Fine Sand for Use in PC Concrete

Final Report for MLR-88-6

March 1989

Highway Division
Iowa Department of Transportation

Fine Sand For Use

In P.C. Concrete

Final Report
MLR-88-6

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Table of Contents

Abstract	1
Introduction	2
Objective	4
Materials	4
Scope	4
Testing	5
Discussion of Results	8
Conclusions	14
Recommendations	15
Appendix	16

Disclaimer

The contents of this report reflect the views of the author and do not necessarily reflect the official view of the Iowa Department of Transportation. This report does not constitute a standard, specification or regulation.

ABSTRACT

In several locations of Iowa, it is becoming more difficult to produce concrete sand consistently at a reasonable cost. Both ASTM and AASHTO have specifications for concrete sands that allow a finer, poorer graded sand than Iowa specifications.

The objective of the study was to develop standard mix designs to permit the use of finer graded sand for p.c. concrete. Three hundred cylinders were made from five sands available in the state. Based on the results of the study, the following is recommended.

1. Create another class of concrete sand by:
    a. Lowering the current mortar strength ratio from 1.5 to 1.3
    b. Raising the allowance for the percent passing one sieve and retained on the next from 40 to 45.
    c. Including a provision that 25 to 60 percent passing the number 30 sieve is required for the sand.
2. Modify the standard paving mixes with and without fly ash for use with the finer sand as follows:
    a. 8% more cement and fly ash for B-2 to B-5 mixes.
    b. 7% more cement and fly ash for A-2 to A-5 mixes.
    c. 5% more cement and fly ash for C-2 to C-5 mixes and water reduced mixes.

INTRODUCTION

The specifications for concrete sand in Iowa have been used for many years with very good results. In several locations of the state, it is becoming more difficult to produce concrete sand consistently at a reasonable cost. Both ASTM and AASHTO have specifications for concrete sands that allow a finer, less well graded sand than the Iowa specification. An earlier study included in Appendix B concluded that finer sand may be feasible in Iowa concrete mixes with some modifications. The ASTM and AASHTO specifications are based on the use of trial mix testing prior to construction. Iowa does not currently use the trial mix procedure.

Changes in the gradation requirements for concrete sand in Iowa are shown in table 1. The specifications published in the 1948 "Standard Specifications for Highway and Bridge Construction" were quite different from the previous specifications.
The major changes were:

1. Limit the gradation so that not more than 40 percent shall pass one sieve and be retained on the sieve with the next higher number.
2. Increase the mortar cube strength ratio to 1.5.
3. Eliminate the option of designing special mixes using sand failing to meet cube strength or gradation requirements.
4. Adopt a #200 sieve requirement of 0 to 2.5% passing.

The changes since 1948 have been to reduce the percent passing the #200 sieve and open up the gradation requirements on the

other sieves. Otherwise, little change has been made in the last forty years.

Table 1. Gradation Changes to Concrete Sand Specifications from 1924 to 1988

	Percent Passing					
	1924a	1930a	1937a	1948e	1960e	1977e
3/8"	100	100	100	100	100	100
#4	95-100	95-100	95-100	95-100	95-100	90-100
#8	85-100	80-100	80- 95	75- 95	75-100	70-100
#16						
#30	15-40	15-40	20-40	20-55		
#50						
#100	0-5	0-5	0-5			
#200				0-2.5	0-1.5	0-1.5
Mortar Strength Ratio	c 1.0b	1.0d	1.0d	1.5f	1.5	1.5

a. Sand failing gradation may be used if mortar strength is adequate.

b. Sand with a mortar strength ratio of between 1.0 and 0.75 due to poor grading may be used provided that the cement is increased to meet minimum compressive strength on concrete made with the project aggregates.

c. The proportions and testing of mortar cubes changed in the 1940's.

d. Sand which fails mortar strength due to poor grading may be used in special mixtures designed by laboratory studies.

e. When fine aggregate is sieved through the following numbered sieves: 4, 8, 16, 30, 50 and 100, not more than 40 percent shall pass one sieve and be retained on the next higher numbers.

f. Sand which has shown satisfactory mortar strength may be accepted without further mortar strength tests so long as its fineness modulus is not less than that of the sand from that source which showed a satisfactory mortar strength minus 0.30.

OBJECTIVE

The objective of the study was to determine the necessary modification to the standard mix designs to permit the use of finer, less well graded sand for concrete mixes.

MATERIALS

The following materials were used in the study:

Cement: Type I, standard laboratory blend of eight portland cements available in Iowa (AC7-350).

Fly Ash: Ottumwa, Class C (ACF8-93)

Air Entraining Agent: Ad Aire, Single Strength, Carter-Waters Corp.

Coarse Aggregate: Martin Marietta (Fort Dodge A94002) (AAC7-29)

Fine Aggregate:
1. Martin Marietta (West Des Moines A77510) (AAS8-112)
2. Giese Construction (Conn A55520) (AAS8-123)
3. Van Dusseldorp (Colfax (A50502) (AAS8-117)
4. Finley (Shenandoah A73504) (AAS8-155)
5. Vulcan Materials (Oxford Mills A53516) (AAS8-154)

SCOPE

Five sands were chosen to represent the range of fine sands in the state. Each sand was tested for gradation, coal, shale, absorption, organic impurities, x-ray diffraction and mortar strength. To build the sands to proper gradations for testing,

fines from the concrete sand were obtained. No fines were available from the Conn Pit. Instead, a portion of the concrete sand was graded and blended into the remaining concrete sand. The gradation chosen and the mortar strength obtained are in Table 2. All aggregate test results are in the Appendix.

It should be mentioned that the fine gradation of Shenandoah sand was tested twice for mortar strength. The first test showed a ratio of 1.50, the same as the coarse gradation. The second test was performed to verify the results. The second run was 1.40. The two results are well within the single-laboratory coefficient of variation for ASTM test procedure C109.

TESTING.

Thirty mixes were made according to ASTM C192 and 300 cylinders were cast and tested for the project. The mixes are as follows:

Mix No.	Mix Designation	Cement (#/yd.^{3})	Fly Ash (#/yd.^{3})	Coarse Agg. (%)	Concrete Sand (%)	Fine Sand (%)
A	C-3-C	513	91	55	45	
B	B-3-C	407	72	55	45	
C	C-3-C	513	91	55		45
D	B-3-C	407	72	55		45
E	C-3-C Mod	529	104	55		45
F	B-3-C Mod	418	82	55		45

The test results are shown in Table 3.

TABLE 2. SUMMARY OF SAND DATA

SOURCE	W. DES MOINES	CONN	COLFAX	SHENANDOAH	OXFORD MILLS
COUNTY	POLK	KOSSUTH	JASPER	PAGE	JONES
OPERATOR	MARTIN MARIETTA	GIESE	VAN DUSSELDOPH	FINLEY	VULCAN MATERIALS
LAB NO			COARSE SAND		
	AAS8-112	AAS8-123	AAS8-117	AAS8-155	AAS8-154
3/8	100	100	100	100	100
#4	99	100	97	96	95
#8	88	94	87	90	89
#16	71	74	73	75	74
#30	43	46	47	43	43
#50	12	18	12	7.2	9.6
#100	1.5	1.9	0.7	0.2	0.8
#200	0.2	0.3	0.1	0.1	0.3
FINE MODULUS	2.86	2.66	2.83	2.89	2.89
MORTAR STR RATIO	1.72	1.50	1.68	1.50	1.63
STRENGTH	7920	6890	7710	6910	7490
% WATER	41	44	42	41	42
% FLOW	115	110	115	110	110
MORTAR SAND LAB NO	AAS8-113	NONE	AAS8-118	AAS8-157	AAS8-156
LAB NO			FINE SAND		
	AAS8-158	AAS8-244	AAS8-243	AAS8-241	AAS8-242
3/8	100	100	100	100	100
#4	99	100	98	98	97
#8	93	95	90	95	94
#16	83	79	80	85	85
#30	62	57	60	57	58
#50	19	19	15	14	13
#100	3.3	1.5	1.5	0.8	1.2
#200	0.4	0.2	0.2	0.3	0.3
FINE MODULUS	2.41	2.48	2.56	2.51	2.52
MORTAR STR RATIO	1.30	1.34	1.45	1.4	1.42
STRENGTH	5970	6150	6660	6460	6530
% WATER	44	49	42	43	43
% FLOW	110	110	110	107	110

