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MICHIGAN DEPARTMENT OF TRANSPORTATION
M•DOT

FREEZE-THAW DURABILITY AND PORE CHARACTERISTICS OF THE MAJOR ROCK CONSTITUENTS IN GLACIAL GRAVEL

MATERIALS and TECHNOLOGY DIVISION

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R. W. Muethel

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ACTION PLAN

1. Materials and Technology Division

   A. Project completed.

   B. Incorporate results of the report into Modulue I of the joint MDOT-MTU-CRREL freeze-thaw study currently in progress.

   C. Conduct an investigation to determine the maximum allowable amount of chert plus soft particles in gravel for use in portland cement concrete.

   D. Conduct research to develop pavement concrete mixtures that are more impervious to moisture, as an alternative to restricting aggregates containing moisture-sensitive constituents.

2. Engineering Operations Committee

   A. Authorize the investigations stated in 1. above.

SUMMARY

The glacial gravel of Michigan contains a mixture of durable and non-durable rock types. The MDOT classification that defines the gravel constituents — friable sandstone, siltstone, shale, and clay ironstone — "soft particles," and chert as deleterious rock types is based upon primarily visual evidence of distress in concrete, such as exposure in popouts. In the 1970s a Departmental freeze-thaw investigation was conducted to establish laboratory test documentation for the classification. Detailed freeze-thaw tests were conducted of the major rock type constituents sorted from a composite of gravel sampled from 49 statewide sources. Results of the freeze-thaw tests supported the MDOT classification of deleterious rock types. Due to time constraints, the evaluation of the carbonate rock fraction was deferred to a later investigation.

A primary objective of this investigation was to evaluate the freeze-thaw durability and pore characteristics of the carbonates in Michigan glacial gravel. The carbonate fraction was found to contain absorptive constituents having low freeze-thaw durability, and undesirable pore characteristics as measured by the Iowa Pore Index test.

The effect of down-sizing and blending to improve the freeze-thaw durability of the gravel carbonate fraction was investigated. Down-sizing resulted in moderate improvement in freeze-thaw performance. Blending of the carbonates with high-durability dolomite produced increasing durability with decreasing amounts of gravel carbonate in the mix.

Blending of the chert and "soft particle" categories with high-durability dolomite was investigated to determine the effect on freeze-thaw durability. Blends of 5, 10, and 15 percent chert with high-durability dolomite, and blends of 5, 10, and 15 percent "soft particle" gravel constituents with high-durability dolomite produced decreasing freeze-thaw durability with increasing deleterious material in the mixes. Blends with greater than 5 percent chert or "soft particle" content resulted in freeze-thaw values below the MDOT acceptance limit.

Specific Gravity and absorption data indicated that most of the chert and "soft particle" deleterious constituents in Michigan glacial gravel can be removed by heavy media beneficiation. The deleterious, absorbent carbonates in the control gravel were found to have a specific gravity considerably lower than the non-absorbent carbonates, indicating that much of such material could be removed by heavy media beneficiation.

The freeze-thaw tests indicated that the freeze-thaw durability of concrete containing gravel could be increased by blending with a high-durability aggregate in the larger grade sizes. Blending would provide the coarse aggregate particle interlock needed to resist pavement slab faulting at cracks, and would effectively dilute the harmful effects of the deleterious material in the gravel.

Iowa Pore Index tests conducted on the individual gravel lithologies showed good correlation with the freeze-thaw durability test results, indicating that the deleterious lithologies display characteristics similar to the carbonates associated with D-Cracking distress in concrete.

Limitation of the amount of deleterious material in coarse aggregate for use in concrete has been the standard practice to achieve adequate durability. The results of this investigation indicate that the deleterious absorptive gravel carbonates which cannot be readily identified by standard inspection techniques do contribute significantly to poor durability, and must be considered as deleterious constituents of the aggregate. However, before this can be accomplished, a method must be developed to identify and quantify the harmful carbonate constituents. Presently, a practical method is not available for use as an acceptance procedure.

An alternative approach to obtain satisfactory aggregate performance should be explored. The development of pavement concrete that is more impervious to moisture could result in the satisfactory use of aggregates that are freeze-thaw susceptible in the high moisture conditions known to exist beneath concrete pavements. The criteria for deleterious material would need to be redefined according to the performance of the aggregate in the impervious concrete mixtures.

INTRODUCTION

Glacial gravels have been used extensively as coarse aggregates in portland cement concrete pavements in Michigan. Many of the older pavements have developed severe deterioration at transverse and longitudinal joints. The deterioration appears to be, in many cases, characteristic of D-cracking distress associated with components of the gravel coarse aggregate. In some cases, the deterioration is greater than that expected for the amount of known deleterious material in the gravel coarse aggregate, indicating the presence of unrecognized low-durability constituents in the gravel.

