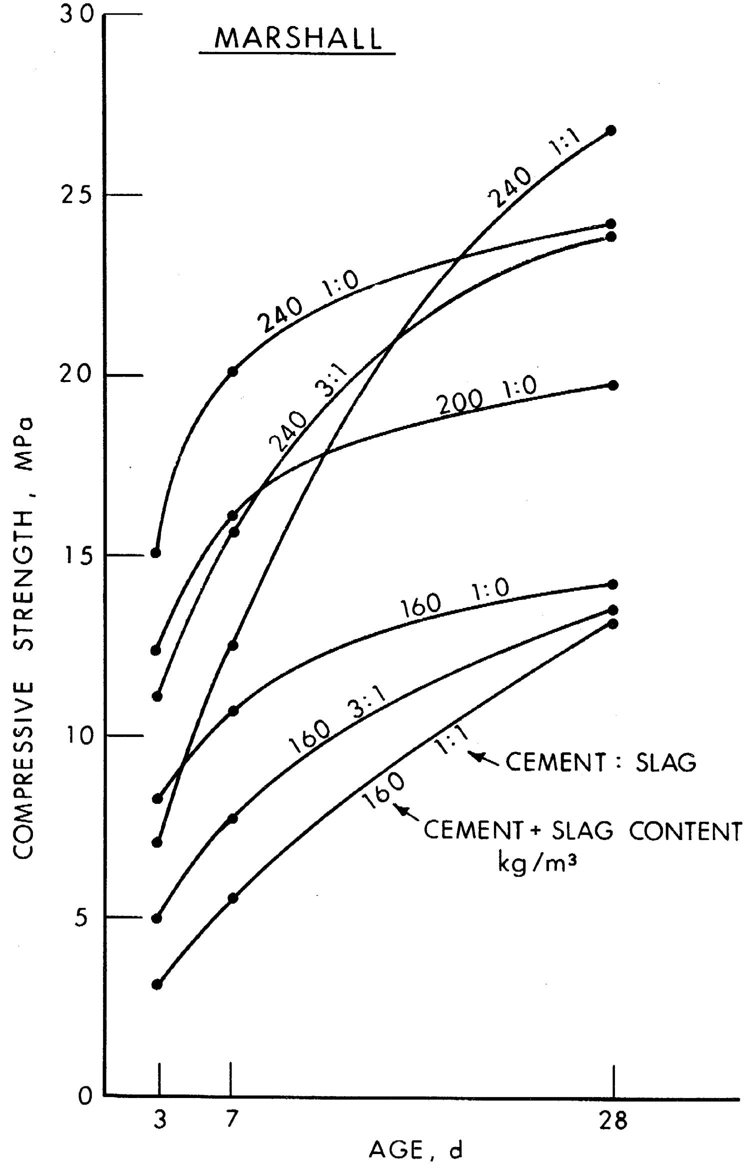


FIG. 1 - COMPRESSIVE STRENGTH vs AGE
COARSE AGGREGATE - MARSHALL

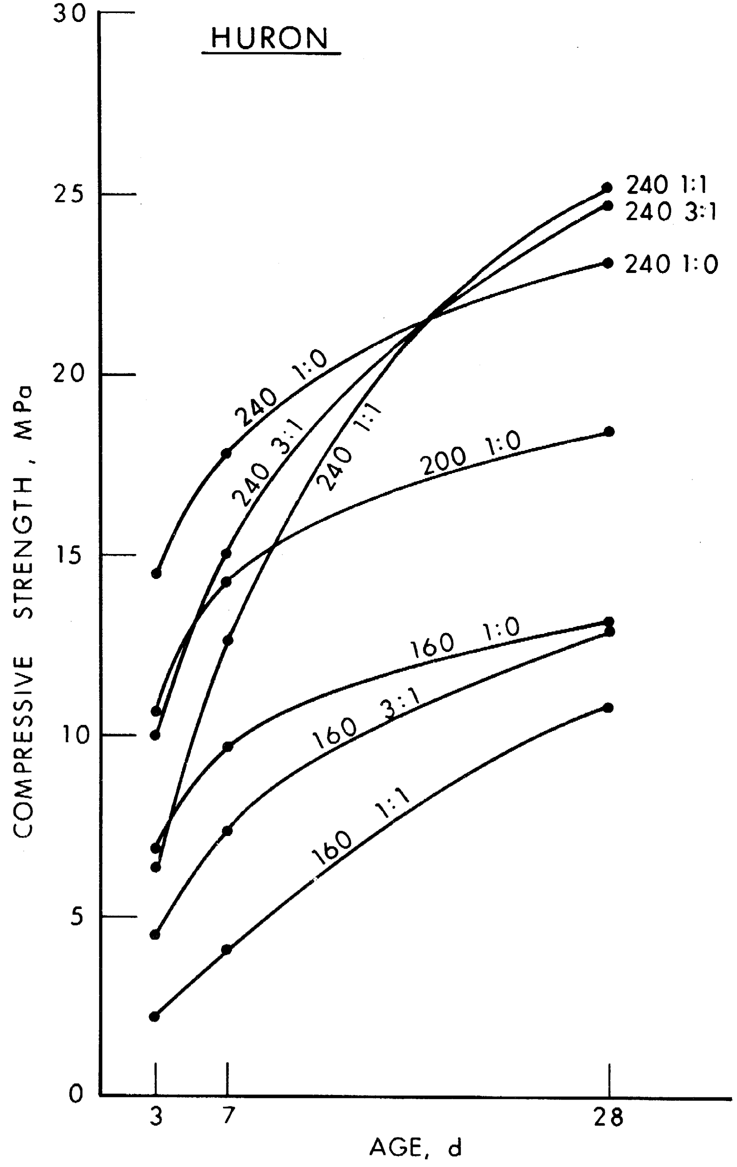


FIG. 2 - COMPRESSIVE STRENGTH vs AGE
COARSE AGGREGATE - HURON

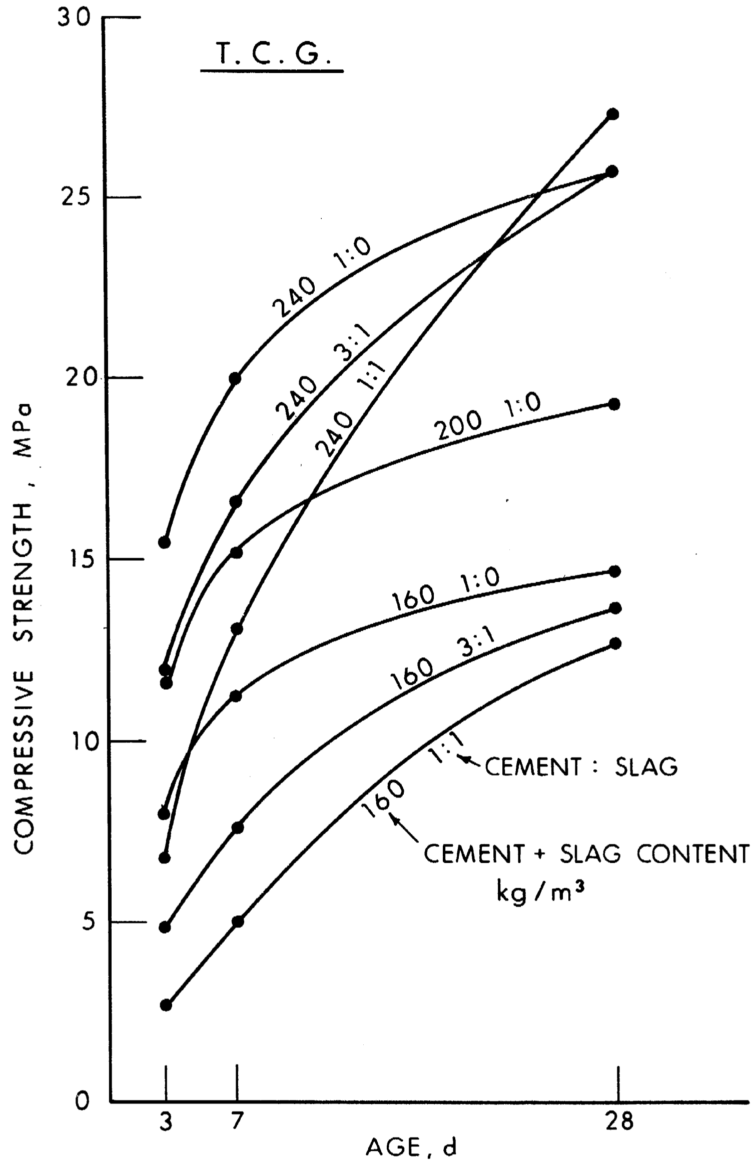


FIG. 3 - COMPRESSIVE STRENGTH vs AGE
COARSE AGGREGATE - T. C. G.

