Final Report
for
Iowa DOT Project HR-1031

Federal Highway Administration
Demonstration Project No. 59
Work Order No. DTFH71-82-59-IA-04

THE USE OF FLY ASH IN HIGHWAY CONSTRUCTION

by
Vernon J. Marks
Office of Materials
Iowa Department of Transportation
Ames, Iowa 50010
(515)239-1447

March 1990

TABLE OF CONTENTS

ABSTRACT

In 1982 the Iowa DOT allowed a successful bidder the option of submitting materials and proportions using fly ash to produce a portland cement concrete (PCC) paving mixture to meet a specified compressive strength. The contractor, Irving F. Jensen, received approval for the use of a concrete mixture utilizing 500 lbs. of portland cement and 88 lbs. of fly ash as a replacement of 88 lbs. of portland cement. The portland cement concrete mixture was utilized on the Muscatine County US 61 relocation bypass paved as project F-61-4(32)--20-70. A Class "C" fly ash obtained from the Chillicothe electric generating plant approximately 100 miles away was used in the project. This use of fly ash in lieu of portland cement resulted in a cost savings of $64,500 and an energy savings of approximately 16 billion BTU. The compressive strength of this portland cement concrete mixture option was very comparable to concrete mixtures produced without the use of fly ash. The pavement has been performing very well. The substitution of fly ash for 15% of the cement has been allowed as a contractor's option since 1984. Due to the cost savings, it has been used in almost all Iowa PCC paving since that time.

ACKNOWLEDGEMENT

This project was partially funded by the Federal Highway Administration in the amount of $39,444 under work order No. DTFH71-82-59-IA-05 as participation in demonstration project No. 59, "The Use of Fly Ash in Highway Construction".

The author wishes to extend appreciation to Joseph Demeter, the Mt. Pleasant Resident Construction personnel, Howard Konrady and the District 5 Materials personnel for their excellent cooperation in testing and evaluation of the project. Appreciation is also extended to Irving F. Jensen Company and their personnel for developing and using a concrete mix proportion utilizing fly ash.

INTRODUCTION

Fly ash is a valuable admixture for portland cement concrete produced from coal burning electric generating plants. It is a pozzolanic material which in the presence of water will combine with calcium to produce a cementitious material. Fly ash particles collected by electrostatic precipitators are spherical and very small. Fly ash is divided into two classes, predominantly on the basis of calcium content. Class "F" fly ash is low in calcium content while Class "C" fly ash has a substantial calcium content. Normally over 51 million tons of fly ash are produced annually in the United States. About 20% of this quantity or 10 million tons is used in the transportation industry. About half of that amount is used in cement and concrete products. Approximately 500,000 tons of good quality fly ash are usually available in Iowa on an annual basis. With improved quality control of fly ash, the Iowa DOT is identifying additional benefits of using fly ash as an admixture in portland cement concrete.

PROJECT LOCATION AND BACKGROUND

This report documents the use of fly ash in Muscatine County project F-61-4(32)--20-70. This project was located in the City of Muscatine on US 61 as the Muscatine bypass from present US 61 at the south edge of Muscatine northerly to Mulberry Street which is also county road X-54 (figure 1). The successful bidder on this project was Irving F. Jensen Co., Inc. of Sioux City, Iowa. The project is 4.257 miles long. This project was let in December 1982 but could not be completed in 1983 because of delays in the preced-

ing grading project. The bid prices were increased slightly to compensate for the increased costs of materials and labor resulting from the delay from 1983 to 1984. This project is a bypass relocation and, therefore, there is no actual traffic data available.

