NATIONAL BUREAU OF STANDARDS REPORT

5624

INSULATING CONCRETES
Interim Report No. 1

by

T. W. Reichard and D. Watstein

To
the Departments of
the Air Force, the Army, and the Navy

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Abstract

A description is given of a series of tests with insulating type concretes designed to develop data to determine, (1) the effect of capping procedure on compressive strength, (2) the effect of size and shape of compressive specimens on compressive strength and (3) the relationship between compressive strength and wet density for perlite aggregate concretes which might be used in specifying minimum strengths in terms of the densities of perlite concretes.

The results indicate that the method of capping insulating concrete specimens has little effect on the compressive strength. The size and shape of specimens of insulating concrete are shown to have considerable effect of the compressive strength for specimens cured in the manner described. It was found that 6-in. cubes and 6- by 12-in. standard cylinders had nearly identical strengths. Smaller cylinders and cubes had strengths ranging from about 50 to 70 percent of the strengths obtained with the standard cylinders.

It is shown that the compressive strength of perlite concretes can be predicted with reasonable accuracy from the wet density of the concrete provided the mix is relatively free of segregation. However, it was found that the strength-wet density relationship was significantly different for the "coated" variety of perlite aggregate tested (Permarock), than for the two "regular" perlites included in the program (Coralux and Panacalite).

In the absence of an acceptable test for extent of segregation, it was proposed that badly segregating perlite mixes be eliminated by specifying a minimum "yield" of 80 percent. A table in this report lists the proposed maximum densities corresponding to a yield of 80 percent for perlite concretes of given proportions.

1. INTRODUCTION

During the past year, the National Bureau of Standards has been engaged in a study of insulating concretes initiated as a Tri-Service Project.[1] This report presents the data developed in three phases of the study.

Phase I was a study of the effect of four capping methods on the compressive strength of cylinders and cubes of insulating concretes.

Phase II was a study of the effect of specimen size and shape on compressive strength of insulating concretes.

In Phase III the compressive strength-wet density relationships were determined for concretes made with three brands of perlite concrete aggregates.

Each of these three phases is discussed separately in the following pages.

2. COMPARISON OF FOUR CAPPING PROCEDURES

(Phase I)

2.1 Scope

The purpose of this phase of the investigation was to determine the effect of the capping method on the apparent compressive strength of insulating concrete.

Two types of control specimens were used: 6- by 12-in. cylinders and 6-in. cubes. The specimens were prepared for

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[1] Tri-Service Projects are sponsored jointly by Departments of Army, Navy and Air Force.

compressive test either by being capped with one of three capping materials or by having ends ground to a flat surface.

The capping materials were a sulphur-silica mixture ("Vitrobond"), a high strength gypsum plaster ("Hydrocal") and a 1/2 in. vegetable fiberboard ("Celotex"). Since the sulphur mixture capping method is accepted [1], [2], and [3] 2/ as one of the most reliable for regular concretes, the strengths of the sulphur mixture capped specimens were used as a standard for comparing the other three.

2.2 Preparation of specimens

2.2.1 Concrete proportions

Table 1 gives the proportions of cement and water used for each batch. The proportions of cement to aggregate was 1:6 by volume for all concretes containing an aggregate. The volume of aggregate was determined in the dry-loose condition.

The cellular concrete was made using the preformed foam method. The amount of foam used varied considerably from batch to batch because of the poor quality of the foam, which was probably due to the age of the foaming agent.

2.2.2 Concrete mixing

The concrete was mixed in a 3 cu ft capacity paddle type mortar mixer which was operated at 60 rpm. The mixing schedule when mixing the perlite or vermiculite concrete was as follows:

1/2 min for mixing cement, water, and air-entraining agent,

2 min mixing with aggregate.

When making the cellular concrete the schedule was the same, with the preformed foam replacing the aggregate and the entraining agent not being used.

The concrete was mixed according to the above schedule except in a few batches when extra mixing was needed to bring the concrete to a pourable consistency (about 8-in. slump).

2/ Numbers in brackets denote references listed at the end of this Report.

Table 1. Mixes Used in Evaluating Effect of Capping Procedure on Compressive Strength.
(Cement to aggregate = 1:6, by volume)

Batch No.	Type of cement	Cement content per cu yd of concrete	Water per bag cement	Aggregate	Air entraining agent per bag of aggregate		Wet density	Oven-dry density	Compressive strength of 6- by 12-in. cylinders 5/
		bags	lb		lb		pcf	pcf	psi
P-III-1	III	5.35	135	Cora.	---	1/	54.9	33.5	423
2	III	5.42	135	"	---	1/	55.6	34.2	465
3	III	5.38	135	"	---	1/	55.3	33.8	463
4	III	3.38	135	Pana.	0.5	2/	34.3	19.6	106
5	III	3.46	143	"	0.2	2/	36.2	20.5	112
6	III	3.76	143	"	0.2	2/	39.4	22.3	155
7	III	3.75	138	"	0.2	2/	39.2	22.0	156
8	III	3.73	138	"	0.2	2/	39.0	22.1	162
V-III-1	III	3.65	173	Verm.	0.13	3/	42.5	23.0	106
2	III	4.04	167	"	0.11	3/	47.0	24.0	138
3	III	4.00	165	"	0.11	3/	46.6	23.8	124
C-III-1	III	6.91	52	None	---	4/	37.3	27.8	164
2	III	8.31	53	"	---	4/	45.8	34.9	300
3	III	6.90	53	"	---	4/	37.5	28.2	198
4	III	5.87	53	"	---	4/	32.2	24.0	123
5	III	7.06	53	"	---	4/	39.3	26.8	157
6	III	6.71	53	"	---	4/	36.5	27.3	184
7	III	7.14	53	"	---	4/	38.8	28.4	146

Table 1 continued.

Table 1. (Continued)

Batch No.	Type of cement	Cement content per cu yd of concrete	Water per bag cement	Aggregate	Air entraining agent per bag of aggregate	Wet density	Oven-dry density	Compressive strength of 6- by 12-in. cylinders 5/
		bags	lb		lb	pcf	pcf	psi
P-I-1	I	3.19	166	Pana.	1.0 2/	37.0	20.4	80
2	I	3.66	158	"	1.0 2/	40.3	22.9	91
3	I	3.75	128	"	1.0 2/	37.0	22.2	92
4	I	3.85	127	"	1.0 2/	38.0	22.5	100
5	I	3.60	122	"	1.0 2/	35.0	21.2	93
6	I	3.46	135	"	1.0 2/	35.3	21.0	83
7	I	3.56	135	"	1.0 2/	36.3	21.7	87
V-I-1	I	4.08	156	Verm.	0.13 3/	44.3	22.5	94
2	I	4.22	162	"	0.13 3/	46.8	24.3	90
3	I	3.31	179	"	0.13 3/	38.6	20.1	63
C-I-1	I	7.63	53	None	-- 4/	41.8	30.9	140
2	I	8.21	53	"	-- 4/	44.5	32.8	212
3	I	8.48	53	"	-- 4/	46.1	34.0	278

1/ Entraining agent added at plant.

2/ 13 percent Protex.

3/ Neutralized vinsol resin dissolved in mixing water.

4/ Preformed foam used. No aggregate.

5/ Average of all four capping procedures.

2.2.3 Materials

2.2.3.1 Aggregates

Two brands of perlite concrete aggregate were used. One of these is expanded in Washington, D. C., and is sold under the brand name of "Panacalite". The other is sold under the brand name of "Coralux" and is expanded in Metuchen, New Jersey. An air entraining agent is incorporated in the New Jersey perlite at the plant. Both perlites are sold in 4 cu ft bags with a nominal net weight of 30 lb, although the actual net weight was about 32 lb.

The vermiculite used was expanded in Washington, D. C., and is sold under the brand name "Zonolite" in 4 cu ft bags with a nominal net weight of 24 lb. The actual net weight of the vermiculite used was about 31 lb per bag. Although Zonolite is normally sold as a stabilized aggregate, i.e. one containing an air entraining agent added to the aggregate at the plant, the unstabilized aggregate was used in this investigation.

2.2.3.2 Cement

The Type I cement was Lehigh portland cement manufactured in Allentown, Pennsylvania. The Type III cement was North American High Early Strength portland cement manufactured in Hagerstown, Maryland.

2.2.3.3 Air entraining agents

The air entraining agent used with the Washington perlite was a 13 percent solution neutralized vinsol resin.

The air entraining agent used with the vermiculite was a dry neutralized vinsol resin powder which was dissolved in the mixing water.

The preformed foam used was made using a proprietary foaming agent manufactured from hydrolyzed waste proteins.

2.2.4 Molding and curing of specimens

Both the 6- by 12-in. cylinder and 6-in. cube specimens were formed in machined steel molds. The concrete was consolidated by shaking the molds by hand.

The molds were filled to overflowing with the excess being cut off just prior to stripping at 24 hr. Four cylindrical specimens and four cubes were prepared from each batch.

After stripping at 24 hr, all specimens were cured on a rack in laboratory air until tested.

2.3 Capping of specimens

For each capping method one 6- by 12-in. cylinder and one 6-in. cube from each batch were used. Prior to capping, any serious departures from planeness were corrected by grinding.

2.3.1 Plaster capping

Specimens were capped with the gypsum plaster capping compound immediately following removal from the molds. The wet plaster was placed on a wet newspaper placed on a level oiled glass plate. The specimen was immediately placed on the plaster and leveled, one surface being capped at a time. After plaster capping the specimens, they were placed with the other specimens of the same batch to cure.

2.3.2 Sulphur mixture capping

The specimens with sulphur-silica caps were capped on the day when they were due to be tested. The specimens were capped with the hot sulphur-silica mixture in an apparatus especially developed for the purpose.

2.3.3 Ground surface

Just prior to testing, the bearing surfaces of the specimens intended to be tested without capping were ground on a flat concrete plate to smooth parallel surfaces. It was found that the flat surface of a lightweight aggregate concrete masonry unit served this purpose well.

2.3.4 Celotex capping

These specimens were tested with a 7- by 7-in. square piece of the 1/2-in. thick Celotex board placed between the specimen and the top and bottom bearing blocks of the testing machine.

2.4 Testing procedure

All specimens made from concrete containing Type III cement were tested when 7 days old. All specimens made from concrete containing Type I cement were tested when 28 days old.

All specimens were tested for compressive strength in a 60,000 lb capacity hydraulic testing machine. The specimens were loaded through a spherically seated head at a rate of not more than one-half the estimated maximum load per minute.

The cubes were placed in the testing machine so that direction of loading coincided with the vertical direction of the cube as cast.

The specimens were loaded until a fracture was apparent. A crushing type failure localized near one end of a cylinder (usually the bottom as cast) shown in figure 1 was considered an incomplete failure while a shear or splitting type fracture (figure 2) was considered to be a complete failure. The load was applied to the incompletely failed specimens for a considerable period after the initial crushing. This procedure was necessary because the maximum load supported by the specimen was not necessarily the load at initial crushing. Figure 3 illustrates the behavior of a specimen exhibiting an incomplete failure.

3. EFFECT OF SIZE AND SHAPE OF SPECIMENS ON THE COMPRESSIVE STRENGTH

(Phase III)

3.1 Scope

The purpose of this phase of the investigation was to develop data necessary to indicate the effect of the size and shape of the test specimen on the compressive strength of insulating concretes. Although the 6- by 12-in. cylinder has become the standard compressive test specimen for insulating concretes, the use of a smaller specimen would be advantageous. Much work with regular concretes has been reported /4/, /5/, /6/, and /7/ on the effect of size and shape of the specimen, but very little has been done with the low strength insulating type concretes. There has been some indication /7/ and /8/ that the shape factors used for regular concretes do not hold for low strength concrete.