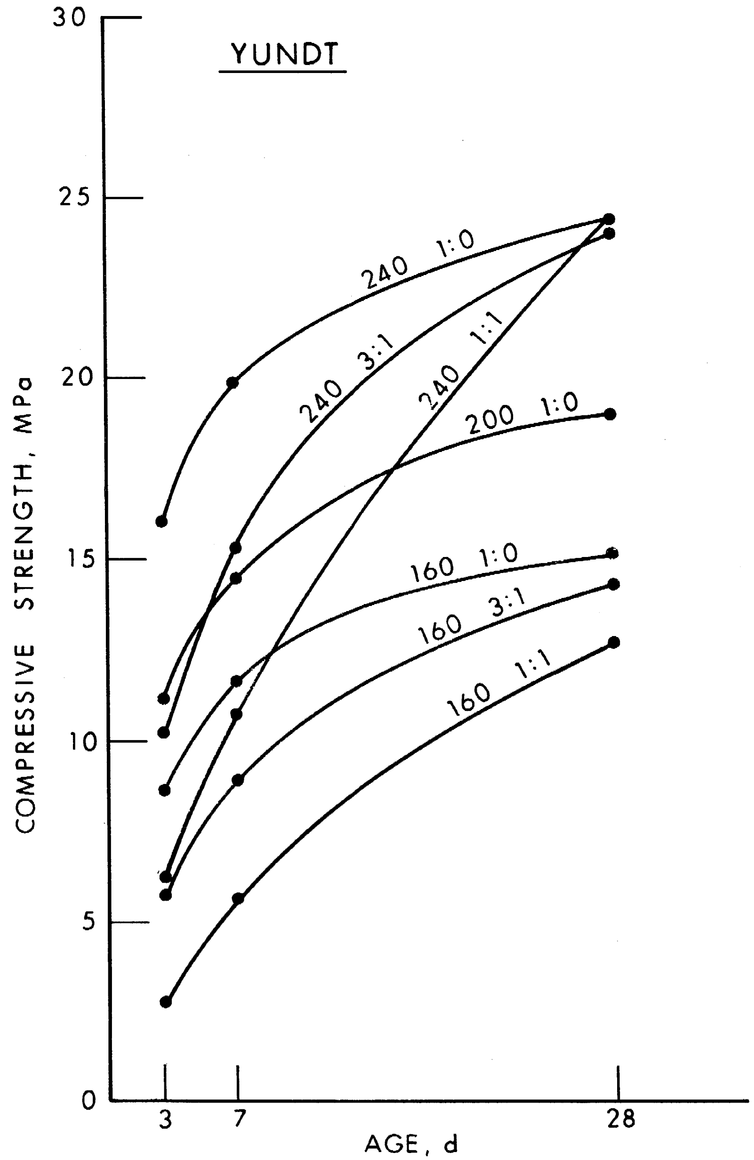


FIG. 4 - COMPRESSIVE STRENGTH vs AGE
COARSE AGGREGATE - YUNDT

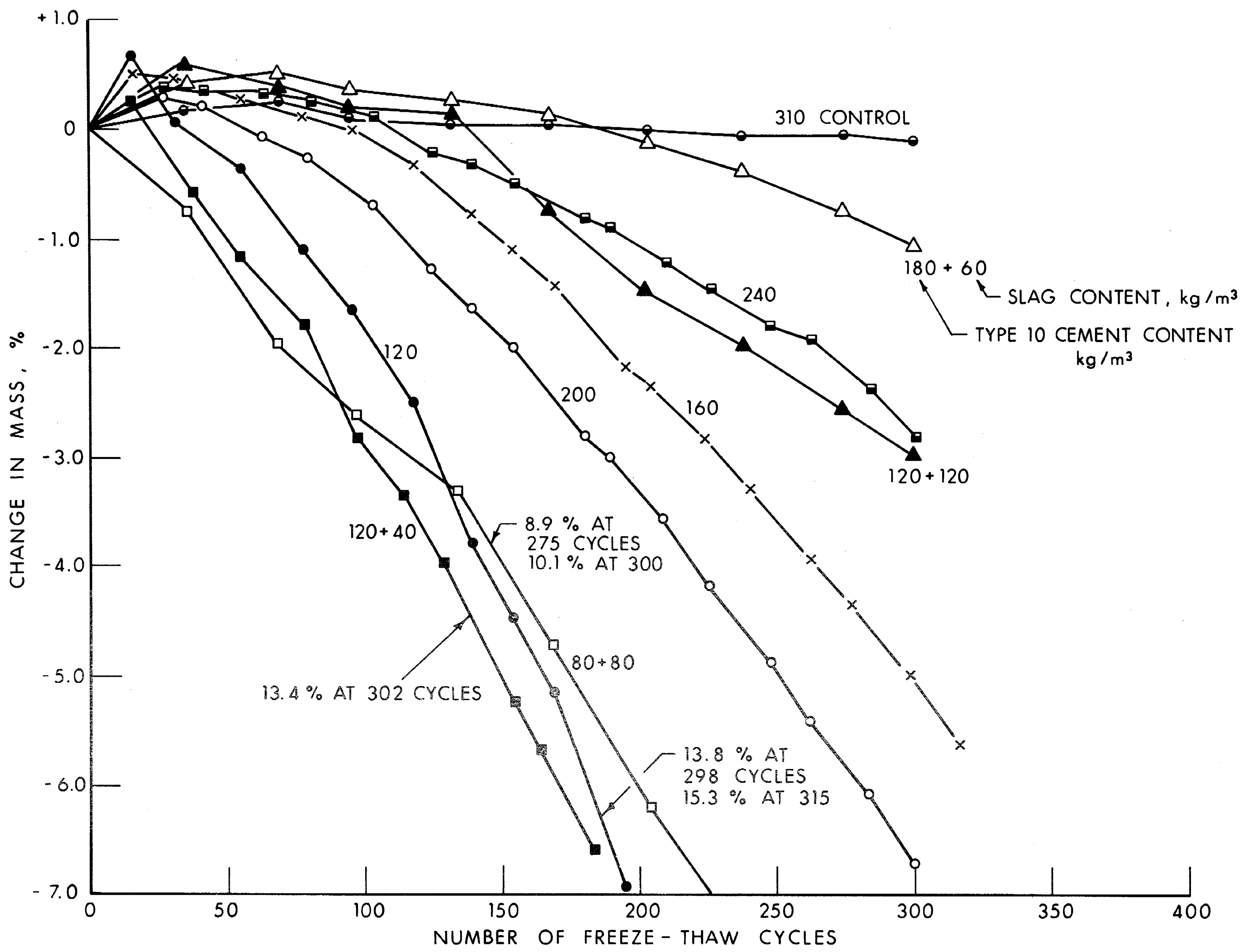
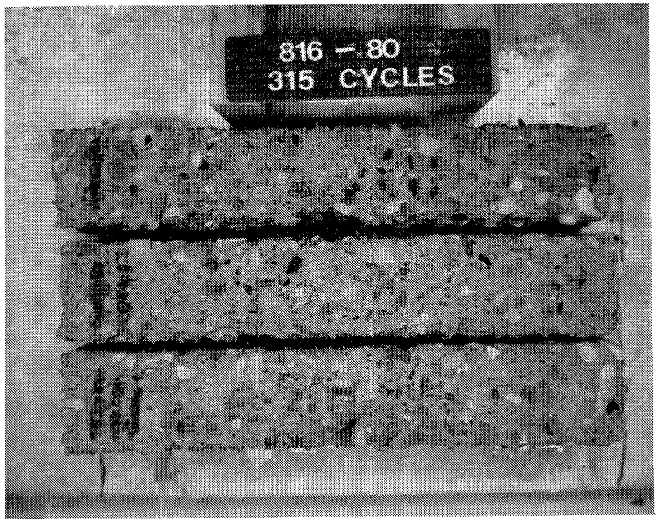
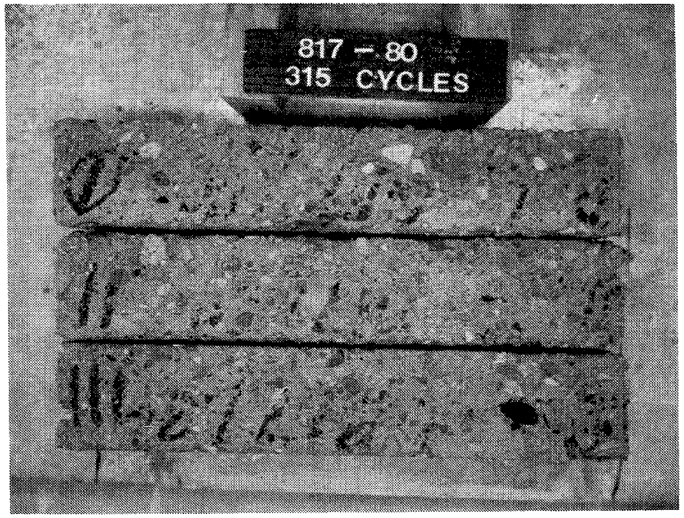


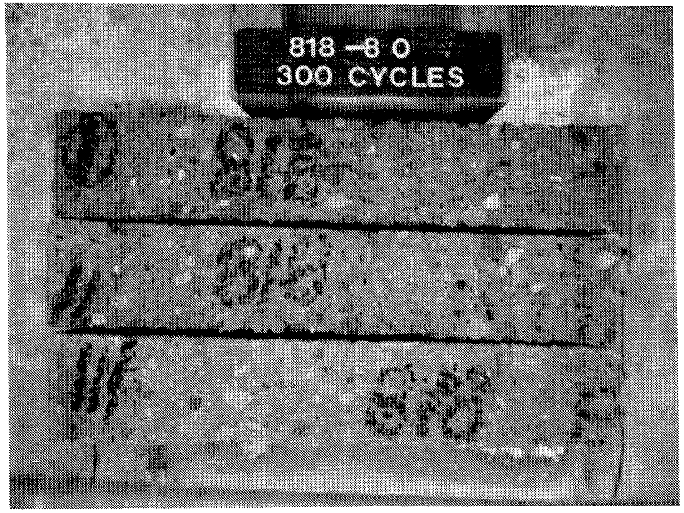
FIG. 5 - FREEZE - THAW TEST RESULTS (MARSHALL AGGREGATE)



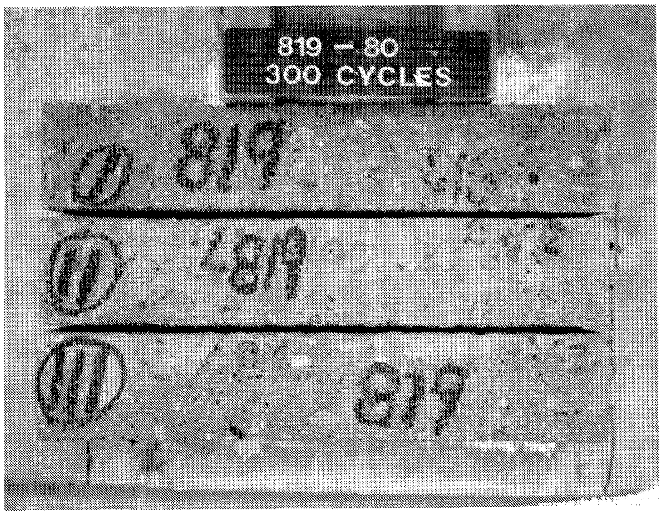
Cement Content 120 kg/m^3



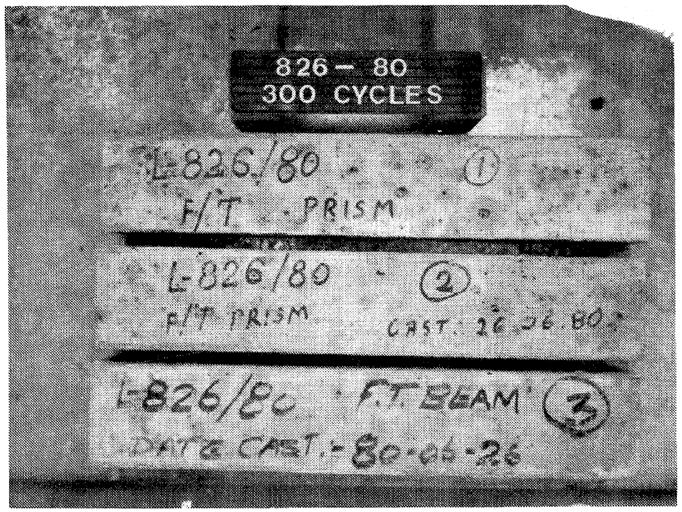
160 kg/m^3



200 kg/m^3



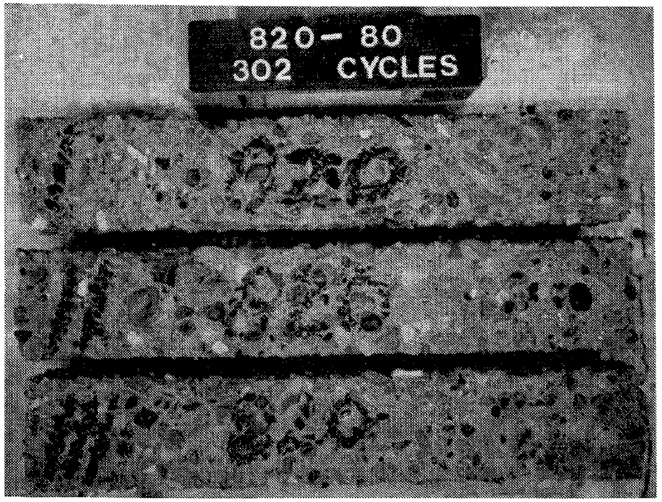
240 kg/m^3



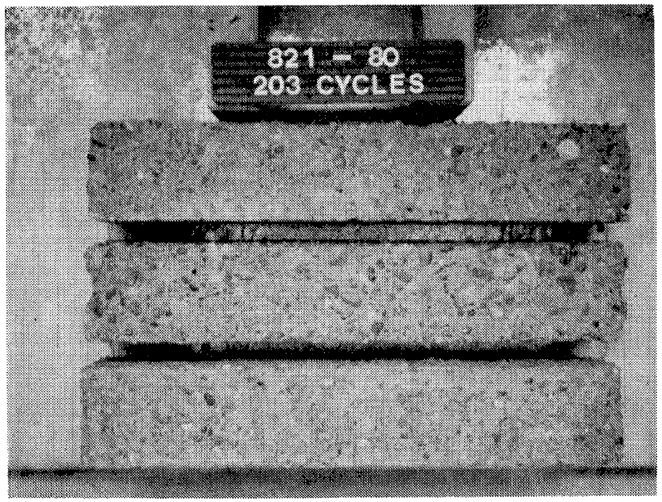
310 kg/m^3 (Control)

Fig. 6. Appearance of Freeze-Thaw Prisms at Termination of the Exposure.

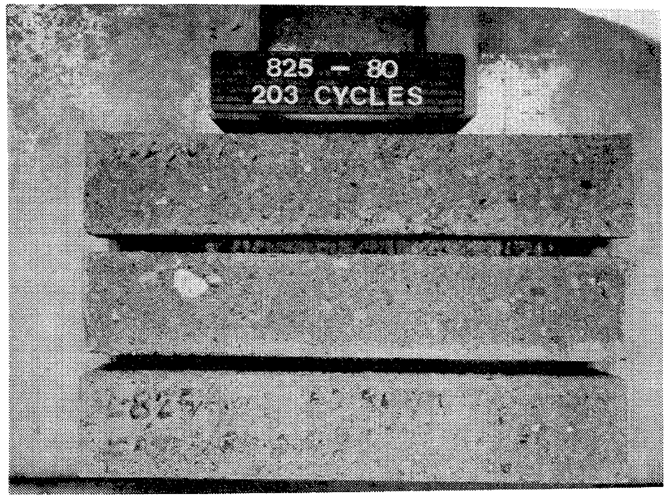
MARSHALL AGGREGATE



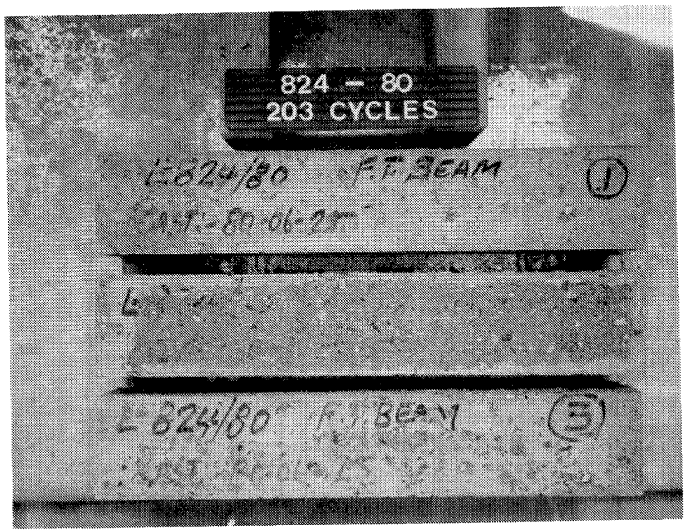
Cement + slag content 120+40 kg/m^3



80+80 kg/m^3



180+60 kg/m^3



120+120 kg/m^3

Fig. 7. Appearance of Freeze-Thaw Prisms at Termination of the Exposure.

