Engineering Research Institute

University of Michigan

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Progress Report

Study of Concrete Containing Fly Ash From Trenton Channel Station

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PROGRESS REPORT

Study of Concrete Containing
Fly Ash from Trenton Channel Station

Synopsis

Pursuant to an agreement with the Detroit Edison Company to furnish a progress report at this time, the results now available of laboratory work conducted at the University of Michigan on the use of Trenton Channel fly ash in concrete are reported herein.

A series of batches of air-entrained concrete, involving nearly 500 test specimens, have been made containing a wide range of fly ash contents. The ingredients of the concretes are typical of those normally used in concrete in this area. Darex air-entraining admixture was used in all the batches in such amounts as to provide sufficient air to insure a high degree of resistance to weathering. Most of the work reported herein pertains to the strength of these concretes as determined by compression tests on standard 6" x 12" cylinders made and cured under uniformly controlled laboratory conditions. Test ages up to 28 days, only, are included in this report. Specimens for 90 days and 1 year have been made, the results of which will be available later. Similarly, volume change bars have been made, the results from which will be reported later.

Sufficient repeat tests were made, it is believed, to reliably establish the trends of the data. However, caution is advised against predicting strength of job concrete from these data unless suitable safety factors are utilized to compensate for possible field variations in mixing, curing, and proportioning.

Preliminary examinations of the results indicate that if advantage is taken of the added workability of the fly ash mixes by increasing the stone content over that used in plain concrete, a substantial increase in compressive strength of the lean mixes (4 sacks of cement per cubic yard) is possible by the use of moderate amounts of Trenton fly ash. This strength increase is apparent at ages of 1 day, 3 days, 7 days, and 28 days. High fly ash content in the lean mixes (300 lbs. per cubic yard) tend to reduce early strength but increase the 28-day strength. Varying quantities of Trenton ash in the richer mixes (5 and 6 sacks of cement per cubic yard) appeared to have relatively little effect on compressive strength up to the 28-days age. However, analysis indicates that increased amounts of ash increased the rate of strength gain between 7 and 28 days for all cement contents and the inference can be made that the fly ash in the richer mixes may have significant strength effects at later ages.

Of necessity, substantially greater amounts of Darex air-entraining admixture were used in the fly ash mixes than in the plain cement mixes in order to obtain the desired air content of about 4-5 per cent. Greater amounts of fly ash increased the admixture requirement. The concretes without fly ash required about 4 fluid ounces per cubic yard of concrete whereas the highest Darex requirement, 17 ounces, occured for the 4 sack concrete containing 300 lbs. of ash per cubic yard.

The data reported are susceptible to types of analyses which are not presented here, as it is believed preferable to await the results from

Marysville and Conners Creek fly ashes which also are currently under study. Progress is being made in the establishment of a pattern of behavior of the three ashes both as to similarities and some important differences.

Introduction

Under sponsorship of the Detroit Edison Company, laboratory studies have been started by the Engineering Research Institute of the University of Michigan concerning the use of fly ash in portland cement concrete. This progress report is being issued pursuant to the project proposal wherein it was agreed that a report would be prepared following completion of 28-day compressive strength tests on a series of exploratory concrete mixes using fly ash from the Detroit Edison Company Trenton Channel Station.

In deciding to begin the investigation with this series of mixes, it was believed that (1) information for future concrete mixture design would be provided and (2) strength and volume change values would be established over a range of cement and fly ash contents from which certain key mixes could be later selected for further study. The aggregates and cement were to be typical of those used in the local area for general use concrete. The range of cement and fly ash contents is planned to be more extensive than has been described in the available literature of similar studies. Despite the voluminous literature available on fly ash in concrete, specific information is lacking regarding selection of mix designs except for restricted uses or for concrete involving aggregates not normally employed in the Detroit area. Some design methods impose a burden on the consumer as they involve testing of trial mixes and it can be particularly hoped that this study will alleviate this situation.

The first series of mixes has been made with only air-entraining concrete. Field observation and laboratory data acquired over the past 15 years by many investigators has shown the superiority of air-entrained concrete for all except the most exceptional uses and prejudice in its favor has naturally developed. The thought is advanced that if the Edison Company extensively markets fly ash for general use, then the long range success of such a program is linked with the success of the concrete industry itself. Many of the present ills of that industry stem from a lack of recognition of the importance of proper air-entrainment in the plastic mixes now demanded by the average consumer. This lack is evidenced by far too early deterioration of some concrete. A portion of this deterioration is due to unsuitable aggregates, which is not a factor in the current investigation. It is suggested that the Edison Company may wish to minimize future complaints by encouraging the use of air-entrainment where fly ash is involved even though, as is being developed in this program of study, special problems arise for which the solution is not yet clear, and further recognizing the substantial loss in strength in the richer mixes resulting from the degree of air-entrainment which is considered desirable for maximum weather resistance.

Mix Design

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. Design of the fly ash mixes present a problem of concrete proportioning for which there is no well-established precedent. However, every method of plain concrete proportioning recognizes that optimum design results from a maximum coarse aggregate content and since fly ash imparts a marked increase in plasticity to the mortar constituent, it has been found possible to incorporate greater coarse aggregate contents in the fly ash mixes with the same apparent workability. Some proportioning methods relate the maximum size of the coarse aggregate with the fineness modulus of the sand to establish the stone content. Finer sands permit higher stone contents. Since the added fly ash can be considered as supplementing the fines in the sand at the time of making the plastic concrete, higher stone contents are called for by conventional principles of proportioning concrete.

Concrete with three cement contents have been investigated; namely 4, 5, and 6 sacks per cubic yards. Three fly ash contents for the 5 and 6 sack concrete and 4 fly ash contents for the 4 sack concrete have been used. Control mixes containing no fly ash have been made for each of the cement contents.

