ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

Progress Report

STUDY OF FLY ASH FROM ST. CLAIR AND CONNERS CREEK STATIONS IN NONAIR-ENTRAINED CONCRETE

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Project 2211-5-P

DETROIT EDISON COMPANY
DETROIT, MICHIGAN

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SYNOPSIS

This report gives the results of a study of the use of fly ash from the St. Clair and Conners Creek stations of the Detroit Edison Company in nonair-entrained concrete. Previous reports have dealt with the use of fly ash from these stations in air-entrained concrete.

The strengths of comparable mixes made with the St. Clair and with the Conners Creek fly ashes are very close, indicating that there may be no appreciable difference in the effect of the two fly ashes on the compressive strength of nonair-entrained concrete up to 28 days of age. As in the earlier studies with air-entrained concrete, fly ash in lean mixes improves the strength over lean, plain cement mixes at early ages, while the fly ash in the richer mixes tends to depress the strength somewhat.

The fly ash suppresses the already small amount of air entrained in this concrete, thus making it more susceptible to frost action if exposed to weathering. Data to support this conclusion are not contained herein but will be reported separately. Mention of this is made here, however, as an important precaution in the use of nonair-entrained fly-ash concrete.

The strength of job concrete should not be predicted from the data contained in this report unless suitable safety factors are utilized to compensate for possible field variations in proportioning, mixing, and curing.

OBJECTIVE

The purpose of this investigation is to study the properties of fly ash and concrete containing fly ash. The specific purpose of the phase of the research covered by this report is to determine the effect of fly ash from the St. Clair and Conners Creek stations of the Detroit Edison Company in nonair-entrained concrete, as indicated by workability, compressive strength, and volume change.

It is anticipated that the results of this investigation will provide useful information for those interested in the use of fly ash in portland-cement concrete.

INTRODUCTION

This report on the use of Detroit Edison Company fly ash covers the use of such ash from the St. Clair and Conners Creek power plants in nonair-entrained concrete. The data presented herein were developed in laboratory studies performed by the Engineering Research Institute of the University of Michigan, pursuant to a contract between the Institute and the Detroit Edison Company.

As in the preceding reports on air-entrained concrete containing fly ash, this report contains only data from compressive-strength tests up to 28 days of age. Results from compressive-strength specimens for testing at 90 days and one year and from volume-change bars will be given in a later report.

Some matter pertaining to test procedures which was covered previously will be omitted here to avoid repetition.

This report is concerned with the use of St. Clair and Conners Creek fly ashes in nonair-entrained concrete exclusively. It is recommended that this concrete be used only where it will not be exposed to freezing action in the presence of moisture.

MIX DESIGN

The mix-design procedure was identical with that used in the previous studies of fly ash in concrete. Increased stone contents over those recommended by the American Concrete Institute for use in normal concrete were again employed in the fly-ash mixes to take full advantage of the plasticity of the mortar constituent provided by the addition of fly ash.

Concrete with cement contents ranging from 3.0 to 6.5 sacks per cubic yard of concrete was investigated. Cement contents were selected so that in most cases, a comparison could be made with the air-entrained concrete containing fly ash, the results of which were previously reported. St. Clair fly ash in four ash contents for 3.5-, 4.5-, and 5.5- sack mixes was used. Four ash contents of Conners Creek fly ash were used in mixes with 4.0, 5.0, and 5.5 sacks of cement per cubic yard. Mixes containing 6.5 sacks of cement without fly ash were made for comparison. In addition, mixes were made with four different amounts of

St. Clair fly ash and 3.0 sacks of high-early-strength cement per cubic yard.

The "Recommended Practice for Selecting Proportions for Concrete" (ACI 613-54), the standard of the American Concrete Institute, was again used as the design basis for mixes containing no fly ash and was modified for use as the design basis for the fly-ash mixes.

MATERIALS

The concrete materials were the same as those used previously, with the exception of the cement. The series was started using the same cement as was used in the previous series with St. Clair fly ash in air-entrained concrete. This cement was a blend of equal amounts of Huron, Peerless, and Wyandotte brands. Near the end of the making of the batches it was necessary to order additional cement. Due to labor troubles and the high demand for cement during the spring, it was not possible to obtain Wyandotte cement from suppliers in the Ann Arbor area. Thus, it was decided to substitute Peninsular cement. The results do not indicate that this substitution caused any noticeable difference in the concrete.

High-early-strength cement was used for one group of mixes. This consisted of a blend of equal amounts of Aetna, Huron, and Peerless brands. The results of chemical and physical tests of this cement are shown in the appendix.

The other materials were the same as previously reported, namely, one-inch maximum-size natural-gravel coarse aggregate, natural sand having a fineness modulus of 3.0, and fly ash from the St. Clair and Conners Creek stations. The fly ashes were from the same drums as those used in the study of fly ash in air-entrained concrete, and the analyses of these ashes have been presented in the reports on their use in air-entrained concrete.

FABRICATION OF SPECIMENS AND TEST PROCEDURES

The methods of mixing, molding, curing, and testing remained the same as in the previous series with St. Clair fly ash in air-entrained concrete. The paraffined cardboard molds were again removed from the cylinders approximately 24 hours after molding, just prior to placing the cylinders in the moist-fog room for curing.

DISCUSSION OF TEST RESULTS

The concrete-mix data and compressive-strength results are shown in detail in the appendix in the tables for the various cement contents and for the two fly ashes. Important aspects of the data have been summarized from these tables and are presented in the body of the report.

1. COARSE-AGGREGATE CONTENT

The greater amounts of coarse aggregate, which were workable in air-entrained concrete containing fly ash, were found to be equally workable in nonair-entrained concrete with both the St. Clair and Conners Creek ashes. The coarse-aggregate content was varied according to both the cement content and the fly-ash content since the increased fines in the mix from either source will give greater plasticity. Table I gives the values found satisfactory for one-inch maximum-size-pebble coarse aggregate and sand with a fineness modulus of 3.0 used in nonair-entrained mixes with St. Clair and Conners Creek fly ashes. The value used for mixes with no fly ash is as recommended by the American Concrete Institute. The value, V_S, is expressed as the dry-rodded volume of coarse aggregate per unit volume of concrete.

TABLE I

VOLUME, V_S, OF DRY-RODDED COARSE AGGREGATE PER UNIT VOLUME OF CONCRETE

Fly Ash,	Cement Content, sack/cu yd						
lb/cu yd	3.0	3.5	4.0	4.5	5.0	5.5	6.5
0	.64	.64	.64	.64	.64	.64	.64
50				.72	.72	.72	
70	.68						
100		.72	.72	.75	.75	.75	
140	.72						
150		.75	.75	.78	.78	.78	
200		.78	.78	.81	.81	.81	
210	.76						
250		.81	.81				
280	.80						

2. WORKABILITY OF LEAN MIXES

In the low-cement-content mixes without fly ash (3-sack, particularly), there was not sufficient fine material for easy finishing. The fresh concrete had the appearance of a wet sand-gravel mixture. As soon as the concrete was dumped from the mixer, large quantities of water drained from the mixture. As a result, the concrete caked so that low slumps were obtained with little reference to the amount of water added at the mixer.

The addition of at least 70 pounds of fly ash per cubic yard of concrete to the 3-sack mixes provides the necessary fines to give the concrete plasticity and workability. The 3.5-sack concrete also requires some fly ash for good workability. With the air-entrained concrete, the addition of fly ash was not necessary for good plasticity in the 3.5-sack mixes since the entrained air bubbles acted to supplement the fine material in the mix.

3. COMPRESSIVE STRENGTH

Average values of compressive strengths up to 28 days of age are presented in Tables II and III. The results are much the same as with these fly ashes in air-entrained concrete, in that the fly ash in the lean mixes improves the compressive strength over the lean, plain cement mixes at all ages through 28 days, while fly ash in the richer mixes depresses the strength somewhat in nearly every case.

There do not appear to be any great differences in the strengths attained for comparable mixes with the two fly ashes. Variations between comparable 5.5-sack mixes with St. Clair and Conners Creek fly ashes up to 28 days of age appear to be in the range as might be caused by experimental error.

The mixes containing 3 sacks of high-early-strength cement plus St. Clair fly ash were investigated because there have been reports indicating that such a mixture is presently being used in some operations. As indicated previously, when fly ash is not used in such a mix, it is unworkable. The addition of fly ash improves the physical characteristics, resulting in a strength improvement over the plain cement mix from the first day. These mixes with high-early-strength cement show strength improvement over mixes with a higher cement content but made with regular cement.

Table IV shows the strength of the fly-ash mixes at each age expressed as a percent of the strength of the plain cement mixes of the same cement content.