MARSHALL AGGREGATE

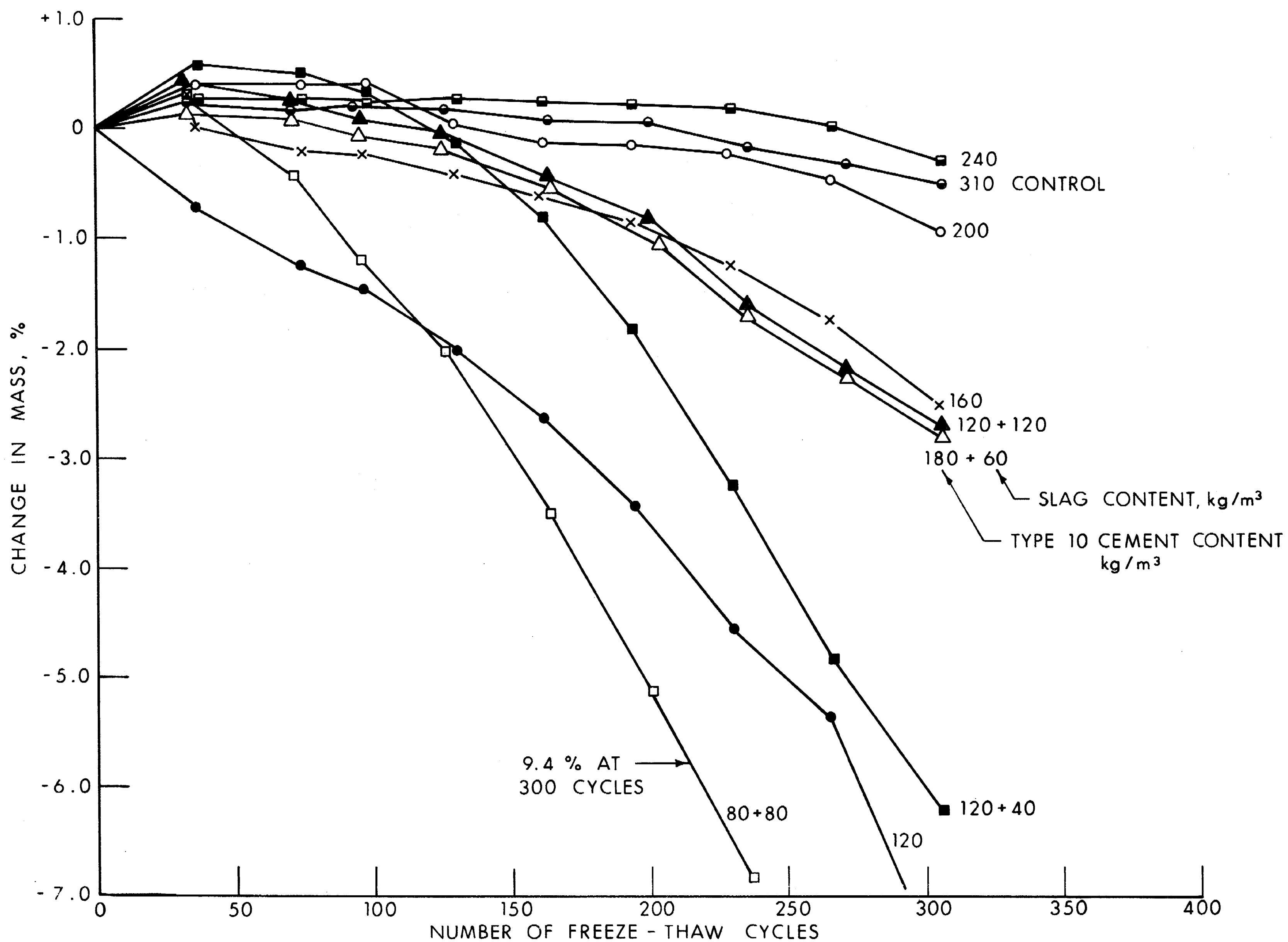
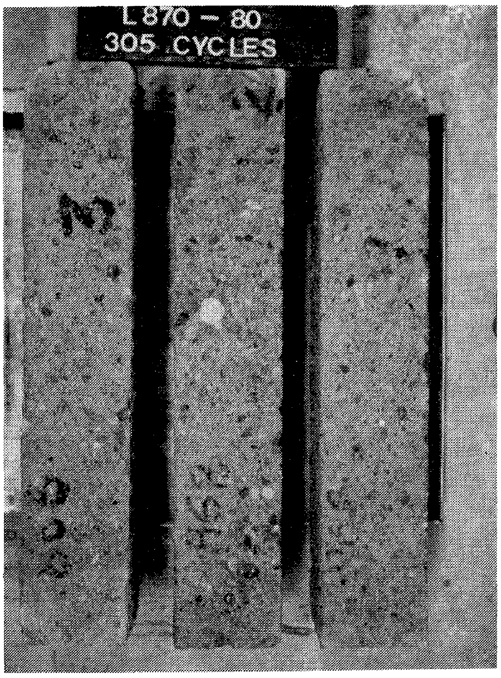
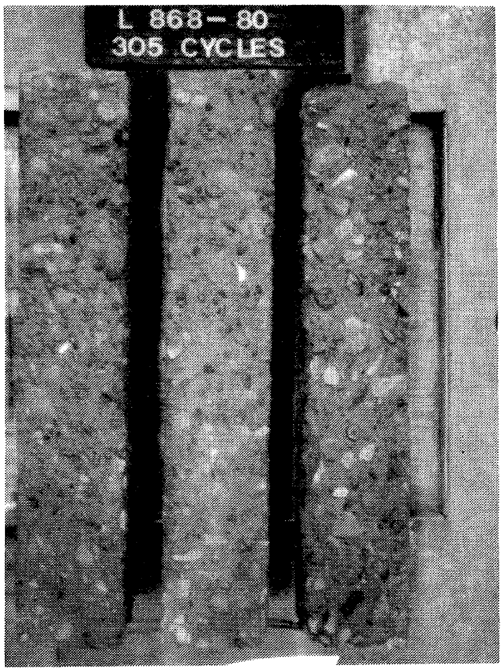


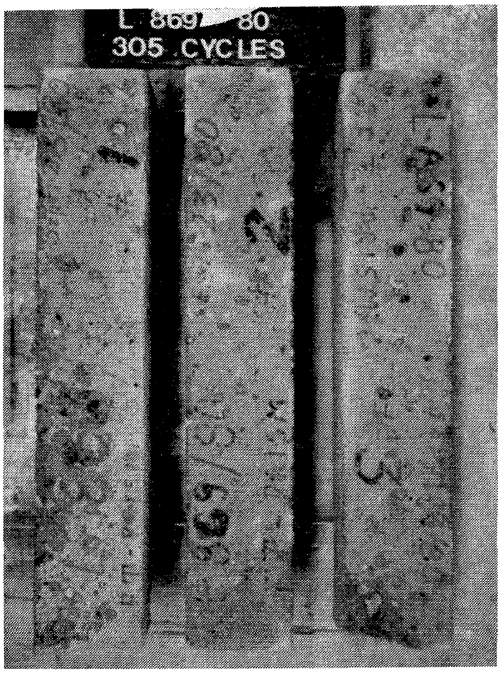
FIG. 8 - FREEZE - THAW TEST RESULTS (HURON AGGREGATE)



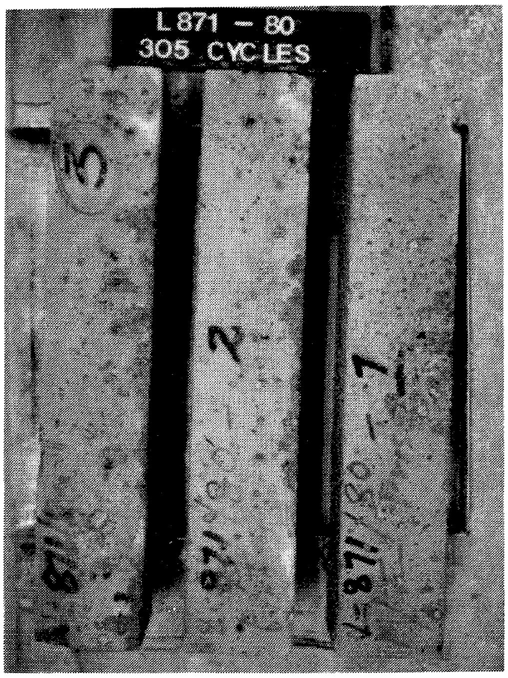
Cement content 120 kg/m^3



160 kg/m^3



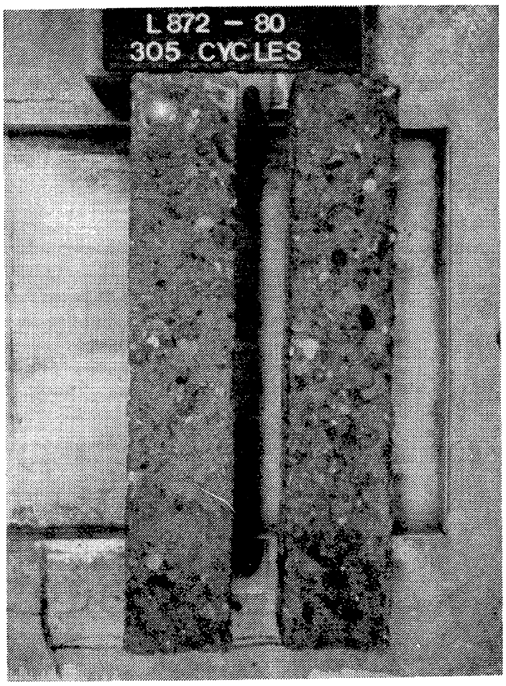
200 kg/m^3



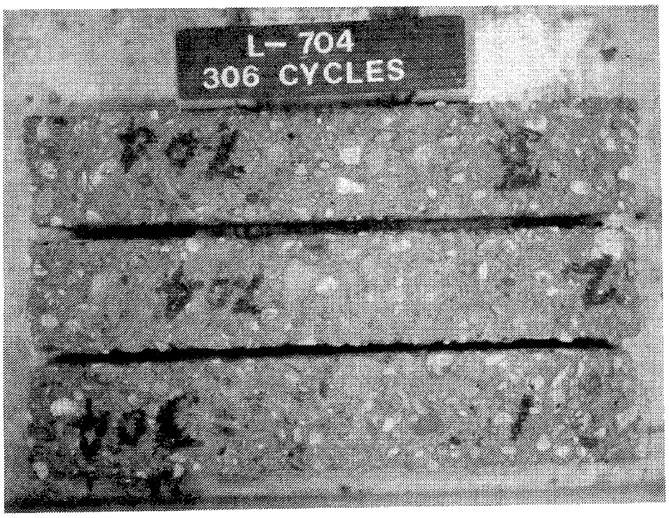
240 kg/m^3

Fig. 9. Appearance of Freeze-Thaw Prisms at Termination of Exposure.

