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MICHIGAN
STATE HIGHWAY DEPARTMENT
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WALLACE STONE INVESTIGATION

PART III

COOPERATIVE LABORATORY STUDY OF WALLACE LIMESTONE WITH THE NATIONAL CRUSHED STONE ASSOCIATION

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Progress Report

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COOPERATIVE LABORATORY STUDY OF WALLACE LIMESTONE
WITH THE NATIONAL CRUSHED STONE ASSOCIATION

This is part of a comprehensive authorized investigation to determine the suitability of Wallace crushed stone from Bay Port for highway construction purposes. The investigational program includes three specific studies which are –

1. An examination of Bridges UB-1 and UB-2 of 33-6-4 in Lansing to determine the cause of scaling on parts of the superstructure. This work was completed and reported on February 28, 1952, Research Laboratory Report No. 170.
2. A cooperative laboratory study with the National Crushed Stone Association to determine the physical and chemical properties of Wallace Stone in relation to durability under freeze-thaw action. This study is the subject of this report.
3. A field survey of existing highway pavements and bridges in which Wallace Stone from Bay Port has been used, in order to evaluate performance of concrete in service. This study has been completed and a final report is in preparation.

The main purpose of this investigation is to study the quality of Wallace limestone and, in portland cement concrete, to determine its effect, if any, on the durability of this concrete in freezing and thawing. Comparative results with the National Crushed Stone Association were obtained by the exchange of test beams and subsequent testing.

This report presents pertinent information concerning the materials under study, concrete mix design, laboratory testing procedures, geologic description of the materials, results of various tests on the aggregates, and in particular those from the comparative freeze-thaw tests.

Materials

All of the materials needed for making both regular and air-entrained concrete beams were furnished the NCSA Laboratory by the Michigan State Highway Research Laboratory. A crushed limestone coarse aggregate from Port Inland, Michigan was used as a control or comparison aggregate. The materials were:

Cement	Peerless, Type I, Detroit. Spec. grav. 3.14
Sand	Boichot, 2NS, Lansing
Coarse Aggregate	Wallace crushed limestone, 6A grading
Coarse Aggregate	Inland " " 6A grading
Air-entraining agent	Darex A.E. solution, Eddy Company, Lansing

Mix Design

The crushed limestone aggregates were used in a concrete mix designed according to the MSHD Mortar Voids method. The following design features were followed:

Cement content, sacks/cyd.	5.5
b/b_0 ratio	0.76
Relative water content (regular)	1.215
(A. E.)	1.15
Slump, inches	2 to 3
Air content, regular concrete, percent	1 to 2
Air content, A. E. concrete, percent	4 to 5
Total mixing time, $1\frac{1}{2}$ cu.ft. revolving drum mixer, minutes	5

The approximate batch quantities were computed to be:

Cement, pounds	18.8
Sand, dry, pounds	52.6
Coarse aggregate, dry, pounds	66.0
Total water, pounds	11.0
Volume, cu. ft.	0.982
Darex for A. E. concrete, ounces	0.10

Mix Procedure

The coarse aggregates were allowed to saturate under water for 24 hours and the sand stood with excess surface water for the same period. The mixer was moistened and the wet crushed stone and sand were weighed and placed in the drum. Cement and mix water were added and the entire batch was allowed to turn over for five minutes at about 21 rpm. The batch was dumped out into a damp tray and turned with a shovel a few times prior to measuring the slump. The air content was measured with an Acme meter and this observed percentage was corrected for air in the aggregate portion of the concrete. Six beams, each 3- by 3- by 15 in. were molded in two layers, rodding each layer 50 times with a 3/8-inch bullet nosed rod. The steel molds were lined with waterproof paper. The sides were spaded and the tops finished off with a wood float. Stainless steel studs 1/4 in. by 3/4 in. were molded in the ends of each beam to determine length change during freeze-thaw tests.

When the six beams from each of the four batches of concrete had cured 14 days in the fog room, two of them were packed in saturated sawdust and wrapped in wet burlap for shipment to the NCSA in Washington, D. C. A total of eight beams were sent in two separate shipments to the NCSA. The same number of beams were received from corresponding concrete mixes made at the NCSA laboratory.

The concrete mixer used was a Sears & Roebuck revolving drum type of 1½ cubic feet capacity. This mixer has three curved mixing blades spaced equally around the inner sides of the drum. The drum revolved at about 21 revolutions per minute.

Characteristics of the Fresh Concrete

The physical characteristics of the freshly mixed concrete for the two types of concrete and different aggregates are presented in Table I.

Curing

As soon as the beams were finished, they were placed in a fog room at 75°F. and protected against dripping water. The molds were stripped after 24 hours and the beams marked and placed back in the fog room for a total curing time of 26 days.

TABLE I. CHARACTERISTICS OF FRESH CONCRETE

Coarse Aggregate	Regular Concrete Inland	Regular Concrete Bay Port	Air-Entrained Concrete Inland	Air-Entrained Concrete Bay Port
Code Marking	IN	BP	INAE	BPAE
Cement, sacks/cyd.	5.49	5.51	5.47	5.40
Water-cement ratio	0.538	0.516	0.551	0.538
Slump, inches	3-1/4	2	5	2-3/4
Fine aggregate, dry wt., lb.	52.6	52.6	49.4	49.4
Coarse aggregate, dry wt., lb.	66.0	66.0	66.0	66.0
Cement, lb.	18.8	18.8	18.8	18.8
Total water, lb.	11.00	11.00	11.22	11.38
Batch volume, cu. ft.	.989	.989	1.01	1.01
Unit weight, lbs/cu.ft.	151.0	151.4	147.0	145.6
Air content, gross, percent	1.5	1.4	4.7	5.1
Air content, net, percent	0.9	0.8	4.1	4.5

Freeze and Thaw Testing Procedure

When the concrete beams had cured for 26 days in the fog room, they were placed in a water bath at 70°F. for 48 hours. After this initial saturation period the weight, length, fundamental frequency, and specific gravity of each beam were determined. The beams were placed on end in rectangular rubber containers, covered with water, and placed in an alcohol-water freezing bath maintained at -15°F. The beams were frozen overnight for 16 hours and thawed for 8 hours in a tank full of running tap water at 55°F. The freeze-thaw cycle changed only on week ends when the specimens were frozen for 64 hours instead of the usual 16. On days when sonic measurements were made, the beams to be tested were removed from their boots in the thawing tank after 5 hours and placed in water at 70-75°F. for 2 hours before measurements were taken. This was done to bring specimens to initial room temperature for testing.