Materials

1. Fly ash. Approximately one ton of fly ash from the Trenton Channel Station

was furnished to the laboratory for these tests. This was shipped the latter part of January, 1954, and presumably represents the product collected at this station shortly prior to this time. Approximately one-half of the original shipment is still available for further tests. The portion of the analysis of the fly ash, with certain longer time test results to be later reported, is shown in Table I-A in the appendix. Analyses were conducted in accordance with A.S.T.M. "Method of Test for Fly Ash as an Admixture for Portland Cement Concrete" (A.S.T.M. C311-53T), except for the mortar strength tests. Three types of mortar strength tests have been conducted: (1) Using the fly ash as a 20 per cent by weight addition to the cement, (2) Replacing 25 per cent of the Ottawa sand by an equal weight of fly ash, (3) Containing fly ash equivalent to 25 per cent, by weight, of the cement with a reduction in sand equal to weight of added fly ash. Test (1) used hand mixed mortars and Tests (2) and (3) used the newly adopted machine mixed mortars. It appears that the American Society for Testing Materials may adopt Method (3) as a standard method rather than the methods shown in A.S.T.M. C311-53T where elevated curing temperatures are employed.

2. Portland Cement. An "anonymous" portland cement has been used consisting of a blend of equal parts by weight of three brands widely used in the Detroit area; namely, Wyandotte, Huron, and Peerless. It is recognized that different cements attain different strength levels at given ages and their chemical composition may be such as to influence the rate of strength development when incorporated with pozzolanic materials. In this series of exploratory tests, it seemed desirable to use an "average" cement consisting of the blend. The cements were purchased as Type I (non-air-entraining in equal sized lots. However, several of the sacks of one brand of cement have been found to be Type I-A (air-entraining) and have

had to be discarded, thus the supply of this brand will have to be replenished earlier than the other brands in order to continue the work. It would appear that this can be done without seriously affecting the strength levels and gives justification for using the "blend" system. The usual laboratory tests on the cement are shown in Table II-A. Two compressive strengths are shown resulting from hand and machine mixed controls for the fly ash tests. The strengths using machine and hand mixing do not differ significantly.

3. Fine Aggregate. Natural sand from the Killins Gravel Company located about 3 miles west of Ann Arbor was used in all the specimens. The physical test results of this sand are shown in Table III-A.

4. Coarse Aggregate. Natural gravel from the Killins Gravel Company was used in all the specimens. The physical test results of this gravel are shown in Table IV-A. It is believed this material is quite typical of pebbles for average concrete furnished in this area. The soft stone content is slightly high for Michigan State Highway Department specification material.

5. Air-Entraining Admixture. The air-entraining admixture, Darex, manufactured by the Dewey and Almy Chemical Company was used throughout this series of tests. This was purchased locally from a firm which furnishes transit mix concrete.

Fabrication of Specimens and Test Procedures

American Society for Testing Materials methods were generally followed in making and testing the specimens. The aggregates were air dried before use by spreading in a thin layer on the floor. Drying was hastened by a fan blowing air across the drying aggregates. The use of dry aggregate aided in more accurate determination of the water content of the mixes.

Concrete was mixed in a Blystone mixer having rotating paddles on a horizontal shaft. The mixer was "buttered" each day before using with a mixture of sand, cement, and water to coat the tub and paddles. The dry concrete materials were weighed on an 800-lb. capacity Toledo scale and placed in the mixer in the following sequence: pebbles, sand, fly ash, and cement. In order to prevent dusting, there was no dry mixing of the materials. The mixing water was weighed on an Ohaus Solution balance having a 40-lb. capacity and most of the water was introduced before starting the mixer. Simultaneously with the starting of the mixer, the measured amount of Darex was added and the mixing was continued for a 2-minute period. During the 2-minute interval additional water was added to adjust the slump. Following the 2-minute mixing, a 2-minute rest period was given with the mixer stopped followed by a 3-minute final mix. Occasionally, small adjustments in the water were made during the early part of the final 3-minute mixing period. Water not used was weighed back so that the amount actually used could be accurately determined.

After mixing, the concrete was dumped into a moistened flat pan and the slump and air tests were simultaneously conducted. These were followed by a weight per cubic foot determination, using a one-half cubic foot calibrated measure. An Acme pressure air meter was used for determining the air content.

The batch contained nominally 2.8 cubic feet of concrete, sufficient to make 12 test cylinders 6" x 12". This furnished two cylinders for each age of 1 day, 3 days, 7 days, 28 days, 90 days, and 1 year. Waxed cardboard molds with metal bottoms were used for casting the cylinders. The molds, immediately after filling, were covered by steel plates to prevent water evaporation from the fresh concrete.

Three batches of concrete were made on different days for each condition of test, thus furnishing 6 test cylinders for each age for each condition. A random sequence of making the batches was followed. However, plain cement batches were always made first on a given day so that these batches would contain no carry-over of mortar from a previous fly ash batch.

Volume change bars were made from the third round of mixes. Two bars, 2" x 2" x 11", with stainless steel measuring studs were made from each batch. These are to be stored under water for 90 days, after which they will be dried at 73° F. in a relative humidity of 50-60 per cent. Length measurements are made at 1 day, 7 days, 28 days, 60 days, 90 days and at about 1-month intervals during the subsequent drying period.

The following day after making the batches, all cylinders except the 1-day were stored in the moist fog room. The 1-day cylinders were stripped of their cardboard molds and immediately capped with Hydrostone capping plaster on each end. Caps were cast against hardened, polished one-half inch thick special steel plane bearing plates. At 24 hours age, the 1-day cylinders were broken in a Riehle 300,000 lb. testing machine. The other cylinders are similarly capped and tested at their designated ages.

Discussion of Test Results

The major portion of the concrete data so far acquired using Trenton Channel fly ash is shown in detail in the appendix in Tables V-A, VI-A, and VII-A for 4-sack, 5-sack, and 6-sack concrete, respectively. In general, summaries of important aspects of the data have been prepared from these tables and are presented in the body of the report. Space has been left in the tables to enter the 90-day and 1-year strengths when they become available.