TABLE 3. SUMMARY OF TEST RESULTS

MIX NO	SAND	CEMENT (#/YD3)	FLY ASH (#/YD3)	W/C+ FA	AIR (%)	SLUMP (IN.)	COMPRESSIVE STR. 7-DAY	COMPRESSIVE STR. 28-DAY	MORTAR STRENGTH	FINENESS MODULUS	SPECIFIC SURFACE
1A	WEST O.M.	513	91	0.392	6.0	1.50	4830	6460	1.7	5.51	12.37
1B	WEST O.M.	407	72	0.472	6.0	1.00	4150	5400	1.7	5.51	12.37
1C	WEST O.M.	513	91	0.402	6.4	1.50	5090	6030	1.3	5.31	15.66
1D	WEST O.M.	407	72	0.509	6.5	1.25	4000	4990	1.3	5.31	15.66
1E	WEST O.M.	529	104	0.399	6.2	1.25	5120	6520	1.3	5.31	15.66
1F	WEST O.M.	418	82	0.488	6.4	1.25	4050	5300	1.3	5.31	15.66
2A	CONN	513	91	0.475	6.0	1.25	4810	6560	1.5	5.43	13.77
2B	CONN	407	72	0.584	6.0	1.00	3620	5210	1.5	5.43	13.77
2C	CONN	513	91	0.466	6.5	1.25	4590	6280	1.3	5.34	14.71
2D	CONN	407	72	0.583	6.6	1.25	3060	4550	1.3	5.34	14.71
2E	CONN	529	104	0.443	6.4	1.50	4790	6380	1.3	5.34	14.71
2F	CONN	418	82	0.592	5.8	1.25	3550	4910	1.3	5.34	14.71
3A	COLFAX	513	91	0.382	5.8	1.50	5320	6460	1.7	5.50	12.37
3B	COLFAX	407	72	0.460	6.2	1.25	4150	5310	1.7	5.50	12.37
3C	COLFAX	513	91	0.407	6.3	1.50	5210	6400	1.4	5.38	14.17
3D	COLFAX	407	72	0.491	6.5	1.25	3860	5080	1.4	5.38	14.17
3E	COLFAX	529	104	0.385	6.0	1.25	5490	6360	1.4	5.38	14.17
3F	COLFAX	418	82	0.476	6.2	1.25	4420	5600	1.4	5.38	14.17
4A	SHENANDOAH	513	91	0.382	6.1	1.50	4990	6020	1.5	5.53	11.45
4B	SHENANDOAH	407	72	0.466	6.2	1.50	3690	4760	1.5	5.53	11.45
4C	SHENANDOAH	513	91	0.402	6.0	1.25	5050	6130	1.4	5.36	14.02
4D	SHENANDOAH	407	72	0.484	6.5	1.25	4080	5030	1.4	5.36	14.02
4E	SHENANDOAH	529	104	0.385	6.3	1.50	5180	6660	1.4	5.36	14.02
4F	SHENANDOAH	418	82	0.476	6.5	1.25	4220	5330	1.4	5.36	14.02
5A	OX. MILLS	513	91	0.382	5.5	1.25	5450	6610	1.6	5.53	12.02
5B	OX. MILLS	407	72	0.466	5.9	1.25	4750	5630	1.6	5.53	12.02
5C	OX. MILLS	513	91	0.397	6.0	1.25	5160	6350	1.4	5.36	14.03
5D	OX. MILLS	407	72	0.484	6.6	1.25	3680	4550	1.4	5.36	14.03
5E	OX. MILLS	529	104	0.374	6.1	1.25	5310	6270	1.4	5.36	14.03
5F	OX. MILLS	418	82	0.458	7.5	1.50	3670	4650	1.4	5.36	14.03

NOTES: MIX A AND B ARE WITH COARSE SAND
MIX C THROUGH F ARE WITH FINE SAND
STRENGTH AVERAGES ARE BASED ON FIVE CYLINDERS

DISCUSSION OF RESULTS

The test results are shown graphically in Figures 1 through 5. The trend for most of the sands was:

1. The fine sand produced lower strength mixes.
2. Adding 5 percent cement and fly ash to the fine sand mixes increased the strength.

With the Shenandoah sand this trend did not exist. The strength was consistently higher when the fine sand was used in place of the concrete sand. The results would be consistent with the data obtained from the mortar strength testing on the sand. The mortar strength changed little despite the changed gradation. Figures 1 through 5 also indicate that the B mix is more noticeably affected by the change in sand gradation.

Table 4 shows the overall averages for the six different mix types. The difference between the C mix with coarse sand and the C mix with fine sand is 180 psi at 28 days. A statistical signif-cance test was performed assuming normal distribution and standard deviations of 300 psi. A 180 psi difference in the average strengths is significant at the 0.05 level of significance.

FIGURE 1. MIX 1 COMPRESSIVE STRENGTH WEST DES MOINES SAND (A77510)

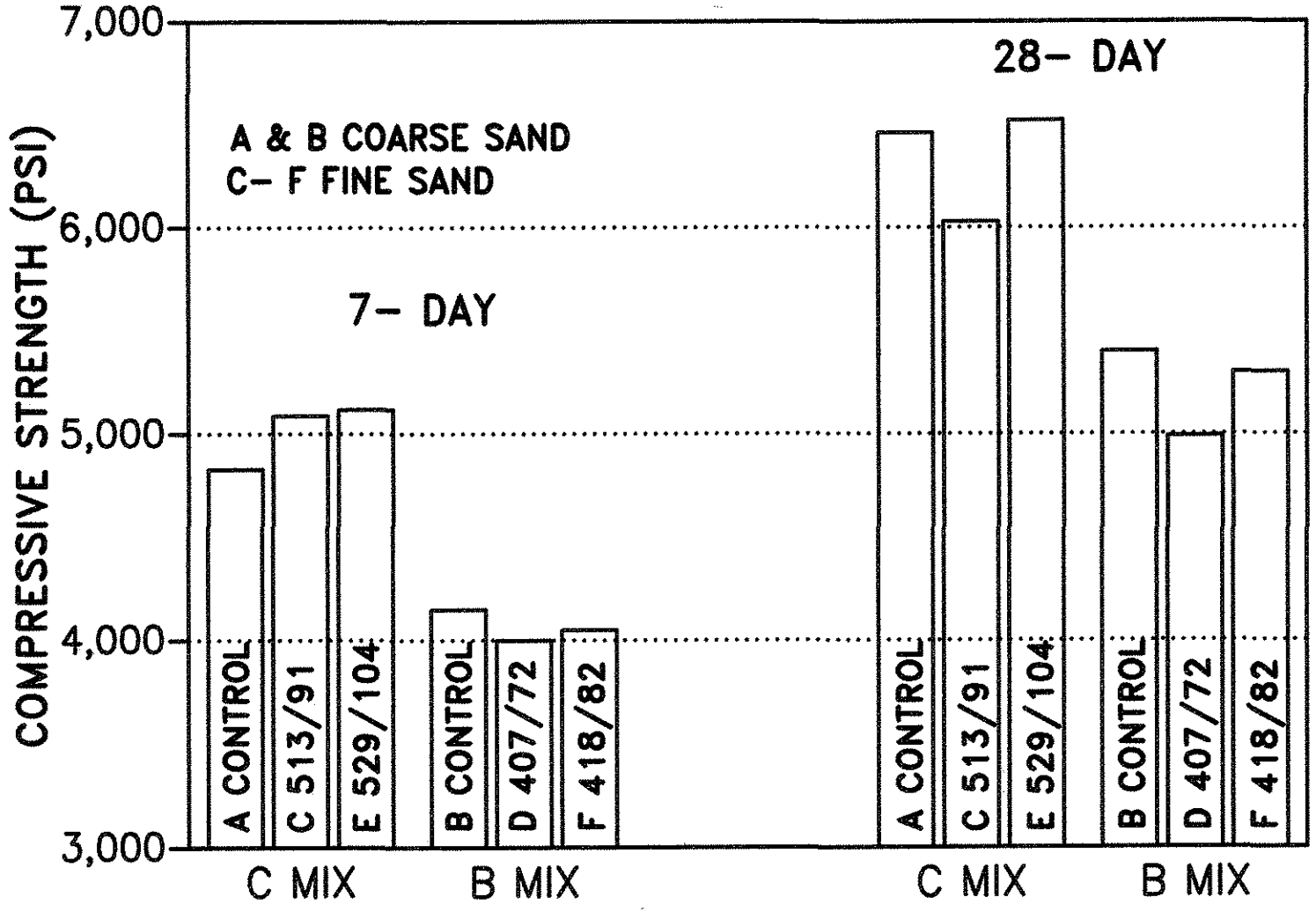


FIGURE 2. MIX 2 COMPRESSIVE STRENGTH CONN SAND (A55520)