TABLE II

SUMMARY OF RESULTS
ST. CLAIR FLY ASH

Nominal Cement Content, sack/cu yd	Actual Cement Content, sack/cu yd	Fly Ash, lb/cu yd	Net Mixing Water lb/cu yd	Net Mixing Water gal/sack	Air Content, percent	Slump, in.	Compressive Strength, psi 1 day	7 days	28 days	90 days	1 year
	3.01	0	272	10.87	1.6	2.92	523	1606	2182		
3.0	3.01	70	259	10.37	1.1	4.58	593	1934	2791		
(High-Early-	3.00	140	264	10.56	0.8	4.58	633	1894	2855		
Strength	3.01	210	262	10.46	0.9	5.00	686	2019	3287		
Cement)	2.95	280	284	11.36	0.9	4.58	617	1841	3074		
	3.50	0	268	9.21	1.8	2.50	407	1593	2255		
	3.51	100	250	8.57	1.1	3.83	507	2000	3198		
3.5	3.52	150	258	8.83	0.9	5.08	493	1940	3263		
	3.53	200	256	8.80	1.0	3.75	515	1893	3300		
	3.50	250	263	9.01	0.9	4.17	576	2017	3091		
	4.49	0	261	6.96	1.8	3.25	622	2244	3329		
	4.50	50	246	6.58	1.1	3.00	922	2898	4233		
4.5	4.50	100	253	6.75	1.0	4.17	891	2918	3833		
	4.49	150	260	6.94	0.9	4.17	765	2438	3687		
	4.52	200	277	7.40	0.9	3.83	816	2658	4176		
	5.48	0	258	5.57	1.9	4.08	1202	3189	4114		
	5.56	50	251	5.49	1.1	4.58	1193	3528	4301		
5.5	5.55	100	262	5.72	0.9	4.33	1131	3162	4173		
	5.50	150	276	6.02	0.9	4.33	1069	3023	3984		
	5.51	200	284	6.21	1.0	4.25	1024	3003	4135		
6.5	6.47	0	262	4.85	1.7	5.00	1520	3689	4690		

TABLE III

SUMMARY OF RESULTS
CONNERS CREEK FLY ASH

Nominal Cement Content, sack/cu yd	Actual Cement Content, sack/cu yd	Fly Ash, lb/cu yd	Net Mixing Water		Air Content, percent	Slump, in.	Compressive Strength, psi				
			lb/cu yd	gal/sack			1 day	7 days	28 days	90 days	1 year
	4.02	0	273	8.19	1.2	4.17	455	1908	2768		
	4.02	100	252	7.55	1.0	3.25	617	2423	3584		
4.0	4.01	150	250	7.52	1.0	3.75	592	2325	3898		
	4.00	200	263	7.92	1.0	4.08	688	2450	3937		
	4.00	250	275	8.26	0.9	5.25	658	2213	3643		
	4.97	0	259	6.22	1.9	4.08	890	2856	3568		
	4.99	50	254	6.10	1.1	3.67	1042	3349	4254		
5.0	5.01	100	261	6.27	1.0	4.67	961	3144	4093		
	5.01	150	274	6.59	0.8	5.17	887	2851	3883		
	5.05	200	277	6.66	0.8	4.00	952	2870	4063		
	5.48	0	258	5.57	1.9	4.08	1202	3189	4114		
	5.47	50	262	5.71	1.1	4.17	1056	3278	4584		
5.5	5.50	100	264	5.75	1.0	4.00	1158	3148	4024		
	5.47	150	274	5.98	1.0	4.83	1106	3061	3984		
	5.50	200	292	6.38	1.0	3.92	955	3031	4201		
6.5	6.47	0	262	4.85	1.7	5.00	1520	3689	4690		

TABLE IV

COMPRESSIVE STRENGTH OF FLY-ASH MIXES EXPRESSED AS PERCENT OF STRENGTH OF PLAIN CEMENT MIXES OF THE SAME CEMENT CONTENT.

Cement, sack/cu yd	Fly Ash Source	Fly Ash lb/cu yd	1 day	7 days	28 days
3.0 (High-Early-Strength Cement)	St. Clair	70	113	120	128
		140	121	118	131
		210	131	126	151
		280	118	115	141
3.5	St. Clair	100	125	126	142
		150	121	122	145
		200	127	119	146
		250	142	127	137
4.0	Conners Creek	100	136	127	129
		150	130	122	141
		200	151	128	142
		250	145	116	132
4.5	St. Clair	50	148	129	127
		100	143	130	115
		150	123	109	111
		200	131	118	125
5.0	Conners Creek	50	117	117	119
		100	108	110	115
		150	100	100	109
		200	107	100	114
5.5	St. Clair	50	99	110	105
		100	94	99	101
		150	89	95	97
		200	85	94	101
5.5	Conners Creek	50	88	103	111
		100	96	99	98
		150	92	96	97
		200	79	95	102

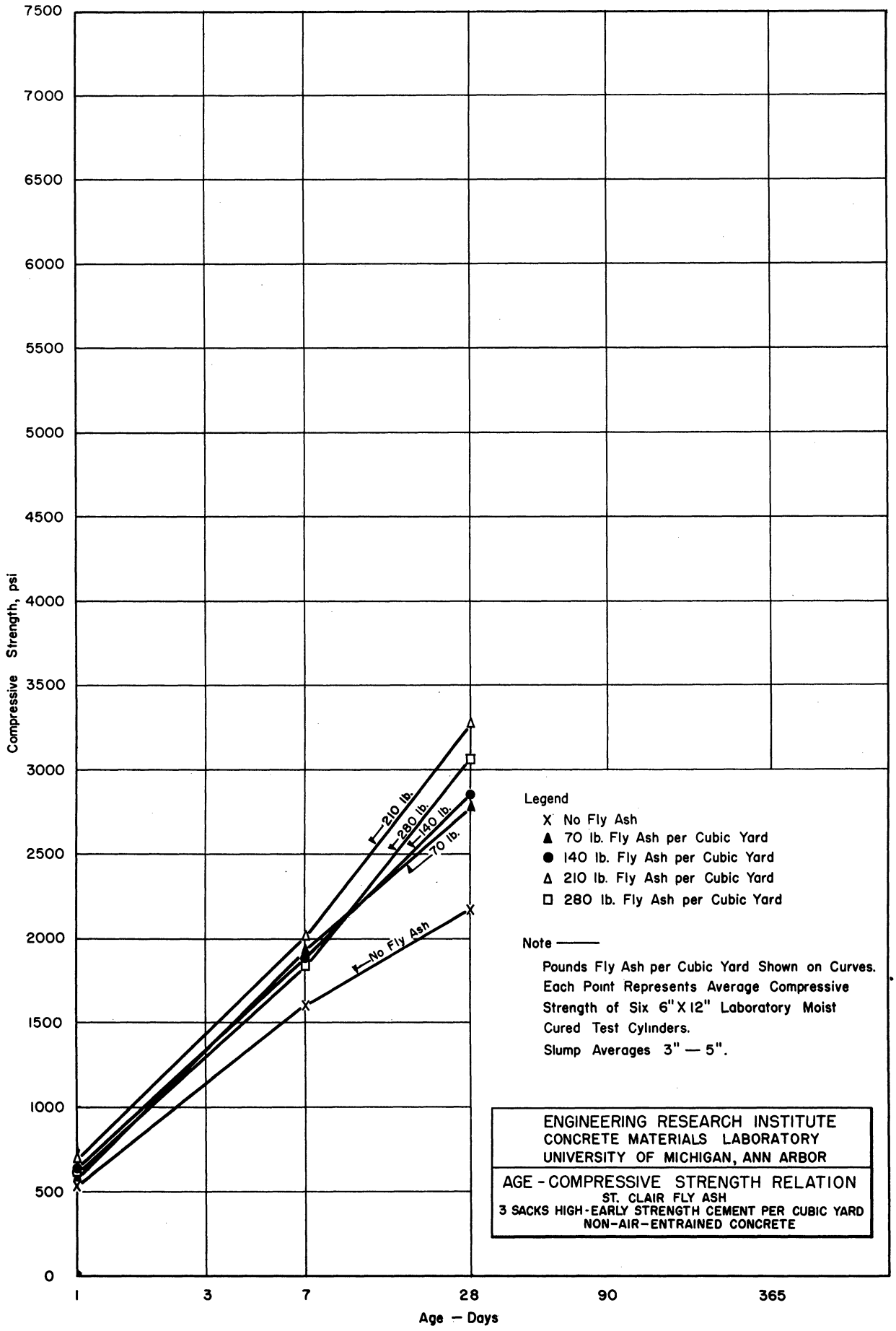
The average strengths for each of the cement and fly-ash contents have been plotted against the age in Figures 1 to 7. Strength gain is generally orderly, as in the case of the fly ashes used in air-entrained concrete.

4. AIR CONTENT OF CONCRETE

This study was designed and conducted as an investigation of fly ash in nonair-entrained concrete. However, all cement entrains a small amount of air to give the concrete some degree of durability in weathering. The air content of the mixes with both St. Clair and Conners Creek fly ashes was considerably below that of the plain cement mixes. The air contents for the fly-ash mixes range from 0.8 to 1.1 percent with an average of 0.97 percent. The air contents of the plain cement mixes range from 1.2 to 1.9 percent with an average of 1.70 percent entrained air.

While the air content in both cases is too small to prevent deterioration of concrete exposed to weathering in the presence of moisture, the fly-ash concrete, because of its lower air content, will be more susceptible to frost action than the plain cement concrete. Thus, it becomes increasingly necessary to use proper air entrainment in all fly-ash concrete which may be exposed to the weather in northern climates, particularly where moisture is supplied to the concrete, such as in the case of sidewalks, pavement slabs, or retaining walls with poorly drained backfills.

