Technical Report Documentation Page

1. Report No. R-1493	**2. Government Accession No.**	**3. MDOT Project Manager**
4. Title and Subtitle Graphical Analysis of Freeze-Thaw Test Results		**5. Report Date** May 2007
		6. Performing Organization Code
7. Author(s) Robert W. Muethel		**8. Performing Org. Report No.**
9. Performing Organization Name and Address Michigan Department of Transportation Construction and Technology Division P.O. Box 30049 Lansing, MI 48909		**10. Work Unit No. (TRAIS)**
		11. Contract No.
		11(a). Authorization No.
12. Sponsoring Agency Name and Address Michigan Department of Transportation Construction and Technology Division P.O. Box 30049 Lansing, MI 48909		**13. Type of Report & Period Covered**
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract
According to the Michigan Test Method MTM 115, the results of freeze-thaw tests of aggregates are computed from expansion values recorded at the termination of testing. Intermediate expansion measurements obtained throughout the testing cycle are recorded but not used in the final computation of expansion. A graphical analysis procedure including these measurements revealed that the freezing and thawing produced expansions that follow exponential, power, and linear correlations. The expansions computed by the standard procedure were shown to closely match values predicted by the graphs.

17. Key Words freeze-thaw expansions, aggregates, graphical analysis		**18. Distribution Statement** No restrictions. This document is available to the public through the Michigan Department of Transportation.	
19. Security Classification - report Unclassified	**20. Security Classification - page** Unclassified	**21. No. of Pages**	**22. Price**

MICHIGAN DEPARTMENT OF TRANSPORTATION
MDOT

Graphical Analysis of Freeze-Thaw Test Results

R. W. Muethel

Materials Section
Construction and Technology Division
Research Report R-1493

Lansing, Michigan
May 2007

ACKNOWLEDGEMENTS

The author wishes to thank Thomas Woodhouse for providing the expansion data necessary for this analysis. Also thanks to Robert Miller for the graphics and technical review of the correlations.

SUMMARY

A graphical analysis procedure was used to examine the rates and amounts of freeze-thaw expansion recorded by concrete test beams containing selected aggregates. The graphical analysis procedure included intermediate freeze-thaw expansion measurements to develop curves that followed exponential, power, and linear correlations. Expansions predicted by the correlation curves generated by the intermediate expansion data closely matched the expansions calculated according to the standard test method computations that use only expansions at the end of the test.

OBJECTIVES

The objectives of the graphical analysis were to investigate the types of correlations shown by the expansions of concrete beams, and to compare the freeze-thaw expansions computed according to the MTM 115 procedure with those predicted by the correlations developed by the graphical analysis. The analysis includes typical examples of the major aggregate types used in concrete.

SAMPLES

Six aggregates were selected to represent both synthetic and natural types that record high to low freeze-thaw expansions in the freeze-thaw test conducted according to the Michigan Test Method MTM 115 (1).

Synthetic, absorbent aggregates are represented by expanded shale, blast furnace slag, and recycled Portland cement concrete. The slag, normally tested with non-vacuum saturation, was included to show the resulting freeze-thaw expansion when subjected to vacuum-saturation pre-treatment used for all other aggregate types. Heterogeneous gravel, containing many differing rock type categories including varying percentages of deleterious aggregate, was included to represent Michigan glacial gravels. Heterogeneous quarried stone containing both dense and absorbent rock subtypes was included as an example of southeastern Michigan sources. Homogeneous quarried stone containing only dense particles with low absorbency was included as an example of similar regional sources.

Table 1 lists the aggregates by source name and Aggregate Source Index (ASI) numbers. The reference numbers in the table indicate the corresponding MDOT freeze-thaw test reports noted in the References section of this report. The table also includes descriptions of the aggregate types contained in the samples.

TABLE 1 Samples				
Sample No.	Source	ASI No.	Ref. No.	Aggregate Type
1	Carolina Solite	99-004	2	Expanded Shale
2	Levy (Dix)	82-019	3	Blast Furnace Slag
3	I-94 PCC	99-003	4	Recycled Concrete
4	Round Lake	46-047	5	Heterogeneous Gravel
5	Rockwood	58-008	6	Heterogeneous Quarried Stone
6	Cedarville	49-065	7	Homogeneous Quarried Stone

GRAPHICAL ANALYSIS OF FREEZE-THAW EXPANSIONS

Graphical plots of freeze-thaw expansions showed exponential, power, or linear correlations. The most highly absorbent aggregates produced expansions that followed exponential correlations, and had premature failures early in the test. Exponential functions increase most rapidly, while power functions increase more slowly. The smallest increases are represented by linear functions. These observed functions correlate strongly with actual deterioration rates.

The heterogeneous gravel produced an expansion that followed a power correlation curve. The heterogeneous quarried stone produced an exponential correlation with rapidly increasing expansion toward the end of the test. The homogeneous quarried stone produced a very low expansion that followed a linear correlation.

