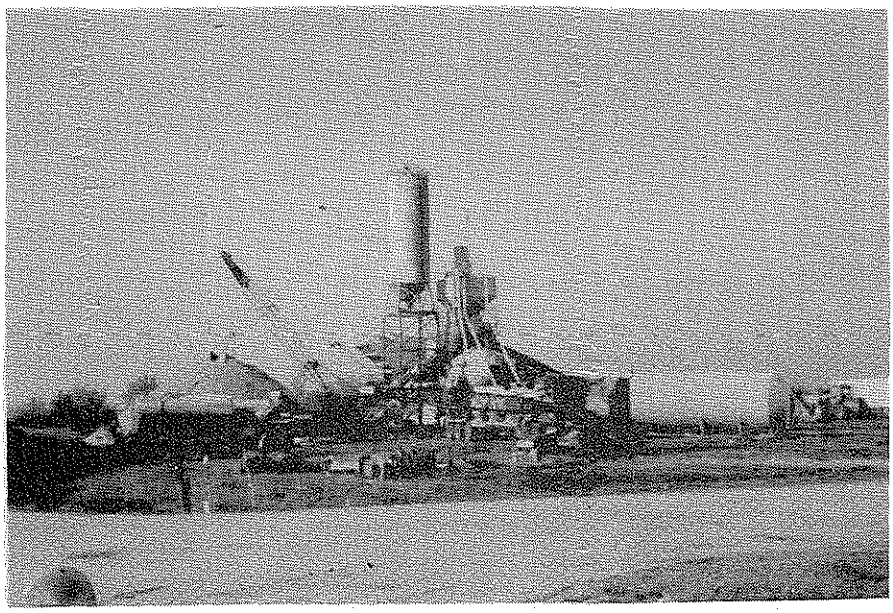
EVALUATION OF FLY ASH IN PORTLAND CEMENT CONCRETE PAVEMENT IN MONONA COUNTY, IOWA



FINAL REPORT
FOR
IOWA HIGHWAY RESEARCH BOARD
PROJECT HR-200

IN COOPERATION WITH

ORVILLE D. IVES, P.E.
MONONA COUNTY ENGINEER
JANUARY 1980

DEPARTMENT OF TRANSPORTATION
IOWA
HIGHWAY DIVISION

Disclaimer

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EVALUATION OF FLY ASH

IN

PORTLAND CEMENT CONCRETE PAVEMENT

IN

MONONA COUNTY, IOWA

BY

ORVILLE D. IVES, P.E.
MONONA COUNTY ENGINEER

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MONONA COUNTY PROJECT HR-200

FM-67(3)--55-67

INTRODUCTION

In today's era of spiraling costs, environmental regulations and shortages of various raw materials, it is interesting to note that we may not be utilizing all available materials. One of the underused materials is fly ash. Although it has been used in some asphalt work, I doubt that this use of fly ash is utilizing it to its full potential.

In this project we were utilizing this material as a cement substitute and not as a mineral filler. Iowa has had very limited use of fly ash in portland cement concrete so we can benefit some from the experience of other states. Both Minnesota and North Dakota have used fly ash with good results.

Nationwide, fly ash is available in large quantities from hundreds of power plants, but we, as engineers, using this for paving material must note that the principal product of a generating plant is electrical power. Much fly ash produced is not of suitable quality for use as a cementing agent.

The fly ash used in this project was uniform and of high quality. (Appendix A) This fly ash was produced by Port Neal Plant #3 in Sioux City, Iowa. This plant produces approximately 181,000 tons per year.

Usually only plants which burn coal from a single source, ground finely and uniformly for combustion, and collected by an electrical precipitator can deliver the quality of fly ash required.

As Monona County is close to Sioux City, I have at different times considered the use of fly ash and welcomed the opportunity to pursue a research project utilizing fly ash as a cementing agent.

I believe if we, as engineers, are willing to incorporate some of these by-products where it is advisable to do so, we can help the nation save energy. The savings will be in transportation of raw materials, the cost of the disposing of fly ash as a waste material and in the processing of portland cement.

OBJECTIVES

The primary objectives of this research project were:

1. Determine and recommend solutions for problems relating to shipping, storing and batching of fly ash.

2. Establish a procedure for batching, mixing and placing uniform concrete with specified air content and consistency.

3. Demonstrate that concrete of comparable quality can be produced.

PROJECT LOCATION

The project is located on Monona County Road E-54, beginning two miles north of Blencoe, Iowa, at Old 75 and extending

easterly for five miles. It is incorporated in Monona County Project FM-67(3)--55-67.

PROJECT FUNDING

The project was funded with Monona County Farm-to-Market funds. Funding for additional costs to the project were approved by the Research Board as follows:

Administration and Testing (excluding core testing)	$ 3,000.00
Coring and core testing	6,300.00
Additional Contractor Set-Up Costs	4,000.00
Contingency for Maintenance	3,000.00
Total	$16,300.00

TEST SECTION AND MIX PROPORTIONS

The project was constructed by the Irving F. Jensen Co., Inc. of Sioux City and included six sections (Figure 1) with different mix proportions. (Appendix B) They are as follows:

1. Standard B-4 mix (approximately ½ mile) Referred to in this report as Mix #1.

2. Standard B-6 mix (approximately ½ mile) Referred to in this report and Mix #6.

3. Modified B-4 mix with a 10% cement reduction and fly ash replacement at 1.5 times that weight (approximately 1 mile) Referred to in this report as Mix #2.

4. Modified B-6 mix with a 15% cement reduction and fly ash replacement at 1.5 times that weight (approximately 1 mile) Referred to in this report as Mix #3.

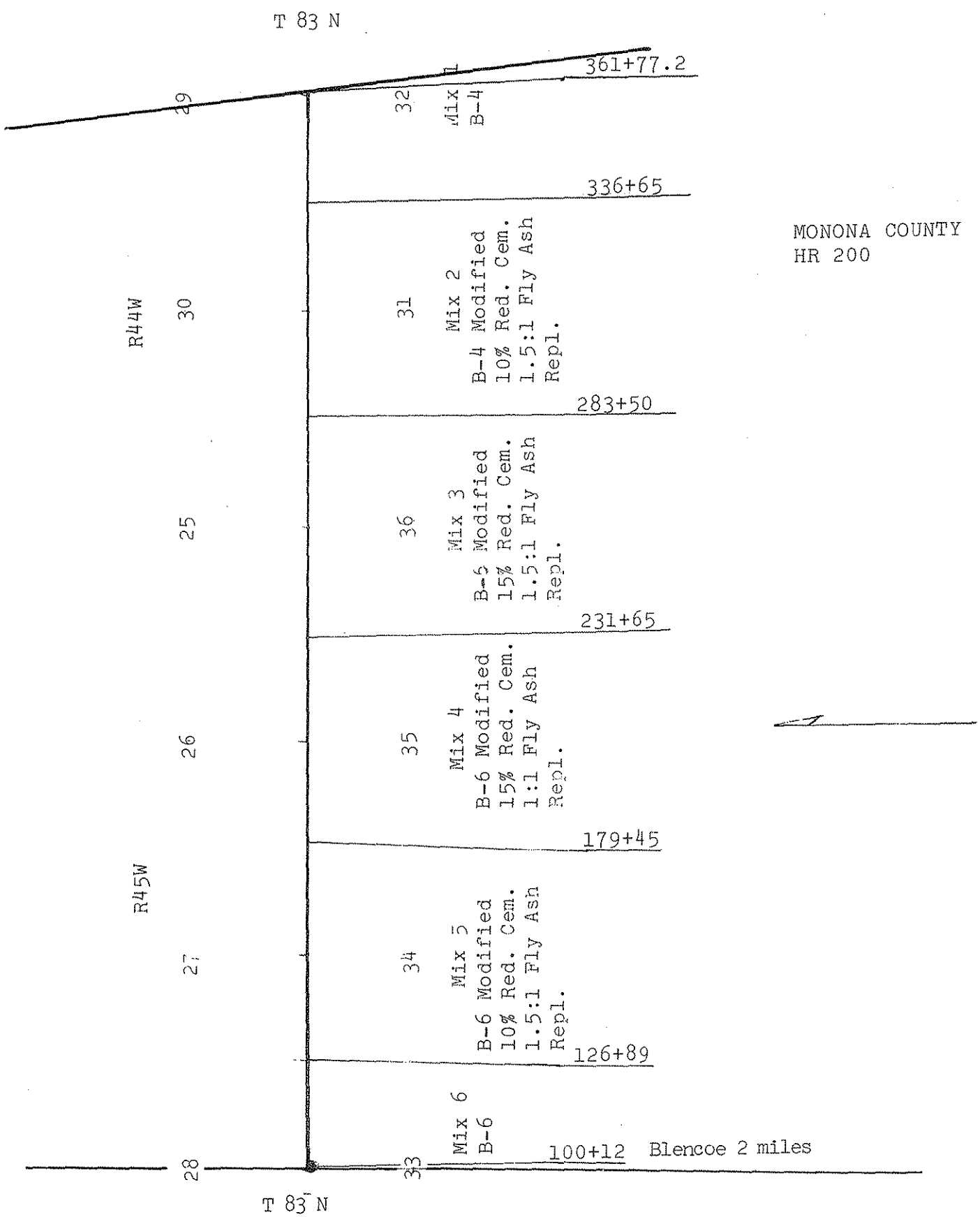


Figure 1. PROJECT LAYOUT FOR MONONA COUNTY HR-200

5. Modified B-6 mix with 15% cement reduction and replacement with equal weight of fly ash (approximately 1 mile) Referred to in this report as Mix #4.