For this phase of the investigation six types of specimens were cast from each batch of concrete. Some of the specimens from each batch were tested at early age while the balance were tested at full-cure age, i.e., 7 days for Type III cement or 28 days for Type I cement.

The strengths of individual specimens were rated relative to the full-cure strength of the standard 6- by 12-in. cylinders.

3.2 Preparation of the Specimens

3.2.1 Concrete Proportions and Mixing

Table 2 gives the proportions of cement aggregate and water used in each batch. A 13 percent solution of vinsol resin was used as the air entraining agent except for batch P-III-2 where preformed foam was used.

The concrete was mixed in the paddle type mortar mixer which was operated at 60 rpm. The cement, water, and entraining agent were mixed for 30 seconds before adding the aggregate. The concrete was then mixed for 2 more minutes. When the preformed foam was used, the cement and water were mixed 15 seconds before adding the foam. This mixture was then mixed for 15 seconds before the aggregate was added and mixed for 2 minutes.

No attempt was made to mix to a predetermined wet density.

3.2.2 Materials

The aggregate used was the perlite concrete aggregate expanded in Washington, D. C. All other materials used are described under Phase I of this report.

3.2.3 Molding the specimens

From each batch of concrete the following specimens were prepared:

Six - 2-in. cubes
Six - 2- by 4-in. cylinders
Six - 3- by 3-in. cylinders
Six - 3- by 6-in. cylinders
Three - 6-in. cubes
Three - 6- by 12-in. cylinders

Table 2. Mixes Used in Evaluating Effect of Size and Shape of Specimens on Compressive Strength. 1/

Batch	Type of cement	Cement content per cu yd of concrete	Water per bag cement	Ratio of cement to perlite by volume	Damp curing	Wet density	Oven-dry density	Compressive strength of 6- by 12-in. cylinders (fully cured) 2/
		bags	lb		days	pcf	pcf	psi
P-I-6-1	I	3.77	122	1:6	2	36.4	21.5	108
P-I-5-1	I	4.52	100	1:5	2	38.8	24.6	150
P-I-6-2	I	4.09	138	1:6	2	42.0	24.2	142
P-I-5-2	I	5.14	105	1:5	2	45.0	29.0	274
P-III-6	III	4.26	140	1:6	1	44.0	24.8	200
P-III-5	III	5.00	110	1:5	1	44.7	27.5	278
P-III-2	III	5.19	62	1:2.5	1	35.5	24.6	127

1/ Only perlite concretes were used in this phase of work.

2/ Ends of cylinders were ground to plane surfaces.

All specimens but the 3- by 3-in. and 3- by 6-in. cylinders were formed in machined metal molds. The 3- by 3-in. and 3- by 6-in. cylinders were formed in waxed cardboard molds. These molds are sold as one quart ice cream containers. The actual diameter of these cylinders was 3.37 in., while the test height differed slightly from the nominal height. The 3- by 3-in. cylinders were cut from 3- by 6-in. cylinders.

The metal molds were filled to overflowing with the excess being cut off just prior to stripping.

The specimens made in the cardboard molds were cut to size after removal from the molds.

3.2.4 Curing

The specimens made from Type I cement were left in the molds for 2 days. The specimens made from Type III cement were left in the mold for 1 day.

After removal from the molds all specimens were left in the laboratory air until tested.

3.2.5 Test procedure

Table 3 shows the test schedule followed.

All specimens were tested only for compressive strength. They were tested in a 60,000 lb capacity hydraulic testing machine at a rate of not more than half the expected maximum load per minute.

The bearing surfaces of all specimens were ground smooth and parallel to opposite faces. The cubes were loaded so that the direction of loading coincided with the vertical direction of the cube as cast. No capping material was used.

4. COMPARATIVE TESTS OF "PERMAROCK", "PANACALITE" AND "CORALUX" PERLITE CONCRETES

(Phase III)

4.1 Scope

The purpose of this phase of the investigation was to determine the relationship between the wet density and strength for concretes made using three brands of perlite aggregate. Inasmuch as a definite relationship between wet density and

Table 3. Schedule of Test Specimens Used in Evaluating Effect of Size and Shape of Specimens. [1]

Specimen size	Type I cement test age	Type III cement test age
	days	days
2-in. cube	7	3
2-in. cube	28	7
2- by 4-in. cylinder	7	3
2- by 4-in. cylinder	28	7
3- by 3-in. cylinder	7	3
3- by 3-in. cylinder	28	7
3- by 6-in. cylinder	7	3
3- by 6-in. cylinder	28	7
6-in. cube	28	7
6- by 12-in. cylinder	28	7

[1] Three specimens of each size were tested at each age and with each type of cement.

compressive strength could only be determined for mixes reasonably free from segregation, an attempt was also made to devise a test procedure which might be suitable as a measure of the degree of segregation of insulating concretes. The wet density of these concretes suggested itself as suitable index for field control of segregation.

The three perlites used in this study were a so-called "coated" perlite ("Permarock"), and two "regular" perlites ("Coralux" and "Panacalite"). The recommended mixes for the coated perlite called for considerably larger amounts of water than the regular perlite mixes. The producer also asserted that the use of entrained air was unnecessary in preventing segregation when using the coated perlite. The mixes of coated perlite were prepared exactly as recommended by the producer of the coated perlite to evaluate his rather "different" mix design criteria.

The recommended mixes for the regular perlites were not strictly adhered to. More water and less entraining agent was used in many batches of the regular perlite concrete in order to simulate possible field conditions. However, there was sufficient air entrained to prevent segregation in all batches of the regular perlite concretes.

For the purpose of this paper, all batches mixed with an air entraining agent are called air entrained perlite concretes.

4.2 Preparation of specimens

4.2.1 Concrete mixes

Table 4 shows the recommended mix proportions for the Permarock concretes. The recommended water content was sufficient to yield a pourable mix for most batches.

Table 4. Recommended Proportions of Permarock Concretes

Permarock mix designation	1 cu yd batch			Batch with 1 bag of cement	
	Water	Cement	Permarock	Water	Permarock
	gal	bags	bags	lb	bags
LD-4	78	4	8	162	2.0
LD-5	80	5	8	133	1.6
LD-6	81	6	8	112	1.3

Table 5 shows the Perlite Institute's recommended mix proportions for regular perlites. A few batches were made using the Permarock aggregate using Perlite Institute's recommended mix proportions.

Table 5. Perlite Institute's Recommended Mix Proportions

Mix	1 cu yd batch				Batch with 1 bag of cement	
	Water	Cement	Perlite	Air entraining agent	Water	Perlite
	gal	bags	bags	pints	lb	bags
1:6	54	3.85	6.75	6.75	100	1.50
1:5	59.5	5.40	6.75	6.75	92	1.25
1:4	61	6.75	6.75	6.75	75	1.00

The actual mix proportions used are shown in Tables 6 and 7. The batch size was about 2 cu ft and the perlite was proportioned in fractions of a bag.

Table 6. Permarock Concretes (Average of six or more 6- by 12-in. cylinders)

Producers mix designation	NBS batch No.	Cement content per cu yd concrete	Water content per sack of cement	Type cement	Speed of mixing	Total No. of revolutions	Segregation	Yield	Densities			Cure 1/	Compressive strength	Sonic "E" (test condition)	Strength oven-dry density ratio
									Wet	Test	Oven-dry				
		sacks	lb		rpm			%	pcf	pcf	pcf		psi	10^6 psi	
LD-4	R-A	4.1	162	I	30	270	Mild	82	48.5	34.4	30.5	A	211		6.92
LD-4	R-B	4.2	162	I	30	180	Mild	79	50.2	34.9	31.0	A	218		7.03
LD-4	R-C	4.0	162	I	30	270	Mild	90	46.2	33.0	29.7	A	156		5.59
LD-4 2/	H-A	3.6	162	III	30	165	Very mild	93	42.5	33.2	27.1	B	117	.118	4.32
LD-4 2/	H-B	4.7	162	III	30	225	Excessive	70	56.0	43.0	33.9	B	175	.175	5.16
LD-4 2/	H-C	4.6	162	III	30	240	Excessive	72	55.0	42.8	33.9	B	187	.175	5.52
LD-4	AH-A	3.8	162	III	30	150	Very mild	90	44.5	33.9	26.1	B	130	.118	4.98
LD-4	AH-B	3.6	177	III	30	120	Mild	95	44.6	34.4	26.9	B	120	.121	4.46
LD-4	AH-C	3.3	162	III	30	120	Very mild	103	38.7	26.1	21.4	B	73	.077	3.26
LD-4	SMB4-A	3.5	162	III	12	120	Very mild	97	40.9	35.0	26.6	B	108	.122	4.07
LD-4	SMB4-B	4.1	162	III	12	174	Mild	83	47.7	39.8	30.2	B	156	.153	5.17
LD-4	SMB4-C	4.8	162	III	12	204	Excessive	71	56.3	42.9	32.6	B	233	.195	7.15
LD-5	R-A	4.8	133	I	30	90	Very mild	94	48.5	35.8	30.6	A	186		6.08
LD-5	R-B	4.7	133	I	30	60	Mild	96	47.7	34.5	29.9	A	155		5.13
LD-5	R-C	5.7	133	I	30	142	Excessive	80	58.5	40.1	34.1	A	326		9.56
LD-5	H-A	4.5	133	III	30	120	Mild	93	46.8	36.8	29.4	B	171	.148	5.82
LD-5	H-B	4.5	133	III	30	120	Mild	93	46.8	40.4	31.2	B	158	.153	5.06
LD-5	H-C	4.4	133	III	30	120	Very mild	95	45.9	36.1	28.5	B	209	.157	7.34
LD-5	SMB5-A	5.4	133	III	12	132	Excessive	79	55.1	45.3	32.6	B	257		7.88
LD-5	SMB5-B	5.0	155	III	12	300	Very mild	84	56.7	48.4	36.6	B	325		8.89
LD-5	SMB5-C	5.3	133	III	12	144	Mild	80	53.9	43.9	32.8	B	234		7.14
LD-6	H-A	5.2	112	III	30	75	Very mild	97	47.9	38.9	31.2	B	297	.209	9.52
LD-6	H-B	5.9	112	III	30	60	Mild	85	54.5	46.5	36.5	B	381	.268	10.44
LD-6	H-C	5.7	112	III	30	90	Very mild	89	52.7	43.4	34.3	B	387	.244	11.28
LD-6	H-D	6.0	112	III	30	120	Mild	84	55.3	47.8	37.6	B	416	.293	11.06
LD-6	SMB6-A	6.4	112	III	12	132	Mild	80	58.1	49.0	36.9	B	361		9.78
LD-6	SMB6-B	6.1	112	III	12	120	Very mild	83	56.0	47.5	35.4	B	368		10.39
LD-6	SMB6-C	6.2	112	III	12	126	Very mild	82	56.7	48.8	36.7	B	376		10.25

1/ Cure A for Type I cement - 1 day in mold, 3 days damp cured, 24 days in lab. air.
Cure B for Type III cement- 1 day in mold, 1 day damp cured, 5 days in lab. air.
Cure C for Type III cement -1 day in mold, 6 days in lab. air. (Specimens subjected to Cure C were those tested and previously described under Phase I).

