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16. Abstract

Coarse Aggregates for use in Portland Cement concrete pavements are tested for Freeze-Thaw (F-T) durability properties by many state departments of transportation (DOT). Various test methods for determining F-T durability properties and corresponding specifications, are employed by the DOT's. This investigation compares the F-T rating test methods, specifications and test results of five mid-western states DOT's (Illinois, Kansas, Michigan, Minnesota and Ohio). Each state DOT received and tested splits from the samples of coarse aggregate taken from four limestone/dolomite sources. The DOT's followed their normal testing protocol for evaluating coarse aggregate F-T properties. Each state DOT assessed the coarse aggregate as if for use in premium pavements that include 1-inch maximum size material. The participating state DOT's justification for their individual test procedures and associated specifications is not questioned in this study. This investigation is specifically intended to provide a bench mark for each DOT to use as a basis for comparison of their coarse aggregate F-T rating programs.

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MICHIGAN DEPARTMENT OF TRANSPORTATION
MDOT

Multi-State Coarse Aggregate Freeze-Thaw Comparison

Thomas B. Woodhouse

Testing and Research Section
Construction and Technology Support Area
Research Project TI-2042
Research Report R-1469

Lansing, Michigan
July 2005

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The Michigan Department of Transportation (MDOT) would like to thank the laboratory staff from the Illinois, Kansas, Minnesota and Ohio departments of transportation for their participation in this study.

Table of Contents

Executive Summary

Four Sources of limestone / dolomite coarse aggregate were sampled by the Michigan Department of Transportation (MDOT), and distributed to five state DOT's (Illinois, Kansas, Michigan, Minnesota and Ohio). Each state DOT evaluated the four coarse aggregate samples for compliance with their specific freeze-thaw specifications for maximum or nominal maximum 1-inch coarse aggregate.

The four sources of coarse aggregate sampled are identified as follows:

Source **A**; **Wallace Stone**, in Bay County Michigan, Mi. Source Number 32-4
Source **B**; **Rockwood Stone**, in Monroe County Michigan, Mi. Source Number 58-8
Source **C**; **Cedarville**, in Mackinac County Michigan, Mi. Source Number 49-65
Source **D**; **Marblehead Quarry**, in Ottawa County Ohio, Mi. Source Number 93-1

The summary of results from the study, based on each state DOT's applicable specification requirements for high commercial ADT (premium) pavements, is as follows:

Aggregate Source

State DOT	A	B	C	D
Illinois	Fail	Fail	Pass	Fail
Kansas	Fail	Fail	Pass	Pass
Michigan	Pass	Fail	Pass	Fail
Minnesota	Pass	Fail	Pass	Fail
Ohio	Fail	Fail	Pass	Pass

Cedarville: Passed all the participating state DOT's applicable specifications.

Rockwood Stone: Failed all the participating state DOT's applicable specifications.

Wallace Stone and Marblehead Quarry: Failed 3 and passed 2 state DOT's applicable specifications.

Details regarding the coarse aggregate samples and the individual state DOT test methods and specifications are included in the body of this report.

Project Summary

Objective

This freeze-thaw (F-T) durability rating study was conducted to compare and benchmark the coarse aggregate F-T durability test methods, test results, specifications and relative quality ratings of five mid-western states (Illinois, Kansas, Michigan, Minnesota, Ohio).

Research Plan by Task

The study encompassed the following tasks. The duration for the entire study was approximately nine months.

Task 1: Sampling

MDOT selected, sampled, processed and delivered aggregate samples to the four other participating state DOT's. This task was initiated in September, 2004, and completed in November, 2004.

Task 2: Data Collection

Each state DOT tested the aggregate samples provided by MDOT, using their respective F-T related test procedures. This task was completed in May, 2005.

Task 3: Reporting

Participating states reported their final results to MDOT, as well as information regarding their test methods, specifications, rankings, and other information developed during testing. This task was completed in May, 2005.

After compiling the data and information provided by the participating state DOT's, MDOT submits a draft report to the participating states on June 17, 2005 for their respective comments.

MDOT issues a final report for the project on July 15, 2005.

Objective

This freeze-thaw (F-T) durability rating study was conducted to compare and benchmark the coarse aggregate F-T durability test methods, test results, specifications and relative quality ratings of five mid-western states (Illinois, Kansas, Michigan, Minnesota, Ohio).

Background

Some aggregate producers have expressed concern that the test methods and specifications developed and employed by state departments of transportation (DOT's) for evaluating the freeze-thaw (F-T) resistance of coarse aggregates may lead to disparities in coarse aggregate source quality ratings from state to state. Given that each state may have specific rationale for adopting their F-T test procedures and specifications, these data are not intended to make a judgment as to the validity of a given test method or specification, but rather to provide a comparison of results.

Five state DOT's (Illinois, Kansas, Michigan, Minnesota, Ohio) volunteered to be take part in the data collection necessary to compare coarse aggregate F-T durability acceptance test ratings. Each state received four coarse aggregate samples gathered from four quarried limestone/dolomite sources. The coarse aggregates were selected by the Michigan Department of Transportation (MDOT) with the objective of choosing sources representing historic F-T results that ranged from highly F-T resistant, to borderline F-T resistant, based on Michigan's F-T test procedures and specifications. The coarse aggregate samples provided to the participating DOT's were maximum size 1 inch (3/4 inch nominal maximum). Illinois required an additional small amount of 1 inch material. Kansas required only ½ and 3/8 inch material for their test. The four samples were identified by the letters A, B, C, and D. Each state DOT tested the samples in their own laboratory according to their own unique methods, and rated each aggregate sample test result using their own F-T specification requirements for high average daily traffic (ADT) volume Portland cement concrete (PCC) pavement with coarse aggregate gradation, as listed in Table 10.

Summary of Laboratory Findings

General results from testing, and information about individual state DOT testing procedures and specifications are presented in the accompanying tables. Table 1 enumerates MDOT's petrographic examination of aggregate sub-types found within each coarse aggregate sample. Tables 2 through 6 provide information about each state's test methods and specifications. The Pass/Fail criteria documented in Table 7 is derived from each state's specification for coarse aggregate F-T durability when used in high commercial ADT (premium) PCC pavement. Table 8 represents how each state DOT ranked the four coarse aggregate samples for F-T durability. Table 9 lists F-T test results for each coarse aggregate source, and each participants F-T specification limit for high commercial ADT (premium) pavement. Table 10 (included in appendix A) provides specific information about each participating states standard aggregate gradation that includes ¾ inch material, similar to the Michigan Series 6AAA coarse aggregate. Appendix B includes photographs of equipment and specimens from the participating state DOT's.