Figure A1 of the Appendix contains an example plot of the least squares best-fit correlation generated from the graphical analysis of the freeze-thaw measurements obtained at intervals throughout the freeze-thaw test cycles. The correlated expansion per 100 cycles of freezing and thawing obtained from the correlation curve was computed from the number of freeze-thaw cycles at which expansion of 0.1 percent was reached on the correlation curve, whereas the standard method of computing the expansion per 100 cycles of freezing and thawing uses interpolation of the expansions and associated cycles of freezing and thawing that occur directly before and after reaching 0.1 percent total expansion or 300 cycles. The average expansion for a nine-beam set is reported for each sample.

Table 2 includes a comparison of the freeze-thaw expansions reported for the MTM 115 Tests and expansions predicted by the graphical correlations. The reported values are shown to closely match those predicted by the graphical correlations. Figure A2 of the Appendix contains the curves generated by the graphical analysis procedure.

TABLE 2 **Freeze-Thaw Expansions**					
			Expansion, %/100 Cycles		
Sample No.	Source	ASI No.	MTM-115 Report	Predicted from graphs	Curve Type
1	Carolina Solite	99-004	0.525	0.526	Exponential
2	Levy (Dix)	82-022	0.100	0.116	Exponential
3	I-94 PCC	99-003	0.067	0.109	Exponential
4	Round Lake	46-047	0.160	0.164	Power
5	Rockwood	58-008	0.044	0.042	Exponential
6	Cedarville	49-065	0.003	0.003	Linear

CONCLUSIONS

The correlations developed from the graphical analysis procedure show that the freeze-thaw expansion of concrete during the MTM 115 test occurs at regular, predictable exponential, power, and linear rates.

The freeze-thaw expansion values computed according to the MTM 115 procedure were closely matched by those that were predicted by the correlation curves generated from the intermediate expansion measurements obtained at intervals during the freeze-thaw tests.

