ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

PROGRESS REPORT

STUDY OF CONCRETE CONTAINING FLY ASH FROM MARYSVILLE STATION

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Project 2211

DETROIT EDISON COMPANY
DETROIT, MICHIGAN

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SYNOPSIS

This is the second progress report pertaining to use of Detroit Edison Company fly ash in air-entrained concrete. The first progress report, dated May 15, 1954, dealt with Trenton Channel ash exclusively. This report gives similarly acquired data for fly ash from the Marysville station and draws a few comparisons with the results from the Trenton study.

Concrete containing the Marysville ash developed slightly lower strengths under comparable conditions than that containing Trenton ash. The most significant difference between the two ashes, judged from the presently available data including compressive-strength tests up to the 28-day age, is their different requirement for air-entraining admixture to obtain the air content considered necessary for maximum weather resistance. Marysville ash requires three or more times more Darex than Trenton ash, making the Darex requirement of some consequence in the cost of the concrete.

Caution is again advised against predicting strength of job concrete from the data contained herein unless suitable safety factors are utilized to compensate for possible field variations in mixing, curing, and proportioning.

STUDY OF CONCRETE CONTAINING FLY ASH FROM MARYSVILLE STATION

Introduction

On May 15, 1954, a progress report was issued concerning the use of Trenton Channel fly ash in air-entrained concrete. The data presented therein were developed from laboratory studies started by the Engineering Research Institute of the University of Michigan persuant to a contract between the Institute and the Detroit Edison Company.

This second report contains similarly acquired data for Marysville fly ash. Again, only data obtained from compressive-strength tests up to 28-day age is now available and can be presented at this time. Results from volume-change bars and strength specimens of 90-day and 1-year age will be given in a later report.

Repetitious matter pertaining to test procedures, etc. which were covered in the Trenton Channel report will be omitted here since the testing procedures for the two fly ashes remained unchanged.

This report pertains to the use of Marysville fly ash in air-entrained concrete exclusively. Darex air-entraining admixture was used in all the mixes in such amounts as to obtain the amount of air considered desirable to obtain maximum weather resistance.

Mix Design

Mix-design procedure was identical with that used in the Trenton Channel fly-ash series, viz., full advantage was taken of the added plasticity of the mortar constituent provided by the addition of fly ash, and, consequently, increased stone contents were used over those normally employed in concrete not containing fly ash.

Control specimens with no fly ash were not made in this series since the procedures and materials were identical with those of the Trenton Channel series and it was considered that the control specimens just

previously made in that study would suffice. It will be recalled that the "Recommended Practice for Selecting Proportions for Concrete" currently being considered for adoption by the American Concrete Institute was used as the design basis for the mixes not containing fly ash.

Concrete with three cement contents have again been investigated, viz., 4, 5, and 6 sacks per cubic yard. Three fly-ash contents for the 5- and 6-sack concrete and four fly-ash contents for the 4-sack concrete have been used. Attention is particularly called to the fact that the increments of fly ash have been stepped down 50 pounds per cubic yard from that used in the Trenton Channel lean-concrete series (4 sacks per cubic yard), since preliminary examination of the concrete strengths appeared to indicate the desirability of lower ash contents for the Marysville material.

Materials

With the exception of the fly ash, all concrete materials were identical with those used previously in the Trenton Channel fly-ash study, viz., 1-inch maximum size natural-gravel coarse aggregate, natural sand having fineness modulus of 3.0, and an "anonymous" cement consisting of a blend of equal amounts of Peerless, Wyandotte, and Huron. The Marysville ash used was furnished in January, 1954. The portion of the analysis of this ash now available is shown in Table I-A in the appendix.

Fabrication of Specimens and Test Procedures

The methods of mixing, curing, and testing the specimens were identical with those used in the Trenton Channel study.

Discussion of Test Results

Detailed tabulation of the Concrete-mix data and compressive-strength results are shown in the appendix in Tables II-A, III-A, and IV-A, for the 4-sack, 5-sack, and 6-sack concrete, respectively.

