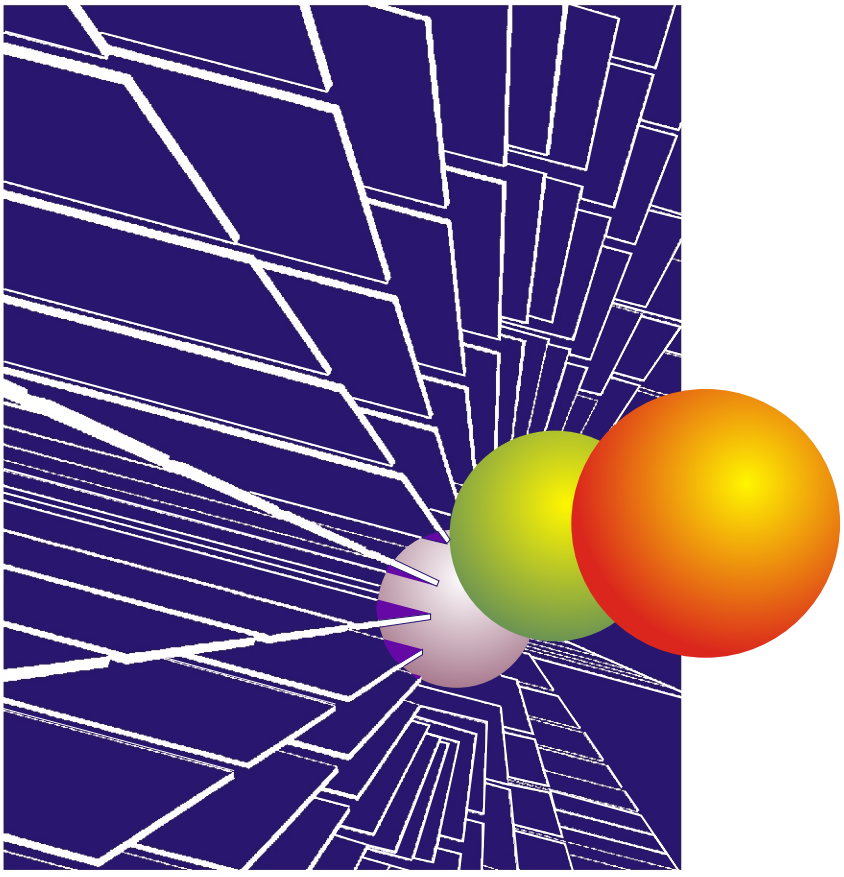
MoDOT

Research, Development and Technology

RDT 04-005

Comparison of Compressive Strengths Using 4x8 vs. 6x12 Cylinders for Prestress Concrete

RI 03-038



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15. Supplementary Notes
The investigation was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. Abstract
The purpose of this investigation was to develop a correlation between 4 by 8-in. and 6 by 12-in. cylinders for the same mix design at the same age using Class A-1 concrete (prestress concrete). With this correlation, prestress/precast companies can use smaller cylinders in prestress fabrication.

This paper presents laboratory test results from three different concrete mix designs. The mixes differed mainly by the amount of cementitious material. The research conducted should provide prestress/precast companies reliable compressive strength acceptance data to ensure the concrete has reached its appropriate strengths.

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Final Report

RI 03-038
RDT 04-005

COMPARISON OF COMPRESSIVE STRENGTHS USING 4x8 vs. 6x12 CYLINDERS FOR PRESTRESS CONCRETE

MISSOURI DEPARTMENT OF TRANSPORTATION
RESEARCH, DEVELOPMENT AND TECHNOLOGY

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JEFFERSON CITY, MISSOURI
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EXECUTIVE SUMMARY

Recently, prestress/precast companies requested using smaller cylinder specimens, in particular 4 by 8-in. cylinders, for concrete compressive strength tests. The Missouri Department of Transportation (MoDOT) allows only the standard 6 by 12-in. cylinders in prestress fabrication. There is debate over the strengths of the 4 by 8-in. cylinders compared to 6 by 12-in. cylinders. Typically, strengths of 4 by 8-in. cylinders are known to be higher than strengths of 6 by 12-in. cylinders for the same mix at the same age. Therefore, a research investigation was performed to determine if there was a consistent relationship between 4 by 8-in. and 6 by 12-in. cylinders, so a correlation could be established.

This paper presents laboratory test results from three different mix designs. The mixes differed mainly by the cement content. The main findings and recommendations are summarized as follows:

- Consistently, the 4 by 8-in. cylinders broke higher than the 6 by 12-in. cylinders.
- The maximum and minimum percent difference between an individual 4 by 8-in. cylinder and an individual 6 by 12-in. cylinder was +10% and 0%, respectfully.
- Generally, the difference of compressive strengths between the 4 by 8-in. cylinders and the 6 by 12-in. cylinders increased over time.
- Allow the use of 4 by 8-in. cylinders with a correction factor of 0.94 when determining compressive strength acceptance of MoDOT Class A-1, prestress, concrete at the plant with a semi-controlled environment.
- When fabricating the 4 by 8-in. cylinders, AASHTO T 23 requirements shall be followed, which specifies a “small rod” and two equal depth layers, rodded 25 times per layer.
- The retainer used with neoprene pads when testing for compressive strength of the 4 by 8-in. cylinders should be constructed according to ASTM C 1231.

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INTRODUCTION

There is a growing interest among prestress/precast companies in using smaller cylinder specimens, particularly 4 by 8-in. cylinders, for concrete compressive strength tests. With smaller cylinders a person can handle them easier, spend less time and effort preparing them, and use less material. However, there is a debate over the strengths of the 4 by 8-in. cylinders compared to 6 by 12-in. cylinders. Typically, strengths of 4 by 8-in. cylinders are known to be higher than strengths of 6 by 12-in. cylinders for the same mix at the same age. Therefore, a laboratory research project was conducted to determine if there could be a comparison between the cylinders and then a correlation established.

OBJECTIVES

The objective of this investigation is to determine how the compressive strengths of 4 by 8-in. cylinders compare to the compressive strengths of 6 by 12-in. cylinders for the same mix design specified in Missouri Department of Transportation (MoDOT) Specifications for prestress concrete.