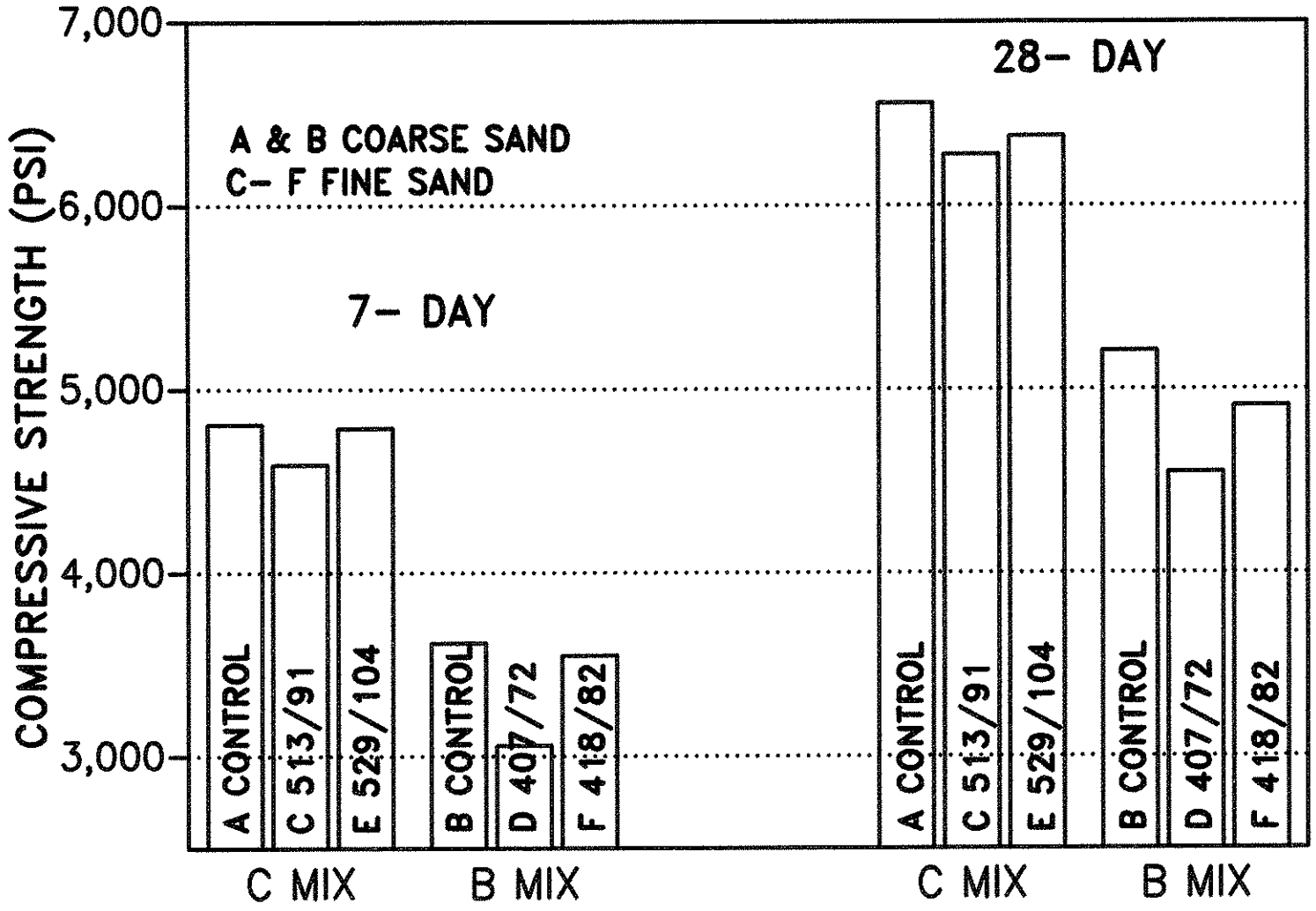


FIGURE 3. MIX 3 COMPRESSIVE STRENGTH COLFAX SAND (A50502)

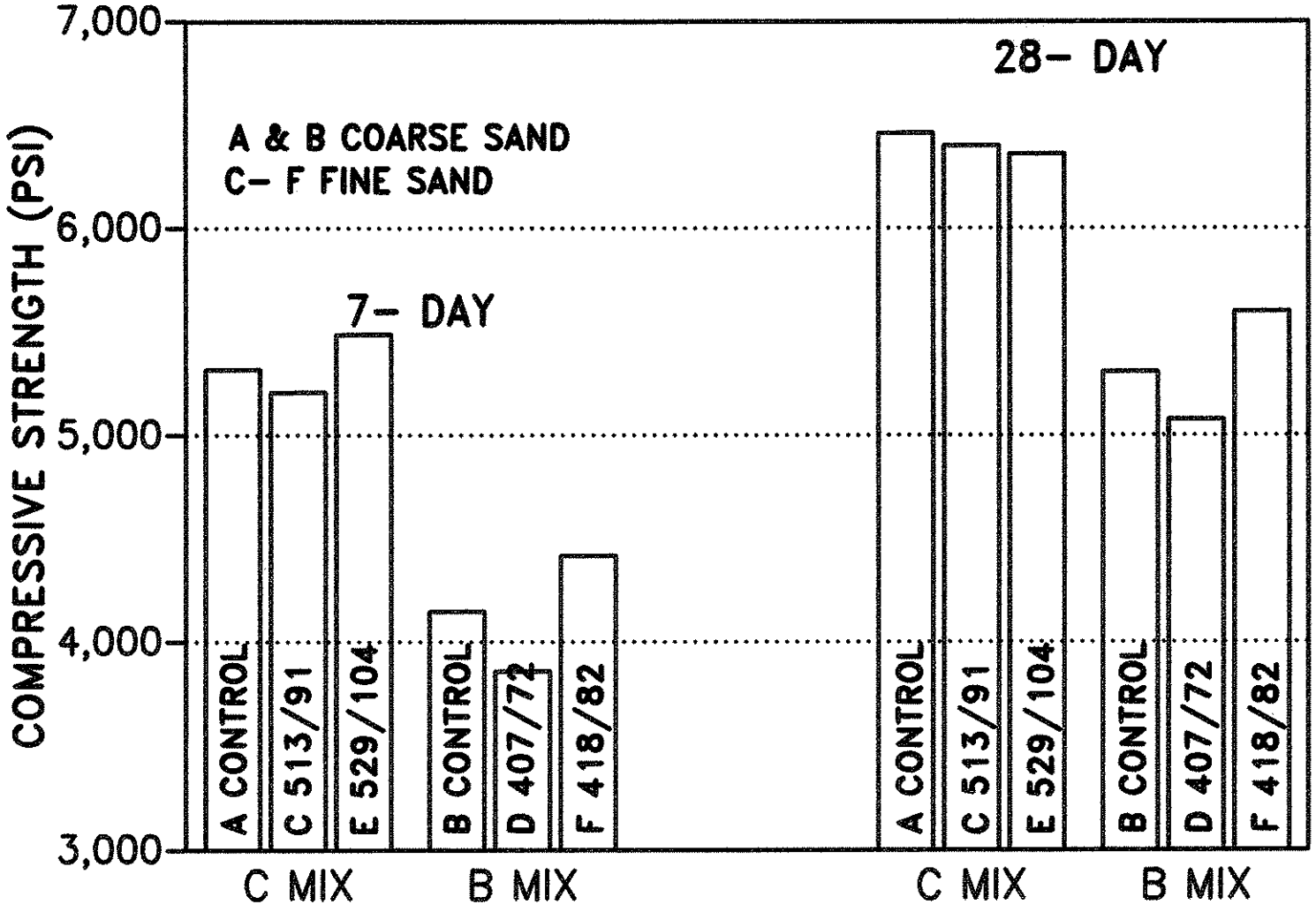


FIGURE 4. MIX 4 COMPRESSIVE STRENGTH SHENANDOAH SAND (A73504)

