Iowa State Highway Commission
Materials Department
Special Investigations

Research Project R-229
Final Report

LIGHTWEIGHT AGGREGATE use in Structural Concrete

APRIL 9, 1969

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ACKNOWLEDGEMENT -

We wish to express our appreciation to Mr. J. H. Boemler and Prestressed Concrete of Iowa, Inc., Iowa Falls, for their cooperation on this project.

We also wish to thank Mr. John Lane, Portland Cement Concrete Engineer, and Mr. Bernard C. Brown, Testing Engineer, for their direction and assistance in this project.

LIGHTWEIGHT AGGREGATE USE IN STRUCTURAL CONCRETE

1.0 INTRODUCTION

The Iowa State Highway Commission has adopted a number of rigid safety requirements that the Bureau of Public Roads has set forth as standards for road construction. One of these safety requirements is the elimination of two piers on Interstate grade separations, thus leaving two long spans. These longer spans lower the ability of prestressed concrete beams to compete economically with steel beams. In an effort to be more competitive, the prestressing companies have been studying the use of lightweight aggregate in structural concrete.

2.0 PURPOSE

The purpose of this project is to determine which of the three lightweight aggregates proposed for use by Prestressed Concrete of Iowa, Inc., Iowa Falls, will produce concrete with sufficient strength and durability to be used by the Iowa State Highway Commission for structural concrete. The effects of curing on the structural concrete will also be studied.

3.0 MATERIALS

Three lightweight aggregates were used in this study. They were:

HAYDITE

Source: Carter-Waters Corporation, Centerville, Iowa

Lab. Nos.	AAG7-247, AAG7-371*, AAG7-302*, AAG7-273, AAG7-266		
Sp. Gr. (S.S.D.)	1.876	1.905	
% ABs. (S.S.D.)	8.85	7.20	
% Loss Method "A" Freeze and Thaw	2.9		1.7
% Wear, LA Abrasion, Grading C	22		25
Unit Weight (Lb/Cu.Ft.)			
+4	55.1	57.69	
-4		53.38	
MIX		55.07	

Gradation	% Passing	% Passing
3/8"	100	100
#4	55	59
#8	8.5	3.8

*No aggregate tests were performed on these samples, but since they were from the same source, it is assumed that they would produce similar results.

IDEALITE

Source: The Idealite Company, 821 Seventeenth Street, Denver, Colorado

Lab. No.	AAG7-314
Sp. Gr. (S.S.D.)	1.627
% Abs. (S.D.D.)	7.73
% Loss Method "A" Freeze & Thaw	2.8
% Wear, LA Abrasion Grading B	22
Unit Weight (Lb/Cu.Ft.)	55.37

Gradation	Blend Grading % Passing	Med. Grading % Passing
1"	100	-
3/4"	99	-
1/2"	81	-
3/8"	42	100
#4	14	62
#8	4.0	12

MATERIALITE

Source: Material Service, Division of General Dynamics Corporation
300 W. Washington Street, Chicago, Illinois

Lab. No.	AAG7-355
Sp. Gr. (S.S.D.)	1.580
% Abs. (S.D.D.)	8.3
% Loss Method "A" Freeze & Thaw	3.1
% Wear, LA Abrasion Grading B	29
Unit Weight (Lb/Cu.Ft.)	52.89

Gradation	% Passing
3/4"	100
1/2"	91
3/8"	38
#4	2.0

The Fine Aggregate used for Lab. Mixes (AAS7-41) was from Hallett's Pit at Ames complying with Section 4110 of the Standard Specifications. It had the following gradation:

Sieve Size	% Passing
3/8"	100
#4	99+
#8	94
#16	70
#30	35
#50	8.2
#100	0.8
#200	0.4

For the Plant Mixed concrete, fine aggregate from Welden Brothers in Iowa Falls was used.

Pozzolith 100R, a product of the Master Builders Company, 2490 Lee Boulevard, Cleveland, Ohio, was used as an additive to yield more desirable characteristics with respect to strength and workability. Lot Nos. P-477-G7 and P-310-E7 as tested under Lab. Nos. AAM7-36 and AAM7-21 respectively, were used in this project, with little variation between the two lots.