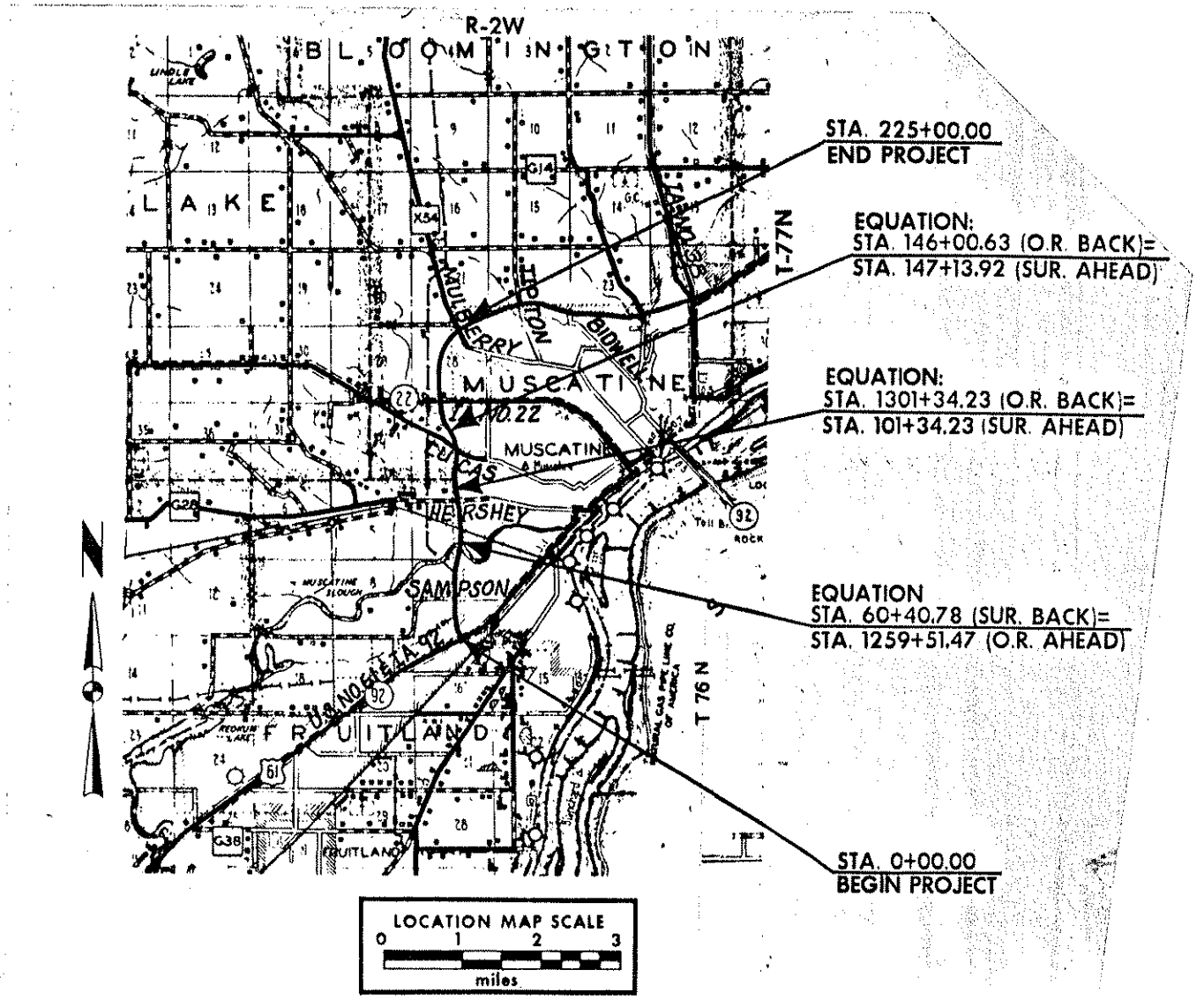

Figure 1 Project Location

The simulated average daily traffic based upon computer analysis was calculated to be 5,708 vehicles per day, with a predicted traffic volume in 20 years of over 8,000 vehicles per day. This simulated traffic calculation determined that there were 11% trucks. The average daily traffic based upon actual traffic data on US 61 just south of this project in 1984 was determined to be 5,080 vehicles per day with 15.7% trucks. The actual 1988 traffic was 7210 vehicles per day with 15.5% trucks.

This project contains portland cement concrete pavement in thicknesses of 6, 8, 9, 9½ and 10 inches, depending on the street or highway. The mainline US 61 is a 10" thick 4-lane divided roadway (Figure 2) with skewed contraction joints with load transfer assemblies at a spacing of 20 ft. The pavement was placed on a select clay subgrade with a maximum grade on the mainline of 4.20%. Some areas of peat and unstable soils were excavated and replaced with higher quality material. In one cut area, 8,600 ft. of shoulder subdrain were used to prevent water problems. This project would be located in a Region 1-A in regard to the climatic zones based on Thornthwaite Potential Evapotranspiration and Moisture Index which would indicate that it has a high potential for the presence of moisture and also a high potential for severe winters and frost penetration.

