EVALUATION OF FLYASH IN LEAN CONCRETE BASE AND CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

Experimental Feature

Final Report
OR 85-01

by

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INTRODUCTION

This report documents the five-year performance of a continuously reinforced concrete pavement constructed with flyash. The study area was located on Interstate 5 (Southbound), south of Albany, Oregon. Visual inspections of the pavement surface, final laboratory test results and recommendations for use are included in this report.

Background

Flyash is a byproduct of the coal combustion process used in modern electric power production plants. In the past, it was allowed to pass out of the smoke stack, causing serious air pollution. Stricter pollution control standards have now eliminated this problem. The coal burning plants are now equipped with "bag houses," or electrostatic devices for capturing the flyash before it leaves the stack. Thus, one problem was eliminated and another one created; the coal burning plants now have vast stockpiles of flyash. In 1984, the Environmental Protection Agency listed flyash as the single largest solid waste disposal problem in the United States.

This condition prompted the Federal Highway Administration (FHWA) to promote the investigation into the use of flyash. Several seminars and workshops were held in the early 1980's discussing the use of flyash in highway construction. In 1985, a more firm action was taken; FHWA Deputy Administrator, Lester Lamm, sent a letter to FHWA Regional Administrators on January 4, 1985, instructing them to revise all guidelines that discriminate against the use of flyash. Previously, the Environmental Protection Agency had reminded the FHWA that Section 6002 of the Resource Conservation Recovery Act, which calls for the use of waste materials, applied to any agency receiving federal funding.

"For the FHWA, that means any agency that buys more than $10,000 worth of concrete per year must remove restrictions on flyash where technically appropriate. If it is not appropriate there must be documentation to prove so. States could be denied federal aid for anything if they disallow flyash. FHWA has a year to make the change." (See Reference #4)

The Oregon State Highway Division (OSHD) had been using flyash concrete since 1981 through price agreements or by special provision. Good results were obtained on these projects, and in 1984, the Materials Section published a report of these findings.(2) This report contains specifications for flyash, mix design procedures and testing procedures for the flyash. Final recommendations of this report included the following:

> It is recommended that flyash not be allowed in bridge decks, PCC pavements, or in prestressed concrete at this time. Further study should be undertaken to determine the feasibility of using flyash in this manner.

In 1985, the OSHD Bridge Section waived the restrictions on flyash use in prestressed structures and on bridge decks, because there was no pertinent experimental data on which to base an argument against the use of flyash.

The OSHD Paving Committee requested that a study be conducted on a construction project using flyash in continuously reinforced concrete pavement. A paving project on Interstate 5 near Albany, Oregon, was selected. This project was completed in October, 1985. No major construction problems with the flyash were encountered.

In August, 1986, the Research Section published an interim report which concluded the following:

> At this time, based on the 1984 program and this project, the use of flyash in lean concrete base and continuously reinforced concrete pavement cannot be classified as 'technically inappropriate.' It appears adding flyash to PCC doesn't cause construction difficulties, but in fact increases concrete's workability.
>
> Due to the time delay in attaining strength, traffic cannot be allowed on the flyash as soon as on a normal concrete surface. This may result in as much as four days' delay. In projects where four or more stages are necessary, this could be significant.

STUDY OBJECTIVES

Proposed research on this project included five main objectives:

1. To test and evaluate the physical characteristics of flyash concrete in comparison to non-flyash concrete. Tests will be conducted to see if flyash concrete meets OSHD specifications for compressive strength and if the current specifications for flyash can be used without modification in flyash concrete.

2. To document the differences in construction characteristics, if any, between flyash concrete and non-flyash concrete, and to determine if the use of flyash concrete poses any significant construction problems.

3. To evaluate the long-term performance of flyash concrete compared to non-flyash concrete over a period of five years to determine if there are any significant differences in durability.

