1301

Last copy ?

FREEZE-THAW EVALUATION OF SELECTED ROCK TYPES FROM A COMPOSITE SAMPLE OF MICHIGAN GRAVEL

MICHIGAN DEPARTMENT OF TRANSPORTATION

MATERIALS and TECHNOLOGY DIVISION

FREEZE-THAW EVALUATION OF SELECTED ROCK TYPES FROM A COMPOSITE SAMPLE OF MICHIGAN GRAVEL

R. W. Muethel

Research Laboratory Section
Materials and Technology Division
Research Project 88 TI-1323
Research Report No. R-1301

Lansing, August 1989

Summary

The glacial gravels of Michigan contain a mixture of durable and non-durable rock types. The MDOT classification that defines the gravel constituents: friable sandstone, siltstone, shale, clay ironstone and chert as deleterious rock types is based upon primarily visual evidence of distress in concrete, such as exposure in pop-outs. Laboratory test documentation to support the classification has been lacking.

Twenty-four rock types sorted from glacial gravel obtained from 49 selected sources were subjected to the standard MDOT Laboratory acceptance tests for aggregates, including those for freeze-thaw durability, abrasion loss, and sulfate soundness loss. Additional information was obtained from specific gravity, absorption, and Iowa Pore Index determinations.

Results of the laboratory tests supported the MDOT classification. The deleterious rock types showed low freeze-thaw durability in concrete; the durable rock types showed high durability. The durable rock types exhibited no ill effects from vacuum saturation pre-treatment for freeze-thaw testing. Most of the deleterious rock types displayed undesirable pore characteristics similar to the D-cracking carbonates investigated in Iowa. The deleterious rock types also recorded lower specific gravities and higher absorptions than the durable rock types indicating that heavy media separation can remove most of the deleterious rock types from Michigan glacial gravels. The carbonate rock constituents including possible D-cracking particles were not evaluated, but will be investigated in a separate study.

Background

This report covers a study of the engineering properties of the lithological constituents of Michigan gravels. The main objectives of the study were to determine the freeze-thaw durability of the individual rock types found in gravel, and to provide documentation to substantiate the Department's classification of deleterious gravel constitutents. The study was conducted at the Testing Laboratory and required the sampling of approximately 32,000 lb of aggregates from 49 representative sources statewide. The aggregates were sorted into 24 rock types representing the major lithological components of the glacial gravel deposits in Michigan. Although parts of the study have been completed for several years, this is the first time they have been reported.

Material from the individual rock type separations was subjected to the standard laboratory acceptance tests for aggregates required by the 1973 MDOT Standard Specifications for Highway Construction in effect at that time (1). The tests included freeze-thaw durability, Los Angeles and Deval abrasion, and magnesium sulfate soundness. In addition to the standard acceptance tests, supplemental tests were conducted, including Los Angeles and Deval abrasion tests on saturated aggregate. Test data included the results of specific gravity and absorption determinations conducted for mix design information.

Surplus aggregates from the study were tested later for Iowa Pore Index data and resistance to wear track tire-polishing, both under separate research investigations. This report presents a summary of the results of the freeze-thaw tests, specific gravity, absorption, and Iowa Pore Index findings as related to the freeze-thaw durability of the lithological components of glacial gravel.

Samples

A representative composite of the glacial gravel deposits of Michigan was obtained by sampling from 49 selected sources situated in the major glacial deposits in the upper and lower peninsulas. The make-up of the sampled material was as follows:

Type of Aggregate	No. of Sources	Approximate Quantities	
		lbs	Percent
Heavy Media Separated Gravel	17		
Sink Material		5,750	18.0
Float Material		5,100	16.0
Non-HMS Gravel	26	17,062	53.6
Quarried Carbonates	3	3,438	10.8
Beach Gravel	1	188	0.6
Bedrock Outcrops	2	312	1.0
Totals	49	31,850	100.0

Gravel was sampled from both heavy media-separated (HMS) and non-HMS production to obtain a complete representation of the lithologies in the gravel deposits. A small amount of material was sampled from two bedrock outcrops and a beach deposit to obtain supplemental quantities of the low-percentage rock types felsite, friable sandstone, and vitreous chert. Also, special hand-picked samplings of the low-percentage rock types schist and clay ironstone were conducted to obtain sufficient quantities for testing.