Two blends of R-11 cement (AC6-2344 and AC7-5637) were used in making the mixtures. An R-11 blend is composed of 7 different brands of Type I cement mixed together in equal proportions. There was no appreciable difference in the two blends, therefore it can be assumed that the cement in the mixtures did not affect the results.

4.0 LABORATORY PROCEDURE

It was originally planned that the concrete would be batched, mixed and cured for the first day at the prestress plant. After curing by steam, radiant heat or simply by being covered with plastic, the concrete beams and cylinders would then be transported to the laboratory and removed from the molds.

Nine beams and cylinders were made at the prestress plant using saturated Haydite Lightweight Aggregate. The following proportions were used for 1 cu.yd.:

Cement	700 lb.
Sand	1324 lb. (S.S.D.)
Haydite	850 lb.*
Pozzolith 100R =	21 oz. (3 oz./100 lb. of cement)

Water necessary for desired consistency.
Desirable slump = 2 1/2 - 3 in. max.

Sets of three beams and three cylinders were cured by each of the methods available. Durability factors were determined per ASTM-C-291 with the following exceptions: (1) The beams were 18" long. (2) Their locations in the freezer were unchanged. (3) One end of the beam was placed toward the bottom of the freezer for the entire test. (4) The beams were normally read at 56 cycle intervals.

The compressive strength of the cylinders was computed per ASTM C-39.

The modulus of elasticity was determined at the same time as the cylinders were tested to failure in compression.

*The Haydite in this plant mix was on an "as found" basis, and no correction was made for moisture content.

The cylinders were not moist for testing. Two lines were drawn around the cylinders two inches from each end (8 inches apart). The mechanical strain jacket was then positioned around the cylinder. The three set screws on the upper ring of the strain jacket were positioned on the upper line and adjusted so the jacket was not rubbing on the cylinder. The two set screws at the base were positioned on the line. One side of the strain jacket was held at 8 inches with a fixed rod that was spring loaded so all movement was measured on the other side by one dial. The resulting stress and strain were plotted on a graph and the slope of a straight line through the points from no stress to the stress representing 0.4 f_c was determined to be the modulus of elasticity.

Because of the inconvenience caused by making the beams at the plant and then transporting them to Ames, it was decided to do the balance of the work at the Ames Laboratory.

In the laboratory, eleven batches of concrete were mixed. The following proportions were used for 1 cu. yd.:

HAYDITE MIX

Mix Numbers		6-9
Lightweight Aggregate Condition	Mix No's.	6-7 Saturated 8-9 Air Dry
Cement		709 lbs.
Sand		1341 lbs. (S.S.D.)
Haydite		861 lbs. (Oven dry basis)
Pozzolith (100R)		21.3 oz.

Haydite Gradation	Sieve Size	% Passing
	3/8"	100
	#4	36
	#8	1.4

IDEALITE MIX

Mix Numbers		10-13	14
Lightweight Aggregate Condition		10, 11 Saturated 12, 13 Air Dry	Air Dry
Cement		747 lb.	761 lb.
Sand		1140 lb. (S.S.D.)	1162 lb.
Idealite		934 lb. (Oven dry basis)	952 lb. (Oven dry basis)
Pozzolith (100R)		22.4 oz.	22.8 oz.
Idealite Gradation	Sieve Size	% Passing	% Passing
	3/4"	100	-
	1/2"	91	-
	3/8"	71	100
	#4	38	36
	#8	8	1.4

MATERIALITE MIX

Mix Numbers		15-16
Lightweight Aggregate Condition		15 Saturated 16 Air Dry
Cement		701 lb.
Sand		1143 lb.
Materialite		920 lb. (Oven dry basis)
Pozzolith (100R)		21.0 oz.
Materialite Gradation	Sieve Size	% Passing
	3/4"	100
	1/2"	94
	3/8"	39
	#4	2.0

Three to six cylinders and three beams were made from each mix. The beams were cured as specified in the Bureau of Public Roads, "Interim Report on Concrete Prepared with Lightweight Aggregate" (September 27, 1962). This consisted of moist room curing (ASTM C-511) for 7 days, 50% relative humidity at 73°F. for 14 days, and 7 more days of moist curing. At the age of 28 days the beams were subjected to rapid freezing in air and thawing in water (ASTM C-291).