1. Coarse-Aggregate Content. Use of a lower increment of fly ash in the 4-sack concrete for Marysville ash (100 lb per cubic yard) required an additional evaluation of the stone content to obtain proper workability. Table I gives the values found satisfactory for both Trenton Channel and Marysville ashes for 1-inch maximum size aggregate and a sand having a fineness modulus of 3.0. The value V_S is expressed as 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 lb/cyd	4 Sack	5 Sack	6 Sack
0	0.64	0.64	0.64
100	0.72		0.75
150	0.78	0.78	0.75
200	0.81	0.78	0.75
250	0.81	0.78	
300	0.81		

2. Strength Results. Average values of compressive strengths up to the 28-day age have been tabulated in Table II. Attention is called to the fact that the strengths of the control specimens not containing fly ash are results from the Trenton Channel study. New control specimens were not made, as previously indicated.

As in the case of Trenton Channel fly ash, the most prominent feature of the strength results is the substantial increase of strength of the lean fly-ash mixes over the lean plain cement mixes at the 28-day age. Table III shows the strength of both Trenton Channel and Marysville fly ash at each age expressed as percentage of strength of the plain cement mixes having the same cement content. With few exceptions, the tabulation indicates reduced strength for the Marysville ash with respect to the Trenton ash for a corresponding fly-ash content, cement content, and age. Better strength equivalence of the two ashes is obtained if comparison is made of the strengths of the concrete containing, in each case, 50 lb per cubic yard less Marysville ash than Trenton ash.

Comparison of the rate-of-strength gain between 7- and 28-day age has been summarized in Table IV. As indicated in the Trenton Channel study, the leaner mixes gain strength faster, and increased amounts of either Trenton or Marysville ash tend to hasten this strength gain.

Figures 1 to 3 show the average strengths plotted against age. Strength gain is again orderly as in the case of Trenton ash.

