RESEARCH REPORT
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EXPERIMENTAL CONCRETE PAVEMENT CONTAINING FLY-ASH ADMIXTURES
I-64-2 (72) 18 and F 552 (15) on KY 841 at I 64

Final Report

by

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TO: J. R. Harbison
State Highway Engineer

DATE: April 7, 1971

SUBJECT: Research Report; "Experimental Concrete Pavement Containing Fly-Ash Admixture"; I 64-2(72)18, F 552(15); Jefferson Freeway

The report enclosed is somewhat routine inasmuch as it documents a repeat of a portion of an earlier experimental project. The previous project was on Poplar Level Road; our final report was dated July 1966 (KYHPR-64-1). Special Provision No. 70 was used also on the Jefferson Freeway project. However, there was no "control section" involved in the current project. The Jefferson Freeway project was authorized by the BPR under P.P.M. 60-2 only (now PPM 20-6.3).

The most significant findings from both projects concern the water requirements of the concrete containing the fly-ash admixture. Whereas laboratory tests indicated reasonable expectations of a reduction in water demand in the fly-ash concrete -- in comparison to normal concrete -- these expectations were not realized during construction of either project; and so that peculiar phenomenon persists and remains unexplainable.

We will consider this the final report on the Jefferson Freeway project unless some peculiarity arises in the future performance of the pavement.

Respectfully submitted,

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INTRODUCTION

Hydration of portland cement is accompanied by the liberation of lime, and free lime contributes little, if any, to strength and may actually have a weakening effect. One bag of normal cement may contain 10.4 pounds of available lime; a six-bag concrete mixture would contain approximately 62 pounds of lime per cubic yard. In event all of the lime were leached from the mass, the porosity would increase appreciably and the durability might be greatly reduced. Progressive carbonation of the lime, however, reduces the likelihood of all lime being leached from the mass.

Certain siliceous materials (pozzolans) produce hydraulic cement when mixed with lime. Fly ash is one of the most common artificial pozzolans. The chemical composition and physical properties of fly ash are variable and depend largely upon the source of coal, method of burning, equipment, and method of collecting. Generally, fly ash produced at a particular plant using coal from a common source and operating at a steady load is fairly uniform. The addition of fly ash to portland cement concrete provides a pozzolan for reaction with lime liberated during hydration of the cement. The quantity of fly ash necessary to "fix" the lime in a given concrete mixture may be estimated theoretically from chemical analyses of the fly ash and cement. However, the addition of fly ash to a concrete mixture may appreciably affect physical properties of the fresh and (or) hardened mixture and thereby must be considered when proportioning mixes. The optimum quantity of fly ash to use in mixtures, adjusted to obtain a reduction in cement content, should be established from tests using the proposed job cement and aggregates.

Many of the particles in fly ash are spherical and impart a lubricating effect to most concrete mixtures. Fineness affects pozzolanic activity and the finer fly ashes generally exhibit accelerated pozzolanic activity and thus high early strengths. Fineness and roundness of the fly ash also affect the water requirement for concrete mixtures, and most studies indicate a reduced water requirement when using fly ash having a high fineness. Fly ash reportedly improves workability and plasticity, reduces bleeding and segregation, and increases ultimate compressive strength and modulus of elasticity.

A definite disadvantage in the use of fly ash in concrete is the added effort in batching and controlling the additional material. The material is also difficult to handle since its flow characteristics are similar to those of water or fluidized powders. Mixtures containing high percentages of fly ash are reportedly difficult to finish and have a somewhat gummy property. Lower early strengths are most commonly experienced in mixtures in which the fly ash is used as a replacement of a portion of the cement. There is also evidence that fly ash concrete is less resistant to freezing and thawing when cured for a short period and then followed by drying. Fly ash is also reported to reduce the resistance of concrete to deicing salts and abrasion and increases creep in prestressed concrete.