The cylinders (plant and laboratory mixed) were cured according to ASTM C-330 (moist cured to age of 7 days then 50% relative humidity and 73°F. until testing at 28 days).

5.0 INTERPRETATION OF RESULTS

The following durability factors were obtained for the plant mixed specimens: Radiant heat cure - 9, Covered with plastic - 11, Steam cure - 8. These durability factors were not acceptable.

Strengths obtained at 28 days were as follows: Radiant heat cure - 7265, Covered with plastic - 7525, Steam cure - 7445. The 28 day strength values were acceptable, but because of the durability factors the results could not be used to make valid conclusions.

A modulus of elasticity was determined for one of the plant mixed cylinders. The value obtained was 3.25×10^6 psi.

Table 1 is a summary of the results obtained with the plant mixed specimens.

The specimens mixed in the Laboratory (Table 2) were tested for compressive strength at 7 and 28 days. The Haydite mixes had strengths at 7 days from 4900 - 5130 psi. Seven day strengths for the Idealite mixtures ranged from 5370 - 6370 psi. No strength tests were run on the Materialite cylinders at 7 days.

Cylinders from Haydite mixes No. 7 and 8 were tested at 28 days with strengths of 6835 and 6720 psi being determined respectively. Idealite cylinders from mixes 11, 12 and 14 had 28 day strengths of 7250, 7580 and 7970 (27 day) psi respectively. Strengths obtained for the Materialite mixes Numbers 15 and 16 were 6685 and 6460 psi respectively. All strengths obtained were acceptable.

The following values for the modulus of elasticity were obtained:

Mix No.		Lightweight Aggregate	7 Day (psi)	28 Day (psi)	
6		Haydite	2.86×10^6	- - - -	
7		Haydite	- - - - -	3.58×10^6	
8		Haydite	2.92×10^6	3.54×10^6	
11		Idealite	- - - - -	3.20×10^6	
12		Idealite	- - - - -	3.44×10^6	
14	(Finer)	Idealite	- - - - -	3.43×10^6	(27 day)
15		Materialite		3.27×10^6	
16		Materialite		3.34×10^6	

Durability factors were obtained for beams from all but one mix. Because of some of the beams crumbling, it was hard to determine a precise value. Durability factors for beams of the various mixes were as follows:

6 (Haydite) 2 @ 27, 1 @ 100
7 (Haydite) 2 @ 22, 1 @ 100
8 (Haydite) - 100
9 (Haydite) - 100
10 (Idealite) - 7
11 (Idealite) - 5
12 (Idealite) - 97
13 (Idealite) - 97
14 (Idealite) - None Determined
15 (Materialite) - 5
16 (Materialite) - 2 Beams @ 16, 1 @ 24

The results obtained for durability factors indicate that the condition of the aggregate for mixing has a direct effect on the durability. Those mixes with saturated aggregate for mixing (Mix No's. 6,7,10,11 and 15) all had very poor durability factors.

The condition of the beams after freeze and thaw was also used as an indication of the durability of the concretes. Figures 1 - 9 show the beams after testing. The only beams not pictured were those from Mix 11. They were badly cracked after 24 cycles in the freeze and thaw machine.

The beams made with air dry Idealite (Fig. 5, 6) had the least external deterioration after freeze and thaw. The beams made from air dry Materialite look good (Fig. 8) but were only tested for 27 cycles. They had durability factors of 5 and 19, much too low for acceptance.

Table 2 is a summary of the results for the laboratory mixed specimens.

6.0 SUMMARY

Sufficient strengths were obtained for all mixes. Only two types of mixes produced beams with durability factors acceptable for this study - the mixes made with air dry Haydite and air dry Idealite.

The effects of curing on plant mixed specimens were inconclusive because the mixes were made with saturated aggregate and the durability factors obtained from these mixes were too low to have much significance.

In order to produce concrete with acceptable durability, it is necessary to use air dried aggregate when mixing. This is a conclusion that can be drawn from this study. The Standard Specification 2403.04 (Paragraph A) states that "coarse aggregate shall be kept continuously and thoroughly wet for at least 48 hours before being used in the concrete". ACI Standards 1965 (ACI 614-59) states that the aggregate should be damp and implies that thoroughly wet aggregate will not give concrete with acceptable durability. The Standard Specifications were wrong and have been changed by Specification 624, "Special Provisions for Lightweight Concrete Bridge Units".

