INVESTIGATION 72-3

FREEZE AND THAW TEST

OF

CHOUTEAU LIMESTONE

FINAL REPORT

MISSOURI STATE HIGHWAY DEPARTMENT

DIVISION OF MATERIALS AND RESEARCH

RESEARCH SECTION

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JEFFERSON CITY, MISSOURI

ABSTRACT

The purpose of this investigation was to determine the relative freezing and thawing resistance properties of a particular Chouteau Limestone. Three coarse aggregates which have known laboratory freeze-thaw (of concrete beams) behavior were included as a relative basis of analysis. The aggregates were graded in the laboratory and placed in the concretes after specific periods of storage in water. Freeze and thaw tests consisted of an accelerated two cycles per day method and a slower one cycle per week method.

In addition, various physical properties and other soundness tests were determined on all aggregate used in this investigation.

CONTENTS

INTRODUCTION

The limestone coming from the Chouteau group of Compton, Sedalia and Northview formations has not been accepted for use in portland cement concrete pavements. Rejection of this stone was based on previous studies conducted in 1952 on Chouteau Limestone from McClain Quarry, three miles southwest of Montgomery City, NE¼,SW¼, Sec. 2, T 48N, R 6W, Montgomery City.

The results of that study pertaining to the Chouteau Limestone was:

> "McClain Stone, essentially the same as that furnished us for this series of tests, should not be approved for use in concrete at this time. Concretes made with this aggregate have shown an excessive expansion during curing, and this expansion may be responsible for the reduced flexural strengths and the mediocre resistance to freezing and thawing obtained with these concretes. The cause of this excessive and apparently progressive expansion is not presently known."

Essentially, the problem with this stone was an aggregate-cement reaction of either a carbonate or silica nature whereby expansions caused by such reactions produce microfracturing of the paste.

The source of Chouteau Limestone submitted in 1972 (two ledges) for use in portland cement concrete pavement construction came from the old McSorley Quarry now the Kelly Lime and Rock Company, located one mile southwest of Newark, Missouri, Knox County. This particular source had been considered previously in 1965. That study was limited to alkali carbonate tests only, with no positive expansions occurring. The deposition of this inquiry was handled by the results of other laboratory tests. However, before that study was concluded, the Missouri Geological Survey was asked to evaluate the stone to determine if it was of the Chouteau Formation. Their opinion indicated that it was of the "Undifferentiated Chouteau" as defined by various geological tests.

This report is a summary of the results of laboratory tests, freeze and thaw tests, absorption and alkali carbonate tests made on the Chouteau Limestone submitted in 1972.

CONCLUSIONS

A previous study (1952) indicated that "Concretes made with Chouteau Limestone (McClain Quarry) had shown an excessive expansion during curing ...". The Chouteau Limestone used in this study did not show this characteristic.

The Chouteau Limestone used in this study, when tested by the Sodium Sulfate Soundness Method, had high percent losses indicating questionable performance when used in concrete pavements.

When vacuum saturated, the results indicate the Chouteau Limestone to be a marginal performance aggregate when tested by the fast freeze-thaw cycle test. When soaked for 2 or 24 hours, the Chouteau Limestone used in this study, when tested by either the slow or fast freeze-thaw cycle test, would require an undetermined length of time for critical saturation to cause failure.

IMPLEMENTATION

The results of the laboratory studies on the Chouteau Limestone as submitted would indicate that it is of marginal behavior and as such its use as a coarse aggregate in portland cement concrete pavements would be questionable.

SCOPE

The Chouteau Limestone was obtained from two individual ledges, crushed and screened in the laboratory, and re-combined by four fraction batching. The aggregates used for comparison were obtained from stockpiles, screened in the laboratory, and re-combined by four fraction batching. The only mix design variable introduced, other than the type of coarse aggregate, was the moisture content of the aggregate prior to batching. Three specific soak periods were used to saturate the aggregate prior to mixing, vacuum saturation then store in water a minimum of three days, soak in water for 24 hours and soak in water for 2 hours.

The freeze and thaw tests were conducted using two methods, one accelerated and one a long-term test. The main difference in methods, which are described in detail in Appendix C, is the thaw period. With the accelerated method, 2 cycles are obtained each working day with a total thaw of 3 hours per day; whereas the long term method allows for 1 week's thaw or soak period between each 16 hour freeze cycle.

Sample beams with the Chouteau Limestone were placed in the outdoor pit for continued observation.

A total of 168, 3½ x 4½ x 16 inch beams were made and tested to establish the freeze and thaw resistance of the concretes mentioned above. Specifics of the mix design and batching procedures are shown in Appendix B.

RESULTS OF LABORATORY TESTS

The Chouteau Limestone used in this test had a different lithological appearance when compared with samples from Chouteau ledges exposed in Central Missouri. This stone is medium-grained, fossiliferous, argillaceous, dolomitic limestone whereas the normal Chouteau is characterized by fine grained and less dolomitic in part with some shale seams. The Compton and Sedalia formations of the Chouteau group in the Central Missouri area are definable, however, to the northeast, these formations merge to such a degree that it is not feasible to subdivide them. This combined unit is therefore designated as "Undifferentiated Chouteau".

The Division has studied the chemical properties of various sources of Chouteau Limestone in connection with the alkali carbonate program. From that data, the Chouteau Limestone has exhibited a very wide range in the amount of chemical compounds present. For example, Calcium Carbonate may vary from 20% to 95%, generally greater than 72%; Magnesium Oxide from 1% to 10%; Insoluble Residue from 2.5% to 54%; Loss on Ignition from 17% to 42%, generally above 36%; and probable Dolomite contents of 5% to 100%, normally below 45%. Table 1 shows the chemical test results on samples of the stone used in this study and the -#4 material which was the residue from crushing.

The chemical analyses for the stone and the -#4 material compare very well within samples, however, some minor variations

Table 1

Chemical Analyses of Chouteau Limestone

	Sample			
	Ledge 1		Ledge 2	
Test Characteristic	Stone	-#4	Stone	-#4
Percent Loss on Ignition	42.18	42.04	41.40	40.76
Percent Carbon Dioxide*	42.25	42.22	41.32	41.11
Percent Insoluble Residue	3.20	3.16	5.30	5.82
Percent Silicon Dioxide	3.04	3.00	4.98	5.36
Percent Calcium Oxide	53.33	53.25	52.25	51.86
Percent Calcium Carbonate*	95.18	95.04	93.26	92.56
Percent Magnesium Oxide	0.37	0.40	0.28	0.38
Percent Magnesium Carbonate*	0.77	0.83	0.59	0.79
Percent Ferris Oxide	0.35	0.31	0.39	0.47
Percent Aluminum Oxide	0.71	0.63	0.59	0.53
Percent Sulfur Trioxide	0.26	0.28	0.32	0.44
Percent Sodium Oxide	0.06	0.07	0.06	0.05
Percent Potassium Oxide	0.01	0.01	0.01	0.01
Percent Dolomite**	3.53	3.80	2.70	3.62

* Calculated values
** Calculated as maximum possible that may be present

exist between samples. Therefore, the Chouteau used in this study, when compared with the previous information, shows the calcium carbonate is high and slightly different between samples. The magnesium oxide is low in both samples and slightly variable within one aggregate sample. If the assumption is made that all the magnesium oxide determined chemically is derived from dolomite, then very little dolomite can be expected to be present in this limestone.

Normally, the prescence of sufficiently large quantities of dolomite will create a situation whereby the aggregate will react with sodium hydroxide being manifest in the form of resultant volume expansions. Samples of the two ledges of Chouteau limestone involved in this investigation were subjected to the rock prism, alkali carbonate test. The results of the observations, shown in Table 2, indicate that no detrimental reactions occurred due to the lack of expansion. This stone, therefore, should create no problems resulting from excessive expansions during the curing period of concrete in which it may be used.

Sodium and magnesium sulfate soundness tests were made for each of the two ledges of Chouteau Limestone and the one sample of Bethany Falls Limestone. The results of the duplicate tests, shown in Table 3, indicate the magnesium sulfate test to have less differential between duplicates than the sodium sulfate test. However, the difference between the Bethany Falls and the Chouteau limestones is not pronounced in the magnesium sulfate

Table 2

Rock Prism Expansion Tests

Sample	Expansion (%) 2 Wk.	4 Wk.	8 Wk.	12 Wk.	16 Wk.
Chouteau - Ledge 1 - Sample 1					
H-1	0	0.006	0	0.024	0.018
H-2	-0.016	-0.022	-0.022	-0.022	-0.022
P-1	0	0.006	0.006	0.019	0.019
P-2	-0.013	-0.019	-0.013	-0.006	-0.006
Chouteau - Ledge 1 - Sample 2					
H-1	0.012	0.012	0.006	0.018	0.018
H-2	0.018	0.012	0.012	0.018	0.018
P-1	0	-0.006	-0.013	-0.032	-0.025
P-2	0	-0.006	-0.006	0.030	0.024
Chouteau - Ledge 2 - Sample 1					
H-1	-0.012	-0.006	-0.006	-0.006	-0.006
H-2	0.019	0.012	0.012	0.037	0.031
P-1	0.006	0	-0.006	0.006	0
P-2	0	0	0.006	-0.006	-0.006
Chouteau - Ledge 2 - Sample 2					
H-1	0	-0.006	-0.006	0.037	0.006
H-2	0.006	0	0	0.044	0.019
P-1	0.025	0.006	0.006	0.006	0.006
P-2	0.025	0.013	0.006	0.045	0.038

Note: Generally, these prisms are 1.6 inches in length, therefore, a 0.006% change in length is only an actual change of 0.0001 inch.

Table 3

Magnesium and Sodium Sulfate Soundness Tests

Coarse Aggregate	Sample No.	Ident No.	Test Fraction	Actual Percent Loss Magnesium	Actual Percent Loss Sodium
Chouteau L#1	1	RG-73-2	1-1/2"-3/4"	2.1	10.2
			3/4"-3/8"	4.2	18.1
			3/8"-#4	16.0	15.3
			Blended(1)	7.1	17.1
	2	RG-73-4	1-1/2"-3/4"	1.2	11.0
			3/4"-3/8"	4.0	16.0
			3/8"-#4	12.3	15.0
			Blended(1)	6.0	11.8
Chouteau L#2	1	RG-73-1	1-1/2"-3/4"	4.4	12.4
			3/4"-3/8"	3.7	16.5
			3/8"-#4	21.7	17.7
			Blended(1)	8.2	16.6
	2	RG-73-3	1-1/2"-3/4"	1.6	11.9
			3/4"-3/8"	4.1	19.1
			3/8"-#4	18.0	18.0
			Blended(1)	7.5	18.5
Bethany Falls	1(2)	RG-73-5	1-1/2"-3/4"	5.1	8.7
			3/4"-3/8"	8.0	6.9
			3/8"-#4	10.7	4.3
			Blended(1)	8.6	6.3

(1) To correspond to the gradation used in batching the aggregate, the three fractions shown were combined 3.0: 72.0: 25.0, respectively.