6. Modified B-6 mix with 10% cement reduction and fly ash replacement at 1.5 times that weight (approximately 1 mile) Referred to in this report as Mix #5.

TESTING AND EVALUATION

Additional testing done on this project by Monona County was as follows:

1. Determine the modulus of rupture at 7, 14, 28 and 56 days (4-6" x 6" x 33" beams per section)

2. Cylinders (6-4½" x 9" per section) for compressive strength determination at 3, 7 and 14 days

3. Coring (5 per section) for compressive strength determination at 7 days, 14 days, 28 days, 6 months and 1 year.

The Iowa Department of Transportation obtained and tested 3-4" x 4" x 18" durability beams per section.

EQUIPMENT

The equipment used on the project was essentially the same as a normal paving project. A Rexnord Model S plant with a single 9 yard drum produced the concrete.

The major change was a 100 ton silo adjacent to the mixing tower for storage of the fly ash (see page 7) with an air slide pipe for feeding fly ash into the cement weigh bin. A second

limit switch was added to the cement scales and the batching was automatically controlled. (see page 8)

Some problems were encountered with the boot between the silo and the air slide in early operations. This boot was modified with a steel cylinder connection. I believe if the steel cylinder had been cone shaped, it would have provided a better connection. (see page 8)

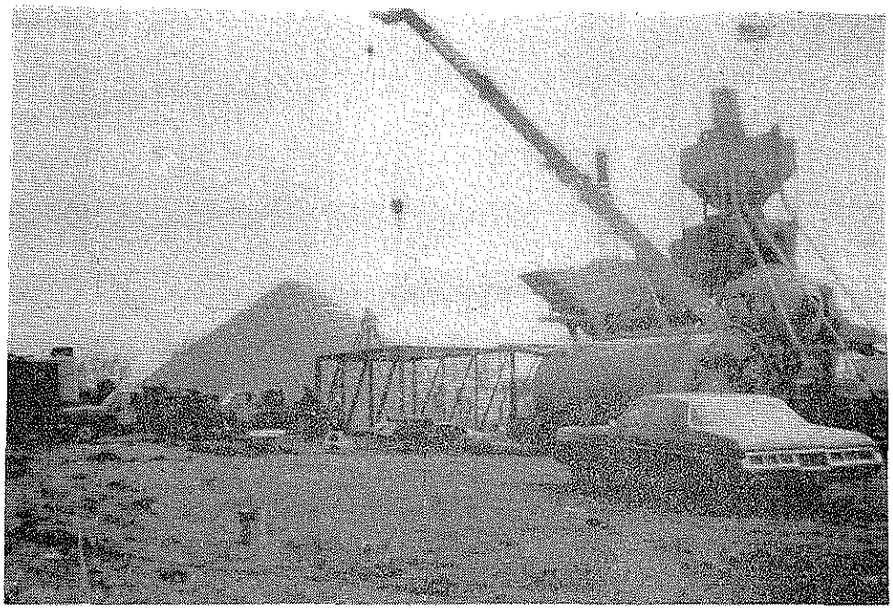
Initial air volume was not enough for the fly ash silo and another air compressor was provided to furnish more air.

No special problems occurred in controlling plant dust with the Buffalo Forge dust control unit. Some problems were encountered with fly ash dust in the connection between the silo and the air slide. It might be noted that fly ash is very fine and will almost leak out where water will not. (18% is retained on a 325 wet sieve).

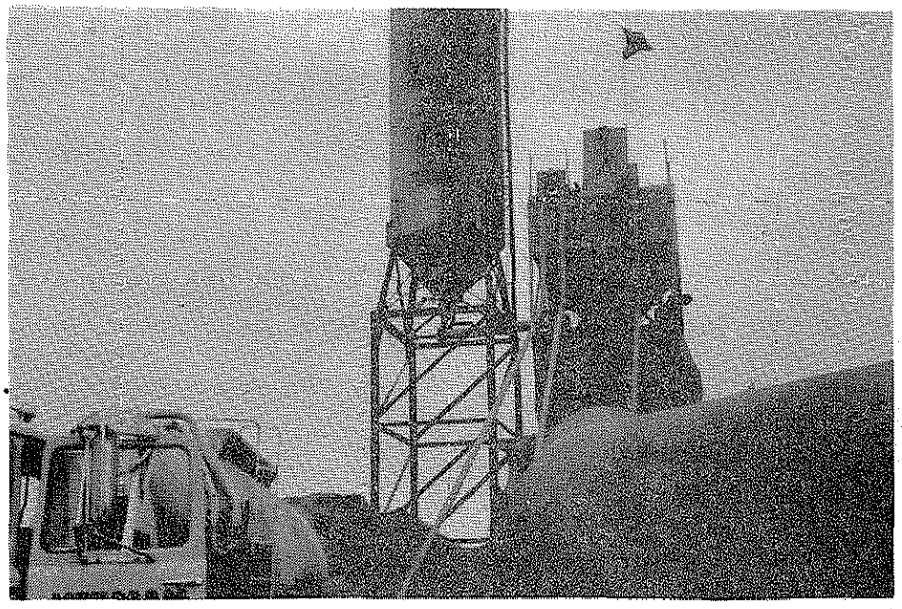
The fly ash was hauled to the plant site in regular cement delivery trailers.

Out on the grade a CMI "Iowa Special" Autograde trimmed the subgrade just ahead of the Rex Town and Country paver. (see page 9)

Plastic subgrade sheeting was used on this project along with 12 foot transverse bars alternating on 4 foot centers each side of centerline.