The Idealite was chosen for use by Prestressed Concrete of Iowa, Inc. because it had good durability and the least external deterioration after freeze and thaw. Although the Haydite had good durabilities, it was not selected because the ends of beams made with it crumbled badly during freeze and thaw cycles. The Materialite durabilities were too low for consideration.

7.0 APPENDIX

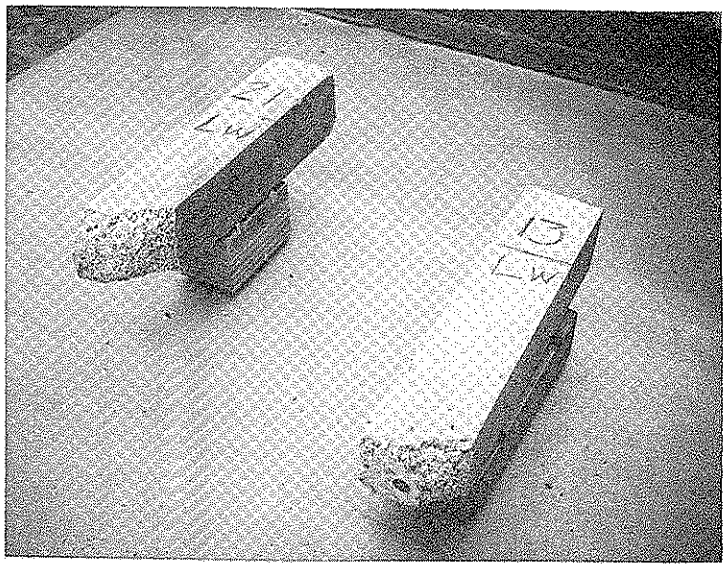

Figure 1 - Beams 13, 21 - Made with Saturated Haydite

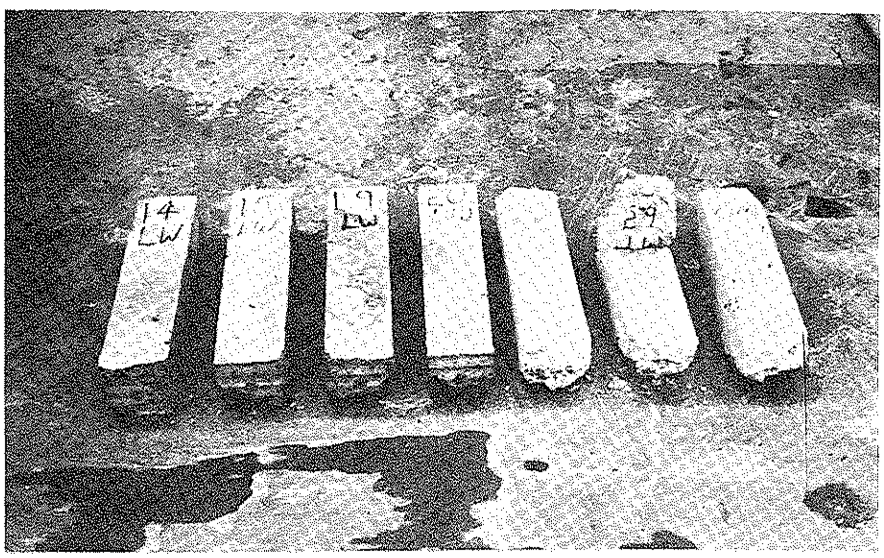

Figure 2 - Beams 14, 15, 19, 20 - Made with Saturated Haydite
Beams 28, 29, 30 - Made with Saturated Idealite