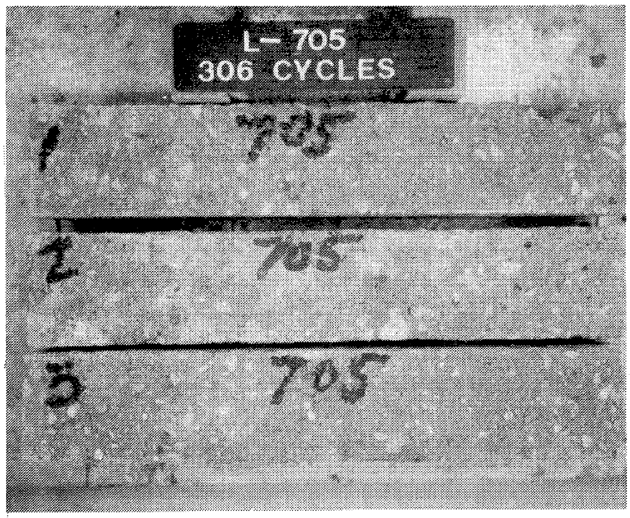
HURON AGGREGATES



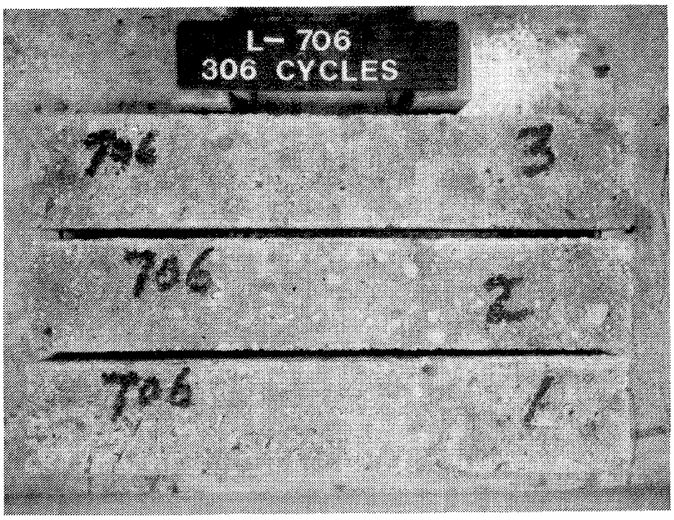
120 kg/m^3



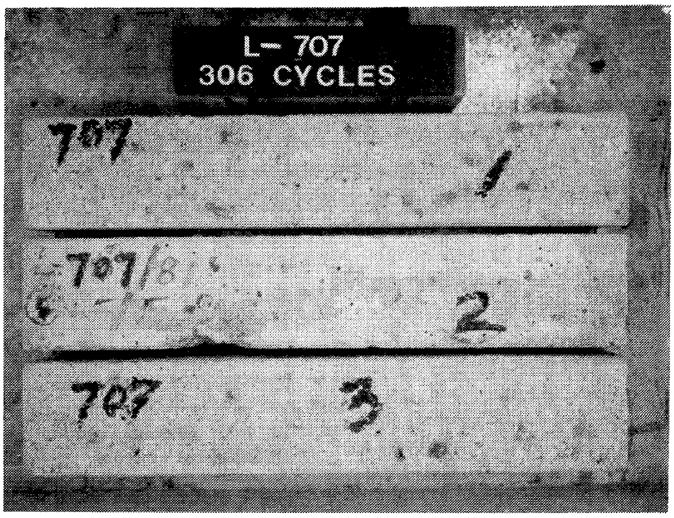
Cement + slag content
160 kg/m^3



200 kg/m^3



240 kg/m^3



310 kg/m^3 (Control)

Fig. 10. Appearance of Freeze-Thaw Prisms at Termination of Exposure.
HURON AGGREGATES

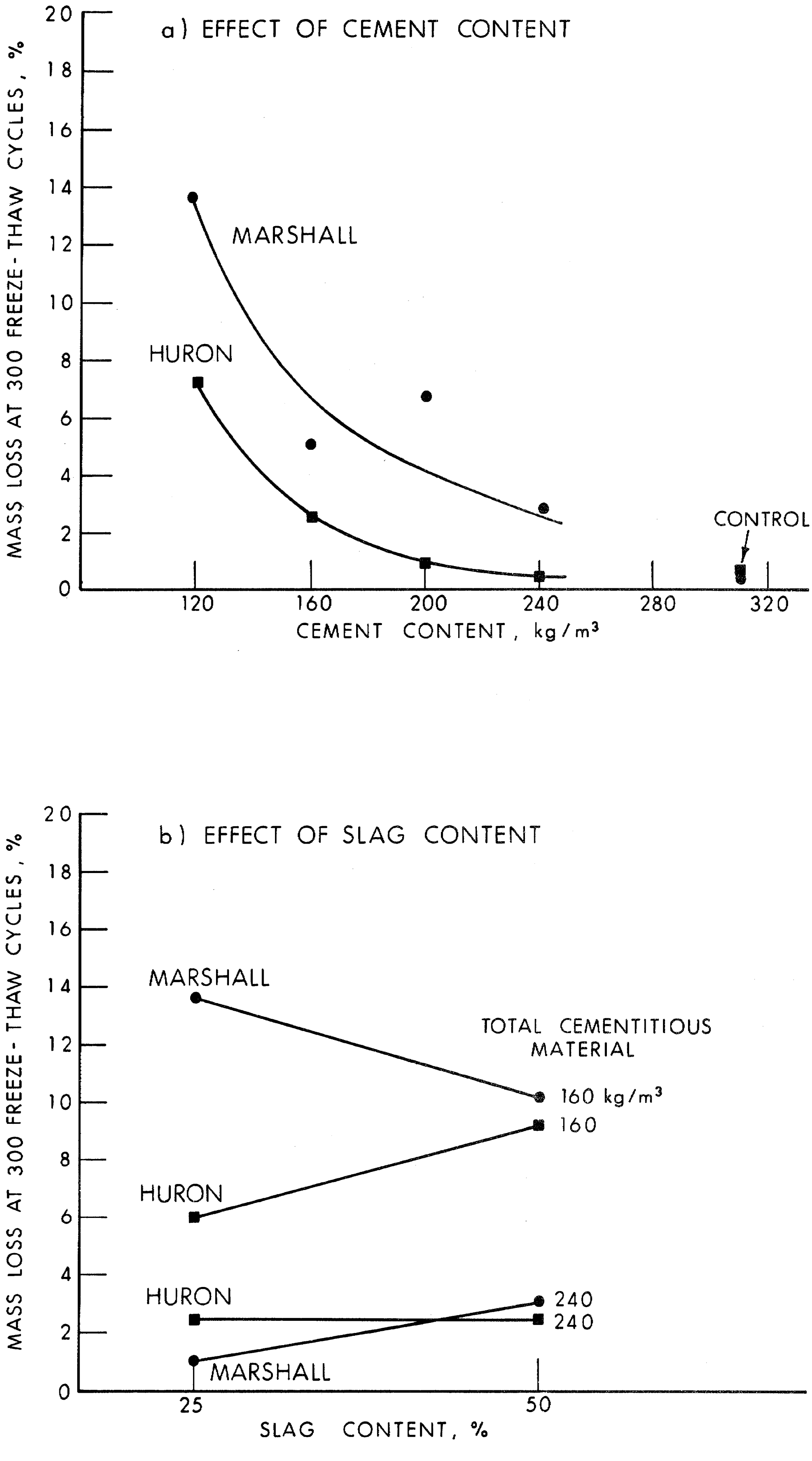


FIG. 11 - EFFECT OF CEMENT AND SLAG CONTENT ON THE FREEZE - THAW RESISTANCE

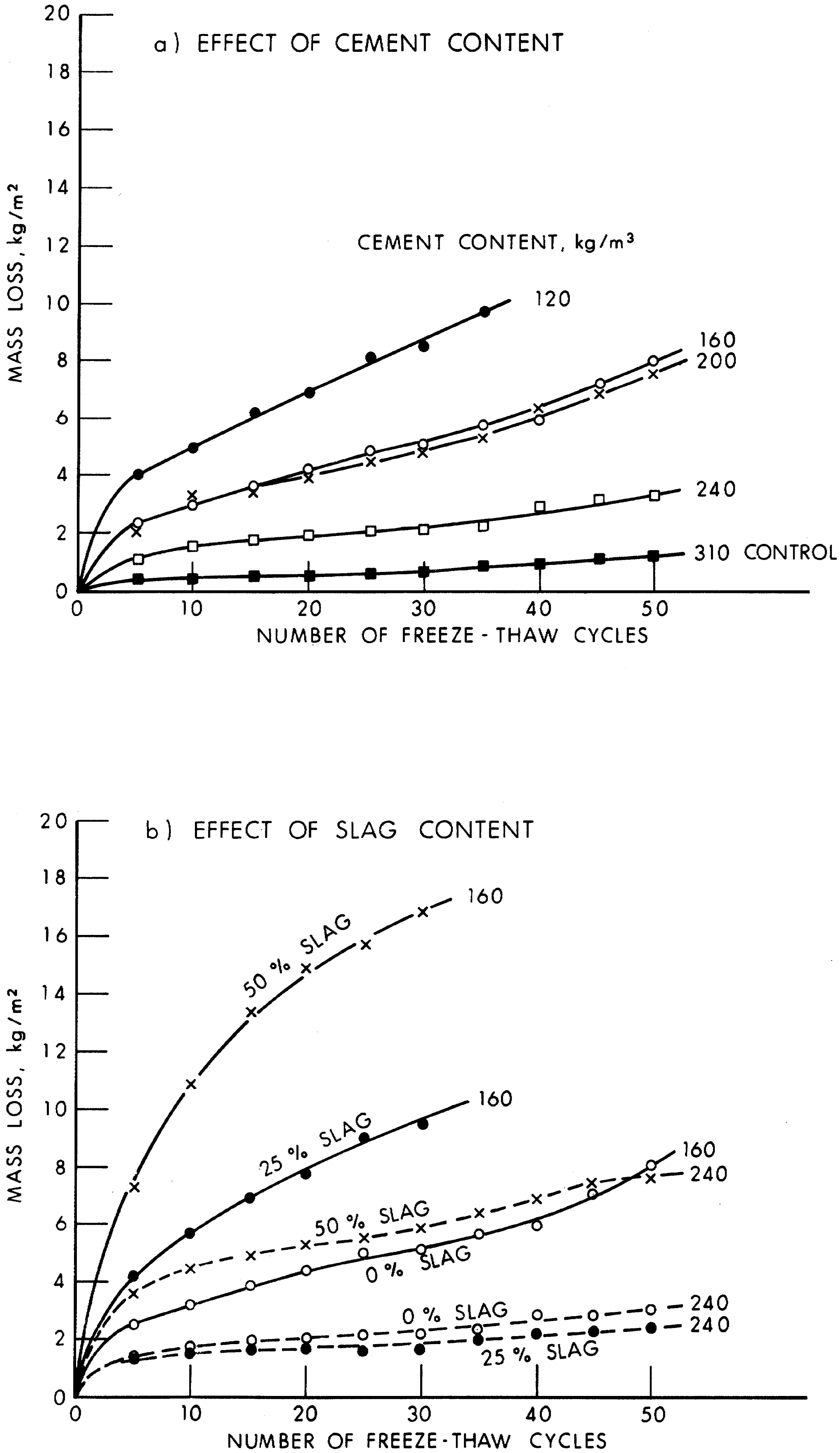
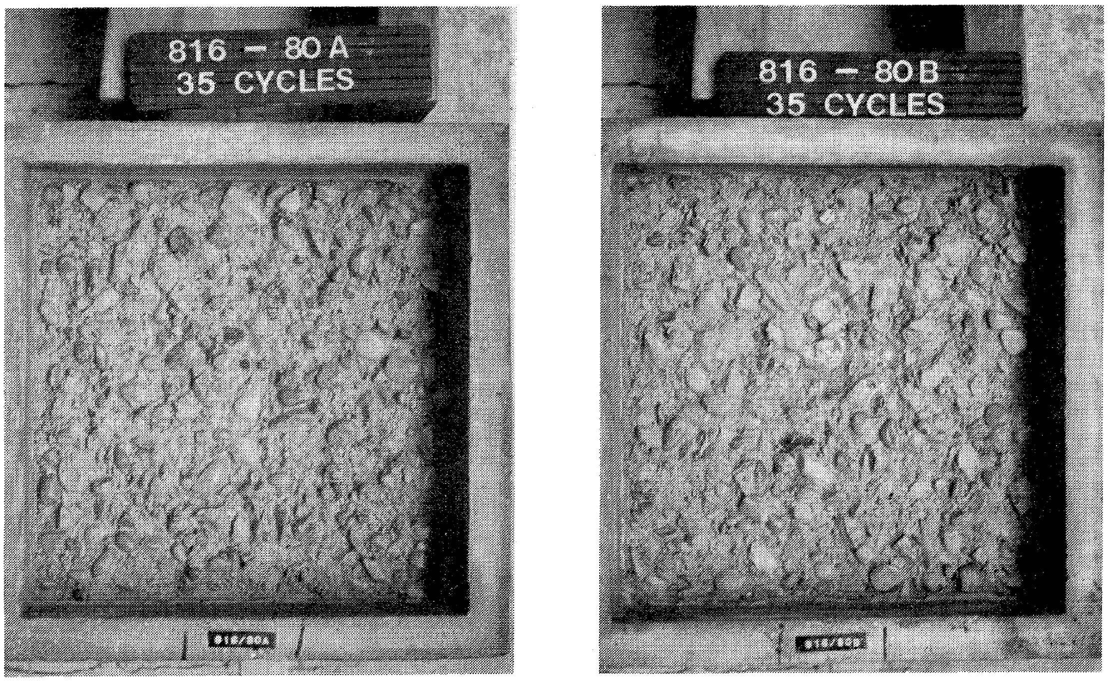
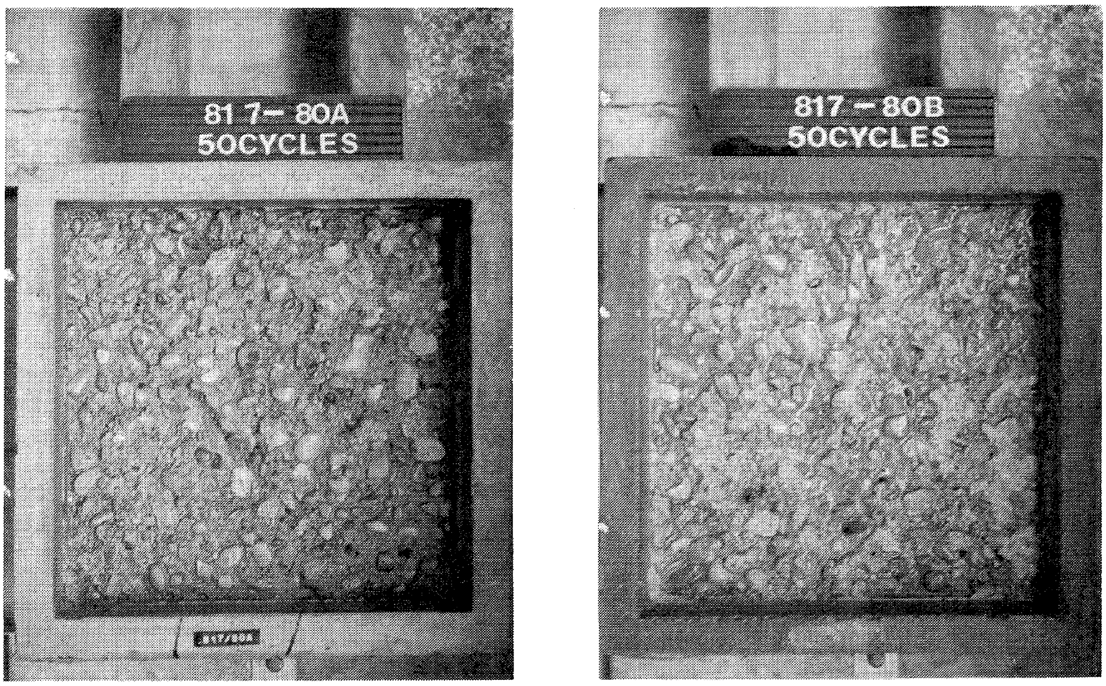