1. Coarse Aggregate Content. As previously mentioned, stone contents of the fly ash mixes were increased over those of the plain cement mixes providing the same apparent workability. The values used for the fly ash mixes were found by observation of a few hand mixed batches and minor changes were made during the course of making the machine mixed batches as indicated in the tabulation. The stone contents are designated as V_s, this denoting the volume of dry-rodded coarse aggregate per unit volume of concrete. The advantage of this method of expressing the stone content is that once it is established that satisfactory workability is obtained with a given maximum size coarse aggregate (1 inch in this case) and a sand of given fineness modulus, then office computation only is needed to compute aggregate proportions for future batches regardless of whether the coarse

aggregate be gravel, crushed stone, or slag. It is only necessary to know the dry-rodded weight per cubic foot of the aggregate. Table I shows the values of V_s found satisfactory in this work. These values should be checked against field experience before making final recommedations. Some users might consider the concrete furnished using these values as unduly harsh or uneconomical due to higher cost of stone. If higher sand contents are demanded, loss in strength can be expected.

Table I. Volume, V_s, of Dry-Rodded Coarse Aggregate per Unit Volume of Concrete

Fly Ash lb./cu. yd.	4-Sack	5-Sack	6-Sack
0	0.64	0.64	0.64
100	--	--	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. Selection of Fly Ash Contents. Choice of fly ash contents to be studied was arbitrary. In general, the upper range was extended somewhat beyond that frequently reported in the literature. As a practical matter, ash contents below 100 lb. per cubic yard of concrete were not used since it seemed doubtful if lesser amounts would be employed unless some important advantage in using such a small amount could be demonstrated. It is recognized that it may be a matter of later regret, when the 90-day and 1-year strength results become available, that a greater range of ash contents was not studied.

3. Control of Concrete Mixes. Attempt was made throughout the program to adjust the Darex air-entraining admixture content to provide 4 to 5 per cent air in the concrete with a slump near 4 inches. High slump mixes tend to entrain more air and low air mixes tend to diminish the yield. Thus the three factors, slump, air content, and cement content are interrelated.

Some of the mixes shown on the tabulation rather seriously violate the desired values but the average of the three mixes for each condition is generally more satisfactory.

4. Strength Results. Individual cylinder strengths are shown on the detailed tabulations in the appendix. A few of the cylinders were apparently faulty and have been omitted from the average. This was done when (1) the strength of the cylinder differed considerably from its companion cylinder from the same batch and simultaneously, (2) this strength differed considerably from the average of the 6 cylinders. Average values have been tabulated in Table II.

Probably the most obvious 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. In order better to understand the strength development of these fly ash mixes in comparison with the plain cement mixes, Table III has been prepared showing the strength of the fly ash mixes at each age expressed as percentage of strength of the plain cement mixes having the same cement content.

Table III. Compressive Strength of Fly Ash Mixes Expressed as Per Cent of Strength of Plain Cement Mixes of Same Cement Content

Cement sk./cu. yd.	Fly Ash lb./cu. yd.	1 Day	3 Days	7 Days	28 Days
4	150	130	121	116	131
4	200	112	108	108	122
4	250	104	101	100	122
4	300	94	99	96	115
5	150	107	94	97	99
5	200	96	101	98	108
5	250	93	94	92	103
6	100	96	101	94	96
6	150	99	96	93	97
6	200	75	93	89	97

TABLE II

SUMMARY OF RESULTS
TRENTON CHANNEL FLY ASH

Nominal Cement Content, sk./cyd.	Actual Cement Content, sk./cyd.	Fly Ash, lb./cyd.	Net Mixing Water		Air Content, per cent	Slump, inches	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	150	224	6.72	4.0	3.2	10.3	909	1878	2656	4022		
	4.09	200	233	6.98	4.0	3.8	11.4	789	1673	2462	3749		
	4.07	250	250	7.51	4.0	4.3	14.4	730	1569	2273	3753		
	4.05	300	267	8.00	4.1	4.0	17.3	659	1532	2185	3545		
5.0	5.11	0	228	5.48	5.5	3.5	4.2	1080	2088	3002	3993		
	5.04	150	239	5.75	5.4	4.4	11.9	1151	1971	2903	3967		
	5.08	200	255	6.12	4.5	3.5	13.0	1040	2114	2939	4313		
	5.07	250	263	6.32	4.3	4.3	16.5	1005	1958	2753	4127		
6.0	6.06	0	239	4.77	5.7	4.7	4.2	1449	2505	3576	4633		
	6.10	100	247	4.94	4.7	4.6	9.9	1395	2522	3368	4449		
	6.11	150	261	5.22	4.4	3.8	11.6	1430	2413	3332	4506		
	6.00	200	273	5.47	4.5	4.3	14.3	1094	2335	3169	4505		

Although the percentage values in the above tabulation show some disconcerting variations, the trend is definite for the 4-sack low fly ash content mixes to develop strengths superior to the plain cement mixes. The trend is more pronounced at the 28 day age than at earlier ages and appears to diminish with increasing amounts of fly ash. Strength levels of the 5- and 6-sack fly ash mixes do not appear to be greatly influenced up to 7 days age by the presence of the fly ash. However, there is a trend for relative strength gain at 28 days.

In Table IV is a tabulation showing the ratio of 28-day to 7-day strengths of the various mixes. Unless analyzed carefully, the tabulation above and this one appear to be contradictory. However, the tabulation above refers to strength levels of fly ash mixes with respect to plain cement mixes of the same cement content and the tabulation below refers to rate of strength development of all the mixes.