Data to support the above observations on the weather resistance of fly-ash concrete are now being acquired and will be separately reported. For view of its importance, however, salient features are here presented.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7000
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5500
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4500
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3500
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1500
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500
0
Compressive Strength, psi
1
3
7
28
90
365
Age — Days
210 lb.
280 lb.
140 lb.
70 lb.
No Fly Ash
Legend
X No Fly Ash
▲ 70 lb. Fly Ash per Cubic Yard
● 140 lb. Fly Ash per Cubic Yard
Δ 210 lb. Fly Ash per Cubic Yard
□ 280 lb. Fly Ash per Cubic Yard
Note ——
Pounds Fly Ash per Cubic Yard Shown on Curves.
Each Point Represents Average Compressive Strength of Six 6" X 12" Laboratory Moist Cured Test Cylinders.
Slump Averages 3" — 5".
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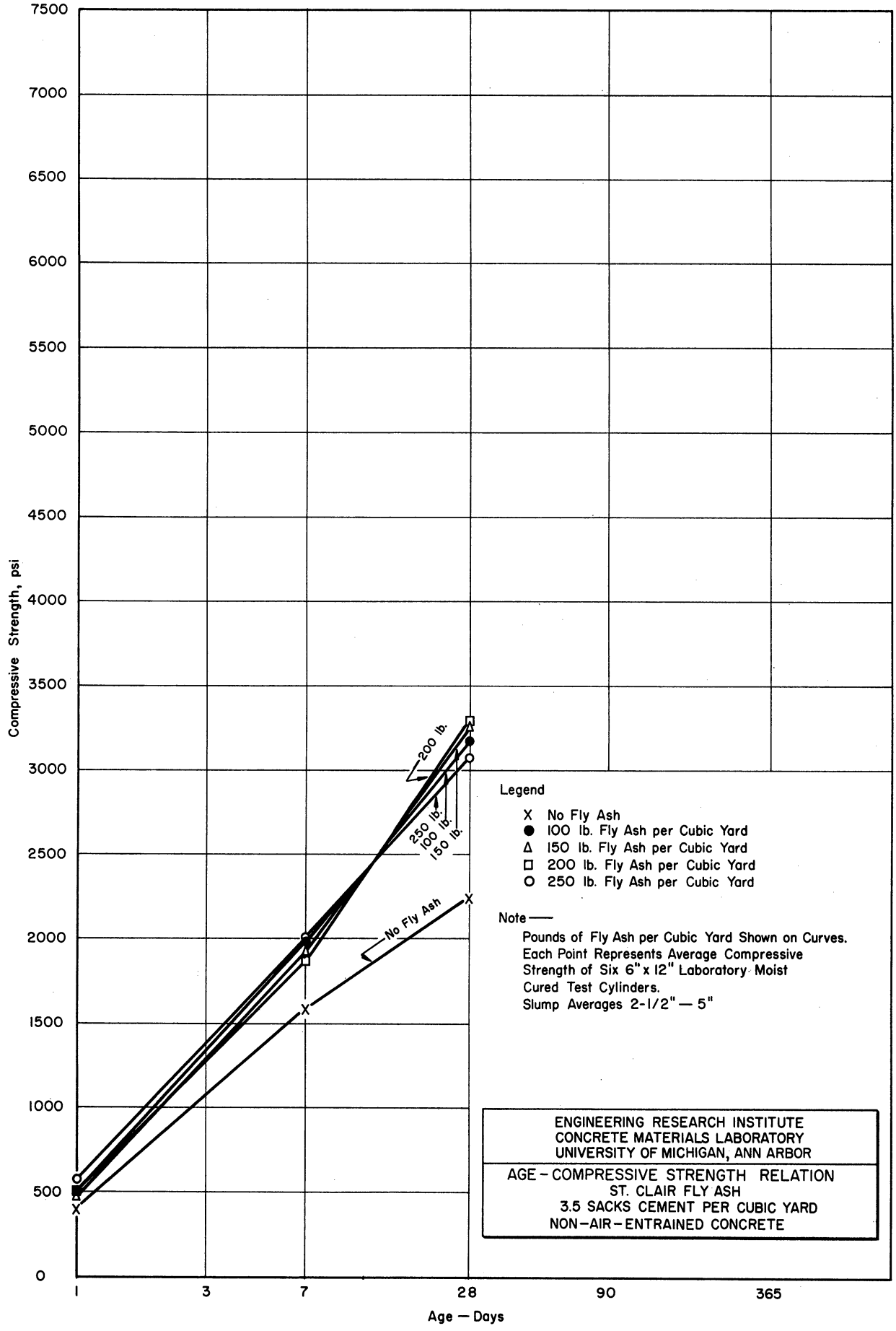
AGE - COMPRESSIVE STRENGTH RELATION
ST. CLAIR FLY ASH
3 SACKS HIGH-EARLY STRENGTH CEMENT PER CUBIC YARD
NON-AIR-ENTRAINED CONCRETE

Fig. 1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Compressive Strength, psi
1
3
7
28
90
365
Age — Days
200 lb.
250 lb.
100 lb.
150 lb.
No Fly Ash
Legend
X No Fly Ash
● 100 lb. Fly Ash per Cubic Yard
Δ 150 lb. Fly Ash per Cubic Yard
□ 200 lb. Fly Ash per Cubic Yard
○ 250 lb. Fly Ash per Cubic Yard
Note —
Pounds of Fly Ash per Cubic Yard Shown on Curves.
Each Point Represents Average Compressive Strength of Six 6" x 12" Laboratory Moist Cured Test Cylinders.
Slump Averages 2-1/2" — 5"
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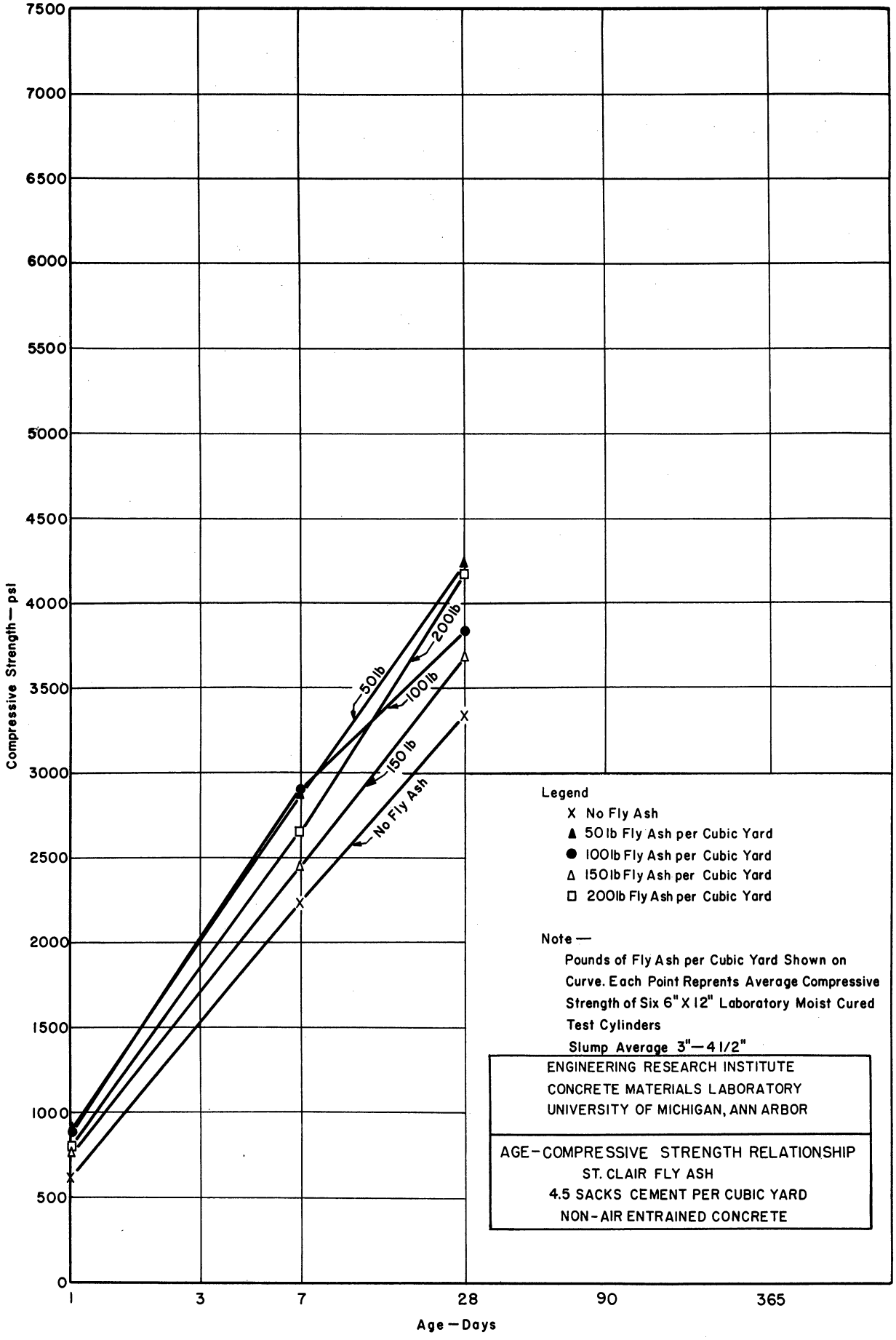
AGE - COMPRESSIVE STRENGTH RELATION
ST. CLAIR FLY ASH
3.5 SACKS CEMENT PER CUBIC YARD
NON-AIR-ENTRAINED CONCRETE