REFERENCES

1. Michigan Test Method for Testing Concrete for Durability by Rapid Freezing in Air and Thawing in Water, MTM 115.

2. MDOT Report of Test, Freeze-Thaw No. 03FT-10
   Carolina Solite, ASI# 99-004, Lab. No. 03A-3134 (Sample 1)

3. MDOT Report of Test, Freeze-Thaw No. 89FT-31
   Levy (Dix), ASI# 82-019, Lab. No. 89A-3972 (Sample 2)

4. Tested for information, no report issued.
   I-94 Recycled PCC, ASI# 99-003, 83A-2527 (Sample 3)

5. MDOT Report of Test, Freeze-Thaw No. 99FT-25
   Round Lake, ASI#46-047, Lab. No. 99A-3204 (Sample 4)

6. MDOT Report of Test, Freeze-Thaw No. 03FT-06
   Rockwood, ASI# 58-008, Lab. No. 03A-3026 (Sample 5)

7. MDOT Report of Test, Freeze-Thaw No. 01FT-19
   Cedarville, ASI# 49-065, Lab. No. 01A-3176 (Sample 6)

APPENDIX A

FREEZE - THAW EXPANSION

Beam 99A - 3204-1-3

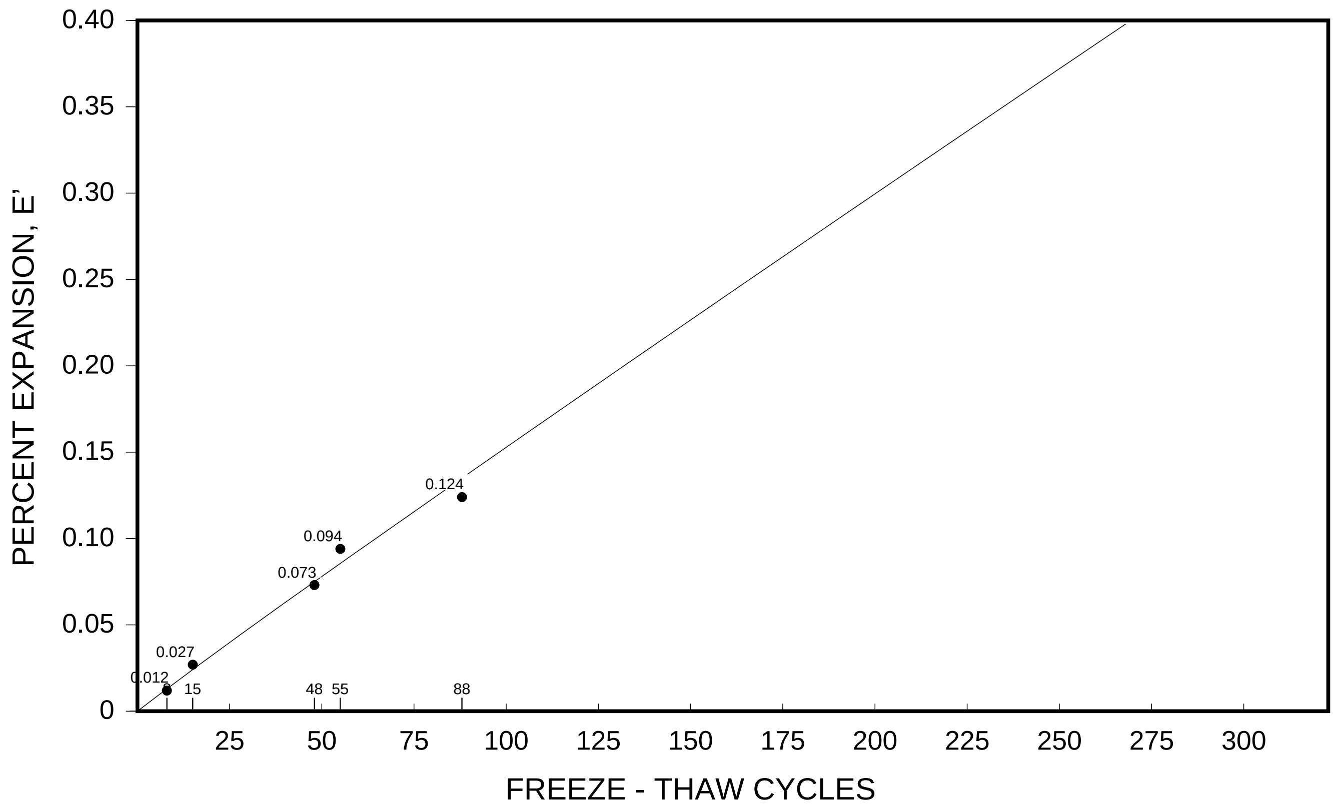

Figure A1. Heterogeneous Gravel

FREEZE - THAW EXPANSION

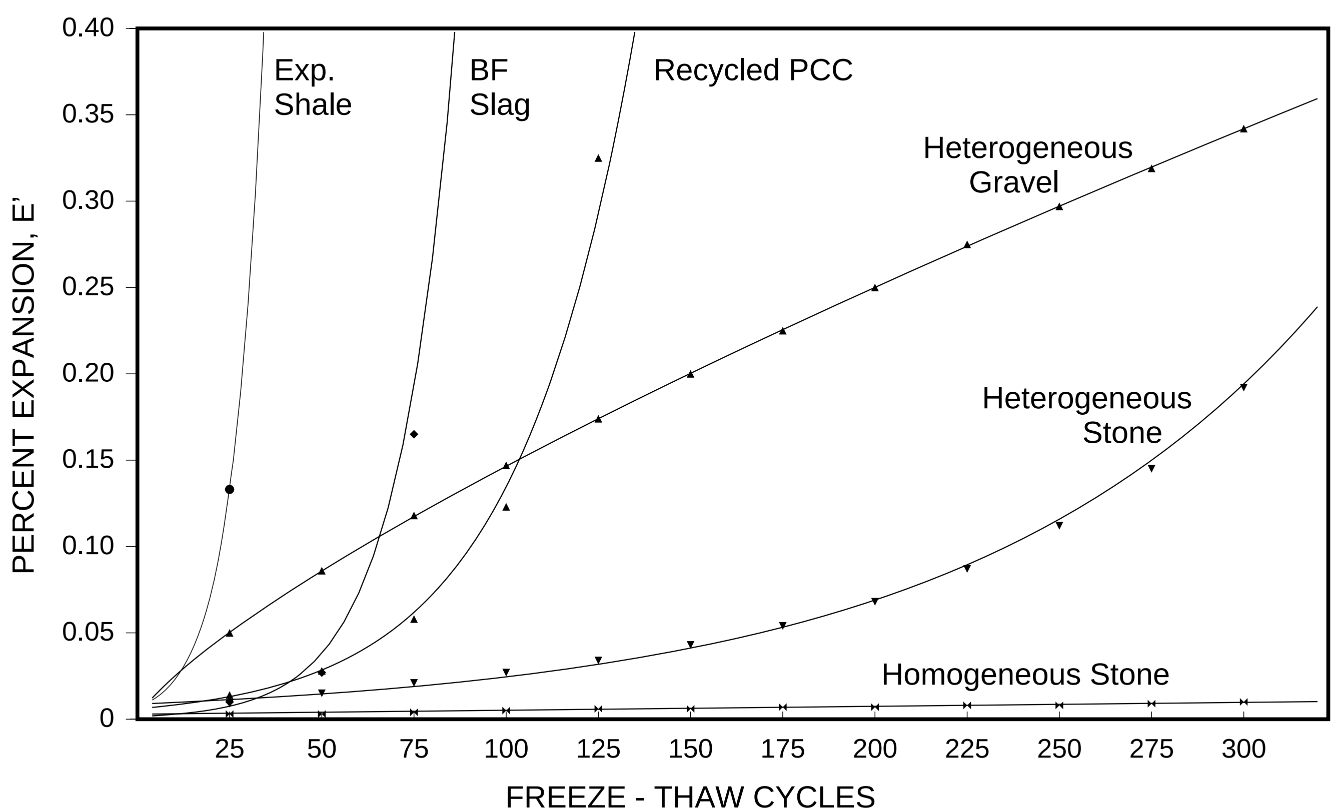

Figure A2. Plots of F-T Correlation Curves