2/ Anti-Foam agent added.

Table 7. Air Entrained Perlite Concretes

Cement to perlite by volume	NBS batch No.	Cement content per cu yd concrete	Water content per bag cement	Type Cement	Brand of perlite	Speed of mixing	Total No. of revolutions mixed	Yield	Air[2/] entraining agent per bag perlite	Densities			No. of 6- by 12-in. cylinders in batch	Cure [1/]	Compressive strength	Sonic "E" (Test condition)	Strength oven-dry density ratio
										Wet	Test	Oven-dry					
		bags	lb			rpm		%	lb	pcf	pcf	pcf			psi	10^6 psi	
1:6	6WA	4.11	120	I	Wash.	40	120	110	.11 a	40.0	27.5	25.4	7	A	179	.129	7.05
	6WB	4.22	120	I	Wash.	40	120	107	.11 a	41.0	28.0	25.8	7	A	199	.137	7.72
	6WC	4.18	120	I	Wash.	40	120	108	.11 a	40.7	27.8	25.7	7	A	191	.136	7.43
	6BAA	4.14	100	III	Permarock	40	80	109	1.0 b	37.0	31.6	25.2	6	B	150	.131	5.95
	6WSA	4.07	120	I	Wash.	40	80	111	.11 a	39.5	28.6	25.9	8	A	179		6.59
	6WSB	4.32	120	I	Wash.	40	200	104	.11 a	42.1	29.6	26.6	8	A	214		8.05
	6WSC	4.80	120	I	Wash.	40	300	94	.11 a	46.7	32.7	28.9	8	A	303		10.48
	TPH1	5.35	135	III	N.J.	60	120	84	c	53.8	42.6	33.0	4	C	423		12.82
	TPH2	5.42	135	III	N.J.	60	120	83	c	55.6	43.8	33.9	4	C	465		13.73
	TPH3	5.38	135	III	N.J.	60	120	83	c	55.3	43.5	33.6	4	C	463		13.78
	TPH6	3.76	143	III	Wash.	60	120	120	.24 a	39.4	26.8	22.5	4	C	155		6.90
	TPH7	3.75	143	III	Wash.	60	120	120	.24 a	39.2	27.1	22.5	4	C	156		6.93
	TPH8	3.73	138	III	Wash.	60	120	121	.24 a	39.0	27.1	22.9	4	C	162		7.07
1:5	5WA	4.75	112	I	Wash.	40	120	114	.11 a	43.3	30.4	27.8	7	A	247	.151	8.88
	5WB	4.96	112	I	Wash.	40	120	109	.11 a	45.2	32.4	29.2	7	A	276	.165	9.45
	5WC	5.10	112	I	Wash.	40	120	106	.11 a	46.5	34.2	30.5	7	A	300	.174	9.84
	5BAA	4.73	92	III	Permarock	40	80	114	1.0 b	39.4	33.4	27.1	6	B	172	.153	6.35
	C5A	5.13	94	III	N.J.	40	80	105	c	43.3	35.2	29.6	4	B	259		8.75
	C5B	5.11	94	III	N.J.	40	80	106	c	43.3	35.4	29.4	6	B	258		8.78
	SL3	4.96	104	III	Wash.	40	120	109	.33 b	43.8	33.3	28.2	2	B	236		8.37
	SL4	4.75	93	III	Wash.	40	80	114	.75 b	39.9	35.1	26.2	3	B	232		8.85
	SL6	5.59	94	III	N.J.	40	80	97	c	48.4	43.7	32.6	3	B	418	.262	12.83
	SL7	4.75	93	III	Wash.	40	80	114	.75 b	39.9	35.0	26.9	3	B	258	.180	9.59
	SL8	5.11	94	III	N.J.	40	80	106	c	43.5	39.1	29.9	3	B	293	.202	9.80
1:4	4WA	6.05	90	I	Wash.	40	80	111	.12 a	48.5	36.6	32.4	7	A	337	.175	10.40
	4WB	5.92	90	I	Wash.	40	80	114	.12 a	47.4	34.7	31.5	7	A	336	.199	10.66
	4WC	6.25	90	I	Wash.	40	80	108	.12 a	49.9	36.5	32.9	7	A	383	.216	11.64
	4BAA	5.87	75	III	Permarock	40	100	115	1.0 b	43.4	38.9	31.3	6	B	266	.206	8.50

[1/] See footnote 1, Table 6.

[2/] a = 13% Protex; b = 10 1/2% NVX; c = entraining agent added at plant.

4.2.2 Concrete mixing

The air entrained perlite concretes were mixed in a 3 cu ft paddle type mortar mixer normally operating at a speed of 40 rpm. Several batches, however, were mixed at a speed of 60 rpm. The normal mixing times were:

1/4 min, cement and water only
1/4 min, with air entraining agent
2 min, with perlite

Since no attempt was made to mix to a predetermined wet density, most of the batches were molded when pourable. In a few batches the mixing time was varied deliberately to determine the effect of prolonged mixing.

The Permarock concretes were mixed in a 3 cu ft tilt drum concrete mixer normally operated at a speed of 30 rpm. In some batches the speed was reduced to 12 rpm at the suggestion of the producer of the aggregate. Table 8 gives a comparison of the peripheral velocity of the 3 cu ft tilt drum mixer with the velocity of a typical transit type mixer.

Table 8. Comparative Peripheral Velocities in NBS and Transit Type Mixers

Mixer	Type	Capacity	Diameter of drum	Mixing rate	Peripheral velocity 1/
			in.	rpm	ft/min
NBS	Tilt drum	3 cu ft	26	30	204
NBS	Tilt drum	3 cu ft	26	12	82
Transit	(Typical)	5 cu yd	80	10	210

1/ N.R.M.C.A. recommended maximum for transit mixers is 225 ft/min for mixing

The cement and all the water were mixed 1/2 min before the Permarock was added. Then the concrete was mixed until pourable. This consistency corresponded to about 6 in. to 9 in. slump with the 12 in. cone. The mixing time varied considerably and additional water was added to two batches to bring the concrete to a pourable consistency.

4.2.3 Aggregates

Two brands of "regular" perlite aggregates were used in making the air entrained concretes. The perlite expanded in Washington, D. C., is sold under the brand name of "Panacalite" concrete aggregate. The other is sold under the brand name of "Coralux" and was expanded in Metuchen, New Jersey. An air entraining agent is incorporated in the New Jersey perlite at the plant.

The Permarock aggregate was obtained from the producer in Baltimore. According to the producer Permarock is coated with a "nonionic surface active agent" at the expanding plant.

All the perlites are shipped in 4 cu ft bags. A 4 cu ft bag of the regular perlites weighed about 32 lb when used.

A 4 cu ft bag of Permarock perlite with a nominal net weight of 30 lb varied in gross weight considerably. Table 9 gives the gross weights of two shipments of Permarock. The producer was aware of the variance of the bag weights in Shipment A before filling the order for Shipment B.

Table 9. Individual Bag Weights of Two Shipments of Permarock (includes weight of bag of 0.3 lb)

	Gross weights Shipment A	Gross weights Shipment B
	lb/bag	lb/bag
	32.3	30.6
	38.1	30.6
	31.9	30.5
	31.3	31.6
	32.2	31.0
	37.0	32.0
	31.9	31.8
	34.3	30.2
	34.4	30.1
	37.2	30.7
	32.6	30.6
		31.5
Avg.	33.9	30.9

The only test made on the aggregates was a crushing strength test. Table 10 gives the values for the three aggregates at three compactions. The method used is described on page 9 of the Bureau of Reclamation Report No. C-385 entitled, "Properties of Concretes Made with Typical Lightweight Aggregates." The values given are for the average of three tests on each aggregate.

Table 10. Comparison of Crushing
Strengths of Three Perlites

Perlite	Crushing strength, psi Average of 3 tests		
	For 1-in. compaction	For 2-in. compaction	For 3-in. compaction
Permarock	25	87	299
Washington	48	128	336
New Jersey	47	150	381

4.2.4 Molding the specimens

The test specimens were 6- by 12-in. cylinders formed in machined steel molds. Waxed cardboard molds were used for a few batches, but their use was discontinued because of the extra work involved in grinding the ends of the specimens to parallel planes.

The unit weight of the fresh concrete was determined immediately after pouring and recorded as the wet density. The concrete was consolidated in the molds by shaking the molds.

As a rule the concrete was struck off even with the top of the mold when about 3 hr old. In some batches the concrete was struck off at pouring to determine any settlement of the concrete. In other batches the excess concrete was cut off at 24 hr, just prior to stripping the mold.

4.2.5 Curing the specimens

All specimens were left in the molds for 24 hr covered with vapor barrier paper. Upon stripping at 24 hr they were placed in the moist-curing room. The specimens made with Type I cement were left in the curing room for 3 days. The specimens made with Type III cement were left in the curing room 1 day. All specimens were then air-dried in the laboratory air until tested.

It is noted that the curing procedures in Phase III of this study were different from the cure previously described under Phases I and II.

4.2.6 Oven drying

The compressive strength specimens were used to determine the oven-dry weight. After testing, the specimens were dried in an oven at about 105°C until they lost no more than 1 percent of their weight in a 24 hr period.

4.3 Testing procedure

Specimens made from Type I cement were tested at 28 days and those made from Type III cement were tested at 7 days. On the day of the test the specimens were weighed and dimensions measured.

4.3.1 Sonic test

The resonant longitudinal frequency of many of the specimens was determined using the procedure outline in ASTM C215-55T.

The sonic modulus of elasticity (E) was computed using the relation

$$E = V^2 \rho \text{ psi}$$

where V = velocity of sound through the specimen in in./sec

$$V = 2 N \ell$$

where N = fundamental longitudinal frequency, in cycles per second

and ℓ = length of the specimen in inches

and where ρ = weight/in.^{3}/g ; $g = 386.0$ in./sec^2, and weight is in pounds.

4.3.2 Static compressive test

The ends of the specimens were ground to a smooth flat finish on a concrete plate. Opposite ends of the specimens were checked for parallelism before testing. No capping material was used.

The specimens were tested in a Baldwin 60,000 lb capacity hydraulic testing machine. They were loaded through a spherically seated head at a rate of not more than one-half the estimated maximum load per minute.

The specimens were loaded until a visible fracture was noticed. A crushing type failure localized near one end of the cylinder was called an incomplete failure; a shear or splitting type fracture was called a complete failure. The data from all batches which gave incomplete failures were discarded.

Static compressive stress-strain determinations were made on single 6- by 12-in. cylinders from each of three batches of air entrained concretes. This was done to have a comparison of static "E" values with the sonic values. Strain readings were made at convenient increments of loading without interrupting the continuous application of the load.

5. DISCUSSION OF RESULTS

5.1 Effect of capping procedure on compressive strength

The sulphur mixture capped specimens were used as a standard to compare the relative efficiencies of the other three methods. The strengths of the other three specimens of each shape were rated as a percentage of the sulphur capped specimen strength.

The results obtained in this phase of the study are summarized in Table 11. The actual compressive strengths obtained with 6- by 12-in. cylinders and 6-in. cubes are given only for sulphur capped specimens, while only relative values are given for plaster and Celotex capped specimens and for specimens with ground ends. This information is given for perlite, vermiculite and cellular concretes made with both Type I and Type III cements.