Sorting

The aggregate samples were graded into the standard size fractions for testing: 1 in. to 3/4 in., 3/4 in. to 1/2 in., 1/2 in. to 3/8 in., and 3/8 in. to No. 4. Following completion of size grading, the aggregates were separated into the major rock classes by a team of Departmental aggregate inspectors. Final detailed sorting of the aggregates was done microscopically by staff geologists.

In late 1974, sorting of the gravel was completed with exception of the carbonate rock subtypes. Due to time constraints involving a pending shut-down of the freeze-thaw equipment at the Ann Arbor facility and relocation in Lansing with new, uncalibrated equipment, the decision was made to test quarried carbonates representative of those in the gravel samples, thereby completing the suite of freeze-thaw tests with the same equipment. Three northern Michigan sources situated in bedrock formations considered to have contributed substantial carbonate rock material to the glacial gravel deposits were selected to represent the major carbonate types (limestone, dolomite limestone, and dolomite) present in the gravels. The quarried carbonates were from sources that have a record of high freeze-thaw durability. Other quarried carbonates from sources in both northern and southern Michigan are known to have much lower durability but could not be included in the study due to time constraints. Testing of the actual glacial gravel carbonate material was deferred to a later investigation.

Lithological Composition of the Gravel

Glacial gravel in Michigan is a heterogeneous mixture of a large number of lithologies derived from diverse igneous, metamorphic, and sedimentary origins. For the purpose of this investigation the classification was consolidated wherever possible according to related properties. The major rock class categories, therefore, include many subtypes which have similar physical characteristics related to freeze-thaw durability. Table 1 shows the classification which contains 21 lithologies in the three major rock classes. The sedimentary rock class was subdivided into greater detail to obtain specific information on the individual deleterious lithologies which are contained in this category.

Table 2 shows the quarried carbonates representing the three major types present in the glacial gravel.

Due to the large amount of material processed for this investigation, a detailed petrographic composition of the composite gravel was not determined. However, detailed petrographic analyses were conducted on samples from selected sources. Table 3 shows the tabulated results of petrographic analysis of heavy media separated material from a typical source. The sinking portion containing the dense, high-gravity lithologies is used for concrete aggregate. The floating portion containing the absorptive, low-gravity material is used in septic system drainage fields. The percentages of the granite, quartzite, and carbonate rock types in the floating portion indicate that the heavy media specific gravity level for this separation was set relatively high, as is sometimes necessary to remove high-gravity chert and clay ironstone. Gravel produced without the heavy media separation process may contain a considerable variation in lithological content based upon the composition of the deposit.

Freeze-Thaw Tests

Freeze-thaw testing of concrete containing the lithological separations was conducted by the Testing Laboratory Section according to

TABLE 1

Rock Type	Bulk S.G.	ABS, percent			Pore Index	Equivalent Expansion, percent per 100 cycles
	Dry[1]	24H[2]	VAC[3]	DF[4]		
IGNEOUS						
Granite	2.69	0.55	0.67	94	9	0.003
Diorite	2.80	0.42	—	—	4	—
Gabbro	2.96	0.45	0.48	98	4	0.001
Basalt	2.87	0.73	0.91	98	10	0.001
Felsite	2.63	1.09	1.16	96	21	0.002
METAMORPHIC						
Quartzite	2.63	0.40	0.55	95	8	0.002
Tillite	2.73	0.24	0.25	99	4	0.001
Metasediments	2.71	0.47	0.47	98	8	0.001
Schist	2.60	2.56	2.65	76	51	0.010
SEDIMENTARY						
DETRITAL						
(A)Crag (Lime-Cemented Pebbly Sand)	2.41	3.45	4.77	30	19	0.048
Sandstone (Non-Friable)	2.37	3.51	4.64	22	36	0.062
Sandstone (Friable)	2.17	6.56	9.08	4	17	*
Siltstone	2.20	7.56	8.96	2	48	*
Shale	2.12	5.64	5.87	13	106	0.089
Clay Ironstone (Fossiliferous)	2.64	6.65	8.13	0	119	*
Clay Ironstone (Laminated to Massive)	2.37	12.07	14.31	0	423	*
NON-DETRITAL						
(B)Chert (Dense to Vitreous Lustered)	2.56	0.93	0.87	23	30	0.060
Chert (Mottled)	2.41	3.17	3.75	0	76	*
Chert (Porous)	2.37	4.15	4.61	0	96	*
Clay Ironstone (Concretion Shells)	2.49	11.28	12.49	0	304	*
Clay Ironstone (Concretion Centers)	3.24	1.44	1.53	20	12	0.067

*Relative expansions for freeze-thaw durability factors less than 10 are beyond the correlation data base.