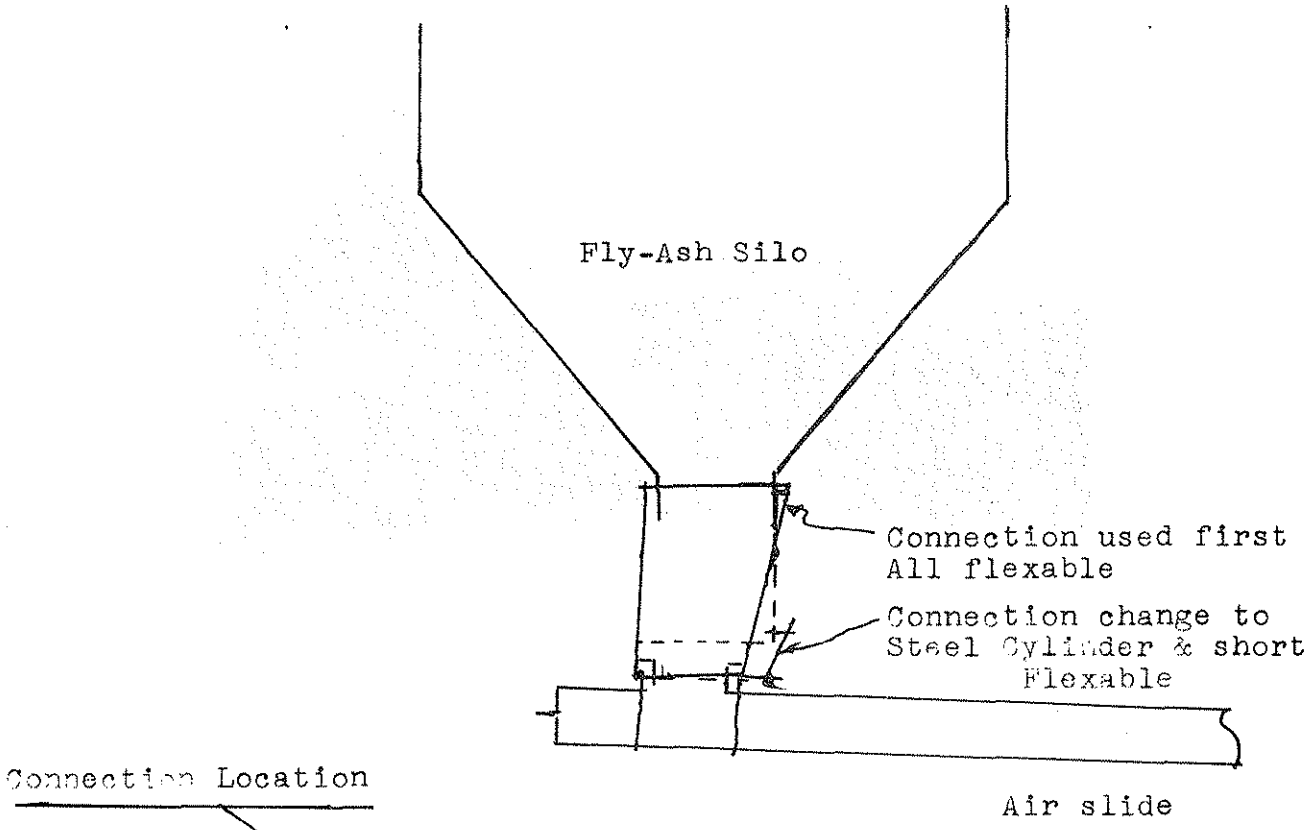


ERECTING FLY ASH SILO

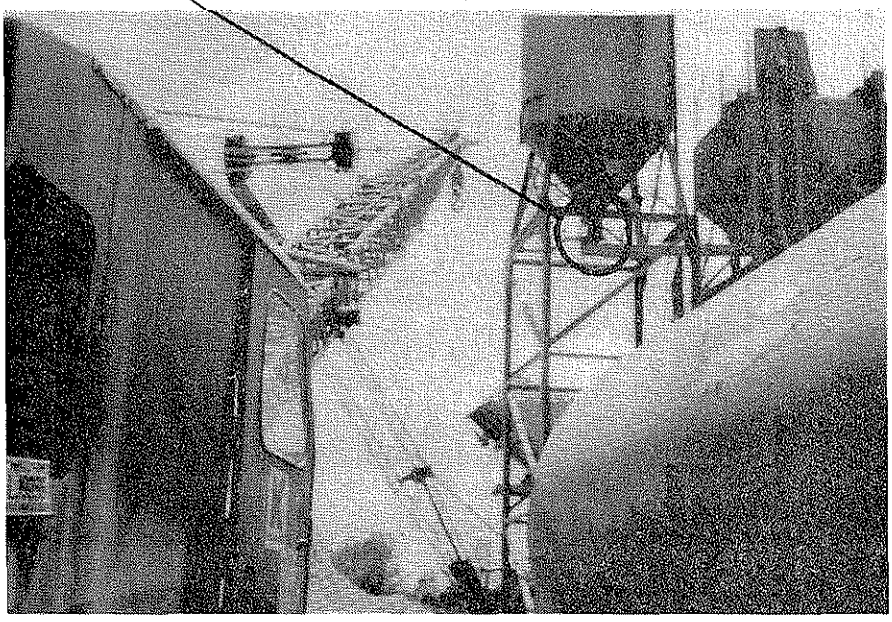


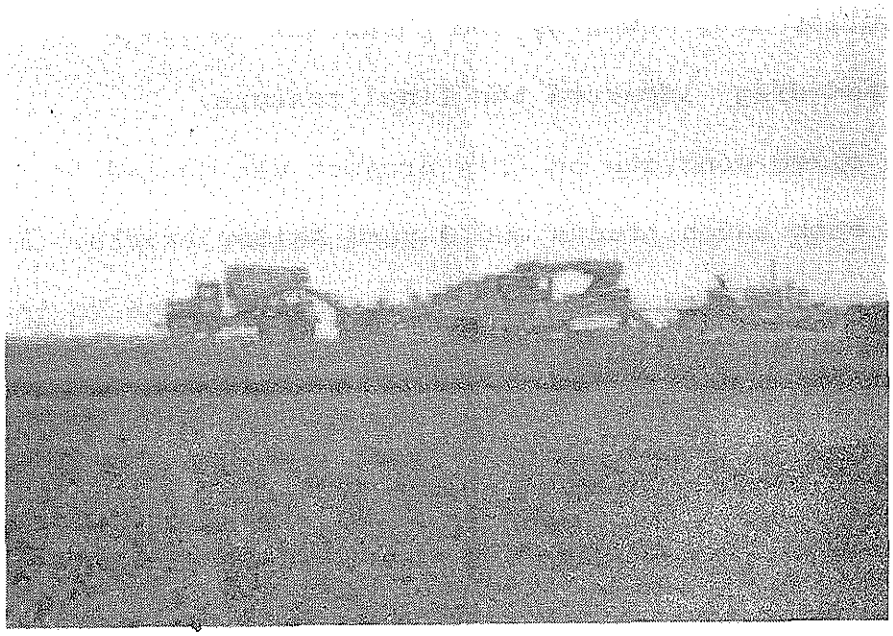
FLY ASH SILO IN PLACE

Monona County HR-200 Air-slide Connection



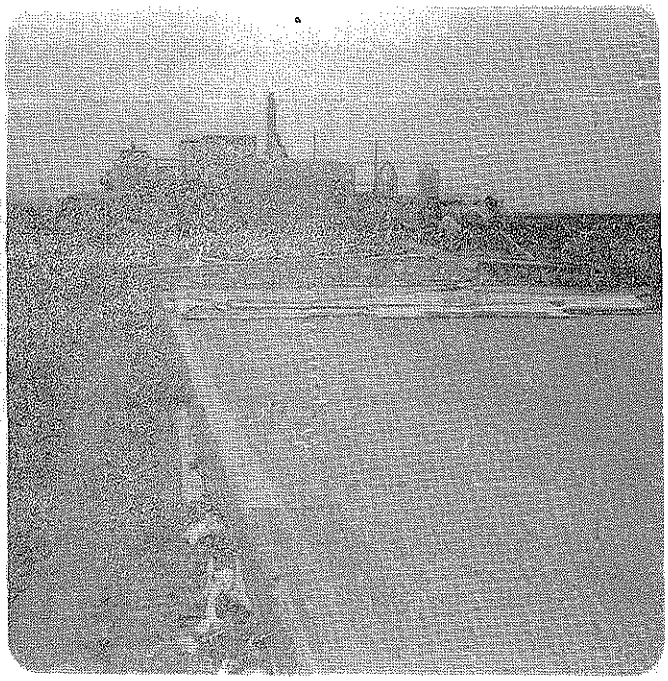
Connection Location





PAVING TRAIN

MIX IN FRONT OF PAVER



FINISHED SLAB

MIX #2

A burlap drag towed by the paver and followed by an astro-grass drag imparted the final texture.

The mixed concrete on this project was hauled to the paver in both batch trucks and 9 yard Agitor trucks. No difference was noted in the mix's workability due to the manner of delivery.

PHYSICAL MIX CHARACTERISTICS

We encountered no problems in controlling the air or slump on the project. Edge raveling was diminished with the use of fly ash. Also the finishers did state that the fly ash mix finished easier. This was probably due to the lubricating qualities of the fly ash. Hand finishing could be done earlier or later with no change in the finish ability of the concrete.

We had no difficulty in the sawing, experienced no raveling at the saw cuts, and had no random cracking on the project. Transverse joints were sawed at 40 foot intervals. All of the cuts were made within 24 hours of placement of the concrete.

Temperature during construction ranged from the low 60's at night to the mid 80's in the day time. I feel this ideal temperature may have some effect on the random cracking and the sawing.

Gilmore time of set laboratory testing on mortar made with a standard cement yielded an initial set of 3.17 hour and a final set of 5.00 hour. Using one part fly ash and four parts standard cement, the results were 5.50 hour for initial set and 7.33 hour for final set or a 58% retardation in initial set and 33% retardation on final set. This retardation characteristic yielded beneficial results in the paving operations.

TEST RESULTS

A summary of test results are in Appendix G. Flexural testing was done on 6" x 6" x 30" beams. Each beam was tested twice. The 7 day average mid-point flexural breaks varied from the low of 434 psi on Mix #5 to high of 601 psi on Mix #1. These 7 day flexural breaks indicated that we were not going to have any problem developing a desirable flexural stength of 550 psi for the normal 14 day opening of the road to traffic. Average mix breaks at 14 days varied from 592 psi on Mix #5 to 686 psi on Mix #6.