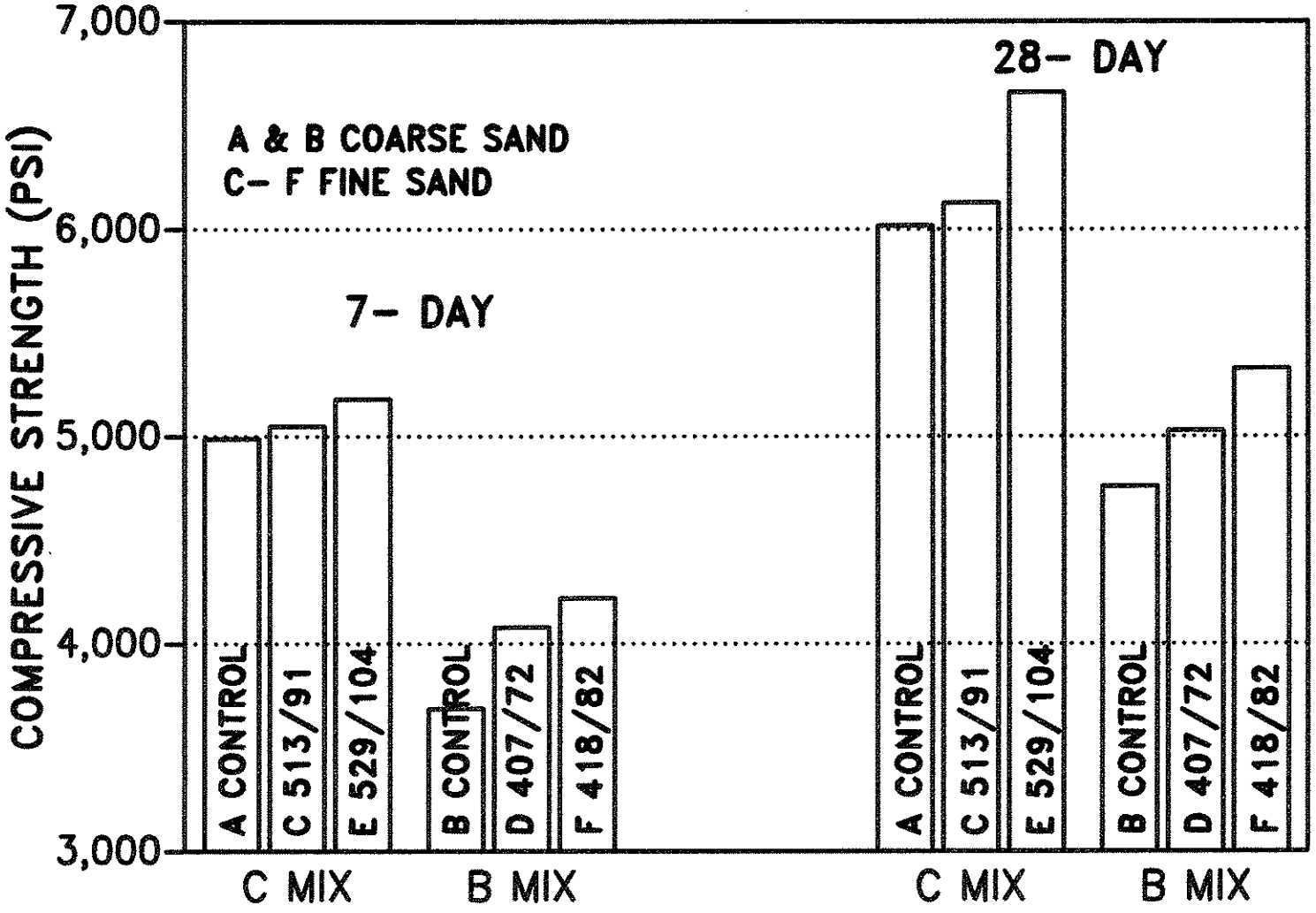


FIGURE 5. MIX 5 COMPRESSIVE STRENGTH OXFORD MILLS SAND (A53516)

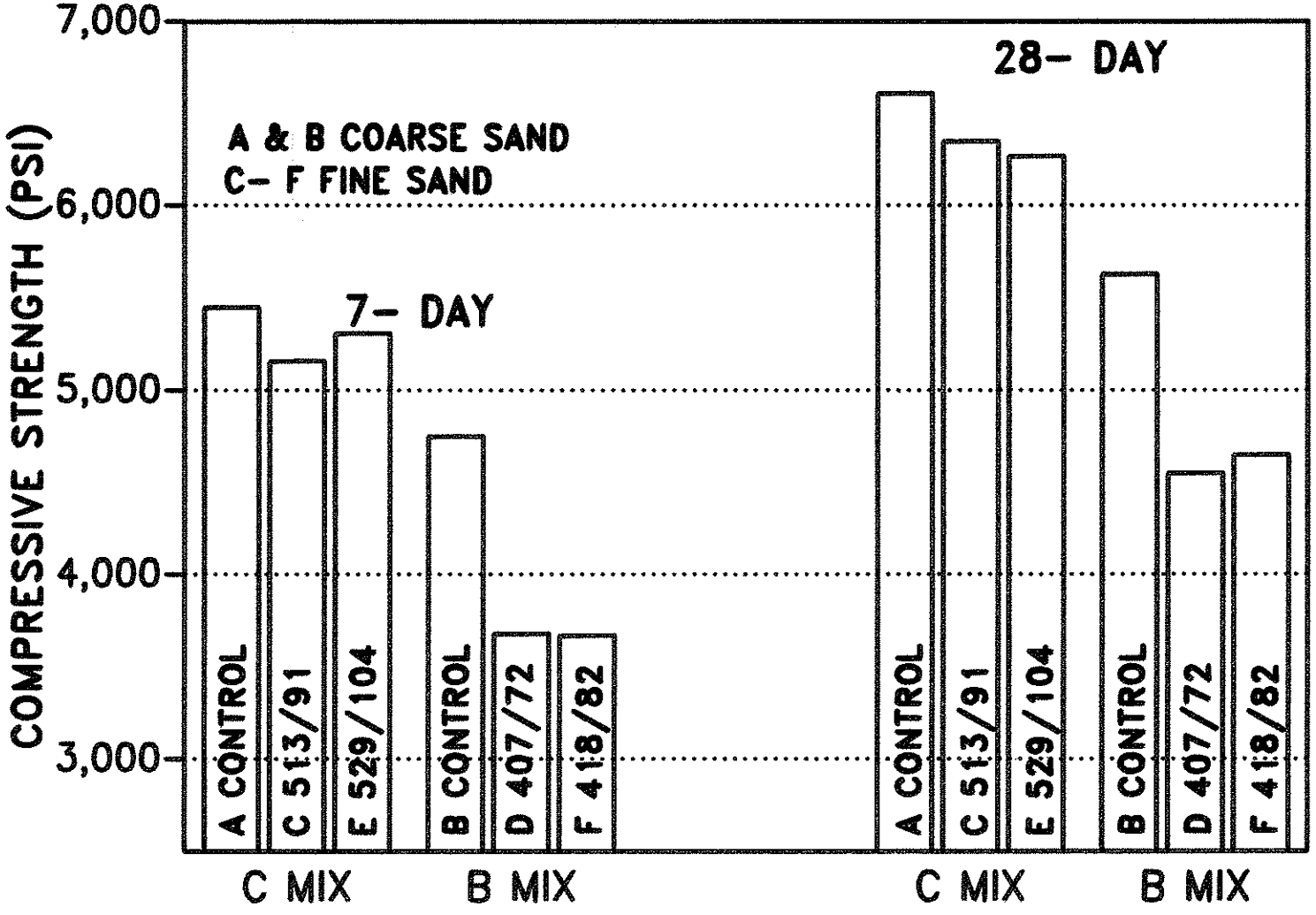


Table 4 Overall Average, Compressive Strength

	C Mix			B Mix	
	7-day	28-day		7-day	28-day
A	5080	6420	B	4070	5330
B	5020	6240	D	3740	4840
C	5180	6440	F	3980	5160

Based on the averages in Table 4, the projected required increase in cementious material factor to obtain equivalent compressive strength with the fine sand =

C mix (28-day) $$\frac{\frac{(6420\text{ psi} - 6240\text{ psi})}{(6440\text{ psi} - 6240\text{ psi})}}{5\%} = 4.5\%$$

C mix (7-day) $$\frac{\frac{(5080\text{ psi} - 5020\text{ psi})}{(5180\text{ psi} - 5020\text{ psi})}}{5\%} = 1.9\%$$

B mix (28-day) $$\frac{\frac{(5330\text{ psi} - 4840\text{ psi})}{(5160\text{ psi} - 4840\text{ psi})}}{5\%} = 7.6\%$$

(7 day) $$\frac{\frac{(4070\text{ psi} - 3740\text{ psi})}{(3940\text{ psi} - 3740\text{ psi})}}{5\%} = 6.9\%$$

CONCLUSIONS

The following conclusions can be obtained from the research:

1. Use of a finer sand grading in concrete will in most instances lower compressive strength.

2. The reduction in compressive strength with finer sand grading may be more severe for leaner mixes.

3. The 7-day compressive strengths were less affected by the grading change than the 28-day.

4. Increasing the cement and fly ash content by a small amount can offset the strength reduction caused by the finer gradation.

RECOMMENDATIONS

The following recommendations are suggested.

1. Add to the specifications a class of sand that is the same as 4110 sand except:

   a. lower the mortar strength ratio from 1.5 to 1.3.

   b. allow 45 percent instead of 40 percent passing one sieve and retained on the next.

   c. Include a provision that material passing the number 30 sieve shall be 25 percent or more and 60 percent or less.

The specification would read as follows:

Section 4111. Class Z Fine Aggregate for Concrete.

4111.01 DESCRIPTION. Class Z fine aggregate for concrete shall be used in mixes specifically permitting its use. Class Z fine aggregate shall meet the requirements of 4110.01 and 4110.02.

4111.02 GRADATION. Class Z fine aggregate for concrete shall meet requirements of Section 4109 for gradation number 1. In addition, when the fine aggregate is sieved through the following numbered sieves -4, 8, 16, 30, 50 and 100 - not more than 45 percent shall pass one sieve and be retained on the sieve with the next higher number.

4111.03 MORTAR STRENGTH. Class Z fine aggregate from an approved source shall have a historic record of mortar strength, determined by Laboratory Test Method 212, of not less than 1.3 times the strength of mortar in which standard sand is used.

2. Modify Section 2301 of the specifications to allow the use of fine sand with a modification to the concrete mixes. The modified mixes should be as follows:

   a. 8% more cement and fly ash for B-2 to B-5 mixes.

   b. 7% more cement and fly ash for A-2 to A-5 mixes.

   c. 5% more cement and fly ash for C-2 to C-5 mixes including water reduced mixes.

   The increase in cementitious material will be one half fly ash and one half cement by weight.