TEST RESULTS

Geologic Description

Inland Limestone: This stone is a light buff-colored magnesian limestone deposited in the Silurian period. Inland limestone is found mostly in the Manistique Dolomite formation and is quite thickly bedded.

Bay Port Limestone: This stone is fairly thin bedded and the entire working face is only 12 to 14 feet thick. It belongs to the upper Mississippian period and contains both Bay Port and Michigan formations. The upper 30 inches or so beneath the overburden is a sandy limestone. Following this sandy limestone in order are: about 3-1/2 feet of fairly dense gray limestone; 6 inches of marine shale containing numerous crinoid fossils; 3 more feet of dense gray limestone; a thin layer of chert nodules; about 4 feet of dark gray magnesian limestone; about 1 foot of dense, dark, buff-colored dolomite containing some chalcopyrite; and finally, a thin floor of carbonaceous shale. A visual examination of produced stone indicates:

Soft, absorbent, sandy limestone	4.6	percent
Fossilized marine shale	1.6	"
Dense, gray limestone	81.7	"
Dense, dark buff, magnesian limestone	12.1	"

The examination indicates that 6.2 percent of the Bay Port material should be classed as deleterious.

Chemical Analysis of Stone

A chemical analysis was made of each type of stone, the results of which are shown in Table II.

TABLE II.—CHEMICAL ANALYSIS OF STONE

Determination	Percent Inland	Percent Bay Port
Loss on ignition	43.20	35.89
SiO_2	0.83	15.54
R_2O_3	0.75	1.44
$CaCO_3$	88.28	75.83
$MgCO_3$	10.14	7.19
Residue in 6N. HCl.	1.67	18.02

Specification Tests on Aggregates

The results of normal specification tests on the fine and coarse aggregates are presented in Table III. The test results show a marked difference in absorption characteristics of the two coarse aggregate materials.

Soundness Tests

Both materials were subjected to the standard magnesium sulfate soundness test and, in addition, to 25 cycles of freezing and thawing in water. The results of these tests are presented in Table IV.

TABLE IV. RESULTS OF SOUNDNESS TESTS

Sieve Fraction	Weight, grams	INLAND Percent Loss	INLAND Corrected Percent	BAY PORT Percent Loss	BAY PORT Corrected Percent
Magnesium Sulfate (5 cycles)					
3/4 - 1-1/2 in.	3,000	0.067	0.03	5.64	2.49
3/8 - 3/4 in.	2,000	1.10	0.52	17.2	7.61
No. 4 - 3/8 in.	600	1.33	0.21	22.5	2.55
Total % loss on original gradation			0.76		12.65
Freezing and Thawing in Water (25 cycles)					
3/4 - 1 in.	500	10.64	1.46	20.00	3.02
1/2 - 3/4 in.	667	25.00	4.91	13.94	2.91
No. 4 - 1/2 in.	633	4.74	2.04	6.16	2.14
Total % loss on original gradation			8.41		8.07

TABLE III.

SPECIFICATION TEST RESULTS ON AGGREGATES

Test Results on Fine Aggregate

Sieve Analysis:

Sieve Size	Total Percent Passing
3/8 in.	100
No. 4	100
No. 8	91
No. 16	70
No. 30	50
No. 50	17
No. 100	2.0

Loss by washing, percent	0.2
Fineness modulus	2.70
Organic plate No.	I
1:3 mortar strength ratio, 7 day	1.15
Bulk Spec. Gravity (S.S.D.)	2.68
Bulk Spec. Gravity (dry)	2.66
Absorption, percent	0.81

Test Results on Coarse Aggregates

Sieve Analysis:

Sieve Size	Total Percent Passing Inland	Total Percent Passing Bay Port
1-1/2 in.	100.	100.
1 in.	76.9	70.85
3/4 in.	63.2	55.75
1/2 in.	43.55	34.85
3/8 in.	16.15	11.5
No. 4	.5	.15

	Inland	Bay Port
Weight per cu. ft., loose, dry	88.8	85.1
Bulk Spec. Grav. saturated, surface dry	2.67	2.65
Bulk specific gravity, dry	2.65	2.615
Absorption, percent, (av. of 2 tests)	0.69	1.31
Apparent specific gravity	2.71	2.715
Absorption, percent, 5 hr. boiling	0.650	1.322
Absorption, percent, (ASTM C 127)	0.597	1.273
Ratio of 24-hr. absorp. to 5 hr. boiling	0.92	0.96

A good portion of the breakdown in the sulfate soundness test was due to the laminated structure of the marine shale portion of the Bay Port stone.

The most notable fact from the soundness tests is that the magnesium sulfate soundness test shows a marked difference in loss between the two aggregates - the Bay Port material having a loss of around 12 percent which checks with previous experience. In the freeze-thaw tests, both aggregates performed about the same.

Freezing and Thawing Tests

The results from the freeze-thaw tests are summarized in Table V and presented graphically in Figures 1, 2 and 3. At the beginning of the program, two air-entrained mixes were made using 1 ounce of Darex per sack of cement, resulting in air contents of about 9 percent. Although the air content of these mixtures was not within the range specified for the tests, the results obtained from these beams are included in Table V as a matter of general interest.