[1] Bulk specific gravity, dry wt. basis

[2] Absorption, percent, after 24 hour soak without vacuum treatment

[3] Absorption, percent, after 24 hour soak with vacuum treatment

[4] Freeze-thaw durability factor, ASTM C 666 Method B; Michigan Test Methods 113, 114, 115.

TABLE 2

Rock Type	Bulk S.G.	ABS, percent			Pore Index	Equivalent Expansion, percent per 100 cycles
	Dry[1]	24H[2]	VAC[3]	DF[4]		
SEDIMENTARY						
QUARRIED CARBONATE						
Limestone	2.65	0.71	0.80	92	19	0.003
Dolomite Limestone	2.65	0.77	0.83	81	27	0.008
Dolomite	2.80	0.47	0.71	95	6	0.002

[1] Bulk specific gravity, dry wt. basis

[2] Absorption, percent, after 24 hour soak without vacuum treatment

[3] Absorption, percent, after 24 hour soak with vacuum treatment

[4] Freeze-thaw durability factor, ASTM C 666 Method B; Michigan Test Methods 113, 114, 115

TABLE 3
PETROGRAPHIC COMPOSITION OF TYPICAL
HEAVY MEDIA SEPARATED GRAVEL

Rock Type	Composition (percent) in Heavy Media Separation	
	Sink	Float
IGNEOUS		
Granite	6.2	7.0
Diorite	1.5	0.3
Gabbro	8.9	0.6
Basalt	9.4	0.0
Felsite	0.3	0.3
METAMORPHIC		
Quartzite	11.5	4.8
Tillite	3.8	0.1
Metasediments	6.0	2.9
Schist	0.3	0.0
SEDIMENTARY		
CARBONATES	48.8	30.2
DETRITAL		
Sandstone	0.8	33.6
Siltstone	0.3	2.7
Shale	0.0	2.3
NON-DETRITAL		
Chert	1.7	15.0
Clay Ironstone (Shells)	0.5	0.2
Totals	100.0	100.0

ASTM C 666 Method B "Resistance of Concrete to Rapid Freezing in Air and Thawing in Water" (2), and Michigan Test Methods 113, 114, and 115 (3) (4) (5). In each test, nine 3 in. by 4 in. by 16-in. concrete beams were cast using vacuum-saturated coarse aggregate in the 3/4 in., 1/2 in., and 3/8 in. sizes, with substitution of a high-durability crushed limestone in the No. 4 size fraction. The substitution in the smallest size fraction greatly reduced the sorting time for the study, and produced no detectable beneficiation bias in the freeze-thaw test results.

The results of the freeze-thaw tests were originally recorded as durability factors computed from the relative dynamic modulus of elasticity determined from sonic measurements as described in ASTM C 666. The durability factor (DF) is calculated as follows:

$$DF = \frac{PN}{M}$$

Where:

DF = durability factor

P = relative dynamic modulus of elasticity at N cycles, percent

N = number of cycles at which P reaches the specified minimum value for discontinuing the test or the specified number of cycles at which the exposure is to be terminated, whichever is less, and

M = specified number of cycles at which the exposure is to be terminated.

The specified values for P and M used to calculate DF were 70 percent and 300 cycles. Tables 1 and 2 include the results of the freeze-thaw tests expressed as durability factors according to a scale from 0 (very low durability) to 100 (very high durability), and as equivalent expansion, percent per 100 cycles of freezing and thawing converted according to the following correlation formula developed by the Structural Services Unit of the Materials and Technology Laboratory.

$$\delta = 0.2772 - \sqrt{0.02016\,(\ln DF) - 0.01613}$$

Where:

δ = expansion, percent per 100 cycles, and

lnDF = natural log of durability factor DF

The correlation is applicable for freeze-thaw durability factors between 10 and 100. Equivalent expansions for durability factors less than 10 are beyond the correlation data base.

The freeze-thaw test results indicate that most of the igneous and metamorphic lithologies recorded high freeze-thaw durability. In contrast, the sedimentary lithologies recorded a wide range of resistance to freezing and thawing. The three quarried northern Michigan carbonates recorded high freeze-thaw durability, whereas most of the non-carbonate sedimentary lithologies recorded low durability factors.