All mixes continued to show increases in flexural strength through the 56 day break. The maximum difference in the average flexural strength of the mixes was 167 psi at 7 days; 94 psi at 14 days; 83 psi at 28 days and 68 psi at 56 days. The twenty-eight day break on beam 4-4 was disregarded for average breaks as it broke 2 3/4" off center.

In checking with past records of pavement placed in Monona County, the following can be noted: The B-4 mix has had higher beam breaks, on the average, than the B-6 or B-8 mixes. Some of this I feel is due to the aggregate used. Most B-6 and B-8 mixes in Monona County use a different source of aggregate than was used in this project. The same source as usually used for B-4 mixes was used for this project. The aggregate used on this project was gravel produced by Peters Construction at Rodney.

Cylinders and cores (Appendix D and E) were tested for compressive strength also and the control and fly ash mixes all were good. (Appendix F) As of this writing, the cores on Mix #2 are the highest on a 28 day core. You might note, however, that this mix produced the lowest strength of all the mixes on the 14 day cylinders.

Durability beams were run on each mix. The results are as follows: Mix #1 (86); Mix #2 (86); Mix #3 (88); Mix #4 (92); Mix #5 (92); Mix #6 (92). Air tests and slump tests on the grade indicated no control problems in the fly ash mixes. We also encountered no problems in switching from one mix to another mix.

When we look at the water-cement ratio, we find the design water-cement ratio was lower on fly ash mixes than on the conventional B-4 or B-6 mix. All mixes except Mix #5 were placed at a water-cement ratio below design mix. (See Appendix G)

All test reports received to date indicate that fly ash used with a reduction of cement and a good sound aggregate will produce a good quality of concrete.

OBSERVATIONS

With the projected amount of fly ash that is and will be available in the State of Iowa, I feel that it is advisable that we continue the use of fly ash in portland cement concrete pavements and also develop the use of fly ash in structural concrete. Due to the workability of the fly ash concrete, it should leave less porous wall finishes and should require less effort for a good finish on flat work.

I do feel from all that I have heard and read on fly ash concrete that entrained air is an important item (approximately 6% - 6.5%) to assure a good product.

The contractor on this project indicated to me that if only one fly ash mix had been used throughout the project, a cost savings of 20 to 30 cents per square yard would have been realized. On this particular project, he indicated a savings of approximately 8 to 10 cents per square yard.

This savings, due to transportation costs, would vary from county to county. With the shortages of cement encountered last summer and the projected increase in the cost of cement and hauling, I believe that future savings will be greater.

Considering a compromise on the designs used in this project, I would recommend reducing cement content 12% and a fly ash replacement of 1.25 to 1.0. The amount of concrete available for use will increase. This represents a mix that appears very comparable to our present paving mixes. I do not believe that we need the 1.5 to 1 replacement on any work.

Development for use of fly ash in portland cement will depend on the ability of the power plants to produce a consistent quality fly ash at all times. If this can be done, I believe we can then recognize fly ash as a by-product and not a waste product.

CONCLUSIONS

The primary objectives of this research project have been achieved. On this project, it was shown that fly ash could be shipped, stored and batched in the same manner as portland cement. Some additional equipment was needed for the storage of fly ash. This included an additional storage silo for the fly ash and a second limit switch on the cement scales.

We were, under field conditions with the use of present specifications for portland cement concrete, able to batch, mix and place a concrete with specified air content and a consistent slump.

The concrete produced has shown to date that it is of comparable quality to standard portland cement concrete.

RECOMMENDATIONS

I would recommend that the use of fly ash be continued and specifications be developed for a fly ash portland cement concrete for paving and structural work.

At the present time, I would recommend this mix be placed only during warm weather.

The control of the quality of the fly ash should be the responsibility of the producer. This would require some type of acceptable test monitoring be established to provide production sampling with test results being provided from each individual producer and plant.

In cool weather, the sawing of the concrete may have to be delayed due to the retarding action of the fly ash in the mix.

For an earlier strength, the use of an admixture should be considered. This would be desirable for formed concrete or cold weather pours.

It might be noted at this point that in the past, we have had problems with excessive heat in large mass concrete pier pours. The slower set of the fly ash concrete could be highly advantageous in this type of usage.

It is my hope that fly ash can be used in future work throughout the State of Iowa. With the results Monona County has on its project, we will be willing to use it in the future.

ACKNOWLEDGEMENTS

The author wishes to extend appreciation to the Monona County Board of Supervisors, to my staff and to all personnel of the Iowa Department of Transportation that made this project possible.

18 MONTHS

EVALUATIONS

SUMMARY OF TEST REPORTS

The final test results are found in Appendices E, F and G.

The test results indicate that the fly ash mixes will have some lower strengths in the first 30 days after placement. By the end of 56 days, the flexual strengths are about equal. The cores indicate a continual growth in strength in all mixes to six months. Very little strength was gained between six months and one year.

Six month cores show very little difference in strength between the various mixes.

Of the mixes used, the B-6 was low on both the six month and one year cores.

The tests on this project indicate that fly ash can be used as a replacement for cement in Portland Cement Pavement.

CONCLUSIONS & RECOMMENDATIONS

At the end of 18 months of service, the different test sections show no difference in wear. Some difference in color is noted between the fly ash and the standard mixes.

The fly ash mix has a tighter wearing surface than the standard mix. The texture depth of the fly ash mix is equal to the texture depth of the standard mix; however, while driving on the surface the fly ash texture appears to have less depth.

With results as satisfactory as we had on this project, Monona County has written special provisions allowing the use of either Class F or Class C fly ash (see Appendix H) on two paving projects for the 1980 construction season. These special provisions call for the removal of 10% of cement by weight and replacing with 1.25 parts of fly ash of the Class C type.

I feel that we could have gone as high as 15% reduction in cement on the mix without sacrificing any strength or durability.

Due to the workability of the fly ash mixes, I feel they will have use in formed concrete and in concrete used for slope protection in various structure applications.

I feel some testing with the use of admixtures for an earlier initial set would be advisable.

The wearability of this project will continue to be monitored for the next 5 to 10 yrs. and compared to other adjacent pavement.

It might be noted here that in 1979, two and three fourths miles of B-4 Portland Cement were added onto the east end of this slab. The traffic on this addition would be about the same as the test sections.

I hope that with these projects and continued research, that we can start utilizing more of our locally available resources thus helping to cut down on the use of energy, both in manufacturing and trucking.

IOWA DEPARTMENT OF TRANSPORTATION
OFFICE OF MATERIALS
TEST REPORT - MISCELLANEOUS MATERIALS
LAB LOCATION AMES

MATERIAL FLY ASH LAB NO. ACM8-13

INTENDED USE PC PAVING

COUNTY MONONA PROJ NO. FM-67(3)--55-67

DESIGN CONTRACT NO. 14660

PRODUCER IOWA PUBLIC SERVICE CONTRACTOR I. F. JENSEN

SOURCE PORT NEAL #3. WOODBURY CO.

UNIT OF MATERIAL SAMPLED FROM TRUCK. TICKET #2766. 48,680 LBS.

SAMPLED BY DICK BEEDLE SENDER'S NO. 3DB8-1525

DATE SAMPLED 5/25/78 REC'D 5/30/78 REPORTED 8/11/78

CHEMICAL ANALYSIS

MOISTURE	0.0%
LOSS ON 800 DEG. C IGNITION	0.09%
SO3	0.65%
SILICON DIOXIDE) ALUMINUM OXIDE) IRON OXIDE)	79.67%

PHYSICAL RESULTS ASTM 311

325 MESH	78.2% PSG.
AUTOCLAVE	.09%
POZZLANIC ACTIVITY	86.3%

COPIES:
MISC. CONC.
J. BUMP
O. IVES
M. I. SHEELER
FM-67(3)--55-67, MONONA

DISPOSITION: COMPLIES WITH SP-212

SIGNED: BERNARD C. BROWN
TESTING ENGINEER

SP-212

IOWA DEPARTMENT OF TRANSPORTATION

Ames, Iowa

SPECIAL PROVISION

for

PORTLAND CEMENT CONCRETE PAVING

USING FLY ASH

March 28, 1978

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

ADD the following to 2301.01:
The location, class, and mix proportion number of concrete to be used shall be as indicated on the plans or the proposal.

ADD the following to 2301.03:

When fly ash is required and used in the mix proportions, the fly ash shall meet the requirements of ASTM C 618 Class C except that the loss on ignition shall be a maximum of 5 percent, the available alkalies shall be limited to a maximum of 1.5 percent, and the total silicon dioxide ($Si0_2$) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3) shall be not less than 70% by weight.