Regular Concrete: Of the regular concrete, beams molded in the Research Laboratory failed more rapidly than the corresponding beams made at the NCSA Laboratory. There was no significant difference in the durability of the two limestones when tested in regular concrete. The lower durability of the beams of both aggregates cast in the Research Laboratory may possibly be due to the fact that these mixtures contained about 1 percent less air than those made by the NCSA. Figures 4 and 5 show the appearance of beams containing the two aggregates at the end of the test. The Wallace Stone beams in Figure 5 show the characteristic dark particles of shaley material usually present in small quantities in this stone but which apparently do not appreciably affect the overall durability of the concrete.

TABLE V

SUMMARY OF FREEZE AND THAW TEST DATA

The following table represents a complete compilation of freeze and thaw test beam data on all beams made by the Highway Research Laboratory, and eight (8) beams received from the National Crushed Stone Association.

Beam Identification & Number	Fresh Concrete			Cycles Freeze & Thaw	Reduction in Modulus, percent	Length Change, percent	Weight Change, percent
	Percent Air (net)	W/C (by wt.)	Slump, inches				
NCSA Beams							
Regular Concrete							
IN – a & d	2.1	.538	3	42	50		– 1.84
BP – a & d	2.1	.550	3	38	50		– 1.67
Air-entrained Concrete							
IN-2- a & d	5.5	.486	2	200	25.7		– 6.37
BPA-2-a & d	4.9	.490	2	200	25.7		– 10.54
MSHD Beams							
Regular Concrete							
IN – 1,2,3,4	0.9	0.535	3-1/4	9	50	+ .077	– 0.15
BP – 1,2,3,4	0.8	0.515	2	6	50	+ .099	+ 0.09
Air-entrained Concrete							
INAE- 1,2,3	9.0	0.504	3	200	3.3	+ .028	– .29
BPAE- 1,2,3	8.6	0.483	3	200	10.1	+ .030	– .89
INAE- 7,8,9	4.1	0.548	5	200	1.7	+ .023	– 1.12
BPAE- 7,8,9	4.5	0.538	2-3/4	200	5.6	+ .014	– .98

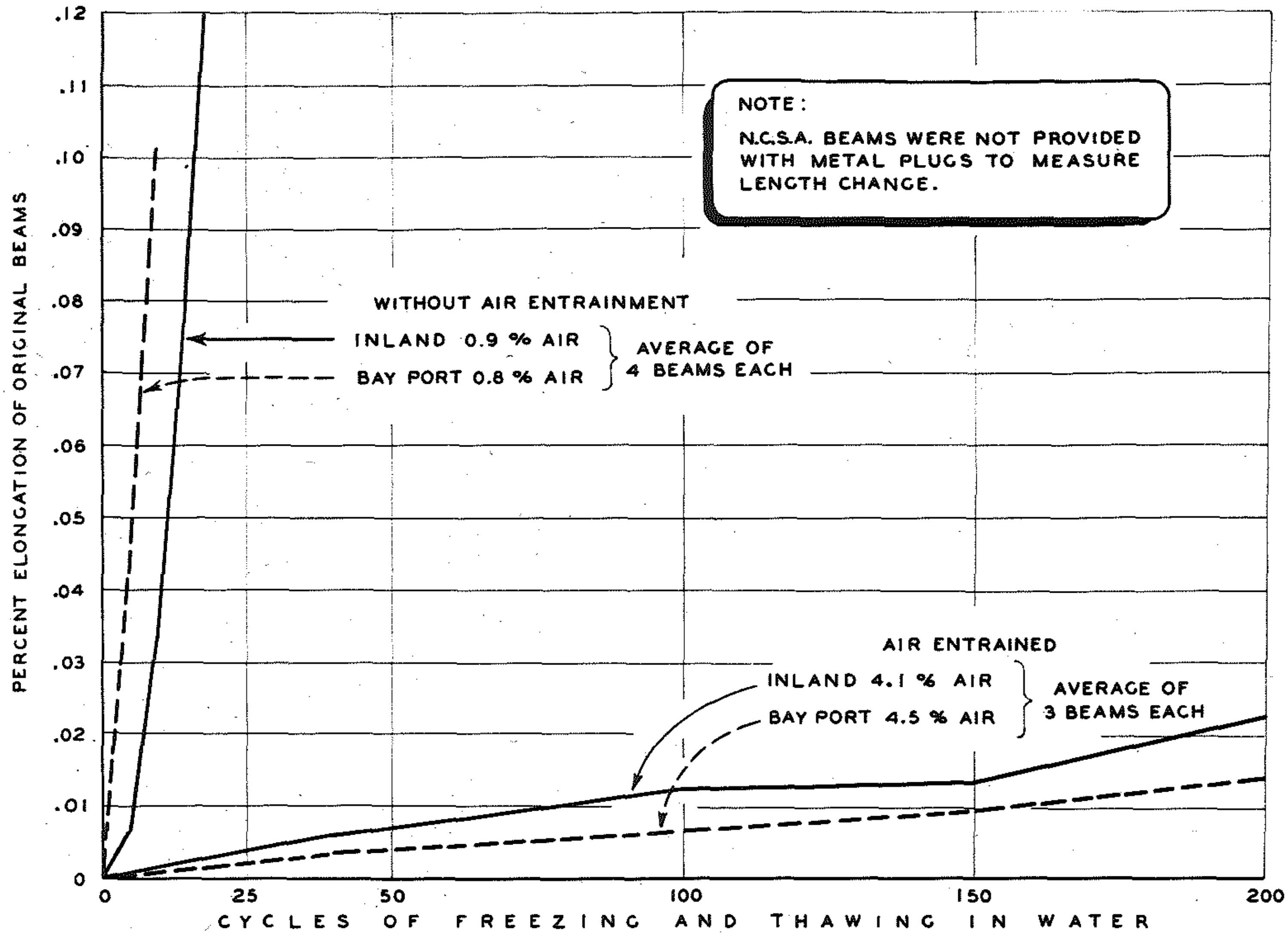
Air-Entrained Concrete: As in the case of regular concrete, there was little difference in the resistance of the two limestones to freezing and thawing when tested in air-entrained concrete. Unlike the regular concrete, however, the air-entrained concrete beams molded in the Research Laboratory showed considerably greater durability in the accelerated test than the corresponding NCSA beams. The Bay Port stone gave very slightly poorer performance in the beams molded here, but at 200 cycles there was no difference at all in the performance of the two sets of beams sent here from the NCSA. Photographs of the beams in this series are shown in Figures 6, 7, 8 and 9.