The freeze-thaw results indicate that the low durability rock types: friable sandstone, siltstone, shale, chert, and clay ironstone are correctly classified as deleterious in the MDOT Specifications for Highway Construction. They also demonstrate that vacuum saturation is not harmful to durable aggregates.

Specific Gravity and Absorption Tests

Bulk specific gravity and absorption determinations were conducted for mix design information according to ASTM C 127 "Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate" (6). Results of the determinations are included in Tables 1 and 2. The absorption measurements indicate an inverse relationship with freeze-thaw durability. Generally, higher absorption leads to lower durability. Excepting the metamorphic rock type, schist, all of the lithologies with absorptions greater than 2 percent recorded low to very low freeze-thaw durability factors. Since schist makes up such a small proportion of the gravel deposits, this rock type is of no practical significance.

Iowa Pore Index Determinations

In 1981 an evaluation of the Iowa Pore Index test was initiated at the laboratory. The pore index test, a rapid procedure, measures the absorption of an aggregate during a 15-minute period of pressure-saturation at 35 psi in a pore index meter. The quantity of water (in ml) absorbed by a 9000-gram sample during the interval between 1 and 15 minutes after pressurization is referred to as the Iowa Pore Index number. A pore index number greater than 27 has been correlated with D-cracking susceptibility in Iowa's carbonate aggregates (7). As part of the evaluation of the Iowa Pore Index test, materials saved from the subject aggregate investigation were tested.

Although the Iowa Pore Index test is used primarily for the evaluation of carbonate aggregates, the results of the determinations on the non-carbonate lithologies indicates a similar correlation between pore index numbers and freeze-thaw durability. The pore index test results are included in Tables 1 and 2.

A few apparent exceptions to the correlation occurred in the absorptive lithologies. The metamorphic rock type schist recorded a freeze-thaw durability of 76 and a pore index number of 51. This lithology, which recorded an absorption greater than 2 percent, might resist freezing and thawing if protected from high moisture conditions. However, popouts caused by schist have been observed, so it does get critically saturated in service.

The sedimentary detrital lithology, friable sandstone, a structurally weak, highly absorptive rock type, recorded a freeze-thaw durability factor of 4 and a pore index of 17. In this case a satisfactory pore structure was counteracted by a lack of strength to resist freeze-thaw stresses. Such aggregates which have the capacity to absorb considerable amounts of water have recorded low freeze-thaw durability if pre-treated by vacuum saturation, but higher freeze-thaw durability if pre-treated by 24 hour soaking (8). However, the freeze-thaw test without prewetting the stone is as much a test of the permeability of the mix as it is an evaluation of the durability of the stone, because the water must reach and penetrate the stone during such testing operations. It has also been found that aggregates may become critically saturated in pavement slabs in less than one year. This reflects the overwhelming importance of pore structure of the cement paste and coarse aggregate in the saturation levels that are reached (9).

The differences in absorption characteristics of the gravel lithologies are shown graphically by plots of the absorption measurements obtained during the pore index determinations. The graphs emphasize the great range of absorbencies present in the gravel constituents. Figures 1 through 5 contain absorption graphs of the 24 lithologies examined in this investigation.

Conclusions and Recommendations

1) The results of the freeze-thaw tests show that the rock types designated as deleterious in the MDOT Standard Specifications for Construction, produce low freeze-thaw durability in concrete.

2) Durable aggregates show no ill effects from vacuum saturation.

3) The results of the Iowa Pore Index tests indicate that most of the deleterious rock types display undesirable pore characteristics similar to the D-cracking carbonates investigated in Iowa.

4) The specific gravity and absorption data indicate that most of the deleterious lithological components in Michigan glacial gravel can be removed by use of a properly adjusted heavy media separation process.

The results of this investigation indicate that the rock types classified as deleterious in the MDOT classification should remain as stated.

The reduction in the freeze-thaw durability of concrete caused by varying amounts of deleterious lithologies in the coarse aggregate is being investigated under a separate research study. That study will also complete the investigation of the freeze-thaw durability of the glacial gravel carbonate fraction deferred from the subject investigation. Any recommended changes in the allowable deleterious particle content in gravel for concrete will be made with the completion of that study. It must be noted here that D-cracking limestones were not included in the subject study.