Coarse Aggregate Characteristics

Table 1, MDOT petrographic composition and Iowa Pore Index test results for the coarse aggregate sources in this study.

Source A

2 Distinct Rock Subtypes

Petrographic Composition	Percent of Sample	Primary Load	Pore Index
Dense Tan/Gray Limestone	91.9	60	33
Dense Dark Brown Limestone	8.1	32	14

Source B

6 Distinct Rock Subtypes

Petrographic Composition	Percent of Sample	Primary Load	Pore Index
Dense Gray/Brown Dolomite	16.6	50	41
Absorbent Grey/Brown Dolomite	61.3	171	28
Absorbent Tan Dolomite	13.7	236	17
Absorbent Mottled Dolomite	4.5	102	146
Shaley, etc. Dolomite	0.7	n/a	n/a
Grey Absorbent Chert	3.2	45	91

Source C

2 Distinct Rock Subtypes

Petrographic Composition	Percent of Sample	Primary Load	Pore Index
Dense White Dolomite	24.9	35	12
Dense Grey Dolomite	75.1	27	12

Source D

2 Distinct Rock Subtypes

Petrographic Composition	Percent of Sample	Primary Load	Pore Index
Dense Grey/Brown Dolmitic Limestone	41.0	68	33
Absorbent Grey/Brown Dolomitic Limest	59.0	217	14

Table 1 Note:
The aggregates were sieved to separate the 5/8-inch size particles for analysis, then oven-dried.
The aggregates were then pressure-saturated in the pore index chamber to be sorted into dense and absorbent subtypes.
Particles were then classified as either having a *dry* appearance or a *damp* appearance.
Particles designated as *dry* are dense to very finely porous. Particles designated as *damp* are absorbent, containing predominantly large, open pores.

Source A (Figure 1) is located in the Bayport Limestone Formation, Meramec Group, of Late Mississippian age. Concrete aggregate from this quarry has light brown to grey color. The particles are fine grained, and dense to slightly porous, with Mohs scratch hardness of 3. Freshly crushed particles have sharp to slightly rounded edges and rough to moderately smooth surfaces. The formation is locally cherty and arenaceous with rounded frosted quartz grains.

As tested by MDOT, Bulk Dry Specific Gravity is 2.62 and 24 hour Absorption Percent is 1.07. Saturated Absorption percent is 1.14.

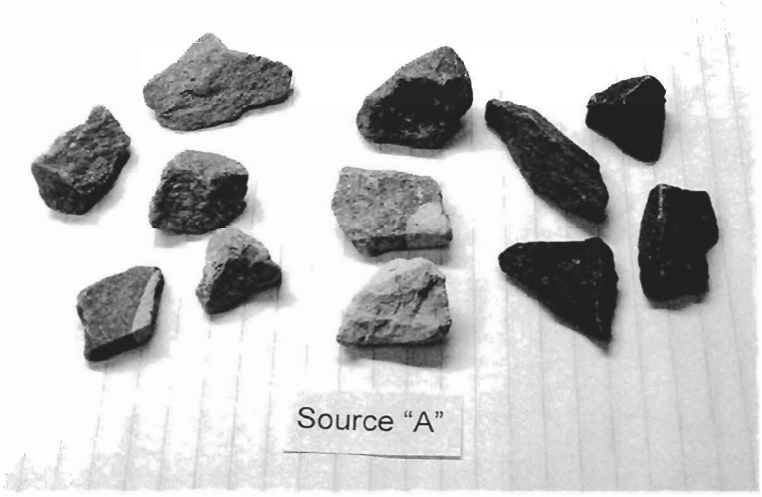


Figure 1

Source B (Figure 2) is located in the base of the Bois Blanc Formation, Detroit River Group, of the Devonian age, and the Raisin River Formation, Bass Island Group, of late Silurian age. Concrete aggregate from this quarry has light brown to grey color. The particles are composed of fine grained to microcrystalline, dense to porous limey dolomite with Mohs scratch hardness of 3-½ to 4. This aggregate has fairly high absorption. Freshly crushed particles have sharp fracture edges and moderately smooth surfaces.

As tested by MDOT, Bulk Dry Specific Gravity is 2.58 and 24 hour Absorption Percent is 2.77. Saturated Absorption percent is 3.79.

Figure 2

Source C (Figure 3) is located in the Engadine Dolomite Formation, Niagaran Group, of Middle Silurian age. Specifically, of the two layers of similar material produced at this source the layer produced at the time of sampling is in the Rapson Creek Dolostone. Concrete aggregate from this quarry generally has white buff, some grey, and mottled white to grey color. The particles are composed of fine grained to micro crystalline, subhedral to anhedral, slightly porous dolomite with Mohs scratch hardness of 3-½ to 4. Freshly crushed particles have sharp fracture edges and rough surfaces.

As tested by MDOT, Bulk Dry Specific Gravity is 2.80 and 24 hour Absorption Percent is 0.40. Saturated Absorption percent is 0.62.

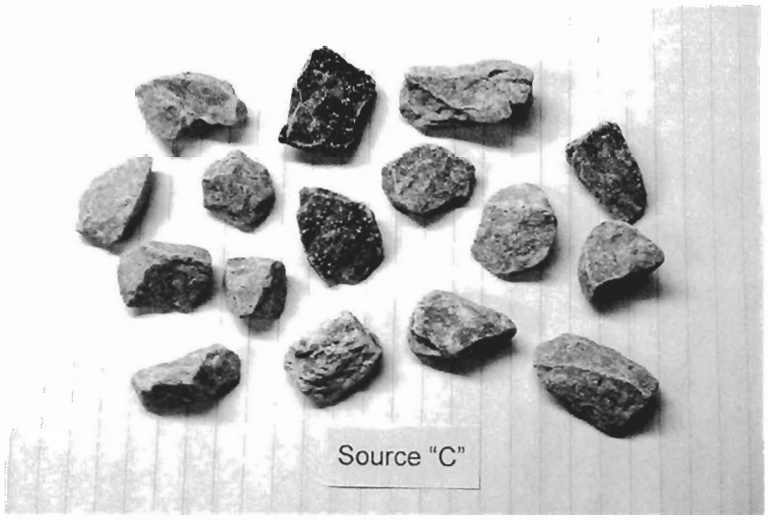


Figure 3

Source D (Figure 4) is located in the Columbus Limestone Formation and the Detroit River Group (Lucas Dolomite) of Devonian age. Concrete aggregate sampled from this quarry is tan to brown and gray in color with some laminations, chert and sparse fossils. The particles range from fine to coarse grained and are absorptive. Some of the particles abrade easily.