TABLE II

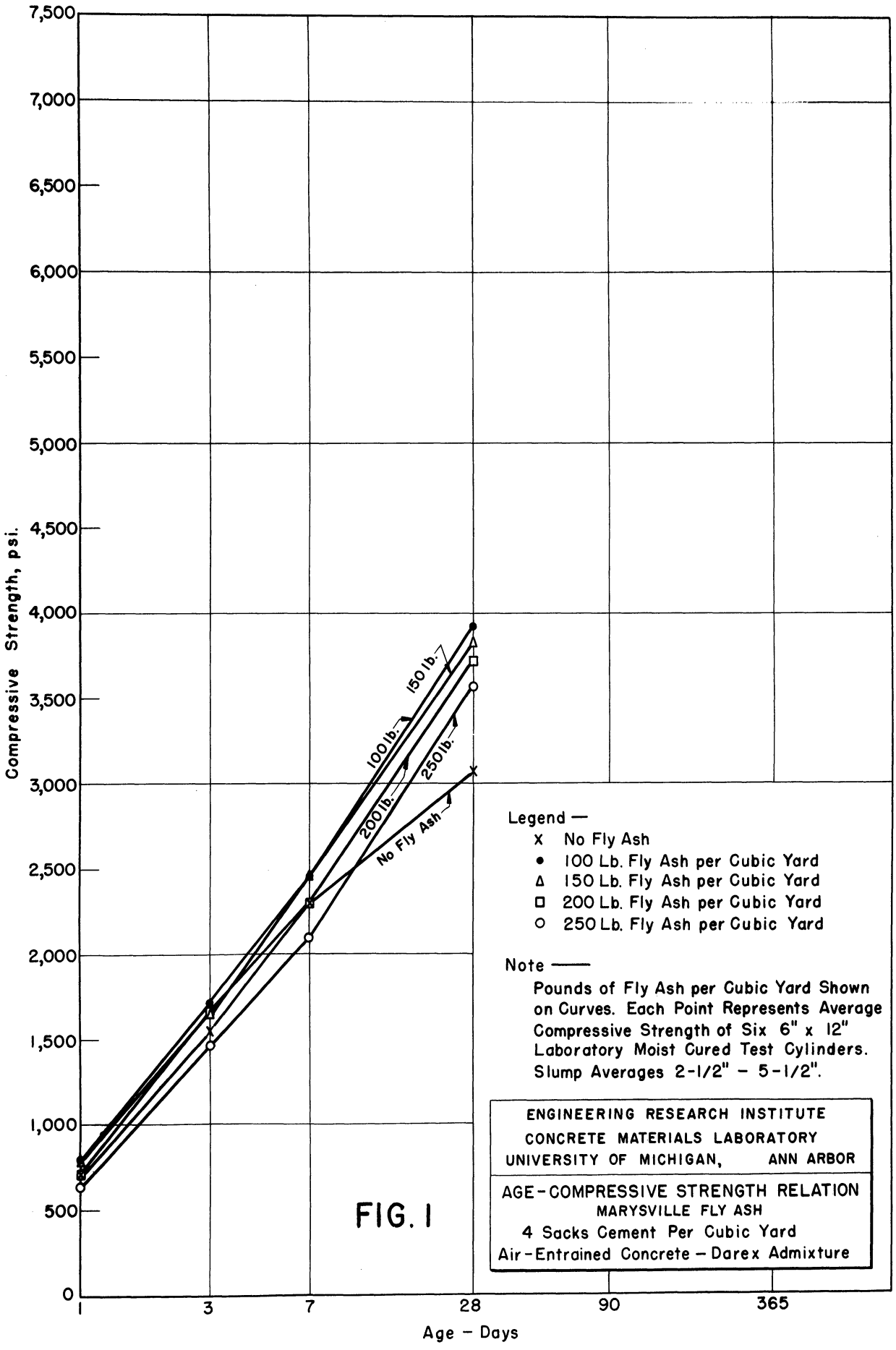
SUMMARY OF RESULTS - MARYSVILLE FLY ASH

Nominal Cement Content, sk/cyd	Actual Cement Content, sk/cyd	Fly Ash lb/cyd	Net Mixing Water		Air Content, percent	Slump, in.	Darex, fluid oz/cyd	Compressive Strength, psi					
			lb/cyd	gal/sk				1 day	3 days	7 days	28 days	90 days	1 year
4.0	4.10	0	231	6.95	5.2	2.5	4.2	702	1546	2282	3070		
	4.05	100	237	7.12	4.2	3.7	16.3	792	1714	2456	3922		
	4.00	150	246	7.38	5.3	3.5	27.4	786	1641	2456	3823		
	3.99	200	260	7.81	4.8	3.9	38.3	723	1663	2396	3724		
	3.98	250	283	8.51	4.9	4.1	49.7	638	1464	2095	3569		
5.0	5.11	0	228	5.48	5.5	3.5	4.2	1080	2088	3002	3993		
	5.04	150	270	6.47	5.3	5.7	31.5	898	1917	2768	4211		
	4.96	200	284	6.82	5.3	4.6	42.3	880	1867	2762	4028		
	5.02	250	298	7.14	5.1	4.4	49.4	886	1831	2615	4237		
6.0	6.06	0	239	4.77	5.7	4.7	4.2	1449	2505	3576	4633		
	5.99	100	259	5.17	5.8	4.6	27.2	1191	2404	3152	4266		
	5.96	150	280	5.61	5.6	4.3	36.9	1126	2113	3145	4243		
	5.98	200	296	5.92	5.6	4.4	45.1	1143	2153	2901	4123		

TABLE III

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

Cement Content, sk/cyd	Fly Ash lb/cyd	Compressive Strengths, Percent							
		1 day		3 days		7 days		28 days	
		Trenton	Marysville	Trenton	Marysville	Trenton	Marysville	Trenton	Marysville
4	100		113		111		108		128
4	150	130	112	121	106	116	108	131	125
4	200	112	103	108	108	108	105	122	121
4	250	104	91	101	95	100	92	122	116
4	300	94		99		96		115	
5	150	107	83	94	92	97	92	99	105
5	200	96	82	101	89	98	92	108	101
5	250	93	82	94	88	92	87	103	106
6	100	96	82	101	96	94	88	96	92
6	150	99	79	96	84	93	88	97	92
6	200	75	80	93	86	89	81	97	89