(2) This sample was prepared by removing all deleterious material prior to testing.

test but is very definite in the sodium sulfate test. The Chouteau exhibits approximately three times as much loss as does the Bethany Falls.

RESULTS OF ABSORPTION STUDIES

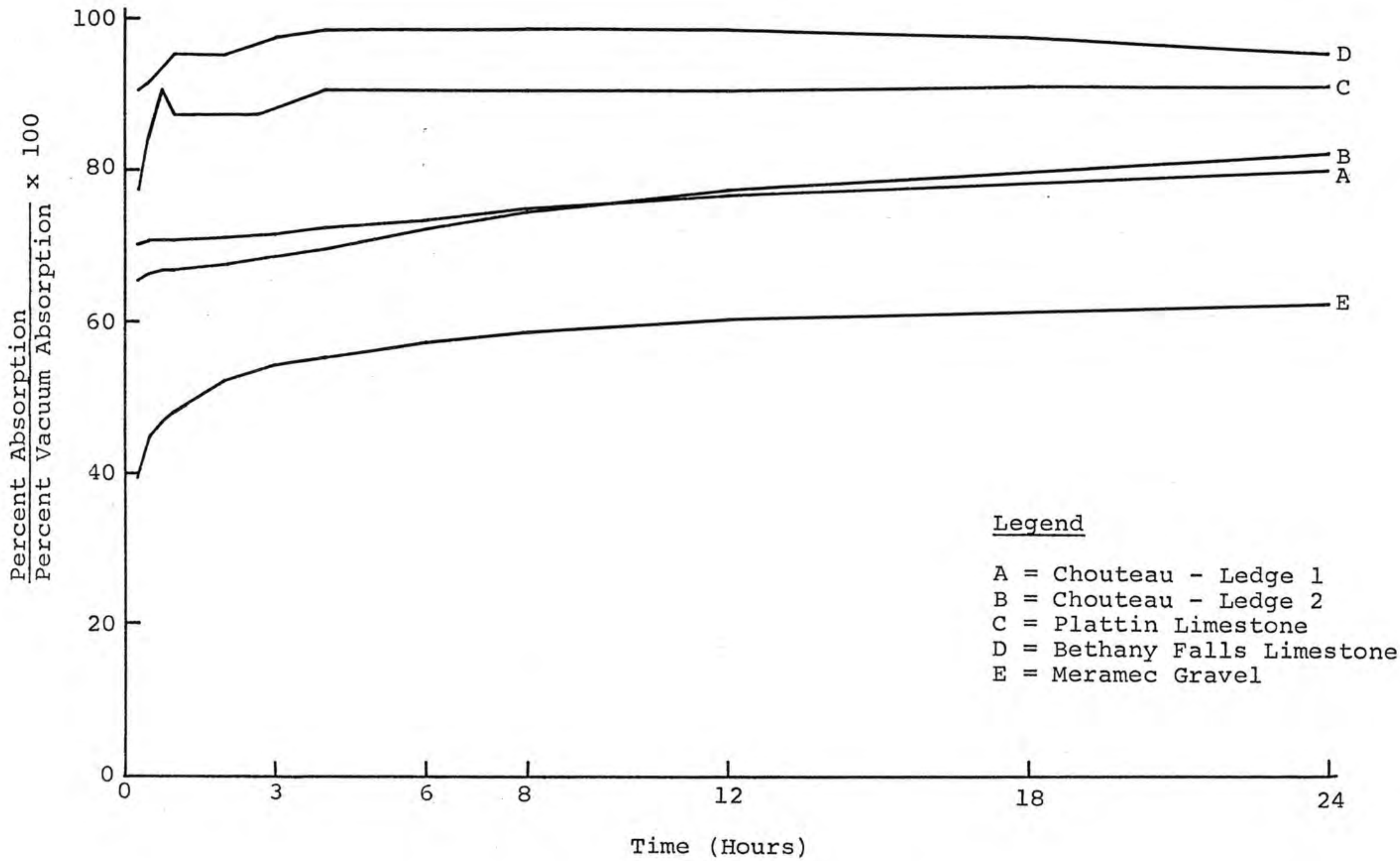
Absorption relationships of coarse aggregate have been used in many of our investigations to show the relative moisture state in which the aggregate is batched. Normally, these relationships are the absorption at two hours versus vacuum absorption. Consideration was given to placing each aggregate in the concrete at a specific state of absorption regardless of the time of soak. However, no specific absorption data was available to estimate the time required to soak each aggregate in order to have a given moisture content.

Absorption curves were established for each aggregate by placing a known oven dry sample in a gravity basket and placing this sample under water. At specific intervals of time, the weight was recorded. This determination was made for a 24 hour period for each sample of stone. From this data, a 24 hour absorption curve was established. The results of this determination at the two hour time period did not agree with those obtained previously by the 2 hour absorption determinations. The absorption curves shown in Figure 1 are the 24 hour curves for aggregate samples having identical gradations as those used to give the mix design criteria in Tables A-2 and A-3.

The curves show the two Chouteau samples and the Meramec Gravel to continue to saturate to some degree after the initial saturation surge. The Plattin and Bethany Falls limestone show a

Figure 1

Saturation of Coarse Aggregates Soaked in Water as a Function of Vacuum Saturation



plateau or slightly resending effect of continued saturation.

Based on these absorption curves, the timed soak periods of 2 hours and 24 hours were chosen for this test. The vacuum saturated condition was also included to measure the relative effects of the most extreme initial moisture condition which can be imposed on the aggregate prior to being used in concrete.

RESULTS OF FREEZE AND THAW TESTS

The results of this laboratory investigation are expressed in terms of the parameters which are measured and recorded during testing. The parameters are permanent dilation, change in weight and change in sonic frequency. The results of this test are shown in Tables 4, 5 and 6 respectively for the three parameters mentioned.

The beams subjected to this test were tested once each week for the slow freeze and thaw test and once for every other cycle for the fast freeze and thaw test. Each value shown in these summary tables represents the average results of four replicate specimens for each mix design or variable.

Another relative measure of the ability of laboratory concrete specimens to resist frost action, by application of a laboratory freeze and thaw test has been described in terms of a parameter labeled "Durability Factor", such as that explained in ASTM Designation C666-73. Even though our freeze and thaw methods do not comply with either of the ASTM Methods as described therein, the relative results obtained by using the durability factor formula should provide a valid analysis as long as they are not construed to mean or are not compared with durability factors derived by other test procedures.

The durability factors obtained by averaging the results for each of the four replicate specimens representing each mix design are shown in Table 7.

Table 4

Permanent Dilation of Concrete Beams Subjected to the Freeze and Thaw Tests

Concrete Identification	Percent Gain in Length During 7-35 Day Cure-70°F			Percent Gain in Length During F & T Cycles-35 Day-40°F			Cycles of F & T at Termination*
	Top	Bottom	Avg.	Top	Bottom	Avg.	
Fast Freeze and Thaw Test Method — Coarse Aggregate Vacuum Saturated							
Chouteau - Ledge 1	0.002	0.002	0.002	0.136	0.068	0.102	211
Chouteau - Ledge 2	0.002	0.002	0.002	0.172	0.048	0.110	245
Plattin Limestone	0.002	0.002	0.002	0.025	0.041	0.033	500
Bethany Falls	0.001	0.003	0.002	0.081	0.070	0.076	157
Meramec Gravel	0.004	0.003	0.004	0.082	0.074	0.078	6
Coarse Aggregate Soaked Two-Hours							
Chouteau - Ledge 1	0.004	0.005	0.004	0.022	0.005	0.014	500
Chouteau - Ledge 2	0.004	0.004	0.004	0.028	-0.001	0.013	500
Plattin Limestone	0.002	0.003	0.003	0.010	0.042	0.026	500
Bethany Falls	0.002	0.003	0.003	0.049	0.032	0.040	68
Coarse Aggregate Soaked 24-Hours							
Chouteau - Ledge 1	0.004	0.003	0.004	0.025	0.008	0.016	500
Chouteau - Ledge 2	0.002	0.002	0.002	0.043	0.012	0.028	500

* 500 cycles, otherwise, specimens failed by loss of sonic modulus of 50% or more at cycle indicated.

Table 4 (Continued)
Permanent Dilation of Concrete Beams Subjected to the Freeze and Thaw Tests

Concrete Identification	Percent Gain in Length During 7-35 Day Cure-70°F Top	Bottom	Avg.	During F & T Cycles-35 Day-40°F Top	Bottom	Avg.	Cycles of F & T at Termination*
			Slow Freeze and Thaw Test Method Coarse Aggregate Vacuum Saturated				
Chouteau - Ledge 1	0.002	0.004	0.003	0.184	0.156	0.170	105
Chouteau - Ledge 2	0.004	0.003	0.004	0.181	0.148	0.164	125
Plattin Limestone	0.004	0.001	0.003	0.199	0.181	0.190**	148
Bethany Falls	0.002	0.005	0.004	0.158	0.128	0.143	34
Meramec Gravel	0.004	0.003	0.004	0.092	0.081	0.086	4
			Coarse Aggregate Soaked Two-Hours				
Chouteau - Ledge 1	0.001	0.004	0.002	0.076	0.067	0.072	150
Chouteau - Ledge 2	0.003	0.005	0.004	0.076	0.062	0.069	150
Plattin Limestone	0.002	0.004	0.003	0.181	0.187	0.184	150
Bethany Falls	-0.005	0.008	-0.002	0.164	0.174	0.169	69
Meramec Gravel	0.002	0.002	0.002	0.105	0.153	0.129	32
			Coarse Aggregate Soaked 24-Hours				
Chouteau - Ledge 1	0.004	0.005	0.005	0.082	0.086	0.084	150
Chouteau - Ledge 2	0.002	0.001	0.002	0.103	0.080	0.092	150

* 150 cycles, otherwise, specimens failed by loss of sonic modulus of 50% or more at cycle indicated.
** Average of three beams - One beam accidently broken at 99 cycles.