Fig. 2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Compressive Strength — psi
1
3
7
28
90
365
Age — Days
50lb
100lb
150 lb
200lb
No Fly Ash
Legend
X No Fly Ash
▲ 50 lb Fly Ash per Cubic Yard
● 100lb Fly Ash per Cubic Yard
Δ 150lb Fly Ash per Cubic Yard
□ 200lb Fly Ash per Cubic Yard
Note —
Pounds of Fly Ash per Cubic Yard Shown on Curve. Each Point Reprents Average Compressive Strength of Six 6" X 12" Laboratory Moist Cured Test Cylinders
Slump Average 3"—4 1/2"
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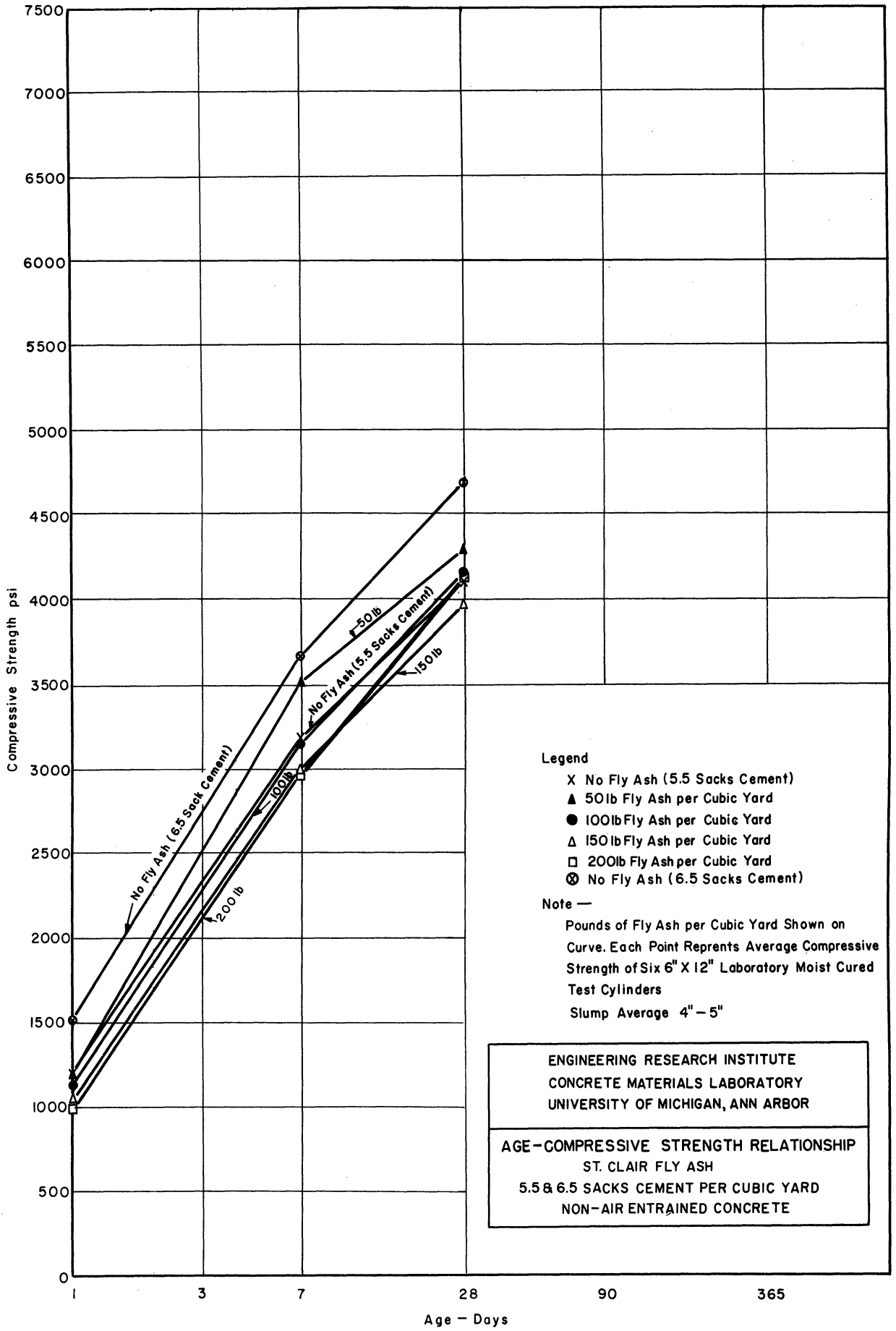
AGE-COMPRESSIVE STRENGTH RELATIONSHIP
ST. CLAIR FLY ASH
4.5 SACKS CEMENT PER CUBIC YARD
NON-AIR ENTRAINED CONCRETE

Fig. 3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Compressive Strength psi
1
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7
28
90
365
Age – Days
No Fly Ash (6.5 Sack Cement)
50lb
No Fly Ash (5.5 Sacks Cement)
150lb
100lb
200lb
Legend
X No Fly Ash (5.5 Sacks Cement)
▲ 50lb Fly Ash per Cubic Yard
● 100lb Fly Ash per Cubic Yard
Δ 150lb Fly Ash per Cubic Yard
□ 200lb Fly Ash per Cubic Yard
⊗ No Fly Ash (6.5 Sacks Cement)
Note —
Pounds of Fly Ash per Cubic Yard Shown on Curve. Each Point Reprents Average Compressive Strength of Six 6" X 12" Laboratory Moist Cured Test Cylinders
Slump Average 4" – 5"
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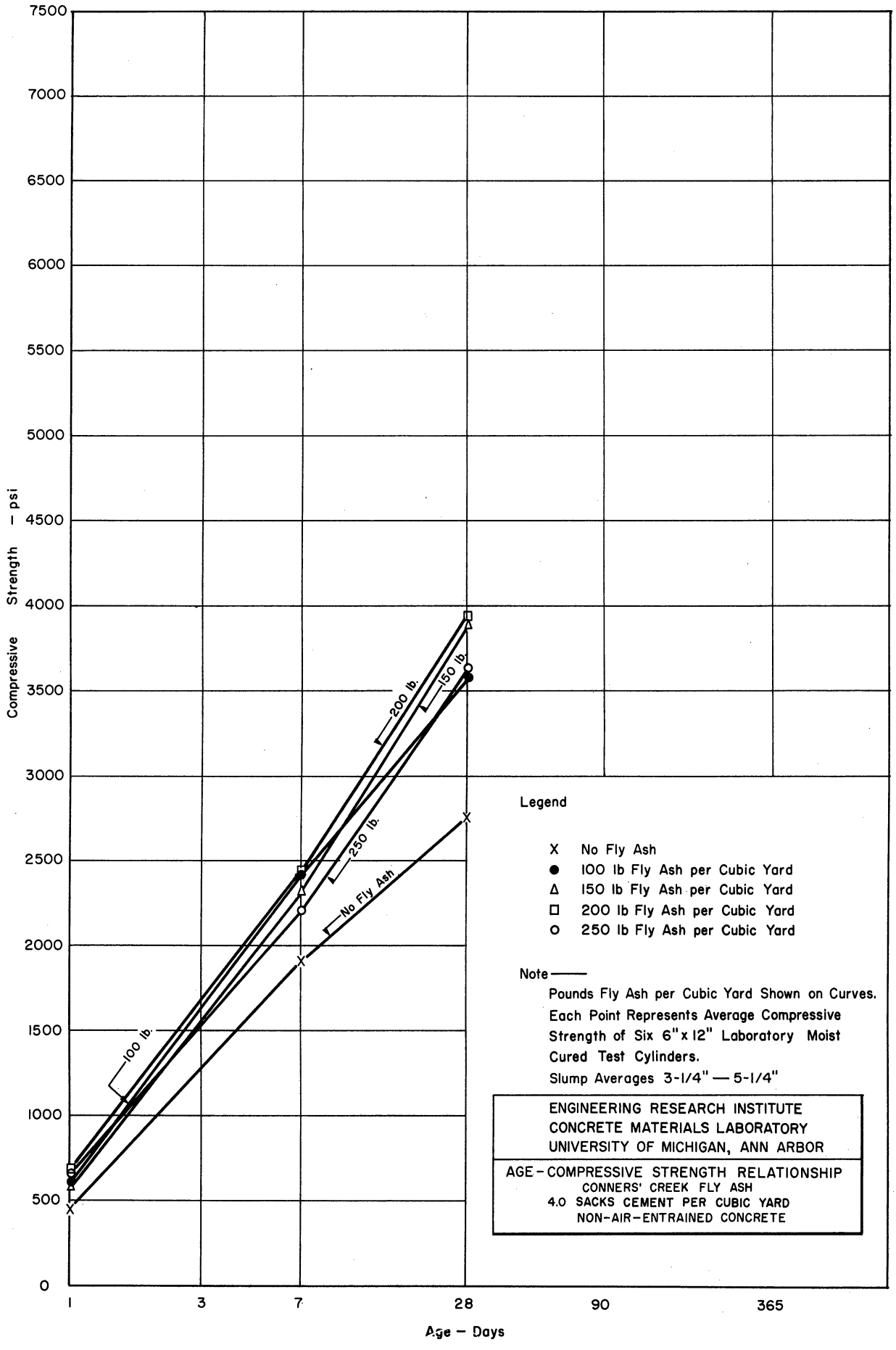
AGE-COMPRESSIVE STRENGTH RELATIONSHIP
ST. CLAIR FLY ASH
5.5 & 6.5 SACKS CEMENT PER CUBIC YARD
NON-AIR ENTRAINED CONCRETE