7,500
7,000
6,500
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Compressive Strength, psi.
1
3
7
28
90
365
Age – Days
150 lb.
100 lb.
250 lb.
200 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" – 5-1/2".
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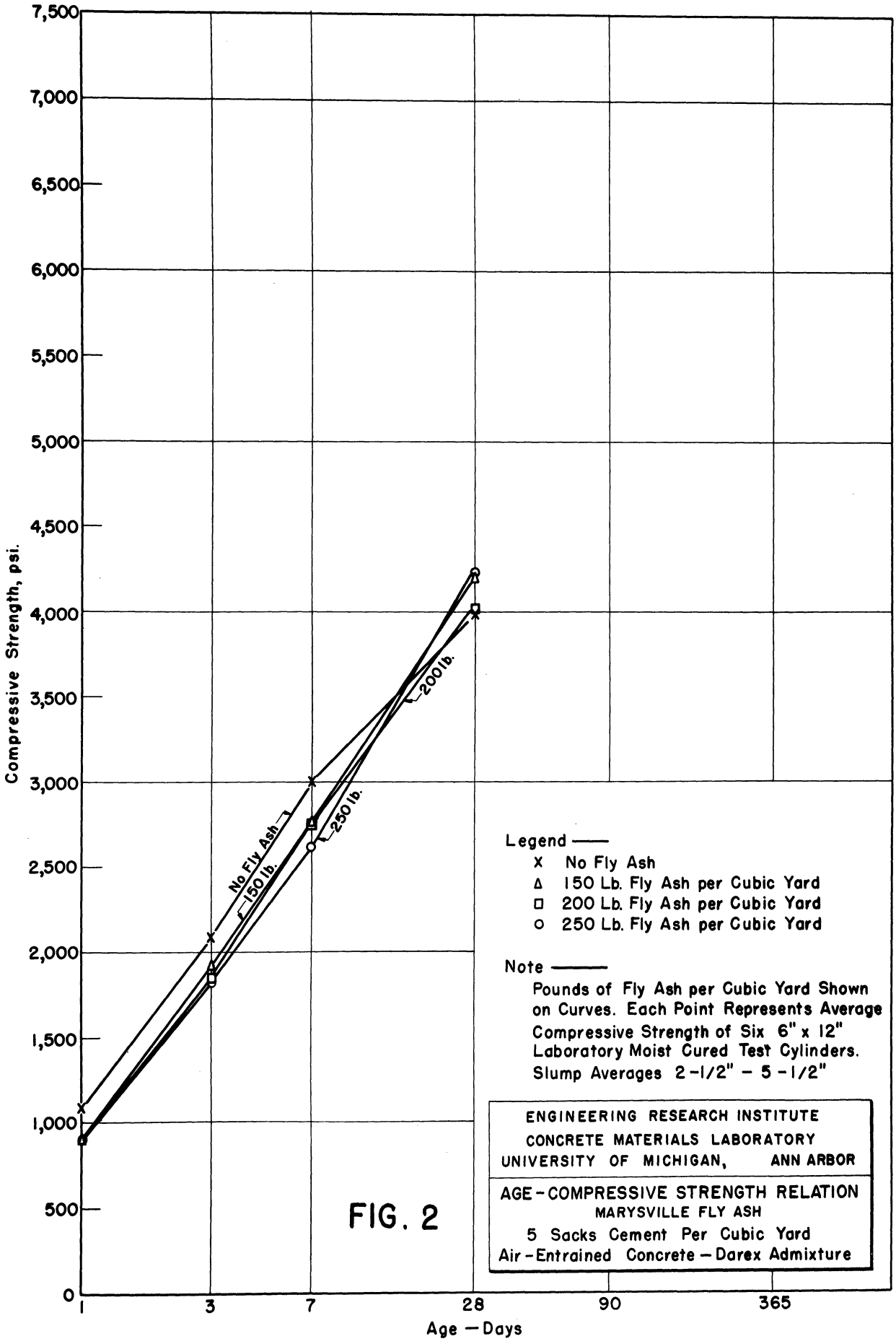
AGE-COMPRESSIVE STRENGTH RELATION
MARYSVILLE FLY ASH
4 Sacks Cement Per Cubic Yard
Air-Entrained Concrete – Darex Admixture
FIG. 1