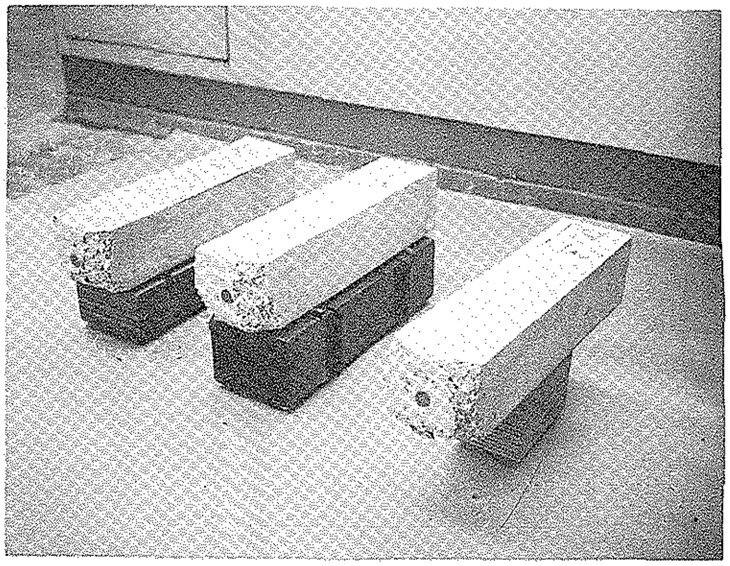

Figure 3 - Beams 16,17,18 - Made with
Air Dry Haydite

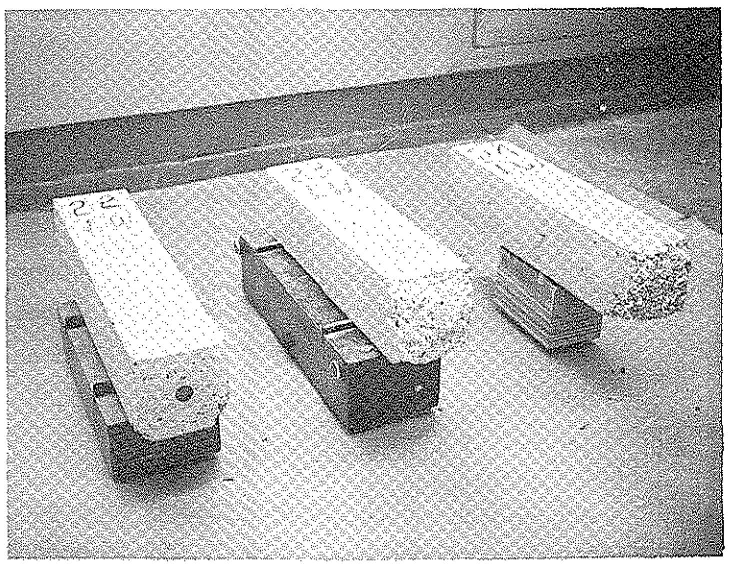

Figure 4 - Beams 22, 23, 24 - Made with
Air Dry Haydite

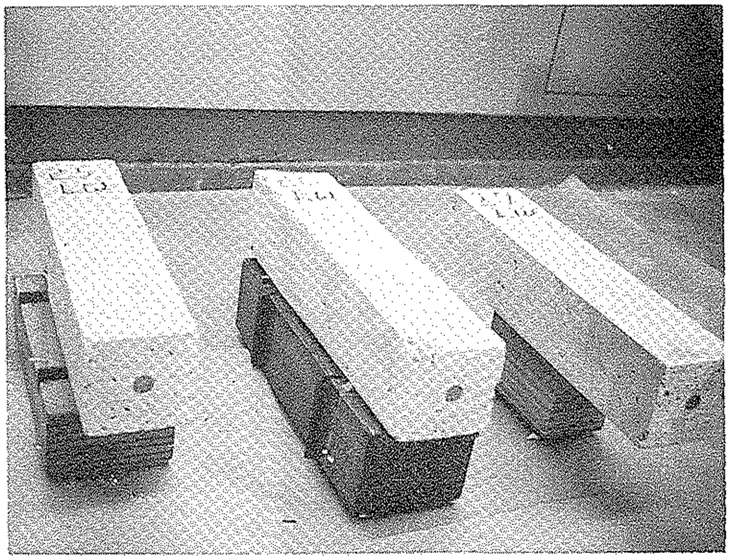

Figure 5 - Beams 25, 26, 27 - Made with
Air Dry Idealite

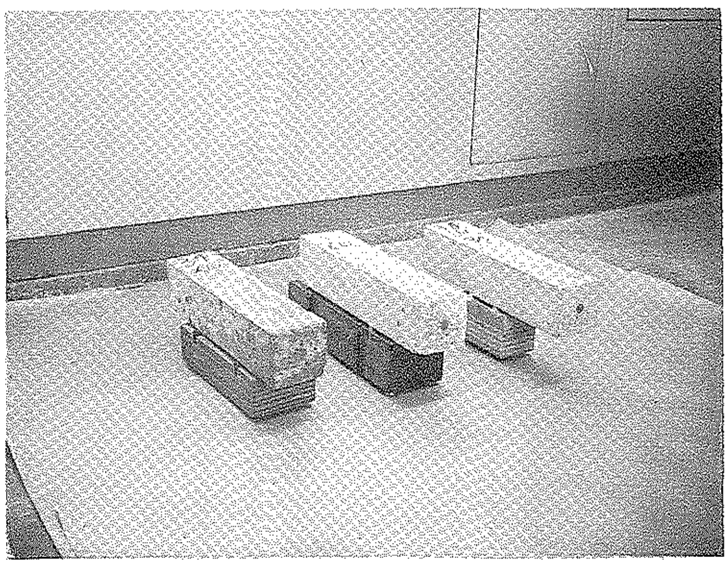