In 1963, the Department of Highways initiated an experimental project* wherein fly ash was

*Hughes, R.D., "Experimental Concrete Pavement Containing Fly-Ash Mixtures," Division of Research, Kentucky Department of Highways, July, 1966. See also - Hughes, R.D., "Experimental Concrete Pavement Containing Fly-Ash Mixtures," **Record** 73, Highway Research Board, 1965; and Whitney, F.D., "A Study of the Use of a Local Fly Ash in Concrete Mixes," Division of Research, Kentucky Department of Highways, April, 1958.

used as a partial cement replacement in a paving concrete. A control and two experimental sections were placed on the Poplar Level Road in Jefferson County. The Experimental A mixtures contained five bags of portland cement and 94 pounds of fly ash per cubic yard. Experimental B mixtures contained five bags of cement and 140 pounds of fly ash per cubic yard. Strength tests indicated the fly ash concretes to be somewhat stronger than the normal concrete at the end of a year. Freeze-thaw specimens of the Experimental A and control mixtures performed somewhat equally to 1600 cycles; whereas, the Experimental B mixtures did not perform nearly as well. A performance survey conducted in 1966 was rather inconclusive, and an additional experimental project was considered essential. Only Experimental A mixtures were to be utilized for further study.

PROJECT DESCRIPTION

In 1969, experimental concrete was placed on a section of the Outer Loop in Jefferson County. The section involved two projects on KY 841 from I 64 to KY 155. Specifically, the projects included were: F 552 (15), Sta 935+00 to 1032+00, and I-64-2 (72) 18, Sta 1032+00 to 1047+50. Placement of experimental concrete was begun on August 13, 1969, by the Ruby Construction Company. The pavement was ten inches thick and was placed on four inches of DGA. The project consisted of two sets of dual lanes (24 feet, each set) and a dividing median.

All concrete was centrally mixed at the site by a Ross Portable Batch Plant having a rated capacity of eight cubic yards. The plant was operated occasionally within the allowable overload range for productions of 8.5 cubic yards. Batching was automatically controlled, except for the fly ash which was weighed manually from the storage hopper. That hopper was mounted above the plant and was not originally a part of the plant. Air, supplied through a conduit mounted on the side of the hopper, was used, as necessary, to aid the flow of fly ash from the unit. The mixer was charged from a conveyor belt - with coarse aggregate, sand, cement, fly ash, in that order.

The ingredients, preparation and control of the mixtures were in accordance with requirements of Special Provision No. 70, appended hereto for convenient reference. Fly ash was obtained from the Louisville Gas and Electric Company. Type I, normal portland cement was supplied by the Lone Star Cement Company and the Louisville Cement Company. The coarse aggregate conformed to gradation requirements for No. 357 and Ohio River sand was the fine aggregate. Daravair was used double strength for air entrainment at the beginning of the project. Air entrainment was not sufficient and Amity, triple strength, air-entrainment admixture was used for completion of the project. Air contents within the permissible range were obtained by use of 48 to 68 ounces of Amity per batch (8 to 8.5 cubic yards).

The concrete was placed in one lift between conventional forms by a Maxon spreader. Wire mesh was placed with a mechanical depressor, and finishing was accomplished with a Rex finishing machine. The final surface was finished with a burlap drag, and a white-pigmented, membrane-forming compound was used for curing.

Beams and cylinders were cast for flexural- and compressive-strength testing at 3, 7, and 28 days and 3 and 6 months. Nine specimens were cast for freeze-thaw testing.

TEST RESULTS AND OBSERVATIONS

All constituents of the experimental concrete were sampled and tested in accordance with departmental specifications and appropriate ASTM standards. Average test results for the materials are listed in Tables 1 through 4. All materials tested were within the specification limits. Average test values for fineness modulus of the sand and water requirement of fly ash mortar indicated a decrease in water requirement of the fly ash concrete might logically be expected. The decrease in water requirement was not achieved in field production, and majority of mixtures utilized the maximum permissible water (34.5 gallons per cubic yard). An average water requirement of 29 gallons per cubic yard was realized for similar experimental fly ash mixtures placed on the Poplar Level Road, Jefferson County, in 1963. Experimental A mixtures placed on the Poplar Level Road were identical in all respects to mixtures placed on the project reported herein.