FIG. 12 - EFFECT OF CEMENT AND SLAG CONTENT ON SALT SCALING RESISTANCE (MARSHALL AGGREGATE)

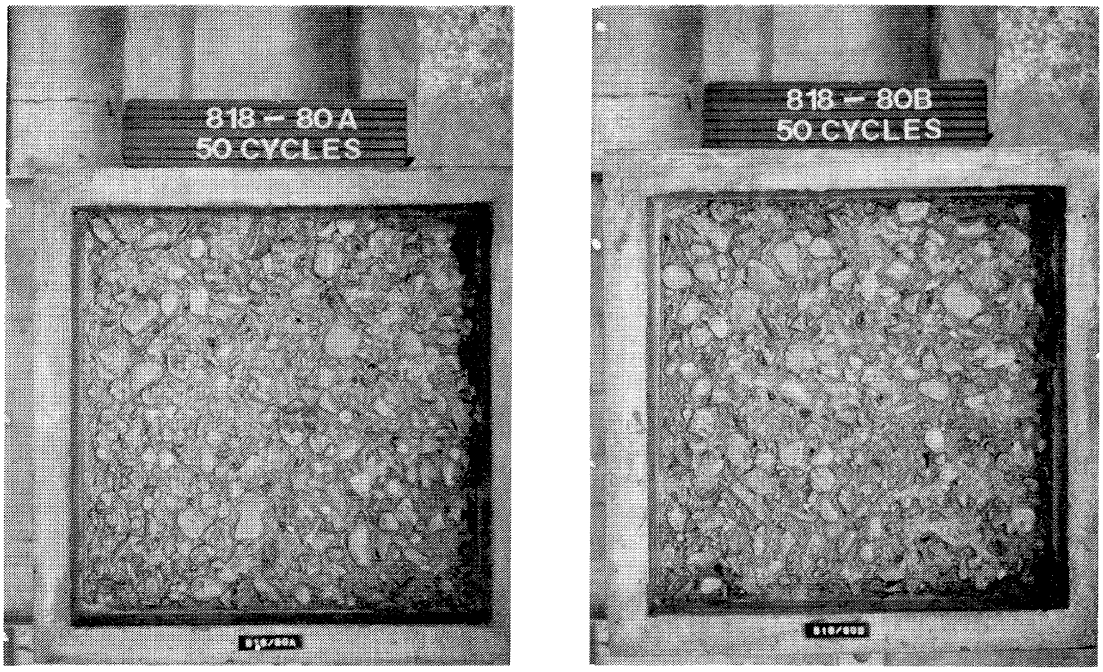


Cement Content 120 kg/m^3

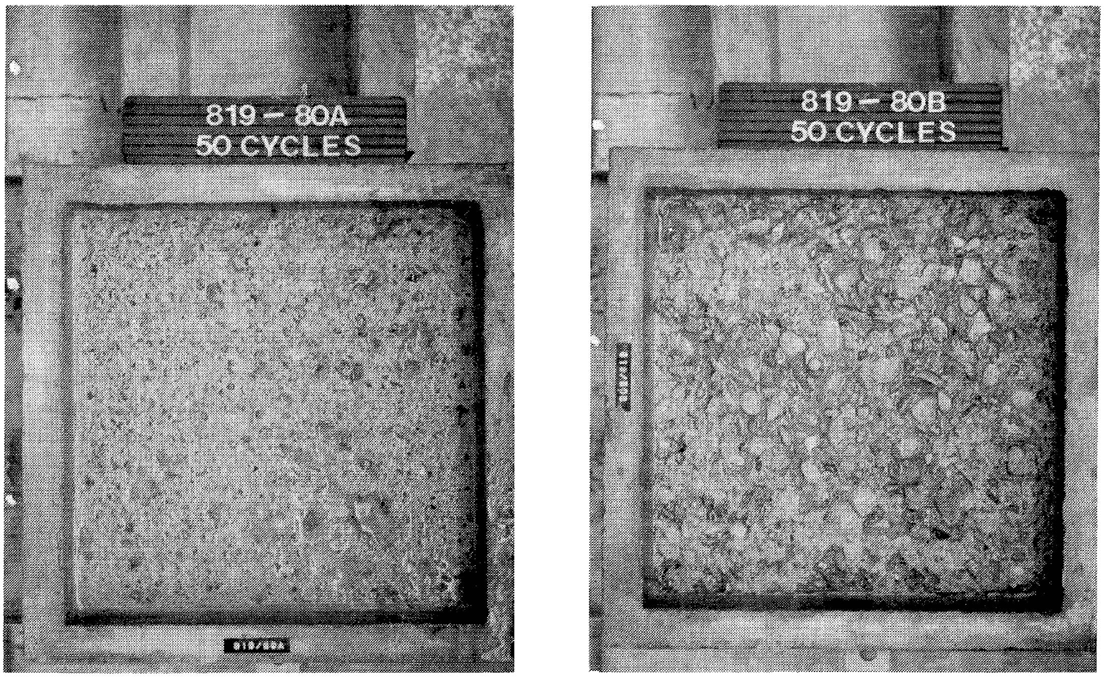


Cement Content 160 kg/m^3

Fig. 13. Appearance of Salt Scaling Slabs at Termination of the Exposure.
<u>MARSHALL AGGREGATE</u>

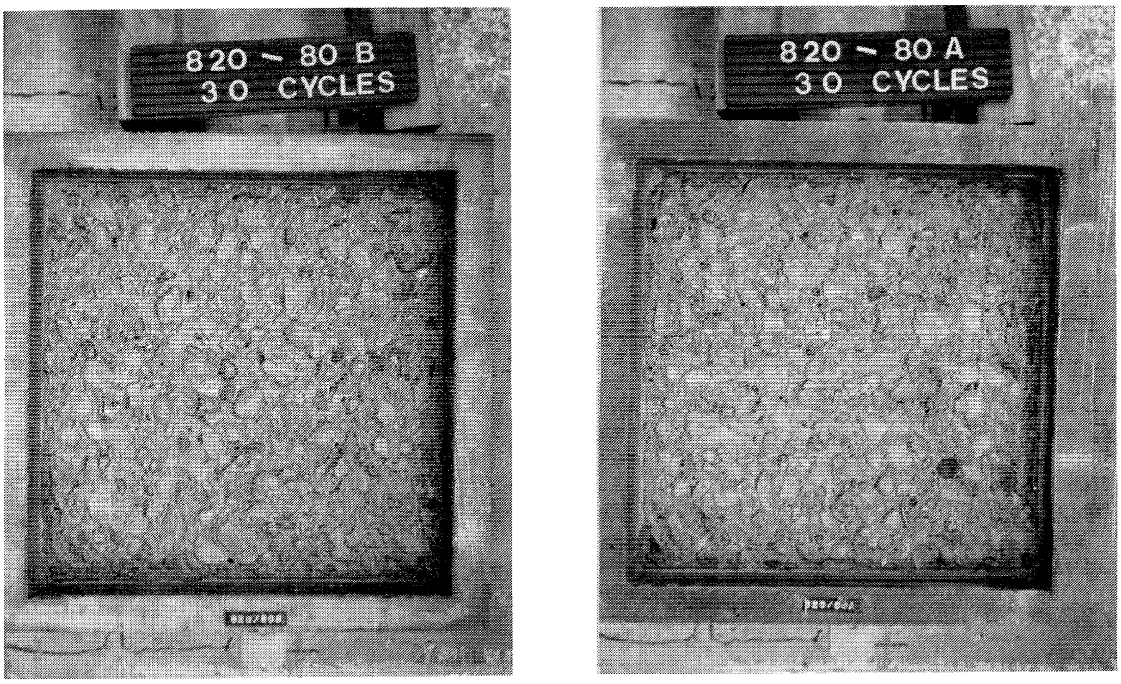


Cement Content 200 kg/m^3

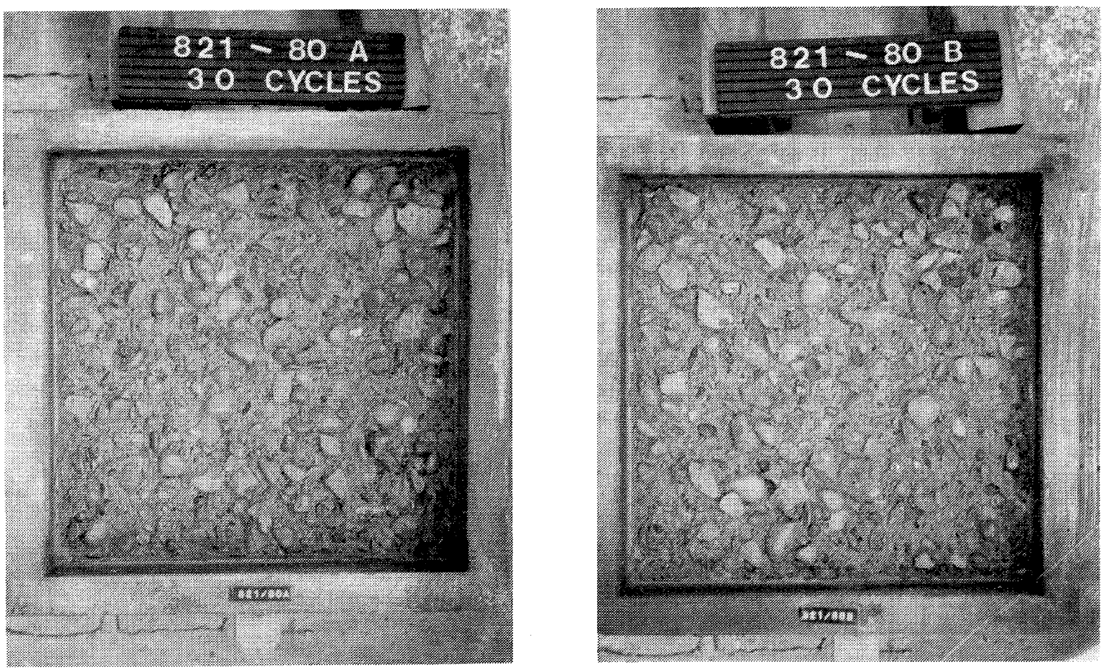


Cement Content 240 kg/m^3

Fig. 14. Appearance of Salt Scaling Slabs at Termination of the Exposure.
MARSHALL AGGREGATE