7,500
7,000
6,500
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Compressive Strength, psi.
1
3
7
28
90
365
Age — Days
No Fly Ash
150 lb.
200 lb.
250 lb.
Legend
X No Fly Ash
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" – 5-1/2"
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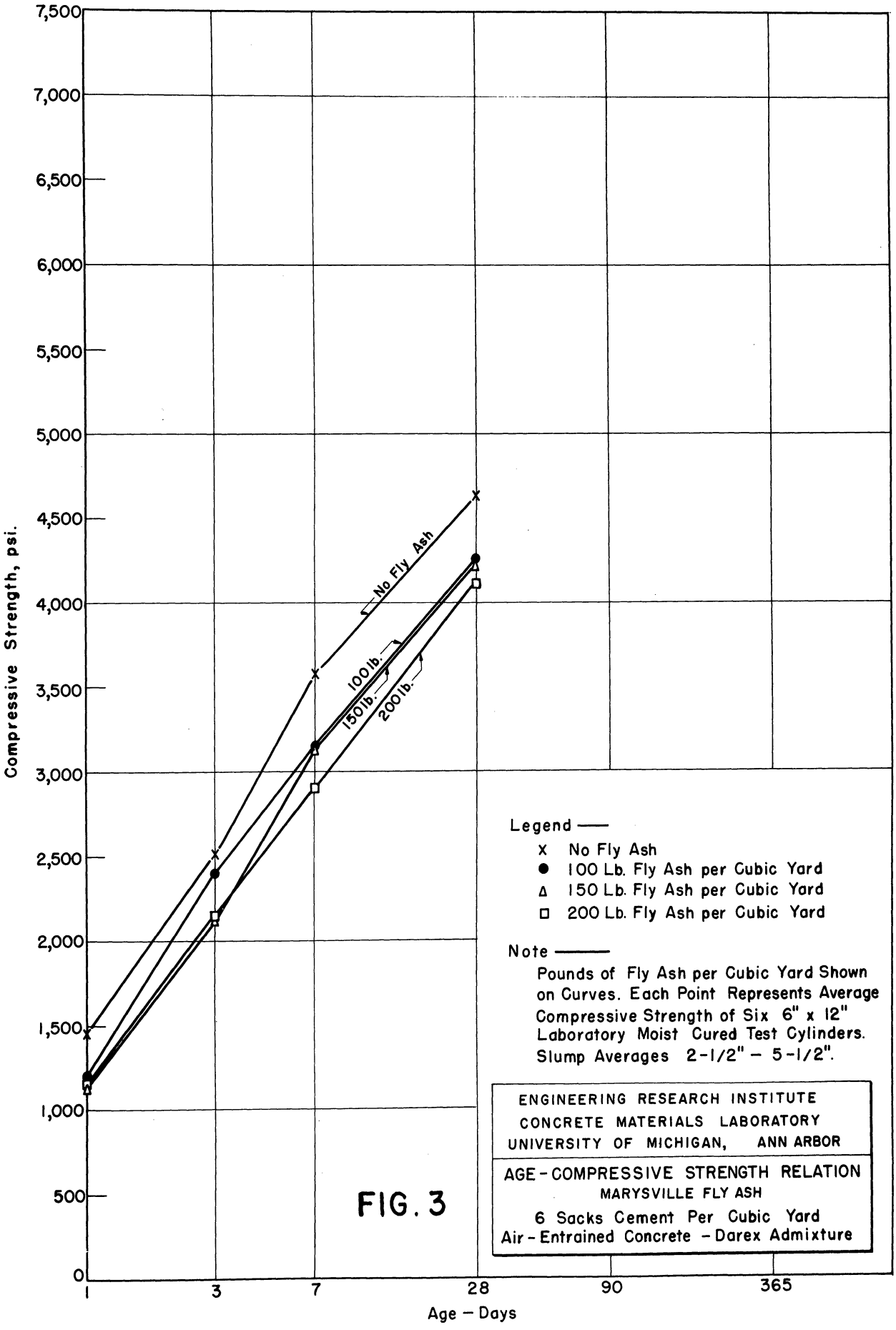
AGE-COMPRESSIVE STRENGTH RELATION
MARYSVILLE FLY ASH
5 Sacks Cement Per Cubic Yard
Air-Entrained Concrete – Darex Admixture