Certain gravels tested at the MDOT Laboratory record freeze-thaw durability results which are lower than expected for the amount of deleterious material identified in the samples, also indicating the presence of unrecognized low-durability constituents in the gravel.

Recent research conducted on the pore structures of carbonate aggregates — major constituents of many Michigan gravel deposits — indicates that certain carbonates contain pore characteristics associated with poor freeze-thaw durability (1). Many of the glacial gravel deposits in Michigan contain heterogeneous mixtures of carbonates in various stages of weathering, and from diverse parent bedrock formations, some of which have strata that exhibit deleterious characteristics.

A specific example of deleterious carbonate in the bedrock is the Trenton Black River Formation which outcrops in the Upper Peninsula and extends to Kingston, Ontario where it has been quarried for use in concrete structures. Due to cement-aggregate reactivity, the concrete structures containing this aggregate have suffered extensive distress (2). In addition to alkali-silica reactivity, aggregate from this source also displays undesirable pore structure as measured by the Iowa Pore Index test. Carbonate rock from this formation and other deleterious bedrock sources that were incorporated into the glacial gravels would be expected to contribute to D-cracking distress in concrete pavements. Quarried carbonates and gravels have been tested extensively for freeze-thaw durability. However, the carbonate components of glacial gravels have not been evaluated separately for freeze-thaw durability.

In the 1970's the Department conducted a study of the freeze-thaw durability of the major rock types in Michigan glacial gravels (3). The primary purpose of the study was to evaluate the MDOT classification of deleterious rock types that can be visually recognized in gravel, as stated in the MDOT Standard Specifications for Construction. Results of the study supported the classification, showing that the rock types considered to be deleterious (friable sandstone, siltstone, shale, clay ironstone, and chert) proved to have poor freeze-thaw durability. Due to time constraints, several objectives of the study were not covered, including the freeze-thaw evaluation of the carbonate rock gravel fraction, and the effects of down-sizing and blending to improve freeze-thaw durability.

This investigation was initiated to complete the remainder of the earlier study. The investigation also includes the results of Iowa Port Index determinations conducted on the aggregates to evaluate the test as a screening procedure for aggregates to be tested for freeze-thaw durability.

The findings from this investigation are to be included as Module I of a cooperative freeze-thaw investigation in which the Michigan Department of Transportation is participating with Michigan Technological University and the Cold Regions Research Engineering Laboratory of the U. S. Corps of Engineers.

SAMPLES

The aggregates selected for this investigation included a high-durability quarried dolomite to be used as a control in blends, and a composite of gravel from two sources. One source was a typical heterogeneous glacial deposit located in south central lower Michigan; samples included sink and float heavy media separated material. The other source was a typical high-carbonate glacial deposit located in northwestern lower Michigan; samples from this latter source were not heavy media beneficiated.

The following list indicates the Michigan aggregate source numbers and locations:

Aggregate	Source No.	Location
Control Dolomite	17-66	Chippewa County
Control Gravel No. 1 (a)	19-24	Clinton County
Control Gravel No. 2 (b)	28-46	Grand Traverse County

(a) Carbonate content, 48 percent
(b) Carbonate content, 84 percent

An inventory of the individual lithologies was made after the sorting of the gravel material was completed. The control gravel samples were found to produce sufficient material for most of the scheduled freeze-thaw mixes. A small amount of additional deleterious material was required to prepare aggregate blends for the freeze-thaw mixes with high deleterious percentages. Most of the needed quantities of the deleterious categories (friable sandstone, siltstone, and clay ironstone) were furnished from surplus stock sampled for the earlier study. However, a supplemental sampling of shale from a source in Alpena County was needed to complete the compositing of deleterious fractions for the blends.

Sample Preparation

The dolomite and gravel 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. The coarse aggregate for freeze-thaw durability testing in the earlier MDOT investigation included substitution of a high-durability quarried carbonate for the standard 3/8-in. to No. 4 fraction in the concrete mixes to reduce sorting time. The substitution produced no detectable beneficiation bias in the freeze-thaw test results. A similar substitution was made in this investigation using the high-durability control dolomite. The gravel passing the 3/8-in. sieve was not used.

Following completion of size grading, portions of the samples were prepared for petrographic examination and Iowa Pore Index determinations. The gravel was then sorted into individual lithologies using microscopical examination. The carbonate gravel fraction was further sorted into non-absorptive and absorptive categories using the Iowa Pore Index chamber to pressure-soak the aggregate. After completion of the sorting, portions of the individual lithologies were prepared for freeze-thaw mixes and Iowa Pore Index determinations.

The standard freeze-thaw mixes required equal quantities of aggregate in the 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 sizes. Two mixes prepared to compare the effect of down-sizing required 1 in. to 3/4 in. aggregate (MDOT 6A gradation), and 3/4 in. to 1/2 in. (MDOT 17A gradation).