It is evident from these tests that differences in making and curing concrete specimens, even when the same materials are used throughout, have a profound effect on the results obtained in the accelerated durability test. In both the regular and air-entrained concrete, there were wide differences in the results obtained on beams of the same materials molded in the two laboratories.

Both the NCSA and MSHD air-entrained beams showed an increase in modulus in the first stages of the test, probably due to continued hydration and hardening of the cement during the thawing phase of the cycle, which more than compensated for any loss in strength from freezing and thawing. This is a fairly common phenomenon, and has occurred quite frequently in other previous tests of this kind.

Concluding Remarks

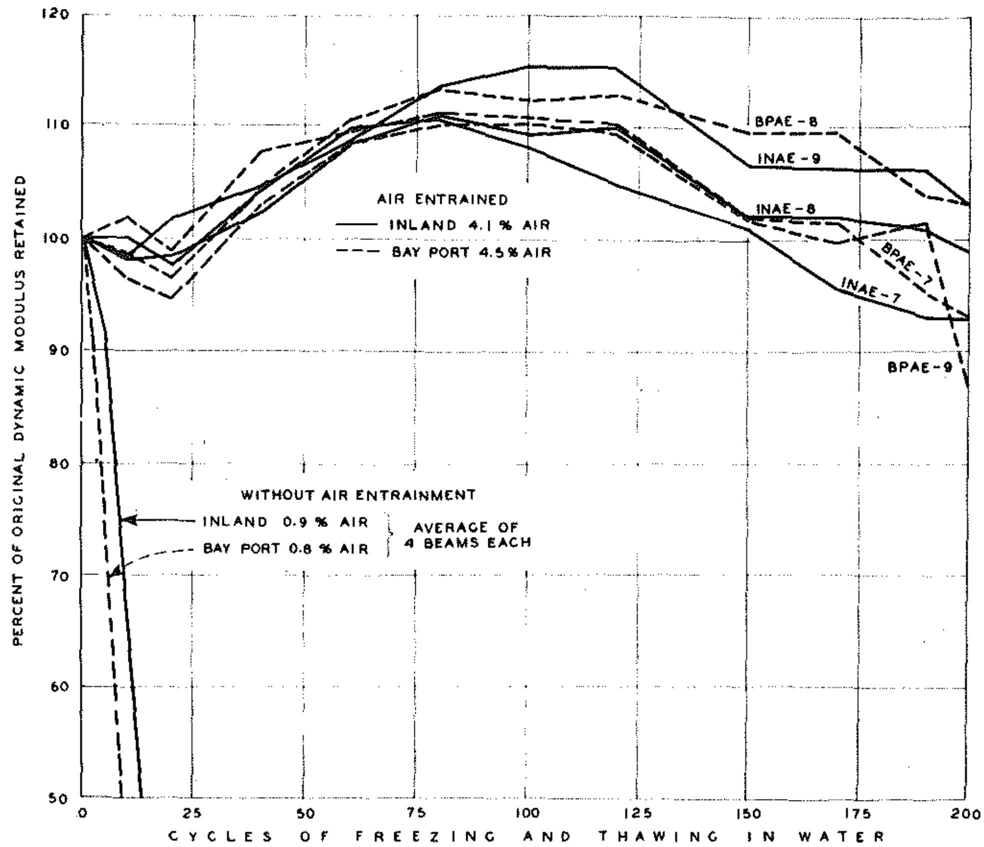
For all practical purposes there was no significant difference indicated in these tests in resistance to freezing and thawing of concrete containing the two aggregates. In air-entrained concrete particularly, both limestones were about equally durable. The Bay Port stone does, however, exibit some popouts or disintegration of coarse aggregate particles arising from the presence of small amounts of deleterious constituents, such as marine shale and absorbent sandstone, in this stone.



PERCENT ELONGATION BY FREEZING AND THAWING

TEST BEAMS CAST BY M.S.H.D.