Approval of the source of fly ash will be required. Fly ash will not be subject to certified gradation testing by the contractor. Inspection will be arranged by the engineer.

ADD the following proportions to 2301.04:

Basic Absolute Volumes Per Volume of Concrete

	B410-1.5	B610-1.5	B615-1.5	B615-1	C410-1.5	C415-1.5	C415-1
Coarse Aggr.	.346770	.275217	.273324	.278943	.329192	.324530	.331826
Fine Aggr.	.346770	.412825	.409987	.418415	.329192	.324529	.331825
Air	.06	.06	.06	.06	.06	.06	.06
Water	.144231	.143637	.143637	.139482	.151947	.155508	.152540
Cement	.083928	.089031	.084117	.084117	.106422	.100562	.100562
Fly Ash	.018301	.019290	.028935	.019043	.023247	.034871	.023247

Approximate Quantities of Materials per Cubic Yard of Concrete: (Pounds)

Coarse Aggr.	1548	1229	1220	1245	1470	1449	1482
Fine Aggr.	1548	1843	1830	1868	1470	1449	1482
Cement	444	471	445	445	563	532	532
Fly Ash	74	78	117	77	94	141	94
Water	243	242	242	235	256	262	257
Design W/C Ratio	.47	.44	.43	.45	.39	.39	.41
Max. W/C Ratio	.53	.50	.49	.51	.45	.45	.47

Note: Fly Ash is included in the water/cement ration calculation.

Those quantities are based on the following assumptions:

Specific Gravity of Cement - 3.14

Specific Gravity of Fly Ash - 2.40

Specific Gravity of Coarse and Fine Aggregate - 2.65

Weight of one cu. ft. of water - 62.4 lbs.

DELETE the second and third paragraphs of 2301.04H.
It is not the intention to increase cement content or to adjust proportions to correct the yield for this project. The mixture characteristics are to be controlled within the limits specified in 2301.04H and I and within the specified maximum water-cement ratio; these are to be modified only with specific, prior authorization of the engineer.

Page 2

ADD the following to 2301.06A:

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 requirements of 2001.20, either Paragraph A, Manual Batching Equipment, or Paragraph B, Automatic Batching Equipment.

ADD the following:

Certain aspects of the work on this project are of a research nature. Because of this, the engineer may modify requirements in order to assure that meaningful research results are obtained.

Monona County FM-67(3)--55-67 PCC Pavement

(Special Provisions Continued)

The concrete shall be Class "B" and fly ash modified Class "B" with proportions and production in accordance with the supplemental specification. The mix proportions and location shall be:

Station to Station		Area sq.yd.	Mix Proportion No.
100+12.0	126+20	6355.8	B6
126+20	179+40	13004.4	B610 - 1.5
179+40	231+50	12735.6	B615 - 1
231+50	283+70	12760.0	B615 - 1.5
283+70	336+40	12882.2	B410 - 1.5
336+40	361+77.2	6202.0	B4

A transition of $\pm$ 50 feet will be allowed on the stations above when changing mix proportions.

FLEXURAL BEAM DATA

Monona County Project FM-67(3)--55-67 HR-200

Beam No.	Mix No.	Air %	Slump inches	W/C Ratio	Mod. of rupture (Days) 7	14	28	56	Loc. Break off CL. inches
1-1	1	5.6	2.50	.531	629	616			1 1.5
1-2	1	7.2	2.00	.503		660		711	.25 .875
1-3	1	5.7	1.25	.497			681	835	1 .75
1-4	1	6.4	1.75	.497	574		740		.25 .375
Average		6.2	1.88	.507	601	638	710	773	
2-1	2	6.5	1.25	.481	547		681		.5 1.125
2-2	2	6.4	2.75	.440	573	653*			0 0
2-3	2	5.5	1.5	.434	535			714	.5 0
2-4	2	6.5	1.75	.409		659		734	1.625 .5
2-5	2	5.3	1.5	.413		584	624		1.75 0
Average		6.0	1.75	.435	552	632	652	724	
3-1	3	6.0	1.00	.450			688	776	1 1.125
3-2	3	5.3	1.50	.442	608	689			.5 .25
3-3	3	5.5	.75	.445	559	646			.5 1.5
3-4	3	7.2	2.00	.418			629	759	.5 .875
3-5	3	6.2	1.75	.418	587*		614		.375 .125
Average		6.0	1.4	.435	585	668	643	768	
4-1	4	6.5	2.00	.441	608	672			.625 1
4-2	4	5.9	1.50	.441			671	710	.5 0
4-3	4	6.3	1.5	.460	481	544			1.5 .5
4-4	4	6.0	1.00	.466			477#	700	2.75 1
Average		6.2	1.5	.452	544	608	671	705	

* 6 or 13 day break

\# Broke too far off center to use

FLEXURAL BEAM DATA

Monona County Project FM-67(3)-- 55-67 HR-200

Beam No.	Mix No.	Air %	Slump inches	W/C Ratio	Mod. of Rupture (Days) 7	14	28	56	LOC. Break .off CL. inches
5-1	5	6.6	2.00	.466			685	723	1.75 .375
5-2	5	6.4	1.5	.457	431	594			.5 0
5-3	5	6.4	1.75	.459	437		678		.125 1.375
5-4	5	6.4	1.75	.486		590		708	0 .25
Average		6.4	1.75	.462	434	592	682	716	
6-1	6	6.4	1.75	.522	515	676			0 1
6-2	6	5.0	1.00	.495		696		756	1 .5
6-3	6	7.3	2.00	.505			736	761	1.125 .25
6-4	6	7.9	2.00	.505	589		716		0 1
6-5	6	7.5	1.75	.525	521@	572@			.375 0
Average		6.8	1.70	.511	552	686	726	758	

@ Fillet beam - Do not use

COMPRESSIVE STRENGTH DATA - CYLINDERS

Monona County Project FM-67--55-67 HR-200

Cylinder No.	Date Taken	Date Tested	% Air	Slump In's.	W/C Ratio	Comp. Str. (days) 3	7	14
C1-1	5-19-78	5-26-78	5.6	2.5	.531		2770*	
C1-2	5-22-78	5-25-78	7.6	2.0	.503	2070		
C1-3	5-22-78	5-25-78	5.5	1.25	.503	2770		
C1-4	5-22-78	5-29-78	5.7	1.25	.511		3580	
C1-5	5-22-78	6- 5-78	6.3	1.75	.511			4670
C1-6	5-22-78	6- 5-78	6.4	1.75	.499			4870
		Average	6.18	1.75	.501	2420	3175	4770
C2-1	5-22-78	5-25-78	6.5	1.25	.481	2200		
C2-2	5-23-78	5-26-78	7.0	1.75	.481	2700		
C2-3	5-24-78	5-31-78	5.5	1.5	.434		3400	
C2-4	5-24-78	5-31-78	6.5	1.75	.409		3400	
C2-5	5-24-78	6- 7-78	5.3	1.5	.409			3790
C2-6	5-24-78	6- 7-78	5.7	1.75	.409			3430
		Average	6.08	1.58	.437	2450	3400	3610
C3-1	5-24-78	5-31-78	6.0	1.0	.405		3900	
C3-2	5-25-78	5-28-78	6.6	1.75	.445	2580		
C3-3	5-25-78	5-28-78	5.3	1.5	.445	2890		
C3-4	5-26-78	6- 2-78	5.5	0.75	.445		3580	
C3-5	5-26-78	6- 9-78	5.7	1.0	.445			4650
C3-6	6- 2-78	6-16-78	7.2	2.0	.418			4020
		Average	6.05	1.33	.434	2735	3740	4335
C4-1	6- 2-78	6- 5-78	6.5	2.0	.441	2360		
C4-2	6- 2-78	6- 5-78	5.5	1.25	.441	2300		
C4-3	6- 2-78	6- 9-78	5.9	1.5	.441		3710	
C4-4	6- 3-78	6-10-78	6.3	1.5	.460		3400	
C4-5	6- 3-78	6-17-78	6.5	2.0	.460			3770
C4-6	6- 3-78	6-17-78	6.0	1.0	.466			3840
		Average	6.12	1.54	.452	2330	3555	3805