As tested by MDOT, Bulk Dry Specific Gravity is 2.49 and 24 hour Absorption Percent is 3.36. Saturated Absorption percent is 4.62.

Figure 4

Comparison of Participating States Testing Procedures:

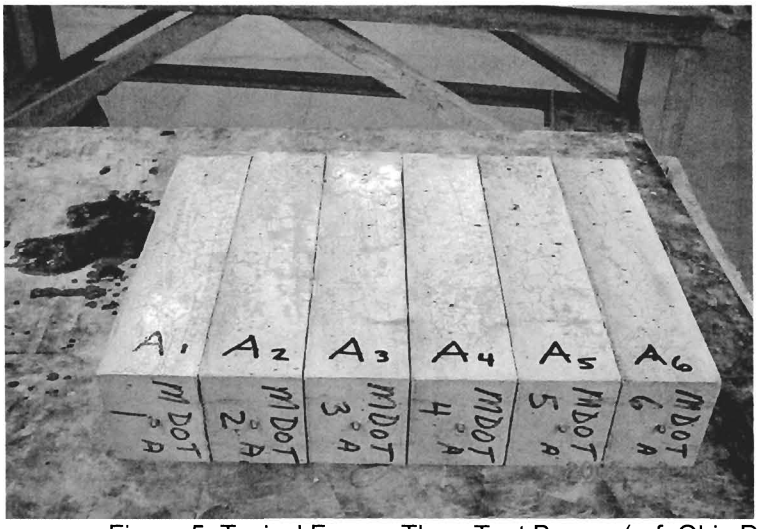


Figure 5, Typical Freeze-Thaw Test Beams (ref. Ohio DOT)

Table 2, Individual State PCC Coarse Aggregate Durability Testing Methods.

	Illinois	Kansas	Michigan	Minnesota	Ohio
ASTM C88 (Magnesium Sulfate Soundness)				X	
(Sodium Sulfate Soundness)	X				X
ASTM C666	X	X	X		X
Procedure A					
Procedure B	X	X	X		X
Years of Testing Program	20	25	50	Approx. 15	26
Frequency of Testing (Site)	2 years (9)	3 per yr (8)	5 Years (1)	Yearly, (6)	2 Years (4)
Individual Source Strata Tested?	Yes (10)	Yes	No (2)	No	No
Spot checks between F-T tests?	Yes (11)	Yes (7)	Yes (3)	No	Yes (5)
Manufacturer of F-T cycling equipment	Punzak	ScienTemp	ScienTemp		ScienTemp

Table 2 Notes:

1, Sources tested every 5 years or earlier if requested by any party based on changes in material or specifications.
2, Individual strata are not specified or approved separately but may be tested for information.
3, Specific Gravity may not change by more than 0.04 less than the last passing F-T test sample.
4, Marginal sources valid for only 1 year.
5, If notable changes in the Sodium Sulfate Soundness, L.A. Abrasion, Deleterious Material, Specific Gravity or Absorption occur before the expiration date.
6, Marginal sources tested during production.
7, "When any party feels that any change in prequalified status of a quarry is warranted."
8, F-T test run only on Limestones for "on-grade" concrete slabs in projects requiring more than 5000 tons and only on producing sources.
9, Testing every 2 years for sources with <0.031 expansion and every year for sources with >0.030 expansion.
10, If the production method is changed, the material is retested before it is allowed for use.
11, Random samples are taken at concrete plants and tested for quality. Retests may be taken at the source as well.

Table 3, Aggregate Characteristics for PCC F-T Test Batches.

	Illinois	Kansas	Michigan	Minnesota	Ohio
Coarse Aggregate (CA) / Max. Size in. (6)	CA-7 / 1.5	MA-3, Cl. 2 / 1	6 Series / 1.5	CA 50 / 1	Ohio 57 / 1.5
Maximum Size, in. (for F-T test batches)	1.5 (2)	3/4	1		1
F-T Test Gradation - Fixed	x	x	x		
As Received					x
Aggregate Types Tested				Research	
Limestone / Dolomite	x	x	x	x	x
Natural Gravel	x		x	x	x
Igneous / Metamorphic	x		x	x	
Slags	x		x	x	
Other	(7)		(7)		
Moisture Conditioning					
Dried prior to moisture conditioning?	Yes	Yes	Yes		No
Moisture Conditioning procedure	24 hr soak	24 hr soak	Vac Sat (1)		24 hr soak
Fine Aggregate (FA)			Natural		
Gradation Designation	(8)	(5)	2NS (3)		(4)
Moisture Conditioning	24 hr soak	As Received	> SSD		24 hr soak

Table 3 Notes:

1, 24 hour Vacuum Saturation and Soak placing all natural sources in a saturated state prior to mixing.
2, Small amount of 1 inch material provided by MDOT for Illinois test method.
3, 95-100 pass #4, 65-95 pass #8, 35-75 pass #16, 20-55 pass #30, 10-30 pass #50, 0-10 pass #100
4, 100% pass 3/8, 95-100 pass #4, 70-100 pass #8, 38-80 pass #16, 18-60 pass #30, 5-30 pass #50, 1-10 pass #100, 0-5 pass #200
5, 90 - 100% pass #4, 73 - 100 pass #8, 45 - 85 pass #16, 25 - 60 pass #30, 10 - 30 pass #60, 0 - 10 pass #100.
6, Approximate gradation each state ran F-T test to evaluate. (See Table 10)
7, Other types of aggregate may be tested.
8, 100% pass #4, 87% pass #8, 67% pass #16, 42% pass #30, 9% pass #50, 0% pass #100

Table 4, F-T Test Concrete Mixture Details.