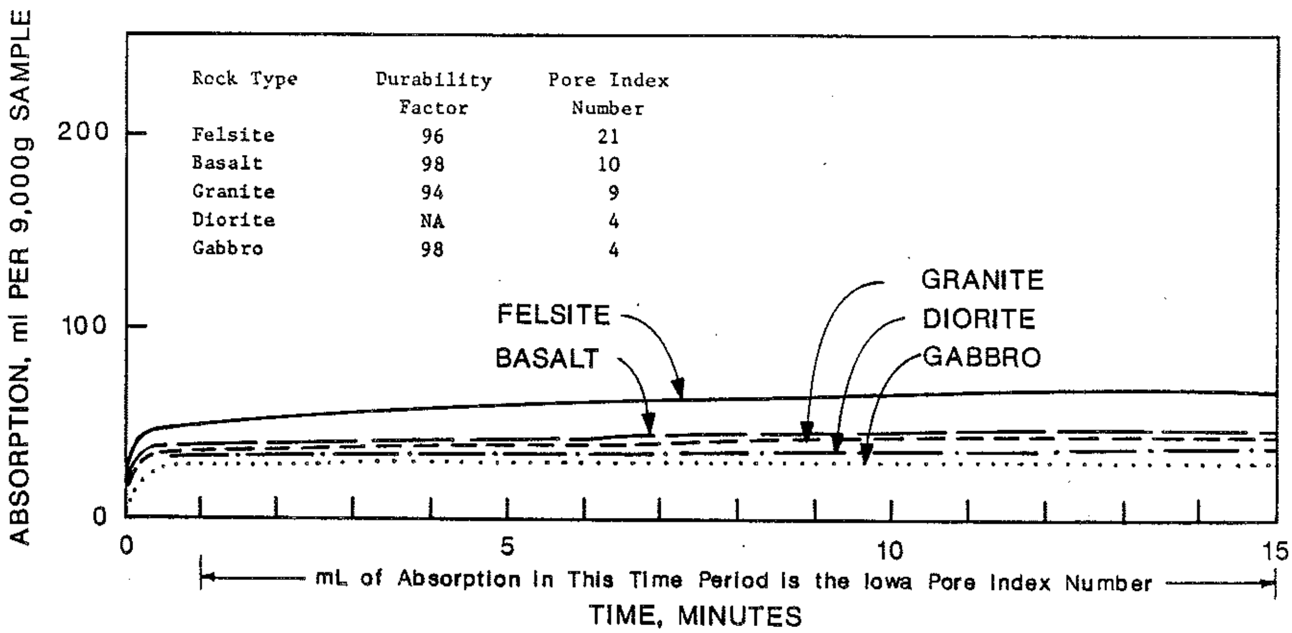

Figure 1. Absorption curves of the igneous gravel lithologies.