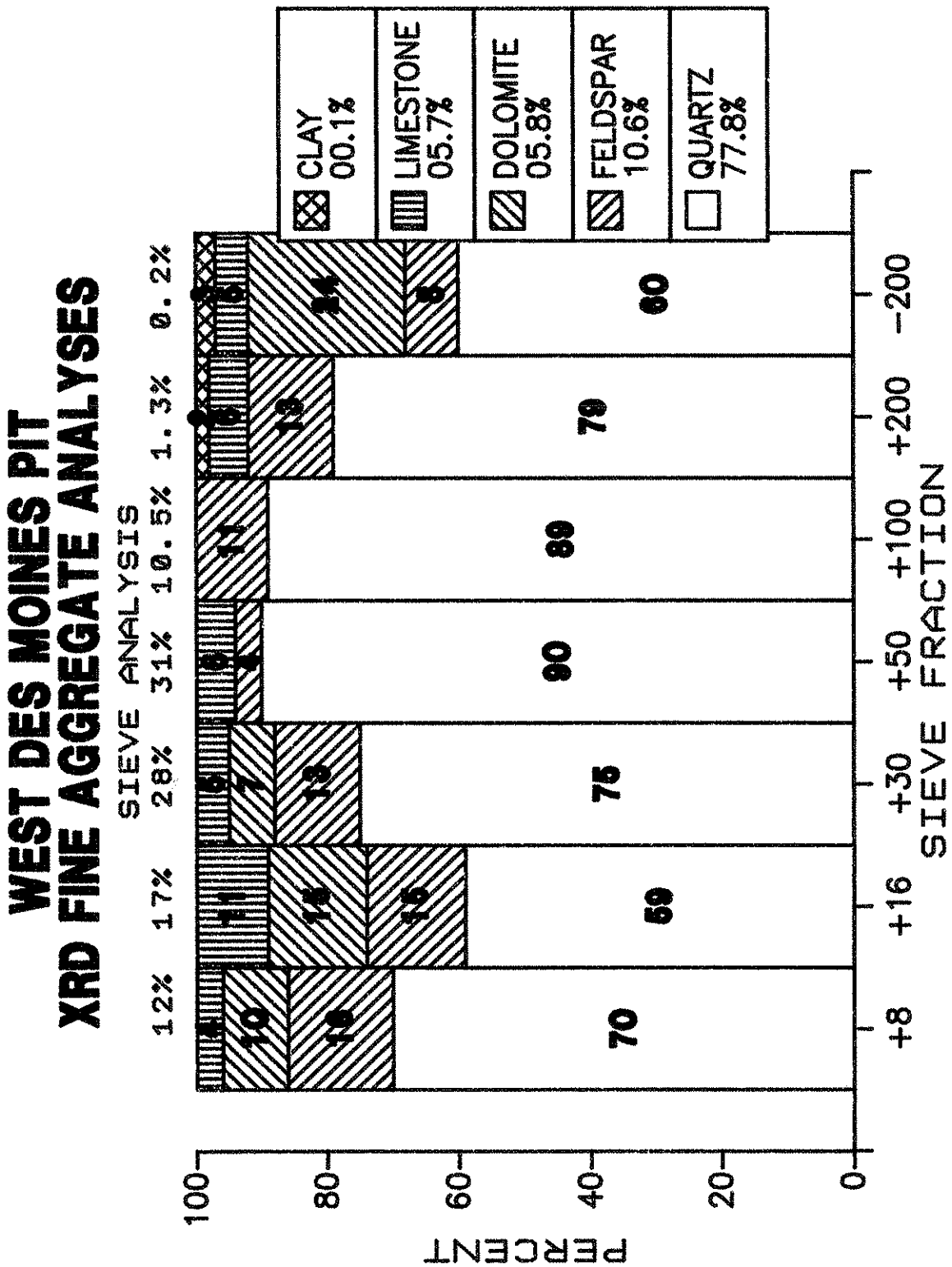
APPENDIX A

SUMMARY OF SAND TESTING

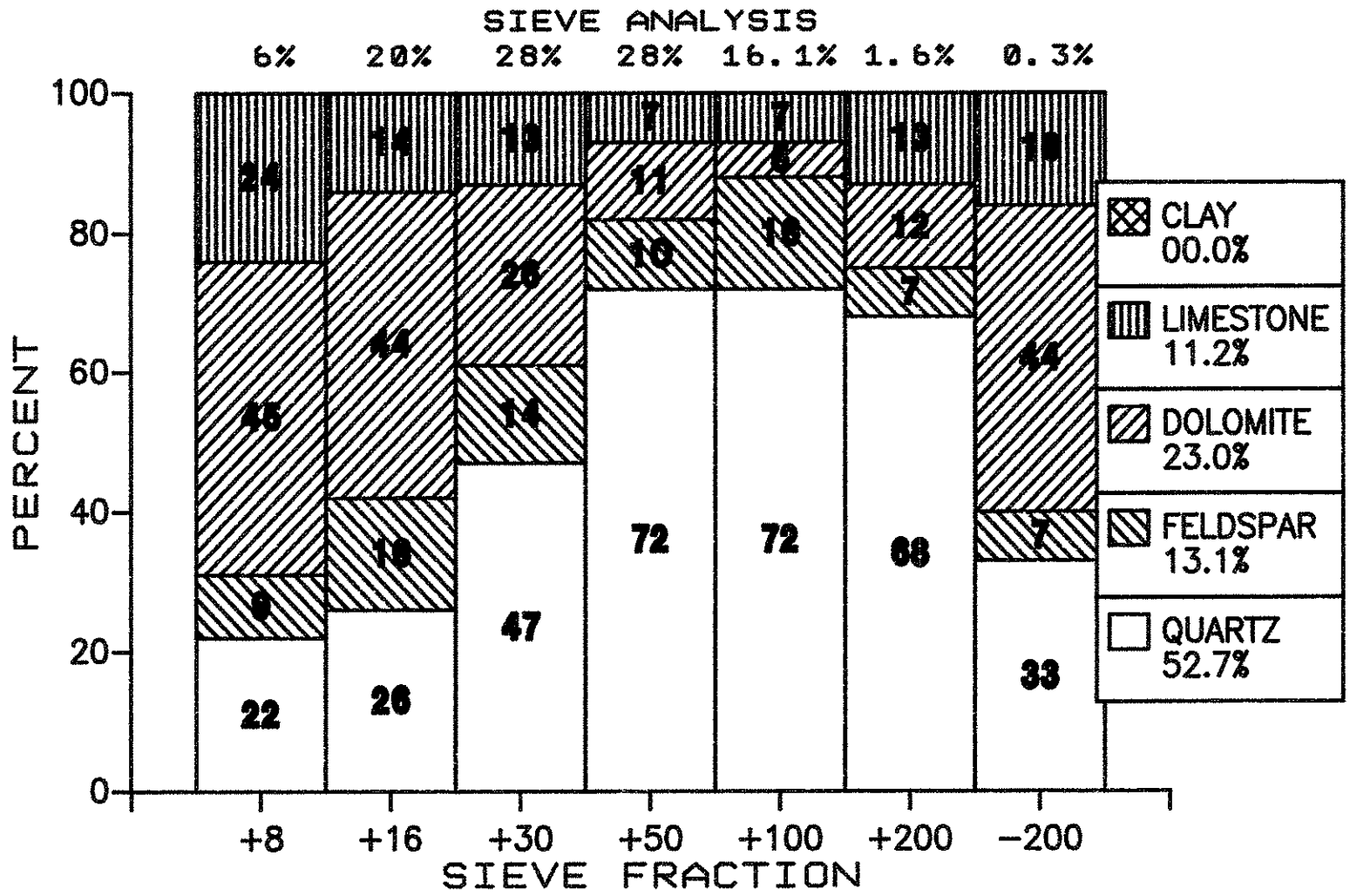
Tests	W. D. M.	Conn	Colfax	Shenandoah	Oxford Mills
Absorption	0.25	1.06	0.30	0.25	0.45
Spec. Gravity	2.66	2.63	2.67	2.64	2.66
Coal	0.1	0.0	0.1	0.0	0.0
Shale	0.1	0.1	0.1	0.1	0.1
Color	#1	#1	#1	#1	#1