Table 5

Change in Weight of Concrete Beams Subjected to the Freeze and Thaw Tests

Concrete Identification	Percent Gain or Loss in Weight: During 35 Day Cure-70°F: Weight 7 Day	Weight 35 Day	Percent Change	During F & T Test-40°F: Weight 35 Day	Weight Terminal	Percent Change	Cycles of F & T at Termination*
Fast Freeze and Thaw Test Method – Coarse Aggregate Vacuum Saturated							
Chouteau - Ledge 1	9660	9687	+0.28	9687	9721	+0.35	211
Chouteau - Ledge 2	9780	9808	+0.29	9806	9824	+0.18	245
Plattin Limestone	10011	10031	+0.20	10033	9947	-0.86	500
Bethany Falls	9923	9945	+0.22	9946	9953	+0.07	157
Meramec Gravel	9618	9636	+0.19	9638	9656	+0.19	6
Coarse Aggregate Soaked Two-Hours							
Chouteau - Ledge 1	9735	9764	+0.30	9764	9676	-0.90	500
Chouteau - Ledge 2	9696	9731	+0.36	9732	9644	-0.90	500
Plattin Limestone	10064	10086	+0.22	10087	10030	-0.56	500
Bethany Falls	9895	9918	+0.23	9920	9853	-0.68	500
Meramec Gravel	9581	9588	+0.07	9603	9618	+0.16	68
Coarse Aggregate Soaked 24-Hours							
Chouteau - Ledge 1	9729	9760	+0.32	9761	9668	-0.95	500
Chouteau - Ledge 2	9613	9641	+0.29	9642	9567	-0.78	500

*500 cycles, otherwise, specimens failed by loss of sonic modulus of 50% or more at cycle indicated.

Table 5 (Continued)

Change in Weight of Concrete Beams Subjected to the Freeze and Thaw Tests

Concrete Identification	Percent Gain or Loss in Weight — During 35 Day Cure-70°F: Weight 7 Day	Weight 35 Day	Percent Change	During F & T Test-40°F: Weight 35 Day	Weight Terminal	Percent Change	Cycles of F & T at Termination*
Slow Freeze and Thaw Test Method — Coarse Aggregate Vacuum Saturated							
Chouteau - Ledge 1	9733	9760	+0.28	9760	9812	+0.53	105
Chouteau - Ledge 2	9631	9653	+0.23	9659	9678	+0.20	125
Plattin Limestone	10020	10043	+0.23	10028*	10047*	+0.19**	148
Bethany Falls	9882	10032	+1.52	10033	10085	+0.52	34
Meramec Gravel	9593	9612	+0.20	9613	9649	+0.37	4
Coarse Aggregate Soaked Two-Hours							
Chouteau - Ledge 1	9675	9707	+0.33	9708	9722	+0.14	150
Chouteau - Ledge 2	9722	9756	+0.35	9756	9760	+0.04	150
Plattin Limestone	10004	10026	+0.22	10026	10044	+0.18	150
Bethany Falls	9963	9988	+0.25	9990	10024	+0.34	69
Meramec Gravel	9675	9695	+0.21	9696	9746	+0.52	32
Coarse Aggregate Soaked 24-Hours							
Chouteau - Ledge 1	9711	9735	+0.25	9741	9724	-0.17	150
Chouteau - Ledge 2	9656	9686	+0.31	9688	9702	+0.14	150

*150 cycles, otherwise, specimens failed by loss of sonic modulus of 50% or more at cycle indicated.
** Average of three beams - One beam accidently broken at 99 cycles.

Table 6

Change in Sonic Frequency of Concrete Beams(1)

Concrete Identification	Curing Period: Sonic Frequency (CPS at 70°F) 7 Days	Curing Period: Sonic Frequency (CPS at 70°F) 35 Days	Curing Period: Percent Change	Freeze and Thaw Test: Sonic Frequency (CPS at 40°F) 35 Days	Freeze and Thaw Test: Sonic Frequency (CPS at 40°F) Terminal	Freeze and Thaw Test: Residual Sonic Frequency (Percent)	Cycles of F & T at Termination*
Fast Freeze and Thaw Test Method — Coarse Aggregate Vacuum Saturated							
Chouteau - Ledge 1	1885	1995	108	1945	1365	49.2	211
Chouteau - Ledge 2	1870	1940	108	1935	1350	48.7	245
Plattin Limestone	2090	2150	106	2160	1980	84.0	500
Bethany Falls	2000	2075	108	2065	1445	49.0	157
Meramec Gravel	2040	2155	112	2075	1380	44.2	6
Coarse Aggregate Soaked Two-Hours							
Chouteau - Ledge 1	1875	1955	109	1945	1935	99.0	500
Chouteau - Ledge 2	1855	1930	108	1920	1880	95.9	500
Plattin Limestone	2095	2170	107	2180	2090	91.9	500
Bethany Falls	1980	2060	108	2070	1800	75.6	500
Meramec Gravel	2030	2110	108	2120	1480	48.7	68
Coarse Aggregate Soaked 24-Hours							
Chouteau - Ledge 1	1880	1960	109	1950	1890	93.9	500
Chouteau - Ledge 2	1850	1920	108	1910	1785	87.3	500

* 500 cycles, otherwise specimens failed by loss of sonic modulus of 50% or more at cycle indicated.

Table 6 (Continued)
Change in Sonic Frequency of Concrete Beams(1)

Identification	Curing Period Sonic Frequency (CPS at 70°F) 7 Days	35 Days	Percent Change	Freeze and Thaw Test Sonic Frequency (CPS at 40°F) 35 Days	Terminal	Residual Sonic Frequency (Percent)	Cycles of F & T at Termination*
Slow Freeze and Thaw Test Method — Coarse Aggregate Vacuum Saturated							
Chouteau - Ledge 1	1890	1960	108	1995	1385	48.2	105
Chouteau - Ledge 2	1850	1920	108	1905	1370	51.7	125
Plattin Limestone	2090	2170	108	2160**	1585**	53.8**	148
Bethany Falls	1995	2080	109	2075	1445	48.5	34
Meramec Gravel	2040	2120	108	2100	1450	47.7	4
Coarse Aggregate Soaked-Two-Hours							
Chouteau - Ledge 1	1880	1950	108	1950	1935	98.5	150
Chouteau - Ledge 2	1870	1940	108	1930	1950	102.1	150
Plattin Limestone	2070	2160	109	2160	1670	59.8	150
Bethany Falls	1990	2070	108	2060	1430	48.2	69
Meramec Gravel	2060	2140	108	2135	1485	48.4	32
Coarse Aggregate Soaked 24-Hours							
Chouteau - Ledge 1	1900	1995	110	1980	1935	95.5	150
Chouteau - Ledge 2	1865	1940	108	1935	1890	95.4	150

* 150 cycles, otherwise, specimens failed by loss of sonic modulus of 50% or more at cycle indicated.
** Average of three beams - One beam accidently broken at 99 cycles.

Table 7

Durability Factors of Concrete Beams Subjected to the Freeze and Thaw Tests

Identification	Modulus of Elasticity ($E \times 10^6$) 7 Day 70°F	35 Day 40°F	Terminal 40°F	Percent Sonic Frequency Remaining At Termination	Cycles of Freeze and Thaw at Termination	Durability Factor (DF)*
Fast Freeze and Thaw Test Method						
Coarse Aggregate Vacuum Saturated						
Chouteau - Ledge 1		5.17	2.56	49.2	211	20.8
Chouteau - Ledge 2		5.03	2.46	48.7	245	23.9
Plattin Limestone		6.56	5.48	84.0	500	84.0
Bethany Falls		5.95	2.91	49.0	157	15.4
Meramec Gravel		5.87	2.61	44.2	6	0.5
Coarse Aggregate Soaked Two-Hours						
Chouteau - Ledge 1		5.10	5.03	99.0	500	99.0
Chouteau - Ledge 2		5.03	4.76	95.9	500	95.9
Plattin Limestone		6.63	6.11	91.9	500	91.9
Bethany Falls		5.94	4.52	75.6	500	75.6
Meramec Gravel		6.10	3.00	48.7	68	6.6
Coarse Aggregate Soaked 24-Hours						
Chouteau - Ledge 1		5.20	4.86	93.9	500	93.9
Chouteau - Ledge 2		4.99	4.34	87.3	500	87.3

* Based on 500 cycles.

Table 7 (Continued)
Durability Factors of Concrete Beams Subjected to the Freeze and Thaw Tests

Concrete Identification	Modulus of Elasticity ($E \times 10^6$) 7 Day 70°F	35 Day 40°F	Terminal 40°F	Percent Sonic Frequency Remaining At Termination	Cycles of Freeze and Thaw at Termination	Durability Factor (DF)*
Slow Freeze and Thaw Test Method — Coarse Aggregate Vacuum Saturated						
Chouteau - Ledge 1	4.82	5.37	2.60	48.2	105	33.7
Chouteau - Ledge 2	4.68	4.98	2.60	51.7	125	43.1
Plattin Limestone	6.09	6.42**	3.51**	53.8**	148	53.1**
Bethany Falls	5.46	5.92	2.89	48.5	34	11.0
Meramec Gravel	5.70	6.06	2.86	47.7	14	1.3
Coarse Aggregate Soaked Two-Hours						
Chouteau - Ledge 1	4.80	5.15	5.10	98.5	150	98.5
Chouteau - Ledge 2	4.73	5.02	5.14	102.1	150	102.1
Plattin Limestone	6.05	6.59	3.97	59.8	150	59.8
Bethany Falls	5.48	5.87	2.85	48.2	69	22.2
Meramec Gravel	5.63	6.07	2.96	48.4	32	10.3
Coarse Aggregate Soaked 24-Hours						
Chouteau - Ledge 1	4.86	5.31	5.05	95.5	150	95.5
Chouteau - Ledge 2	4.70	5.07	4.87	95.4	150	95.4

* Based on 500 cycles.
** Average of three beams - One beam accidently broken at 99 cycles.