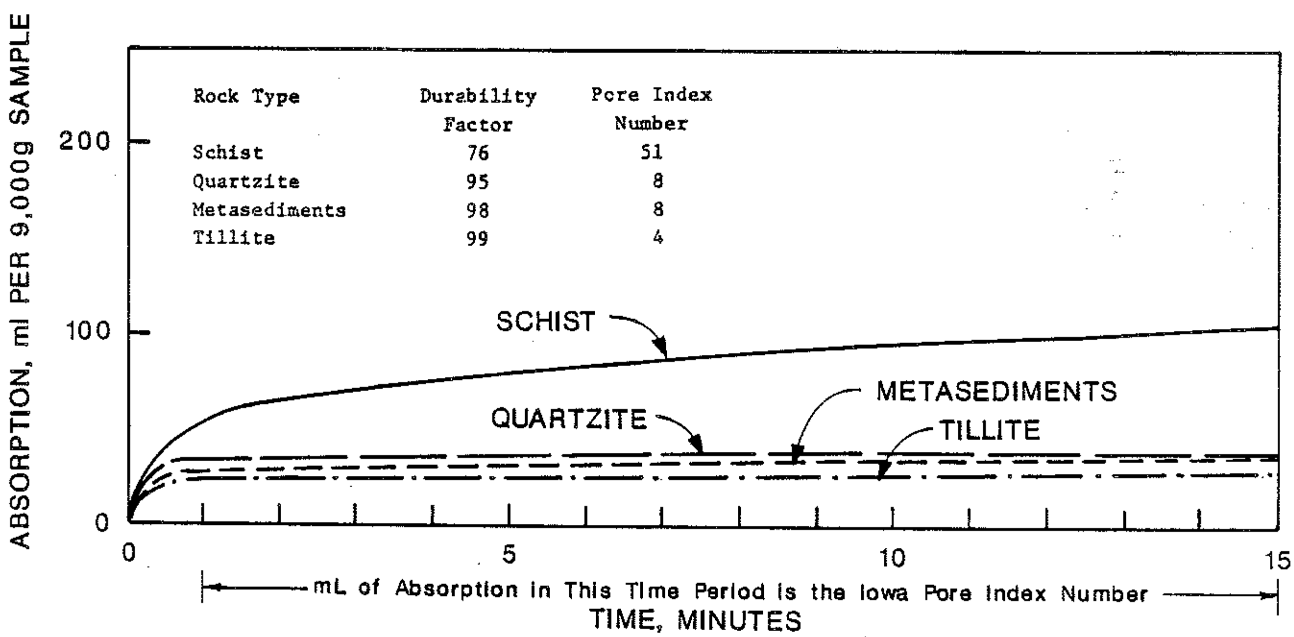

Figure 2. Absorption curves of the metamorphic gravel lithologies.

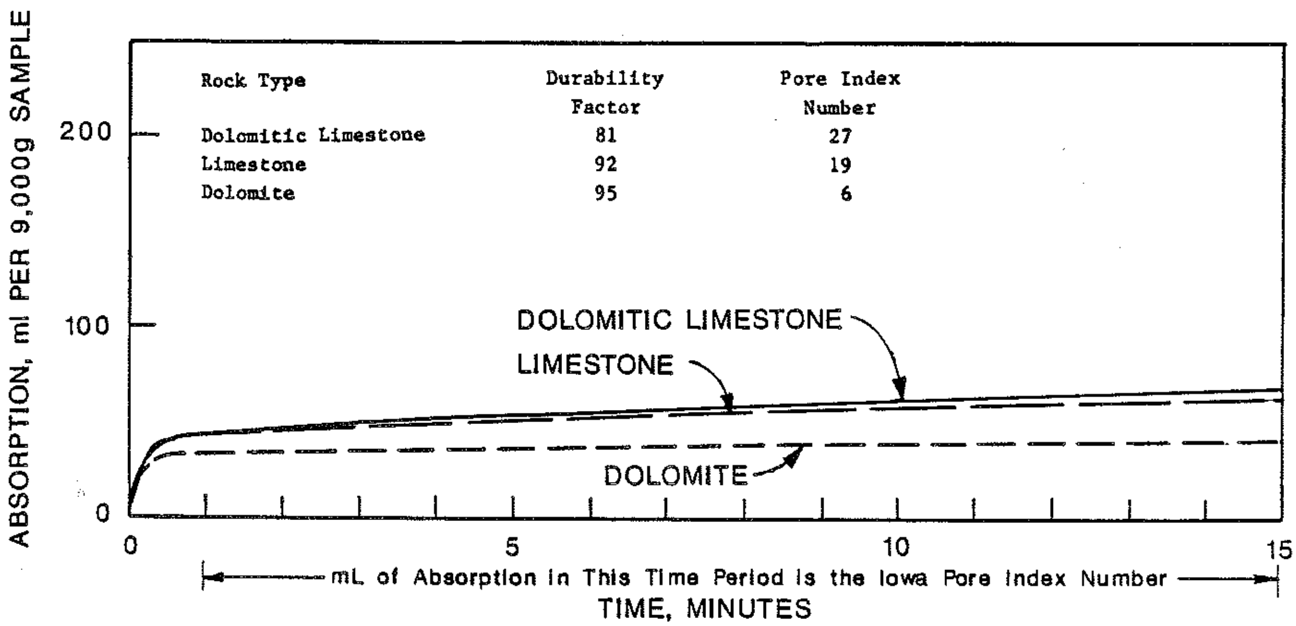

Figure 3. Absorption curves of the sedimentary northern Michigan carbonates (representative quarried material).