*very porous

COMPRESSIVE STRENGTH DATA - CYLINDERS

Monona County Project FM-67--55-67 HR-200

Cylinder No.	Date Taken	Date Tested	% Air	Slump In's.	W/C Ratio	Comp. Str. (days) 3	7	14
C5-1	6- 3-78	6- 6-78	6.6	2.0	.466	2640		
C5-2	6- 5-78	6- 8-78	5.8	2.0	.466	2830		
C5-3	6- 5-78	6-12-78	6.4	1.5	.457		3520	
C5-4	6- 5-78	6-12-78	6.4	1.75	.459		3400	
C5-5	6- 5-78	6-19-78	6.2	1.5	.459			4400
C5-6	6- 6-78	6-20-78	6.4	1.75	.486			3960
		Average	6.30	1.75	.465	2735	3460	4180
C6-1	6- 6-78	6- 9-78	5.7	1.75	.522	2520		
C6-2	6- 6-78	6- 9-78	5.0	0.75	.495	2520		
C6-3	6- 6-78	6-13-78	5.0	1.0	.495		3770	
C6-4	6- 6-78	6-13-78	7.3	2.0	.505		4090	
C6-5	6- 6-78	6-20-78	7.1	2.0	.505			4780
C6-6	6- 6-78	6-20-78	7.9	2.0	.505			4150
		Average	6.33	1.58	.505	2520	3930	4465

Cylinder No.	Mix Identification
C1-1 - C1-6	B-4
C2-1 - C2-6	B410-1.5
C3-1 - C3-6	B615-1.5
C4-1 - C4-6	B615-1
C5-1 - C5-6	B610-1.5
C6-1 - C6-6	B-6

CORING DATA - LAB. NO.ACE8-581-677

Monona County Project FM-67(3) -- 55-67 HR-200

I N F O R M A T I O N A L T E S T S

Mix No.	Station	Lab. No.	Core No.	Dist. ℄	Age at Test Days	Corr. Str. PSI	Computed Str. PSI		% Air Hard Conc.	Uncut Length
							28 day	1 year		
1	355+00	0584	3-2181	9.0R	7	3760	5125	6660	7.5	6.00
	351+00	0585	3-2182	3.0L	7	3800	5180	6735	7.8	6.55
	347+00	0586	3-2183	6.0R	7	4040	5510	7160	6.9	5.80
	343+00	0587	3-2184	9.0L	7	4740	6470	8405	5.9	6.10
	339+00	0588	3-2185	3.0R	7	3470	4730	6150	8.6	6.25
			Average			3962	5403	7022	7.34	
2	334+00	0581	3-2178	9.0L	7	3055	4170	5420	6.3	6.00
	329+00	0582	3-2179	3.0R	7	3660	4990	6490	7.5	5.75
	315+00	0583	3-2180	6.0L	7	3230	4410	5730	7.7	6.15
			Average			3315	4523	5880	7.17	
3	257+52	0600	3-2197	5.0L	7	2695	3675	4775	9.2	6.15
	257+52	0601	3-2198	4.0R	7	2525	3445	4480	10.2	6.35
	242+00	0605	3-2202	9.0L	7	3050	4160	5405	5.9	6.00
	237+00	0606	3-2203	6.0R	7	3005	4095	5325	8.4	6.10
	233+00	0607	3-2204	3.0L	7	3060	4175	5425	8.0	6.30
			Average			2867	3910	5082	8.34	
4	223+00	0608	3-2205	9.0R	7	3240	4420	5745	8.3	5.85
	212+00	0609	3-2206	6.0L	7	2845	3880	5045	8.6	6.00
	202+00	0610	3-2207	3.0R	7	3490	4760	6190	8.8	6.30
	192+00	0611	3-2208	9.0L	7	2945	4015	5215	6.9	6.45
	182+00	0612	3-2209	6.0R	7	2390	3260	4235	9.4	6.05
			Average			2982	4067	5286	8.40	
5	175+00	0613	3-2210	3.0L	7	2745	3745	4865	8.5	5.85
	166+00	0614	3-2211	9.0R	7	3080	4205	5465	6.9	6.60
	156+00	0615	3-2212	6.0L	7	2775	3785	4920	9.6	6.30
	146+00	0616	3-2213	3.0R	7	3140	4285	5570	6.0	6.10
	136+00	0617	3-2214	9.0L	7	3165	4320	5615	7.2	5.75
			Average			2981	4068	5287	7.64	
6	125+00	0618	*3-2215	6.0R	7	3130	4270	5550	9.6	5.55
	126+00	0619	E3-2216	6.0R	7	3100	4230	5495	9.2	6.90
	124+00	0620	E3-2217	6.0R	7	3190	4350	5655	8.1	5.95
	119+00	0621	3-2218	3.0L	7	2850	3885	5050	9.0	5.85
	114+00	0622	3-2219	9.0R	7	3055	4170	5420	8.6	6.20
	105+00	0623	3-2220	6.0L	7	3220	4390	5705	8.0	6.05
	100+00	0624	3-2221	3.0R	7	3520	4805	6245	6.5	6.40
			Average			3152	4300	5588	8.43	

CORING DATA - LAB. NO.ACE8-581-677

Monona County Project FM-67(3) -- 55-67 HR-200

I N F O R M A T I O N A L T E S T S

Mix No.	Station	Lab. No.	Core No.	Dist. ℄ L	Age at Test Days	Corr. Str. PSI	Computed Str. PSI		% Air Hard Conc.	Uncut Length
							28 day	1 year		
1	361+00	0589	3-2286	9.0L	17	4215	4815	6255	6.1	9.40
	356+00	0590	3-2187	6.0R	14	3675	4195	5455	5.6	6.65
	353+00	0591	3-2188	3.0L	14	4060	4635	6020	7.4	5.80
	347+00	0592	3-2189	4.0R	14	3900	4455	5790	8.0	5.90
	340+00	0593	3-2190	7.0L	14	4585	5240	6805	5.3	6.05
			Average			4107	4668	6065	6.48	
2	333+00	0594	3-2191	3.9R	15	4085	4665	6065	6.6	5.60
	319+00	0595	3-2192	4.0L	15	4880	5570	7240	5.1	6.50
	305+00	0596	3-2193	6.0R	14	3920	4475	5815	7.9	6.50
	292+00	0597	3-2194	3.0L	14	3720	4250	5520	7.3	6.70
			Average			4151	4740	6160	6.73	
3	280+00	0598	3-2195	1.5R	15	4265	4870	6325	6.9	5.60
	272+00	0599	3-2196	6.0L	15	3525	4025	5225	7.6	6.15
	262+00	0602	3-2199	3.0R	14	3590	4100	5330	9.1	5.95
	253+00	0603	3-2200	9.0L	14	3980	4545	5905	7.8	6.00
	247+00	0604	3-2201	6.0L	14	3690	4215	5475	9.5	6.30
	238+00	0625	3-2222	9.0L	14	3490	3990	5180	6.4	6.65
			Average			3757	4291	5573	7.88	
4	228+00	0626	3-2223	6.0R	14	2585	2955	3840	8.8	5.90
	218+00	0627	3-2224	8.0R	14	3880	4430	5670	7.5	6.30
	208+00	0628	3-2225	9.0R	14	3585	4090	5315	6.6	6.20
	198+00	0629	3-2226	6.9L	13	2040	2330	3025	9.1	5.80
	188+00	0630	3-2227	3.0R	13	3215	3670	4770	12.5	5.85
			Average			3061	3495	4542	8.90	
5	178+00	0631	3-2228	9.0L	14	3140	3585	4610	8.7	6.20
	168+00	0632	3-2229	6.0L	14	3195	3650	4740	10.6	5.95
	158+00	0633	3-2230	3.0L	14	3150	3600	4675	9.5	5.90
	148+00	0634	3-2231	9.0R	14	3340	3810	4955	8.0	6.45
	138+00	0635	3-2232	6.0L	14	2965	3390	4405	9.0	5.90
			Average			3158	3607	4687	9.16	
6	118+00	0636	3-2233	3.0R	14	3080	3520	4575	9.1	5.80
	114+00	0637	3-2234	9.0L	14	3615	4125	5365	7.1	5.90
	106+00	0638	3-2235	6.0R	14	4255	4860	6315	7.6	6.40
	103+00	0639	3-2236	3.0L	14	3930	4490	5835	7.9	5.80
	100+91	0640	3-2237	9.0R	14	3790	4330	5625	7.1	6.80
			Average			3734	4265	5543	7.76	