	Illinois	Kansas	Michigan	Minnesota	Ohio
Proportioning method	(6)	(4)	Mortar Void	(7)	(2)
Cement type	I	I/II	I		I
Single cement source used	x	x			x
Multiple cement sources blended			(3)		
Specified cement content, lbs/cyd	564	601.6	517		600
Slump parameters, in.	2 to 4	1.5 to 2.5	2 to 3		none
Air Content parameters, %	5.5 +/- 1.5	5 to 7	7, +2 -1		6 +/- 2
Air Entraining product		Air Tite	MBVR (1)		
Water Cement ratio parameter?	0.46	0.44 to 0.49	no (3)		0.5
Water Reducer used?			no		
Coarse Aggregate Content, b/bo		(5)	0.75		(2)
Strength specimens made?	yes	no	yes		no

Table 4 Notes

1, Vinsol Resin from "Master Builders"
2, Ohio DOT Class C Mix Design. Fixed weights for stone, sand, and cement.
3, Michigan blends equal parts of 3 sources of Type I cement. W/C for F-T batches ranges from 0.42 to 0.50.
4, Test Mix parameters fixed by Kansas test method KTMR-22.
5, "25% -3/4 + 1/2, 25% -1/2 +3/8, 50% Fine Aggregate" as specified in KTMR-22.
6, Illinois Modified Method
7, Table 4 not applicable to the Minnesota F-T screening method.

Table 5, F-T Test Specimen and Test Data.

	Illinois	Kansas	Michigan	Minnesota	Ohio
Type of specimens tested	Beams	Beams	Beams	(5)	Beams
Number of specimens tested	3	3	9		6
Concrete batches required for specimens	1	1	3		1
Test specimens cast per batch	3	3	3		6
Beam dimensions, in.	3x4x15	3x4x16	3x4x15.5		3x4x15
Specimen gage point location	Ends	Ends, (7)	Ends, (1)		Ends, (2)
Length of curing, days	14	90	14		15
Type of curing	Fog Room	(6)	(4)		(3)
Normal Max F-T Cycles per specimen	350	300	300		350
Normal F-T cycle length, minutes.	180	180	180		120
Nominal Temperature Range of F-T cycle, F	0 to 40	0 to 40	0 to 40		0 to 40
Length Change, Yes/No	Yes	Yes	Yes		Yes
Relative Dynamic Modulus, Yes/No	No	Yes	No		Yes
Weight Change, Yes/No	No	Yes	No		Yes
Visual Inspection, Yes/No	Yes	Yes	Yes		Yes

Table 5 Notes

1, 13.5 inch gage length. (Gage length is the distance between the inner ends of the gage studs)
2, 13 inch gage length
3, Fog room in molds first 24 hours, then 14 days water immersion.
4, First 24 hrs. in molds under wet burlap, 12 days immersion (standard curing), 1 day immersion at 40 F.
5, Magnesium Sulfate Soundness test is employed for rating F-T durability of coarse aggregates.
6, "Fog room for 67 days, moved to room with 50% relative humidity and temp. 73F for 21 days, place in tempering tank at 70F for 24 hours at 88 days, in freezer 40F for 24 hours at 89 days."
7, 15 inch gage length.

Table 6. Coarse Aggregate F-T durability Testing Requirement and Specification Information.

	Illinois	Kansas	Michigan	Minnesota	Ohio
Purpose of F-T durability testing program	Screen sources for F-T "D-Cracking" characteristics	To reduce the risk of "D-Cracking" in "on-grade" concrete slabs such as concrete pavements.	Determine the relative F-T durability of coarse aggregate sources, and spec. compliance.	To provide sound aggregate for concrete	Qualifier for use in concrete pavements
Specification Requirements, 1" max	Length Change max 0.060 in 350 cycles	Length Change max 0.015% Durability Factor min 97 Soundness min 85%	0.067, 0.040, 0.010% beam expansion per 100 F-T cycles	15% maximim on the Magnesium Sulfate Test	Only for pavements, Area under the curve - 0 to 2.05
Frequency of retesting	Test result >0.030 test yearly. If <0.031 test every 2 years.	3 per year minimum per site for each project requiring > 5000 tons	Minimum testing every 5 years	Once per year	2 years for 0 to 1.0 1 year for 1.01 to 2.05
Exceptions to specification requirements	No F-T specification for superstructure and precast concrete.	None	More restrictive requirements may be imposed based on use	None	None
Failure criteria for 1 inch max size gradation	Length Change % per 350 F-T Cycles	Length Change % per 300 F-T Cycles Durability Factor Soundness	Expansion % per 100 Cycles	Max Loss in the Magnesium Sulfate Soundness Test	Area Under the Curve based on Length Change per 350 cycles
Primary and Secondary values for durability	Test Frequency may be affected. 20 yr. 0.060, 30 yr 0.040 40 yr 0.025	> 5% 3/4" = 0.015% LC & 97 DF < 5% 3/4" = 0.025% LC & 95 DF	Standard - 0.067 High Com. ADT - 0.040 Pre Stress - 0.010	Test Frequency may be affected.	Test Frequency affected - 2 years for 0 to 1.0 1 year for 1.01 to 2.05
Testing exceptions for various coarse aggregate	No	Only test Limestone & Dolomite for on-grade use. Kansas - Class 1 and 2	Blast Furnace Slag, Moisture conditioned by 24 hour soak	No	No, except Test Only Ohio #57 & 67
Limitations on use of coarse aggregate	No, except Downstate Gravels cannot be used in CRCP	All types must pass "Official Quality" Requirements	*No slag in patching, overlay or superstructure *< or> than 1" max usually by special provision only	If paving with quartzite or gneiss, GGBFS or F ash must be used. Must use low C1260 sand when paving.	No Use Only Ohio #57 & 67
Individual strata testing and specifying	Yes - each ledge tested. Production method and gradation separately (1)	Yes	Tested occasionally for info only.	No	No
Frequency of Soundness testing	Must pass soundness test before F-T testing proceeds.	Every F-T test.		Good Sources, 1 per year Borderline Sources - during production	Sample must pass soundness test before F-T testing proceeds.
F-T & Soundness, Correlated with field performance?	(2)	(2)			No

Table 6 Notes: 1. Illinois sources rated according to what production methods, gradations, and ledges have passing test results.
2, Only in that pavements have performed better since administering this test.