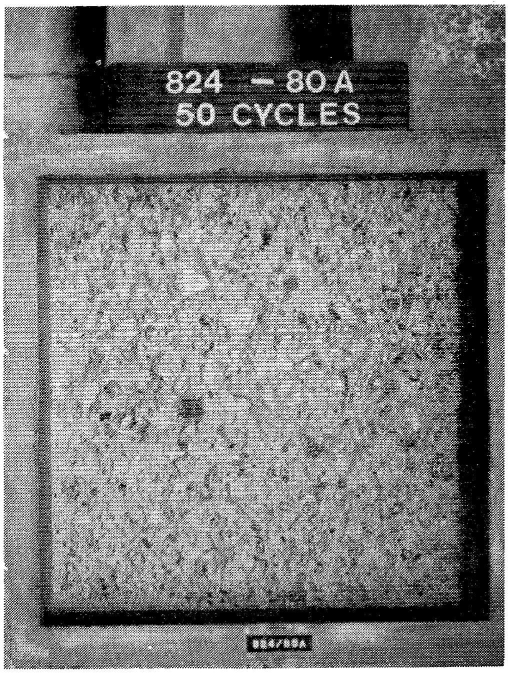


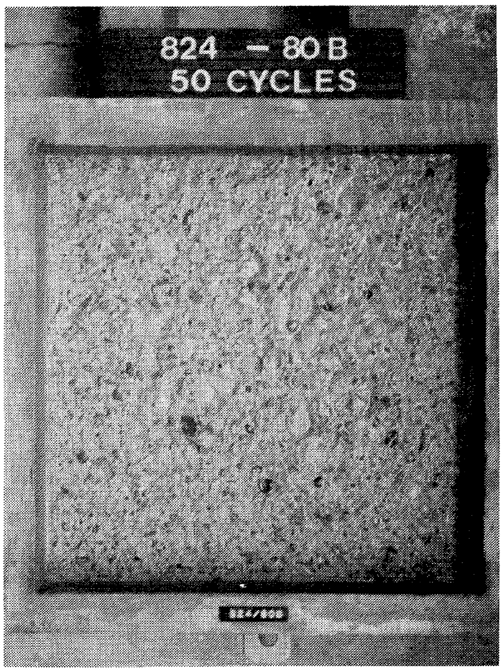
Cement + Slag Content 120+40 kg/m^3



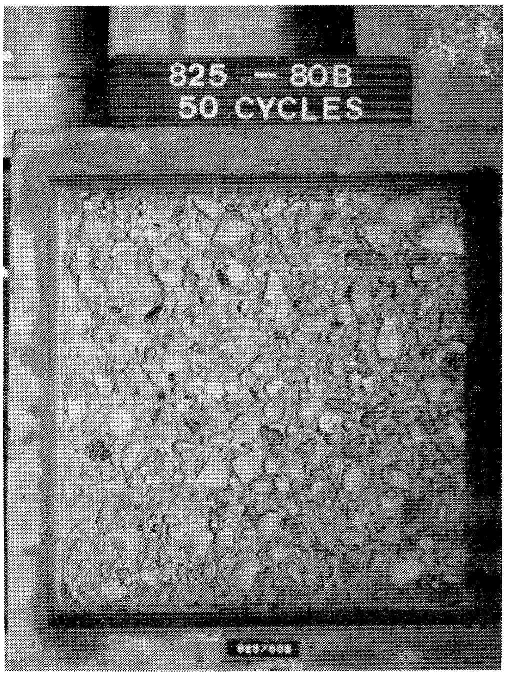
Cement + Slag Content 80+80 kg/m^3

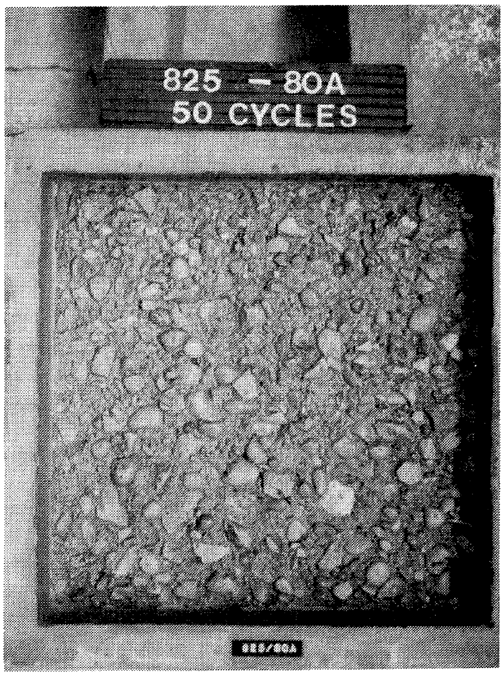
Fig. 15. Appearance of Salt Scaling Slabs at Termination of the Exposure.
<u>MARSHALL AGGREGATE</u>





Cement + Slag Content 180+60 kg/m^3





Cement + Slag Content 120+120 kg/m^3

Fig. 16. Appearance of Salt Scaling Slabs at Termination of the Exposure.
MARSHALL AGGREGATE

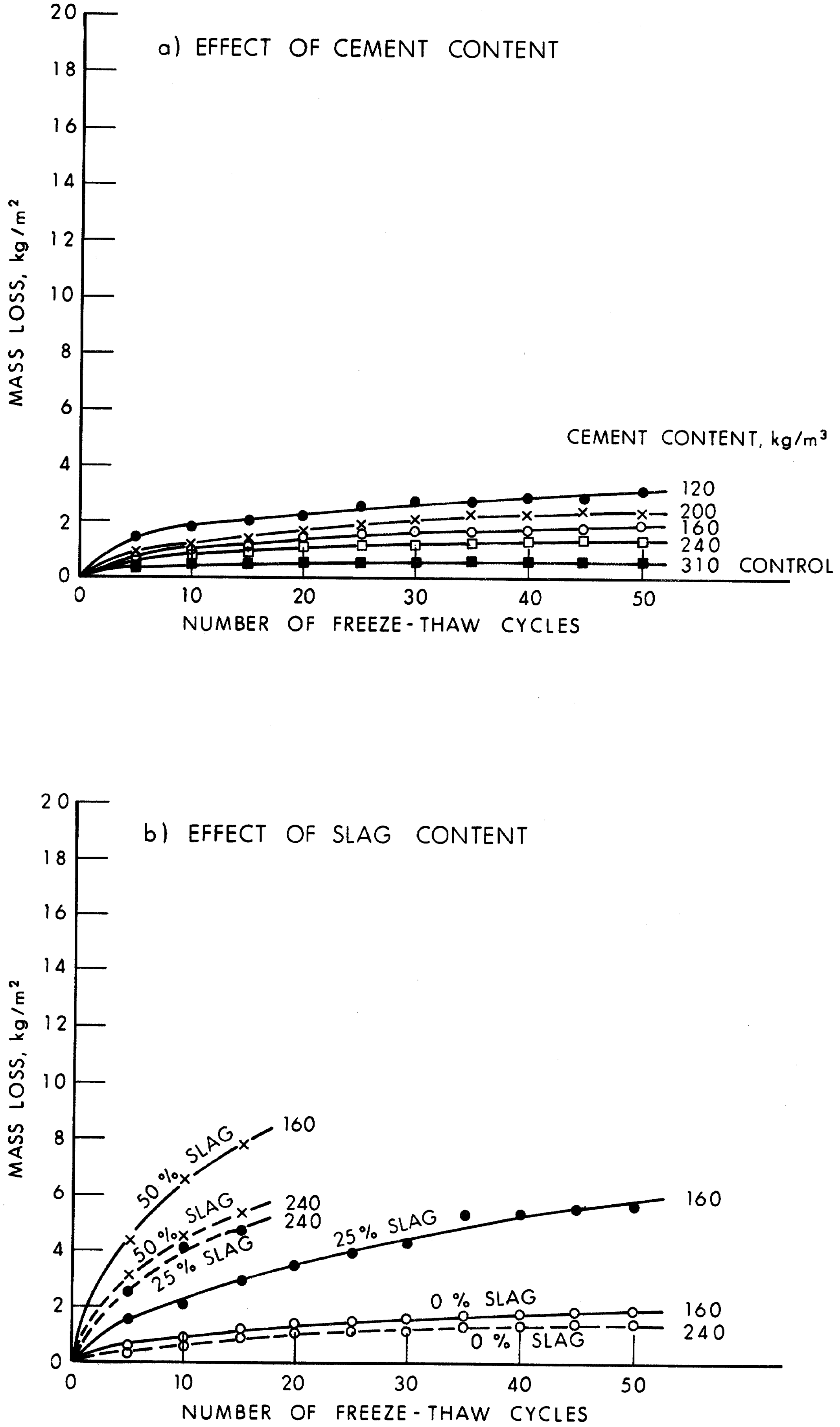
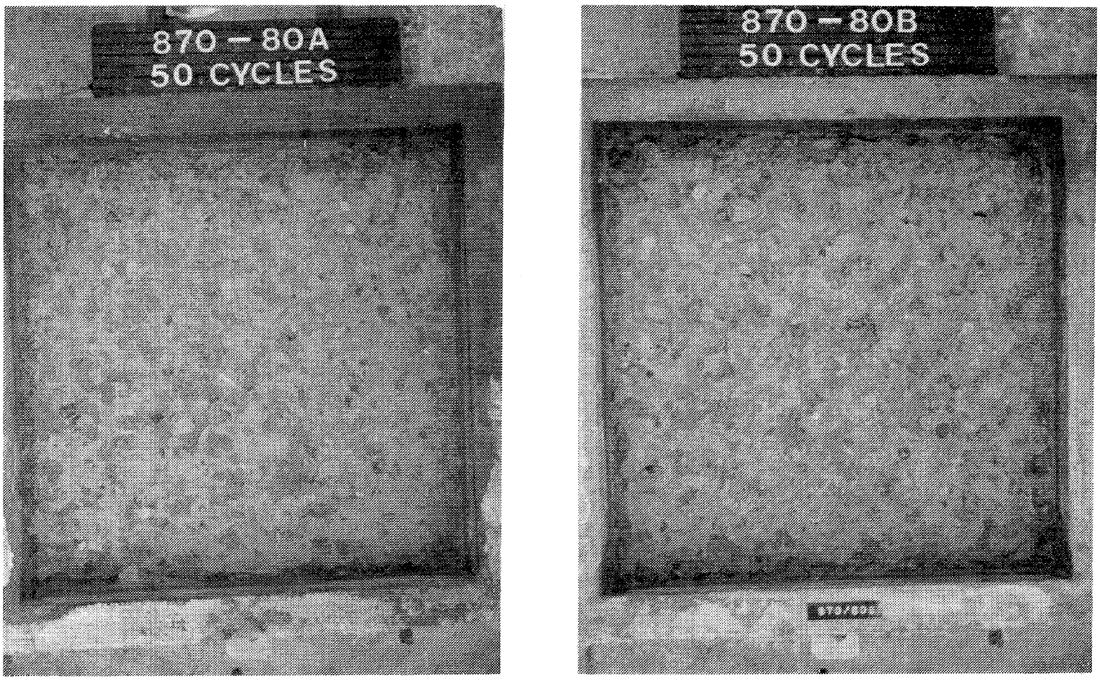
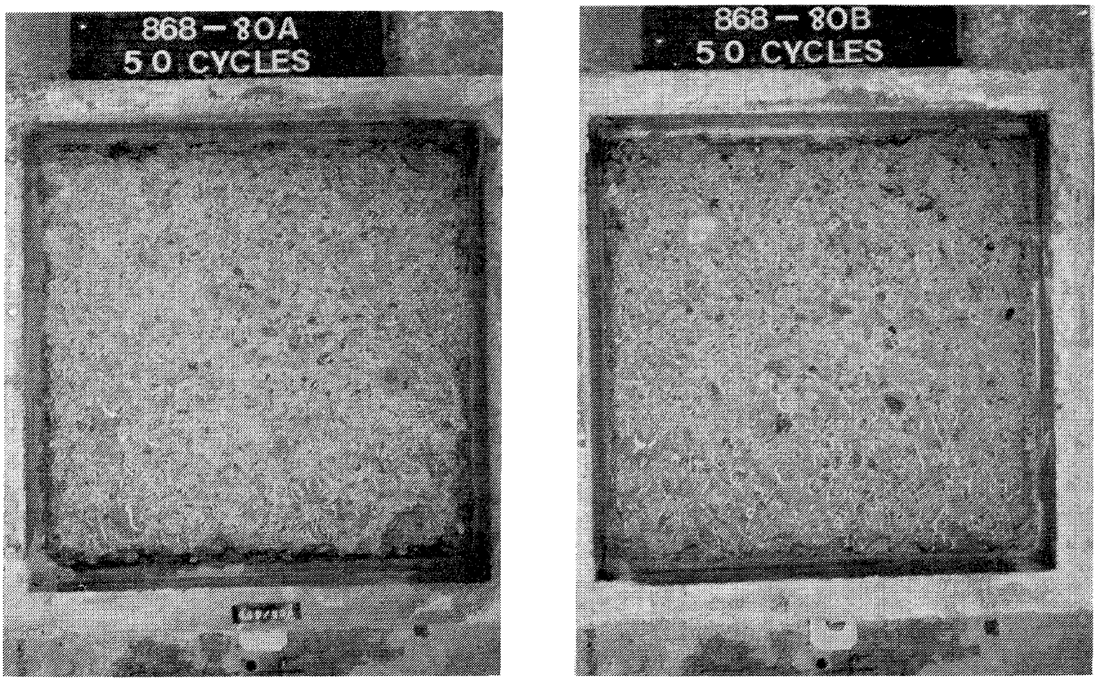