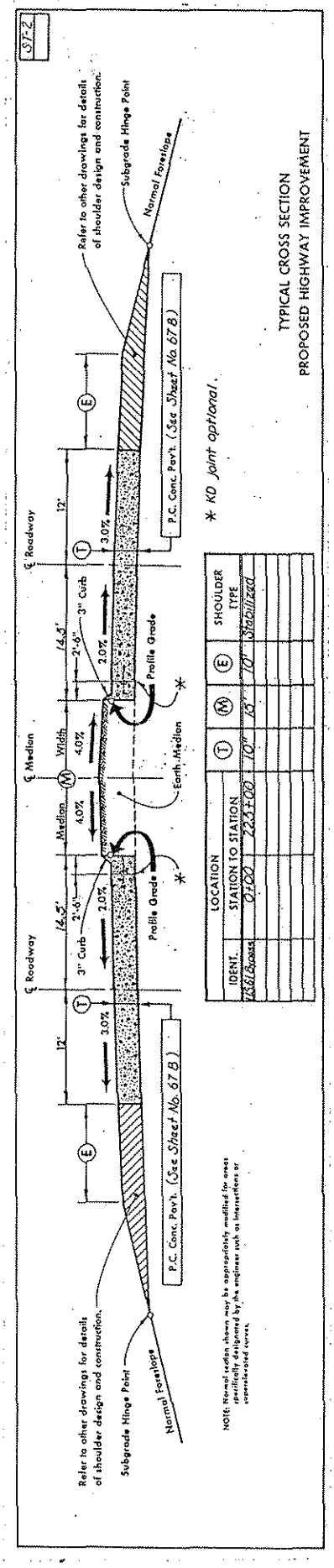

Figure 2 Mainline Typical Cross Section

CONCRETE MATERIALS AND PROPORTIONS

The special provisions for this project allowed the contractor two options in regard to the concrete mix (SP-436, Appendix A). The first option was to use a Class "A" concrete with a requirement of Class 2 durability coarse aggregate. The second option which the contractor elected was a proportion submitted by the contractor which would provided a 28-day compressive strength equal to or greater than 4400 psi when mixed with a slump of approximately 2". This mix would contain at least 500 lbs. of portland cement per cu. yd. in addition to a designated amount of fly ash. A Class 3 durability coarse aggregate was required with the fly ash concrete.

The concrete mixture proposed by the contractor, Irving F. Jensen Co., Inc., used Type I portland cement from the Davenport Cement Co. The coarse aggregate was produced from the Wendling Quarries at Moscow, Iowa, and the sand was from Acme Fuel and Materials of Muscatine. Most of the air entraining agent used on the project was Dri-Crete produced by Acme Fuel & Materials. The water reducing admixture was American Admixture Lubricon 300. The batch weights for the fine and coarse aggregates were adjusted during the project to compensate for yield underrun. The batch weights or proportions used for the majority of the concrete were as follows:

Cement Type I	500 lbs.
Fly Ash Class "C" from Ottumwa	88 lbs.
Coarse Aggregate Wendling Quarries	1,375 lbs.
Fine Aggregate Acme Sands	1,649 lbs.
Water Reducing Admixture Lubricon 300	3 oz. per 100 lbs. of cement

The fly ash was used as replacement for portland cement in the portland cement concrete pavement. The fly ash was supplied from the Ottumwa generating station at Chillicothe, Iowa, approximately 100 miles from the project. It is a Type "C" ash with a 0.33% loss on 800° C ignition. This ash marketed by Midwest Fly Ash has 88.6% passing the 325 mesh screen. The chemical analysis is as follows:

SIO2	35.63
AL2O3	22.44
FE2O3	5.29
SUBTOTAL	63.36
NA2O	2.65
K2O	0.42
ALKALI EQUIVALENT	2.93
AVAILABLE ALKALI	2.07 & 2.01
SO3	2.12
MOISTURE	0.00
LOSS ON 800 DEG. C. IGNITION	0.33
MGO	4.01
CAO	25.44