FIG. 2


7,500
7,000
6,500
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Compressive Strength, psi.
No Fly Ash
100 lb.
150 lb.
200 lb.
1
3
7
28
90
365
Age – Days
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
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" – 5-1/2".
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AGE-COMPRESSIVE STRENGTH RELATION
MARYSVILLE FLY ASH
6 Sacks Cement Per Cubic Yard
Air-Entrained Concrete – Darex Admixture

FIG. 3

TABLE IV

AVERAGE RATIO OF 28-DAY TO 7-DAY
COMPRESSIVE STRENGTHS

Cement Content sk/cyd	Fly Ash lb/cyd	Ratio of 28-Day Strength to 7-Day Strength	
		Trenton	Marysville
4	0	1.35	1.35
4	100		1.60
4	150	1.51	1.56
4	200	1.52	1.55
4	250	1.65	1.70
4	300	1.62	
5	0	1.33	1.33
5	150	1.37	1.52
5	200	1.48	1.46
5	250	1.50	1.62
6	0	1.30	1.30
6	100	1.32	1.35
6	150	1.35	1.35
6	200	1.42	1.42

3. Air-Entraining Admixture Requirement. Substantially greater amounts of Darex air-entraining admixture were required for Marysville ash than for Trenton ash under comparable conditions of use. Table V summarizes the amounts used for the two ashes.

The large amounts of Darex which must be used with Marysville ash make it doubtful that it is economically feasible to use this admixture. Vinsol resin air-entraining admixture would be considerably cheaper.

TABLE V

AMOUNTS OF DAREX AIR-ENTRAINING
ADMIXTURE PER CUBIC YARD OF CONCRETE

Cement Content sk/cyd	Fly Ash lb/cyd	Darex, fluid oz/cyd	
		Trenton Ash	Marysville Ash
4	0	4.2	
4	100		16.3
4	150	10.3	27.4
4	200	11.4	38.3
4	250	14.4	49.7
4	300	17.3	
5	0	4.2	
5	150	11.9	31.5
5	200	13.0	42.3
5	250	16.5	49.4
6	0	4.2	
6	100	9.9	27.2
6	150	11.6	36.9
6	200	14.3	45.1

APPENDIX

TABLE I-A

PROPERTIES OF FLY ASH
(54C-4)

Physical Properties	
Specific surface, air permeability test, sq cm per gm	4578
Compressive strength, 20 percent by weight of portland-cement addition, hand mixing, 73°F cure, percent of control	
7 days	107
28 days	106
90 days	137
Water requirement, percent of control	111
Compressive strength, 25 percent by weight of sand, sand replacement, machine mixing, 73°F cure, percent of control	
7 days	164
28 days	181
90 days	
Water requirement, percent of control	126
Compressive strength, 25 percent by weight of cement, sand replacement, machine mixing, 73°F cure, percent of control	
7 days	153
28 days	155
90 days	
Water requirement, percent of control	105
Drying Shrinkage, 28 days, percent	0.08
Soundness, autoclave expansion, percent	0.03
Specific gravity	2.28
Chemical Properties	
Silicon dioxide (SiO_2), percent	44.5
Magnesium dioxide (MgO), percent	1.5
Sulfur trioxide (SO_3), percent	0.5
Loss on ignition, percent	10.3

TABLE I-A (Concluded)

MARYSVILLE FLY ASH

Mortar Strength Tests

	Compressive Strength, psi (Percent of control in parentheses)		
	7 days	28 days	90 days
20 Percent by Weight of Cement Addition (Hand Mix)			
Control (54C-7)	3252	4969	5171
Fly Ash (54C-2)	3440	5231	7027
	(107)	(106)	(137)

Control Mix	Fly-Ash Mix
750 g cement	750 g cement
2062 g graded sand	150 g fly ash
360 ml water	2062 g graded sand
	400 ml water
105.8% Flow	112.3% Flow

25 Percent by Weight of Sand, Sand Replacement (Machine Mix)

Control (54C-158)		2950	4271
Fly Ash (54C-4)		4825	7713
		(164)	(181)

Control Mix	Fly-Ash Mix
750 g cement	750 g cement
2062 g graded sand	515 g fly ash
365 ml water	1547 g graded sand
	460 ml water
115.4% Flow	112.5% Flow