Fig. 4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Compressive Strength - psi
1
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7
28
90
365
Age - Days
100 lb.
150 lb.
200 lb.
250 lb.
No Fly Ash
Legend
X No Fly Ash
● 100 lb Fly Ash per Cubic Yard
Δ 150 lb Fly Ash per Cubic Yard
□ 200 lb Fly Ash per Cubic Yard
o 250 lb Fly Ash per Cubic Yard
Note
Pounds Fly Ash per Cubic Yard Shown on Curves.
Each Point Represents Average Compressive Strength of Six 6" x 12" Laboratory Moist Cured Test Cylinders.
Slump Averages 3-1/4" — 5-1/4"
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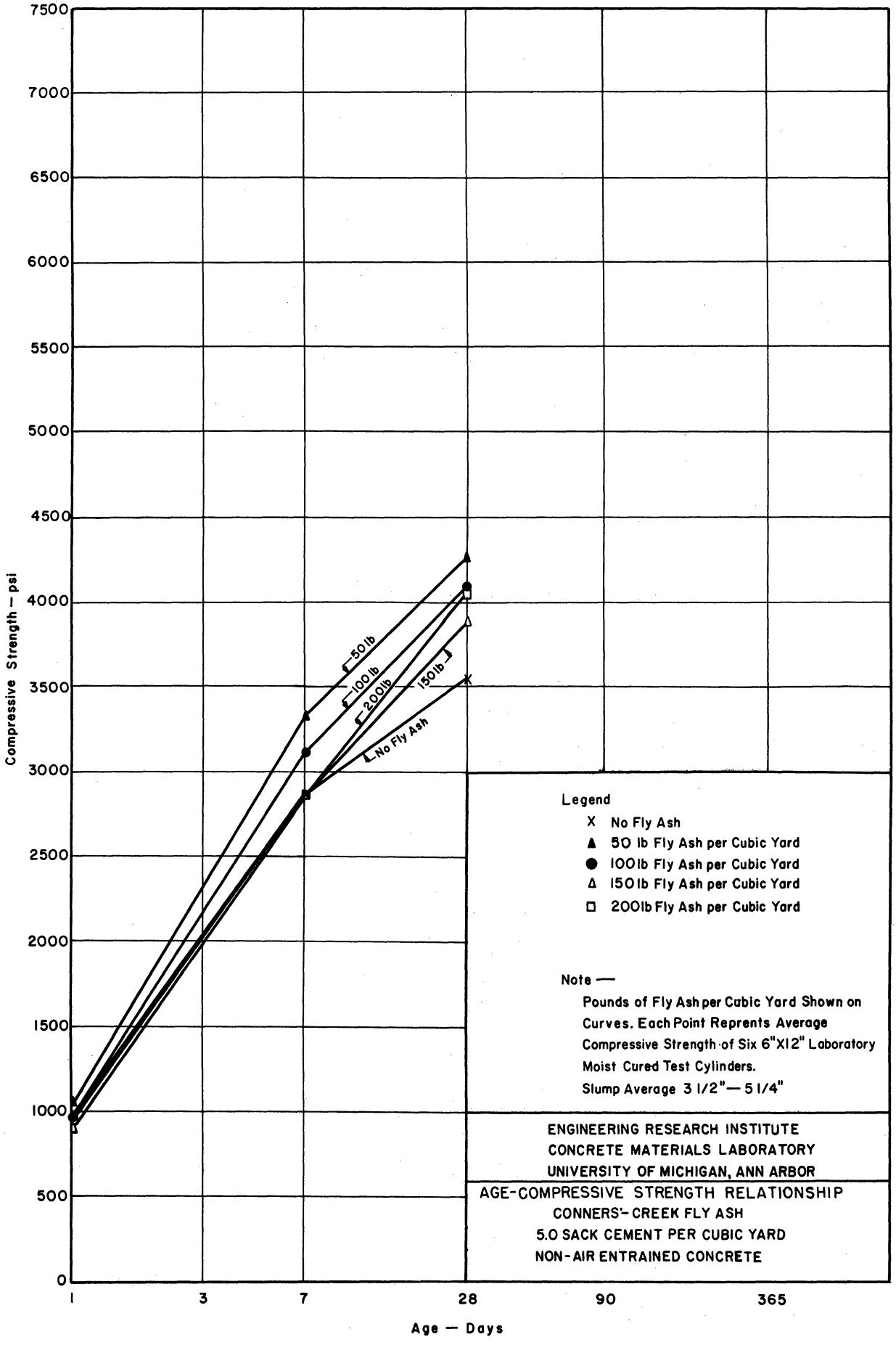
AGE-COMPRESSIVE STRENGTH RELATIONSHIP
CONNERS' CREEK FLY ASH
4.0 SACKS CEMENT PER CUBIC YARD
NON-AIR-ENTRAINED CONCRETE

Fig. 5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Compressive Strength – psi
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28
90
365
Age – Days
50 lb
100 lb
200lb
150lb
No Fly Ash
Legend
X No Fly Ash
▲ 50 lb Fly Ash per Cubic Yard
● 100lb Fly Ash per Cubic Yard
Δ 150lb Fly Ash per Cubic Yard
□ 200lb Fly Ash per Cubic Yard
Note —
Pounds of Fly Ash per Cubic Yard Shown on Curves. Each Point Reprents Average Compressive Strength of Six 6"X12" Laboratory Moist Cured Test Cylinders.
Slump Average 3 1/2" — 5 1/4"
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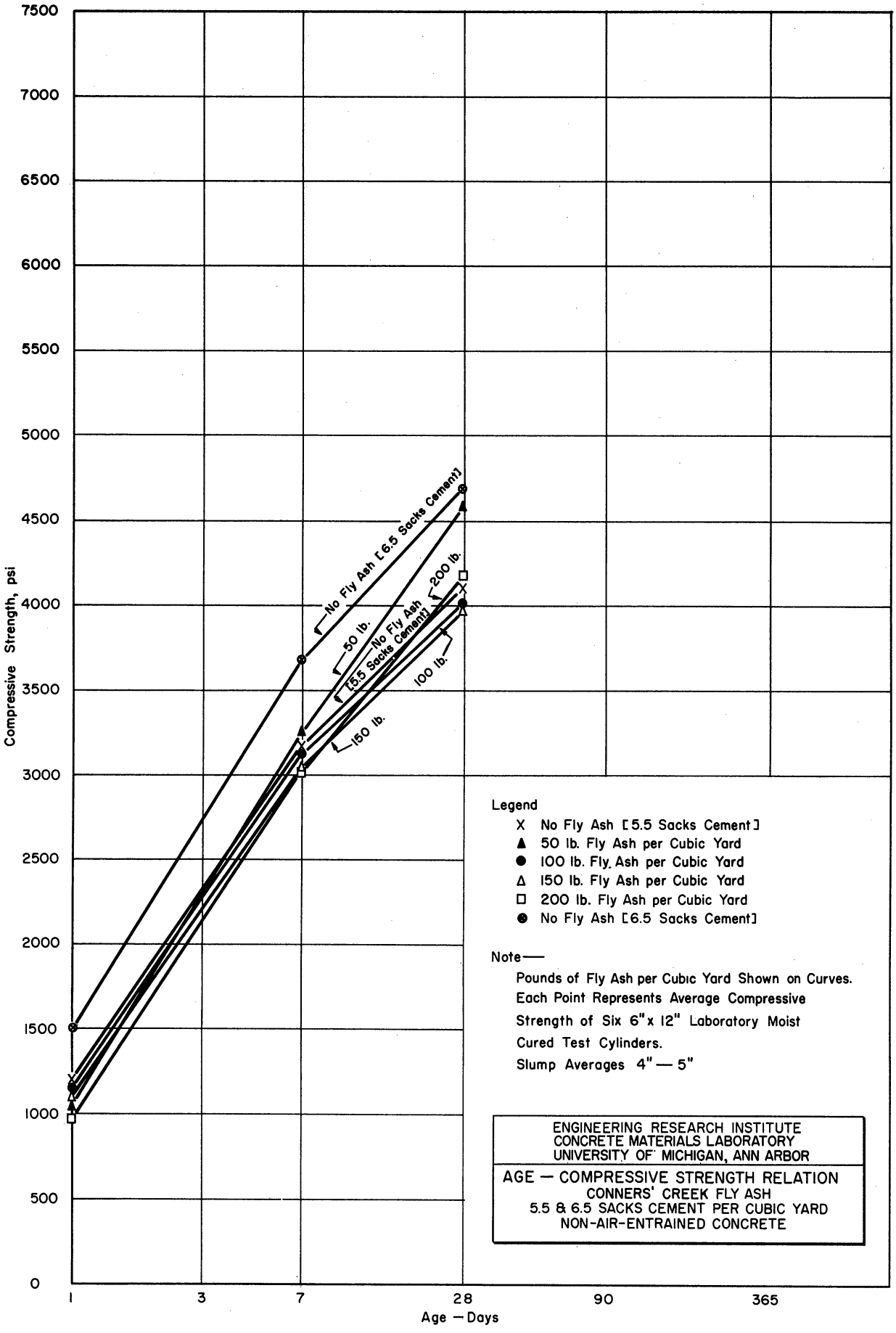
AGE-COMPRESSIVE STRENGTH RELATIONSHIP
CONNERS-CREEK FLY ASH
5.0 SACK CEMENT PER CUBIC YARD
NON-AIR ENTRAINED CONCRETE