A typical coarse aggregate gradation would be:

Sieve Size	% Passing
1"	100
3/4"	74
1/2"	39
3/8"	13
4	2.5
8	1.9
200	1.1

The crushed limestone coarse aggregate from the Wendling Quarries yielded the following quality test data:

16 cycle freeze/thaw Method A	1% loss
Los Angeles Abrasion	34%
Specific Gravity -	2.658
Absorption -	1.52%

A typical gradation for the fine aggregate would be:

Sieve Size	% Passing
3/8"	100
#4	96
#8	87
#16	74
#30	40
#50	4.8
#100	0.7
#200	0.3

The fine aggregate had a specific gravity of 2.667 with 0.0% coal and shale.

CONSTRUCTION

A small amount of miscellaneous pavement was placed during November 1983 but the majority of the pavement was placed during 1984. Concrete placement began April 27, 1984, and was completed June 18, 1984. The weather during this period was reasonably good with minimal rainfall. The central batch, central mix plant, was located at the junction of Lucas Street and the US 61 relocation bypass. The concrete was transported to the paver in agitator trucks, delivered to the side of the roadway and conveyed to a spreader in front of the paver. The paver utilized prod vibrators. The paving operation was very typical of Iowa portland cement concrete placement with the texture being imparted by transverse grooving following an AstroTurf drag. The pavement was cured with a white pigment liquid curing compound.

ECONOMIC BENEFITS

The special fly ash mix allowed for the substitution of 88 lbs. of fly ash for 88 lbs. of cement per cu. yd. of concrete. The cost of the cement FOB Muscatine was $52 per ton while the cost of the fly ash FOB Muscatine was $23.18 per ton. This amounts to a net savings of $28.82 per ton of fly ash substituted for cement. The savings for the 2,239.29 tons used on this project at $28.82 per ton would amount to $64,536.34.

ENERGY CONSERVATION

According to data provided by the US Bureau of Mines, the energy required to produce 1 ton of portland cement would be 7,110,000 BTU. The energy saved on this project by using 2,239.29 tons of fly ash would amount to 15,900,000,000 BTU.

TEST RESULTS

The contractor submitted the materials for the special mix design late in 1982. A concrete mix was made in the Iowa DOT Laboratory at Ames using the materials and proportions proposed by the contractor. An average compressive strength of 5,350 psi was obtained at 28 days from tests on three 6"x12" cylinders. The concrete mixture had an air content of 6.4%, a slump of 2.0" with a water/cement ratio of 0.477. The concrete mixture met all the requirements of Special Provision 436 and approval for the mixture was granted.

Cores were obtained from the pavement soon after construction and reported in July 1984. Seventy-eight cores were obtained with a calculated average 28-day compressive strength of 5,960 psi. The minimum compressive strength was 4,765 psi with a maximum of 7,675 and a standard deviation of 621. The average 28-day strength of 147 cores obtained from other 1984 portland cement pavement projects using Class "A" concrete yielded a compressive strength of 4,175 psi. This fly ash modified concrete utilizing the 500 lbs. of cement plus 88 lbs. of fly ash yielded concrete compressive strengths superior to other portland cement concrete utilizing 589 lbs. of portland cement. There was no problem in maintaining the specified air of 6.5 ± 1.5% on the fresh unvibrated concrete as delivered to the grade. The consistency of the concrete was easily maintained to a specified slump between 1/2" and 2". These tests were conducted periodically throughout the project. Testing to determine the smoothness of the profile with the 25-Foot Profilometer yielded a Profile Index of 7.1 inches/mile for the mainline pavement.

PERFORMANCE

The pavement has been performing very well since construction. A field review on June 4, 1986, revealed some longitudinal and some transverse cracking. There were three transverse cracks fully across and one crack half way across the northbound roadway. There was approximately 100 ft. of longitudinal cracking in the northbound roadway. In the southbound roadway there was no longitudinal cracking and only one transverse crack across the roadway.

A June 1988 survey showed four full width and three cracks across one lane in the northbound roadway. There was 253 ft. of random longitudinal cracking. There was no longitudinal cracking in the southbound roadway. There was one full width and three cracks across one lane in the southbound roadway.

This amount of cracking would be typical of pavement using conventional mixtures without fly ash. The pavement has performed very well for five years with no indication of any PCC deterioration.