CORING DATA - LAB. NO.ACE8-581-677

Monona County Project FM-67(3) -- 55-67 HR-200

I N F O R M A T I O N A L T E S T S

Mix No.	Station	Lab. No.	Core No.	Dist. ℄	Age at Test Days	Corr. Str. PSI	Computed Str. PSI		% Air Hard Conc.	Uncut Length
							28 day	1 year		
1	358+00	0641	3-2238	6.0R	28	3440	3440	4470	7.5	6.00
	348+00	0643	3-2239	3.0L	28	5005	5005	6510	5.8	6.15
	337+00	0644	3-2240	9.0R	28	3990	3990	5185	11.5	6.45
	340+00	0645	3-2241	6.0L	28	4365	4365	5675	11.9	6.10
			Average			4200	4200	5460	9.18	
2	310+00	0642	3-2242	3.0R	27	5045	5045	6555	5.5	6.60
	327+00	0646	3-2243	6.0L	28	4125	4125	5365	8.4	6.15
	317+00	0647	*3-2244	3.0R	28	5510	5510	7165	9.0	5.50
	318+00	0648	E3-2245	3.0R	29	5300	5300	6890	6.1	6.30
	316+00	0649	E3-2246	3.0R	29	5125	5125	6660	6.8	6.20
	307+00	0650	3-2247	9.0L	28	4630	4630	6020	6.9	6.40
	296+00	0651	3-2248	6.0R	28	4565	4565	5930	6.4	6.35
	286+00	0652	3-2249	3.0L	28	4825	4825	6270	6.7	5.90
			Average			4891	4891	6357	6.98	
3	276+00	0653	3-2250	9.0R	29	3350	3350	4355	8.7	6.60
	266+00	0654	3-2251	6.0L	28	4690	4690	6095	6.8	6.20
	255+00	0655	3-2252	3.0R	28	4190	4190	5445	7.9	6.05
	245+00	0656	3-2253	9.0L	28	3610	3610	4695	6.6	5.80
	235+00	0657	3-2254	6.0R	28	2770	2770	3600	7.7	6.30
			Average			3720	3720	4840		
4	225+00	0658	3-2255	3.0L	28	3520	3520	4575	9.7	5.90
	214+00	0659	3-2256	9.0R	28	4450	4450	5785	8.7	6.10
	204+00	0660	3-2257	6.0L	28	3700	3700	4810	8.8	6.25
	194+00	0661	3-2258	3.0R	28	3390	3390	4405	9.2	5.85
	184+00	0662	3-2259	9.0L	28	3380	3380	4395	8.9	6.35
			Average			3690	3690	4795		
5	173+00	0663	*3-2260	6.0R						5.65
	174+00	0664	E3-2261	6.0R	28	4970	4970	6404	6.2	6.10
	172+00	0665	E3-2262	6.0R						5.70
	171+00	0666	E3-2263	6.0R	28	3800	3800	4940	8.4	5.95
	163+00	0667	3-2264	3.0L	28	4060	4060	5280	7.8	5.90
	153+00	0668	3-2265	9.0R	28	4210	4210	5478	6.8	6.15
	143+00	0669	3-2266	6.0L	28	3280	3280	4264	9.0	6.60
	132+00	0670	3-2267	3.0R	28	3250	3250	4225	7.8	6.10
			Average			3930	3930	5105		

CORING DATA - LAB. NO.ACE8-581-677

Monona County Project FM-67(3) -- 55-67 HR-200

I N F O R M A T I O N A L T E S T S

Mix No.	Station	Lab. No.	Core No.	Dist. ℄	Age at Test Days	Corr. Str. PSI	Computed Str. PSI		% Air Hard Conc.	Uncut Length
							28 day	1 year		
6	122+00	0671	3-2268	9.0L	28	4240	4240	5510	5.8	6.75
	115+00	0672	3-2269	6.0R						6.10
	112+00	0673	3-2270	3.0L	28	3650	3650	4745	8.2	6.30
	107+00	0674	3-2271	9.0R	28	4780	4780	6215	5.7	6.60
	102+00	0675	*3-2272	6.0L						5.50
	103+00	0676	E3-2273	6.0L	28	4530	4530	5890	6.9	6.00
	101+00	0677	E3-2274	6.0L	28	4630	4630	6020	4.6	6.60
			Average			4365	4365	5675		

CORING DATA _ LAB. NO.

Monona County Project FM-67(3)--55-67 HR-200

I N F O R M A T I O N A L T E S T S

Mix No.	Station	Lab No.	Core No.	Dist. C.L.	Age @ Test Days	Corr. Str. PSI	Computed Str PSI		% Air Hard Conc.	Uncut Lgth
							28 day	1 yr.		
1	360+00	0900	3-2739	3.0L	185	6275	5045	6560	7.4	6.55
	355+00	0901	3-2740	6.0R	184	5705	4585	5960	7.0	5.70
	350+00	0902	3-2741	9.0L	184	5920	4760	6190	6.6	6.05
	345+00	0903	3-2742	3.0R	184	5970	4800	6240	5.5	5.75
	339+00	0904	3-2743	6.0L	184	6035	4850	6305	7.3	6.30
	Average					5981	4808	6251		
2	334+00	0905	3-2744	9.0R	184	5015	4030	5240	6.8	6.25
	324+00	0906	3-2745	9.0L	184	6450	5195	6750	5.4	5.75
	314+00	0907	3-2746	6.0R	184	4590	3890	4800	8.5	5.90
	304+00	0908	3-2747	9.0L	184	5780	4650	6040	5.7	6.30
	294+00	0909	3-2748	3.0R	184	4905	3940	5725	6.5	5.95
	Average					5348	4341	5711		
3	280+00	0910	3-2749	6.0L	184	5590	4575	5945	7.1	5.75
	270+00	0911	3-2750	9.0R	184	5200	4180	5435	7.9	6.15
	260+00	0912	3-2751	3.0L	184	5585	4490	5840	8.6	6.25
	250+00	0913	3-2752	6.0R	184	6030	4845	6300	6.2	6,25
	240+00	0914	3-2753	9.0L	183	4600	3700	4810	6.1	6.00
	Average					5401	4358	5666		
4	230+00	0915	3-2754	3.0R	183	4165	3350	4355	8.7	5.80
	219+00	0916	3-2755	6.0L	183	4765	3830	4980	8.8	6.55
	209+00	0917	3-2756	9.0R	183	6160	4955	6440	---	6.50
	199+00	0918	3-2757	3.0L	183	4955	3985	5175	8.6	5.70
	189+00	0919	3-2758	6.0R	183	5105	4105	5335	6.9	6.20
	Average					5030	4045	5257		
5	178+00	0920	3-2759	9.0L	183	5880	4730	6145	9.0	5.30
	168+00	0921	3-2760	3.0R	183	5630	4525	5885	5.0	5.70
	158+00	0922	3-2761	6.0L	183	5285	4250	5520	8.1	6.00
	148+00	0923	3-2762	9.0R	183	5065	4070	5290	6.9	6.50
	136+00	0924	3-2763	3.0L	183	6075	4885	6345	7.7	5.65
	Average					5587	4492	5837		
6	125+00	0925	3-2764	6.0R	183	4790	3850	5005	7.2	6.05
	120+00	0926	3-2765	8.0L	183	4830	3880	5045	7.4	5.90
	114+00	0927	3-2766	8.0L	183	4915	3950	5135	9.1	5.70
	108+00	0928	3-2767	6.0R	183	5350	4705	6115	6.8	5.5
	102+00	0929	3-2768	9.0L	183	5205	4185	5440	5.7	9.4
	Average					5018	4114	5348		

CORING DATA _ LAB. NO.