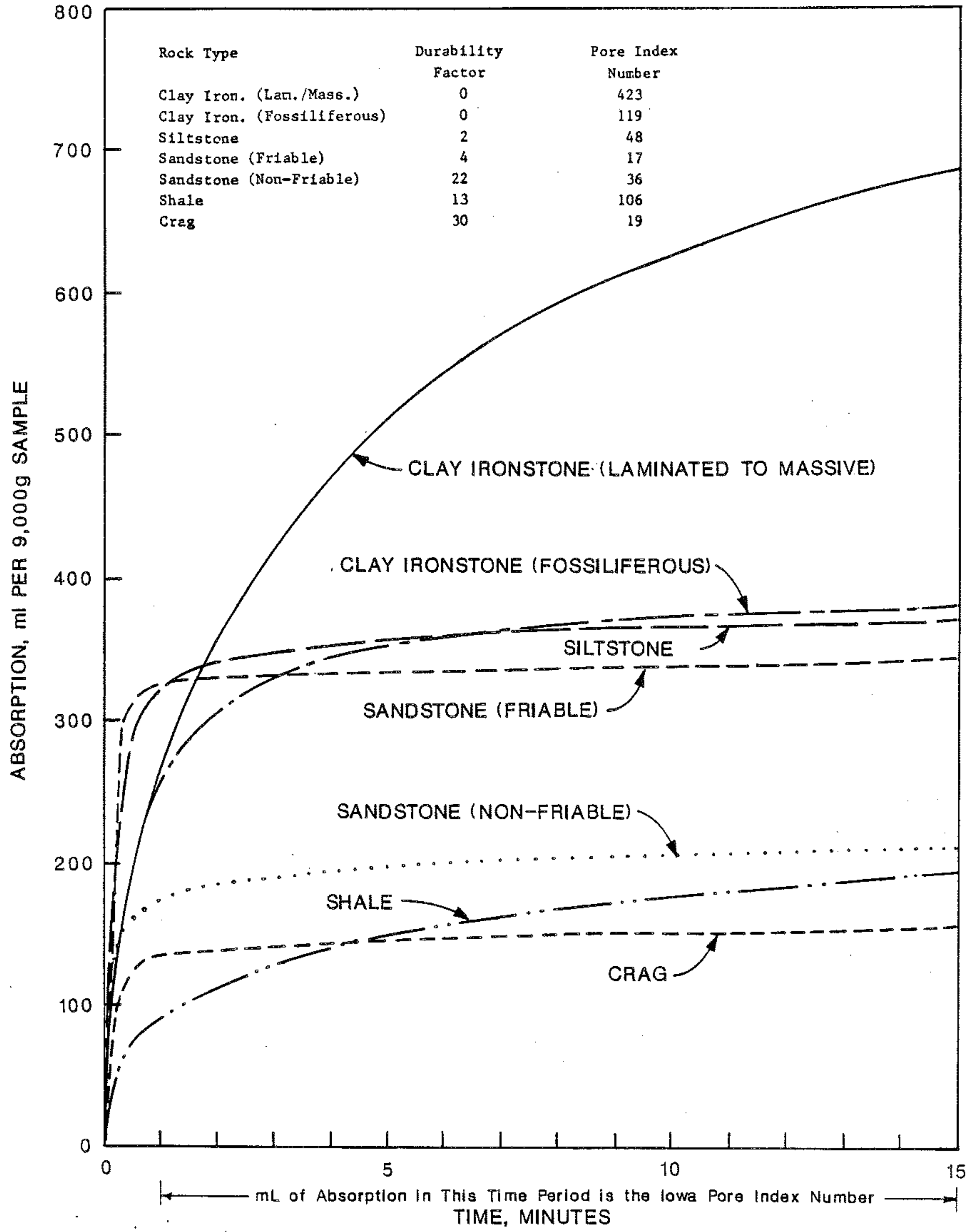

Figure 4. Absorption curves of the sedimentary detrital gravel lithologies.