Figure 6 - Beams 34, 35, 36 - Made with
Air Dry Idealite

Figure 7 - Beams 37, 38, 39 - Made with Finer Air Dry Idealite

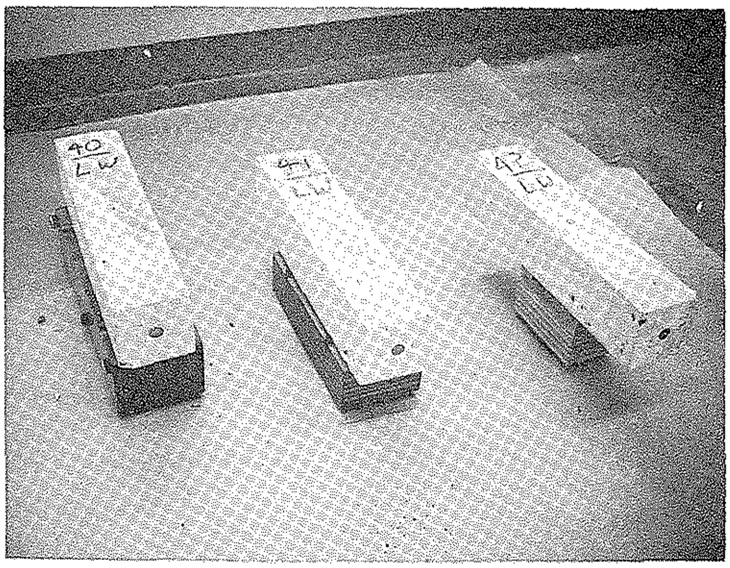

Figure 8 - Beams 40, 41, 42 - Made with Air Dry Materialite (DF = 2 @ 16, 1 @ 24)

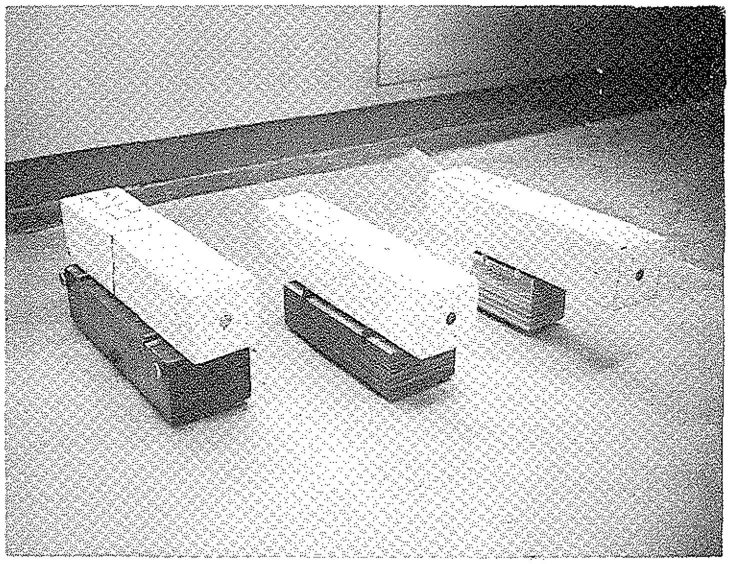

Figure 9 - Beams 43, 44, 45 - Made with
Saturated Materialite (DF = 5)