DISCUSSION OF RESULTS

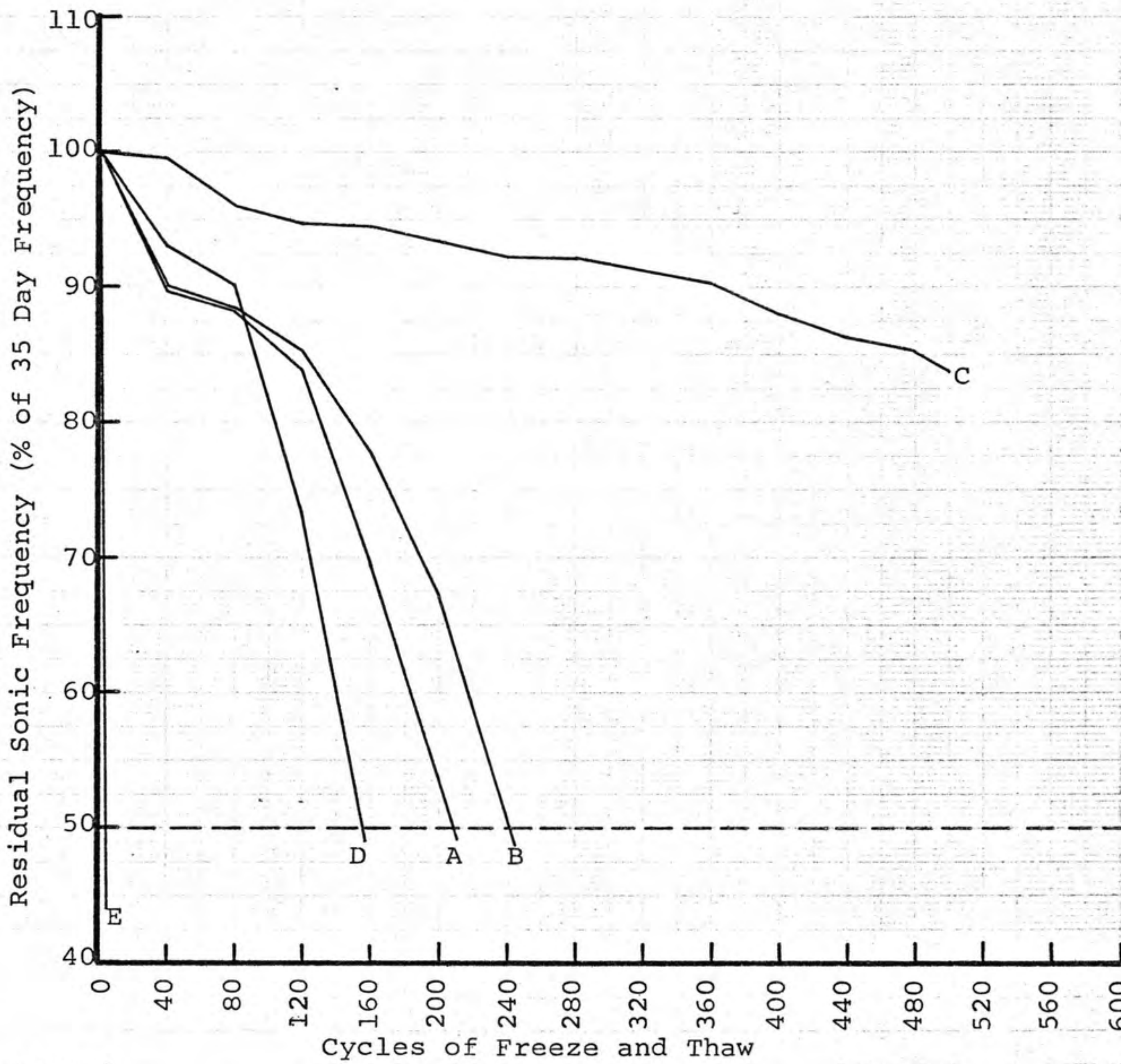
The primary objective of this study was to determine the relative resistance to laboratory freeze and thaw of concrete specimens made with Chouteau Limestone as compared to coarse aggregate of known resistance. The rate of deterioration becomes an item of concern as well as the ultimate relationship of failure at given cycles. Figures 2 through 7 show the relative rates of failure that correspond to the test conditions used. The discussion of differences between aggregate type will primarily center around the vacuum saturated and the two-hour soaked conditions.

Figures 2, 3, 5 and 6 show the Meramec Gravel at the expected rate of failure. The Bethany Falls limestone, being the marginal aggregate in this study failed as expected except for the two-hour soak, fast freeze and thaw method (Figure 3).

The Plattin Limestone showed in all instances an unusual tendency to lose in residual sonic frequency as a result of the laboratory freeze and thaw test. The Physical Laboratory data as shown in Appendix A, does not indicate this material to be different in character to that which is normally used in all freeze and thaw studies which has always been obtained from the same fresh concrete (Appendix B) for the Plattin Limestone, also indicate very good simularity with previous investigations.

Figure 2

Average Residual Sonic Frequency of
Vacuum Saturated Coarse Aggregate
Subjected to the
"Fast" Freeze and Thaw Test

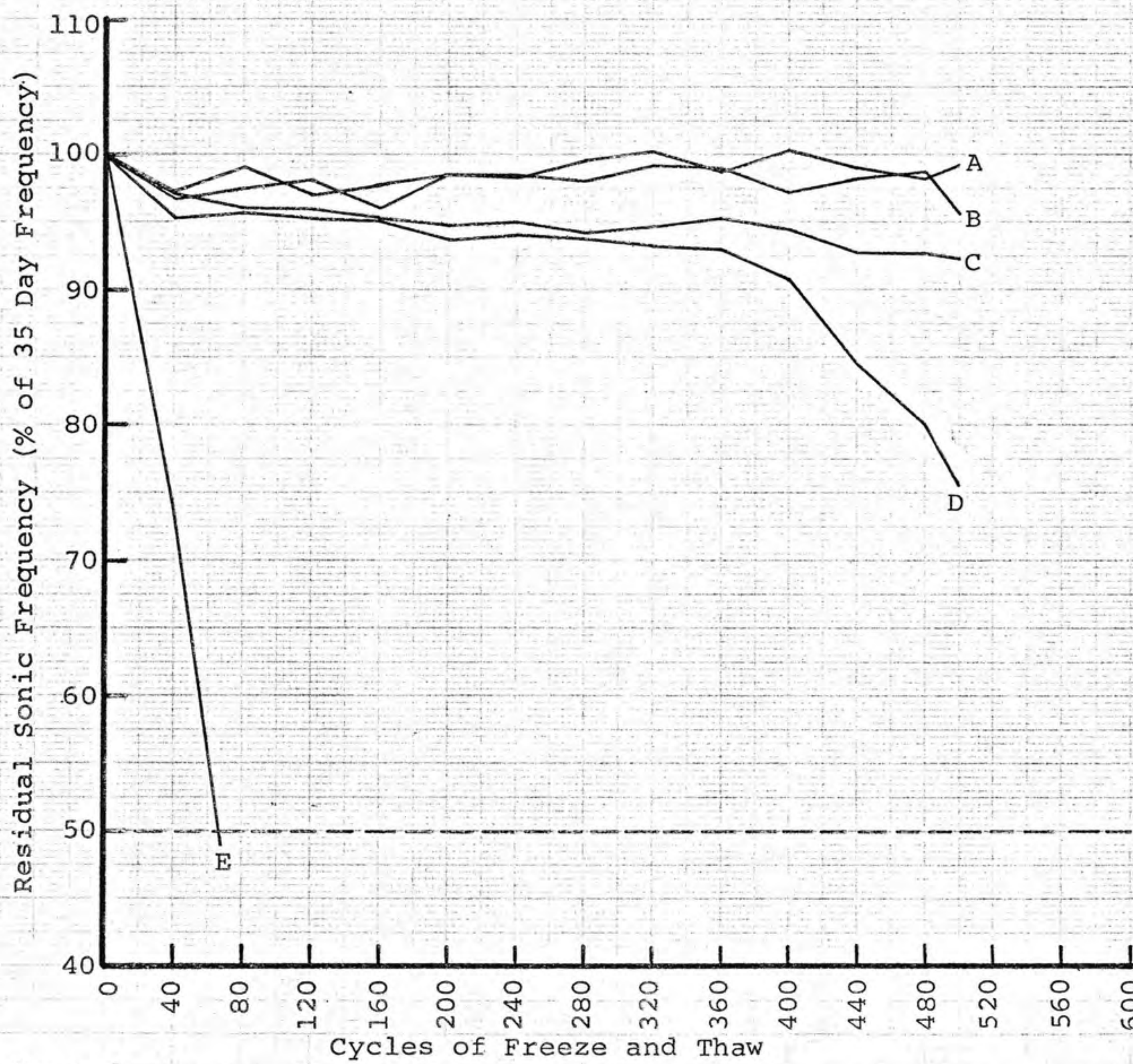


Legend

A = Chouteau - Ledge 1
B = Chouteau - Ledge 2
C = Plattin Limestone
D = Bethany Falls Limestone
E = Meramec Gravel

Figure 3

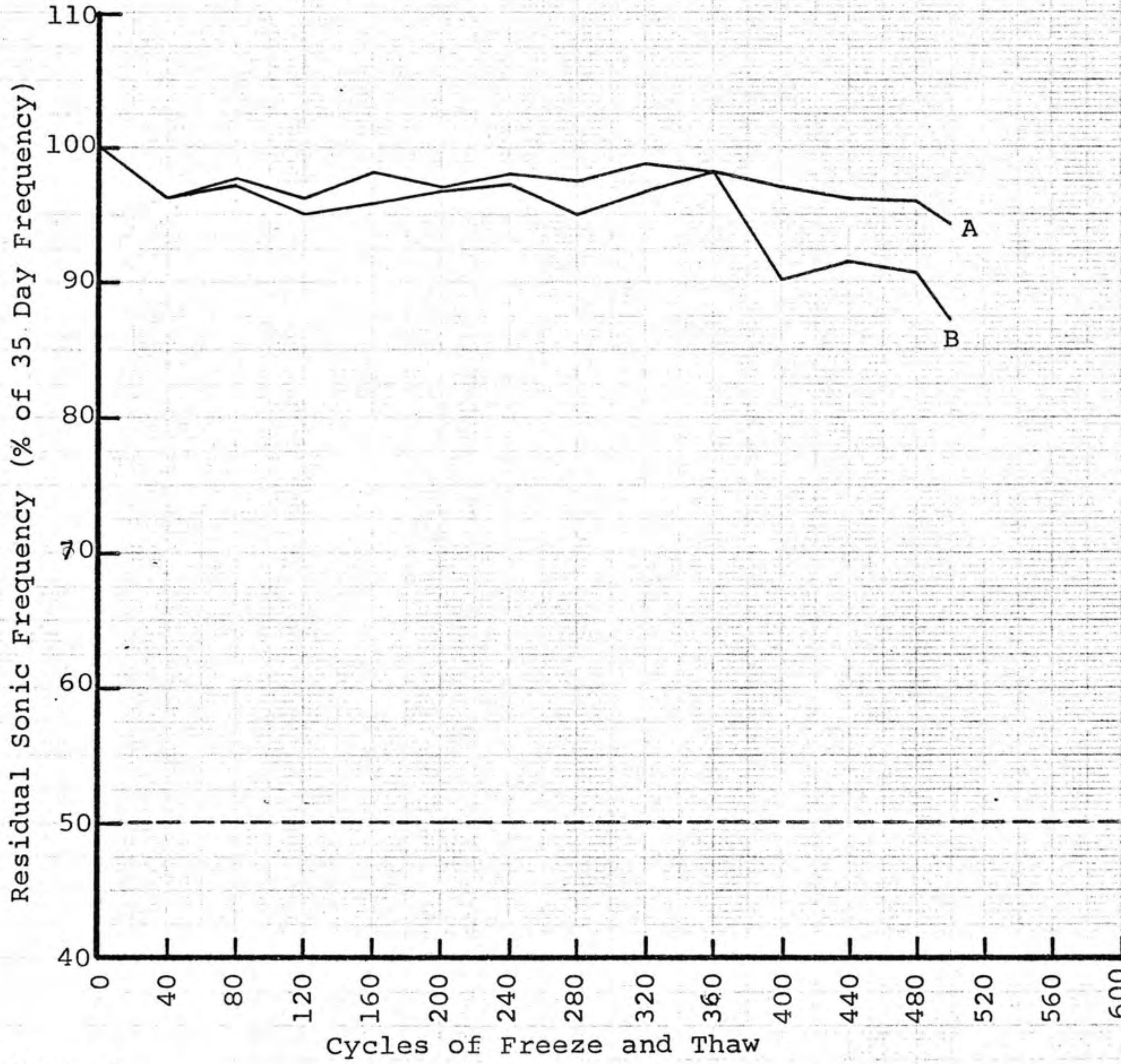
Average Residual Sonic Frequency of
Coarse Aggregate Soaked for Two-Hours
Subjected to the
"Fast" Freeze and Thaw Test