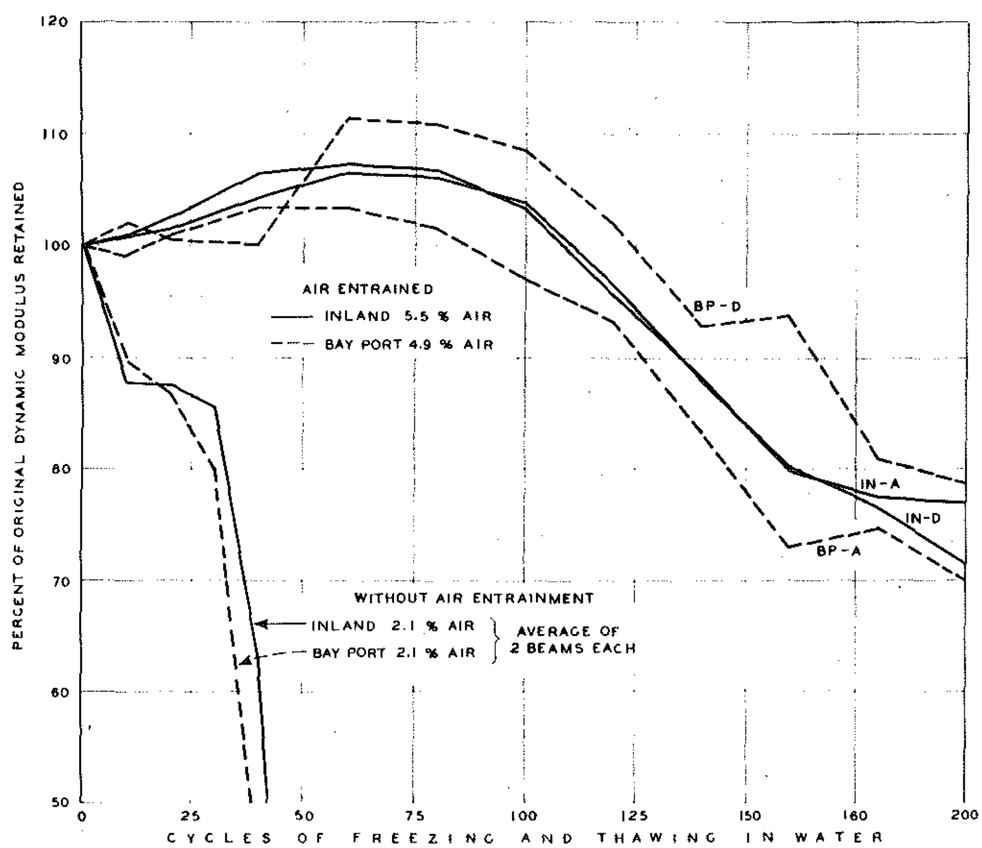
FIGURE 1



PERCENT CHANGE IN DYNAMIC MODULUS BY CYCLES OF FREEZING AND THAWING

TEST BEAMS CAST BY M.S.H.D.

FIGURE 2



PERCENT CHANGE IN DYNAMIC MODULUS BY CYCLES OF FREEZING AND THAWING

TEST BEAMS CAST BY N.C.S.A.

FIGURE 3

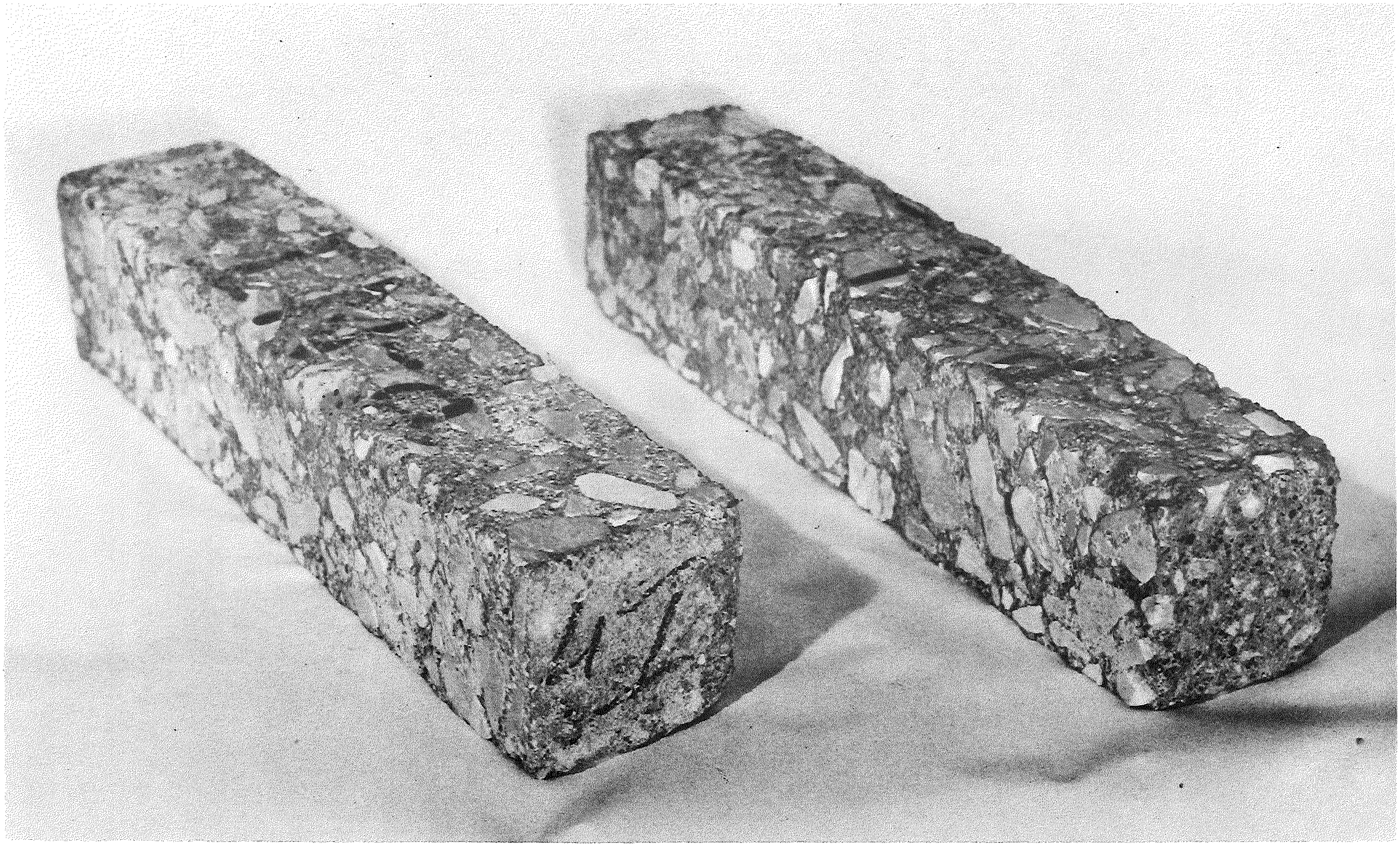


FIGURE 4. N.C.S.A. REGULAR CONCRETE BEAMS MADE WITH INLAND STONE AFTER 42 CYCLES OF FREEZE AND THAW IN WATER AND 50 % REDUCTION IN MODULUS. THE TWO CUT FACES OF EACH BEAM ARE TOWARD CAMERA.