Table 11 Effect of Capping Procedure on Compressive Strengths of Cylinders and Cubes
(Strength of Sulphur Capped Specimens = 100%)

Batch	Concrete	Type of cement	Compressive strengths of sulphur capped specimens		Relative cylinder strengths			Relative cube strengths			Ratio of strengths; sulphur capped to batch average	
			Cylinders	Cubes	Plaster capped	Ground ends	Celotex capped	Plaster capped	ground ends	Celotex capped	Cylinders	Cubes
			psi	psi	%	%	%	%	%	%		
P-III-1	Perlite	III	425	459	105	101	92	107	105	---	1.00	.96
2	"	III	465	472	92	105	102	83	83	93	1.00	1.12
3	"	III	456	425	100	99	107	92	89	114	.99	1.01
4	"	III	109	95	83	99	108	98	108	117	1.03	.94
5	"	III	111	112	96	102	105	92	84	87	.99	1.10
6	"	III	159	110	91	94	105	133	96	139	1.03	.89
7	"	III	174	119	96	75	87	123	112	118	1.12	.88
8	"	III	161	158	102	107	94	97	90	82	.99	1.08
Avg.			---	---	96	98	100	103	96	107	1.02	1.00
V-III-1	Vermiculite	III	106	108	99	101	98	91	84	87	1.00	1.10
2	"	III	138	132	100	99	99	101	97	99	1.00	1.01
3	"	III	129	123	94	94	95	85	80	98	1.04	1.10
Avg.			---	---	98	98	97	92	87	95	1.01	1.07
C-III-1	Cellular	III	167	---	105	97	89	---	---	---	1.02	---
2	"	III	297	340	106	95	104	94	88	89	.99	1.08
3	"	III	204	193	106	80	101	112	92	93	1.03	1.01
4	"	III	129	113	93	98	90	111	87	100	1.05	1.01
5	"	III	---	---	---	---	---	---	---	---	---	---
6	"	III	198	193	---	91	88	109	97	96	1.08	1.00
7	"	III	142	118	109	99	---	128	103	100	.97	.93
Avg.			---	---	104	93	94	111	93	96	1.02	1.01
P-I-1	Perlite	I	88	66	---	83	89	92	115	85	1.10	1.00
2	"	I	96	82	82	110	85	107	102	102	1.06	.97
3	"	I	96	78	---	94	93	---	109	101	1.04	.96
4	"	I	101	--	102	92	103	98	105	90	1.01	---
5	"	I	98	107	86	95	100	87	97	---	1.05	1.05
6	"	I	85	73	88	101	103	102	103	107	1.02	.97
7	"	I	94	84	92	83	---	92	89	91	1.03	1.08
Avg.			---	---	90	94	96	96	103	96	1.05	1.01
V-I-1	Vermiculite	I	94	91	103	93	101	105	84	98	1.00	1.03
2	"	I	91	86	102	99	92	104	101	101	1.01	.98
3	"	I	68	61	90	91	93	94	92	96	1.08	1.05
Avg.			---	--	98	94	95	101	93	92	1.03	1.02
C-I-1	Cellular	I	141	136	95	101	101	98	92	92	1.01	1.05
2	"	I	222	223	91	90	100	89	93	103	1.05	1.04
3	"	I	273	287	102	102	103	87	97	96	.98	1.06
Avg.			---	---	96	98	101	91	94	94	1.01	1.05
Grand Avg. for individual specimens					97	96	97	100	96	99	1.03	1.02
Coefficient of variation for relative strengths of individual specimens					7	8	7	13	9	12	4	6

The results indicate that there were no significant differences in the compressive strengths obtained by the four capping methods, for both cylinders and cubes. The maximum difference between grand average values of relative strengths was observed for cylinders and cubes with ground ends; these strengths departed 4 percent from the grand average obtained with sulphur capped specimens. It was also observed that somewhat greater variability can be expected with cubes than with cylinders. The coefficients of variation [9] for relative strengths of individual cube specimens ranged from 9 to 13 percent, while for cylinders these coefficients ranged from 7 to 8 percent. The relatively large values of coefficients of variation were attributed in part to the lower strengths associated with the "incomplete failures" illustrated in figure 1. The incomplete failures almost always occurred in the cast bottom of the specimen, and generally in the batches with a high water content. This implies that incomplete failure was probably due to water gain at the bottom of the specimen.

The sulphur-silica capping method gave slightly higher strengths with a lower coefficient of variation than the other three methods. However, the advantages of using a sulphur cap seem to be outweighed by the convenience and economy of using the ground surface method or by using a Celotex cap.

5.2 Effect of size and shape of specimens

Although the program as originally scheduled is only about one-third completed, the results indicate that for a satisfactory correlation between the conventional 6- by 12-in. cylinder strength and smaller type specimen strengths the curing schedule must be considered. The curing schedule as used thus far in this phase is not completely satisfactory because the rapid drying of the small specimens results in less favorable curing for the smaller specimens.

Table 12 shows the relative strength of the various specimens for each batch. The 28-day strengths of the 6- by 12-in. cylinders made with Type I cement (7 days for Type III cement) for each batch were used as the standard of comparison. The strengths obtained at the ages of 7 and 28 days for specimens of Type III and Type I cements respectively are termed "full-cure" strengths in the following discussion, while the strengths obtained at the ages of 3 and 7 days are termed "early" strengths.

Table 12. Compressive Strengths of Various Specimens Expressed as Ratios to Strengths of Fully-Cured 6- by 12-in. Cylinders. (Each value is average of three specimens).

Batch	Relative "Early" Strengths 1/ %				Relative "Full-Cure" Strengths 2/ %					"Full-Cure" 2/ Strength of 6" x 12" cylinder
	3"x6" cyl.	3"x3" cyl.	2"x4" cyl.	2" cube	6" cube	3"x6" cyl.	3"x3" cyl.	2"x4" cyl.	2" cube	
										psi
P-1-6-1	51	59	--	61	92	63	71	67	67	108
P-1-5-1	57	79	--	51	99	66	74	67	63	150
P-1-6-2	54	69	50	61	98	53	65	51	82	142
P-1-5-2	63	87	68	70	97	66	65	68	73	274
P-111-6	34	37	68	61	112	--	71	61	61	200
P-111-5	55	57	65	65	101	63	68	66	64	278
P-111-2	41	52	69	66	73	55	74	68	76	127
Avg.	51	63	64	62	96	61	70	64	69	183

1/ "Early" strength corresponds to 3 day strength for Type III cement and 7 day strength for Type I cement.

2/ "Full-cure" strength corresponds to 7 day strength for Type III cement and 28 day strength for Type I cement.

The "full-cure" and "early" strengths of the small specimens are compared with the "full-cure" strengths of the 6- by 12-in. cylinders in Table 12. The average "early" strengths of the small specimens ranged from 61 to 64 percent of the strengths of comparable "full-cure" strengths of 6- by 12-in. cylinders. There was only a small increase in the strengths of the small specimens when they were given the "full-cure", except for the 6-in. cubes. The "full-cure" strengths of the small cylinders and the 2-in. cubes ranged from 61 to 70 percent of the "full-cure" strengths of the 6- by 12-in. cylinders, whereas for the 6-in. cubes this ratio was 96 percent. This indicates a lack of the necessary moisture for curing of the smaller cylinders and cubes which are stored in air following 1 and 2 days curing in the molds for cements of Type III and Type I, respectively.

By combining the data from phase I with the date from this phase, the ratio of 6-in. cube strengths to 6- by 12-in. cylinder strengths for 37 batches of insulating concretes can be considered. For a total of about 130 specimens of each shape the average ratio is 95 percent with a coefficient of variation of 9 percent.

Because it is difficult to secure well molded small size specimens such as the 2-in. cubes and the 2- by 4-in. cylinders of insulating type concretes in the field, it is thought that future work in this study would be concentrated on the use of 3- by 6-in. and 3- by 3-in. cylinder specimens in addition to the 6- by 12-in. control cylinders. It is thought that a 3- by 6-in. cylinder, when damp cured for 4 days (Type I cement) and then air dried until tested, should give very close to the same results as the 6- by 12-in. cylinder when cured in this way.

Since the variability of results is generally higher with smaller specimens, it seems advisable to use a sample of four of the smaller cylinders if and when they are used in place of the three 6- by 12-in. cylinders normally used as a sample.

5.3 Comparative properties of three perlite aggregate concretes

5.3.1 Permarock concretes

In making insulating concretes of lightweight aggregate the usual practice is to entrain considerable amounts of air in the mix. The primary purpose of the entrained air is to produce a viscous foam from the cement-water grout which will prevent the segregation of the lightweight aggregate from the grout. By increasing the amount of air entraining agent above that which is necessary to prevent segregation the yield of the concrete can be kept above 100 percent even though the actual aggregate volume may be reduced by the mixing action. The use of entrained air also reduces the amount of mixing water necessary to produce a concrete of pourable consistency.

The producer of Permarock asserts that, since perlite is stronger than air, a better product can be produced without air entrainment. However, the coating agent used on the Permarock seems to act as an air-entraining agent as some entrainment was apparent, especially in the higher yield batches. It was found that with yields of 95 percent or greater there was no segregation of the Permarock concretes. With yields of about 85 percent to 95 percent the segregation was mild.

When an air-entraining agent was added to the Permarock, as well as to the regular type perlites, the yield was generally at least 100 percent and no segregation occurred. When the amount of air entraining agent is greater than the amount necessary to prevent segregation for either aggregate, the wet density-strength curve is shifted slightly above the curve for mixes with normal air content because of the smaller amounts of water needed. However, excessive air entrainment appears to have but little effect on the oven-dry density-strength curve.

The two specially designated points in figures 4, 5, and 8, represented by the large symbols, are for Permarock batches with an anti-foam agent added by the producer. This removal of air resulted in an increase of density without a corresponding increase in strength. It appears that any air present in the normal mixes is beneficial.

Similarly, the specially designated points in figures 4, 5, 6, and 8, represented by the semi-solid symbols, are batches with excessive segregation. Some very badly segregated batches, caused by too much mixing water, or excessive mixing, were discarded and are not shown.

The effect of the rate of mixing was investigated and the results are shown in figures 5, 6, and 7. It can be seen that reduction of the mixer speed had no significant effect on the weight-strength relationship. Since mixing tends to break down the aggregate thereby releasing some water, the Permarock concrete becomes heavier and wetter with increased mixing. When the mix becomes too wet, excessive segregation occurs increasing the scatter of density-strength data. Some of the spread in the points on figures 4, 5, 6, 7, and 8 is probably due to variations in the aggregate itself. If the Permarock concrete is mixed in a transit type mixer of 4 cu yd capacity, 32 bags of aggregate would be used in one batch. This amount of aggregate is about the same as the total used in this investigation. It is possible that the concrete mixed in such a manner would not fall below the minimum wet density-strength curve as shown in figure 4, if the segregation is not allowed to become excessive.

Table 8 gives the mix and test data for the Permarock concretes made according to the producer's recommendations.

5.3.2 Air entrained perlite concretes

Figure 9 shows the relationship between wet density and strength for air entrained perlite concretes using the three brands of aggregate. Figure 10 shows the relationship between the strength for these concretes and their oven-dry weight.

The relationship between the wet density and the compressive strength shown in figure 9 is linear and the scatter of points is slight. The only mixes which departed from this linear relationship were those which contained more air than was necessary to prevent segregation. The points corresponding to the high air contents lie well above the line in figure 9 reflecting the lower water content realized with increased air entrainment.