25 Percent by Weight of Cement, Sand Replacement (Machine Mix)

Control (54C-158)		2950	4271
Fly Ash (54C-4)		4521	6600
		(153)	(155)

Control Mix	Fly-Ash Mix
750 g cement	750 g cement
2062 g graded sand	188 g fly ash
365 ml water	1875 g graded sand
	385 ml water
115.4% Flow	113.3% Flow

TABLE II-A

4-SACK CONCRETE DATA - MARYSVILLE FLY ASH

Batch No.	Date Made	Fly Ash lb/cyd	Actual Cement Content sk/cyd	V_s**	Material Proportions lb/cyd			Actual w/c, gal/sk	Wt. Fresh Concrete, lb/cu ft	Pressure Air Content, Per Cent	Slump in.	Darex, fluid oz/cyd	Compressive Strength psi					
					Sand	Stone	Net Water						1 day	3 days	7 days	28 days	90 days	1 year
53	3-30-54	100	4.02	.78	954	2211	241	7.24	146.2	4.9	3.5	16.3	740 690	1555 1500	2295 2190	3515 3885		
59	4-2-54	100	4.12	.78	954	2211	234	7.03	149.5	3.1	3.25	16.3	760 775	1945 1945	2740 2580	4205 4295		
70	4-7-54	100	4.02	.72	1112	2041	236	7.09	145.8	4.6	4.25	16.3	900 885	1715 1625	2490 2440	3850 3780		
	Average	100	4.05	.76	1007	2154	237	7.12	147.2	4.2	3.7	16.3	792	1714	2456	3922		
47	3-26-54	150	4.00	.78	905	2211	246	7.37	145.8	4.9	3.25	27.7	705 690	1625 1645	2315 2490	3920 3465		
56	3-31-54	150	4.06	.78	871	2211	240	7.21	146.4	5.1	3.25	27.7	725 740	1715 1625	2790 2740	4205 4030		
69	4-7-54	150	3.94	.78	888	2211	252	7.56	143.1	5.9	4.0	26.7	935 920	1625 1610	2155 2245	3500 3815		
	Average	150	4.00	.78	888	2211	246	7.38	145.1	5.3	3.5	27.4	786	1641	2456	3823		
46	3-24-54	200	3.96	.81	742	2296	258	7.73	143.8	5.3	3.75	39.1	635 690	1500 1520	2245 1625*	3655 3500		
62	4-5-54	200	4.03	.81	712	2296	258	7.73	145.1	4.4	3.75	37.5	775 725	1765 1800	2630 2810	3850 4185		
67	4-6-54	200	3.99	.81	730	2296	265	7.96	144.4	4.7	4.25	38.4	775 740	1450* 1730	2155 2140	3465 3690		
	Average	200	3.99	.81	728	2296	260	7.81	144.4	4.8	3.9	38.3	723	1663	2396	3724		
43	3-23-54	250	3.98	.81	624	2296	282	8.48	142.7	4.4	4.25	48.9	565 600	1380 1415	2120 1820*	3320 3695		
50	3-29-54	250	3.95	.81	612	2296	286	8.60	141.5	5.5	3.75	50.5	585 600	1290 1290	2140 1960	3500 3445		
66	4-6-54	250	4.02	.81	578	2296	282	8.46	142.2	4.9	4.25	49.8	740 740	1680 1730	2065 2190	3885 3570		
	Average	250	3.98	.81	605	2296	283	8.51	142.1	4.9	4.1	49.7	638	1464	2095	3569		