Legend
A = Chouteau - Ledge 1
B = Chouteau - Ledge 2
C = Plattin Limestone
D = Bethany Falls Limestone
E = Meramec Gravel

Figure 4

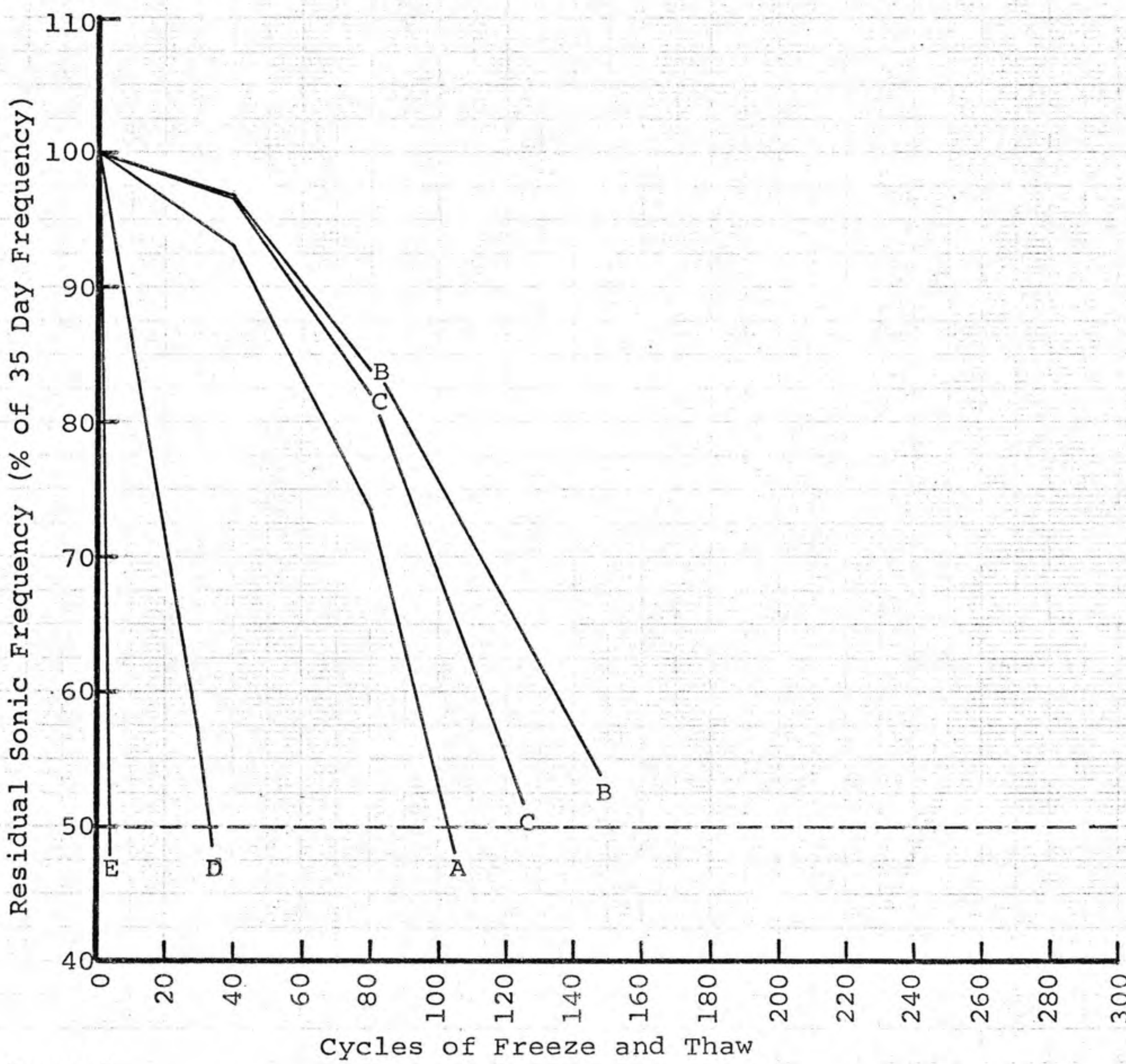
Average Residual Sonic Frequency of
Coarse Aggregate Soaked for Twenty-Four Hours
Subjected to the
"Fast" Freeze and Thaw Test



Legend
A = Chouteau - Ledge 1
B = Chouteau - Ledge 2

Figure 5

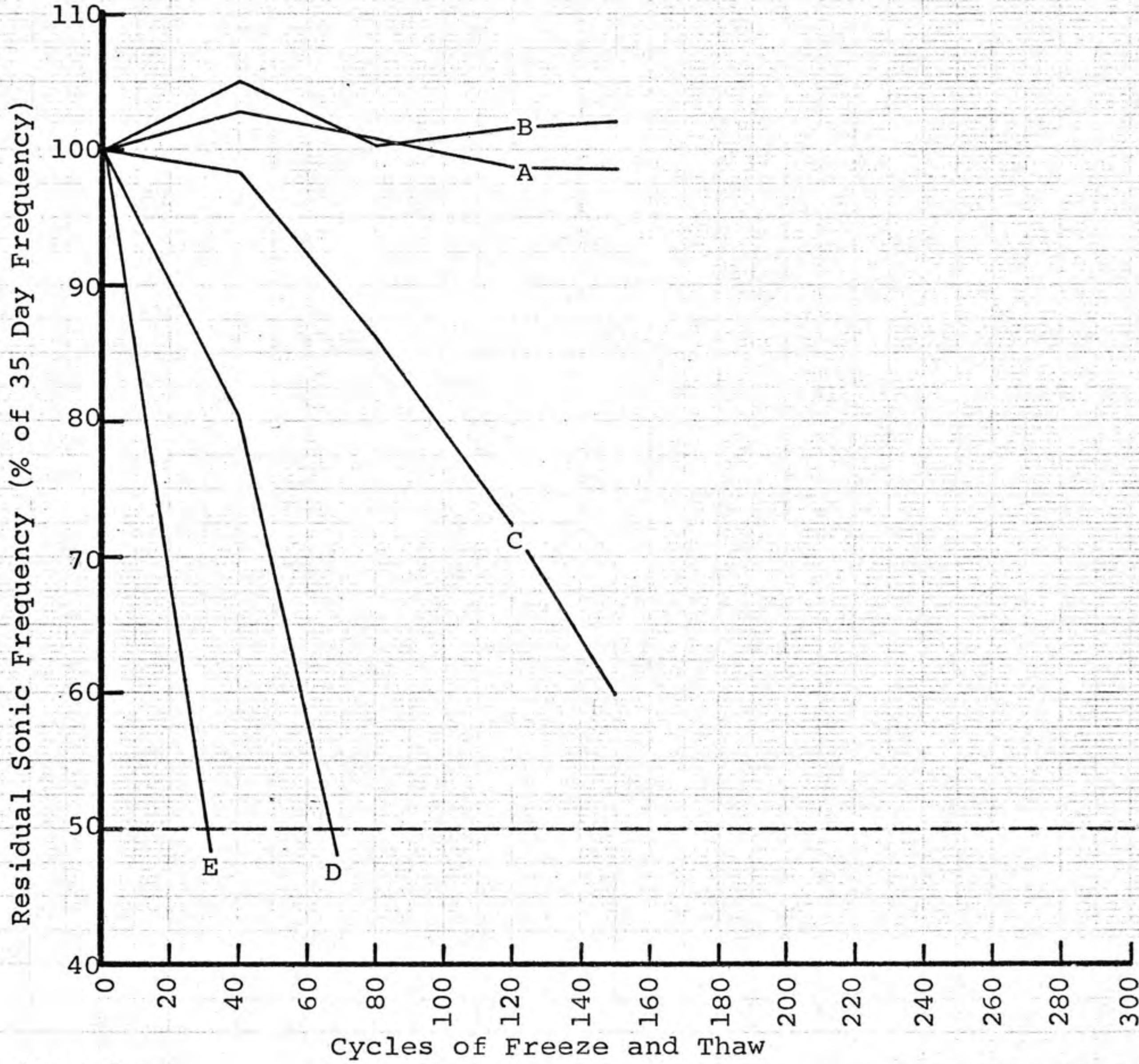
Average Residual Sonic Frequency of
Vacuum Saturated Coarse Aggregate
Subjected to the
"Slow" Freeze and Thaw Test



Legend
A = Chouteau - Ledge 1
B = Chouteau - Ledge 2
C = Plattin Limestone
D = Bethany Falls Limestone
E = Meramec Gravel