The same data on compressive strengths are presented in figure 10 plotted against oven dry densities. The relationship between the strength and density is not as clearly defined in figure 10 as it is in figure 9. Furthermore, it is noted that in figure 10 the points corresponding to high air contents do not lie above the data obtained with normal air contents but are fairly uniformly dispersed.

The effect of prolonged mixing on mixes containing less than the recommended amount of air entraining agent is brought out by the NBS 1:6 mix (batches 6WS-A, B and C) listed in Table 7. As the duration of mixing was increased from 2 to 7.5 min, the yield decreased from 111 to 94 percent and the oven dry density increased from 25.9 to 28.9 lb per cu ft. However, when a larger amount of air entraining agent is used, prolonged mixing tends to entrain more air resulting in lighter concrete.

The New Jersey perlite which has the entraining agent incorporated at the plant normally produces a high air content concrete. The amount of air entrained depends on the amount and method of mixing and the water content. Excess water tends to dilute the entraining agent and make it less effective in entraining air. Increasing the time of mixing tends to increase the air content when the mixing action is similar to that of the paddle mixer used in mixing the air entrained concretes in this investigation.

No attempt was made to get more than an indication of the effect of mixing time and the effect of the rate of mixing was not investigated, although it has been claimed that air entrained insulating concrete can only be made in a high speed mixer.

It is obvious from the graphs shown that Permarock concretes must be considered as a product different from the air-entrained perlite concretes when both are mixed according to the respective producers' recommendations.

5.3.3 Recommended practice for securing a perlite concrete having specified properties

Different investigators studying the properties of lightweight aggregate concretes have shown that the property of concrete of a given aggregate, most useful in predicting its compressive strength is the unit weight of the concrete. The results shown in figure 9 confirm the fact that a well-defined relationship exists between the compressive strength and the unit weight of the concrete made of a given aggregate and cured in a specified manner. This observation is valid only with respect to workable mixes without excessive segregation. It is clear that when segregation is such as to permit cement paste to accumulate in the bottom of the cylinder molds, the compressive strength is adversely affected.

It appears from the study of the data obtained with Permarock, Panacalite and Coralux perlites that it is not sufficient to specify the density of concrete in order to secure a certain minimum compressive strength. It is also necessary to specify that a concrete be relatively free of segregation in order to be reasonably sure that a given perlite concrete will follow the strength-wet density relationships shown in figures 4 and 9.

In the absence of any acceptable test for degree of segregation, it is proposed that badly segregating perlite concretes be eliminated by specifying a minimum "yield" of 80 percent and the corresponding maximum wet density for perlite concretes of given proportions. "Yield" is defined as the ratio, expressed as a percentage, of the volume of the fresh concrete to the dry loose volume of the aggregate used. Table 13 gives the proposed maximum wet densities for three mixes each of the two types of concrete. These limits are based on mix proportions set forth in Tables 4 and 5.

Table 13. Proposed Maximum Wet Densities Using Producer's Mix Proportions.

Permarock concretes		Air entrained perlite concretes	
Mix	Maximum density	Mix	Maximum density
	lb/cu ft		lb/cu ft
LD 4	49	1:6	51
LD 5	54	1:5	57
LD 6	58	1:4	64

Table 14 gives the minimum wet densities required to obtain certain compressive strengths for each concrete; these values were taken from the minimum wet density-strength curves shown in figures 4 and 9. It is expected that most batches of concretes will give strengths slightly greater than the indicated values.

Table 14

Required compressive strength, 6- by 12-in. cylinder	Permarock concrete minimum wet density	Air entrained Washington or New Jersey perlite concrete minimum wet density
psi	pcf	pcf
100	42	35
150	47	38
200	51	41
250	54	44
300	56	46
350	58	49
400	60	52
450	61	55

Since the cylinder strength of the concrete will also depend on the curing method and the amount of moisture in the specimen when tested, it is emphasized that the strength-wet density relationship presented here is valid only if the test specimens are cured as described.

References

[1.] "ASTM Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field," C31-55, ASTM Standards, Part 3, 1955.

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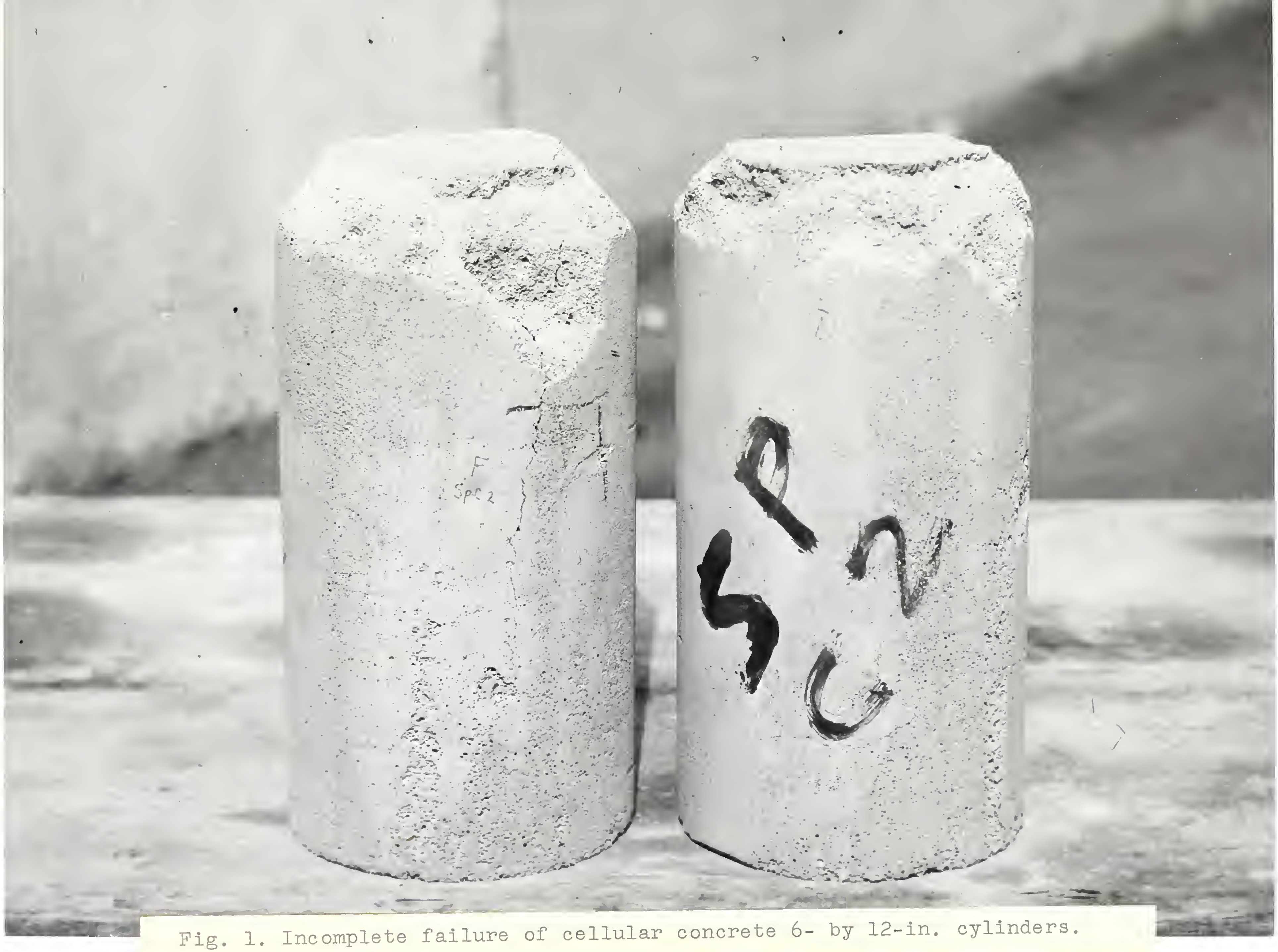


Fig. 1. Incomplete failure of cellular concrete 6- by 12-in. cylinders.

Fig. 2. Complete failure of cellular concrete 6- by 12-in. cylinders.

