FREEZE AND THAW

OF

MANUFACTURED SAND

Research Investigation 90-14

May 1994

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EXPERIMENTAL DESIGN

Problem Statement:

Are Manufactured sands, produced from limestone and dolomite, acceptable for use as fine aggregate in masonry concrete?

Experimental Approach:

Extensive literature search was made using the following resources:

1. American Concrete Institute
2. Concrete International
3. Transportation Research Record
4. National Sand and Gravel Association
5. National Aggregate Association
6. National Ready Mixed Concrete Association
7. Published research reports within Materials and Research Division.

Evaluation of all applicable ASTM and AASHTO standard test methods was conducted.

Specific evaluation consisted of concrete freeze-thaw durability using ASTM C666, Method B, 4-hour 22-minute cycle time; 28-Day compressive strength, AASHTO T 22; microscopical determination of air content in hardened concrete and percent air in mortar, ASTM C 457; slump and air content of freshly mixed concrete, AASHTO T 119 and AASHTO T 152; salt scale resistance, ASTM C 672; and chloride permeability, AASHTO T 277.

To evaluate material differences and to represent as wide an area as possible, the sources of manufactured sand evaluated in this study were:

1. Amazonia limestone, Avenue City, Missouri.
2. Burlington limestone, Springfield, Missouri.
3. Bonneterre Dolomite, Elvins, Missouri.
4. Keokuk-Burlington limestone, Mount Airy, Missouri.

Missouri River sand from Capital Sand Company of Jefferson City, Missouri was used as the control sand.

Two coarse aggregates having different freeze and thaw characteristics were used:

1. Callaway limestone, Holts Summit, Missouri.
2. Bethany Falls limestone, Randolph, Missouri.

All concrete was air entrained using Ad-Aire air entraining agent. All mix designs called for Gradation D coarse aggregate and 45 percent sand.

BATCHING OF CONCRETE

There were two 1.65 and one 1.8 cu. ft. batches per combination which included each of the following:

1 Freeze-thaw beam

1 Flexural control beam

1 6" x 12" compressive strength cylinder, (1-day and 7-day compressive strength cylinders were made from each of the 1.8 cu. ft. batches.)

1 Rapid chloride permeability cylinder (4" x 8")

2 6" x 12" cylinders for microscopical determination of air content in hardened concrete and percent air in mortar from each combination, (forty altogether.)

1 Salt scale panel

Mix design factors are given in Table B-1. Three batches of each mix design were made to provide the desired number of specimens (3) for each manufactured sand, coarse aggregate, and cement factor combination. These batches were randomized and batched on dates shown in Table B-2.

All coarse aggregate retained on the #4 sieve was pre-conditioned by soaking in water for 24 hours. All -#4 aggregate was air dry at the time of batching. Effective water was calculated according to Section 501.6 in the Construction Manual.

Concrete was mixed in a Lancaster SW laboratory mixer according to AASHTO T-126. Slump and air content determinations were made immediately following the final mixing period. Characteristics of fresh concrete are given in Table B-3. All concrete was air entrained.

CURING PROCEDURES

Immediately after molding, all specimens were placed on shelves in a moist environment at 73øF for 20-24 hours prior to de-molding. After de-molding, the freeze-thaw and flexural control beams were stored in saturated lime water for 34 days prior to testing. The cylinders were stored on shelves in the aforementioned moist environment for 27 days prior to testing.

DISCUSSION AND RESULTS

Water Demand

The average water cement ratio for each mix design is presented in Figure D-7. Note that, as expected, those mix designs with Missouri River sand ("S" as second digit) had the lowest w/c ratios. This is reasonable because of the rounded sand particles. The manufactured sands required higher water content to maintain workability. The water required for the manufactured sands was roughly one half gallon greater per sack than for the Missouri River sand.

Mix Design

Batching was controlled with slump and percent air content. Uniformity is shown by the data presented in Table C-3. Slumps for 6.6 cement factor varied from 1.5" to 3.5". Slumps for 7.8 cement factor varied from 1.75" to 3.5". Air content for the 6.6 cement factor varied from 4.9% to 6.7% and the air content for the 7.8 cement factor varied from 4.8% to 6.7%.