PRESENT CONDITIONS

Current practice for prestress/precast companies is to make 6 by 12-in. cylinders for compressive strength tests. They are then broke to determine the compressive strength of the concrete for transfer (release of prestress strains), form removal, shipping, and to verify ultimate strength. With the discrepancies between the 4 by 8-in. and 6 by 12-in. cylinders, the research will help determine if the use of 4 by 8-in. cylinders should be allowed, and if compressive strength test results from the 4 by 8-in. cylinders should be used with or without a correction factor.

TECHNICAL APPROACH

The materials, mix designs, fabrication, and testing were applicable to both types of cylinders and were carefully chosen for an accurate comparison between the 4 by 8-in. and 6 by 12-in. cylinders.

Material Sources

The source/manufacturer and description of the materials that were used for this study are as follows:

Coarse Aggregate (62%):	Lead Belt Materials, Park Hills, MO Gradation E Dolomite Derby-Doe Run, Ledge 1-4
Fine Aggregate (38%):	Holliday Sand and Gravel, Lenexa, KS Missouri River Sand, Class A

Cement:	Lafarge Type 1 Cement Kansas City, MO New Finish Mill #4
Air Entrainment:	Grace – Daravair 1400
Water Reducer:	Grace – Daracem 19

Mix Designs

The laboratory study used Class A-1 concrete requirements. Three mix designs were used representing MoDOT's standard A-1 mixes used in prestress production. Mix 1 contained a total cementitious content of 6.40 sacks/yd^3, Mix 2 contained a total cementitious content of 7.20 sacks/yd^3, and Mix 3 contained a total cementitious content of 8.00 sacks/yd^3. For each mix, three batches were required to make a total of 24 specimens, consisting of twelve 6 by 12-in. cylinders and twelve 4 by 8-in. cylinders, for determining compressive strength at 1, 3, 7 and 28 days (3 specimens per age).

Trial Batching and Specimen Fabrication

After the aggregate characteristics, total cementitious contents, and water reducer dosages were established, numerous trial batches were produced in the development of the three mix designs. The unknown variables, which included air entrainment agent and water, were varied in the trial batches until a target slump of 2.50 inches and target air content of 6% were achieved for each mix design. The water/cement ratio was established at these target values. Mix designs and concrete characteristics are found in Table 1. Laboratory mix design batch sheets for each batch are included in Appendix A.

Once the target slump and air content were established, concrete test specimens were fabricated from each mix. The concrete test specimens were made and cured according to AASHTO specifications. The 4 by 8-in. cylinders were made using a "small rod", with two equal depth layers and rodded 25 times per layer. The concrete specimens representing the three mix designs were tested for compressive strength properties in accordance with the appropriate AASHTO/ASTM specifications. The end retainers used in the compressive strength testing of the 4 by-8in. cylinders were specially constructed meeting ASTM C 1231 requirements. There were no AASHTO provisions made about end retainers for the 4 by 8-in. cylinders. Figure 1 shows the dimensions of the end retainer used in conjunction with neoprene pads for uniform load distribution during testing. The AASHTO/ASTM specifications that were used in this study are listed in Table 2.

DISCUSSION AND RESULTS

Compressive strength data were collected from 1, 3, 7, and 28 day concrete test specimens from both the 4 by 8-in. cylinders and 6 by 12-in cylinders. Three specimens per age per mix were tested. Average compressive strengths of each mix design are listed in Table 3. Figure 2 graphically illustrates the average compressive strengths of each mix design. Individual compressive strengths and concrete characteristics for each batch are located in Appendix B.

The percent difference between the 4 by 8-in. and the 6 by 12-in. cylinders were calculated for the three mixes. The calculation assumed that the 4 by 8-in. cylinder would break higher than the 6 by 12-in cylinder. Therefore, the positive percentage represents the percentage at which the 4 by 8-in. cylinder broke higher than the 6 by 12-in. cylinder. A negative percentage represents the percentage at which the 4 by 8-in. cylinder broke lower than the 6 by 12-in. cylinder. The average percent difference between the 4 by 8-in. and the 6 by 12-in. cylinders are listed in Table 4. Figure 3 graphically illustrates the percent difference between the 4 by 8-in. cylinders and the 6 by 12-in. cylinders.

As expected, the 4 by 8-in. cylinder results were consistently higher than results of the 6 by 12-in. cylinders. This difference appeared to increase at later ages and higher strengths. Based on the compressive strength differences observed in this study, a multiplier of 0.94 applied to the results of the 4 by 8-in. cylinders should provide reliable compressive strength data, which can be used in lieu of 6 by 12-in. cylinder strength data. This would enable fabricators to use 4 by 8-in. cylinders on a routine basis resulting in easier handling and saving in time, effort and material.

CONCLUSIONS

The main findings of this study are summarized as follows:

1. Consistently, the 4 by 8-in. cylinders broke higher than the 6 by 12-in. cylinders.

2. In only two cases (Mix 2, Batch B at 1 day and Mix 3, Batch B at 1 day) the 4 by 8-in. cylinders broke lower than the 6 by 12-in. cylinders. However, the difference in compressive strength was less the 30 psi in both cases.

3. Mix 2, Batch A at 1 day had the lowest percent difference of compressive strengths between an individual 4 by 8-in. cylinder and an individual 6 by 12-in. cylinder, which was 0%.

4. Mix 2, Batch C at 7 day had the largest percent difference of compressive strengths between an individual 4 by 8-in. cylinder and an individual 6 by 12-in. cylinder, which was 10%.

5. Generally, the difference of compressive strengths between the 4 by 8-in. cylinders and the 6 by 12-in. cylinders increased over time.

RECOMMENDATIONS

Based upon research from the literature review, laboratory test results, and observations Research, Development, and Technology presents the following recommendations:

1. Prestress/precast companies should be allowed to use 4 by 8-in. cylinders when determining compressive strengths.

2. Compressive strength results of the 4 by 8-in. cylinders should be multiplied by a correction factor of 0.94 when determining the compressive strength of MoDOT prestress concrete.