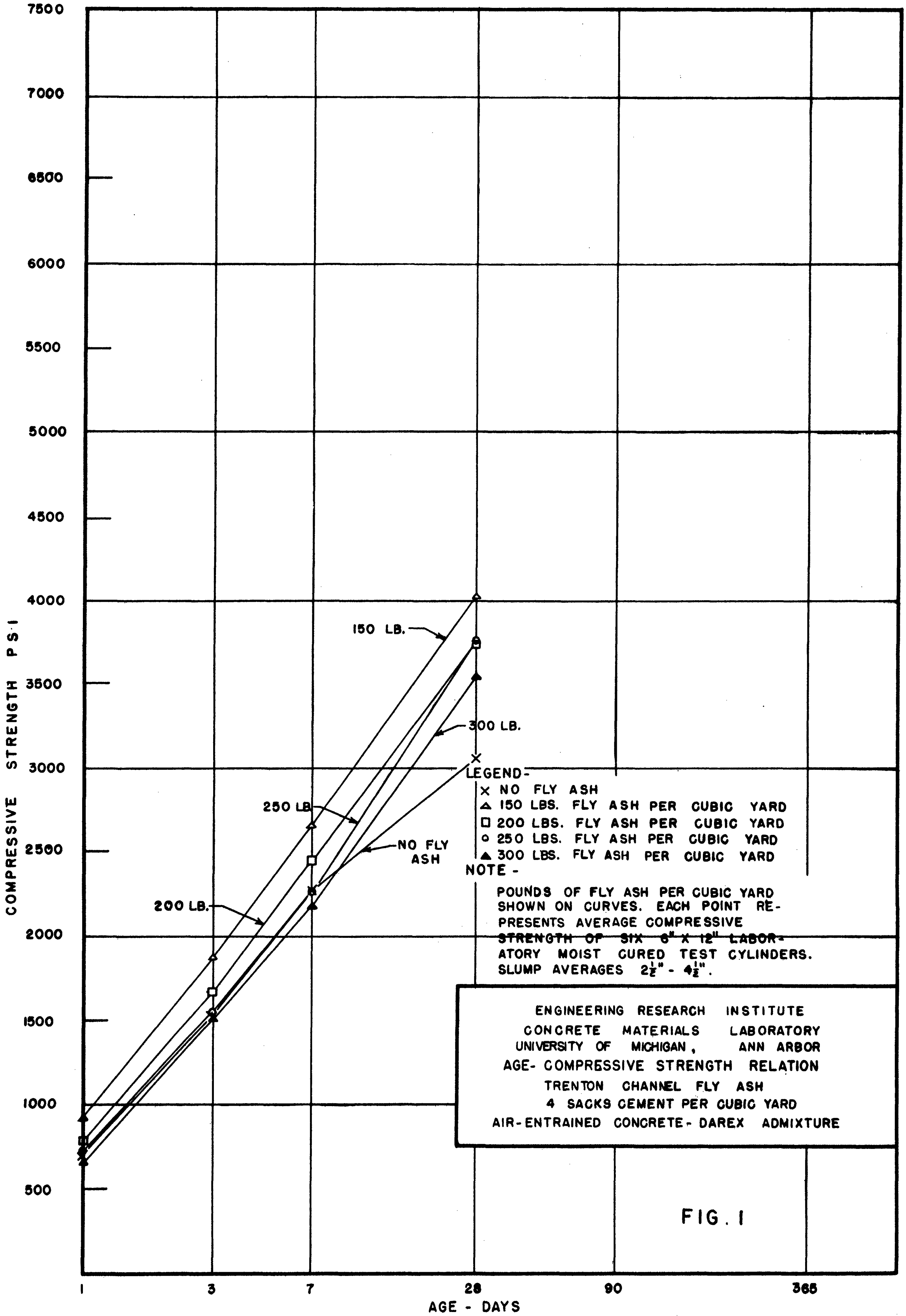
Table IV. Average Ratio of 28-Day to 7-Day Compressive Strength

Cement Content sk./cu. yd.	Fly Ash lb./cu. yd.	Ratio of 28-Day Strength to 7-Day Strength
4	0	1.35
4	150	1.51
4	200	1.52
4	250	1.65
4	300	1.62
5	0	1.33
5	150	1.37
5	200	1.48
5	250	1.50
6	0	1.30
6	100	1.32
6	150	1.35
6	200	1.42

The tabulation indicates that lean mixes, whether containing fly ash or not, gain strength faster than rich mixes between 7 and 28 days and increasing amounts of fly ash hasten this strength gain for all cement contents.

Average strengths of the various mixes are shown plotted on a logarithmic time scale on Figs. 1-3. Strength development appears to be fairly orderly for all the mixes for 1-day, 3-days, 7-days, and 28-days. It does not appear, for practical purposes, that the expected strength at early ages of fly ash concrete need be considered much different for the same curing conditions from that expected for ordinary concrete for a given 28-day strength.

5. Air-Entraining Admixture Requirement. About 4 fluid ounces of Darex per cubic yard of concrete were required to obtain the desired amount of air in the plain concrete. The Darex requirement of the fly ash concrete varied depending upon the amount of fly ash used and the cement content. For a given fly ash content, rich mixes required more Darex and for a given cement content higher fly ash content mixes required more admixture. The highest Darex requirement, 17 ounces per yard, was required by the 4-sack concrete containing 300 lbs. of ash per cubic yard.