COARSE AGGREGATE GRADATION

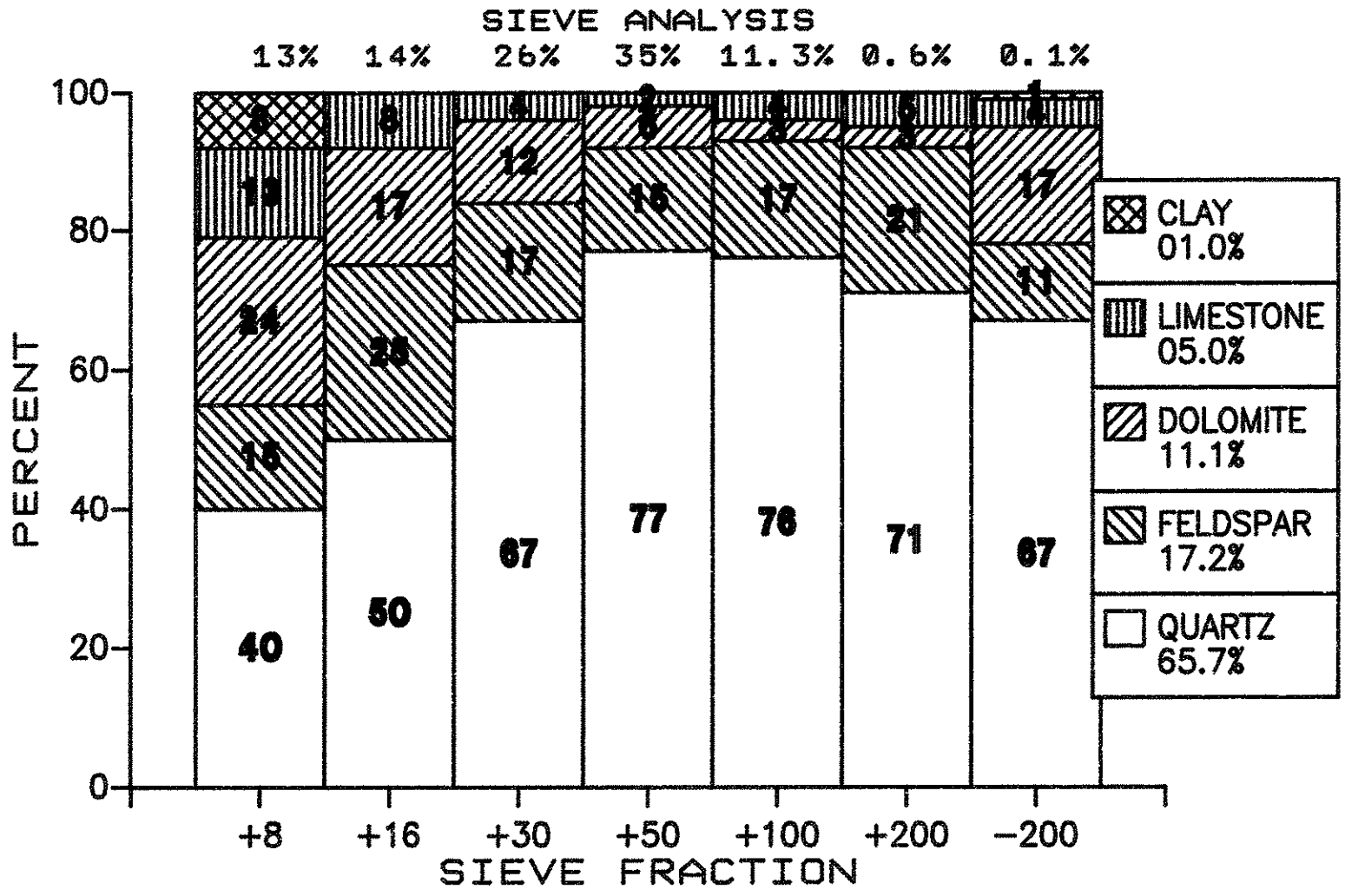
Sieve Size	% Passing
1"	100
3/4"	77
1/2"	40
3/8"	12
#4	0.5
#200	0.3


WEST DES MOINES PIT
XRD FINE AGGREGATE ANALYSES
SIEVE ANALYSIS
12%
17%
28%
31%
10.5%
1.3%
0.2%
CLAY 00.1%
LIMESTONE 05.7%
DOLOMITE 05.8%
FELDSPAR 10.6%
QUARTZ 77.8%
PERCENT
100
80
60
40
20
0
+8
+16
+30
+50
+100
+200
-200
SIEVE FRACTION