DISCUSSION

The Iowa DOT has funded substantial research in regard to use of fly ash in the transportation industry. Earlier research had indicated that there may be some problem with concrete durability using some fly ash-aggregate combinations. Recent research with high quality fly ash has shown that in general the fly ash will improve the durability of the portland cement concrete pavement. Research to evaluate the sulfate resistance of fly ash concretes has just been initiated. Iowa DOT specifications were changed in 1984 to encourage the use of fly ash in portland cement concrete. Due to cost savings, it has been used in almost all Iowa PCC paving since that time.

Cores are obtained from all Iowa DOT portland cement concrete pavement projects. Compressive strengths are determined on all of these cores. Data from 1984 and 1985 (Appendix B) has shown that

portland cement concrete containing fly ash yields compressive strengths very comparable to portland cement concrete without fly ash.

CONCLUSIONS

This project using fly ash in portland cement concrete supports the following conclusions:

1. The use of fly ash in portland cement concrete yields a substantial cost savings on most Iowa DOT projects.

2. The use of fly ash as a replacement for portland cement results in a substantial energy savings.

3. High quality portland cement concrete pavement can be produced using fly ash as a replacement for a portion of the portland cement.

Appendix A
Special Provision SP-436

Iowa Department of Transportation

SPECIAL PROVISIONS
for

PCC PAVEMENT

F-61-4(32)--20-70 Muscatine County

December 21, 1982

THE STANDARD SPECIFICATIONS, SERIES 1977, ARE AMENDED BY THE FOLLOWING SPECIAL PROVISIONS. THESE SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS AND SUPPLEMENTAL SPECIFICATIONS.

Section 2301 shall apply with the following modifications:

DELETE all of 2301.01 and add the following in lieu thereof.

2301.01 DESCRIPTION. Concrete pavement for this project shall consist of a single course of portland cement concrete, using either Option I or Option II, as shown in the proposal. The bidder shall bid only one option, and the award will be made on the basis of the option bid.

When using Option II, the bidder must have a mix design approved by the Office of Materials prior to the date of the letting. These approvals will be filed with the Contracts Engineer. A bidder shall have only one approval on file. Only one mix design request will be considered from a prospective bidder. The requester shall identify the prospective bidder. An approved mix design will be considered the property of the prospective bidder until after the letting; another bidder may bid using this approval only on authorization from the requester made to the Office on Materials.

DELETE all of 2301.03 and add the following in lieu thereof:

2301.03 MATERIALS. All materials shall meet the requirements for the respective items in Part IV of the Standard Specifications.

The requirements of 2301.04 shall apply, with the exception of the first two paragraphs and Paragraphs B, C, and D. Paragraph E, Class M Concrete, shall be applicable only for locations specifically authorized by the engineer.

CONCRETE MIX REQUIREMENTS. Depending on the option selected and bid by the contractor, and on which the contract is awarded, the following shall apply:

A. Option I. Class A concrete shall be used. The provisions of 2301.04A shall apply. Class 2 durability coarse aggregate shall be required.

B. Option II. The mixture, as submitted by the contractor and approved by the engineer, shall be used in accordance with the provisions for Water, Consistency, and Entrained Air Content of 2301.04. The requirements for the contractor's mix design are as follows:

1. Approval will be based on a concrete with a 28-day compressive strength, equal to or greater than 4,400 psi, when mixed with a slump of approximately 2 inches.
2. Fly ash shall meet requirements of ASTM C 618. The source of fly ash shall be one approved by the engineer.
3. Class F or Class C fly ash may be used in the mixture as shown below:
   a. Class F fly ash may be used to replace a maximum of 15% of portland cement at the rate of 1.25 parts of fly ash (by weight) to one part of portland cement (by weight).
   b. Class C fly ash may be used to replace a maximum of 15% of the portland cement at the rate of one part of fly ash (by weight) to one part of portland cement (by weight).
4. The cement content shall be a minimum of 500 lbs. per cu. yd. of concrete.
5. The aggregates shall meet respective requirements of Section 4115, any gradation listed, and Section 4110.
6. The aggregate combination may be suggested by the requester, and will be included as part of the mix design approval.
7. The coarse aggregate shall meet Class 3 durability requirements.
8. Conventional water-reducing admixtures (not super plasticizers) shall be used in the mixture. The admixture shall be of a brand included in I.M. 403 for concrete pavement, and it shall be used at the recommended dosage included therein.
9. Samples of each aggregate shall be taken and identified by a certified aggregate technician. The requester will be responsible for delivery of aggregate samples, a cement sample, and the water reducing admixture to the Ames Laboratory. The Office of Materials will arrange for a sample of fly ash from the source designated by the requester.
10. A request for approval must be made, and samples submitted, by November 2, 1982, to allow time for necessary laboratory work. The requester is encouraged to make arrangements by telephone with the Office of Materials (515) 239-1226, and to obtain information on material sources and sample size.