Average, compressive- and flexural-strength test results are presented in Table 5. For comparative purposes, average strength test results for Experimental A and control mixtures placed on the Poplar Level Road are included. With the exception of three-day test specimens, average strengths of specimens cast from mixtures placed on this project were below those of specimens cast from both Experimental A and control mixtures placed on the Poplar Level Road. The free water requirements per cubic yard were 34.5, 30.1, and 31.0 gallons respectively for this project, Experimental A, and control mixtures. Average air contents and slumps for the project were 5.8 percent and 2.5 inches. Average air content and slump for both mixtures for the Poplar Level Road project were 4.8 percent and 2.6 inches. Specification requirements for air content on this project were 6±2 percent; whereas, requirements for the previous project were 3 to 6 percent.

Average compressive and flexural strengths of specimens cast from mixtures placed on the two projects are plotted versus age at testing in Figures 1 and 2. Since those figures are graphical representations of the data presented in Table 5, the effect of variation in water requirement upon strength of the various mixtures is again evident. Tables 6 and 7 contain compressive strength test results from cores obtained from both the mainline pavement and the KY 155 interchange. The age of the cores at time of testing ranged from 45 to 72 days, and the average age of all cores at the time of testing was 62 days. The average compressive strength of all cores was 4753 psi. Although not necessarily significant, the 62-day compressive strength indicated on Figure 1 is 4700 psi.

Freeze-thaw specimens were moist cured for 14 days prior to initiation of tests. The tests were conducted in a manner similar to that outlined in ASTM Designation: C291-67. Durability factors for nine specimens tested to 300 cycles of freeze-thaw ranged from 98.9 to 102.3 and averaged 100.4 Durability factors for specimens cast from Experimental A and control mixtures on the Poplar Level Road project averaged 100.5 and 98.9, respectively, for 300 cycles of freeze-thaw. These averages indicate that little or no variation in durability may be expected when fly ash is used as a partial cement replacement in proportions utilized on the projects reported herein. Variation in water requirement for the various mixtures is certainly not reflected in average values of durability factors.

Finishers reported the fly ash concrete to be rather sticky or gummy and more difficult to finish than conventional, portland cement concrete. A similar report was made by finishers on the Poplar Level Road project. The surface texture of the experimental pavements appeared normal and no unusual conditions were observed.

The project was let to contract in 1968 and the unit bid price for the pavement was $6.45 per square yard. The statewide average for 10-inch cement concrete pavements for 1968 was $5.64 per square yard, and the 1968 average for all 10-inch pavements within the highway district in which the experimental project was located was $5.56 per square yard.

A performance survey was conducted six months after completion of the project, and no signs of distress were observed. At that time, the volume of traffic had been relatively light, and the survey was conducted primarily for the purpose of noting paving defects. Table 8 is a summary of observations on the Poplar Level Road in the summer of 1970. It may be noted herein that the experimental section contained an appreciably larger number of spalls and pop-outs than did the control section. The number of spalls and pop-outs for 8460 feet of control section would be 30 and 22 respectively. Therefore, the variation in lengths of the sections does not account for the differences in numbers of defects observed per section.

CONCLUSIONS

The projects discussed herein have domonstrated that fly ash may be used as a partial cement replacement for paving concrete. No savings in costs were realized on either of the two projects. Savings might be realized in the event fly ash concrete were used as an alternate to conventional portland cement concrete. The overall performance of experimental sections on the Poplar Level Road was not as good as that of the control section; however, variation in performance of the various sections was really not significant. Periodic performance surveys will be continued and will be reported in the event of significant developments.