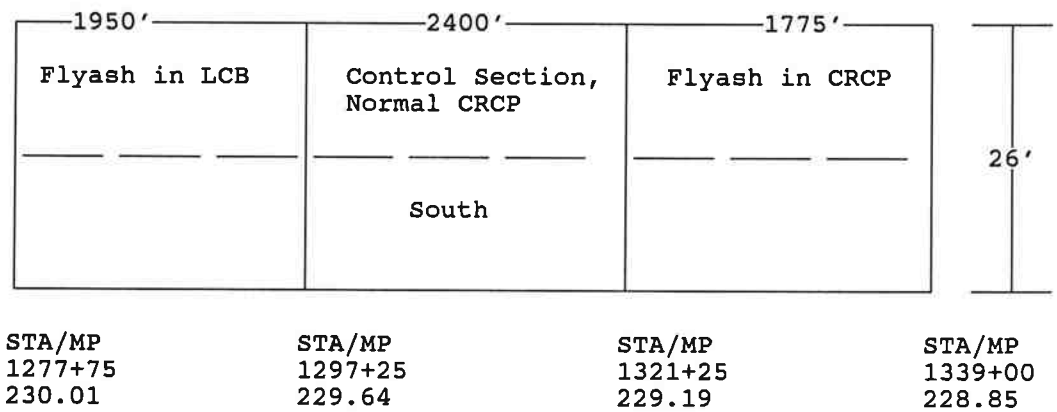
4. To determine if the current procedures for designing non-flyash concrete are applicable to the design of flyash concrete pavements.

5. To document the differences in construction costs between flyash concrete and non-flyash concrete.

LOCATION

Two test sections were included in the North Albany - Corvallis/Lebanon Interchange Section on Interstate 5, south of Albany, Oregon (Linn County). One test section consisted of flyash in lean concrete base (LCB) material, and the other section consisted of flyash in continuously reinforced concrete pavement (CRCP) material. Both test sections are located in the southbound lanes, separated by a 2,400-foot-long control section (See diagram below). The 1,950-foot-long LCB test section, from MP 230.01 to MP 229.64, was constructed on August 29, 1985. The 1,775-foot-long CRCP test section, from MP 229.19 to MP 228.85, was constructed on September 4, 1985.

SOUTHBOUND I-5, FLYASH TEST SECTION



The LCB and CRCP flyash mix designs used for the project test sections were similar to those without flyash, except for cement content. Basically, the amount of cement was reduced and replaced by flyash at a rate of 1:1.25 (by weight).

The portland cement used in the test section, as well as in most of the project, was Ideal, Type 1-11. The flyash was Class F, from Centralia, Washington. The type of flyash was critical, as other types can cause problems with flash setting or low strength. The lean concrete mixture consisted of recycled PCC materials run through a crusher and graded to cement traded base gradation.

CONSTRUCTION

An independent silo and feed system was brought onto the job to incorporate the flyash into the mixtures. Due to the limited number of weigh hoppers on the batch plant, the flyash was weighed in the cement hopper after the cement had been properly weighed in. The feed mechanism for the flyash was wired into the computer, and the new mix design was entered. This allowed for double weighing in the hopper at the proper rates.

From the plant, the flyash mixtures were hauled by dump truck to the work site. The mix was then dumped, conveyed, spread, vibrated and laid to grade with conventional PCC paving equipment.

As the material was rushed ahead of the paver, the flyash- modified mixtures seemed to hold together better and stay more homogeneous than the non-flyash mixtures. The mix without flyash appeared to have a more crumbling look, as the larger aggregate separated slightly from the mass.

The roundish flyash particles, while reducing the water required in the mix, created a lubricating effect that could be seen in the ease the paving machine moved through a large head of flyash material as compared to the mix without flyash. Behind the finishing machine, the surface texture of the flyash mixtures appeared to be more sealed than the normal mix. This made the hand finishing and floating noticeably easier. The finishing workers said they could tell the difference in the mixtures and preferred the flyash modified mixtures. Both mixtures with flyash showed a noticeable increase in workability compared to the mixtures without flyash. This was most evident in the LCB mixture, where the recycled aggregate materials had caused harshness throughout the job in the non-flyash mix.