FIG. 17 - EFFECT OF CEMENT AND SLAG CONTENT ON SALT SCALING RESISTANCE (HURON AGGREGATE)

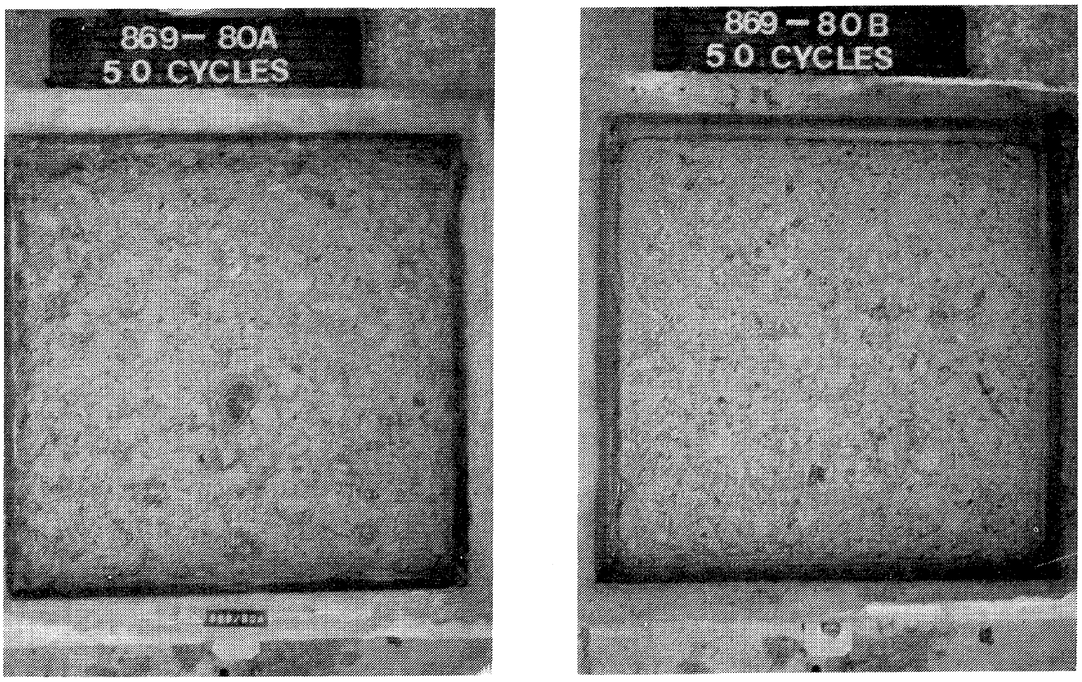


Cement Content 120 kg/m^3

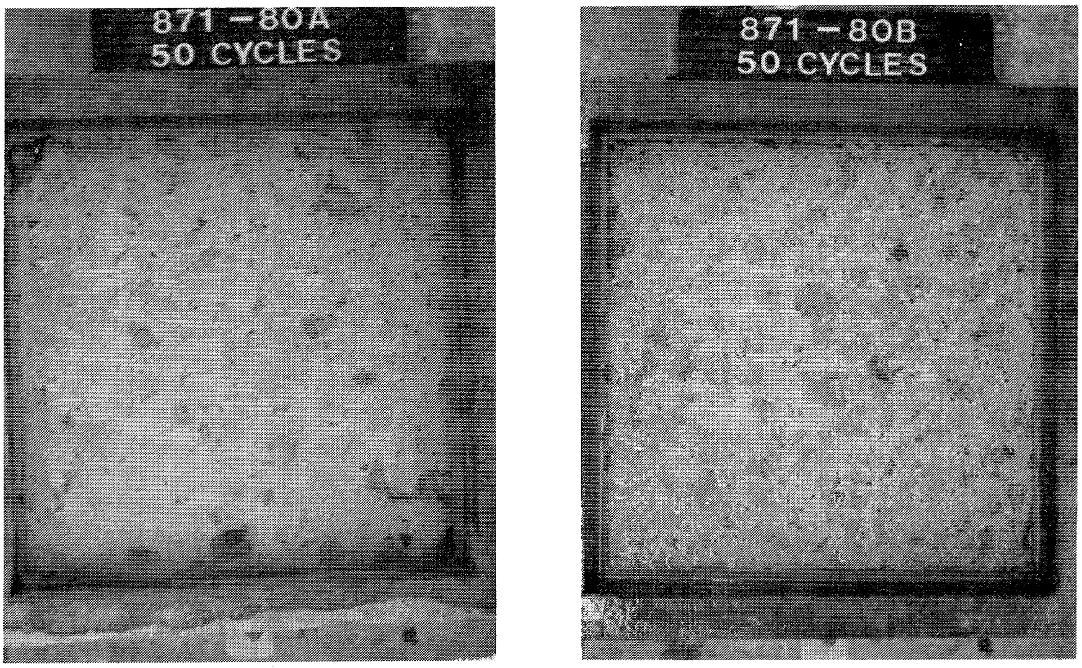


Cement Content 160 kg/m^3

Fig. 18. Appearance of Salt Scaling Slabs at Termination of the Exposure.
<u>HURON AGGREGATE</u>

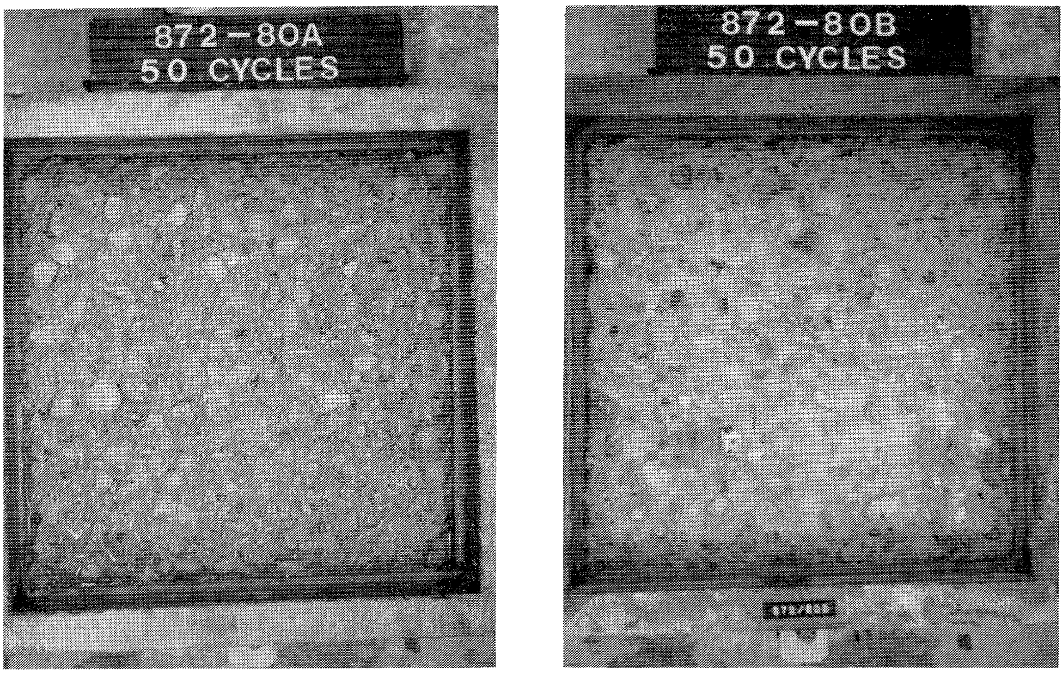


Cement Content 200 kg/m^3

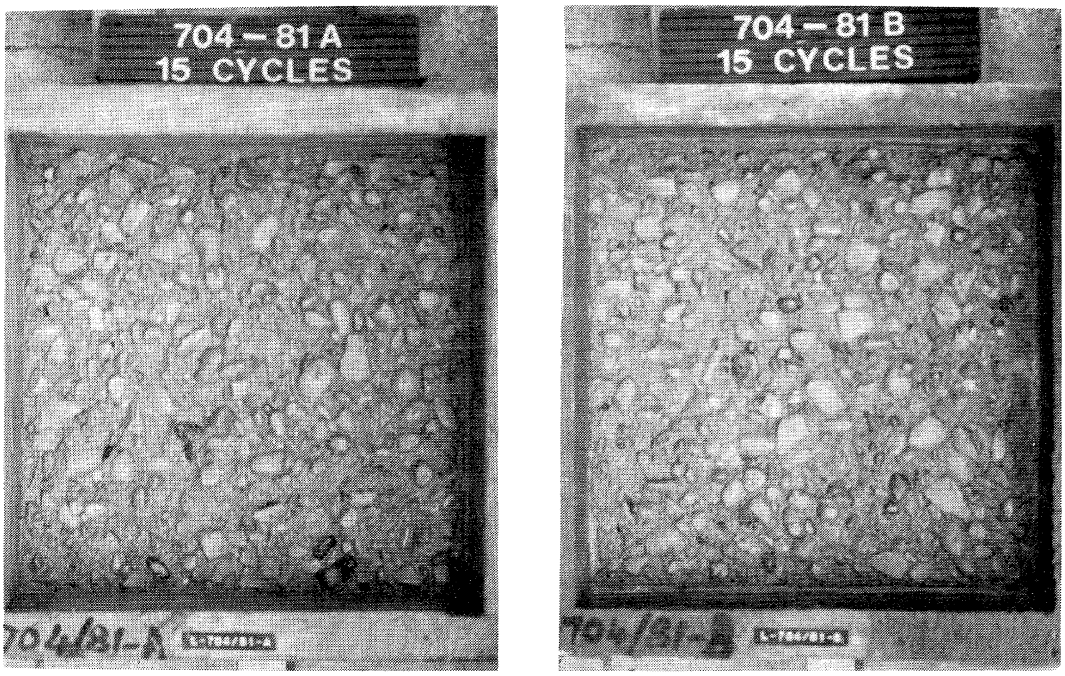


Cement Content 240 kg/m^3

Fig. 19. Appearance of Salt Scaling Slabs at Termination of the Exposure.
HURON AGGREGATE