Freeze-Thaw Durability (ASTM C 666, Method B, 5-Hour)

A set of three concrete beams, made from each of the 20 mix designs included in this study, was subjected to 300 freeze-thaw cycles or 60% retained modulus whichever came first using a cycle time of 4 hours and 22 minutes. Three basic tests which were periodically conducted on all test beams during freeze and thaw cycling were length change, weight change, and change in relative dynamic modulus of elasticity as derived from fundamental sonic frequency. Durability factors were derived from the relative dynamic modulus values. Weight data was summarized and tabulated, but was not included in this report.

A summary of durability factors and percent length change are given in Table D-1. Concrete having durability factors of 90 or greater are generally considered to be freeze-thaw resistant. Note that the mix designs using Amazonia limestone manufactured sand and Bonneterre Dolomite manufactured sand, with 6.6 cement factor and Bethany Falls limestone coarse aggregate had durability factors of 86.7 and 86.6 respectively. These durability factors were the lowest of the investigation except for the Missouri River sand with Bethany Falls limestone coarse aggregate and a 6.6 cement factor which had a durability factor of 68.9. Both the Amazonia limestone and the Bonneterre Dolomite had acceptable durability factors when used in mixes using the 7.8 cement factor. Figures D-1 through D-5 show relative modulus of elasticity (%) plotted against number of freeze-thaw cycles for each mix design combination. The reductions in the relative modulus values correspond to the reductions in durability factors.

Rapid Chloride Permeability (AASHTO T 277)

Results of rapid chloride permeability tests are given in Table E-1. All mix designs have average readings falling in the moderate range of 2,000-4,000 coulombs. This means that over a period of time chlorides will penetrate this concrete and cause corrosion of embedded steel.

Compressive Strength of Cylinders

Compressive strength of 6" x 12" concrete cylinders at 28 days are given in Table B-4. Values shown are averages of three cylinders for each of the 20 mix designs (sets). Even though the compressive strengths were significantly different, all were acceptable. The highest compressive strengths were exhibited by the concrete using Bonneterre Dolomite manufactured sand from Elvins, Missouri.

Flexural Strength of Control Beams

Flexural texts were conducted according to ASTM C 293, "Flexural Strength of Concrete (Simple Beam with Center-Point Loading)" to confirm the relative modulus results.

Table B-4 shows that the mix designs using 6.6 cement factor and Bethany Falls limestone from Randolph, Missouri, with Amazonia limestone from Martin Marietta at Avenue City Missouri, Bonneterre Dolomite from Lead Belt Material Co. at Elvins, Missouri, and Missouri River sand from Capital Sand Company at Jefferson City Missouri had percent changes in flexural strength of 36.9, 41.8, and 60.2 percent respectively which correspond to the loss in relative modulus of elasticity values at 300 cycles of testing.

Salt Scale Resistance

Salt scale resistance tests were run using salt scale panels according to ASTM C 672. All panels showed scaling rated as very slight.

Linear Traverse Test

The average air content of fresh and hardened concrete was calculated and plotted as shown in Figure D-6. In all but two cases, (BA6 and BG6), the percent air in the fresh concrete was higher than that of the hardened concrete. In the cases of BA6 and BG6 this discrepancy was probably due to poor consolidation of the fresh concrete in the mold which entrapped air and caused the hardened percent air content in those specimens to give high values. These higher air contents apparently did not effect the results obtained from these concretes.

CONCLUSIONS

1. Manufactured sands, produced from limestone and dolomite, appear to be satisfactory for use in masonry concrete.
2. Blanket approval of manufactured sand produced from limestones and dolomites is not recommended because there was a significant range in durability factors demonstrated by this study.
3. Concrete using Burlington limestone manufactured sand from Springfield, Missouri and Keokuk-Burlington manufactured sand from Mount Airy, Missouri was high in freeze thaw durability whether a 6.6 or 7.8 cement factor was used.
4. Concrete using Bethany Falls limestone coarse aggregate and designed with a cement factor of 7.8 sk/cu yd generally had durability factors greater than concrete designed with 6.6 sk/cu yd regardless of the type of sand used.
5. Concrete designed with Bethany Falls limestone coarse aggregate, Missouri river sand fine aggregate and a cement factor of 6.6 sk/cu yd had an average durability factor of 68.9%. This is significantly lower than all other mixes with Bethany Falls limestone using manufactured sand and a cement factor of 6.6 sk/cu yd. It would appear that using manufactured sand in combination with Bethany Fall limestone improves durability over the use of Missouri river sand when designed with a cement factor of 6.6 sk/cu yd.
6. Durability factors for concrete using Callaway limestone were in excess of 94% regardless of cement factor or the type of sand used.
7. Chloride permeability results were in the moderate acceptability range which indicates these concretes should not be subjected to deicing chemicals such as bridge decks.
8. Manufactured sands produced from limestones and dolomites are not recommended for use where subject to vehicular traffic and polishing.