TYPICAL COMPRESSIVE LOAD-DEFORMATION CURVE FOR SPECIMENS EXHIBITING LOCAL CRUSHING NEAR ONE END

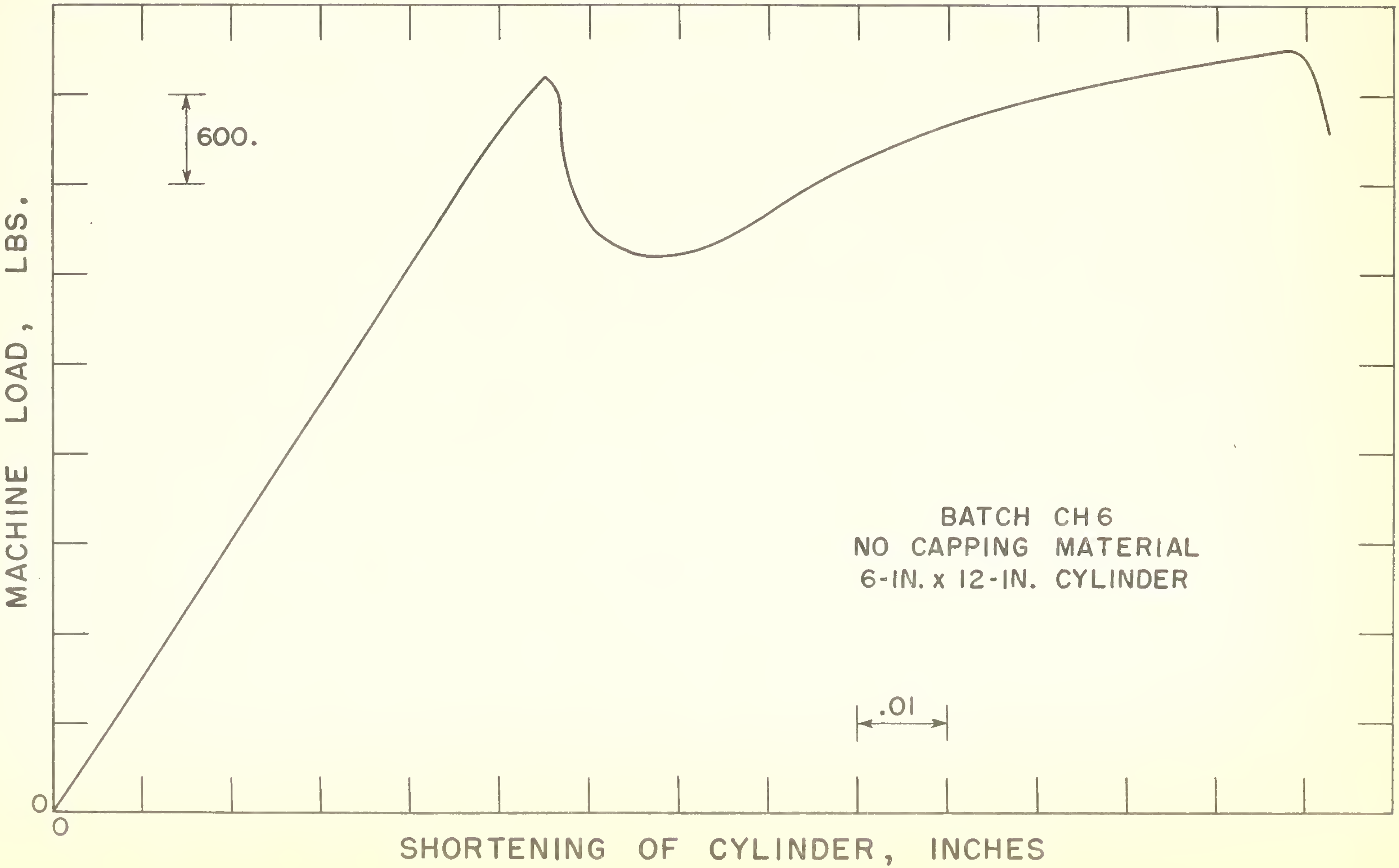


FIG. 3

"PERMAROCK" CONCRETES
WET DENSITY VS. COMPRESSIVE STRENGTH

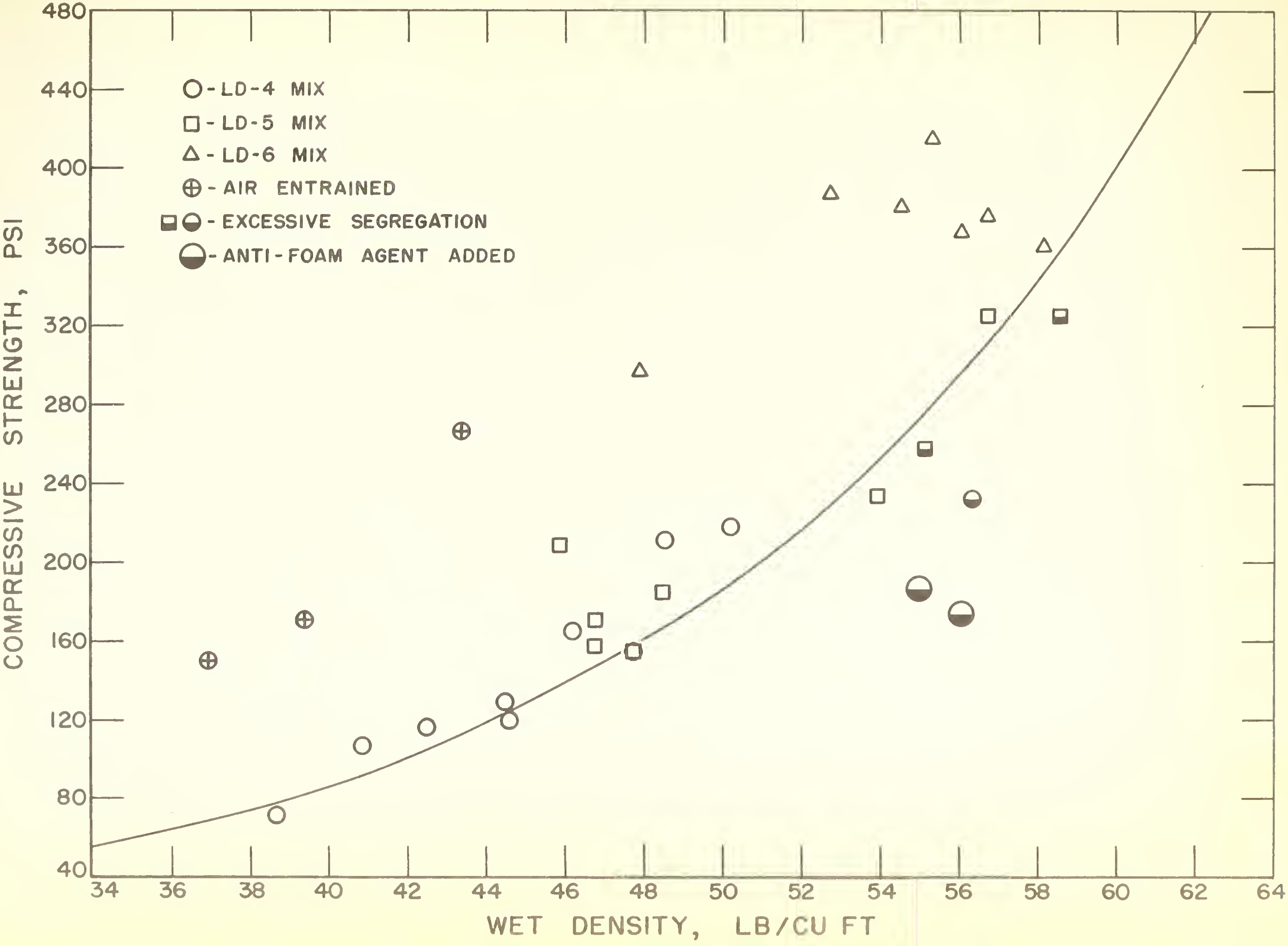


FIG. 4

LD-4 "PERMAROCK" CONCRETES
WET DENSITY VS. COMPRESSIVE STRENGTH

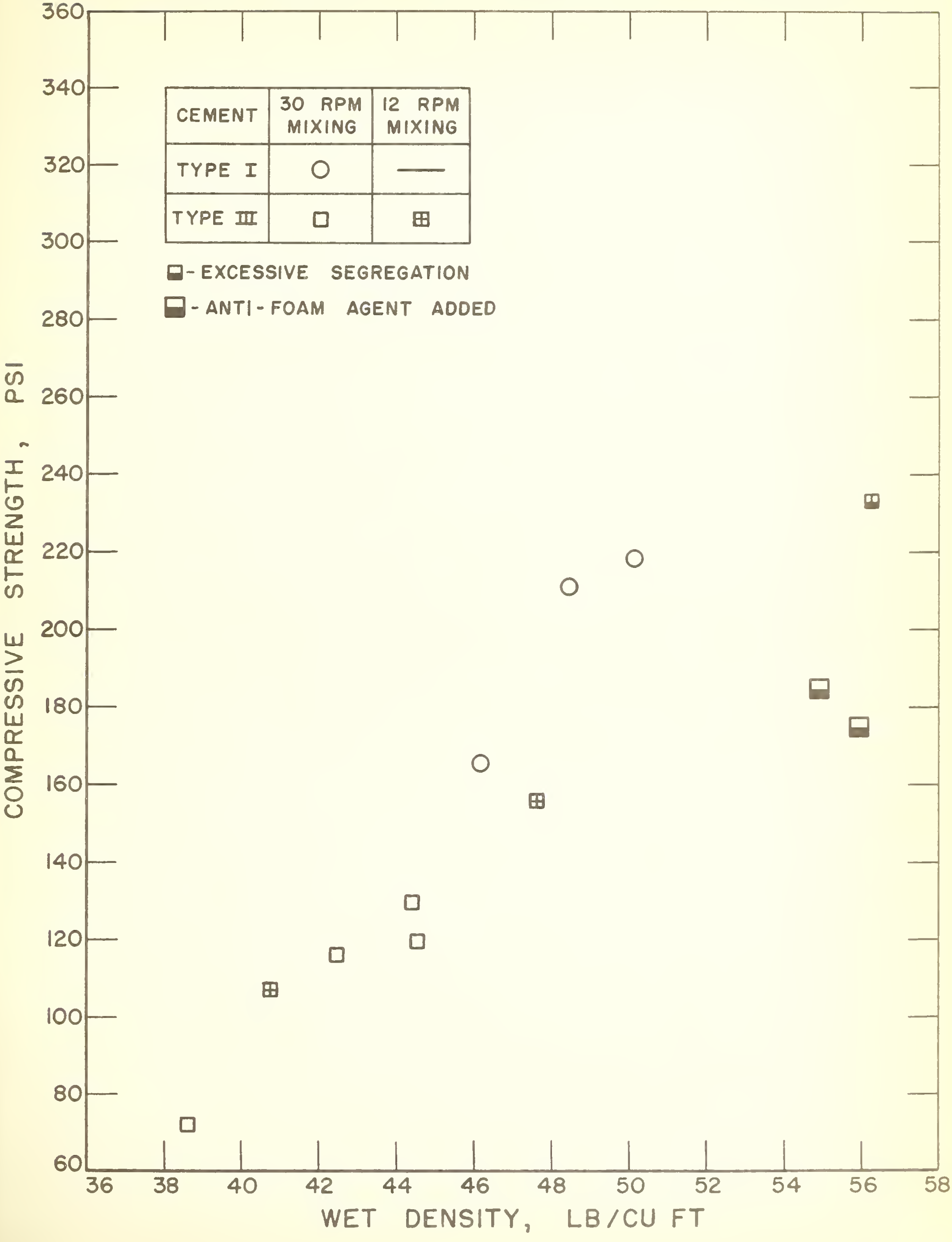


FIG. 5

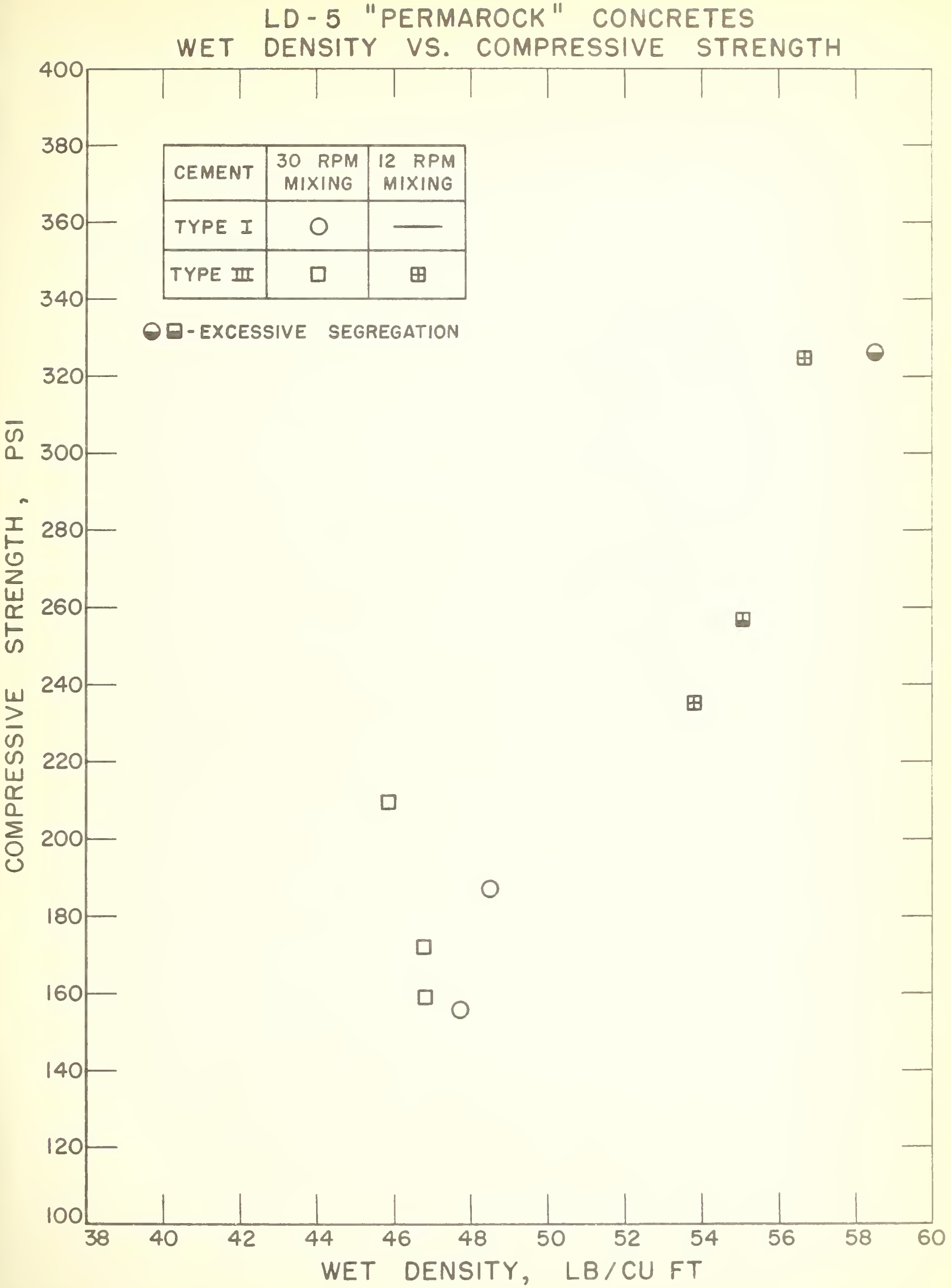

LD-5 "PERMAROCK" CONCRETES
WET DENSITY VS. COMPRESSIVE STRENGTH
CEMENT
30 RPM MIXING
12 RPM MIXING
TYPE I
TYPE III
◒ ⊟ - EXCESSIVE SEGREGATION
COMPRESSIVE STRENGTH, PSI
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
WET DENSITY, LB/CU FT
38
40
42
44
46
48
50
52
54
56
58
60