7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
COMPRESSIVE STRENGTH P.S.I
1
3
7
28
90
365
AGE - DAYS
150 LB.
300 LB.
250 LB.
NO FLY ASH
200 LB.
LEGEND -
× NO FLY ASH
△ 150 LBS. FLY ASH PER CUBIC YARD
□ 200 LBS. FLY ASH PER CUBIC YARD
○ 250 LBS. FLY ASH PER CUBIC YARD
▲ 300 LBS. 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 2½" - 4½".
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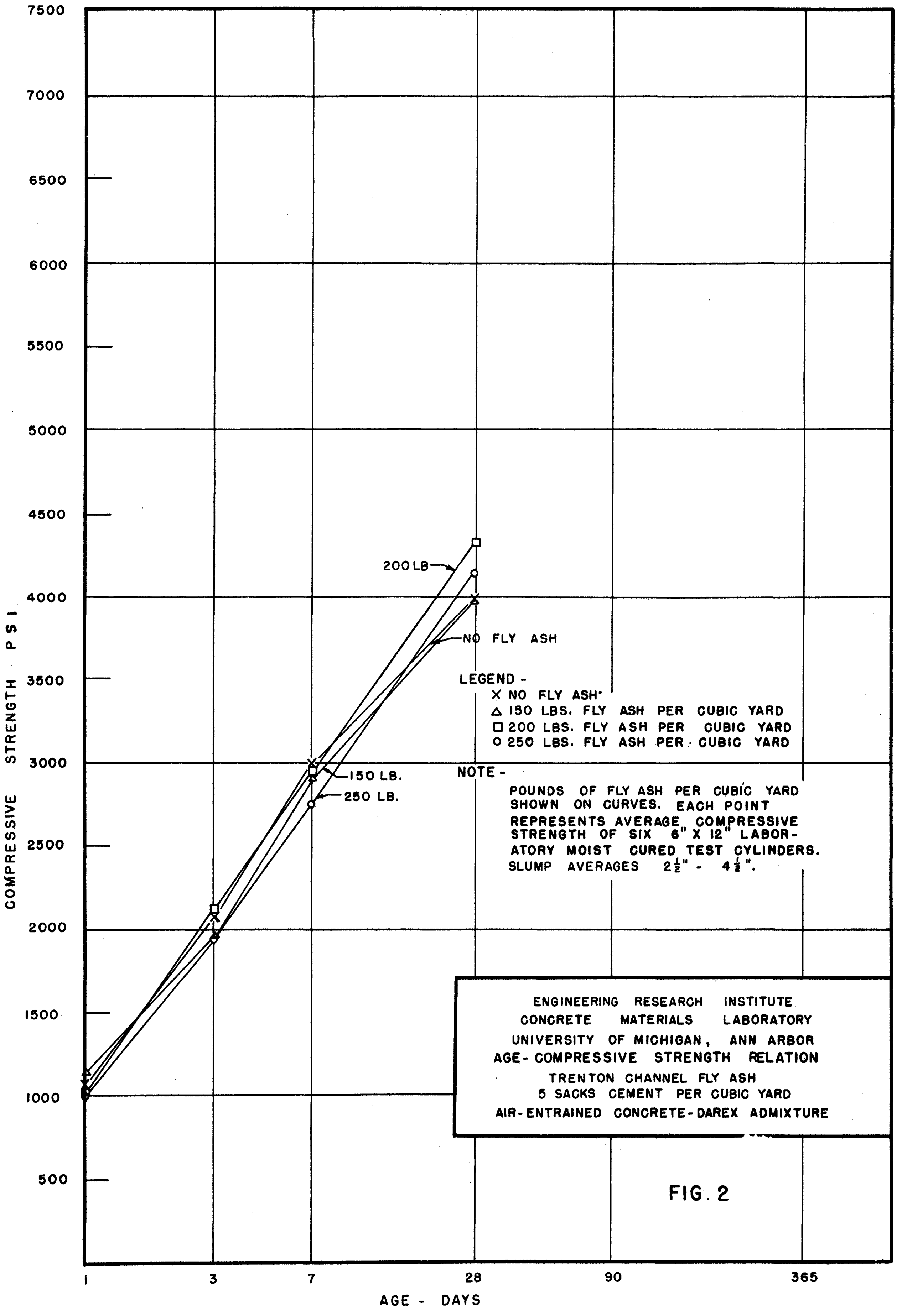
AGE- COMPRESSIVE STRENGTH RELATION
TRENTON CHANNEL FLY ASH
4 SACKS CEMENT PER CUBIC YARD
AIR-ENTRAINED CONCRETE - DAREX ADMIXTURE