Test Results

Table 7, PCC Coarse Aggregate Source Durability Compliance for High Commercial ADT Pavement.
For Aggregate Grades Using Maximum or Nominal Maximum 1-inch coarse aggregate gradation. (8)

PASS / ***FAIL***

State	Aggregate Source A	B	C	D	Notes
Illinois	Fail	Fail	Pass	Fail	(1)
Kansas	Fail	Fail	Pass	Pass	(7)
Michigan	Pass	Fail	Pass	Fail	(2,6)
Minnesota	Pass	Fail	Pass	Fail	(3)
Ohio	Fail	Fail	Pass	Pass	(4,5)

Table 7 Notes:

1, Sources "A" & "D" would not have been accepted for F-T testing, or pavement use based on their failure of Illinois deleterious count limits.
Sources "A" and "B" Fail Illinois F-T specifications for 30 and 40 year pavement. (also see note 5 in Table 8)
2, Pass \ Fail results based on Michigan's specification for "High Commercial ADT Pavement", 0.040% dilation per 100 F-T cycles.
3, Soundness (Magnesium Sulfate) Loss at 5 cycles for any fraction of the coarse aggregate as used in the work. (15%)
4, Source "D" considered marginal (Testing every year, according to Ohio testing method)
5, Sources "A" and "B" not approved. According to Ohio testing method no retesting allowed without written substantiation from the producer that significant changes have been made to improve the quality of the aggregate.
6, Source "D" passes MDOT's standard specification but fails the more restrictive specification for high ADT pavement.
7, Source "B" fails for use in pavement concrete where greater than 5% retained on the 19mm sieve is specified, but would pass for concrete using coarse aggregate gradations with less than 5% retained on the 19mm sieve.
8, Maximum 1 inch coarse aggregate gradation roughly equivalent to Michigan 6AAA, (Kansas MA-3 - Class 2, Ohio #57, Minnesota CA-50, Illinois CA-7) (See Table 10)

Table 8, Ranking of Coarse Aggregate sample test results from highest durability to lowest durability.

Ranking 1 to 4.

State	Aggregate Source A (1)	B	C	D	Notes
Illinois	3	4	1	2	(5)
Kansas	4	3	1	2	(3)
Michigan	2	4	1	3	(4)
Minnesota	2	4	1	3	
Ohio	4	3	1	2	(2)

Note: A ranking of 1 = Most Durable, and 4 = Least Durable

Table 8 Notes:

1, Source "A" absorbs 94% of the Saturated Absorption in 24 hours of soaking (see source "A" description).
2, Ohio durability specification based on area under the curve after 350 F-T cycles.
3, Source "C" ranks only slightly higher than source "D" based on Durability Factor.
4, Source "A" passes MDOT specifications and ranks higher than sources "B and D" because F-T distress occurs much later in the F-T cycling
process than with sources "B" and "D". Therefore Source "A" withstood many more F-T cycles than sources "B & D" when all are saturated.
5, The Illinois rankings listed, are based solely on the Illinois **F-T Test** results. Preliminary testing according to Illinois procedures would
have eliminated sources "A" and "D" from F-T testing, and any use in PCCP. Also, source "B" is what Illinois determined to be a "borderline" source based on their preliminary tests, "and would constitute more testing before F-T testing".

Table 9, Individual State Test Results vs. Specifications for High Commercial ADT PCC Pavement.

Final Test results for sources A, B, C, & D

Illinois (5)		**Kansas**		**Michigan**		**Minnesota**		**Ohio**	
Spec.	Result	Spec. (4)	Result	Spec. (2)	Result	Spec.	Result (1)	Spec. (3)	Result
Maximum exp. In 350 cycles **0.025 (6)**	**A** - 0.045	Max. exp. in 300 cycles > 5% 3/4" **0.015**	**A** - 0.074	Maximum exp. per 100 cycles **0.040**	**A** - 0.019	Max. Loss for any Fraction **15**	**A** - 14.92	Area Under the Curve Maximum **2.05**	**A** - 5.32
	B - 0.054		**B** - 0.017		**B** - 0.070		**B** - 34.00		**B** - 4.28
	C - 0.009		**C** - 0.009		**C** - 0.001		**C** - 3.30		**C** - 0.05
	D - 0.011		**D** - 0.009		**D** - 0.062		**D** - 16.88		**D** - 1.61

Table 9 Notes:

1, For the Minnesota Magnesium Sulfate Soundness test the table includes only the largest loss on a size fraction at 5 cycles. (Minnesota Spec is, "Loss at 5 cycles for any fraction of coarse aggregate used in the work")

2, Michigan DOT specification for High Commercial ADT Pavement is 0.040 percent expansion per 100 F-T cycles.

3, Ohio durability specification based on Area Under the Curve after 350 F-T cycles.

4, Kansas F-T expansion % specification limit for coarse aggregate gradations with greater than 5% retained on the 3/4 inch sieve is 0.015.

Specification for Durability Factor for coarse aggregate gradations with greater than 5% retained on the 3/4 inch sieve is "97".

5, Illinois would not have F-T tested sources "A" and "D" based on their failure of deleterious count limits in a preliminary screening test.

Only source "C" would have been approved for use in 30 or 40 year pavement. Source "B" failed the F-T test for 30 and 40 year pavements, and was considered borderline in preliminary quality tests.

6, Illinois F-T specifications are 0.060 for 20 year pavement, 0.040 for 30 year pavement and 0.025 for 40 year pavement.

Discussion of Results

Although F-T test methods and specifications vary from state to state, it is interesting to find that the durability rankings of the four coarse aggregate sources are quite similar. Source "B" (Rockwood Stone) failed all 5 participating state DOT's durability specifications for use in high commercial ADT (premium) pavements with approximately 1 inch maximum aggregate gradation. Source "C" (Cedarville) passed all participating state DOT's durability specifications. Although Source "A" (Wallace Stone) passes the F-T durability specifications for Minnesota and Michigan, it did not pass the Illinois, Ohio, and Kansas specifications. Source "D" (Marblehead Quarry) failed 3 of the state DOT specifications. However it was considered marginal by one state, and passed the other. Source "A" absorbed water rapidly enough to reach 94 percent of its saturated absorption level in 24 hours of soaking. Whereas, source "D" absorbed 74 percent, source "B" - 73 percent, and source "C" - 65 percent of their saturated absorption levels for the same 24 hour soaking period.