Figure 6

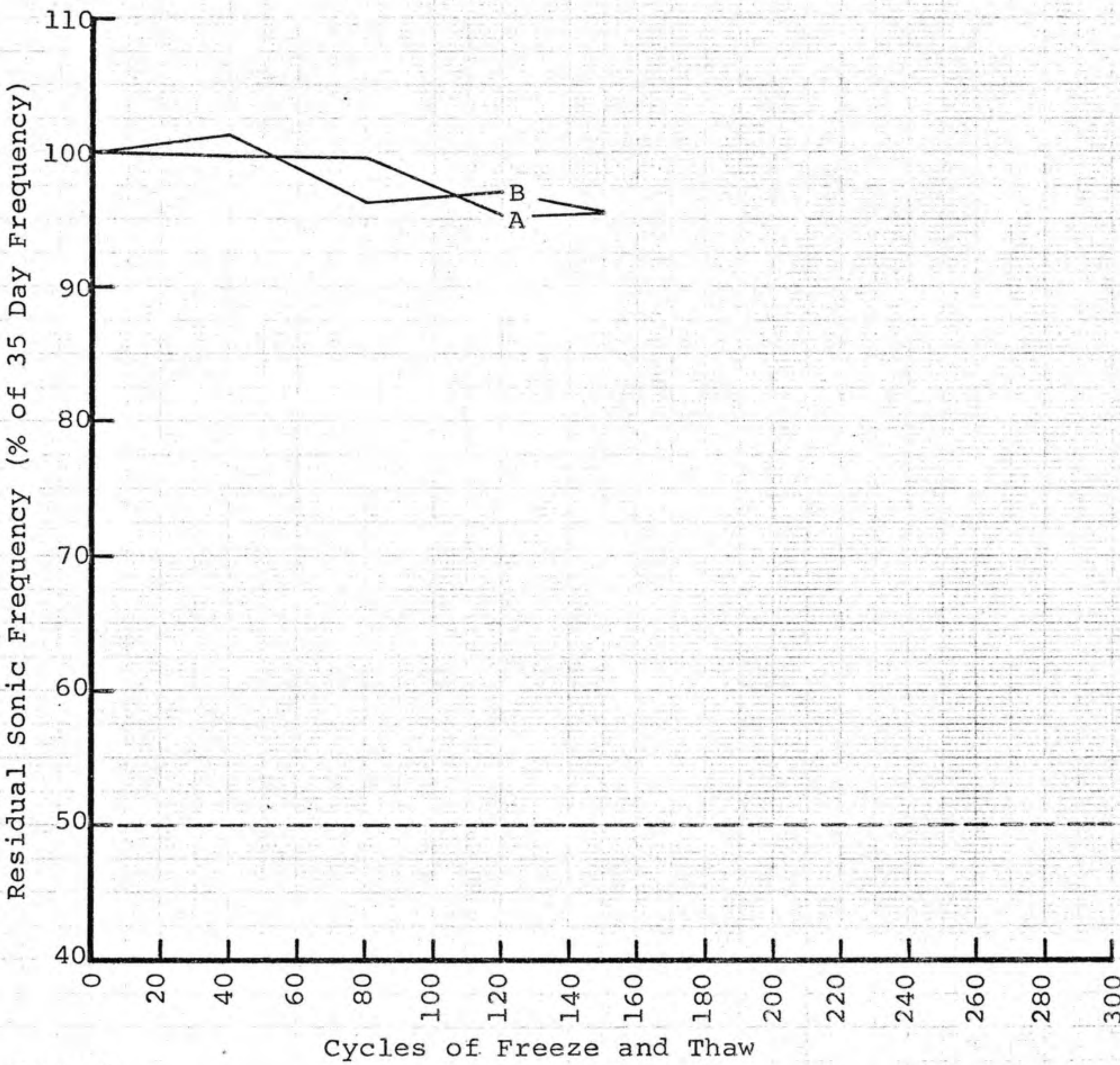
Average Residual Sonic Frequency of
Coarse Aggregate Soaked For Two-Hours
Subjected to the
"Slow" Freeze and Thaw Test



Legend
- A = Chouteau - Ledge 1
- B = Chouteau - Ledge 2
- C = Plattin Limestone
- D = Bethany Falls Limestone
- E = Meramec Gravel

Figure 7

Average Residual Sonic Frequency of
Coarse Aggregate Soaked for Twenty-Four Hours
Subjected to the
"Slow" Freeze and Thaw Test



Legend
A = Chouteau - Ledge 1
B = Chouteau - Ledge 2

Therefore, the tendency for this sample of Plattin Limestone to behave in this manner is not common, and can not be explained by the physical properties or the mix design data.

The concrete beams after failure in the freeze and thaw test or at the point of termination of the study were broken in flexure to verify the concrete strengths. The pieces of the broken beams are kept until the study is reported for verification of materials used should the case arise as it had with the Plattin limestone. Therefore, by visual observation of the broken surfaces of the concrete beams made with the Plattin Limestone, it was apparent that the Plattin Limestone used in this series of tests was not comparable in appearance to the Plattin normally used as a control aggregate. The facility from which these samples were obtained does have the variation in their product as indicated by these samples. Apparently, from the production which the sample was taken for this study, more of the gray to light gray, fine to medium grained limestone was included. Previous aggregate samples were basically composed of the dark gray-black, fine grained material.

With the previous discussion of the Plattin Limestone which has been used as a standard of the best performing coarse aggregate in the freeze and thaw studies, it is apparent that there is some variability within the source from which the Plattin is being obtained and that specific note of this fact should be made for future studies and a more comparable sample be obtained from the better material.

The Chouteau Limestone showed some variation in results which are dependent on the saturation condition at the time of mixing. Figures 2 and 5 indicate that, for the vacuum saturated condition, the Chouteau Limestone has a fairly low resistance to freeze and thaw. In the fast freeze and thaw test, the Chouteau is very comparable to the Bethany Falls limestone. In the slow freeze and thaw, the Chouteau is somewhat slower in rate of failure, however, it does continue to fail, thus giving low durability factors, as shown in Table 7.

The Chouteau Limestone showed fairly consistent results in both the fast and slow freeze and thaw tests when used in a partially saturated condition. The Chouteau maintained a level of resistance to deterioration exceeding all the other coarse aggregates used. The possibility of the slow freeze and thaw method causing saturation of the concrete specimens is evident with the Bethany Falls and Plattin Limestones. The eventual saturation of a concrete specimen does seem to occur in the fast freeze and thaw method, however, similar results appear to be given by both methods, with the exception of the Plattin as discussed earlier.

The study of the absorption characteristics of the coarse aggregate, as previously discussed in this report, indicated the Chouteau Limestone may continue to saturate after the two hour soak as used in the freeze and thaw test. Therefore, samples of the Chouteau Limestone were prepared and soaked for 24 hours prior to mixing. Figures 4 and 7 show the relative rate of deterioration as subjected to the fast and slow freeze and thaw test. Neither of the Chouteau samples show, at the termination of the tests, a significant lack of resistance to freeze and thaw. These results do show, however, slightly more deterioration than the specimens having coarse aggregate soaked for only 2 hours. This is also indicated by the relative durability factors as shown in Table 7.

These results of the concrete specimens have been explained in terms of the residual sonic frequency based on the 35 day value as the specimen went into the freeze and thaw test. As the specimens are terminated by either failure to the pre-assigned reduction in sonic frequency or by termination of the test itself, the beams are broken to determine their flexural strength. Table B-3 shows the relative loss in flexural strengths of each set of specimens. These values correlate well with the indicated reduction in strength as indicated by the durability factors in Table 7.

The data thus presented and discussed in this report indicate that the Chouteau Limestone samples as submitted for this study do possess the necessary characteristics that when saturated to a critical state will cause failure when subjected to the freeze and thaw test. However, there is also shown the possibility that the Chouteau may never become critically saturated by natural means.

APPENDIX A

MATERIALS

Fine Aggregate:

The fine aggregate used in this phase of the laboratory testing was a Missouri River sand having the physical properties shown in Table A-1. This sand was in an air dry condition when used. Two fractions of sand were used for batching; 3/8" to #16 and -#16, blended at 23.0 and 77.0 percent respectively.

Coarse Aggregate:

The principle aggregate under consideration in this study was two ledges of the Chouteau group exposed in the Kelly Lime and Rock Company mine. The location of this mine is approximately 1.0 mile southwest of Newark, Missouri. This particular limestone does not have the same visual characteristics which are normally considered as being those for the Chouteau group. This material is a more medium-coarse crystalline limestone with some fine grained argillaceous sediments, especially in the middle and upper sections of the formation.

To evaluate the relative performance of this Chouteau Limestone, three aggregates were included. They were Plattin Limestone, obtained from Federal Materials Company, at Cape Girardeau, Missouri, Bethany Falls Limestone, obtained from Midwest Precote Company at Randolph, Missouri, and Meramec Gravel obtained from a source on the Meramec River in District 6.

The same gradation for each of the four coarse aggregates were used in fabrication of the concrete beams.

The physical characteristics of these coarse aggregates are shown in Tables A-2 through A-5. The data shown in Table A-4 are the percent of saturation at either 2 or 24 hours soak as calculated against the vacuum saturation determinations.

<u>Cement</u>:

Alpha portland cement was obtained from the St. Louis, Missouri, plant. This cement was obtained because previous freeze and thaw tests used this cement source for a comparison standard. Properties of this cement are shown in Table A-6.

<u>Air-Entraining Agent</u>:

A vinsol resin solution was used as an air-entraining agent for these concretes. The formulation was as follows:

45.5 grams of vinsol resin
6.8 grams of NaOH
Plus sufficient distilled water to make 2000 ml.

<u>Mixing Water</u>:

Tap water at room temperature was used. A quantity of water sufficient for an entire day's run was drawn and allowed to set for at least 2 hours prior to being used.

Table A-1

Properties of Fine Aggregate

Gradations: Percentage Passing	Fraction +16 Sieve	Fraction -16 Sieve	Combined 0.23 to 0.77
3/8" Sieve	100.0	100.0	100.0
No.4 Sieve	95.0	100.0	98.8
No.10 Sieve	52.0	100.0	89.0
No.20 Sieve	0.2	78.0	60.1
No.30 Sieve	0.2	55.0	42.4
No.40 Sieve	0.1	38.0	29.3
No.50 Sieve	0.1	24.0	18.5
No.100 Sieve	0.1	1.0	0.8
No.200 Sieve	0	0.3	0.2
Bulk Specific Gravity	2.5948	2.6115	2.6077
Bulk Specific Gravity (SSD)	2.6042	2.6178	2.6147
Apparent Specific Gravity	2.6193	2.6280	2.6260
Absorption, percent (30 min.)	0.4	0.2	0.25
(24 hours)	0.4	0.2	0.25

Note: Generally the moisture content of the sand as used was 0.10 percent.