3. The 4 by 8-in. cylinders may only be used for Class A-1 concrete, prestress concrete, at the plant with semi-controlled environment.

4. When fabricating the 4 by 8-in. cylinders, AASHTO T 23 requirements shall be followed, which specifies a “small rod” and two equal depth layers, rodded 25 times per layer.

5. The end retainer used with neoprene pads when testing for compressive strength of the 4 by 8-in. cylinders should be constructed according to ASTM C 1231.

Mix No.	Batch	w/c ratio	Slump (in)	Air (%)	Cementitious Content (sacks/yd^3)
1	A	0.385	2.00	5.6	6.40
	B	0.385	3.50	7.8	6.40
	C	0.385	2.50	6.0	6.40
Average		**0.385**	**2.67**	**6.5**	**6.40**
2	A	0.345	3.00	6.6	7.20
	B	0.345	2.25	5.7	7.20
	C	0.350	1.50	5.3	7.20
Average		**0.347**	**2.25**	**5.9**	**7.20**
3	A	0.315	1.00	4.9	8.00
	B	0.315	2.00	4.6	8.00
	C	0.315	0.75	3.9	8.00
Average		**0.315**	**1.25**	**4.5**	**8.00**

Table 1 – Fresh Concrete Characteristics

Test Description	Specification Method
Air Content	AASHTO T152
Slump	AASHTO T119
Laboratory Specimen Fabrication and Curing	AASHTO T126
Compressive Strength for the 4 by 8-in. cylinder	ASTM C1231
Compressive Strength for the 6 by 12-in. cylinder	AASHTO T22

Table 2 – AASHTO Specifications

Mix No.	Size	Avg. Compressive Strength (psi)			
		1-Day	3-Day	7-Day	28-Day
1	6x12	2990	4410	5390	7130
	4x8	3120	4650	5740	7560
2	6x12	3770	5270	6230	8150
	4x8	3800	5490	6570	8500
3	6x12	4670	6180	7080	8570
	4x8	4770	6530	7520	9300

Table 3 – Compressive Strengths

Mix No.	Percent Difference			
	1-Day	3-Day	7-Day	28-Day
1	+4%	+5%	+6%	+6%
2	+1%	+4%	+5%	+4%
3	+2%	+5%	+6%	+8%
Avg.	+2%	+5%	+6%	+6%