*Not included in average

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

TABLE III-A

5-SACK CONCRETE DATA - MARYSVILLE FLY ASH

Batch No.	Date Made	Fly Ash lb/cyd	Actual Cement Content sk/cyd	V_s**	Material Proportions lb/cyd			Actual w/c, gal/sk	Wt. Fresh Concrete, lb/cu ft	Pressure Air Content, Per Cent	Slump in.	Darex, fluid oz/cyd	Compressive Strength psi					
					Sand	Stone	Net Water						1 day	3 days	7 days	28 days	90 days	1 year
48	3-26-54	150	4.97	.78	754	2212	276	6.61	143.8	5.5	5.5	30.9	795 795	1730 1820	2650 2740	4170 4115		
54	3-30-54	150	5.20	.78	635	2212	261	6.27	145.4	4.5	4.75	30.9	1060 1025	2015 1995	2860 2775	4170 4330		
60	4-2-54	150	4.95	.78	754	2212	273	6.54	143.2	6.0	6.75	32.6	885 830	1855 2085	2650 2935	4345 4135		
	Average	150	5.04	.78	714	2212	270	6.47	144.1	5.3	5.7	31.5	898	1917	2768	4211		
45	3-24-54	200	4.92	.78	693	2212	284	6.82	142.3	5.5	5.0	42.3	865 885	1785 1785	2755 2615	3960 4080		
51	3-29-54	200	4.94	.78	676	2212	289	6.93	142.3	5.4	4.75	42.3	830 775	1765 1855	2755 2720	4100 4010		
63	4-5-54	200	5.02	.78	632	2212	280	6.72	142.8	5.1	4.0	42.3	990 935	2065 1945	2755 2970	4150 3870		
	Average	200	4.96	.78	667	2212	284	6.82	142.5	5.3	4.6	42.3	880	1867	2762	4028		
57	3-31-54	250	5.01	.78	543	2212	302	7.24	141.8	5.0	4.75	50.5	795 775	1785 1785	2670 2740	4525 4715		
65	4-6-54	250	5.05	.78	543	2212	294	7.05	142.5	5.1	4.0	48.9	920 970	1800 1820	2490 2420	3885 3885		
71	4-9-54	250	5.00	.78	565	2212	298	7.14	142.0	5.2	4.5	48.9	920 935	1835 1960	2755 2615	4310 4100		
	Average	250	5.02	.78	550	2212	298	7.14	142.1	5.1	4.4	49.4	886	1831	2615	4237		

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

TABLE IV-A

6-SACK CONCRETE DATA - MARYSVILLE FLY ASH

Batch No.	Date Made	Fly Ash lb/cyd	Actual Cement Content sk/cyd	V_s**	Material Proportions lb/cyd			Actual w/c, gal/sk	Wt. Fresh Concrete, lb/cu ft	Pressure Air Content, Per Cent	Slump in.	Darex, fluid oz/cyd	Compressive Strength psi					
					Sand	Stone	Net Water						1 day	3 days	7 days	28 days	90 days	1 year
49	3-26-54	100	5.95	.75	826	2126	266	5.32	144.3	5.6	5.0	27.7	1080 1130	2280 2385	3075 2935	3940 4450		
55	3-30-54	100	6.01	.75	800	2126	253	5.05	144.2	5.9	4.25	27.7	1185 1220	2475 2370	3040 3305	4115 4240		
61	4-2-54	100	6.00	.75	800	2126	257	5.14	144.0	6.0	4.5	26.1	1220 1310	2545 2370	3250 3305	4450 4400		
	Average	100	5.99	.75	809	2126	259	5.17	144.2	5.8	4.6	27.2	1191	2404	3152	4266		
44	3-24-54	150	5.95	.75	731	2126	275	5.51	142.8	6.1	4.25	39.1	1150 1165	2085 2190	3235 3145	4115 4205		
52	3-29-54	150	5.93	.75	743	2126	281	5.63	143.1	5.5	4.5	35.8	990 1080	2065 2100	3235 3110	4330 4450		
64	4-5-54	150	6.00	.75	704	2126	284	5.68	143.4	5.2	4.25	35.8	1185 1185	2120 2120	2985 3160	4310 4045		
	Average	150	5.96	.75	726	2126	280	5.61	143.1	5.6	4.3	36.9	1126	2113	3145	4243		
58	3-31-54	200	6.01	.75	622	2126	296	5.92	142.7	5.2	4.25	45.6	970 990	2155 2120	2970 2810	4260 4205		
68	4-7-54	200	5.99	.75	622	2126	294	5.88	142.3	6.0	4.0	45.6	1325 1290	2120 2155	2755 2775	4065 4135		
72	4-9-54	200	5.95	.75	622	2126	298	5.95	141.3	5.5	5.0	44.0	1165 1115	2210 2155	3005 3110	3940 4135		
	Average	200	5.98	.75	622	2126	296	5.92	142.1	5.6	4.4	45.1	1143	2153	2901	4123		

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