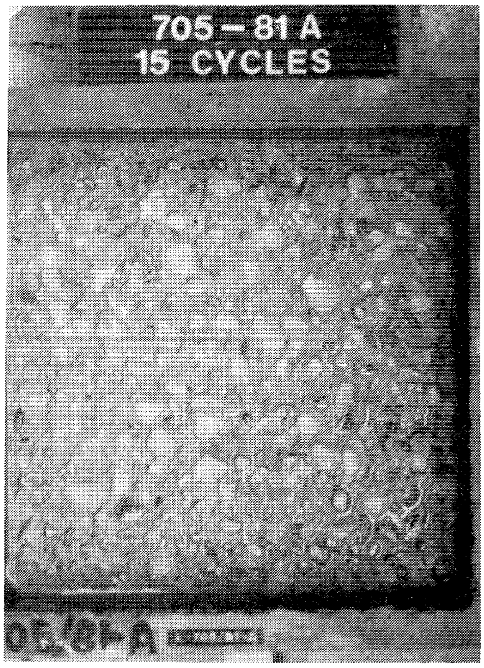


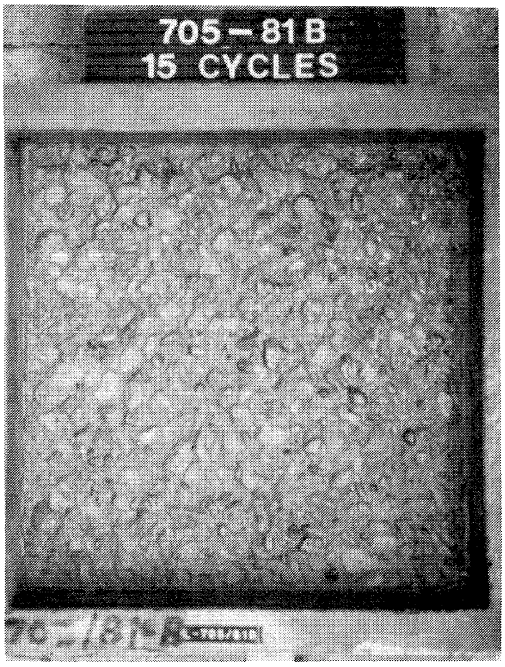
Cement + Slag Content 120+40 kg/m^3



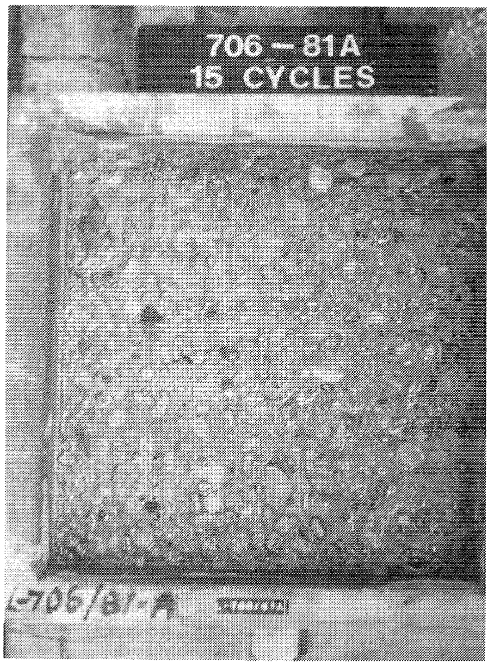
Cement + Slag Content 80+80 kg/m^3

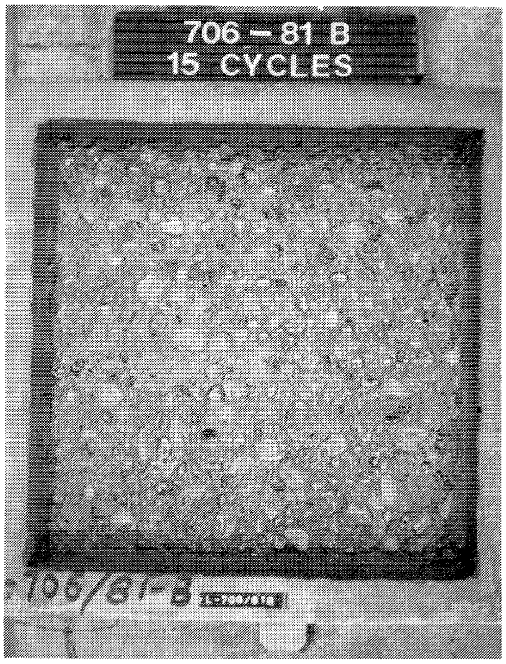
Fig. 20. Appearance of Salt Scaling Slabs at Termination of the Exposure.
HURON AGGREGATE





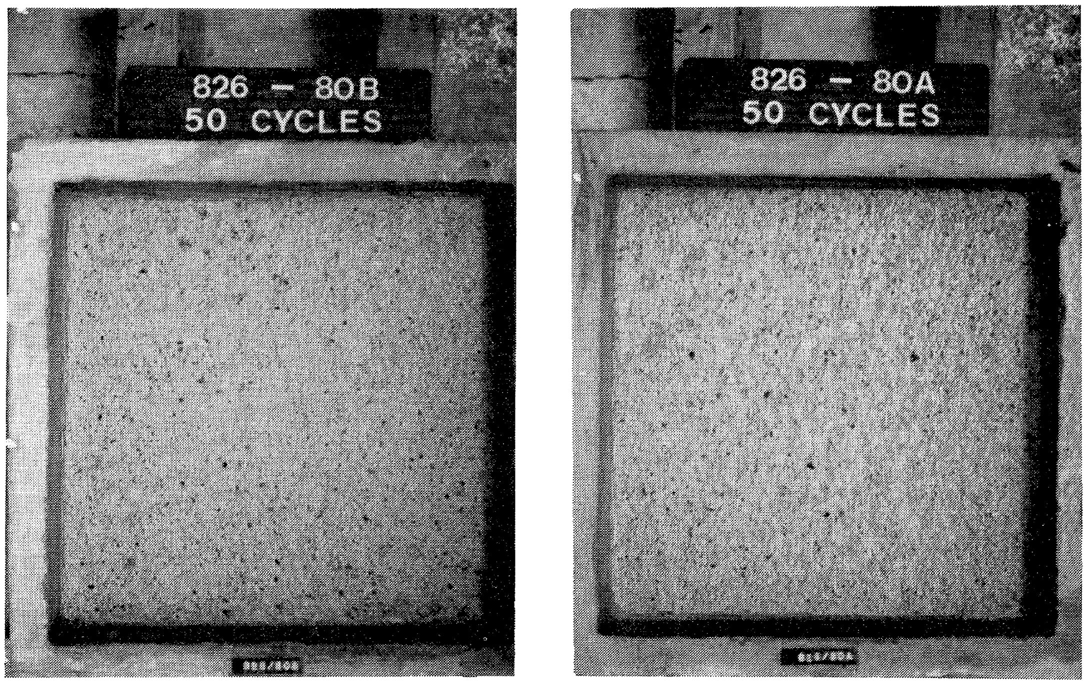
Cement + Slag Content 180+60 kg/m^3



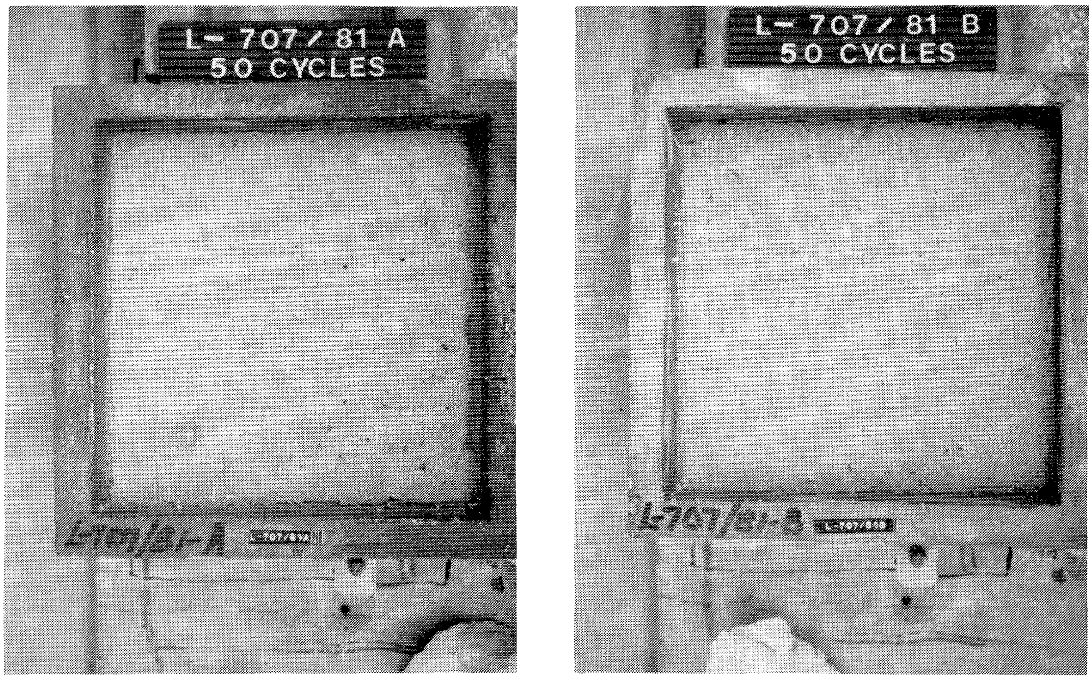


Cement + Slag Content 120+120 kg/m^3

Fig. 21. Appearance of Salt Scaling Slabs at Termination of the Exposure.
HURON AGGREGATE

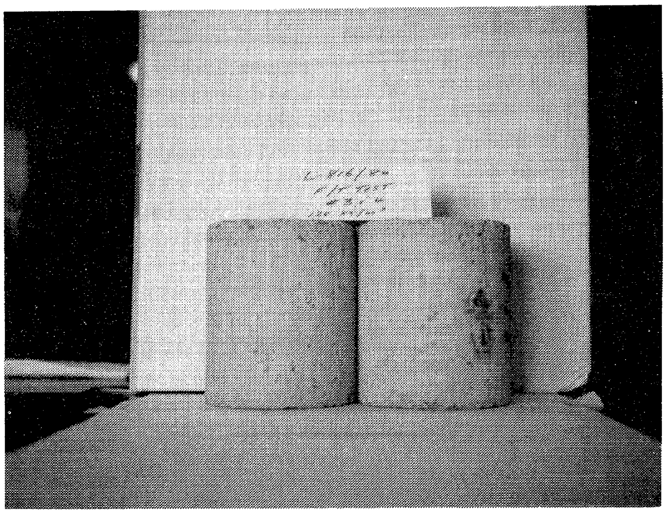


Marshall Aggregate Series

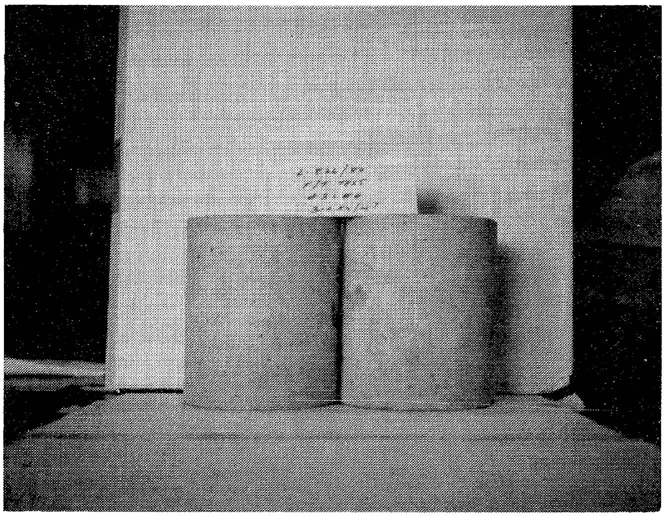


Huron Aggregate Series

Fig. 22. Appearance of Control Salt Scaling Test Slabs (Cement Content 310 kg/m^3) at Termination of the Exposure.

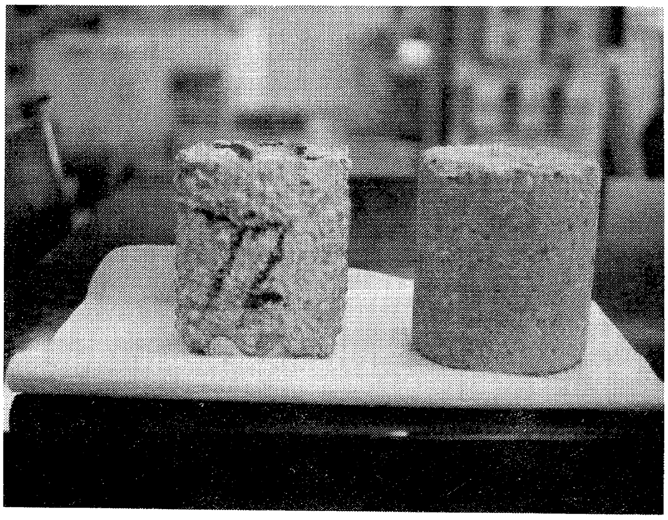


Cement Content
120 kg/m^3



310 kg/m^3

Lean concrete specimens



Soil-Cement specimens

Left- mass loss 13.1%
Cement Content 95kg/m^3

Right-mass loss 4.0%
Cement Content 118 kg/m^3

Fig. 23. Appearance of Freeze-Thaw Specimens after Completion of the Test (ASTM D560-57).