Table 4 – Percent Difference

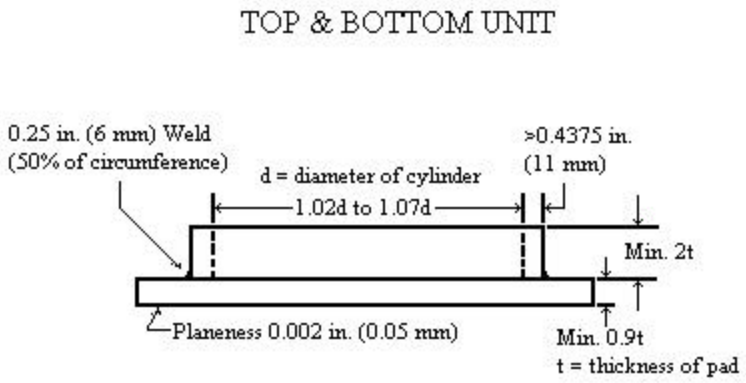


Figure 1 – End Retainer Dimensions for 4 by 8-in. specimens

Figure 2 - Average Compressive Strength

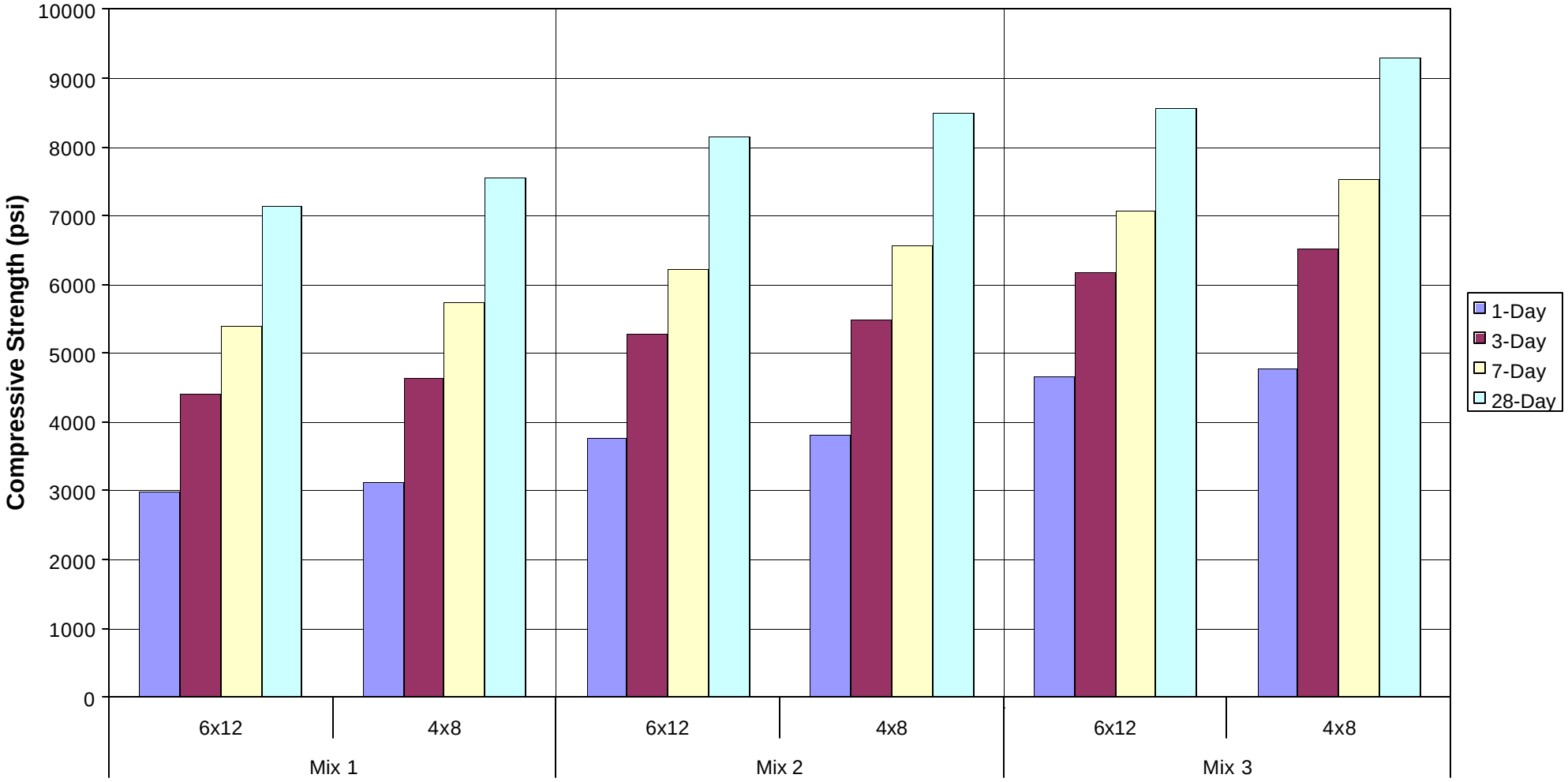
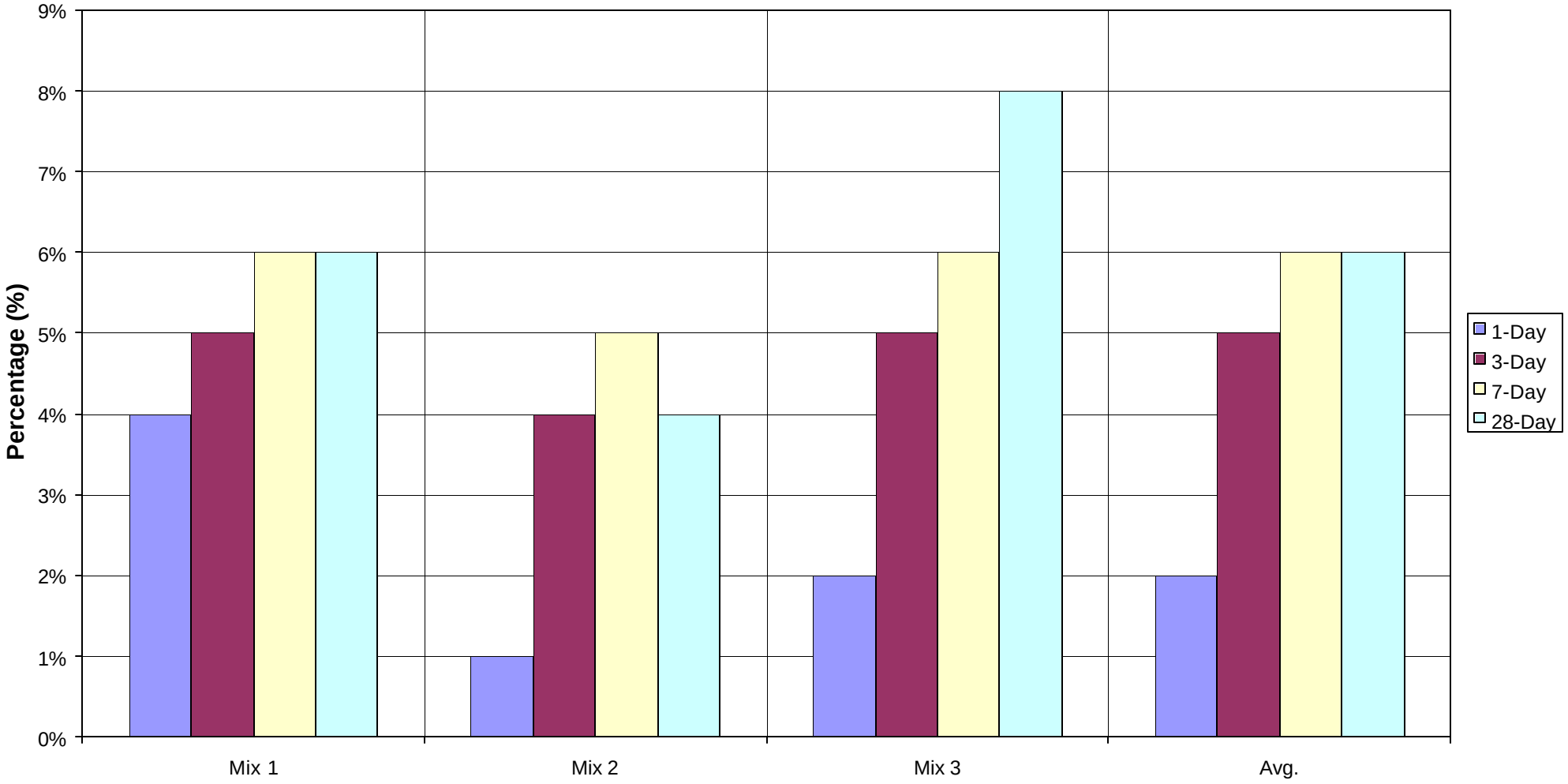


Figure 3 - Percent Difference



Appendix A

Mix Design Sheets

6.4 sack mix

CONCRETE BATCHING PROGRAM

Mix No. 1
Batch A

W/C Ratio: 0.385

	SP. GR.	CEMENTITIOUS LBS / CU. YD	DESIGN WATER LBS / CU. YD	DESIGN AIR	ABSOLUTE VOLUME	SCALE WEIGHT (1.0 Ft^3)	SCALE WEIGHT 1.80 FT^3	
CEMENT	3.15	602			0.1134	22.30	40.13	Lbs.(Cement)
Flyash	2.62	0			0.0000	0.00	0.00	lbs. (Flyash)
GGBFS	2.88	0			0.0000	0.00	0.00	lbs. (Slag)
Silicia Fume	2.24	0			0.0000	0.00	0.00	lbs.(Silicia Fume)
		602	231.77		0.1376	10.18	18.08	Lbs.(Water)
			4.34	5.5%	0.0550			
					0.3060			