Fig. 6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Compressive Strength, psi
1
3
7
28
90
365
Age — Days
No Fly Ash [6.5 Sacks Cement]
50 lb.
No Fly Ash [5.5 Sacks Cement]
200 lb.
100 lb.
150 lb.
Legend
X No Fly Ash [5.5 Sacks Cement]
▲ 50 lb. Fly Ash per Cubic Yard
● 100 lb. Fly Ash per Cubic Yard
Δ 150 lb. Fly Ash per Cubic Yard
□ 200 lb. Fly Ash per Cubic Yard
⊛ No Fly Ash [6.5 Sacks Cement]
Note—
Pounds of Fly Ash per Cubic Yard Shown on Curves.
Each Point Represents Average Compressive Strength of Six 6"x 12" Laboratory Moist Cured Test Cylinders.
Slump Averages 4" — 5"
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AGE — COMPRESSIVE STRENGTH RELATION
CONNERS' CREEK FLY ASH
5.5 & 6.5 SACKS CEMENT PER CUBIC YARD
NON-AIR-ENTRAINED CONCRETE

Fig. 7

APPENDIX

TABLE I-A

PROPERTIES OF HIGH-EARLY-STRENGTH CEMENT

55C-120

Physical Properties

Normal consistency, percent	26.4
Time of set, Gillmore	
Initial	3 hr, 50 min
Final	5 hr, 50 min
Autoclave expansion, percent	0.07
Air in mortar, percent	9.9
Tensile strength, psi	
1 day	278
3 days	402
7 days	422
28 days	473
Compressive strength, psi	
1 day	1750
3 days	3933
7 days	4292
28 days	5650

Chemical Properties

Ultimate analysis
Percent by weight

Silicon dioxide	SiO_2	20.6
Aluminum oxide	Al_2O_3	5.6
Ferric oxide	Fe_2O_3	3.0
Calcium oxide	CaO	63.0
Magnesium oxide	MgO	2.3
Sulfur trioxide	SO_3	2.9
Loss on ignition		2.1
Sodium oxide	Na_2O	0.21
Potassium oxide	K_2O	0.66

Proximate analysis
Percent by weight

Loss on ignition		2.0
Tricalcium silicate	$3CaO.SiO_2$	50.0
Dicalcium silicate	$2CaO.SiO_2$	22.0
Tricalcium aluminate	$3CaO.Al_2O_3$	10.0
Tetracalcium aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	9.0
Calcium sulphate	$CaSO_4$	5.0
Magnesia	MgO	2.0
Total alkali expressed as Na_2O		0.65

TABLE II - A

3-SACK, REGULAR-CONCRETE DATA — ST. CLAIR FLY ASH
(HIGH-EARLY-STRENGTH CEMENT, TYPE III)

Batch No.	Date Made	Fly Ash, lb/cu yd	Actual Cement Content, sack/cu yd	V_s**	Material Proportions, lb/cu yd			W/C, gal./sack	Wt. Fresh Concrete, lb/cu ft	Pressure Air Content, percent	Slump, in.	Compressive Strength, psi (6" x 12" Cylinders)				
					Sand	Stone	Net Water					1 day	7 days	28 days	90 days	1 year
214	4-11-55	0	3.01	0.64	1612	1814	269	10.77	149.8	2.1	1.25	580	1890	2455		
												565	1750	2615		
249	5-12-55	0	3.03	0.64	1553	1814	267	10.69	148.3	1.3	3.5	620	1715	2295		
												560	1680	2350		
295	6-14-55	0	3.00	0.64	1569	1814	279	11.16	148.0	1.5	4.0	410	1345	1680		
												405	1255	1695		
	Average	0	3.01	0.64	1578	1814	272	10.87	148.7	1.6	2.92	523	1606	2182		
216	4-11-55	70	2.99	0.68	1483	1928	264	10.56	150.4	1.3	2.75	600	1890	2915		
												600	1945	2880		
245	4-27-55	70	3.04	0.68	1431	1928	258	10.32	150.9	1.0	5.75	645	1945	2705		
												645	2100	2595		
293	6-13-55	70	2.99	0.68	1464	1928	256	10.22	149.7	0.9	5.25	535	1890	2720		
												530	1835	2930		
	Average	70	3.01	0.68	1459	1928	259	10.37	150.3	1.1	4.58	593	1934	2791		
215	4-11-55	140	3.00	0.72	1310	2041	264	10.57	151.2	1.2	4.0	760	2140	2860		
												740	2140	3250*		
241	4-25-55	140	3.01	0.72	1301	2041	269	10.77	150.4	0.6	4.75	560	1680	2580		
												570	1610	2650		
296	6-14-55	140	3.00	0.72	1259	2041	258	10.33	149.4	0.7	5.0	585	1765	3075		
												585	2030	3110		
	Average	140	3.00	0.72	1290	2041	264	10.56	150.3	0.8	4.58	633	1894	2855		
217	4-11-55	210	3.02	0.76	1112	2155	268	10.72	152.1	1.2	5.00	635	2030	3235		
												620	1980	3465		
239	4-25-55	210	3.01	0.76	1080	2155	267	10.67	150.4	0.7	5.75	635	1800	2755		
												655	1800	2670		
291	6-13-55	210	3.00	0.76	1086	2155	250	10.00	149.5	0.7	4.25	775	2155	3885		
												795	2350	3710		
	Average	210	3.01	0.76	1093	2155	262	10.46	150.7	0.9	5.00	686	2019	3287		
218	4-14-55	280	2.99	0.80	913	2268	278	11.14	150.2	1.2	3.25	740	2030	3110		
												740	1910	2845		
240	4-25-55	280	2.86	0.80	1065	2268	287	11.50	149.5	1.0	4.50	585	1520*	2490*		
												585	1765	2790		
292	6-13-55	280	3.01	0.80	836	2268	286	11.43	148.4	0.6	6.0	515	1785	3320		
												535	1715	3305		
	Average	280	2.95	0.80	938	2268	284	11.36	149.4	0.9	4.58	617	1841	3074		

* Not included in average
** Denotes volume of dry-rodded coarse aggregate per unit volume of concrete

TABLE III - A

3.5-SACK REGULAR-CONCRETE DATA — ST. CLAIR FLY ASH

Batch No.	Date Made	Fly Ash, lb/cu yd	Actual Cement Content, sack/cu yd	V_s**	Material Proportions, lb/cu yd			W/C, gal./sack	Wt. Fresh Concrete, lb/cu ft	Pressure Air Content, percent	Slump, in.	Compressive Strength, psi (6" x 12" Cylinders)				
					Sand	Stone	Net Water					1 day	7 days	28 days	90 days	1 year
206	4-7-55	0	3.54	0.64	1553	1814	256	8.79	149.9	2.3	1.0	460	1855	2775		
												440	1980	2755		
254	5-19-55	0	3.49	0.64	1546	1814	276	9.48	148.1	1.6	4.5	445	1590	2260		
												450	1590	2155		
266	5-27-55	0	3.48	0.64	1568	1814	273	9.35	148.5	1.4	2.0	330	1325	1855		
												315	1220	1730		
	Average	0	3.50	0.64	1556	1814	268	9.21	148.8	1.8	2.5	407	1593	2255		
201	4-5-55	100	3.52	0.72	1284	2041	237	8.14	150.6	1.2	2.5	600	2280	3605		
												600	2085	3550		
225	4-15-55	100	3.50	0.72	1321	2041	260	8.93	152.1	1.1	6.0	490	1945	3075		
												485	1890	2970		
278	6-2-55	100	3.51	0.72	1299	2041	252	8.64	151.2	1.0	3.0	440	1910	3005		
												425	1890	2985		
	Average	100	3.51	0.72	1301	2041	250	8.57	151.3	1.1	3.83	507	2000	3198		
198	4-5-55	150	3.52	0.75	1139	2126	259	8.88	151.1	1.1	4.0	565	2050	3445		
												565	2065	3605		
256	5-19-55	150	3.51	0.75	1139	2126	261	8.95	150.7	0.8	6.0	510	1960	3180		
												510	1785	3040		
279	6-2-55	150	3.53	0.75	1139	2126	253	8.66	150.9	0.8	5.25	405	1925	3145		
												405	1855	3160		
	Average	150	3.52	0.75	1139	2126	258	8.83	150.9	0.9	5.08	493	1940	3263		
199	4-5-55	200	3.49	0.78	995	2211	265	9.09	149.5	1.1	4.0	530	1835	3620		
												495	1910	3480		
231	4-19-55	200	3.55	0.78	988	2211	245	8.40	151.1	1.3	3.25	635	2100	2970		
												605	2100	3215		
267	5-27-55	200	3.54	0.78	988	2211	259	8.90	151.3	0.6	4.0	405	1715	2755*		
												420	1695	3215		
	Average	200	3.53	0.78	990	2211	256	8.80	150.6	1.0	3.75	515	1893	3300		
197	3-10-55	250	3.47	0.81	874	2296	263	9.03	148.9	1.0	4.0	610	1925	2825		
												610	1925	2140*		
236	4-21-55	250	3.54	0.81	859	2296	260	8.93	151.3	0.9	4.0	645	2030	2790		
												640	2015	2825		
294	6-13-55	250	3.50	0.81	859	2296	265	9.08	149.9	0.8	4.5	475	2120	3640		
												475	2085	3375		
	Average	250	3.50	0.81	864	2296	263	9.01	150.0	0.9	4.17	576	2017	3091		