TABLE 1. Physical Properties of Coarse Aggregate

Specific Gravity (SSD)	2.71
Percent Absorption	1.40
Percent Wear (Los Angeles)	2.91
Percent Elongated Pieces	negligible

TABLE 2. Physical Properties of Fine Aggregate

Specific Gravity (SSD)	2.65
Percent Absorption	0.40
Sand Equivalent	94
Fineness Modulus	3.10
Coal or Lignite	0
Percent Deleterious	0
Percent Elongated Pieces	negligible
7-Day Strength Ratio	120.1

TABLE 3. Physical Properties of Cements

Specific Gravity	3.15
Fineness (Blaine)	3443
Soundness	0.025
3-Day Compressive Strength (psi)	2763
7-Day Compressive Strength (psi)	3348

TABLE 4. Physical Properties of Fly Ash

Specific Gravity	2.55
Fineness (Blaine)	7839
Percent Passing No. 325 Sieve	91
Soundness	0.031
Mean Particle Diameter (microns)	8.8
3-Day Compressive Strength (psi)	3588
7-Day Compressive Strength (psi)	5040
Water Requirement, Percent of Control	96
Percent Shrinkage of Motar Bars, 28-Days	0.008
Percent (by weight) Vinsol Resin (10.66% Solution) for 18% Air	0.167

TABLE 5. Strength Test Data

LOCATION	DATE Placed	COMPRESSIVE STRENGTH (PSI)*					FLEXURAL STRENGTH (PSI)**				
		3 Days	7 Days	28 Days	3 Mo	6 Mo	3 Days	7 Days	28 Days	3 Mo	6 Mo
Experimental KY 841	8-18-69	2960	3570	4453	5265	5662	662	700	1026	1125	1088
	8-26-69	3030	3263	4367	5468	5685	700	800	1025	1050	1175
	9-9-69	2110	2713	3410	5081	5524	500	575	800	800	841
	Average	2701	3182	4077	5271	5624	621	692	950	992	1036
Experimental Poplar Level Road	Average	2534	3620	4903	6135	6519	603	850	1080		1425
Control Poplar Level Road	Average	2727	3577	4779	6106	6718	734	871	1175		1247

*Average of three specimens
**Average of three specimens, third-point loading

TABLE 6. Core Strengths, Mainline
(I-64-2(72)18 and F 552(15))

LOCATION	CORE NO.	STATION NO.	AGE (DAYS)	STRENGTH (PSI)	PAVEMENT THICKNESS (INCHES)
Left Northbound Lane	1	941+95	55	3465	10.5
	2	952+20	67	5415	10.2
	3	960+20	66	4910	10.3
	4	970+30	66	5775	10.6
	5	980+30	65	4980	10.6
	6	990+25	61	5195	10.3
	7	1000+18	61	4185	10.4
	8	1010+25	61	4690	11.0
	9	1020+20	60	4765	10.5
	10	1030+25	58	4620	10.5
		Average		4800	10.5
Right Northbound Lane	11	938+90	55	3755	10.2
	12	949+15	67	4835	10.2
	13	959+20	66	4980	10.3
	14	969+35	66	5630	10.3
	15	979+20	65	5775	10.2
	16	989+35	61	4475	10.2
	17	999+25	49	3895	10.5
	18	1009+25	65	3755	10.4
	19	1019+15	64	4980	10.5
		Average		4676	10.3
Left Southbound Lane	20	939+48	55	4260	10.2
	21	948+30	68	5845	10.4
	22	958+25	69	5770	10.4
	23	968+15	69	4330	10.6
	24	978+16	70	5270	10.2
	25	988+25	70	4765	10.1
	26	998+25	72	4690	10.3
	27	1008+25	72	4620	10.1
	28	1018+17	72	4825	10.2
		Average		4875	10.3
Right Southbound Lane	29	938+60	55	4040	10.1
	30	947+07	68	4765	10.3
	31	957+10	69	5775	10.1
	32	967+20	69	4185	10.7
	33	977+22	70	5415	10.6
	34	987+20	70	5415	10.3
	35	997+30	72	4040	10.3
	36	1007+25	72	4765	10.1
	37	1017+15	72	3825	10.5
		Average		4692	10.3
	Overall	Average		4762	10.4