FIG. 1


7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
COMPRESSIVE STRENGTH PSI
1
3
7
28
90
365
AGE - DAYS
200 LB
NO FLY ASH
150 LB.
250 LB.
LEGEND -
× NO FLY ASH
△ 150 LBS. FLY ASH PER CUBIC YARD
□ 200 LBS. FLY ASH PER CUBIC YARD
○ 250 LBS. FLY ASH PER CUBIC YARD
NOTE -
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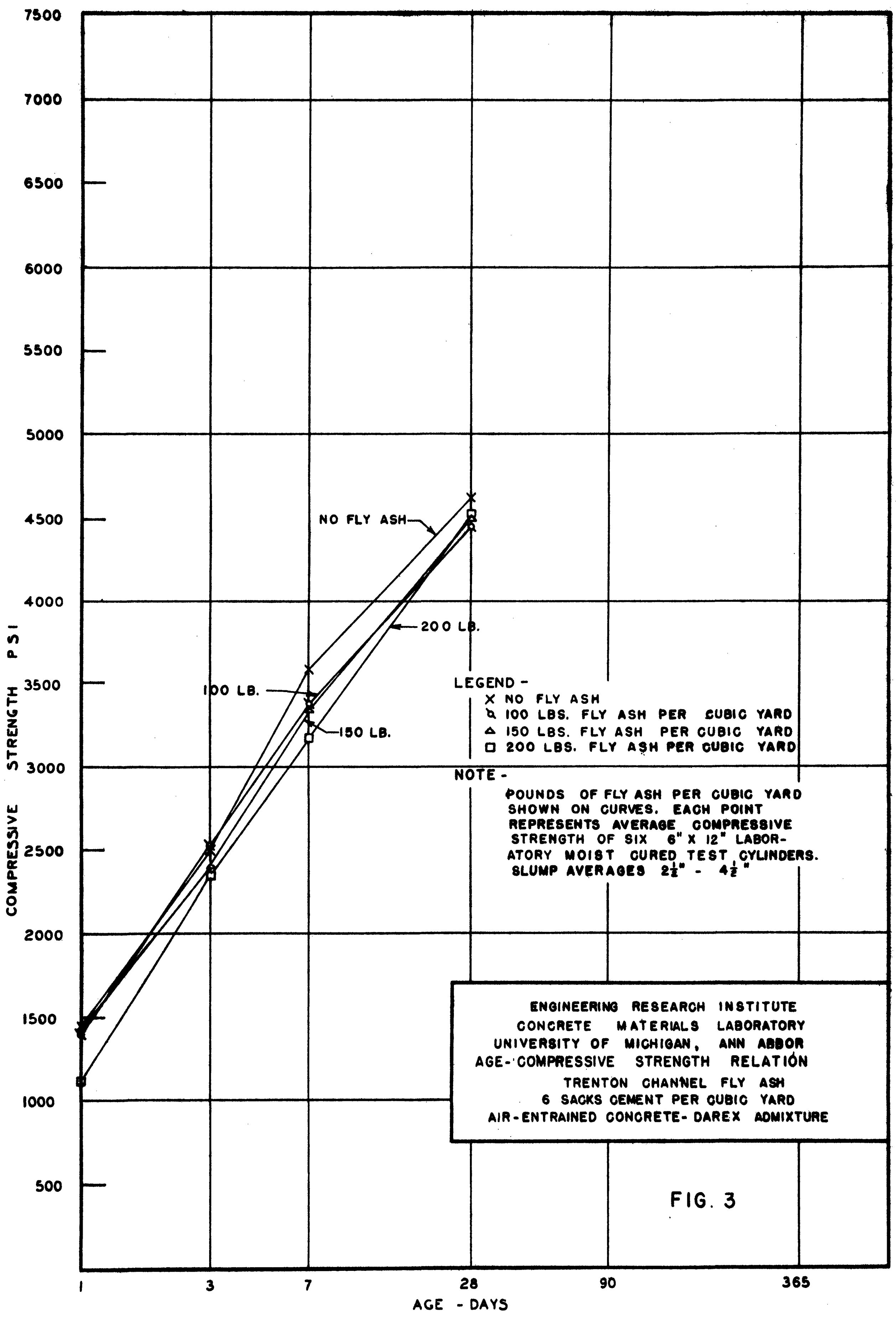
AGE- COMPRESSIVE STRENGTH RELATION
TRENTON CHANNEL FLY ASH
5 SACKS CEMENT PER CUBIC YARD
AIR-ENTRAINED CONCRETE-DAREX ADMIXTURE

FIG. 2


7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
COMPRESSIVE STRENGTH PSI
1
3
7
28
90
365
AGE - DAYS
NO FLY ASH
200 LB.
100 LB.
150 LB.
LEGEND -
X NO FLY ASH
100 LBS. FLY ASH PER CUBIC YARD
150 LBS. FLY ASH PER CUBIC YARD
200 LBS. 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 2½" - 4½"
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AGE-COMPRESSIVE STRENGTH RELATION
TRENTON CHANNEL FLY ASH
6 SACKS CEMENT PER CUBIC YARD
AIR-ENTRAINED CONCRETE- DAREX ADMIXTURE

FIG. 3

A P P E N D I X

TABLE I-A

PROPERTIES OF FLY ASH

54C-159

Physical Properties

Specific Surface, air permeability test, sq. cm. per gram	2960
Compressive Strength, 20 per cent by weight of portland cement addition, hand mixing, 73°F. cure, per cent of control	
7 days	104
28 days	105
90 days	--
Water requirement, per cent of control	110
Compressive Strength, 25 per cent by weight of sand, sand replacement, machine mixing, 73°F. cure, per cent of control	
7 days	136
28 days	150
90 days	--
Water requirement, per cent of control	117
Compressive Strength, 25 per cent by weight of cement, sand replacement, machine mixing, 73°F. cure, per cent of control	
7 days	149
28 days	154
90 days	--
Water requirement, per cent of control	100
Drying Shrinkage, 28 days, per cent	0.086
Soundness, autoclave expansion, per cent	0.02
Specific Gravity	2.42

TABLE I-A (Continued)

TRENTON FLY ASH
54C-159
MORTAR STRENGTH TESTS

20 Per Cent by Weight of Cement Addition (Hand Mix)

	Compressive Strength, psi. 7 Days	28 Days	90 Days
Control (54C-158)	3129	4463	
Fly Ash	3271 (104)	4721 (105)	

Control Mix	Fly Ash Mix
750 g. cement	750 g. cement
2063 g. graded sand	150 g. fly ash
350 ml. water	2063 g. graded sand
	387 ml. water
100.2% Flow	106.1% Flow

25 Per Cent by Weight of Sand, Sand Replacement (Machine Mix)

	7 Days	28 Days	90 Days
Control (54C-158)	3283	4650	
Fly Ash	4458 (136)	6975 (150)	

Control Mix	Fly Ash Mix
750 g. cement	750 g. cement
2063 g. graded sand	515 g. fly ash
350 ml. water	1545 g. graded sand
	408 ml. water
103.2% Flow	103.7% Flow

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

	7 Days	28 Days	90 Days
Control (54C-158)	2950	4271	
Fly Ash	4392 (149)	6579 (154)	

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
	365 ml. water
115.4% Flow	110.3% Flow

(Per cent of control in parenthesis)

TABLE II-A

PROPERTIES OF CEMENT

54C-158

Physical Properties

Specific Surface, air permeability, sq. cm. per gram	3133		
Autoclave Expansion, per cent	0.08		
Normal Consistency, per cent	24.8		
Time of set, Gilmore			
Initial	4:00		
Final	6:00		
Tensile Strength, psi.			
7 Days	358		
28 Days	462		
Compressive Strength, psi.	Hand Mix	Machine Mix	
7 Days	3129	3283	2950
28 Days	4463	4650	4271
90 Days	--	--	--
Air in Mortar, per cent	12.0		