Table 1

MATERIALS DEPARTMENT
DATA SHEET

Lightweight Aggregate (Haydite)
Plant Mixed Specimens

Mix No.	1	2	3	4	5
Cylinder No.	1-LW, 2-LW, 3-LW	4-LW, 5-LW, 6-LW	7-LW, 8-LW, 9-LW		1-A, 3-A, 5-A, 6-A
Condition at Mixing	Wet	Wet	Wet	Wet	Damp
Compressive Strength 28 day	7265	7525	7445		
43 day					1-A, 3-A=6410
Splitting Tensile Strength 43 day					5-A, 6-A= 382
Density, Lb./Cu.Ft.					
Absorption			7-LW = 7.3 8-LW = 9.1		
Date Made	8-10-67	8-10-67	8-14-67	8-14-67	
Initial Cure	Radiant Heat 13-14 Hr. @ 165-170°F.	Covered by Tarp for 14 Hr.	Steam Cure 15 Hr. 140-150°F.		
Modulus of Elasticity, (Tested Dry) 43 day					3.25×10^6 psi.
Beam Nos.	1-LW, 2-LW, 3-LW	4-LW, 5-LW, 6-LW	7-LW, 8-LW, 9-LW	10-LW, 11-LW, 12-LW	
Durability Factor	9	11	8		
Cycles	45	56	39		
Growth, Inches - Cycles	.096 - 64	.161 - 88	.066 - 56		
Beam Condition					

Table 2

MATERIALS DEPARTMENT
DATA SHEET
Lightweight Aggregate and Lightweight Concrete

Mix No.	6	7	8	9	10	11	12	13	14	15	16
Cylinder Nos.	4551- 4555	4561- 4565	4556- 4560	4566- 4570	4577- 4582	4583- 4588	4571- 4576	4589- 4594	4595- 4600	4610- 4612	4607- 4609
Lightweight Agg.	Haydite	Haydite	Haydite	Haydite	Idealite	Idealite	Idealite	Idealite	Idealite (finer)	Materialite	Materialite
Condition for mixing	Saturated	Saturated	Air dry	Air dry	Saturated	Saturated	Air dry	Air dry	Air dry	Saturated	Air dry
Cement Sacks/yd.	7.49	7.59	7.58	7.49	7.93	8.05	7.92	7.90	8.10	7.25	7.66
Slump	2 1/2	3.0	2 3/4	2 1/2	3.0	3 1/2	3.0	2 1/2	2 1/2	4 1/2	4 1/2
Compressive Str. 7 day	4900	5130	4910	4985	5620	5370	5935	5845	6370		
28 day		6835	6720			7250	7580		7970*	6685	6460
Splitting Tensile Str. 28 day	437			383	398			367			
Mod of Elasticity 7 day	$2.86x10^6$		$2.92x10^6$								
28 day		$3.58x10^6$	$3.54x10^6$			$3.20x10^6$	$3.44x10^6$		$3.43x10^6$	$3.27x10^6$	$3.34x10^6$
Concrete Abs.		6.76	7.58			6.99	6.11		7.58	6.6	9.25
Beam Nos.	13-15 LW	19-21 LW	16-18 LW	22-24 LW	28-30 LW	31-33 LW	25-27 LW	34-36 LW	37-39 LW	43-45 LW	40-42 LW
Durability Factor	2 @ 27 1 @ 100	2 @ 22 1 @ 100	100	100	7	5	97	97		5	2 @ 16 1 @ 24
Cycles	133 321	110 316	321	305	36	24	312	308	2-209 1-241	27	78 121
Growth (No.-Growth-Cycles) Inches	2-.067-159 1-.052-321	2-.100-143	.045-321	.045-305	.215-78	.056-31	.004-312	.005-308	3-.066-185	.046-38	2-.041-105 1-.040-129
Beam Condition	Bottom end crumbling	ends crumbled	Bottom end crumbling	Bottom end crumbling	Disint-egrated	Badly cracked	very good	very good	top & bottom crumbled		
Aggregate Abs.	8.85	7.20			7.73					8.3	
"A" F & T	2.9, 1.7				2.8					3.1	
LA Abrasion	(C)22,25				(B)22					(B)29	

* 27 day