APPENDIX A

MATERIALS

MATERIALS

Coarse Aggregate:

Coarse aggregate used in this investigation was the laboratory standard, Callaway limestone, Beck Quarries, Holts Summit, Mo. and Bethany Falls limestone, Great Midwest Mining Corp., Randolph, Mo. All coarse aggregate retained on the No. 4 sieve was 24-hour soaked while all coarse aggregate passing the No. 4 sieve was air dried prior to batching. Unit weights and absorptions for coarse aggregates are shown in Table A-2. Bulk specific gravities for coarse aggregates are shown in Table A-3. Gradation for each coarse aggregate was manufactured to meet specification 1005.1.5, Gradation D, as shown below:

Bethany Falls and Callaway Gradation D

Sieve	Percent Passing Manufactured Specification		Gradation	Sieve	Gradation
1	100	1	100		
3/4	98	3/4	90-100		
1/2	60	3/8	15-45		
3/8	30	#4	15-45		
#4	3		0-5		
#8	0				

Fine Aggregate:

Manufactured sand used in this investigation were graded according to Missouri Standard Specification No. 1005.2.4.2., as shown below:

(1) Amazonia limestone from Martin Marietta, Avenue City Mo.

Sieve Size	Manufactured Gradation	Gradation Specification
4	100	100
8	94	
10		80-100
16	64	
20		50-75
30	31	
50	12	15-30
100	5	2-10
200	3.7	

(2) Burlington limestone from Griesemer Stone Co., Springfield, Mo.

Sieve Size	Manufactured Gradation	Gradation Specification
4	100	100
8	90	
10		80-100
16	56	
20		50-75
30	31	
50	15	15-30
100	6	2-10
200	3.8	

(3) Bonneterre Dolomite, Lead Belt Material Co., Elvins, Mo.

Sieve Size	Manufactured Gradation	Gradation Specification
4	100	100
8	89	
10		80-100
16	64	
20		50-75
30	38	
50	18	15-30
100	7	2-10
200	2.5	

(4) Keokuk-Burlington limestone, Moberly Stone Co., Airy, Mo.

Sieve Size	Gradation Manufactured Gradation	Gradation Specification
4	100	100
8	92	
10		80-100
16	64	
20		50-75
30	40	
50	20	15-30
100	8	2-10
200	3.7	

(5) Missouri River sand from Capital Sand Co., Jefferson City, Mo.

Gravities and absorptions of these aggregates are listed in Table A-1.

Sieve Size	Gradation Manufactured Gradation	Gradation Specification
4	100	100
8	96	
10		80-100
16	66	
20		50-75
30	36	
50	20	15-30
100	8	2-10
200	5	

Cement:

The cement used in this investigation was Type I portland cement, manufactured by Missouri Portland Cement Company of Sugar Creek, Missouri. A copy of the certification is shown in Table A-4 giving physical and chemical properties.

Air-Entraining Agent:

Ad-Aire, single strength, manufactured by Carter-Waters Company was used for all batches of concrete.

Mixing Water:

Tap water at room temperature was used. Water was stored in a covered container in the mixing room overnight prior to mixing.