FIG. 6

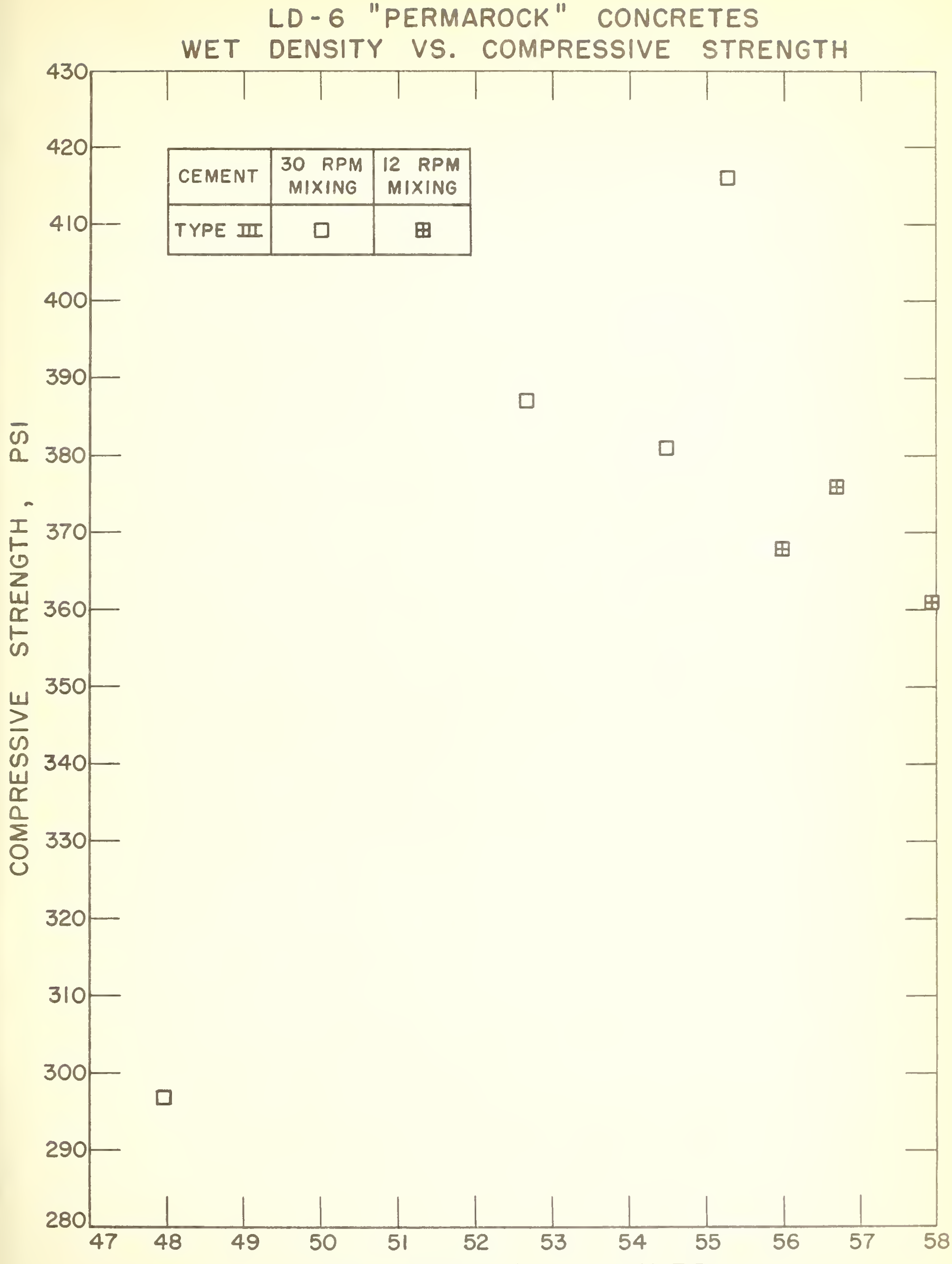

LD-6 "PERMAROCK" CONCRETES
WET DENSITY VS. COMPRESSIVE STRENGTH
CEMENT
30 RPM MIXING
12 RPM MIXING
TYPE III
□
⊞
COMPRESSIVE STRENGTH, PSI
430
420
410
400
390
380
370
360
350
340
330
320
310
300
290
280
47
48
49
50
51
52
53
54
55
56
57
58
WET DENSITY, LB/CU FT