As stated above, durability specifications for coarse aggregates used in Portland cement concrete differ from state to state. This is primarily due to the fact that they are based on regional considerations in conjunction with the particular testing protocol chosen by the respective DOT laboratories. Specifications may be more or less restrictive, and disagreements may arise concerning their limits. Questions may also arise concerning specification differences between DOT's. State DOT's strive to set the coarse aggregate F-T test requirements high enough safeguard against premature coarse aggregate related freeze-thaw deterioration.

Conclusions

This report to the participating state DOT's is meant only to present the pertinent information gathered within the context of this study. Its intent is to provide the participating states a comparison of their test methods, results, and F-T acceptance criteria as they apply to 1 inch maximum or nominal maximum size coarse aggregate gradations (limestone/dolomite) when used in high commercial ADT (premium) Portland cement concrete pavements. Hence, It is the prerogative of each individual state DOT to draw their respective conclusions relative to the comparison of test methods and results presented in this study.

Each of the five state DOT's participating in this study employ coarse aggregate F-T evaluation programs to address their needs. Two durability evaluation methods commonly employed in one form or another are the soundness test (AASHTO T 104, ASTM C88), and the F-T test (ASTM C666). Each state DOT's test methods address testing variables such as aggregate moisture conditioning and grading, cement content, coarse aggregate content, air content, curing methods, F-T cycling, guidelines for testing beam specimens, and reporting results. These state-specific evaluation and specification requirements were customized in response to particular local concerns such as aggregate availability, site specific field conditions, climatic considerations, as well as type and quality of local aggregates. Also, the severity of F-T related pavement problems historically encountered by state DOT's may affect the relative emphasis toward testing and ranking coarse aggregates for F-T durability. Some states may have more restrictive methods and specifications reflective of their local F-T materials related issues. Hence, it is important to exercise caution when attempting to draw a general assessment relative to the significance of any contrasting methods and results identified in this report. Questions regarding specific test procedures, or acceptance policies and specifications, should be directed to the participating states.

APPENDIX

Appendix A

Table 10, Standard Coarse Aggregate Gradations used in PCC Pavement and Rated for F-T Durability.

Coarse Aggregate
Michigan Class 6AAA

Sieve Analysis Total % Passing									
1.5 in	1 in	3/4 in	1/2 in	3/8 in	#4	#8	#30	#60	#100
100	95-100	60-85	30-60		0-8				

Coarse Aggregate
Ohio #57

Sieve Analysis Total % Passing									
1.5 in	1 in	3/4 in	1/2 in	3/8 in	#4	#8	#30	#60	#100
100	95-100		25-60		0-10	0-5			

Mixed Aggregate
Kansas MA-3 (Class 2 - Greater than 5 percent retained on the 3/4 inch sieve)

Sieve Analysis Total % Retained										
1.5 in	1 in	3/4 in	1/2 in	3/8 in	#4	#8	#16	#30	#50	#100
0	0	0-12	Note 1	Note 1	Note 1	Note 1	Note 1	Note 2	Note 2	95-100

Note:
1, Retain a maximum of 24 percent and a minimum of 8 percent of the material on each individual sieve.
2, Retain a maximum of 15 percent and a minimum of 8 percent of the material on each individual sieve.

Coarse Aggregate
Minnesota CA 50

Sieve Analysis Total % Passing									
1.5 in	1 in	3/4 in	1/2 in	3/8 in	#4	#8	#30	#60	#100
	100	85-100		30-60	0-12				

Coarse Aggregate
Illinois
CA-7

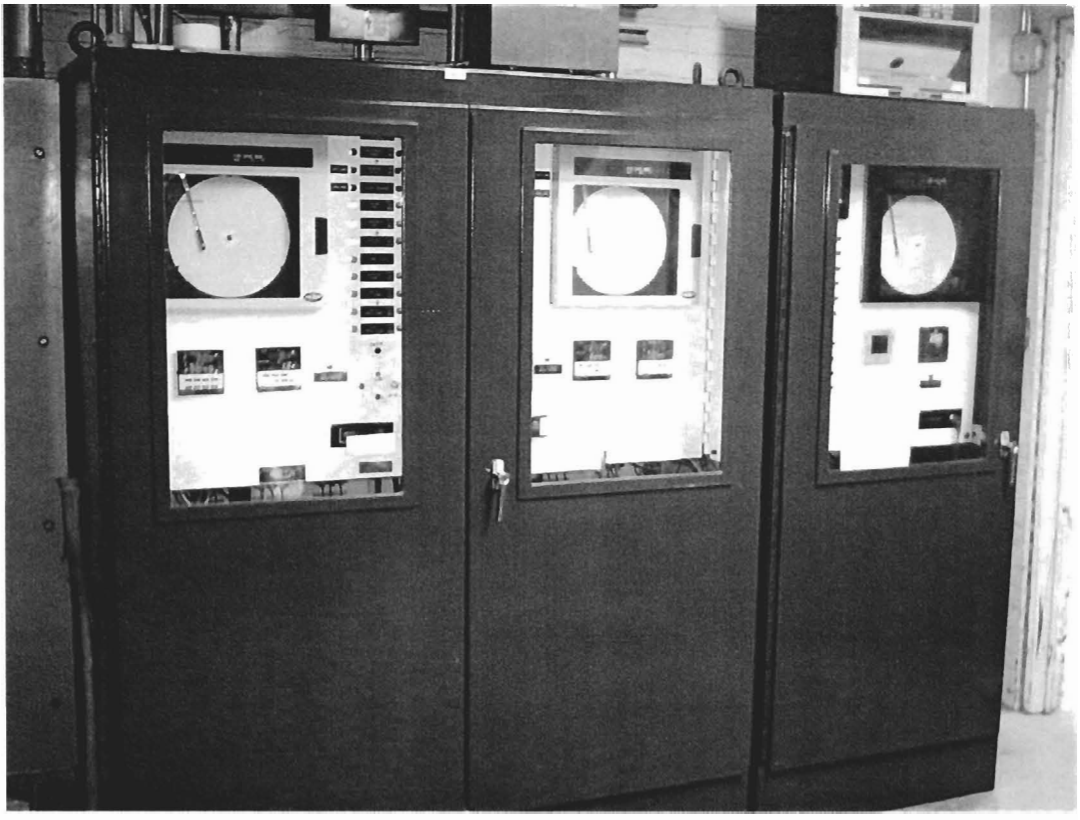
Sieve Analysis Total % Passing									
1.5 in	1 in	3/4 in	1/2 in	3/8 in	#4	#8	#30	#60	#100
100	95+-5		45+-15		5+-5				

Appendix B

Photographs of Equipment and Specimens from the participating state DOT's.