POST-CONSTRUCTION

The surface texture and curing compound could not be applied to flyash mixtures as quickly as it did in the normal concrete. This was anticipated, due to the retarded curing rate of the flyash. The additional cure time required was not significant enough to be detrimental to the operation. The retarded curing times in the mixtures were reflected in the cylinder breaks. The twenty-eight day strengths recorded from flyash cylinders were lower than normal strengths but were within acceptable limits. At sixty days, the flyash concrete strengths were comparable to the normal concrete strengths. (See Table A). It appears the 20% cement replacement rate used in the LCB may have been too high, as the strengths did not meet those of the mixture without flyash. The PCC flyash mixture, with a 15% replacement rate, exceeded the strength of the PCC without flyash in some cases.

COST ANALYSIS

Cement for the project was bid at $70/ton, while flyash (as cement substitute) used in the test section cost $39/ton, plus a $3/ton charge for handling. Therefore, paving concrete costs can be reduced as much as 40% by using flyash as a replacement for concrete. The savings were not realized on this project, however, since the contractor was unfamiliar with flyash and included in his bid a "margin of safety" percentage, in case of construction difficulties. Because the flyash concrete was actually easier to work than normal concrete, the safety margin ended up as pure profit for the contractor. Without this extra percentage, approximately $1,736 was saved using flyash. Had flyash been used in the paving concrete mixture throughout the entire project, a cost savings in excess of $47,000 could have been realized.

LONG TERM MONITORING

The flyash test sections have been monitored for five years. In October, 1990, the final visual inspection was completed. Overall, the project still looks almost new and is rated as "very good".

Flyash Section in 1990
Interstate 5, Southbound at MP 229.075

Visual inspections for surface defects in the new CRCP project were made annually over a period of five years. Definitions from the "Highway Pavement Distress Identification Manual" were used to classify the types of distress observed. This manual lists twenty different types of distress common to CRCP projects in the United States. Results of the visual inspections are summarized in Appendix C. The flyash PCC section had more transverse cracks than the control section or the lean concrete base section but had fewer popouts. Rutting was also lower in the flyash section than in the other two sections. The distress observed was not serious in any of the test areas, and the differences between sections were minor.

Further testing was done on cores taken from the roadway test sections six months after the project was completed. The cores were tested for compressive strength and surface permeability. A summary of the results are included in Table A. No statistical significant difference was found between the flyash and control samples.

TABLE A

COMPRESSIVE STRENGTH TEST RESULTS

CONCRETE MIX STRENGTHS (PSI Averages) Days	7	14	28	61	90	180
Lean Concrete Base (Compressive Strengths)						
with flyash* (20% cement replaced)	605	737	951	1118	1180	1117
without flyash*	845	1020	1298	1367	1395	
without flyash**	951		1850			
PCC Paving (Compressive Strengths)						
with flyash* (15% cement replaced)	3882	4573	5130	5900	5720	6175
without flyash*		4904		5772	6155	6511
without flyash**	4167		5209			
Lean Concrete Base (Flexural Strengths)*						
with flyash			185			
without flyash			283			
PCC (Flexural Strength of Single Samples)*						
with flyash		535	635	530		
without flyash		550	560	655		

PERMEABILITY TESTS (lbs of Cl^-/yd^3)

PCC Paving	depth tested 1/8" to 1/21"	1/2" to 1"
flyash	12.5	5.6
control	14.3	6.0

* Data from cylinder breaks from test section.
** Data from averages of cylinder breaks from July 10, 1985 until September 3, 1985.
*** Data from cylinder breaks throughout project.

CONCLUSIONS AND RECOMMENDATIONS

1. Individual flyash concrete load batching times showed an increase over "normal" concrete batching times due to the inclusion of flyash in each batch. The increase resulted from the momentary change-over time from the cement and flyash silos. Also, additional time was required to determine the total weight of flyash plus cement, which was greater than the weight of cement in the normal concrete.

2. No problems were observed during delivery, spreading, or paving operations of the flyash-modified mixes.

3. The lean concrete base appeared to achieve a more dense finish when flyash was incorporated in the mix, and the hand finishing operations were less labor-intensive as reported by paving contractor representatives.