TABLE 7. Core Strengths, KY 155 Interchange (I-64-2(72)18 and F552(15))

LOCATION	CORE NO.	STATION NO.	AGE (DAYS)	STRENGTH (PSI)	PAVEMENT THICKNESS (INCHES)
Ramp 1	40	14+20	48	4835	10.3
	42	936+85	49	4620	10.7
		Average		4728	10.5
Ramp 1A	41	10+06	45	4475	10.5
Ramp 3	43	25+97	45	4835	11.2
Ramp 5	44	11+30	46	4765	10.2
Ramp 7	38	943+20	47	3610	10.0
	39	23+85	46	3755	10.4
		Average		3683	10.2
	Overall	Average		4707	10.4

TABLE 8. Poplar Level Road

SECTION	CONTROL	EXPERIMENTAL A
Section Length (feet)	6430	8460
Total Cracks (feet/feet)*	0.363	0.366
Spalls	23	119
Pop-Outs	17	43

* Feet of longitudinal and transverse cracks per lineal foot of pavement

KENTUCKY DEPARTMENT OF HIGHWAYS

SPECIAL PROVISION NO. 70
FLY ASH ADMIXTURE FOR
PORTLAND CEMENT CONCRETE PAVEMENT

This Special Provision shall be applicable only when indicated on the plans, in the proposal, or in the bidding invitation; and when so indicated, shall supersede any conflicting requirements of the Department's current Standard Specifications. Any Article or Section referred to herein is contained in the Standard Specifications.

I. DESCRIPTION

The requirements for "Cement Concrete Pavement" in Section 307 are modified hereinafter to provide for the use of "Fly Ash" as an admixture in the portland cement concrete. The design of the concrete mixture will be adjusted accordingly.

II. MATERIALS

The fly ash shall meet the requirements of ASTM C350, except that the maximum per cent of "Loss on ignition" shall not exceed 6.0 per cent, and fly ash from different sources shall not be mixed or used alternatively without the written permission of the Engineer.

III. EQUIPMENT

Dispensing and weighing equipment for the fly ash shall conform to the same requirements as specified for cement in Article 307.3.2.

IV. STORING AND HANDLING MATERIALS

The storing and handling of fly ash shall be in accordance with Article 307.3.3-B as specified for cement.

V. PREPARATION AND CONTROL OF THE CONCRETE MIXTURE

The preparation and control of the concrete mixture shall be as specified in Article 307.3.4 with the following exceptions:

1. The concrete mixture shall be designed to contain 1.25 barrels of cement and 94 pounds of fly ash per cubic yard rather than the 1.5 barrels of cement specified in Article 307.3.4

2. The cement content per cubic yard shall be maintained within a tolerance of plus or minus .01 barrel, and the fly ash content per cubic yard shall be maintained within a tolerance of plus or minus 1 pound.

3. In designing the concrete, the volume of fly ash in excess of the volume of the cement it replaces shall be considered as part of the volume of the fine aggregate in the mixture.

4. The maximum free water content of the mixture shall not exceed 34.5 gallons per cubic yard.

5. The air content of the mixture shall be as required in Article 307.3.4 This may necessitate using a larger volume of the air-entraining admixture than usual, due to the fly ash content of the mixture.

VI. MEASUREMENT AND PAYMENT

The "Fly Ash' will not be measured for payment, as the cost thereof shall be considered as incidental to the "Cement Concrete Pavement."

APPROVED April 15, 1968

A. O. NEISER
STATE HIGHWAY ENGINEER