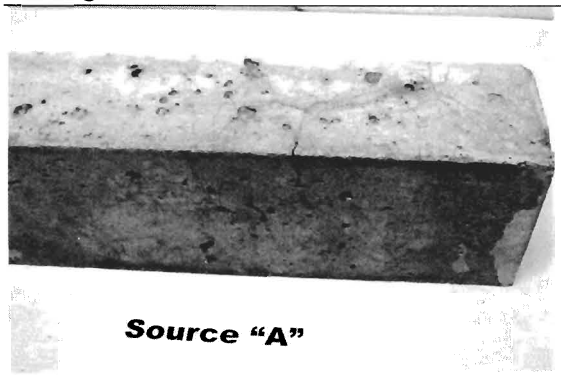
Examples of aggregate particles from the four sources of aggregate selected for the study.

Illinois Freeze-Thaw Equipment



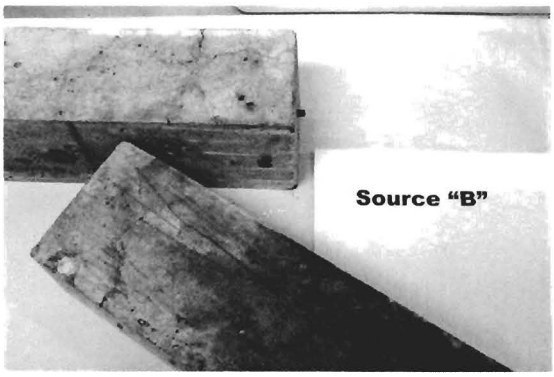
Illinois Freeze-Thaw Test Beams.

Michigan, Test Beams



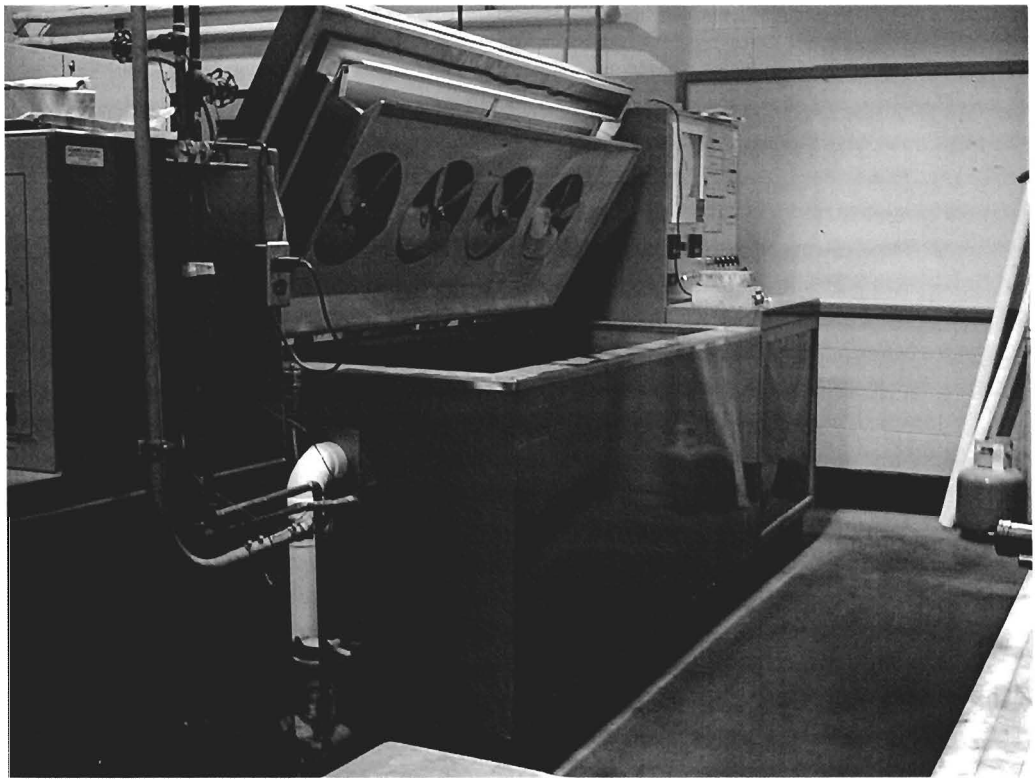
Beams from Source "A" did not reach 0.100 percent expansion in 300 F-T cycles.

In the Michigan test method, F-T beams are removed from the testing machine if they reach 0.100 percent expansion, or at 300 F-T cycles, whichever is sooner.



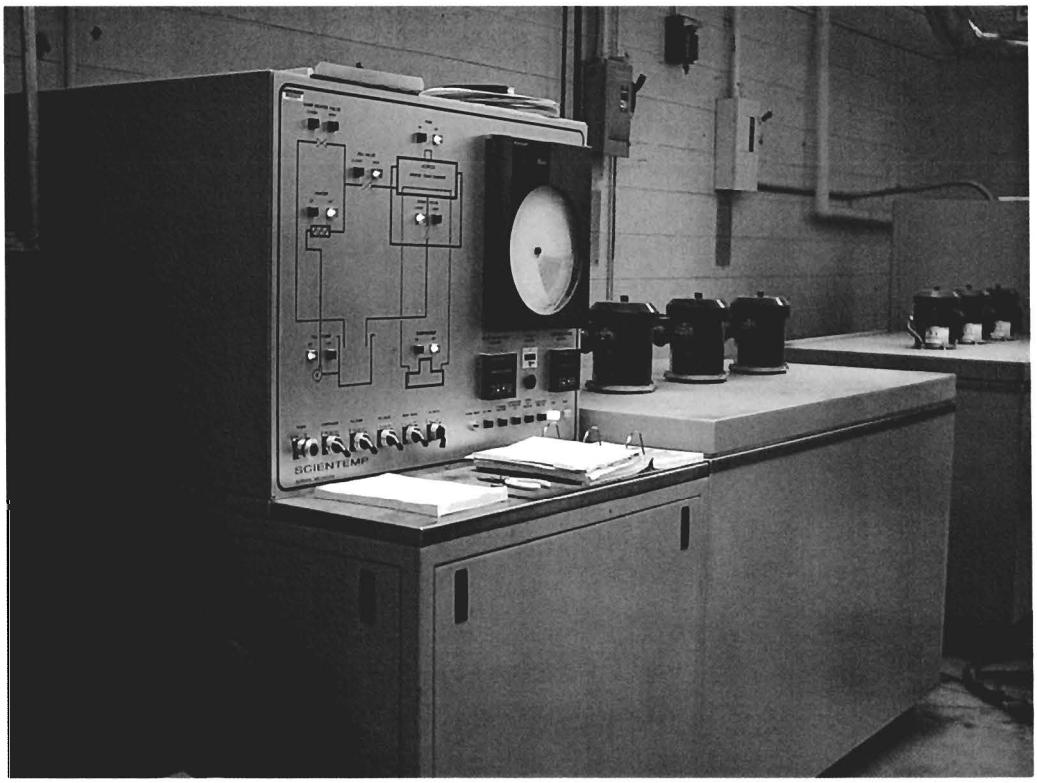
Beams made from Source "B" lasted an average of 154 cycles before reaching 0.100 percent expansion.