4. Though not demonstrated by this project, the use of flyash in highway construction could result in significant cost savings. Cement for the project was bid at $70/ton. Flyash (substitute) used in the project cost $39/ton, with a $3/ton charge for handling. Approximately $2,073 of cement was replaced with $1,538 of flyash within the lean concrete base, and $4,700 of cement was replaced with $3,569 of flyash within the paving concrete. Had flyash been used in the paving concrete mixture throughout the entire project, a cost savings in excess of $47,000 could have been realized.

5. Though not equal at early ages, the final, twenty-eight day strengths of the flyash modified lean and paving concretes are acceptable. However, due to the time delay in attaining strength, traffic cannot be allowed on the flyash concrete as soon as on a normal concrete surface. This may result in as much as a four-day delay. In projects where four or five paving stages are necessary, this time delay could be significant.

6. After five years, all three sections are in very good condition. The differences in distresses between sections is very insignificant, and flyash concrete appears as durable as conventional concrete pavement.

Based on these observations, the use of flyash in lean concrete base and continuously reinforced concrete pavement should not be classified as "technically inappropriate." The current specifications for flyash concrete appear valid and can be used without modifications. Current procedures for designing non-flyash concrete may be used for the design of flyash concrete pavements.

APPENDIX A

CHEMICAL AND PHYSICAL ANALYSES OF FLYASH

Laboratory No. 85-12
Sample Idnet: Centralia Steam Plant, Comp #134, Dockets #17447-17502, 1-4-85
Date Received: 1-15-85

ASTM: C618

CHEMICAL COMPOSITION (%):
Class F Specs

Silicon Oxide (SiO_2)	46.6		
Aluminum Oxide (Al_20_3)	24.6		
Iron Oxide (Fe_20_3)	6.6		
Total (SiO_2 + Al_20_3 + Fe_20_3)		77.80	70.0 min.
Sulfur Trioxide (SO_3)		.63	5.0 max.
Calcium Trioxide (CaO_3)		8.80	
Moisture Content		.06	3.0 max.
Loss on Ignition		.11	12.0 max.

PHYSICAL TEST RESULTS:

Fineness		
Retained on #325 Sieve (%)	16.59	34.0 max.
Pozzolanic Activity Index		
w/Portland Cement (%) ratio to Control @ 28 days	97.00	75.0 min.
w/lime @ 7 days (psi)	1107.00	800.0 min.
Water Requirement, % of Control	97.00	105.0 max.
Soundness		
Autoclave Expansion (%)	.05	0.8 max.
Specific Gravity	2.26	

* Loss on Ignition is now 5% maximum, unless test samples have been approved. (OSHD has a higher standard of 1.5%, see Page 12.)

APPENDIX B

SPECIFICATIONS

701.07 Flyash

Types: Flyash shall be Class C or Class F conforming to AASHTO M 295, including Tables 1, 2 and 2A, except that:

1. Loss on ignition (LOI) shall be 1.5% maximum.

2. Moisture content shall be 1% maximum.

3. Amount retained on the No. 325 sieve shall be 30% maximum.

4. Available alkalies, as Na_2O, shall be 1.5% maximum, except this maximum may be increased to 2.0% when the flyash is to be used in areas considered free of potentially reactive aggregates, as determined by the Engineer of Materials.

5. In Table 2, the Pozzolanic Activity Index shall be 75% minimum of control.

6. In Table 2A, Mortar Expansion for the job mixture at fourteen days shall be less than or equal to the control at 14 days.

Prequalification of Flyash: The sources of flyash shall be prequalified by the Engineer of Materials before use on this project. The prequalification shall not be more than one year old. Sampling and testing of flyash for prequalification shall conform to ASTM C 311, except that one twenty-pound test sample shall be submitted in a sealed container and shall be a composite sample representing 2,000 tons of flyash production. The sample shall be received at the Engineering Lab at least eight weeks before its use on the proposed project.

Flyash that has been prequalified will be accepted for immediate use, provided that requirements of certification as set forth in Subsection 106.08 of the Standard Specifications are met.