FINE AGGREGATE: **MISSOURI RIVER - HOLLIDAY SAND & GRAVEL**

% Sand= 38.0

SP. GR. (DRY)	DESIGN ABS. VOL.	ABSOLUTE VOLUME	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) 1.80 (FT^3)	SCALE WEIGHT (AIR DRY) 1.80 (FT^3)	
2.615	0.2637	0.2637	43.03	43.05	0.05	0.4	77.46	77.50	Lbs.(Sand)

COARSE AGGREGATE: **Park Hills, Durby Doe Run**

% Coarse Aggregate = 62.0

FRACTION	SP. GR. (DRY)	PERCENT CA FRACT.	DESIGN ABS. VOL.	ABSOLUTE VOLUME	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	SCALE WEIGHTS (AIR DRY) 1.80 (FT^3)	
1" - #4	2.645	100.0	0.4303	0.4303	0.05	2.1	71.02	71.05	127.89	Lbs.(CA)

AIR METER:

	Run 1	Run 2
Reading =	5.6	5.6
Aggr.Corr =	0.3	0.3
%Air =	5.3	5.3

Slump: 2 in.

WATER REDUCER:

	14.000	OZ/100 LBS CEMENT
Assumed 65% Water	166.164	CC
	0.238	lbs. (water correction)

AIR AGENT:

0.610	OZ/100 lb. cement
7.240	CC
0.015	lbs. (water correction)

6.4 sack mix

CONCRETE BATCHING PROGRAM

Mix No. 1
Batch B

W/C Ratio: 0.385

	SP. GR.	CEMENTITIOUS LBS / CU. YD	DESIGN WATER LBS / CU. YD	DESIGN AIR	ABSOLUTE VOLUME	SCALE WEIGHT (1.0 Ft^3)	SCALE WEIGHT 1.80 FT^3	
CEMENT	3.15	602			0.1134	22.30	40.13	Lbs.(Cement)
Flyash	2.62	0			0.0000	0.00	0.00	lbs. (Flyash)
GGBFS	2.88	0			0.0000	0.00	0.00	lbs. (Slag)
Silicia Fume	2.24	0			0.0000	0.00	0.00	lbs.(Silicia Fume)
		602	231.77		0.1376	10.18	18.08	Lbs.(Water)
			4.34	5.5%	0.0550			
					0.3060			

FINE AGGREGATE: **MISSOURI RIVER - HOLLIDAY SAND & GRAVEL**

% Sand= 38.0

SP. GR. (DRY)	DESIGN ABS. VOL.	ABSOLUTE VOLUME	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) 1.80 (FT^3)	SCALE WEIGHT (AIR DRY) 1.80 (FT^3)	
2.615	0.2637	0.2637	43.03	43.05	0.05	0.4	77.46	77.50	Lbs.(Sand)

COARSE AGGREGATE: **Park Hills, Durby Doe Run**

% Coarse Aggregate = 62.0

FRACTION	SP. GR. (DRY)	PERCENT CA FRACT.	DESIGN ABS. VOL.	ABSOLUTE VOLUME	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	SCALE WEIGHTS (AIR DRY) 1.80 (FT^3)	
1" - #4	2.645	100.0	0.4303	0.4303	0.05	2.1	71.02	71.05	127.89	Lbs.(CA)

AIR METER:

	Run 1	Run 2
Reading =	7.8	7.8
Aggr.Corr =	0.3	0.3
%Air =	7.5	7.5

Slump: 3 1/2 in.

WATER REDUCER:

	14.000	OZ/100 LBS CEMENT
Assumed 65% Water	166.164	CC
	0.238	lbs. (water correction)

AIR AGENT:

0.610	OZ/100 lb. cement
7.240	CC
0.015	lbs. (water correction)

6.4 sack mix

CONCRETE BATCHING PROGRAM

Mix No. 1
Batch C

W/C Ratio: 0.385

	SP. GR.	CEMENTITIOUS LBS / CU. YD	DESIGN WATER LBS / CU. YD	DESIGN AIR	ABSOLUTE VOLUME	SCALE WEIGHT (1.0 Ft^3)	SCALE WEIGHT 1.80 FT^3	
CEMENT	3.15	602			0.1134	22.30	40.13	Lbs.(Cement)
Flyash	2.62	0			0.0000	0.00	0.00	lbs. (Flyash)
GGBFS	2.88	0			0.0000	0.00	0.00	lbs. (Slag)
Silicia Fume	2.24	0			0.0000	0.00	0.00	lbs.(Silicia Fume)
		602	231.77		0.1376	10.18	18.08	Lbs.(Water)
			4.34	5.5%	0.0550			
					0.3060			

FINE AGGREGATE: **MISSOURI RIVER - HOLLIDAY SAND & GRAVEL**

% Sand= 38.0

SP. GR. (DRY)	DESIGN ABS. VOL.	ABSOLUTE VOLUME	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) 1.80 (FT^3)	SCALE WEIGHT (AIR DRY) 1.80 (FT^3)	
2.615	0.2637	0.2637	43.03	43.05	0.05	0.4	77.46	77.50	Lbs.(Sand)

COARSE AGGREGATE: **Park Hills, Durby Doe Run**

% Coarse Aggregate = 62.0

FRACTION	SP. GR. (DRY)	PERCENT CA FRACT.	DESIGN ABS. VOL.	ABSOLUTE VOLUME	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	SCALE WEIGHTS (AIR DRY) 1.80 (FT^3)	
1" - #4	2.645	100.0	0.4303	0.4303	0.05	2.1	71.02	71.05	127.89	Lbs.(CA)

AIR METER:

	Run 1	Run 2
Reading =	6.0	6.0
Aggr.Corr =	0.3	0.3
%Air =	5.7	5.7

Slump: 2 1/2 in.