TABLE A-1

ABSORPTION AND SPECIFIC GRAVITY OF MANUFACTURED AND RIVER SAND

Sand	% Absorption	Bulk Specific Gravity (dry)
Amazonia limestone Martin Marietta Avenue City, Mo.	1.4	2.63
Burlington limestone Griesemer Stone Co. Springfield, Mo.	1.0	2.63
Bonneterre Dolomite Lead Belt Mat'l. Co. Elvins, Mo.	1.0	2.81
Keokuk-Burlington limestone Moberly Stone Co. Mount Airy, Mo.	1.7	2.58
Missouri River sand Capital Sand Co. Jefferson City, Mo.	0.4	2.63

TABLE A-2

ABSORPTION AND UNIT WEIGHT OF COARSE AGGREGATE

Coarse Aggregate	24 Hour Absorption 1-3/4	3/4-1/2	1/2-3/8	3/8-4	4-10
Bethany Falls	1.4	1.6	1.7	2.1	2.0
Callaway	0.9	1.1	1.1	1.3	1.0

	Unit Weight Pounds per cubic foot
Bethany Falls	99
Callaway	97

TABLE A-3

BULK SPECIFIC GRAVITY OF COARSE AGGREGATES

Coarse Aggregate	Bulk Specific Gravity (Dry) 1-3/4	3/4-1/2	1/2-3/8	3/8-4	4-10
Bethany Falls	2.61	2.61	2.60	2.58	2.57
Callaway	2.64	2.62	2.62	2.63	2.63

Coarse Aggregate	Bulk Specific Gravity (S.S.D.) 1-3/4	3/4-1/2	1/2-3/8	3/8-4	4-10
Bethany Falls	2.65	2.64	2.64	2.62	--
Callaway	2.66	2.66	2.66	2.66	--

APPENDIX B

MIX DESIGN AND PHYSICAL TESTS

TABLE B-1

CONCRETE MIX DESIGN FACTORS

Coarse Aggregate Gradation	D
Sand Content (%)	45
Air Content (%)	5.5 ñ 1.5
Slump (in.)	4.0 Max.
Cement Factor (sacks/cu. yd.)	6.6 and 7.8

Aggregate Proportions by Absolute Volume:

45% Manufactured sands or Missouri river sand
55% Coarse aggregate

Manufactured sand used:

Amazonia limestone, Martin Marietta, Avenue City, Mo.
Burlington limestone, Griesemer Stone Co., Springfield, Mo.
Bonneterre Dolomite, Lead Belt Mat'ls. Co., Elvins, Mo.
Keokuk-Burlington limestone, Moberly Stone Co., Airy, Mo.

River sand used:

Missouri River sand, Capital Sand Co., Jefferson City, Mo.

Coarse aggregate used:

Callaway limestone, Beck Quarries, Holts Summit, Mo.
Bethany Falls limestone, Great Midwest Mining Corp., Randolph, Mo.

All aggregate retained on the #4 sieve was soaked for 24 hours, while all other aggregate was air dried at the time of batching.

Missouri Standard Specifications for Highway Construction, 1990 were used for:

Coarse Aggregate: Section 1005.1 and Gradation D requirements of Section 1005.1.5

Fine Aggregate: Section 1005.2 and Gradation requirements of Section 1005.2.4.1 (for Missouri River sand)
Section 1005.2.4.2 (for manufactured sand)

TABLE B-2

SEQUENCE OF BATCHING

Mix Day	Batch Order	Coarse	Fine	Cement Factor	Ident.
Monday	1	B	S	7.8	BS71-11MS
(05/04/92)	2	B	S	6.6	BS61-11MS
	3	C	M	6.6	CM61-11MS
	4	B	D	6.6	BD61-11MS
	5	C	A	6.6	CA61-11MS
	6	C	A	7.8	CA71-11MS
Tuesday	7	C	D	6.6	CD61-12MS
(05/05/92)	8	B	G	7.8	BG71-12MS
	9	B	A	7.8	BA71-12MS
	10	C	D	7.8	CD71-12MS
	11	B	M	6.6	BM61-12MS
Wednesday	12	C	S	7.8	CS71-13MS
(05/06/92)	13	B	G	6.6	BG61-13MS
	14	B	A	6.6	BA61-12MS
	15	B	M	7.8	BM71-13MS
	16	C	G	6.6	CG61-13MS
Thursday	17	C	S	6.6	CS61-14MS
(05/07/92)	18	C	M	7.8	CM71-14MS
	19	B	D	7.8	BD71-14MS
	20	C	G	7.8	CG71-14MS
	21	B	S	6.6	BS62-14MS
Monday	22	B	G	7.8	BG72-21MS
(05/11/92)	23	B	S	7.8	BS72-21MS
	24	C	A	7.8	CA72-21MS
	25	C	M	6.6	CM62-21MS
	26	C	D	7.8	CD72-21MS
	27	B	D	6.6	BD62-21MS
Tuesday	28	B	M	7.8	BM72-22MS
(05/12/92)	29	B	G	6.6	BG62-22MS
	30	B	M	6.6	BM62-22MS
	31	C	A	6.6	CA62-22MS
	32	C	D	6.6	CD62-22MS
Wednesday	33	C	S	6.6	CS62-23MS
(05/13/92)	34	C	G	6.6	CG62-23MS
	35	C	G	7.8	CG72-23MS
	36	B	A	7.8	BA72-23MS
	37	B	A	6.6	BA62-23MS
Thursday	38	C	M	7.8	CM72-24MS
(05/14/92)	39	C	S	7.8	CS72-24MS
	40	B	D	7.8	BD72-24MS
	41	B	G	7.8	BG73-24MS