Job Control: For each fifty tons of each class of flyash used on this project, a ten-pound sample will be tested for fineness, moisture content, specific gravity, loss on ignition, soundness and air entrainment of mortar. A minimum of one sample will be tested for each class of flyash.

AASHTO M 295

1. SCOPE

1.1 This specification covers flyash and raw or calcined natural pozzolan for use as a mineral admixture in concrete when cementitious or pozzolanic action, or both, is desired or where both objectives are to achieved. (?)

Note 1 - Finely divided materials may tend to reduce the entrained air content of concrete. Hence, if a mineral admixture is added to any concrete for which entrainment of air is specified, provision should be made to assure that the specified air content is maintained by air content tests and by use of additional air-entraining admixture or use of an air-entraining admixture in combination with air-entraining hydraulic cement.

Note 2 - The values stated in inch-pound units are to be regarded as the standard.

2. APPLICABLE DOCUMENTS

2.1 ASTM Standards:

- C 204 Standard Test Method for Fineness of Portland Cement by Air Permeability Apparatus
- C 260 Specifications for Air-Entraining Admixtures for Concrete
- C 311 Sampling and Testing Flyash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete

3. CLASSIFICATIONS

3.1 Class N - Raw or calcined natural pozzolans that comply with the applicable requirements for the class as given herein, such as some diatomaceous earths, opaline cherts and shales; tuffs and volcanic ashes or pumicites, any of which may or may not be processed by calcination; and various materials requiring calcination to induce satisfactory properties, such as some clays and shales.

3.2 Class F - Flyash normally produced from burning anthracite or bituminous coal that meets the applicable requirements for this class as given herein. This class flyash has pozzolanic properties.

3.3 Class C - Flyash normally produced from lignite or subbituminous coal that meets the applicable requirements for this class as given herein. The class of flyash, in addition to having pozzolanic properties, also has some cementitious properties. Some Class C flyashes may contain lime contents higher than 10%.

Note 3 - Currently the usual replacement of cement by Class C flyash does not exceed 20%.

4. DEFINITIONS

4.1 pozzolans - siliceous or siliceous and aluminous materials which in themselves possess little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

4.2 flyash - finely divided residue that results from the combustion of ground or powdered coal.

5. CHEMICAL REQUIREMENTS

5.1 Flyash and natural pozzolans shall conform to the requirements as to chemical composition prescribed in Table 1.

6. PHYSICAL REQUIREMENTS

6.1 Flyash and natural pozzolans shall conform to the physical requirements prescribed in Table 2. Supplementary optional physical requirements are shown in Table 2A.

7. METHODS OF SAMPLING AND TESTING

7.1 Sample and test the mineral admixture in accordance with the requirements of ASTM Method C 311. The pozzolanic reactivity test shall be made with cement only, and specimens will be tested at an age of seven days.

7.2 Use cement of the type proposed for use in the work and, if available, from the mill proposed as the source of the cement, in all tests requiring the use of hydraulic cement.

8. STORAGE AND INSPECTION

8.1 The mineral admixture shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment. Every facility shall be provided the purchaser for careful sampling and inspection, either at the source or at the site of the work, as may be specified by the purchaser.

9. REJECTION

9.1 The mineral admixture may be rejected if it fails to meet any of the requirements of this specification.

9.2 Packages varying more than 5% from the stated weight may be rejected. If the average weight of the packages in any shipment, as shown by weighing fifty packages taken at random, is less than that specified, the entire shipment may be rejected.

9.3 Mineral admixture in storage prior to shipment for a period longer than six months after testing may be rejected if it fails to meet the fineness requirements.

10. PACKAGING AND MARKING

10.1 When the mineral admixture is delivered in packages, the class, name and brand of the producer, and the weight of the material contained therein, shall be plainly marked on each package. Similar information shall be provided in the shipping invoices accompanying the shipment of packaged or bulk mineral admixture.