WATER REDUCER:

	14.000	OZ/100 LBS CEMENT
Assumed 65% Water	166.164	CC
	0.238	lbs. (water correction)

AIR AGENT:

0.610	OZ/100 lb. cement
7.240	CC
0.015	lbs. (water correction)

7.2 sack mix

CONCRETE BATCHING PROGRAM

Mix No. 2
Batch A

W/C Ratio: 0.345

	SP. GR.	CEMENTITIOUS LBS / CU. YD	DESIGN WATER LBS / CU. YD	DESIGN AIR	ABSOLUTE VOLUME	SCALE WEIGHT (1.0 Ft^3)	SCALE WEIGHT 1.80 FT^3	
CEMENT	3.15	677			0.1276	25.07	45.13	Lbs.(Cement)
Flyash	2.62	0			0.0000	0.00	0.00	lbs. (Flyash)
GGBFS	2.88	0			0.0000	0.00	0.00	lbs. (Slag)
Silicia Fume	2.24	0			0.0000	0.00	0.00	lbs.(Silicia Fume)
		677	233.57		0.1386	10.22	18.10	Lbs.(Water)
			3.89	5.5%	0.0550			
					0.3212			

FINE AGGREGATE: **MISSOURI RIVER - HOLLIDAY SAND & GRAVEL**

% Sand= 38.0

SP. GR. (DRY)	DESIGN ABS. VOL.	ABSOLUTE VOLUME	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) 1.80 (FT^3)	SCALE WEIGHT (AIR DRY) 1.80 (FT^3)	
2.615	0.2579	0.2579	42.09	42.11	0.05	0.4	75.76	75.80	Lbs.(Sand)

COARSE AGGREGATE: **Park Hills, Durby Doe Run**

% Coarse Aggregate = 62.0

FRACTION	SP. GR. (DRY)	PERCENT CA FRACT.	DESIGN ABS. VOL.	ABSOLUTE VOLUME	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	SCALE WEIGHTS (AIR DRY) 1.80 (FT^3)	
1" - #4	2.645	100.0	0.4209	0.4209	0.05	2.1	69.46	69.50	125.09	Lbs.(CA)

AIR METER:

	Run 1	Run 2
Reading =	6.6	6.6
Aggr.Corr =	0.3	0.3
%Air =	6.3	6.3

Slump: 3 in.

WATER REDUCER:

	14.000	OZ/100 LBS CEMENT
Assumed 65% Water	186.865	CC
	0.268	lbs. (water correction)

AIR AGENT:

0.720	OZ/100 lb. cement
9.610	CC
0.020	lbs. (water correction)

7.2 sack mix

CONCRETE BATCHING PROGRAM

Mix No. 2
Batch B

W/C Ratio: 0.345

	SP. GR.	CEMENTITIOUS LBS / CU. YD	DESIGN WATER LBS / CU. YD	DESIGN AIR	ABSOLUTE VOLUME	SCALE WEIGHT (1.0 Ft^3)	SCALE WEIGHT 1.80 FT^3	
CEMENT	3.15	677			0.1276	25.07	45.13	Lbs.(Cement)
Flyash	2.62	0			0.0000	0.00	0.00	lbs. (Flyash)
GGBFS	2.88	0			0.0000	0.00	0.00	lbs. (Slag)
Silicia Fume	2.24	0			0.0000	0.00	0.00	lbs.(Silicia Fume)
		677	233.57		0.1386	10.22	18.10	Lbs.(Water)
			3.89	5.5%	0.0550			
					0.3212			

FINE AGGREGATE: **MISSOURI RIVER - HOLLIDAY SAND & GRAVEL**

% Sand= 38.0

SP. GR. (DRY)	DESIGN ABS. VOL.	ABSOLUTE VOLUME	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) 1.80 (FT^3)	SCALE WEIGHT (AIR DRY) 1.80 (FT^3)	
2.615	0.2579	0.2579	42.09	42.11	0.05	0.4	75.76	75.80	Lbs.(Sand)

COARSE AGGREGATE: **Park Hills, Durby Doe Run**

% Coarse Aggregate = 62.0

FRACTION	SP. GR. (DRY)	PERCENT CA FRACT.	DESIGN ABS. VOL.	ABSOLUTE VOLUME	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	SCALE WEIGHTS (AIR DRY) 1.80 (FT^3)	
1" - #4	2.645	100.0	0.4209	0.4209	0.05	2.1	69.46	69.50	125.09	Lbs.(CA)

AIR METER:

	Run 1	Run 2
Reading =	5.7	5.7
Aggr.Corr =	0.3	0.3
%Air =	5.4	5.4

Slump: 2 1/4 in.

WATER REDUCER:

	14.000	OZ/100 LBS CEMENT
Assumed 65% Water	186.865	CC
	0.268	lbs. (water correction)

AIR AGENT:

0.720	OZ/100 lb. cement
9.610	CC
0.020	lbs. (water correction)

7.2 sack mix

CONCRETE BATCHING PROGRAM

Mix No. 2
Batch C

W/C Ratio: 0.350

	SP. GR.	CEMENTITIOUS LBS / CU. YD	DESIGN WATER LBS / CU. YD	DESIGN AIR	ABSOLUTE VOLUME	SCALE WEIGHT (1.0 Ft^3)	SCALE WEIGHT 1.80 FT^3	
CEMENT	3.15	677			0.1276	25.07	45.13	Lbs.(Cement)
Flyash	2.62	0			0.0000	0.00	0.00	lbs. (Flyash)
GGBFS	2.88	0			0.0000	0.00	0.00	lbs. (Slag)
Silicia Fume	2.24	0			0.0000	0.00	0.00	lbs.(Silicia Fume)
		677	236.95		0.1406	10.34	18.32	Lbs.(Water)
			3.94	5.5%	0.0550			
					0.3232			

FINE AGGREGATE: **MISSOURI RIVER - HOLLIDAY SAND & GRAVEL**

% Sand= 38.0

SP. GR. (DRY)	DESIGN ABS. VOL.	ABSOLUTE VOLUME	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) 1.80 (FT^3)	SCALE WEIGHT (AIR DRY) 1.80 (FT^3)	
2.615	0.2572	0.2572	41.97	41.99	0.05	0.4	75.54	75.58	Lbs.(Sand)

COARSE AGGREGATE: **Park Hills, Durby Doe Run**

% Coarse Aggregate = 62.0

FRACTION	SP. GR. (DRY)	PERCENT CA FRACT.	DESIGN ABS. VOL.	ABSOLUTE VOLUME	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	SCALE WEIGHTS (AIR DRY) 1.80 (FT^3)	
1" - #4	2.645	100.0	0.4196	0.4196	0.05	2.1	69.26	69.29	124.72	Lbs.(CA)

AIR METER:

	Run 1	Run 2
Reading =	5.3	5.3
Aggr.Corr =	0.3	0.3
%Air =	5.0	5.0

Slump: 1 1/2 in.