TABLE III-A

TESTS ON FINE AGGREGATE

Sieve Analysis	
Passing, per cent by weight	
3/8 inch sieve	100
No. 4 "	99
No. 8 "	87
No. 16 "	61
No. 30 "	38
No. 50 "	12
No. 100 "	2.0
Loss by washing, per cent	0.8
Specific Gravity	2.60
Absorption, per cent	1.46
Fineness Modulus	3.01
Organic Matter, Plate Number	I
1:3 Mortar Strength ratio	
7 days	1.35

TABLE IV-A

TESTS ON GRAVEL

Sieve Analysis	
Passing, per cent by weight	
1 inch sieve	100
½ inch "	37
No. 4 "	3.8
Loss by washing	0.5
Deleterious particles, per cent	
Soft and Non-durable	3.2
Chert	3.7
Hard absorbent sandstone	1.0
Thin or Elongated	0.1
Incrusted particles (Greater than 1/3 surface area)	0.8
Incrusted particles (Less than 1/3 surface area)	0.4
Los Angeles "B" abrasion, per cent	20.9
Specific Gravity	2.64
Absorption, per cent	1.50
Weight per cu. ft., dry rodded, lb.	105

TABLE V-A

4-SACK CONCRETE DATA - TRENTON CHANNEL FLY ASH

Batch No.	Date Made	Fly Ash lb./cyd.	Actual Cement sk./cyd.	V_s **	Material Proportions lb. per cyd. Sand	Stone	Net Water	W/C gal. per sk.	Wt. of Fresh Concrete lb./cu. ft.	Pressure Air Content Per Cent	Slump in.	Darex Fluid oz./cyd.	Compressive Strength, psi. (6" x 12" cylinders) 1 day	3 days	7 days	28 days	90 days	1 year
4	2/19/54	0	4.18	.64	1312	1812	245	7.36	146.9	4.5	2.0	4.9	780 710	1610 1620	2385 2350	3285 3375		
16	3/2/54	0	4.14	.64	1408	1812	220	6.60	148.1	4.5	2.0	3.9	760 775	1645 1765	2490 2560	3695* 3145		
30	3/12/54	0	3.97	.64	1460	1812	229	6.88	144.3	6.5	3.5	3.9	585 600	1345 1290	1925 1980	2825 2720		
	Average	0	4.10	.64	1393	1812	231	6.95	146.4	5.2	2.5	4.2	702	1546	2282	3070		
20	3/5/54	150	4.10	.78	905	2211	217	6.51	148.3	3.6	2.0	9.8	935 1005	1980 2030	2915 2740	4680 4415		
28	3/10/54	150	4.01	.78	939	2211	231	6.93	146.9	4.2	4.5	9.8	900 970	1835 1910	2740 2595	4260 3975		
38	3/19/54	150	4.05	.78	939	2211	224	6.72	148.2	4.1	3.0	11.4	795 850	1785 1730	2420 2525	3320 3480		
	Average	150	4.05	.78	928	2211	224	6.72	147.8	4.0	3.2	10.3	909	1878	2656	4022		
7	2/22/54	200	4.16	.75	792	2124	227	6.83	144.9	4.9	3.75	11.4	795 865	1750 1715	2615 2580	3905 3905		
19	3/3/54	200	4.07	.81	764	2296	230	6.89	147.2	3.9	2.75	11.4	850 865	1785 1695	2580 2525	3500 3905		
34	3/16/54	200	4.04	.81	772	2296	241	7.23	147.0	3.3	5.0	11.4	670 690	1520 1570	2260 2210	3675 3605		
	Average	200	4.09	.79	776	2239	233	6.98	146.4	4.0	3.8	11.4	789	1673	2462	3749		
10	2/23/54	250	4.18	.75	739	2124	233	7.06	145.7	4.0	3.75	13.0	790 760	1835 1835	2475 2665	3800 4100		
26	3/9/54	250	4.00	.81	702	2296	258	7.74	145.5	3.9	4.75	14.0	635* 725	1415 1380	2050 2225	3550 2970*		
35	3/16/54	250	4.02	.81	675	2296	258	7.74	145.0	4.0	4.5	16.3	705 670	1465 1485	2225 1995	3535 3780		
	Average	250	4.07	.79	705	2239	250	7.51	145.4	4.0	4.3	14.4	730	1569	2273	3753		
15	3/1/54	300	4.04	.75	788	2124	263	7.90	145.7	3.6	3.75	15.7	670 705	1625 1645	2385 2490	4065 3640		
29	3/10/54	300	4.08	.81	568	2296	265	7.95	145.5	4.0	4.0	17.3	705 690	1555 1520	2225 2210	3710 3355		
39	3/19/54	300	4.03	.81	568	2296	272	8.15	143.7	4.6	4.25	18.9	585 600	1430 1415	1890 1910	3075 3425		
	Average	300	4.05	.79	641	2239	267	8.00	145.0	4.1	4.0	17.3	659	1532	2185	3545		

* Not included in average.