TABLE B-2 (cont.)

SEQUENCE OF BATCHING

Mix Day	Batch Order	Coarse	Fine	Cement Factor	Ident.
Monday	42	B	M	6.6	BM63-31MS
(05/18/93)	43	C	M	6.6	CM63-31MS
	44	B	M	7.8	BM73-31MS
	45	C	D	7.8	CD73-31MS
	46	B	S	6.6	BS63-31MS
Tuesday	47	C	G	7.8	CG73-32MS
(05/19/92)	48	C	A	7.8	CA73-32MS
	49	C	D	6.6	CD63-32MS
	50	C	S	6.6	CS63-32MS
	51	C	A	6.6	CA63-32MS
Wednesday	52	B	D	6.6	BD63-33MS
(05/20/92)	53	C	G	6.6	CG63-33MS
	54	C	D	7.8	BD73-33MS
	55	C	M	7.8	CM73-33MS
	56	C	S	7.8	CS73-33MS
Thursday	57	B	A	6.6	BA63-34MS
(05/21/92)	58	B	A	7.8	BA73-34MS
	*59	B	S	7.8	BS73-34MS
	*60	B	G	6.6	BG63-34MS

*Remakes of bad batches

TABLE B-3

CHARACTERISTICS OF FRESH CONCRETE
(RANGES OF VALUES)

A = Amazonia limestone, Martin Marietta, Avenue City, Mo.

	Bethany Falls Lms.		Callaway Lms.	
Combination Ident.	BA6	BA7	CA6	CA7
Design C.F.	6.6	7.8	6.6	7.8
Cement Factor (sk/cu yd)	6.53- 6.58	7.76- 7.81	6.55- 6.63	7.79- 7.85
Air Content (%)	4.9 - 5.8	5.4 - 6.0	5.0 - 6.2	4.9 - 5.6
W/C Ratio (gal.sk.)	5.30- 5.50	4.85- 4.90	5.10- 5.25	4.80- 4.85
Slump (inches)	1.8 - 2.5	1.8 - 2.5	2.0 - 2.5	2.5 - 3.0

G = Burlington limestone, Griesemer Stone Co., Springfield, Mo.

Combination Ident.	BG6	BG7	CG6	CG7
Design C.F.	6.6	7.8	6.6	7.8
Cement Factor (sk/cu yd)	6.51- 6.58	7.72- 7.83	6.54- 6.61	7.78- 7.83
Air Content (%)	5.8 - 6.7	5.1 - 6.5	5.3 - 6.3	5.1 - 5.7
W/C Ratio (gal./sk.)	5.50- 5.50	4.85- 4.90	5.30- 5.35	4.77- 4.85
Slump (inches)	3.0 - 3.5	2.8 - 3.0	2.0 - 2.8	2.5 - 3.5

D = Bonneterre Dolomite, Lead Belt Mat'l. Co., Elvins, Mo.

Combination Ident.	BD6	BD7	CD6	CD7
Design C.F.	6.6	7.8	6.6	7.8
Cement Factor (sk/cu yd)	6.53- 6.59	7.73- 7.84	6.49- 6.61	7.81- 7.83
Air Content (%)	5.7 - 6.5	4.8 - 6.3	5.4 - 6.3	5.1 - 5.4
W/C Ratio (gal./sk.)	5.35- 5.50	4.90- 4.91	5.26- 5.35	4.75- 4.85
Slump (inches)	2.5 - 3.2	2.8 - 3.5	1.8 - 3.0	2.8 - 3.5

M = Keokuk-Burlington limestone, Moberly Stone Co., Airy, Mo.