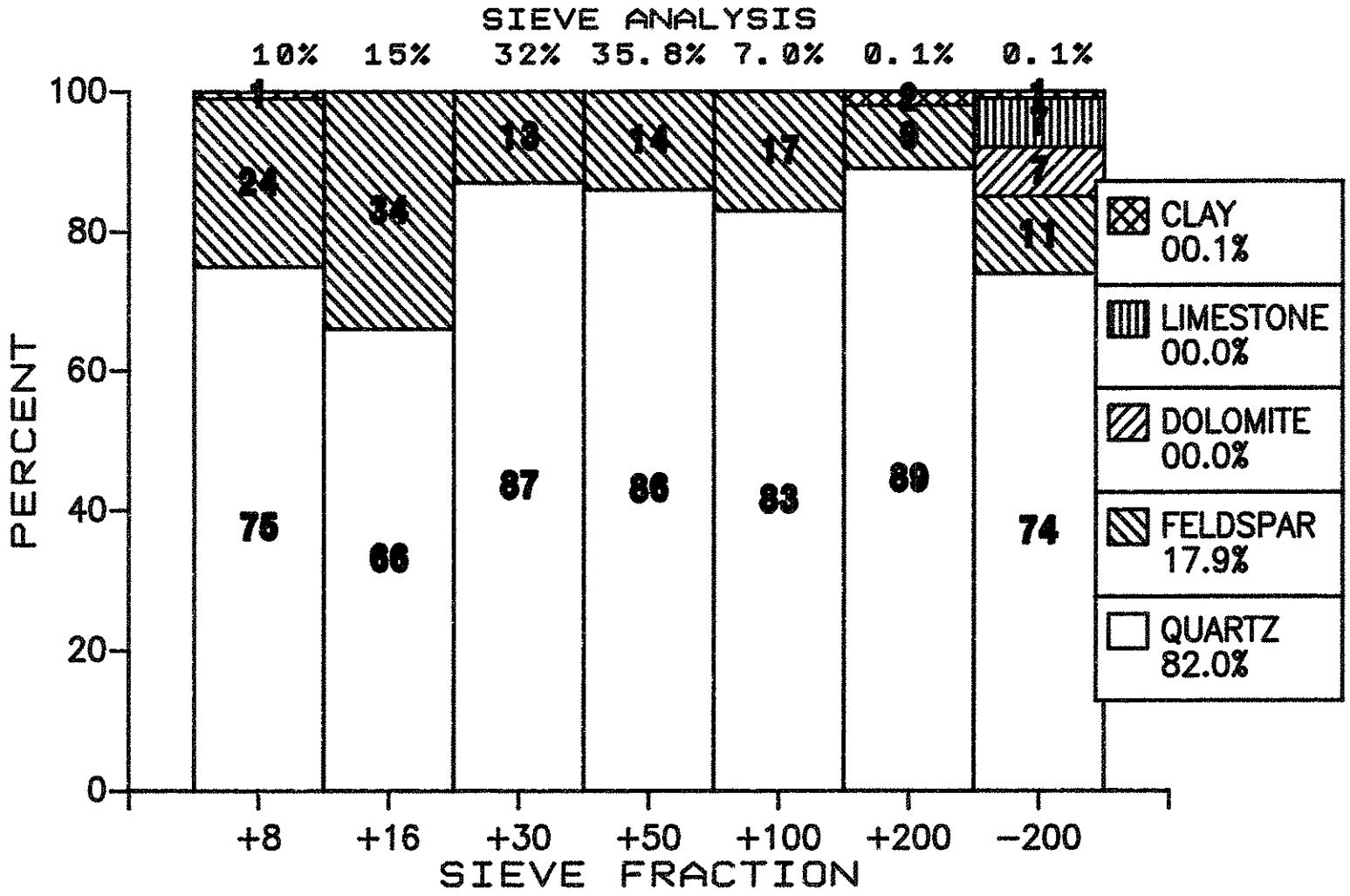
XRD PETROGRAPHIC ANALYSIS OF RIVER SAND
CONN PIT



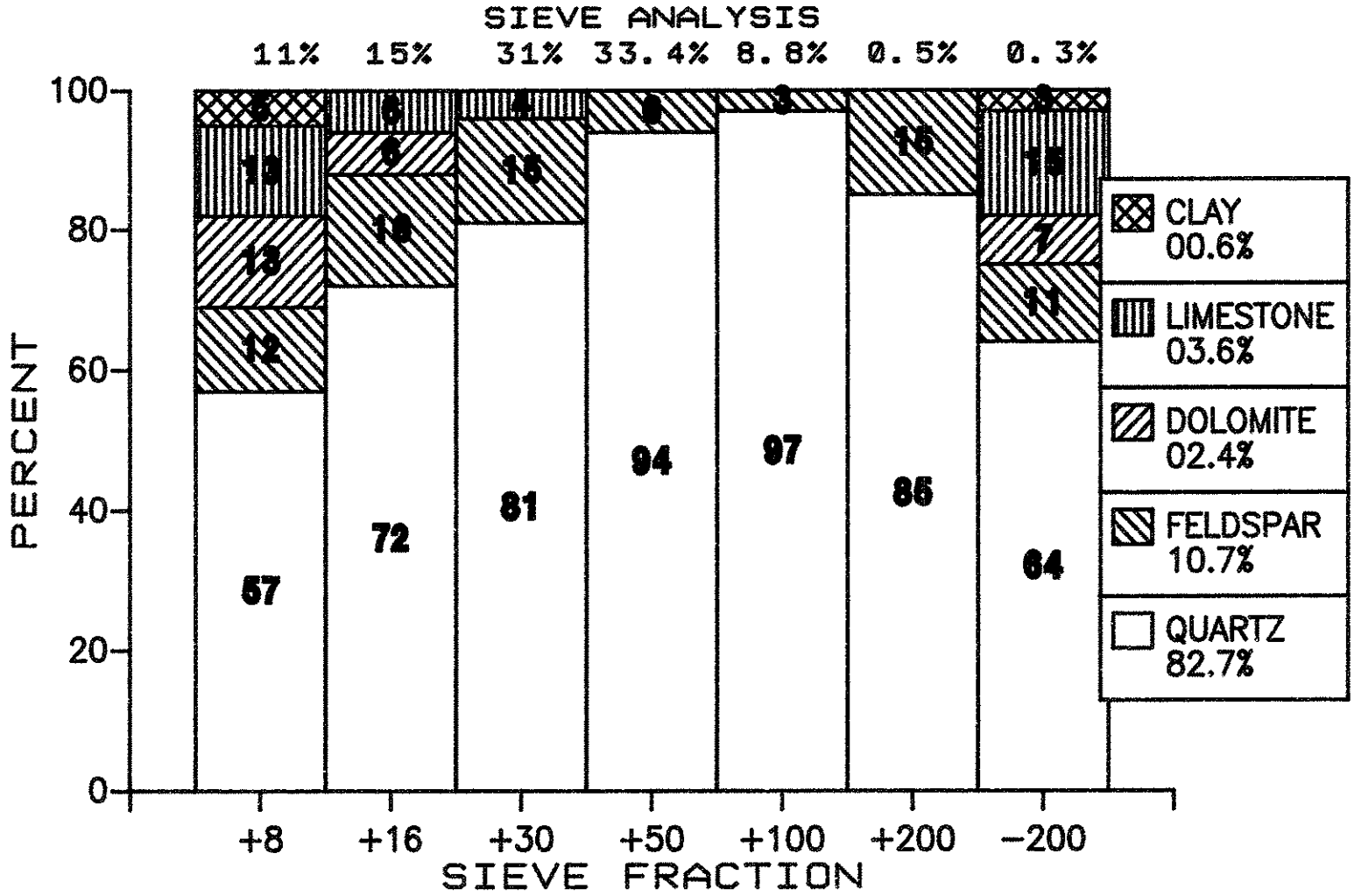
COLFAX PIT
XRD FINE AGGREGATE ANALYSES



SHENANDOAH PIT
XRD FINE AGGREGATE ANALYSES



OXFORD MILLS PIT
XRD FINE AGGREGATE ANALYSES



APPENDIX B

MLR 88 8

A Study of Fine Sand From Nine Mile Island At Dubuque

Kevin Jones
Cement and Concrete Engineer

May, 1988

INTRODUCTION

The specifications for concrete sand in Iowa have been used for many years with very good results. In several locations of the state, it is becoming more difficult to produce concrete sand consistently at a reasonable cost. Both ASTM and AASHTO have specifications for concrete sands that allow a finer, poorer graded sand than the Iowa specification. The ASTM and AASHTO specifications are based on the use of trial mix testing prior to construction. Iowa does not currently use the trial mix procedure.

Changes in the gradation requirements for concrete sand in Iowa are shown in table 1. The specification published in the 1948 "Standard Specifications for Highway and Bridge Construction" were quite different from the previous specifications. The major changes were:

1. Limit the gradation so that not more than 40 percent shall pass one sieve and be retained on the sieve with the next higher number.

2. Increase the mortar cube strength ratio to 1.5.

3. Eliminate the option of designing special mixes using sand failing to meet cube strength or gradation requirements.

4. Adopt a #200 sieve requirement of 0 to 2.5% passing.

The changes since 1948 have been to reduce the percent passing the #200 sieve and open up the gradation requirements on the other sieves. Otherwise, little change has been made in the last forty years.

Table 1. Gradation Changes to Concrete Sand Specifications from 1924 to 1988

	Percent Passing					
	1924a	1930a	1937a	1948e	1960e	1977e
3/8"	100	100	100	100	100	100
#4	95-100	95-100	95-100	95-100	95-100	95-100
#8	85-100	80-100	80- 95	75- 95	75-100	70-100
#16						
#30	15-40	15-40	20-40	20-55		
#50						
#100	0-5	0-5	0-5			
#200				0-2.5	0.1.5	0-1.5
Mortar Strength Ratio c	1.0b	1.0d	1.0d	1.5f	1.5	1.5

a. Sand failing gradation may be used if mortar strength is adequate.

b. Sand with a mortar strength ratio of between 1.0 and 0.75 due to poor grading may be used provided that the cement is increased to meet minimum compressive strength on concrete made with the project aggregates.

c. The proportions and testing of mortar cubes changed in the 1940's.

d. Sand which fails mortar strength due to poor grading may be used in special mixtures designed by laboratory studies.

e. When fine aggregate is sieved through the following numbered sieves: 4, 8, 16, 30, 50 and 100, not more than 40 percent shall pass one sieve and be retained on the next higher number.

f. Sand which has shown satisfactory mortar strength may be accepted without further mortar strength tests so long as its fineness modulus is not less than that of the sand from that source which showed a satisfactory mortar strength minus 0.30.

OBJECTIVE

The objective of the study was to determine the feasibility of using a finer sand than is now allowed by Iowa D.O.T. specifications in portland cement concrete.

MATERIALS

The following materials were used in the study:

Cement: Type I, standard laboratory blend of eight portland cements available in Iowa (AC7-350).

Fly Ash: Ottumwa, Class C (ACF8-22).

Coarse Aggregate: Martin Marietta (Fort Dodge A94002) (AAC7-28).

Fine Aggregate:
1. Cordova, IL AIL502 (AAS7-0196)
2. Nine Mile Island, Dubuque A31502 (AAS8-0003)
3. Nine Mile Island, Dubuque A31502 (AAS8-0004).

Air Entraining Agent: Ad Aire, Single Strength, Carter Waters Corp.

PROCEDURE

Five mixes were made and tested as shown in Table 2. Mixes 1 through 3 are the standard C-4-C mix proportions. Mix 4 and 5 are mixes with 5 percent more cement and fly ash than mixes 1 through 3. Table 3 is the aggregate gradations for the mixes. The strength results are shown graphically in Figure 1 and 2.

TABLE 2 MIX RESULTS

Mix No.	Sand	Cement #/Yd.3	Fly Ash #/Yd.3	W/C + F.A.	Air Content %	Slump (In.)	Strength (PSI) Compressive 7 Day	Compressive 28 Day	Flexural 7 Day	Flexural 28 Day
1	Dubuque Fine	529	95	0.380	6.5	1.25	5050	6250	740	790
2	Dubuque Coarse	529	95	0.376	6.2	1.0	5570	6480	780	840
3	Cordova	529	95	0.372	6.5	1.25	5420	7060	790	880
4	Dubuque Fine	556	100	0.363	6.0	1.25	5370	6450	840	850
5	Dubuque Coarse	556	100	0.367	6.0	1.25	5500	6360	830	850

TABLE 3 AGGREGATE GRADATONS

(Percent Passing)

Sieve No.	Nine Mile Island Fine	Nine Mile Island Coarse	Cordova	Fort Dodge Coarse Aggr.
1"				100
3/4"				77
1/2"				40
3/8"	100	100	100	12
#4	99	94	99	0.5
#8	93	75	93	0.3
#16	81	60	79	
#30	58	47	44	
#50	12	18	8.5	
#100	0.6	2.3	1.0	
#200	0.3	0.8	0.2	
Fineness Modulus	2.56	3.04	2.75	
Mortar Strength Ratio	1.4	1.3	1.6	

Combined Grading (Percent Passing)

1"	100	100	100
3/4"	88	88	88
1/2"	70	70	70
3/8"	56	56	56
#4	50	47	50
#8	47	38	47
#16	41	30	40
#30	29	24	22
#50	6.2	9.2	4.4
#100	0.4	1.3	0.6
#200	0.3	0.6	0.2
Fineness Modulus	4.82	5.06	4.92
Specific Surface (Sq. Ft./Lb.)	14.9	14.2	13.4