Table A-2

Bulk Specific Gravity and Bulk Specific Gravity (Saturated Surface Dry) of Coarse Aggregates

Coarse Aggregate	Bulk Specific Gravity 1" to 3/4"	Bulk Specific Gravity 3/4" to 1/2"	Bulk Specific Gravity 1/2" to 3/8"	Bulk Specific Gravity 3/8" to #4	Blended (b)	Bulk Specific Gravity (SSD or VSSD) (a) 1" to 3/4"	Bulk Specific Gravity (SSD or VSSD) (a) 3/4" to 1/2"	Bulk Specific Gravity (SSD or VSSD) (a) 1/2" to 3/8"	Bulk Specific Gravity (SSD or VSSD) (a) 3/8" to #4	Blended (b)
Material Vacuum Saturated from Oven Dry Condition										
Chouteau - L #1	2.5280	2.5022	2.4978	2.4785	2.4957	2.5951	2.5776	2.5750	2.5636	2.5738
Chouteau - L #2	2.5000	2.4928	2.4773	2.4516	2.4785	2.5767	2.5720	2.5624	2.5454	2.5629
Plattin	2.7028	2.6865	2.6927	2.6832	2.6876	2.7128	2.7008	2.7057	2.6983	2.7018
Bethany Falls	2.6190	2.6171	2.5973	2.5992	2.6073	2.6542	2.6537	2.6410	2.6414	2.6472
Meramec Gravel	2.4567	2.4577	2.4284	2.4151	2.4391	2.5245	2.5271	2.5109	2.5053	2.5172
Material Soaked 2 Hours from As Received Condition										
Chouteau - L #1	2.5294	2.5195	2.5066	2.4805	2.5065	2.5800	2.5741	2.5664	2.5494	2.5660
Chouteau - L #2	2.5069	2.4896	2.4815	2.4567	2.4796	2.5630	2.5499	2.5471	2.5363	2.5461
Plattin	2.7190	2.7008	2.6984	2.6882	2.6974	2.7291	2.7139	2.7094	2.7033	2.7104
Bethany Falls	2.6320	2.6244	2.6095	2.5945	2.6131	2.6632	2.6593	2.6446	2.6346	2.6492
Meramec Gravel	2.4655	2.4471	2.4395	2.4147	2.4374	2.5049	2.4903	2.4914	2.4758	2.4873
Material Soaked 24 Hours from As Received Condition										
Chouteau-L #1 (c)	2.5285	2.5080	2.5000	2.4796	2.4992	2.5840	2.5760	2.5690	2.5540	2.5688
Chouteau-L #1 (d)	2.5176	2.5155	2.5030	2.4701	2.5008	2.5773	2.5743	2.5694	2.5529	2.5677
Chouteau-L #2 (c)	2.5030	2.4910	2.4800	2.4540	2.4791	2.5740	2.5610	2.5570	2.5400	2.5551
Chouteau-L #2 (d)	2.5059	2.4933	2.4825	2.4501	2.4799	2.5687	2.5642	2.5564	2.5301	2.5537

(a) All values shown below are understood to be for the SSD or VSSD condition, as the subheadings may indicate.
(b) Blended means the gravity of the aggregate blended to the ratio 2.5:45.5:27.0:25.0 for the four fractions 1" to 3/4", 3/4" to 1/2", 1/2" to 3/8", and 3/8" to #4 respectively.
(c) Values shown were estimated because of the lack of time to prepare samples and make the tests prior to the mixing deadline.
(d) Values from tests made after all concrete mixing was completed as a check on the estimated values.

Table A-3

Two-Hour and Vacuum Absorptions of Coarse Aggregates

Coarse Aggregate	Absorption by Weight (%) 1" to 3/4"	3/4" to 1/2"	1/2" to 3/8"	3/8" to #4	Blended (a)	Absorption by Volume 1" to 3/4"	3/4" to 1/2"	1/2" to 3/8"	3/8" to #4	Blended (a)
Material Vacuum Saturated from Oven Dry Condition										
Chouteau - L #1	2.65	3.01	3.09	3.43	3.13	6.70	7.54	7.73	8.51	7.81
Chouteau - L #2	3.07	3.18	3.44	3.82	3.41	7.67	7.92	8.51	9.37	8.44
Plattin	0.37	0.54	0.48	0.56	0.52	1.01	1.43	1.30	1.51	1.40
Bethany Falls	1.34	1.40	1.68	1.62	1.53	3.52	3.66	4.38	4.22	3.99
Meramec Gravel	2.76	2.82	3.39	3.73	3.20	6.78	6.94	8.24	9.02	7.81
Material Soaked 2 Hours From As Received Condition										
Chouteau - L #1	2.00	2.17	2.38	2.78	2.37	5.06	5.46	5.97	6.89	5.94
Chouteau - L #2	2.24	2.42	2.64	3.24	2.68	5.61	6.04	6.56	7.96	6.65
Plattin	0.37	0.48	0.41	0.56	0.48	1.01	1.31	1.10	1.51	1.30
Bethany Falls	1.18	1.33	1.34	1.55	1.38	3.12	3.49	3.50	4.01	3.61
Meramec Gravel	1.60	1.76	2.13	2.53	2.05	3.94	4.32	5.19	6.10	4.99
Material Soaked 24 Hours from As Received Condition										
Chouteau - L #1	2.37	2.34	2.65	3.35	2.68	5.97	5.88	7.39	8.28	6.89
Chouteau - L #2	2.51	2.84	2.98	3.68	3.08	6.28	7.08	7.39	8.00	7.29

(a) Blended means the gravity of the aggregate blended to the ratio 2.5:45.5:27.0:25.0 for the four fractions 1" to 3/4", 3/4" to 1/2", 1/2" to 3/8" and 3/8" to #4 respectively.

Table A-4

Relationship of Absorptions of Coarse Aggregates Based on the Timed Soak and Vacuum Saturated Conditions

Coarse Aggregate	Absorption Ratio by Weight (%)[a] 1" to 3/4"	3/4" to 1/2"	1/2" to 3/8"	3/8" to #4	Blended[b]	Absorption Ratio by Volume (%)[a] 1" to 3/4"	3/4" to 1/2"	1/2" to 3/8"	3/8" to #4	Blended[b]
Material Soaked 2 Hours From As Received Condition										
Chouteau - L #1	75.47	72.09	77.02	81.05	75.72	75.52	72.41	77.23	80.96	76.06
Chouteau - L #2	72.96	76.10	76.74	84.82	78.59	73.14	79.26	77.08	84.95	78.79
Plattin	100.00	88.89	85.42	100.00	92.31	100.00	91.61	84.62	100.00	92.86
Bethany Falls	88.06	95.00	79.76	95.68	90.20	88.64	95.36	79.91	95.02	90.48
Meramec Gravel	57.97	62.41	62.83	67.83	64.06	58.11	62.25	62.98	67.63	63.89
Material Soaked 24 Hours from As Received Condition										
Chouteau - L #1	89.43	77.74	85.76	97.67	85.62	89.10	77.98	95.60	97.30	88.22
Chouteau - L #2	81.76	89.31	86.63	96.34	90.32	81.88	89.40	86.84	85.38	86.37

(a) All computations are based on the vacuum absorption being the divisor.
(b) Blended means the gravity of the aggregate blended to the ratio 2.5:45.5:27.0:25.0 for the four fractions 1" to 3/4", 3/4" to 1/2", 1/2" to 3/8" and 3/8" to #4 respectively.

Table A-5

Los Angeles Abrasion Test and Alcohol Freeze Test Results on Aggregate as Received

Coarse Aggregate	L. A. Percent Wear	Alcohol Freeze
A	32	Some Unsoundness
B	33	Some Unsoundness
C	22	Some Unsoundness
D	26	(2)
D[1]	-	Some Unsoundness
E	19	Some Unsoundness

Coarse Aggregate D was also sampled for Deleterious Material:

Deleterious Rock	3.3%
Shale	0.3%

(1) This sample was prepared by removing all deleterious material prior to testing.

(2) Some to moderate unsoundness.

Table A-6

Properties of Cement

Physical

Normal Consistency, percent	23.6
Soundness, Autoclave	0.19
Initial Set (Hrs. & Min.)	3:05
Final Set (Hrs. & Min.)	4:35
Tensile Strength, avg. psi	
3 days	322
7 days	472
Compressive Strnegth, avg. psi	
3 days	2055
7 days	3655
Specific Surface, Blaine ($cm^2/g.$)	3700
Specific Gravity	3.15

Chemical

Percent SiO_2 (Silica)	22.18
Percent CaO (Calcium Oxide)	64.21
Percent MgO (Magnesium Oxide)	4.15
Percent Fe_2O_3 (Iron Oxide)	2.12
Percent Al_2O_3 (Aluminum Oxide)	5.38
Percent SO_3 (Sulphur Trioxide)	1.54
Percent Insoluble Residue	0.45
Percent Loss on Ignition	0.66
Percent Na_2O (Sodium Oxide)	0.16
Percent K_2O (Potassium Oxide)	0.17
Percent C_3S (Tricalcium Silicate)	48.9
Percent C_2S (Diacalcium Silicate)	26.8
Percent C_3A (Tricalcium Aluminate)	10.8
Percent Total Alkali as Na_2O Equiv.	0.27

This sample complies with AASHO M85-70 specifications for Type I cement.

APPENDIX B

MIX DESIGN AND BATCHING

The number and distribution of concrete specimens necessary to evaluate each variable in this test is shown in Table B-1. The concrete was batched in either 0.68 or 0.50 cubic foot size for the three or four beams as required. For each specific combination of variables, four comparable batches were necessary to fabricate the required number of specimens. The 48 separate batches were divided equally into four groups which represented four sets of two mixing days each, then were randomized within each group, representing the daily mixing schedules. Mixing was completed over eight consecutive working days.

The fine aggregate was batched in an air-dry state. Allowance was made in the calculated weight of water required for the mix design to provide for the two-hour absorption of the fine aggregate at the time it was used.

The coarse aggregates were either vacuum saturated and stored under water a minimum of 48 hours, soaked for 2 hours, or soaked for 24 hours before batching. All soaking was done at room temperature on as received stone. The vacuum technique used required the coarse aggregate to be oven dried prior to placing in the vacuum machine otherwise the proper vacuum could not be obtained.

The concrete was mixed in a Lancaster SW laboratory mixer. The coarse aggregate, cement and sand were dry mixed for one minute, then water and the air-entraining agent were added and mixed another three minutes. Immediately after mixing, slump and air content determinations were made. The average results of the four batches for each mix design are shown in Table B-2. The material used in these tests was then remixed by hand with the remainder of the batch and the required number of beams molded.