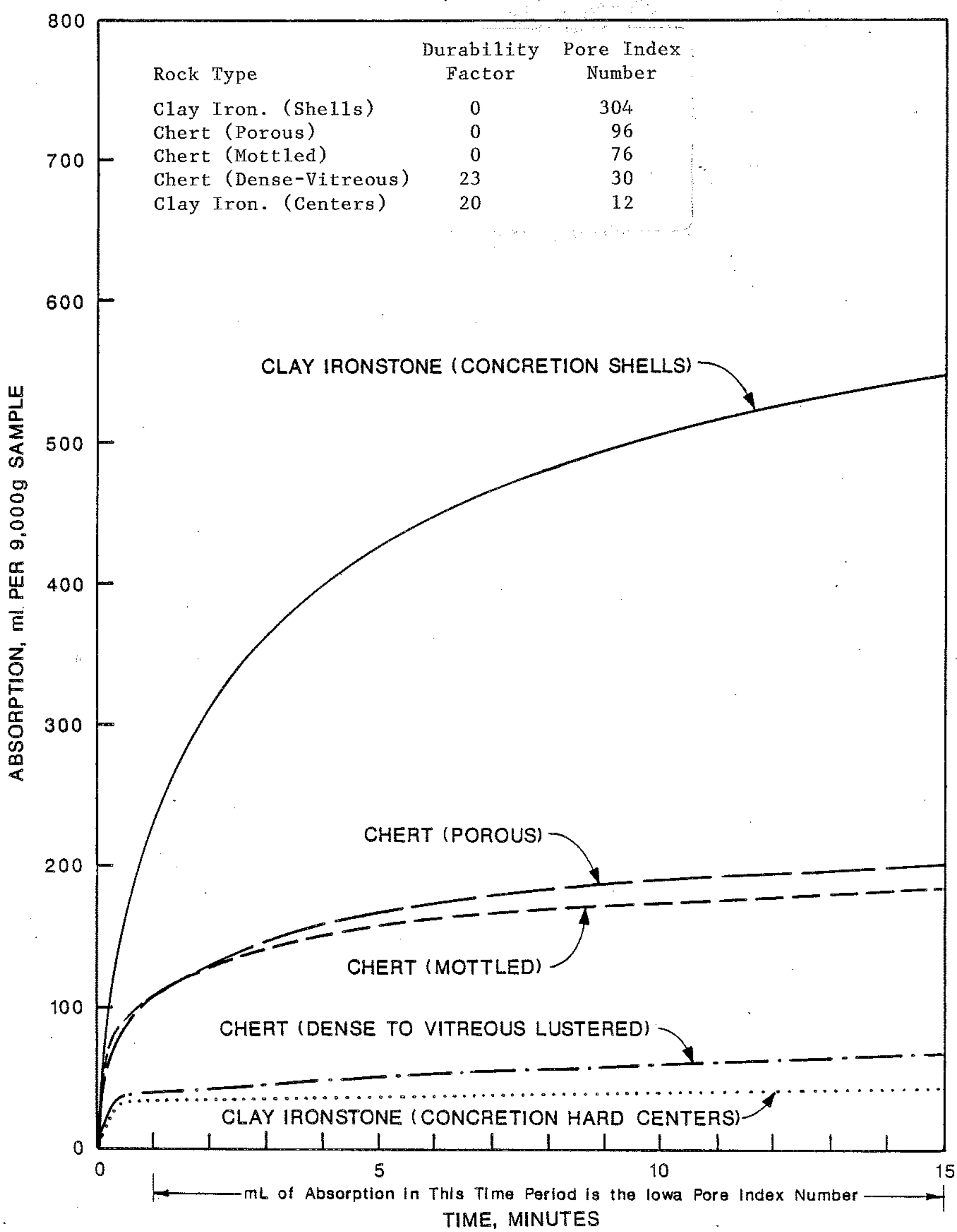

Figure 5. Absorption curves of the sedimentary non-detrital gravel lithologies.

REFERENCES

1. "1973 Standard Specifications for Highway Construction," Michigan Department of Transportation, Lansing, Michigan.

2. "Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing, Procedure B," ASTM C 666.

3. "Method of Selection and Preparation of Coarse Aggregate Samples for Freeze-Thaw Testing," Michigan Test Method 113, Michigan Department of Transportation, Lansing, Michigan.

4. "Method for Making Concrete Specimens for Freeze-Thaw Testing of Concrete Coarse Aggregate," Michigan Test Method 114, Michigan Department of Transportation, Lansing, Michigan.

5. "Method of Testing Concrete for Durability by Rapid Freezing in Air and Thawing in Water," Michigan Test Method 115, Michigan Department of Transportation, Lansing, Michigan.

6. "Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate," ASTM C 127.

7. Meyers, James D., and Dubberke, Wendell, "Iowa Pore Index Test," Interim Report, Iowa Department of Transportation, Ames, Iowa, January 1980.

8. Records for Freeze-thaw test reports from 1954 to 1985, Testing Laboratory Section, Michigan Department of Transportation, Lansing, Michigan.

9. Klieger, P., Stark, D., and Teske, W., "The Influence of Environment and Materials on D-Cracking," Ohio Department of Transportation, June 1978.