FIGURE 1. COMPRESSIVE STRENTH COMPARISON

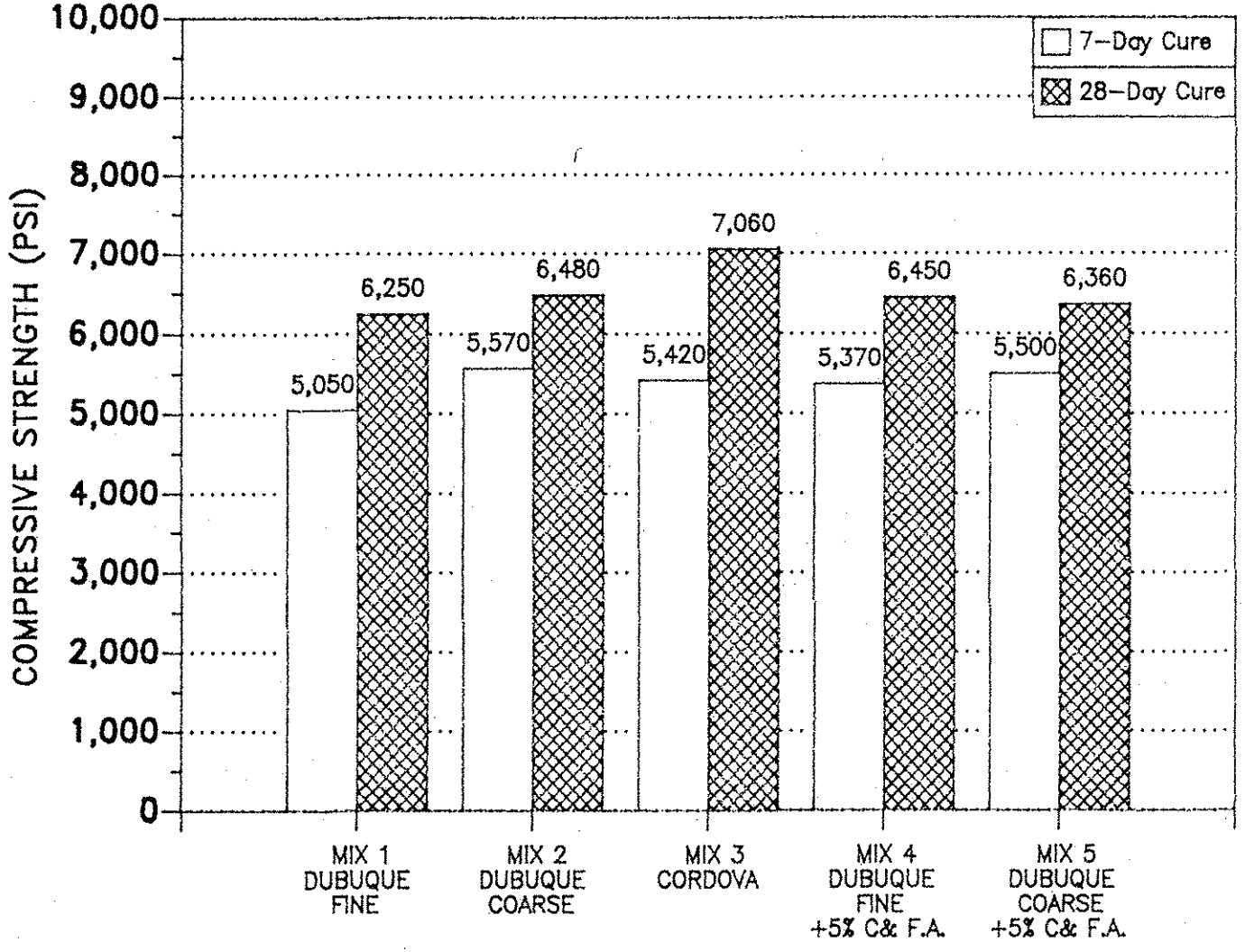
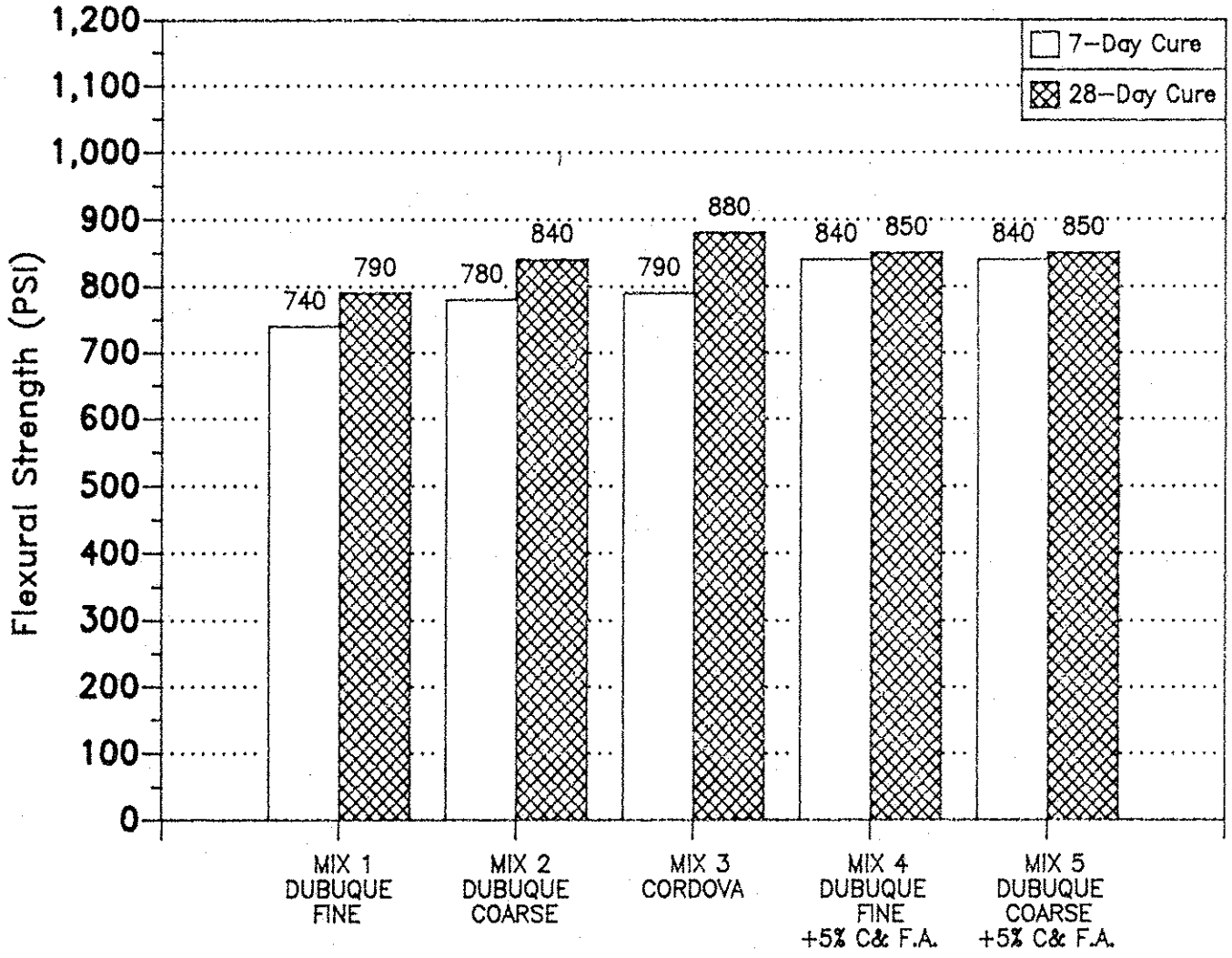


FIGURE 2. FLEXURAL STRENTH COMPARISON



TEST RESULTS

The fine sand from Dubuque tested about 5 percent lower on strength in the C-4-C mix than the coarse sand from Dubuque. The higher cement factor mix with the fine sand compared very favorably with the C-4-C mix and coarse sand. Strengths for the higher cement factor mix and fine sand were within 30 psi on the 28-day compressive and 10 psi on the 28-day flexural of those for the standard C-4-C mix with coarse Dubuque sand.

Results on the higher cement factor mix and coarse Dubuque sand were different than expected. The mixes were repeated and the same result of no strength increase with the higher cement and fly ash content occurred. In order to realize a strength difference, the water to cement ratio (w/c) would normally need to go down. The reduction in w/c for the coarse sand was about half that of the fine sand mix.

Results on the mix with Cordova Mississippi sand were as expected. The fineness modulus of the Cordova sand was between that of the two Dubuque sands. Because the Cordova sand had less material passing the #30 through #200 sieves, the surface area of the aggregate was less which contributed to a slightly lower w/c ratio. The 28-day compressive strength was 580 psi higher than any of the other mixes.

SUMMARY

Aggregate shape, texture and grading do have an affect on concrete strength and workability. The thrust of the study has been to look at the affect of fine aggregate gradation on the concrete strength. A lower compressive and flexural strength was observed at both 7 and 28 days for the C-4-C mix with finer, poorer graded sand. To reduce the water cement ratio and offset the affects of the fine sand, more cement and fly ash were added to the mix. Five percent of additional cement and fly ash was sufficient to increase the strength of the mix to what the C-4-C mix was with a coarser sand.

RECOMMENDATIONS

From the limited study it appears that finer concrete sands may have application in Iowa provided that adjustments to the concrete mixes are made. Based on this study, the following work should be done:

1. Perform tests on at least five other sources of sand representative of sands available from around the state.
2. Examine the effect of silt and organic matter on mortar cube strengths and concrete strengths with finer sand.
3. Formulate specifications and mix designs to provide concrete mixes using finer concrete sand comparable in quality to the current concrete mix designs and specifications.