WATER REDUCER:

	14.000	OZ/100 LBS CEMENT
Assumed 65% Water	186.865	CC
	0.268	lbs. (water correction)

AIR AGENT:

0.720	OZ/100 lb. cement
9.610	CC
0.020	lbs. (water correction)

8.0 sack mix

CONCRETE BATCHING PROGRAM

Mix No. 3
Batch A

W/C Ratio: 0.315

	SP. GR.	CEMENTITIOUS LBS / CU. YD	DESIGN WATER LBS / CU. YD	DESIGN AIR	ABSOLUTE VOLUME	SCALE WEIGHT (1.0 Ft^3)	SCALE WEIGHT 1.80 FT^3	
CEMENT	3.15	752			0.1417	27.85	50.13	Lbs.(Cement)
Flyash	2.62	0			0.0000	0.00	0.00	lbs. (Flyash)
GGBFS	2.88	0			0.0000	0.00	0.00	lbs. (Slag)
Silicia Fume	2.24	0			0.0000	0.00	0.00	lbs.(Silicia Fume)
		752	236.88		0.1406	10.30	18.22	Lbs.(Water)
			3.55	5.5%	0.0550			
					0.3373			

FINE AGGREGATE: **MISSOURI RIVER - HOLLIDAY SAND & GRAVEL**

% Sand= 38.0

SP. GR. (DRY)	DESIGN ABS. VOL.	ABSOLUTE VOLUME	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) 1.80 (FT^3)	SCALE WEIGHT (AIR DRY) 1.80 (FT^3)	
2.615	0.2518	0.2518	41.09	41.11	0.05	0.4	73.97	74.00	Lbs.(Sand)

COARSE AGGREGATE: **Park Hills, Durby Doe Run**

% Coarse Aggregate = 62.0

FRACTION	SP. GR. (DRY)	PERCENT CA FRACT.	DESIGN ABS. VOL.	ABSOLUTE VOLUME	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	SCALE WEIGHTS (AIR DRY) 1.80 (FT^3)	
1" - #4	2.645	100.0	0.4109	0.4109	0.05	2.1	67.81	67.85	122.13	Lbs.(CA)

AIR METER:

	Run 1	Run 2
Reading =	4.9	4.9
Aggr.Corr =	0.3	0.3
%Air =	4.6	4.6

Slump: 1 in.

WATER REDUCER:

	14.000	OZ/100 LBS CEMENT
Assumed 65% Water	207.567	CC
	0.297	lbs. (water correction)

AIR AGENT:

0.800	OZ/100 lb. cement
11.861	CC
0.024	lbs. (water correction)

8.0 sack mix

CONCRETE BATCHING PROGRAM

Mix No. 3
Batch B

W/C Ratio: 0.315

	SP. GR.	CEMENTITIOUS LBS / CU. YD	DESIGN WATER LBS / CU. YD	DESIGN AIR	ABSOLUTE VOLUME	SCALE WEIGHT (1.0 Ft^3)	SCALE WEIGHT 1.80 FT^3	
CEMENT	3.15	752			0.1417	27.85	50.13	Lbs.(Cement)
Flyash	2.62	0			0.0000	0.00	0.00	lbs. (Flyash)
GGBFS	2.88	0			0.0000	0.00	0.00	lbs. (Slag)
Silicia Fume	2.24	0			0.0000	0.00	0.00	lbs.(Silicia Fume)
		752	236.88		0.1406	10.30	18.22	Lbs.(Water)
			3.55	5.5%	0.0550			
					0.3373			

FINE AGGREGATE: **MISSOURI RIVER - HOLLIDAY SAND & GRAVEL**

% Sand= 38.0

SP. GR. (DRY)	DESIGN ABS. VOL.	ABSOLUTE VOLUME	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) 1.80 (FT^3)	SCALE WEIGHT (AIR DRY) 1.80 (FT^3)	
2.615	0.2518	0.2518	41.09	41.11	0.05	0.4	73.97	74.00	Lbs.(Sand)

COARSE AGGREGATE: **Park Hills, Durby Doe Run**

% Coarse Aggregate = 62.0

FRACTION	SP. GR. (DRY)	PERCENT CA FRACT.	DESIGN ABS. VOL.	ABSOLUTE VOLUME	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	SCALE WEIGHTS (AIR DRY) 1.80 (FT^3)	
1" - #4	2.645	100.0	0.4109	0.4109	0.05	2.1	67.81	67.85	122.13	Lbs.(CA)

AIR METER:

	Run 1	Run 2
Reading =	4.6	4.6
Aggr.Corr =	0.3	0.3
%Air =	4.3	4.3

Slump: 2 in.