701.08 Blended Hydraulic Cement

Types: Blended hydraulic cement shall be either portland pozzolan cement or pozzolan-modified cement conforming to AASHTO M 240, supplemented and/or modified as follows:

1. The cement constituent of the blended cement shall conform to Subsection 701.01.

2. The pozzolan constituent of the blended cement shall be a flyash conforming to Subsection 701.07.

3. The pozzolan constituent shall be between 10 and 20% by weight of the blended cement.

4. The contractor shall supply certifications for blended hydraulic cements in conformance with AASHTO M 240, Section 14.

Job Control: For each fifty tons of blended hydraulic cement used, a ten-pound sample will be tested for fineness, specification, specific gravity and loss on ignition.

At the request of the Engineer, a ten-pound sample of the flyash and a ten-pound sample of the cement used in the blended hydraulic cement shall be provided by the Engineer.

Appendix C: Summary of Visual Inspections

Year	Section	Transverse Cracks		Spalls		Longitudinal Cracks		Longitudinal Spalls		Map Cracks	Y Cracks	Pop Outs	Rut Depth x 1/100 foot		Lane/ Shoulder Separation
		L	M	L	M	L	M	L	M	%	%	#	(LT)	(RT)	Inches
	LCB	4.8	0	0	0	0	0	0	0	0	0	0	0.3	0.0	0.25
1986	CNT	5.6	0	0	0	0	0	0	0	0	0	0	0.1	0.3	0.25
	FAC	6.6	0	0	0	0	0	0	0	0	0	0	0.2	0.1	0.25
	LCB	6.8	0	0	0	0	0	0	0	0	0	0	1.0	0.6	0.25
1987	CNT	6.2	0	0	0	0	0	0	0	0	0	0	1.0	0.6	0.25
	FAC	8.8	0	0.6	0	0	0	0	0	0	0	0	1.0	0.5	0.25
	LCB	5.8	0	0.2	0	0	0	0	0	0	0	13	0.9	0.0	0.00
1988	CNT	6.6	0	2.2	0	0	0	0	0	0	0	80	0.7	0.1	0.50
	FAC	8.8	0	5.6	0	0	0	0	0	0	0	10	0.5	0.2	0.50
	LCB	8.2	0	5.4	0	0	0	0	0	0	0	104	1.1	0.1	0.25
1989	CNT	7.6	0	3.2	0	0	0	0	0	0	0	115	0.9	0.2	0.50
	FAC	11.6	0	6.4	1.8	0	0	0	0	0	0	38	1.0	0.0	0.50
	LCB	8.6	0	5.6	0	0	0	0	0	0	0	255	1.4	0.3	0.40
1990	CNT	8.2	0	4.8	0.2	0	0	0	0	0	0	340	1.3	0.5	0.30
	FAC	13.2	0	6.8	2.4	0	0	0	0	0	0	120	1.0	0.3	0.25

LCB = LEAN CONCRETE BASE, WITH FLYASH
CNT = CONTROL, NO FLYASH BASE OR SURFACE
FAC = FLYASH IN CONCRETE SURFACING
L = LOW SEVERITY LEVEL (column heading)
M = MEDIUM SEVERITY LEVEL (see reference #6)
LT = LEFT WHEEL TRACK
RT = RIGHT WHEEL TRACK

BIBLIOGRAPHY

1. Boles, William F., Flyash Facts for Highway Engineers, FHWA-DP-59-8, Pamphlet by the Demonstration Projects Program, FHWA, Washington, D.C. (July 1986)

2. Maloney, Michael J., Evaluation of Flyash as an Admixture in Portland Cement Concrete, Materials Section, Highway Division, Oregon Department of Transportation, Salem, OR (July 1984)

3. Sommerfeld, J. C. and Castellamas, N. J., The Use of Flyash in Highway Construction, A Paper by Demonstration Projects Division, FHWA, Washington, D.C. (June 1982)

4. Flyash Gains with Federal Aid, Engineer News Record (May 2, 1985)

5. Flyash in Highway Construction, Seminar Proceedings for Demonstration Project No. 59, FHWA, Washington, D.C. (November 1985)

6. Roger E. Smith, et al, Highway Pavement Distress Identification Manual, Interim Report, (Washington, D.C.: Federal Highway Administration, March 1979), pp. 150-195.