* Not included in average

** Denotes volume of dry-rodded coarse aggregate per unit volume of concrete

TABLE IV - A

4-SACK REGULAR-CONCRETE DATA — CONNERS CREEK FLY ASH

Batch No.	Date Made	Fly Ash, lb/cu yd	Actual Cement Content, sack/cu yd	V_s**	Material Proportions, lb/cu yd			W/C, gal./sack	Wt. Fresh Concrete, lb/cu ft	Pressure Air Content, percent	Slump, in.	Compressive Strength, psi (6" x 12" Cylinders)				
					Sand	Stone	Net Water					1 day	7 days	28 days	90 days	1 year
207	4-7-55	0	4.04	0.64	1539	1814	266	7.97	151.2	1.7	2.75	460	2100	3055		
												480	2120	2895		
250	5-12-55	0	4.02	0.64	1487	1814	271	8.13	148.7	0.8	5.75	470	1875	2475		
												495	1660*	2580		
277	6-2-55	0	3.99	0.64	1509	1814	283	8.48	148.9	1.2	4.00	405	1680	2740		
												420	1765	2860		
	Average	0	4.02	0.64	1512	1814	273	8.19	149.6	1.2	4.17	455	1908	2768		
208	4-7-55	100	4.02	0.72	1262	2041	249	7.47	151.8	1.4	2.75	585	2405	4065		
												600	2525	3975		
223	4-15-55	100	4.02	0.72	1253	2041	252	7.56	151.7	1.0	3.0	710	2525	3445		
												670	2405	3375		
275	6-1-55	100	4.02	0.72	1244	2041	254	7.62	151.4	0.7	4.0	575	2225	3375		
												560	2455	3270		
	Average	100	4.02	0.72	1253	2041	252	7.55	151.6	1.0	3.25	617	2423	3584		
209	4-7-55	150	4.03	0.75	1108	2126	250	7.52	151.3	1.2	3.75	655	2475	4345		
												670	2510	4330		
251	5-12-55	150	3.99	0.75	1125	2126	250	7.51	150.7	0.9	4.0	600	2260	3535		
												545	2190	3765		
268	5-27-55	150	4.00	0.75	1117	2126	251	7.54	150.8	0.9	3.5	520	1345*	3515		
												560	2190	3005*		
	Average	150	4.01	0.75	1117	2126	250	7.52	150.9	1.0	3.75	592	2325	3898		
195	3-9-55	200	3.99	0.78	971	2211	260	7.81	150.2	1.1	4.0	695	2475	3620		
												650	2245	3745		
224	4-15-55	200	4.02	0.78	963	2211	267	8.03	151.3	0.9	5.5	675	2365	3745		
												660	2245	4115		
289	6-9-55	200	3.99	0.78	963	2211	263	7.91	150.1	0.9	2.75	710	2650	4030		
												735	2720	4365		
	Average	200	4.00	0.78	966	2211	263	7.92	150.5	1.0	4.08	688	2450	3937		
190	3-8-55	250	3.97	0.81	809	2296	277	8.33	149.2	0.9	5.75	635	2030	3160		
												565*	1890	3270		
230	4-19-55	250	4.06	0.81	792	2296	280	8.40	151.9	0.9	6.0	670	2120	2825*		
												680	2100	3215		
287	6-8-55	250	3.96	0.81	818	2296	269	8.06	148.9	0.9	4.0	630	2595	4170		
												675	2545	4400		
	Average	250	4.00	0.81	806	2296	275	8.26	150.0	0.9	5.25	658	2213	3643		

* Not included in average

** Denotes volume of dry-rodded coarse aggregate per unit volume of concrete

TABLE V - A

4.5-SACK REGULAR-CONCRETE DATA — ST. CLAIR FLY ASH

Batch No.	Date Made	Fly Ash, lb/cu yd	Actual Cement Content, sack/cu yd	V_s**	Material Proportions, lb/cu yd			W/C, gal./sack	Wt. Fresh Concrete, lb/cu ft	Pressure Air Content, percent	Slump, in.	Compressive Strength, psi (6" x 12" Cylinders)				
					Sand	Stone	Net Water					1 day	7 days	28 days	90 days	1 year
202	4-6-55	0	4.48	0.64	1543	1814	253	6.75	150.7	2.0	2.75	705*	2350	3585		
												635	2315	3780		
255	5-19-55	0	4.50	0.64	1485	1814	268	7.14	149.5	1.7	3.5	605	1660*	2970		
												640	1875	2930		
274	6-1-55	0	4.50	0.64	1507	1814	262	7.00	150.2	1.8	3.5	600	2295	3460		
												630	2385	3250		
	Average	0	4.49	0.64	1512	1814	261	6.96	150.1	1.8	3.25	622	2244	3329		
213	4-8-55	50	4.47	0.72	1312	2041	240	6.41	151.4	1.4	2.25	1010	3090	4735		
												1025	3145	4680		
243	4-26-55	50	4.52	0.72	1283	2041	249	6.64	152.2	1.0	3.75	935	3200	3940		
												795*	2705	3535*		
270	5-30-55	50	4.50	0.72	1273	2041	250	6.68	151.3	1.0	3.0	815	2525	4030		
												825	2720	3780		
	Average	50	4.50	0.72	1289	2041	246	6.58	151.6	1.1	3.00	922	2898	4233		
219	4-14-55	100	4.49	0.75	1156	2126	258	6.88	152.1	1.1	4.5	885	2720	3500		
												920	2740	3585		
248	4-28-55	100	4.51	0.75	1127	2126	252	6.71	151.2	1.1	4.0	945	3200	3550		
												885	2935	3550		
286	6-8-55	100	4.50	0.75	1137	2126	250	6.67	151.2	0.8	4.0	860	2930	4400		
												850	2985	4415		
	Average	100	4.50	0.75	1140	2126	253	6.75	151.5	1.0	4.17	891	2918	3833		
191	3-8-55	150	4.51	0.78	961	2211	254	6.76	150.2	1.1	3.0	725	2490	3320		
												740	2225	3340		
257	5-19-55	150	4.48	0.78	990	2211	257	6.87	150.5	1.0	4.0	780	2365	3710		
												780	2385	3885		
260	5-20-55	150	4.48	0.78	981	2211	270	7.20	150.6	0.6	5.5	785	2545	3945		
												780	2615	3920		
	Average	150	4.49	0.78	977	2211	260	6.94	150.4	0.9	4.17	765	2438	3687		
212	4-8-55	200	4.46	0.81	844	2296	281	7.51	150.1	1.1	3.5	970	2950	4790		
												885	2895	4735		
232	4-19-55	200	4.54	0.81	776	2296	282	7.52	150.2	0.9	3.0	755	2330	3465		
												725	2385	3655		
285	6-8-55	200	4.56	0.81	776	2296	269	7.17	150.4	0.6	5.0	785	2700	4135		
												775	2685	4275		
	Average	200	4.52	0.81	799	2296	277	7.40	150.2	0.9	3.83	816	2658	4176		