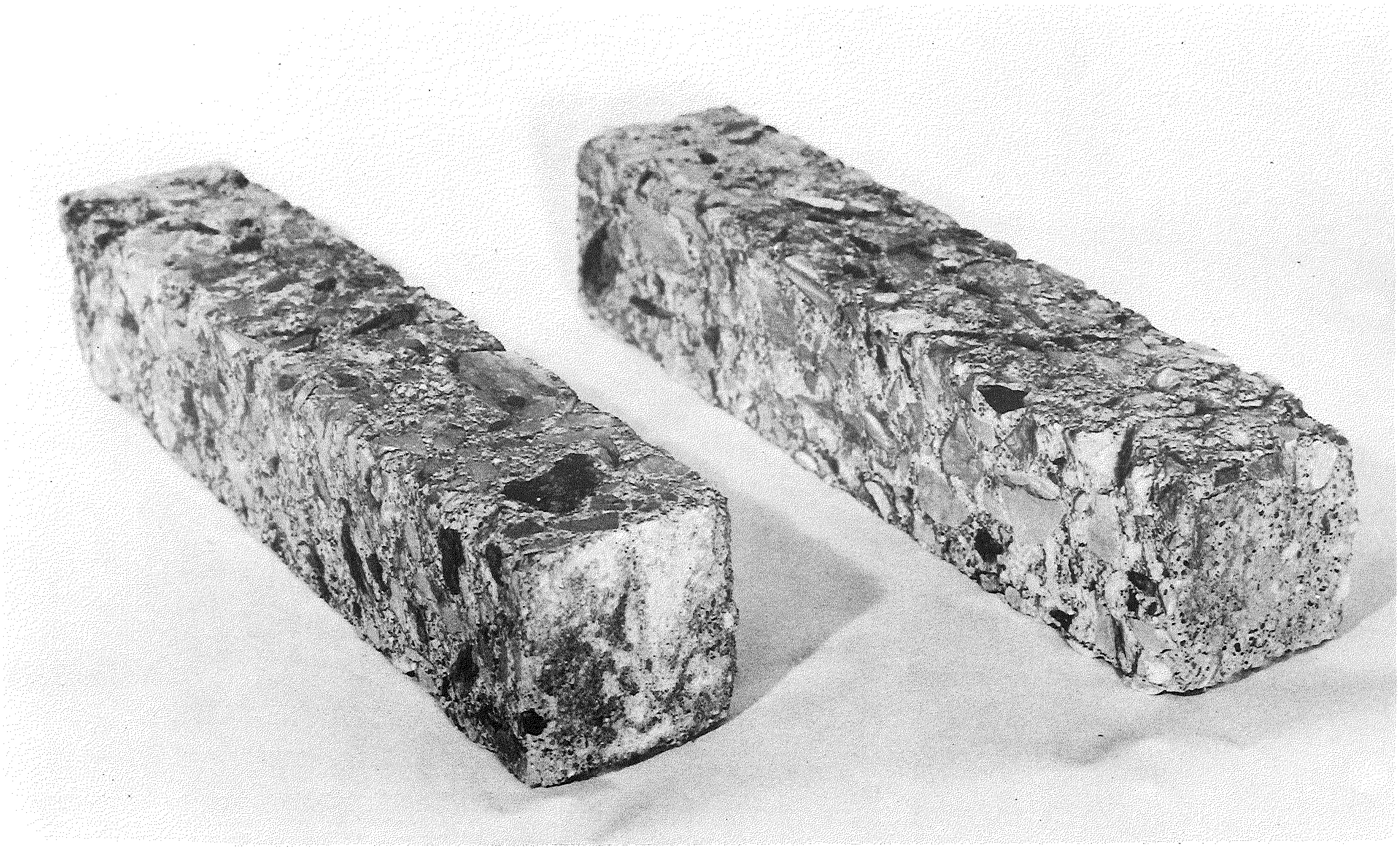


FIGURE 5. N.C.S.A. REGULAR CONCRETE BEAMS MADE WITH BAY PORT STONE AFTER 38 CYCLES OF FREEZE AND THAW IN WATER AND 50 % REDUCTION IN MODULUS. TWO CUT FACES ARE EXPOSED.