Molding of the beams was accomplished in the following manner. The $3\frac{1}{2}$x$4\frac{1}{2}$x16 inch beams were molded by placing two lifts and rodding each 50 times with a 5/8" bullet-pointed rod, spaded around the edges, tapped lightly to settle the concrete, struck off with a metal bar, and finished with a wooden float.

Stainless steel strain gauge plugs were molded into the top and bottom of all beams that were to be subjected to the freeze and thaw test or outdoor exposure. Plugs were made from stainless steel rod 3/8 inch in diameter cut to 3/4 inch in length. The cylindrical surface of the plugs were roughened by machining a spiral groove to aid in bonding. A 1/16 inch hole approximately 3/16 inch deep was drilled in each plug and all burrs removed by very slight hand reaming.

CURING

Immediately after fabrication, the concrete beams were placed in a moist room controlled at approximately 73°F and 95 percent relative humidity. The following day the molds were removed and the concrete beams were weighed in air and water to establish their densities and initial length measurements taken. Thereafter, the beams were handled as follows:

Control Beams: The 48 control beams to be broken in flexure were kept in the moist room on shelves until seven days old, then were stored in limewater at 73 ± 3°F until they were broken in flexure at 35 days.

Slow Freeze and Thaw Beams: The 48 freeze and thaw beams were kept in the moist room on shelves until seven days old, then were stored in limewater at 73 ± 3°F until they were subjected to the slow freeze and thaw test beginning at 35 days. Thereafter, the beams were subjected to one freeze and thaw cycle each week with interum storage in saturated limewater at room temperature.

Fast Freeze and Thaw Beams: The 48 freeze and thaw beams were kept in the same initial curing conditions as the slow cycle beams. After 35 days, however, the beams were subjected to two freeze and thaw cycles daily during the normal work week. The only soak time after 35 days that these beams received was the 1½ hour thaw periods after each cycle. The beams remained in the freezer on the weekends and holidays.

CONCRETE BEAM IDENTIFICATION

To properly identify each individual concrete beam the following abbreviated identification was used:

For Example: A12A-8

The code used in this test is as follows:

Column 1 - indicates the type of coarse aggregate being:
- A = Chouteau Ledge 1
- B = Chouteau Ledge 2
- C = Plattin
- D = Bethany Falls
- E = Meramec Gravel

Columns 2 and 3 - when appropriate indicates the individual beam number and the test to which that beam is to be subjected as follows:

Beam No's.
- 1 thru 4 = Control Beams
- 5 thru 8 = Slow Freeze and Thaw
- 9 thru 12 = Fast Freeze and Thaw
- 13 thru 16 = Pit Beams

Column 4 - indicates the moisture condition of the aggregate prior to mixing as follows:
- A = Vacuum Saturated
- B = 2 Hour Soak
- C = 24 Hour Soak

Column 5 - or the numeral after the hyphen, indicates the mixing day which that beam was molded, being a value from 1 to 8.

The properties of each mix design are shown in Table B-2.

RESULTS OF TESTS ON FRESH CONCRETE AND CONTROL BEAMS

The average air content, slump, water-cement ratio, and cement factor for each mix design are shown in Table B-2. Also shown at the bottom of the table are the grand averages of all mix designs combined and the relative standard deviations for each characteristic.

The results of the flexural tests from the control beams are shown in Table B-3. One break on each of the 14 inch and 7 inch spans were made on each of the control beams and averaged.

The data shown in these tables indicate that the characteristics of the limestone aggregate mix designs were fairly consistent, thereby eliminating the chance for excessive variability between mix designs. The gravel aggregate reflected a slightly lower flexural strength which is expected with this type of stone because of the bonding strength with the matrix.

Table B-1

Distribution of Concrete Specimens

Aggregate Condition	Test Condition	Coarse Aggregate A	B	C	D	E
Vacuum Saturated:	Control	4	4	4	4	4
	Fast F & T	4	4	4	4	4
	Slow F & T	4	4	4	4	4
	Outdoor Pit	4	4	-	-	-
2 Hour Soak:	Control	4	4	4	4	4
	Fast F & T	4	4	4	4	4
	Slow F & T	4	4	4	4	4
	Outdoor Pit	4	4	-	-	-
24 Hour Soak:	Control	4	4	-	-	-
	Fast F & T	4	4	-	-	-
	Slow F & T	4	4	-	-	-
	Outdoor Pit	4	4	-	-	-

Table B-2

Results of Tests Made on Fresh Concrete Immediately After Mixing

Fresh Concrete Test	Coarse Aggregate				
	A	B	C	D	E
Vacuum Saturated Aggregate:					
Air Content (%)	5.260	5.260	5.045	4.770	5.145
Slump (inches)	3.157	3.032	3.060	2.625	3.688
w/c Ratio	0.580	0.585	0.590	0.592	0.578
Cement Factor	1.568	1.565	1.568	1.570	1.572
2 Hour Saturation:					
Air Content (%)	5.500	5.002	4.990	4.600	4.782
Slump (inches)	3.342	3.342	3.000	2.782	3.095
w/c Ratio	0.592	0.590	0.588	0.585	0.568
Cement Factor	1.558	1.565	1.570	1.578	1.580
24 Hour Saturation:					
Air Content (%)	5.240	5.460	-	-	-
Slump (inches)	3.280	3.155	-	-	-
w/c Ratio	0.582	0.578	-	-	-
Cement Factor	1.568	1.565	-	-	-

Evaluation of All Mix Designs Combined:

	$\bar{x}$	
Air Content (%)	5.09	0.44
Slump (inches)	3.13	0.54
w/c Ratio	0.58	0.01
Cement Factor	1.57	0.01

Table B-3
Flexural Strengths of Concrete Beams Subjected to the Freeze and Thaw Tests

Concrete Identification	Control - 35 Day 14" Span	Control - 35 Day 7" Span	Freeze and Thaw Specimen 14" Span	% Loss	7" Span	% Loss
Fast Freeze and Thaw Test Method — Coarse Aggregate Vacuum Saturated						
Chouteau - Ledge 1	918	1013	280	69.5	526	48.1
Chouteau - Ledge 2	909	978	464	49.0	500	48.9
Plattin Limestone	1006	1141	588	41.6	808	29.2
Bethany Falls	963	1100	258	73.2	630	42.7
Meramec Gravel	856	938	236	72.4	328	65.0
Coarse Aggregate Soaked Two-Hours						
Chouteau - Ledge 1	931	987	873	6.2	852	13.7
Chouteau - Ledge 2	904	1001	826	8.6	892	10.9
Plattin Limestone	1062	1167	746	29.8	929	20.4
Bethany Falls	923	1072	685	25.8	812	24.2
Meramec Gravel	943	947	326	65.4	438	53.7
Coarse Aggregate Soaked 24-Hours						
Chouteau - Ledge 1	927	1001	804	13.3	929	7.2
Chouteau - Ledge 2	900	1006	481	46.6	896	10.9

Table B-3 (Continued)

Flexural Strengths of Concrete Beams Subjected to the Freeze and Thaw Tests

Concrete Identification	Control - 35 Day		Freeze and Thaw Specimen			
	14" Span	7" Span	14" Span	% Loss	7" Span	% Loss
Slow Freeze and Thaw Test Method — Coarse Aggregate Vacuum Saturated						
Chouteau - Ledge 1	918	1013	372	59.5	378	62.7
Chouteau - Ledge 2	909	978	422	53.6	452	53.8
Plattin Limestone	1006	1141	333*	66.9*	464*	59.3*
Bethany Falls	963	1100	318	67.0	410	62.7
Meramec Gravel	856	938	306	64.2	365	61.1
Coarse Aggregate Soaked Two-Hours						
Chouteau - Ledge 1	931	987	581	37.6	794	19.6
Chouteau - Ledge 2	904	1001	924	+ 2.2	892	10.9
Plattin Limestone	1062	1167	480	54.8	466	60.1
Bethany Falls	923	1072	305	67.0	372	65.3
Meramec Gravel	943	947	290	69.2	328	65.4
Coarse Aggregate Soaked 24-Hours						
Chouteau - Ledge 1	927	1001	808	12.8	944	5.7
Chouteau - Ledge 2	900	1006	704	21.8	864	14.1

* Average of three beams - One beam accidently broken at 99 cycles.

APPENDIX C

FREEZING AND THAWING TEST PROCEDURES

Long Term Test:

The Missouri long term freeze and thaw test is a modification of the method described by T. C. Powers in his paper "Basic Considerations Pertaining to Freeze and Thaw Tests", ASTM Proceeding, Vol. 55, pp. 1132-1155, 1955. Under the Missouri procedure, the concrete beams are cooled from room temperature to $40^{O}F$ in a water bath for 1.5 hours prior to being placed in the freezer. The concrete beams are frozen in air, the temperature of which is maintained at $0^{O}F$. The beams are thawed by placing in $40^{O}F$ water for 1.5 hours.

The Missouri long term test allows for one cycle of freeze and thaw per week with interim storage at room temperature in a saturated limewater solution. Figure C-1 shows a typical rate of freeze obtained by this method.

Short Term Test:

The Missouri short term freeze and thaw test follows the same thawing and freezing conditions as described for the long term test, however, the storage between cycles is eliminated. Freezing and thawing is accomplished at the rate of two cycles per day. One cycle is the same as that shown in Figure C-1 which occurs overnight and the other cycle is that shown in Figure C-2 which occurs during the normal working day.

The Missouri short term test does not allow for storage in water for extended periods of time. On weekends or periods where the tests are not made, the beams remain in the frozen condition in the freezer.

Common to both of the Missouri Freeze and Thaw test procedures, the recorded results for each beam are the change in length, weight, and fundamental sonic frequency. These tests are made before and after each freeze cycle with the beams in a $40^{O}F$ saturated surface dry condition.

The change in length was measured on a 10 basis with a Whittemore strain gage to the nearest 0.01 inch on both the top and bottom of each beam. Details or the gauge points and methods of setting in the fresh concrete are described in Appendix B.

The change in weight was measured to the nearest gram on a laboratory Toledo balance. Due to handling the concrete beams over a period of many cycles, some chipping of the corners and edges is inevitable. Where possible, notation was made when large chips and excessive changes in weight occurred.

The change in dynamic modulus of elasticity as a function of the change in fundamental sonic frequency was measured electronically by the use of a frequency probe and pickup system complying with that described in ASTM C215.

All the tests are made as quickly as possible to prevent excessive warming or drying of the beams. All correlations to date have not indicated any discrepancy nor variability caused by these methods in the results obtained by these freeze and thaw procedures.