Monona County Project FM-67(3)--55-67 HR-200

I N F O R M A T I O N A L T E S T S

Mix No.	Station	Lab No.	Core No.	Dist. C.L.	Age @ Test Days	Corr. Str. PSI	Computed Str PSI		% Air Hard Conc.	Uncut Lgth
							28 day	1 yr.		
1	359+00	0348	03-2812	3.0R	369	6150	4730	6150	7.1	5.90
	354+00	0349	03-2813	6.0L	366	5670	4360	5670	7.3	6.70
	349+00	0350	03-2814	9.0R	366	4975	3825	4975	7.0	6.70
	344+00	0351	03-2815	3.0L	366	5390	4145	5390	7.3	5.80
	338+00	0352	03-2816	6.0R	366	6340	4875	6340	6.5	6.70
	Average					5705	4387	5705		
2	333+00	0353	03-2817	9.0L	365	6500	5000	6500	5.9	5.90
	323+00	0354	03-2818	3.0R	365	5665	4355	5665	7.6	5.90
	313+00	0355	03-2819	6.0L	365	5805	4465	5805	6.4	6.40
	303+00	0356	03-2820	9.0R	364	5285	4065	5285	7.1	6.50
	293+00	0357	03-2821	3.0L	364	6445	4955	6445	5.3	7.10
	Average					5940	4568	5940		
3	282+00	0358	03-2822	6.0R	364	5610	4315	5610	---	6.70
	272+00	0359	03-2823	9.0L	363	6505	5005	6505	6.3	6.20
	262+00	0360	03-2824	3.0R	362	5850	4495	5850	8.1	5.85
	252+00	0361	03-2825	6.0L	362	6365	4895	6365	6.1	6.50
	241+00	0362	03-2826	9.0R	364	5205	4005	5205	7.2	6.40
	Average					5907	4543	5907		
4	227+00	0363	03-2827	3.0L	364	4880	3750	4880	9.3	5.80
	217+00	0364	03-2828	6.0R	364	5370	4130	5370	8.9	6.20
	207+00	0365	03-2829	9.0L	364	5940	4570	5940	6.8	6.10
	197+00	0366	03-2830	3.0R	363	4370	3360	4370	9.2	6.30
	187+00	0367	03-2831	6.0L	363	5120	3935	5120	8.4	5.90
	Average					5136	3949	5136		
5	177+00	0368	03-2832	9.0R	363	4905	3770	4905	7.9	7.30
	167+00	0369	03-2833	3.0L	361	5460	4200	5460	8.1	6.40
	157+00	0370	03-2834	6.0R	361	5225	4020	5225	6.3	5.90
	147+00	0371	03-2835	9.0L	361	4845	3725	4845	7.4	6.50
	137+00	0372	03-2836	3.0R	361	6490	4990	6490	3.6	6.00
	Average					5385	4141	5385		
6	126+00	0373	03-2837	6.0L	360	4775	3670	4775	6.6	6.10
	121+00	0374	03-2838	9.0R	360	5110	3930	5110	6.7	6.60
	116+00	0375	03-2839	3.0L	360	5570	4285	5570	6.3	5.90
	111+00	0376	03-2840	6.0R	360	4515	3470	4515	8.3	6.20
	105+00	0377	03-2841	9.0L	360	5060	3890	5060	7.0	6.20
	Average					5006	3849	5006		

CYLINDER AND CORES

HR-200, "Fly Ash in P.C. Pavement-Monona County"

Compression Strength in PSI

Appendix F

Mix 1	Ave.	Calculated Ave.	
		28 day	1 yr.
3 day cylinders	2420		
7 day cylinders	3175		
14 day cylinders	4770		
7 day cores	3962	5403	7022
14 day cores	4107	4668	6065
28 day cores	4200	4200	5460
6 month cores	5981	4808	6251
1 year cores	5705	4387	5707
Mix 2			
3 day cylinders	2450		
7 day cylinders	3400		
14 day cylinders	3610		
7 day cores	3315	4523	5880
14 day cores	4151	4740	6160
28 day cores	4891	4891	6357
6 month cores	5348	4341	5711
1 year cores	5940	4568	5940
Mix 3			
3 day cylinders	2735		
7 day cylinders	3740		
14 day cylinders	4335		
7 day cores	2867	3910	5082
14 day cores	3757	4291	5573
28 day cores	3720	3720	4840
6 month cores	5401	4358	5666
1 year cores	5907	4543	5907

CYLINDER AND CORES

HR-200, "Fly Ash in P.C. Pavement-Monona County"

Compression Strength in PSI

Mix 4	Ave.	Calculated Ave.	
		28 day	1 yr.
3 day cylinders	2330		
7 day cylinders	3555		
14 day cylinders	3805		
7 day cores	2982	4067	5286
14 day cores	3061	3495	4542
28 day cores	3690	3690	4795
6 month cores			
1 year cores	5136	3949	5136
Mix 5			
3 day cylinders	2735		
7 day cylinders	3460		
14 day cylinders	4180		
7 day cores	2981	4068	5287
14 day cores	3158	3067	4687
28 day cores	3930	3930	5105
6 month cores	5587	4492	5837
1 year cores	5385	4141	5385
Mix 6			
3 day cylinders	2520		
7 day cylinders	3930		
14 day cylinders	4465		
7 day cores	3152	4300	5588
14 day cores	3734	4265	5543
28 day cores	4365	4365	5675
6 month cores	5018	4114	5348
1 year cores	5006	3849	5006

SUMMARY CONCRETE TEST DATA
Monona County Fly Ash Research
FM-67-(3)--55-67
HR-200

Mix*	Mod. of Rupt. -- Days 7	14	28	56	Cylinders -- Days 3	7	14	Cores -- Days 7	14	28	184	365
1	601	638	710	773	2420	3175	4770	3962	4107	4200	5981	5705
2	552	632	652	724	2450	3400	3610	3315	4151	4891	5348	5940
3	585	668	643	768	2735	3740	4335	2867	3757	3720	5401	5907
4	544	608	671	705	2330	3555	3805	2982	3061	3690	5030	5136
5	434	592	682	716	2735	3460	4180	2981	3158	3930	5587	5385
6	552	686	726	758	2520	3930	4465	3152	3734	4365	5018	5006

*1 B-4 2 B-4 10-1.5 3 B-6 15-1.5 4 B-6 15-1 5 B-6 10-1.5 6 B-6

Average Water-Cement Ratios - Air - Slump

Design Mix No.	1	2	3	4	5	6
Design W/C	.536	.469	.430	.441	.450	.537
Ave. W/C @ beams	.507	.435	.440	.452	.462	.511
Ave. Field W/C	.513	.428	.440	.448	.457	.506
Ave. % Air - Field	6.2	6.0	6.0	6.2	6.4	6.8
Ave. Slump - Inches	1.88	1.75	1.30	1.50	1.75	1.70
Durability	86	86	88	92	92	92

SP-285

IOWA DEPARTMENT OF TRANSPORTATION
Ames, Iowa

Special Provisions
for

PORTLAND CEMENT CONCRETE PAVING USING FLY ASH

Monona County Projects: RS-3090(2)--61-67 and L-37-2--73-67

February 26, 1980

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

On these projects, the contractor may use a concrete mixture utilizing fly ash as a substitute for a portion of the portland cement. This substitution is an option of the contractor. The option includes use of either class of fly ash. With reasonable notice to the engineer, the contractor may change to or from the mixture with fly ash or change the class of fly ash used; however, fly ash of different classes shall not be intermixed. Fly ash may not be substituted for portland cement after September 30th.

ADD the following to 2301.03:

When fly ash is used in the mix proportions, the fly ash shall meet the chemical and physical requirements of ASTM C 618 for the class of fly ash specified, with the following exceptions:

	Class F	Class C*
Loss on ignition	5.0% max.	5.0% max.
Available Alkalies, as Na_2O	1.5% max.	1.5% max.
Silicon Dioxide plus Aluminum Oxide plus Iron Oxide	65% min.	50% min.

*Class C fly ash, in addition to meeting the above requirements, shall have sufficient cementitious qualities, as determined by the Office of Materials, Iowa D.O.T.

Approval of the source of fly ash will be required. Fly ash produced at plants where the limestone injection process is used will not be considered acceptable for use in concrete pavement. Fly ash for use in concrete pavements will only be considered from utility plants that use coal from a single source.

A potential source of fly ash shall furnish the Office of Materials, Iowa D.O.T., test results from an independent laboratory indicating compliance with the above mentioned ASTM specification. This test data shall represent material produced within sixty (60) days of the submittal. The material will then be tested to verify the independent laboratory test data. Upon satisfactory verification, project acceptance will be on a lot-by-lot basis.

Inspection of the fly ash will be arranged by the engineer.

ADD the following to 2301.04:

When a fly ash mixture is used, the substitution shall be as follows:

Class F fly ash - 10 percent of the cement, by weight, shall be removed and replaced with Class F fly ash at a 1⅛ to 1 basis. (1⅛ pounds of fly ash for each pound of cement removed).

Class C fly ash - 15 percent of the cement, by weight, shall be removed and replaced with an equal amount of Class C fly ash, on a pound per pound basis.

The water/cement ratios for the fly ash mixtures are as follows for Class B concrete:

	Class F	Class C
Design w/c ratio - lb./lb.	0.43	0.50
Maximum w/c ratio - lb./lb.	0.49	0.56

Note: Fly ash is included in the water/cement ratio calculation as portland cement.

The change in absolute volumes, due to the fly ash substitution, shall be applied to each aggregate in the same ratio as the ratio of aggregates for that particular mix number (e.g. B-3, 45% Fine Aggr., 55% Coarse Aggr.).

For estimating quantities, the specific gravity of Class F fly ash is assumed to be 2.40 and for Class C fly ash, 2.68 is assumed.

ADD the following to 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 the requirements of 2001.20, either Paragraph A or Paragraph B.

ADD the following to 2301.40:

Furnishing and incorporating fly ash in the concrete will be considered incidental; no separate payment will be made therefor.