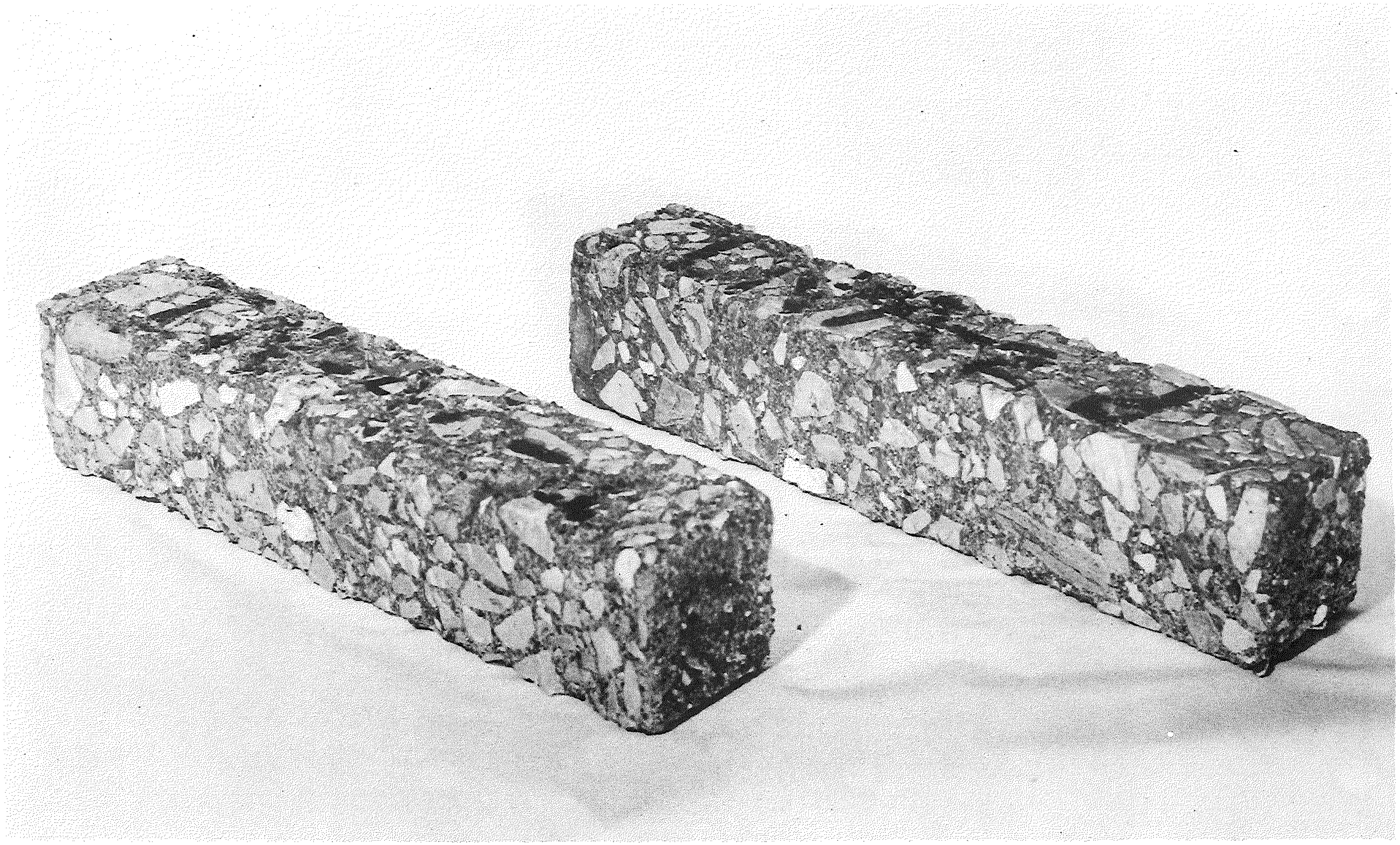


FIGURE 6. N.C.S.A. AIR-ENTRAINED BEAMS MADE WITH INLAND STONE AFTER 200 CYCLES OF FREEZE AND THAW IN WATER AND 26 % REDUCTION IN MODULUS. WEIGHT LOSS = 6.4 %. THE TWO CUT FACES ARE IN VIEW.