Combination Ident.	BM6	BM7	CM6	CM7
Design C.F.	6.6	7.8	6.6	7.8
Cement Factor (sk/cu yd)	6.54- 6.60	7.70- 7.84	6.59- 6.63	7.77- 7.81
Air Content (%)	5.5 - 6.0	5.0 - 6.7	5.1 - 5.6	5.4 - 5.8
W/C Ratio (gal./sk.)	5.50- 5.53	4.85- 4.90	5.30- 5.35	4.85- 4.87
Slump (inches)	2.5 - 2.8	2.8 - 3.5	1.5 - 2.2	2.5 - 2.8

S = Missouri River sand, Capital Sand Co., Jefferson City, Mo.

Combination Ident.	BS6	BS7	CS6	CS7
Design C.F.	6.6	7.8	6.6	7.8
Cement Factor (sk/cu yd)	6.54- 6.57	7.72- 7.82	6.54- 6.57	7.77- 7.82
Air Content (%)	5.9 - 6.0	5.2 - 6.5	5.8 - 6.0	5.3 - 5.9
W/C Ratio (gal./sk.)	4.85- 5.02	4.40- 4.56	4.90- 4.94	4.35- 4.40
Slump (inches)	1.8 - 2.5	2.5 - 3.2	2.8 - 3.2	3.0 - 3.2

TABLE B-4

STRENGTH OF CYLINDERS AND BEAMS

(All Gradation D with 45% sand)

Set	Fine Aggr. Source	Compressive Strength (psi) (28 Day)	Flexural Strength (psi) 35 Day	Terminal	% Change
BA6	A	5287	820	518	-36.9
BA7	A	5377	848	588	-30.7
BD6	D	6090	848	514	-41.8
BD7	D	6067	872	774	-11.2
BG6	G	4713	812	700	-13.7
BG7	G	5443	818	717	-12.4
BM6	M	4813	786	545	-30.6
BM7	M	5120	872	634	-27.2
BS6	S	5847	772	308	-60.2
BS7	S	5890	808	620	-23.3
CA6	A	5250	853	800	- 6.2
CA7	A	5357	800	786	- 1.8
CD6	D	6123	890	835	- 6.2
CD7	D	6327	932	786	-15.7
CG6	G	4740	836	801	- 4.2
CG7	G	5223	826	790	- 4.3
CM6	M	5080	823	786	- 4.5
CM7	M	5417	918	753	-18.0
CS6	S	5447	770	636	-17.3
CS7	S	5890	841	644	-23.5

APPENDIX C

CONCRETE BEAM IDENTIFICATION

CONCRETE BEAM IDENTIFICATION

Identification was given each beam by the following abbreviated code:

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                ÚÄÄÄÄÄÄ¿
      Example:  ³ BS71 ³
                ³      ³
                ³      ³
                ³ 11MS ³
                ÀÄÄÄÄÄÄÄÙ
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Coarse aggregate (First Digit)

B = Bethany Falls limestone, Randolph, Mo.
C = Callaway limestone, Holts Summit, Mo.

Fine aggregate (Second Digit)

A = Amazonia limestone, Avenue City, Mo.
S = Missouri River sand, Jefferson City, Mo.
G = Burlington limestone, Springfield, Mo.
D = Bonneterre Dolomite, Elvins, Mo.
M = Keokuk-Burlington limestone, Airy, Mo.

Cement Factor (Third Digit)

6 = 6.6 sacks/cu. yd.
7 = 7.8 sacks/cu. yd.

Replicate Number (Fourth Digit)

1 = first replicate
2 = second replicate
3 = third replicate

Week Number (Fifth Digit)

1 = first week
2 = second week
3 = third week

Day Number (Sixth Digit)

1 = first day
2 = second day
3 = third day
4 = fourth day

The seventh and eight digits were always "MS" to indicate that this was the evaluation of Manufactured Sand.