PROPORTIONING AND MIXING EQUIPMENT. This equipment shall meet requirements of 2301.05 and 2301.06. Fly ash shall be transported, stored, and batched in such a manner as to keep it dry. Proportioning equipment for the fly ash shall meet requirement of 2001.20, either Paragraph A or Paragraph B.

ALL OTHER APPLICABLE LIMITATIONS TO THIS SPECIFICATION.

A. Under either option, the pavement may be opened for use in accordance with 2301.36.

8. In the application of Option II, should any material used in the mixture become unavailable or unacceptable, the work shall be completed with a mixture and materials in compliance with Option I.

METHOD OF MEASUREMENT. Pavement placed under this contract will be measured in accordance with 2301.39.

BASIS OF PAYMENT. Payment for pavement placed under either option of this contract will be in accordance with 2301.40.

Appendix B
Comparison of the 28-Day Compressive Strength of Concrete With and Without Fly Ash

IOWA DEPARTMENT OF TRANSPORTATION

TO OFFICE: Materials DATE: March 12, 1985

ATTENTION: John Lane REF. NO.: 435.24

FROM: Randy J. Allenstein

OFFICE: Materials Laboratory

SUBJECT: 1984 Portland Cement-Fly Ash Concrete Pavement Strengths

A statistical analysis comparing portland cement concrete pavement core strengths versus portland cement-fly ash concrete pavement core strengths has been completed for 1984. The results are summarized below:

PORTLAND CEMENT CONCRETE

Class	No. of Samples	Mean	Std. Dev.	Low	High	Range
A	147	4176	548.8	3055	5395	2340
B	230	3768	554.8	2460	5895	3435
C	539	4704	701.2	3150	6940	3790

PORTLAND CEMENT-FLY ASH CONCRETE

Class	No. of Samples	Mean	Std. Dev.	Low	High	Range
A	31	4309	425.9	3380	5400	2020
B	240	3751	700.2	2400	5660	3260
C	204	4699	679.9	3285	6835	3550

MODIFIED A-5 MIX-FLY ASH AND WATER REDUCER
(Contractor Mix Design - Muscatine Bypass)

No. of Samples	Mean	Std. Dev.	Low	High	Range
78	5957	621.0	4765	7675	2910

RJA:jrv
cc: C. Huisman
B. Brown
S. Moussalli

Cc Glen Miller 6-11-85
O.K.

Form 000020
2-75 H-2884

IOWA DEPARTMENT OF TRANSPORTATION

To Office: Materials Administration
Date: April 11, 1986
Attention: John Lane
Ref. No.: 435.24
Corrected Report
From: Jeff Nash
Office: Materials
Subject: 1985 Portland Cement-Fly Ash Concrete Pavement Strengths

A statistical analysis comparing portland cement pavement core strengths versus portland cement-fly ash concrete pavement core strengths has been completed for 1985. The results are summarized below.

PORTLAND CEMENT

Class	No. of Samples	Mean	Std. Dev.	Low	High	Range
A	17	4028	818.9	2800	5365	2565
B	264	3662	660.2	2330	5060	2730
C	637	4863	701.9	2885	7785	4900

PORTLAND CEMENT-FLY ASH CONCRETE

Class	No. of Samples	Mean	Std. Dev.	Low	High	Range
A	204	4081	535.1	2635	5485	2850
B	105	3848	599.9	2575	5160	2585
C	702	4910	782.5	3050	7715	4665

amb

cc: B. C. Brown
M. Sheeler
S. Moussalli