Michigan, Freeze-Thaw Equipment

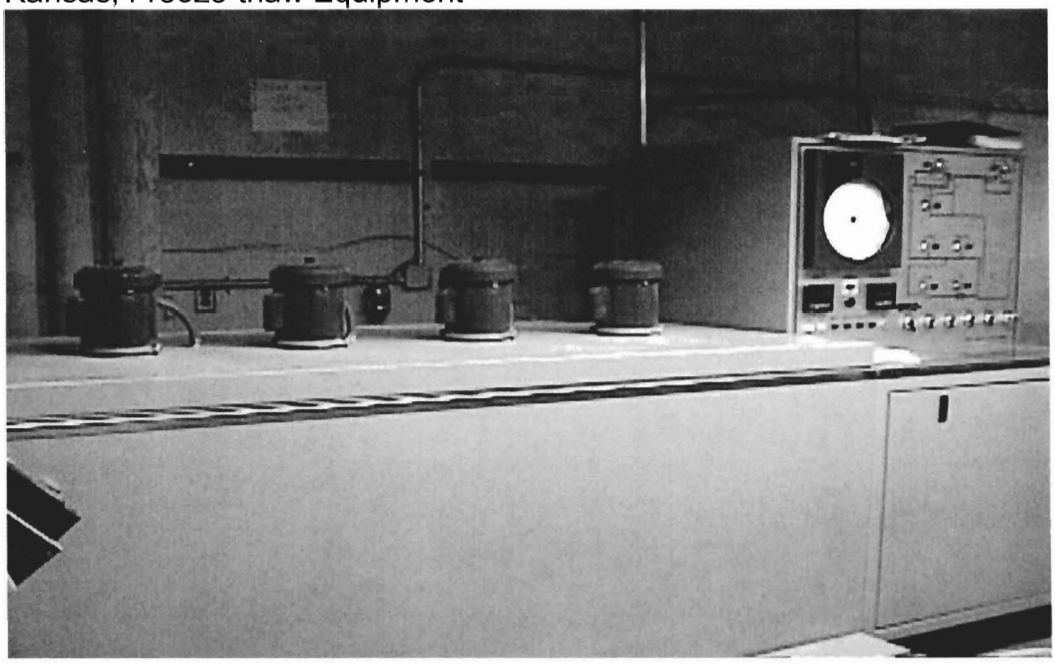


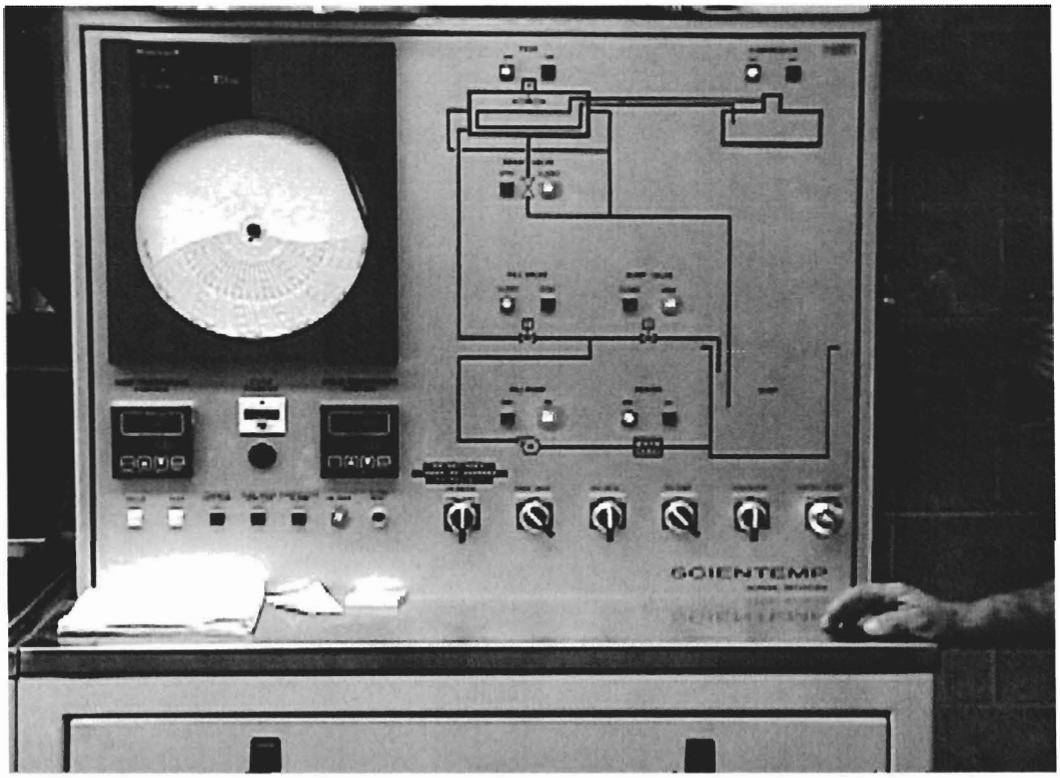
Ohio, Test Beams

Ohio Freeze-Thaw Equipment



Kansas, Freeze-thaw Equipment





Minnesota, Magnesium Sulfate Soundness Equipment