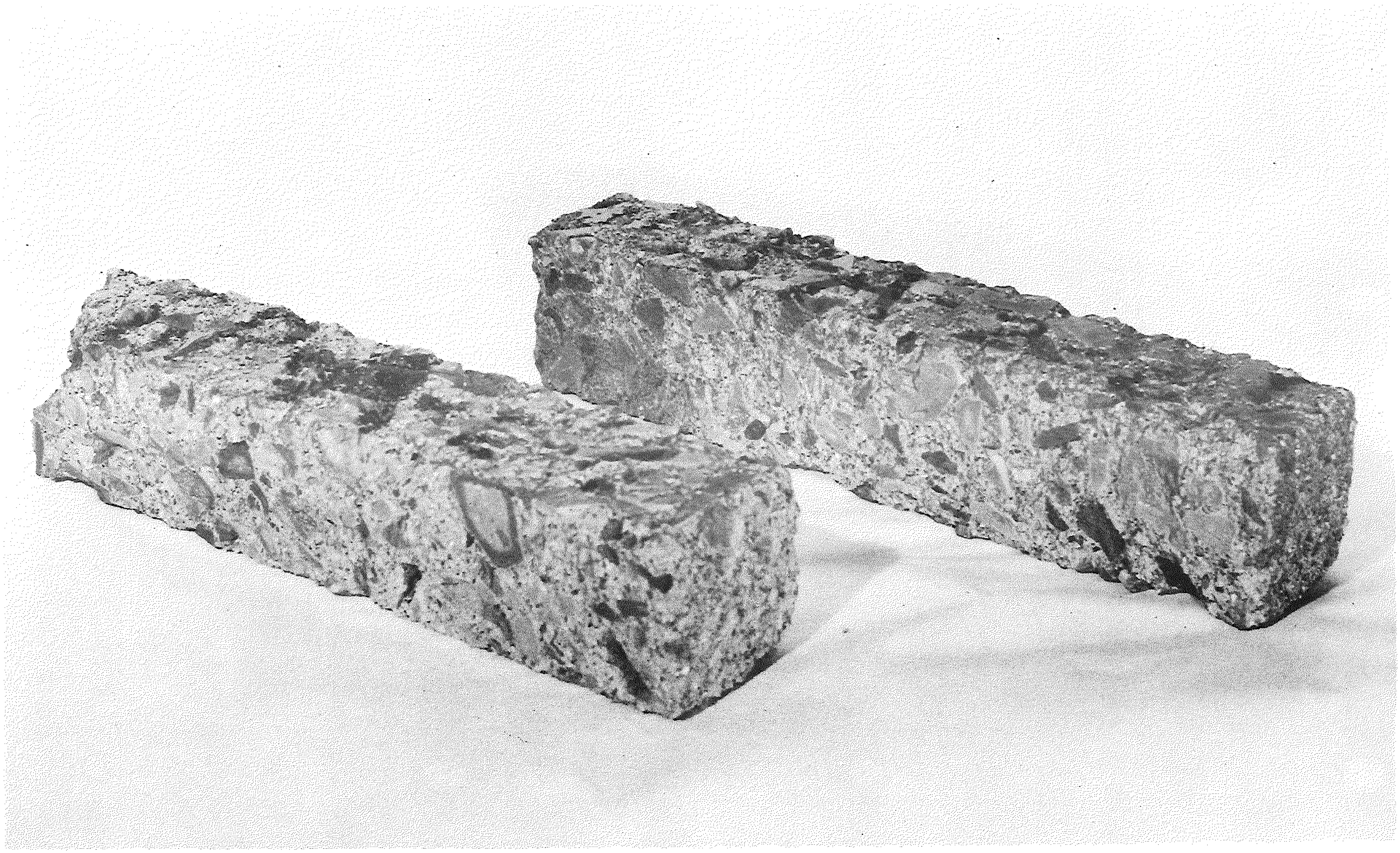


FIGURE 7. N.C.S.A. AIR ENTRAINED BEAMS MADE WITH BAY PORT STONE AFTER 200 CYCLES OF FREEZE AND THAW IN WATER AND 26 % REDUCTION IN MODULUS. WEIGHT LOSS = 10.5 % THE TWO CUT FACES ARE SHOWING.

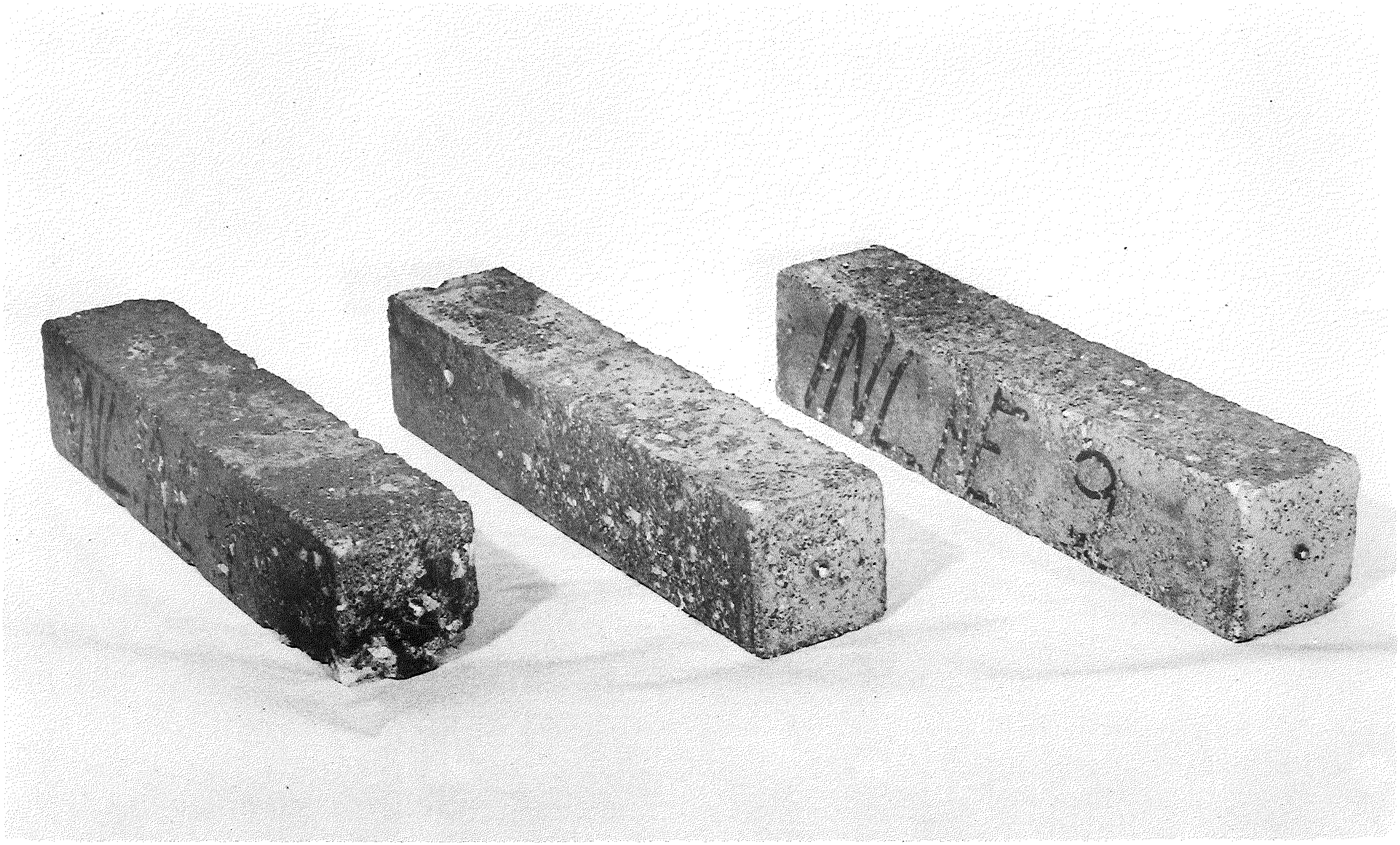


FIGURE 8. M.S.H.D. BEAMS MADE WITH INLAND STONE AFTER 200 CYCLES OF FREEZE AND THAW IN WATER AND 1.7% REDUCTION IN MODULUS. AIR CONTENT = 4.1 %

FIGURE 9. M.S.H.D. BEAMS MADE WITH BAY PORT STONE AFTER 200 CYCLES OF FREEZE AND THAW IN WATER AND 5.6% REDUCTION IN MODULUS. AIR CONTENT = 4.5 %