FIG. 7

"PERMAROCK" CONCRETES
OVEN DRY DENSITY VS. COMPRESSIVE STRENGTH

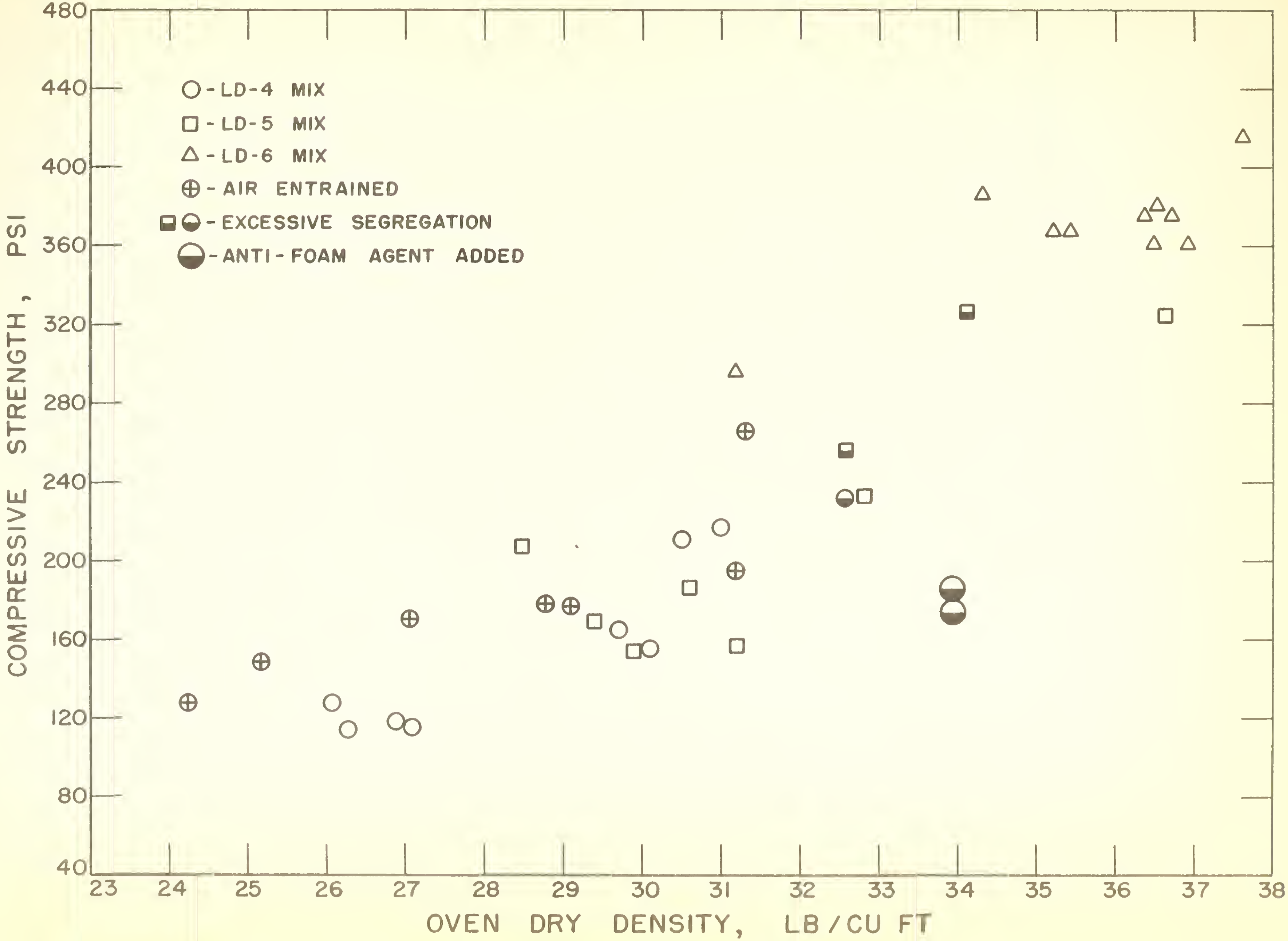


FIG. 8

AIR ENTRAINED PERLITE CONCRETES
WET DENSITY VS. COMPRESSIVE STRENGTH

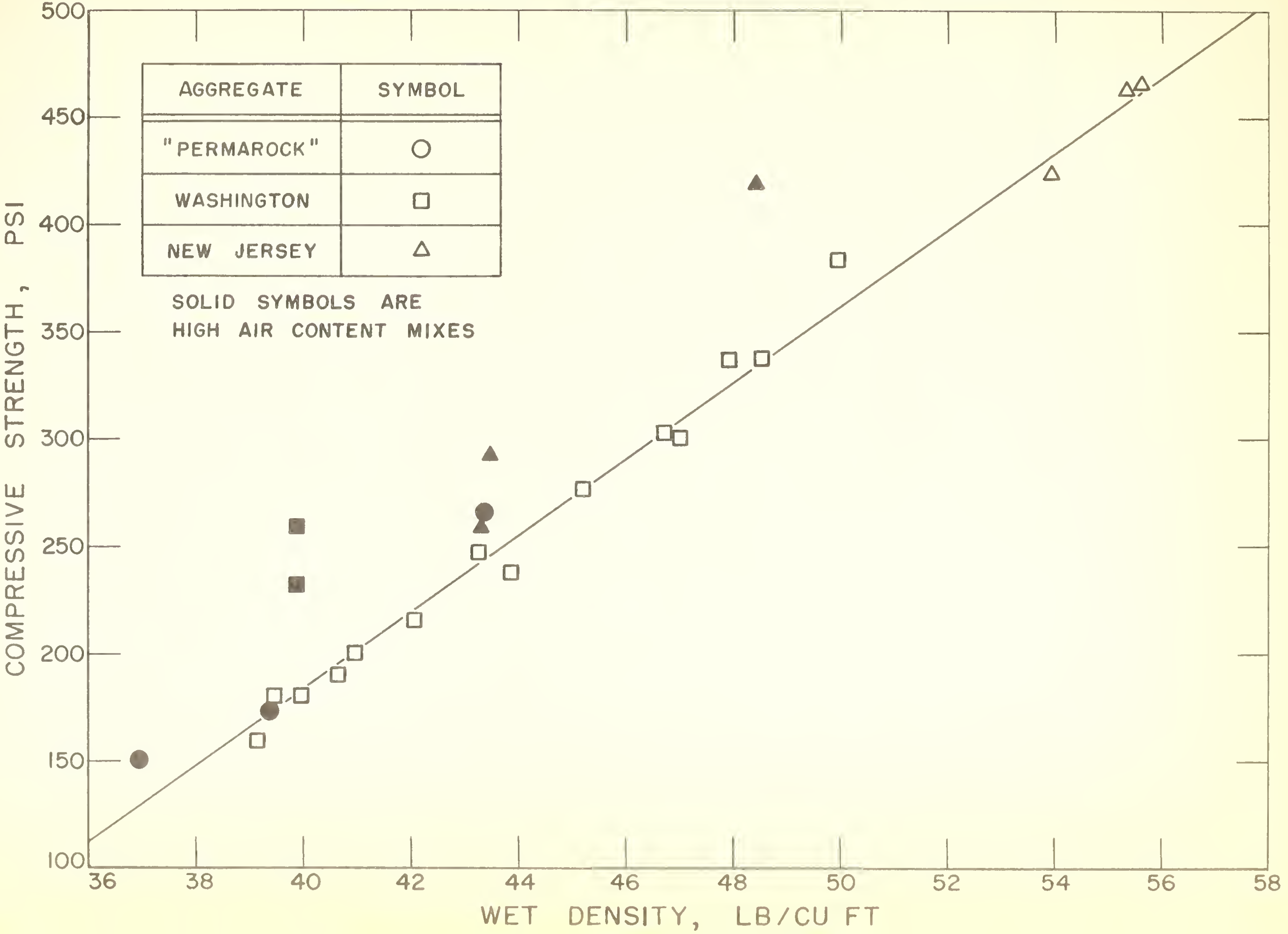


FIG. 9

AIR ENTRAINED PERLITE CONCRETES
OVEN DRY DENSITY VS. COMPRESSIVE STRENGTH

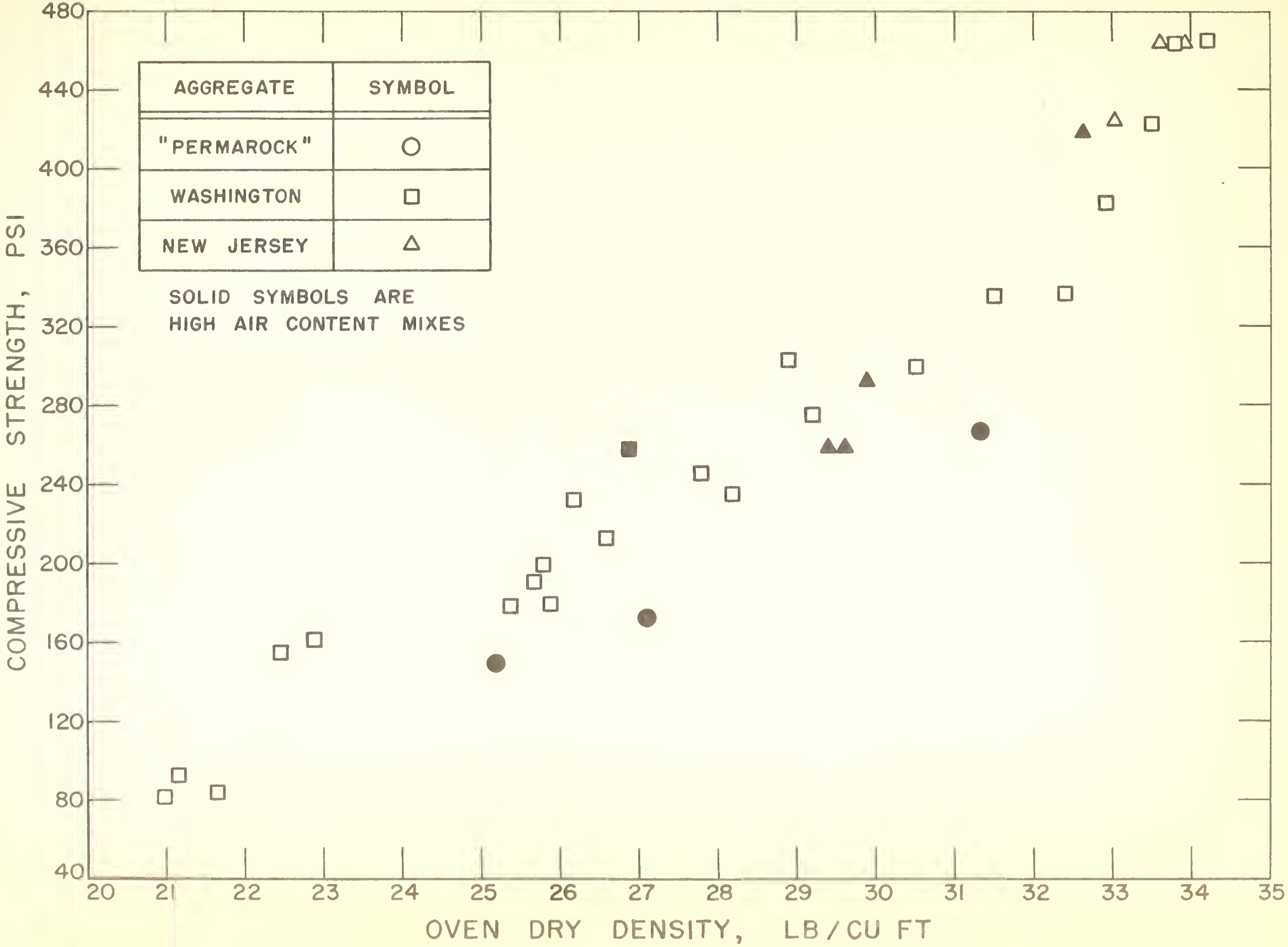
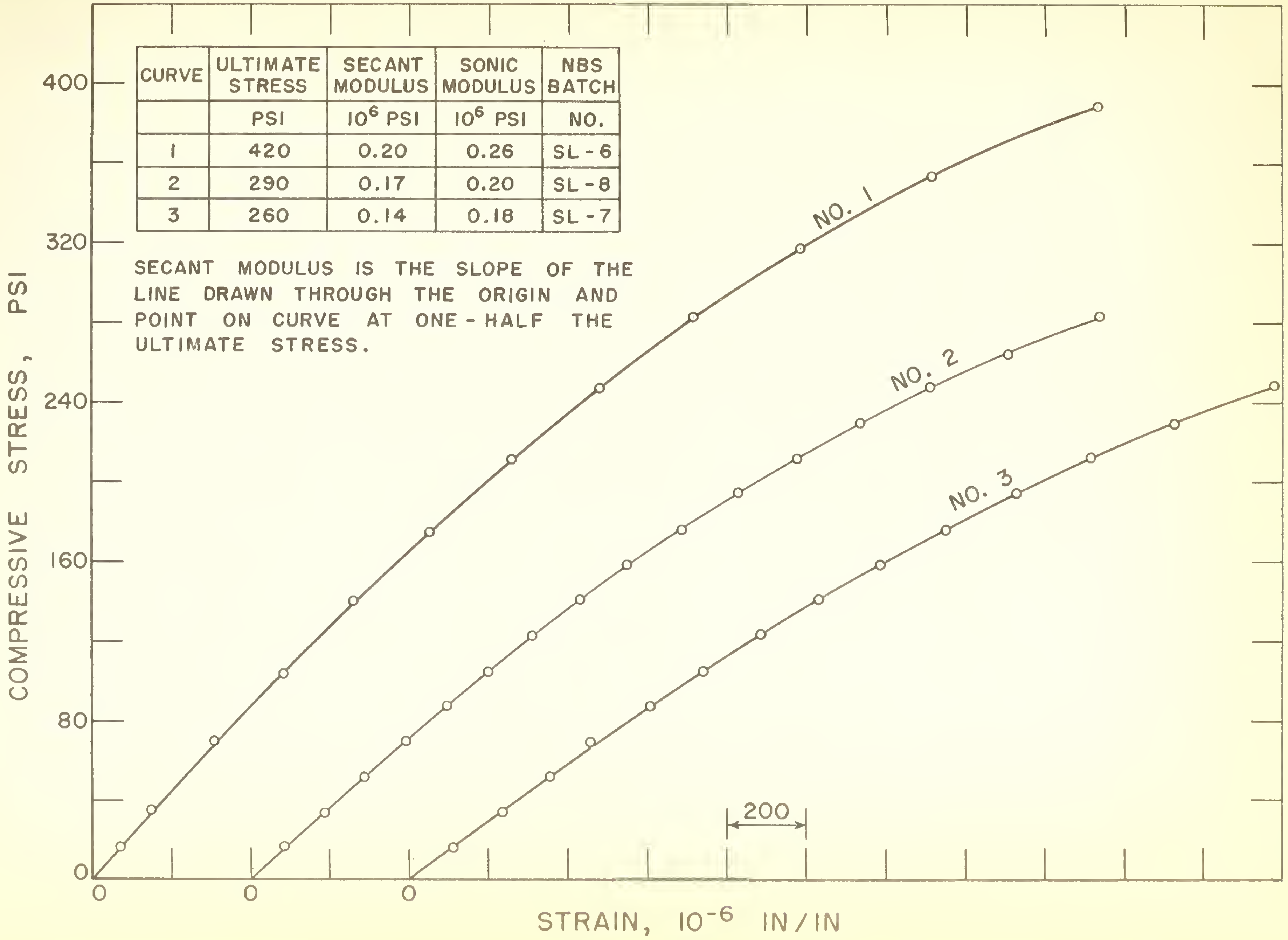


FIG. 10

STRESS-STRAIN CURVES OF PERLITE CONCRETES
STATIC COMPRESSION TESTS ON 6" x 12" CYLINDERS



CURVE	ULTIMATE STRESS	SECANT MODULUS	SONIC MODULUS	NBS BATCH
	PSI	10^6 PSI	10^6 PSI	NO.
1	420	0.20	0.26	SL-6
2	290	0.17	0.20	SL-8
3	260	0.14	0.18	SL-7

SECANT MODULUS IS THE SLOPE OF THE LINE DRAWN THROUGH THE ORIGIN AND POINT ON CURVE AT ONE-HALF THE ULTIMATE STRESS.

FIG. 11

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its headquarters in Washington, D. C., and its major field laboratories in Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside front cover of this report.

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Electricity and Electronics. Resistance and Reactance. Electron Tubes. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology and Lubrication. Engine Fuels.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. AEC Radiation Instruments.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems. Application Engineering.

- Office of Basic Instrumentation
- Office of Weights and Measures

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering.

Radio Standards. Radio Frequencies. Microwave Frequencies. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Calibration Center. Microwave Physics. Microwave Circuit Standards.


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