WATER REDUCER:

	14.000	OZ/100 LBS CEMENT
Assumed 65% Water	207.567	CC
	0.297	lbs. (water correction)

AIR AGENT:

0.800	OZ/100 lb. cement
11.861	CC
0.024	lbs. (water correction)

8.0 sack mix

CONCRETE BATCHING PROGRAM

Mix No. 3
Batch C

W/C Ratio: 0.315

	SP. GR.	CEMENTITIOUS LBS / CU. YD	DESIGN WATER LBS / CU. YD	DESIGN AIR	ABSOLUTE VOLUME	SCALE WEIGHT (1.0 Ft^3)	SCALE WEIGHT 1.80 FT^3	
CEMENT	3.15	752			0.1417	27.85	50.13	Lbs.(Cement)
Flyash	2.62	0			0.0000	0.00	0.00	lbs. (Flyash)
GGBFS	2.88	0			0.0000	0.00	0.00	lbs. (Slag)
Silicia Fume	2.24	0			0.0000	0.00	0.00	lbs.(Silicia Fume)
		752	236.88		0.1406	10.30	18.22	Lbs.(Water)
			3.55	5.5%	0.0550			
					0.3373			

FINE AGGREGATE: **MISSOURI RIVER - HOLLIDAY SAND & GRAVEL**

% Sand= 38.0

SP. GR. (DRY)	DESIGN ABS. VOL.	ABSOLUTE VOLUME	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) 1.80 (FT^3)	SCALE WEIGHT (AIR DRY) 1.80 (FT^3)	
2.615	0.2518	0.2518	41.09	41.11	0.05	0.4	73.97	74.00	Lbs.(Sand)

COARSE AGGREGATE: **Park Hills, Durby Doe Run**

% Coarse Aggregate = 62.0

FRACTION	SP. GR. (DRY)	PERCENT CA FRACT.	DESIGN ABS. VOL.	ABSOLUTE VOLUME	PERCENT MOIST.	PERCENT ABSORP.	WEIGHT (DRY) (1.0 FT^3)	WEIGHT (AIR DRY) (1.0 FT^3)	SCALE WEIGHTS (AIR DRY) 1.80 (FT^3)	
1" - #4	2.645	100.0	0.4109	0.4109	0.05	2.1	67.81	67.85	122.13	Lbs.(CA)

AIR METER:

	Run 1	Run 2
Reading =	3.9	3.9
Aggr.Corr =	0.3	0.3
%Air =	3.6	3.6

Slump: 3/4 in.

WATER REDUCER:

	14.000	OZ/100 LBS CEMENT
Assumed 65% Water	207.567	CC
	0.297	lbs. (water correction)

AIR AGENT:

0.800	OZ/100 lb. cement
11.861	CC
0.024	lbs. (water correction)

Appendix B

Individual Compressive Strength Results

COMPRESSIVE STRENGTH RESULTS

Mix 1- 6.4 sacks/yd^3 Mix	Cementitious Materials	Batch	Size	Portland Cement (lb/yd^3)	WR (oz./yd^3)	Air Agent (oz./yd^3)	W/C Ratio	Slump (in)	Air (%)	1-DAY	3-DAY	7-DAY	28-DAY
1	602	A	6X12	602	84.3	3.7	0.385	2.00	5.6	3050	4440	5450	7010
1	602	B	6X12	602	84.3	3.7	0.385	3.50	7.8	2910	4430	5340	7150
1	602	C	6X12	602	84.3	3.7	0.385	2.50	6.0	3010	4370	5380	7230
AVERAGE							0.385	2.67	6.5	**2990**	**4413**	**5390**	**7130**
								Std. Deviation		72	38	56	111
1	602	A	4X8	602	84.3	3.7	0.385	2.00	5.6	3090	4720	5660	7220
1	602	B	4X8	602	84.3	3.7	0.385	3.50	7.8	2980	4770	5860	7650
1	602	C	4X8	602	84.3	3.7	0.385	2.50	6.0	3290	4470	5710	7800
AVERAGE							0.385	2.67	6.5	**3120**	**4653**	**5743**	**7557**
								Std. Deviation		157	161	104	301
								Percent Difference		+4%	+5%	+6%	+6%

Mix 2- 7.2 sacks/yd^3 Mix	Cementitious Materials	Batch	Size	Portland Cement (lb/yd^3)	WR (oz./yd^3)	Air Agent (oz./yd^3)	W/C Ratio	Slump (in)	Air (%)	1-DAY	3-DAY	7-DAY	28-DAY
2	677	A	6X12	677	94.8	4.9	0.345	3.00	6.6	3750	5390	6330	8520
2	677	B	6X12	677	94.8	4.9	0.345	2.25	5.7	3800	5290	6290	8100
2	677	C	6X12	677	94.8	4.9	0.350	1.50	5.3	3760	5140	6070	7820
AVERAGE							0.347	2.25	5.9	**3770**	**5273**	**6230**	**8147**
								Std. Deviation		26	126	140	352
2	677	A	4X8	677	94.8	4.9	0.345	3.00	6.6	3750	5430	6540	8570
2	677	B	4X8	677	94.8	4.9	0.345	2.25	5.7	3780	5430	6460	8370
2	677	C	4X8	677	94.8	4.9	0.350	1.50	5.3	3860	5600	6720	8550
AVERAGE							0.347	2.25	5.9	**3797**	**5487**	**6573**	**8497**
								Std. Deviation		57	98	133	110
								Percent Difference		+1%	+4%	+5%	+4%

COMPRESSIVE STRENGTH RESULTS

Mix 3- 8.0 sacks/yd^3 Mix	Cementitious Materials	Batch	Size	Portland Cement (lb/yd^3)	WR (oz./yd^3)	Air Agent (oz./yd^3)	W/C Ratio	Slump (in)	Air (%)	1-DAY	3-DAY	7-DAY	28-DAY
3	752	A	6X12	752	105.3	6.0	0.315	1.00	4.9	4680	6140	7050	8510
3	752	B	6X12	752	105.3	6.0	0.315	2.00	4.6	4690	6280	7290	8850
3	752	C	6X12	752	105.3	6.0	0.315	0.75	3.9	4640	6120	6910	8350
AVERAGE							0.315	1.25	4.5	**4670**	**6180**	**7083**	**8570**
								Std. Deviation		26	87	192	255
3	752	A	4X8	752	105.3	6.0	0.315	1.00	4.9	4700	6490	7570	9200
3	752	B	4X8	752	105.3	6.0	0.315	2.00	4.6	4660	6560	7560	9620
3	752	C	4X8	752	105.3	6.0	0.315	0.75	3.9	4940	6530	7420	9090
AVERAGE							0.315	1.25	4.5	**4767**	**6527**	**7517**	**9303**
								Std. Deviation		151	35	84	280
								Percent Difference		+2%	+5%	+6%	+8%