APPENDIX D

FREEZE AND THAW TEST RESULTS

TABLE D-1

DURABILITY FACTOR AND LENGTH CHANGE FREEZE-THAW BEAMS

First Digit - B = Bethany Falls
C = Callaway
Second Digit - A = Amazonia lms. Mfg. Sand, Martin Marietta, Avenue City, Mo.
D = Bonneterre Dolomite, Lead Belt Mat'l. Co. Elvins, Mo.
G = Burlington lms., Griesemer Stone Co., Springfield, Mo.
M = Keokuk-Burlington lms., Moberly Stone Co. Mount Airy, Mo.
S = Missouri River sand, Capital Sand Co., Jefferson City, Mo.
Third Digit - 6 = Cement factor of 6.6
7 = Cement factor of 7.8

Beam Set	Fine Aggr. Source	Beam Density (pcf) (35 Day)	Modulus (35 Day) (Millions)	Relative Modulus %	Durability Factor	Length Terminal	Percent Change (per cycle)
BA6	A	144.4	5.30	86.7	86.7	0.0472	0.1530
BA7	A	143.8	5.30	89.8	89.8	0.0379	0.1265
BD6	D	148.2	5.73	86.5	86.6	0.0394	0.1311
BD7	D	146.8	5.71	92.8	92.8	0.0261	0.0866
BG6	G	142.8	5.12	91.9	91.8	0.0282	0.0941
BG7	G	143.5	5.34	94.6	94.6	0.0125	0.0419
BM6	M	143.3	5.17	91.1	91.1	0.0258	0.0860
BM7	M	142.6	5.15	90.3	90.3	0.0372	0.1239
BS6	S	145.0	6.04	68.9	68.9	0.0934	0.3110
BS7	S	144.4	5.84	89.2	89.1	0.0528	0.1764
CA6	A	145.6	5.12	98.2	98.2	-0.0007	-0.0024
CA7	A	144.4	5.37	96.1	96.1	0.0019	0.0063
CD6	D	149.0	6.06	96.6	96.6	0.0085	0.0284
CD7	D	148.7	5.96	96.7	96.7	0.0083	0.0276
CG6	G	144.5	5.45	95.5	95.5	0.0050	0.0166
CG7	G	143.8	5.33	97.8	97.8	-0.0007	-0.0023
CM6	M	144.8	5.44	94.6	94.6	0.0069	0.0229
CM7	M	143.6	5.37	96.8	96.8	0.0036	0.0119
CS6	S	144.2	5.82	99.0	99.0	0.0057	0.0189
CS7	S	144.9	6.06	96.4	96.4	0.0036	0.0118*

* Average of two beams. CS71 was broken for flexural strength early by mistake.

APPENDIX E

RAPID CHLORIDE PERMEABILITY RESULTS

TABLE E-1

SUMMARY OF RESULTS
RAPID DETERMINATION OF CHLORIDE PERMEABILITY OF CONCRETE
(Coulombs - Total Charge Passed)

	Specimen No.			
Ident.*	1	2	3	Avg.
BA6	6908**	3821	3196	3508***
BA7	3372	4240	3363	3658
BG6	3233	3349	3421	3334
BS7	3094	2785	2619	2833
BD6	3333	3208	3865	3469
BS6	4787	2535	2108	3143
CM6	3375	3459	1910	2915
BD7	3851	2224	1870	2648
CG6	3461	3051	2549	3020
CM7	4356	2911	2290	3186
CS7	4513	2138	2051	2901
CA6	4763	2917	3031	3570
CD6	2518	3150	3189	2952
CS6	5898	2945	2314	3719
CA7	3895	3988	2961	3615
CD7	2797	2452	2154	2468
CG7	4673	3592	2121	3462
BG7	3667	3274	2362	3101
BM6	4540	3143	2620	3434
BM7	3645	3694	2653	3331

Table of Chloride Permeability Equivalents as determined by the charge passed as presented in AASHTO T-277.

Chloride Permeability	Charge Passed (coulombs)	Type of Concrete
High	4,000	High W/C Ratio (=>0.6)
Moderate	2,000-4,000	Mod. W/C Ratio (0.4-0.5)
Low	1,000-2,000	Low W/C Ratio ("Iowa" dense concrete)
Very Low	100-1,000	Latex Modified Concrete Internally Sealed
Negligible	100	Polymer Impregnated Polymer Concrete

*Idents. are same as Concrete Beam Identification (See Appendix C).
**This data is from a broken permeability cylinder.
***This value is the average of specimen two and three.