** V_s denotes volume of dry rodded coarse aggregate per unit volume of concrete.

TABLE VI-A

5-SACK CONCRETE DATA - TRENTON CHANNEL FLY ASH

Batch No.	Date Made	Fly Ash lb./cyd.	Actual Cement sk./cyd.	V_s**	Material Proportions lb. per cyd. Sand	Stone	Net Water	W/C gal. per sk.	Wt. of Fresh Concrete lb./cu. ft.	Pressure Air Content Per Cent	Slump in.	Darex Fluid oz./cyd.	Compressive Strength, psi. (6" x 12" cylinders) 1 day	3 days	7 days	28 days	90 days	1 year
12	2/26/54	0	5.21	.64	1235	1815	226	5.44	145.6	6.7	4.25	4.9	1005 1005 1165 1095 1130 1080 1080	1960 2085 2065 2015 2210 2190 2088	2860 3020 2755 3020 3305 3055 3002	4080 3765 3815 3940 4135 4225 3993		
25	3/9/54	0	5.00	.64	1383	1815	225	5.41	146.1	5.6	3.0	3.9						
40	3/22/54	0	5.12*	.64	1383	1815	233	5.59	149.9*	4.3	3.25	3.9						
	Average	0	5.11	.64	1334	1815	228	5.48	145.9	5.5	3.5	4.2						
5	2/19/54	150	5.05	.75	765	2125	245	5.89	141.6	7.0	6.75	13.0	990* 1110 1235 1270 1060 1080 1151	1800 1700 2175 2210 1995 1945 1971	2685 2700 3180 3250 2670 2935 2903	3885 3655 4610* 4240 4170 3885 3967		
17	3/3/54	150	5.06	.78	780	2210	229	5.51	145.3	4.4	2.5	11.4						
31	3/12/54	150	5.01	.78	811	2210	243	5.85	146.1	4.7	4.0	11.4						
	Average	150	5.04	.77	785	2182	239	5.75	144.3	5.4	4.4	11.9						
8	2/23/54	200	5.22	.75	710	2125	251	6.04	146.7	4.2	2.5	13.0	1150 1150 955 990 970 1025 1040	2245 2225 2155 2120 1960 1980 2114	3075 3005 2970 2825 2880 2880 2939	4380 4330 4575 4415 4065 4115 4313		
21	3/5/54	200	5.04	.78	717	2213	246	5.91	145.3	4.6	3.0	13.0						
33	3/15/54	200	4.98	.78	727	2213	267	6.41	144.6	4.7	5.0	13.0						
	Average	200	5.08	.77	718	2184	255	6.12	145.5	4.5	3.5	13.0						
13	2/26/54	250	5.22	.75	657	2125	248	5.97	146.5	3.6	4.25	14.7	990 1080 1025 990 955 990 1005	2120 2155 1960 2120 1695 1695 1958	2860 2840 2935 2755 2615 2510 2753	4415 4030 4135 3905 3585* 4150 4127		
24	3/8/54	250	5.02	.78	672	2212	269	6.47	145.6	3.9	3.75	16.3						
36	3/17/54	250	4.96	.78	661	2212	271	6.51	143.4	5.3	4.75	18.6						
	Average	250	5.07	.77	663	2183	263	6.32	145.2	4.3	4.3	16.5						

* Not included in average.

** V_s denotes volume of dry rodded coarse aggregate per unit volume of concrete.

Table VII-A

6-Sack Concrete Data - Trenton Channel Fly Ash

Batch No.	Date Made	Fly Ash lb./cyd.	Actual Cement sk./cyd.	V_s**	Material Proportions lb. per cyd. Sand	Stone	Net Water	W/C gal. per sk.	Wt. of Fresh Concrete lb./cu. ft.	Pressure Air Content Per Cent	Slump in.	Darex Fluid oz./cyd.	Compressive Strength, psi. (6" x 12" cylinders) 1 day	3 days	7 days	28 days	90 days	1 year
11	2/25/54	0	6.15	.64	1159	1813	232	4.65	144.7	6.7	4.75	3.9	1450 1220*	2755 2510	3760 3580	4715 4785		
23	3/8/54	0	5.95	.64	1290	1813	240	4.80	145.2	6.4	5.0	4.9	1450 1340	2295 2295	3110 3390	4310 4415		
41	3/22/54	0	6.07	.64	1276	1813	244	4.87	147.6	4.1	4.25	3.9	1485 1520	2615 2560	3765 3850	4910 4665		
	Average	0	6.06	.64	1242	1813	239	4.77	145.8	5.7	4.7	4.2	1449	2505	3576	4633		
14	3/1/54	100	6.22	.75	756	2127	244	4.87	147.2	4.5	4.0	9.1	1305 1465	2765 2400	3480 3585	4645 4415		
27	3/10/54	100	6.08	.75	848	2127	247	4.93	147.5	4.3	4.25	9.8	1500 1380	2385 2490	3125 3305	4345 4665		
42	3/23/54	100	5.99	.75	848	2127	251	5.03	145.4	5.4	5.5	10.7	1360 1360	2475 2615	3535 3180	4365 4260		
	Average	100	6.10	.75	817	2127	247	4.94	146.7	4.7	4.6	9.9	1395	2522	3368	4449		
6	2/22/54	150	6.18	.75	702	2127	258	5.16	146.5	4.5	3.5	11.4	1555 1625	2400 2545	3390 3460	5070 4875		
18	3/3/54	150	6.07	.75	744	2127	257	5.15	145.6	4.3	3.75	11.4	1430 1410	2560 2400	3235 3285	4470 4490		
32	3/15/54	150	6.07	.75	754	2127	268	5.35	146.3	4.3	4.25	12.1	1360 1200	2245 2330	3270 3355	4100 4030		
	Average	150	6.11	.75	733	2127	261	5.22	146.1	4.4	3.8	11.6	1430	2413	3332	4506		
9	2/23/54	200	6.14	.75	648	2127	263	5.27	145.7	4.1	2.75	14.0	1400 1360	2685 2630	3340 3215	4805 4610		
22	3/5/54	200	6.05	.75	674	2127	271	5.43	144.8	4.6	4.5	14.0	1150 1080	2315 2350	3235 3130	4505 4490		
37	3/17/54	200	5.80	.75	786	2127	286	5.71	143.3	4.9	5.75	15.0	760 815	2015 2015	3075 3020	4170 4450		
	Average	200	6.00	.75	703	2127	273	5.47	144.6	4.5	4.3	14.3	1094	2335	3169	4505		

* Not included in average.

** V_s denotes volume of dry rodded coarse aggregate per unit volume of concrete.