* Not included in average

** Denotes volume of dry-rodded coarse aggregate per unit volume of concrete

TABLE VI - A

5-SACK REGULAR-CONCRETE DATA — CONNERS CREEK FLY ASH

Batch No.	Date Made	Fly Ash, lb/cu yd	Actual Cement Content, sack/cu yd	V_s**	Material Proportions, lb/cu yd			W/C, gal./sack	Wt. Fresh Concrete, lb/cu ft	Pressure Air Content, percent	Slump, in.	Compressive Strength, psi (6" x 12" Cylinders)				
					Sand	Stone	Net Water					1 day	7 days	28 days	90 days	1 year
192	3-9-55	0	4.92	0.64	1513	1814	255	6.13	149.5	2.1	3.0	920	2560	3110		
												895	2755	3375		
234	4-20-55	0	5.00	0.64	1447	1814	269	6.45	150.0	1.6	5.25	845	2755	3285		
												840	2615	3375		
288	6-9-55	0	5.00	0.64	1469	1814	254	6.09	150.2	1.9	4.0	920	3180	4080		
												920	3270	4185		
	Average	0	4.97	0.64	1476	1814	259	6.22	149.9	1.9	4.08	890	2856	3568		
211	4-8-55	50	5.01	0.72	1215	2041	249	5.97	151.1	1.5	2.75	1200	3640	4840		
												1220	3780	5070		
242	4-26-55	50	4.98	0.72	1227	2041	256	6.15	151.0	0.9	4.0	1085	3125	3500*		
												1015	2405*	3940		
261	5-20-55	50	4.98	0.72	1227	2041	257	6.18	150.9	0.9	4.25	835	3090	3800		
												895	3110	3620		
	Average	50	4.99	0.72	1223	2041	254	6.10	151.0	1.1	3.67	1042	3349	4254		
203	4-6-55	100	5.02	0.75	1058	2126	267	6.40	151.4	1.2	5.5	885	3040	4275		
												865	3215	4505		
247	4-28-55	100	5.01	0.75	1079	2126	262	6.29	151.6	1.0	5.0	1095	3320	3800		
												1040	3320	3995		
265	5-26-55	100	5.00	0.75	1101	2126	255	6.11	152.0	0.9	3.5	935	3125	3905		
												945	2845	4080		
	Average	100	5.01	0.75	1079	2126	261	6.27	151.7	1.0	4.67	961	3144	4093		
220	4-14-55	150	5.01	0.78	921	2211	274	6.57	151.2	1.1	4.5	955	2845	3305*		
												990	2915	3905		
228	4-18-55	150	5.03	0.78	909	2211	270	6.49	151.2	0.9	5.5	1025	2935	3870		
												995	2845	3815		
276	6-1-55	150	4.98	0.78	921	2211	279	6.70	150.3	0.4	5.5	680	2880	3975		
												675	2685	3850		
	Average	150	5.01	0.78	917	2211	274	6.59	150.9	0.8	5.17	887	2851	3883		
187	3-7-55	200	5.18	0.81	644	2296	270	6.49	150.6	0.9	4.0	935	2755	3745		
												855	2740	4345		
258	5-20-55	200	4.98	0.81	733	2296	278	6.68	149.9	0.7	4.5	920	2825	3955		
												985	2755	4065		
284	6-6-55	200	4.99	0.81	774	2296	284	6.81	150.4	0.8	3.5	980	3090	4030		
												1035	3055	4240		
	Average	200	5.05	0.81	717	2296	277	6.66	150.3	0.8	4.0	952	2870	4063		

* Not included in average

** Denotes volume of dry-rodded coarse aggregate per unit volume of concrete

TABLE VII - A

5.5-SACK REGULAR-CONCRETE DATA — ST. CLAIR FLY ASH

Batch No.	Date Made	Fly Ash, lb/cu yd	Actual Cement Content, sack/cu yd	V_s**	Material Proportions, lb/cu yd			W/C, gal./sack	Wt. Fresh Concrete, lb/cu ft	Pressure Air Content, percent	Slump, in.	Compressive Strength, psi (6" x 12" Cylinders)				
					Sand	Stone	Net Water					1 day	7 days	28 days	90 days	1 year
196	3-10-55	0	5.43	0.64	1469	1814	250	5.46	149.9	2.2	3.0	1235	3180	3815		
												1260	2880	4100		
222	4-15-55	0	5.59	0.64	1413	1814	248	5.41	152.1	1.5	5.25	1375*	3270	4010		
												1135	3320	3995		
283	6-6-55	0	5.43	0.64	1459	1814	267	5.83	150.2	2.1	4.0	1205	3180	4365		
												1175	3305	4400		
	Average	0	5.48	0.64	1447	1814	258	5.57	150.7	1.9	4.08	1202	3189	4114		
189	3-7-55	50	5.70	0.72	1064	2041	255	5.57	152.6	0.9	5.0	975	3285	3905		
												995	3410	4310		
244	4-27-55	50	5.51	0.72	1205	2041	246	5.37	152.5	1.4	3.25	1345	3800	4150		
												1415	3870	4680		
269	5-30-55	50	5.46	0.72	1205	2041	253	5.53	151.4	1.0	5.5	1210	3375	4310		
												1215	3425	4450		
	Average	50	5.56	0.72	1158	2041	251	5.49	152.2	1.1	4.58	1193	3528	4301		
188	3-7-55	100	5.68	0.75	915	2126	259	5.65	151.6	1.0	4.75	1090	3180	4170		
												1080	3270	4225		
237	4-21-55	100	5.47	0.75	1044	2126	273	5.97	151.0	0.9	5.0	1155	2895	3815		
												1165	2810	3800		
273	5-31-55	100	5.50	0.75	1056	2126	253	5.53	151.6	0.9	3.25	1165	3390	4610		
												760*	3425	4415		
	Average	100	5.55	0.75	1005	2126	262	5.72	151.5	0.9	4.33	1131	3162	4173		
221	4-14-55	150	5.46	0.78	896	2211	283	6.18	150.9	0.9	4.5	1080	3090	3745		
												1095	3005	3940		
229	4-18-55	150	5.54	0.78	849	2211	271	5.92	150.8	0.9	4.0	1130	3340	3850		
												1150	3160	4010		
271	5-30-55	150	5.51	0.78	872	2211	273	5.96	151.1	0.9	4.5	950	2755	4030		
												1010	2790	4330		
	Average	150	5.50	0.78	872	2211	276	6.02	150.9	0.9	4.33	1069	3023	3984		
200	4-5-55	200	5.44	0.81	749	2296	289	6.31	150.1	1.4	3.5	955	2985	4860*		
												850*	3200	3995		
235	4-20-55	200	5.55	0.81	677	2296	290	6.34	150.4	0.9	5.25	1020	2630	3710		
												980	2825	3285*		
280	6-3-55	200	5.54	0.81	689	2296	274	5.99	150.1	0.8	4.0	1100	3200	4295		
												1065	3180	4540		
	Average	200	5.51	0.81	705	2296	284	6.21	150.2	1.0	4.25	1024	3003	4135		

* Not included in average

** Denotes volume of dry-rodded coarse aggregate per unit volume of concrete

TABLE VIII - A

5.5-SACK REGULAR-CONCRETE DATA — CONNERS CREEK FLY ASH

Batch No.	Date Made	Fly Ash, lb/cu yd	Actual Cement Content, sack/cu yd	V_s**	Material Proportions, lb/cu yd			W/C, gal./sack	Wt. Fresh Concrete, lb/cu ft	Pressure Air Content, percent	Slump, in.	Compressive Strength, psi (6" x 12" Cylinders)				
					Sand	Stone	Net Water					1 day	7 days	28 days	90 days	1 year
204	4-6-55	50	5.46	0.72	1205	2041	262	5.72	151.7	1.3	4.0	1060	3515	5210		
												1040	3285	4715		
246	4-27-55	50	5.51	0.72	1169	2041	253	5.53	151.4	1.0	4.0	1075	3160	3800		
												1080	3110	3975		
290	6-9-55	50	5.45	0.72	1181	2041	270	5.89	150.6	0.9	4.5	1020	3745*	4895		
												1060	3320	4910		
	Average	50	5.47	0.72	1185	2041	262	5.71	151.2	1.1	4.17	1056	3278	4584		
193	3-9-55	100	5.48	0.75	1044	2126	257	5.61	151.1	1.2	3.5	1165	3215	3250*		
												1185	3180	4080		
238	4-21-55	100	5.51	0.75	1032	2126	264	5.76	151.5	1.2	3.75	1230	2845	3850		
												1290	3090	3640		
264	5-26-55	100	5.52	0.75	1021	2126	270	5.89	151.6	0.7	4.75	1060	3355	4310		
												1015	3200	4240		
	Average	100	5.50	0.75	1032	2126	264	5.75	151.4	1.0	4.00	1158	3148	4024		
194	3-9-55	150	5.45	0.78	908	2211	276	6.01	150.7	1.1	5.25	1080	2670*	3885		
												1040	3005	4225		
227	4-18-55	150	5.52	0.78	884	2211	276	6.02	151.9	0.9	5.0	1175	3375*	3905		
												1145	2985	4045		
259	5-20-55	150	5.45	0.78	884	2211	271	5.92	149.7	0.9	4.25	1115	3180	4065		
												1080	3075	3780		
	Average	150	5.47	0.78	892	2211	274	5.98	150.8	1.0	4.83	1106	3061	3984		
205	4-6-55	200	5.49	0.81	713	2296	293	6.40	150.2	1.2	4.0	885	2970	4875		
												885	3040	4715		
233	4-19-55	200	5.52	0.81	677	2296	290	6.32	149.6	1.0	3.75	945	3055	3675		
												1015	2720	3885		
281	6-3-55	200	5.50	0.81	677	2296	294	6.42	149.1	0.8	4.0	980	3130	3990		
												1020	3270	4065		
	Average	200	5.50	0.81	689	2296	292	6.38	149.6	1.0	3.92	955	3031	4201		
					6.5-SACK REGULAR-CONCRETE DATA											
210	4-8-55	0	6.39	0.64	1398	1814	270	4.99	150.7	1.9	6.0	1645	3920	5245		
												1590	3780	5245		
226	4-18-55	0	6.53	0.64	1340	1814	266	4.91	151.8	1.5	6.0	1490	3285	4240		
												1520	3570	4045		
272	5-31-55	0	6.49	0.64	1349	1814	251	4.64	150.7	1.8	3.0	1445	3780	4700		
												1430	3800	4665		
	Average	0	6.47	0.64	1362	1814	262	4.85	151.1	1.7	5.0	1520	3689	4690		

* Not included in average

** Denotes volume of dry-rodded coarse aggregate per unit volume of concrete