The Iowa Pore Index test procedure required aggregate in the 3/4 in. to 1/2 in. size fraction to eliminate possible size bias in the rates of absorption of the different types of aggregate. The 3/4 in. to 1/2 in. fraction was selected since it represents a considerable portion of the coarse aggregate in conventional concrete mix designs. Aggregate finer than 1/2 in. is not considered to significantly affect the freeze-thaw durability of concrete, according to MDOT laboratory tests of finer gradations.

Petrographic Examination

Petrographic examination was conducted on the control aggregates according to Michigan Test Method MTM 104 (4). Three-hundred particles in each of the noted sieve fractions were examined microscopically. In addition to general petrographic content, the samples were examined specifically for particles considered as deleterious in the MDOT Standard Specifications for Construction. According to the specifications, the rock types friable sandstone (noted as FR sandstone in the tabulations), siltstone, shale, and clay ironstone are classified as "soft" deleterious particles. These rock types are noted by asterisks in the tabulations.

The soft particle types and chert are visually identifiable and comprise the predominant rock types considered as deleterious in the MDOT Standard Specifications for Construction.

The carbonates, classified in the tabulations as non-absorptive and absorptive carbonates, were separated by pressure-saturation in the Iowa Pore Index test chamber and surface drying prior to visual examination.

The 3/8 in. to No. 4 gravel fractions, not included in the freeze-thaw mixes, were not analyzed.

Results of the petrographic examinations are summarized in the following tabulations:

CONTROL DOLOMITE
Source: Drummond Dolomite #2 Pit No. 17-66

Rock Type	Composition of Noted Sieve Fraction, percent				Computed Sample Comp., percent
	3/4-in.	1/2-in.	3/8-in.	No. 4	
Sedimentary:					
Non-Absorptive Carbonates	100.0	100.0	100.0	100.0	100.0
Absorptive Carbonates	0.0	0.0	0.0	0.0	0.0
Totals	100.0	100.0	100.0	100.0	100.0

CONTROL GRAVEL NO. 1
Source: Hall Pit No. 19-24

Rock Type	Composition of Noted Sieve Fraction, percent				Computed Sample Comp., percent
	3/4-in.	1/2-in.	3/8-in.	No. 4	
Igneous/Metamorphic	49.0	49.6	38.3	NA	45.6
Sedimentary:					
Non-Absorptive Carbonates	35.0	35.0	44.7	NA	38.2
Absorptive Carbonates	10.0	9.0	10.7	NA	10.0
Non-Friable Sandstone	0.3	0.7	0.3	NA	0.4
Friable Sandstone*	0.0	0.0	0.0	NA	0.0
Siltstone*	0.3	0.0	0.0	NA	0.1
Shale*	0.0	0.0	0.0	NA	0.0
Clay Ironstone*	0.7	0.7	1.0	NA	0.8
Chert	4.7	5.0	5.0	NA	4.9
Totals	100.0	100.0	100.0	NA	100.0
Soft* + Chert	5.7	5.7	6.0	NA	5.8

CONTROL GRAVEL NO. 2
Source: Walton #2 Pit No. 28-46

Rock Type	Composition of Noted Sieve Fraction, percent				Computed Sample Comp., percent
	3/4-in.	1/2-in.	3/8-in.	No. 4	
Igneous/Metamorphic	9.7	8.5	11.3	NA	9.8
Sedimentary:					
Non-Absorptive Carbonates	70.0	66.9	66.7	NA	67.8
Absorptive Carbonates	13.6	19.3	14.0	NA	15.7
Non-Friable Sandstone	0.0	0.3	0.0	NA	0.1
Friable Sandstone*	0.0	0.0	0.0	NA	0.0
Siltstone*	1.0	1.3	3.3	NA	1.9
Shale*	0.0	0.7	1.0	NA	0.6
Clay Ironstone*	0.0	0.0	0.0	NA	0.0
Chert	5.7	3.0	3.7	NA	4.1
Total	100.0	100.0	100.0	NA	100.0
Soft* + Chert	6.7	5.0	8.0	NA	5.9

COMPOSITE OF CONTROL GRAVEL NO. 1 AND NO. 2
Source: Hall Pit No. 19-24 and Walden #2 Pit No. 28-46

Rock Type	Composition of Noted Sieve Fraction, percent				Computed Sample Comp., percent
	3/4-in.	1/2-in.	3/8-in.	No. 4	
Igneous/Metamorphic	29.4	29.1	24.8	NA	27.8
Sedimentary:					
Non-Absorptive Carbonates	52.5	51.0	55.7	NA	53.0
Absorptive Carbonates	11.8	14.2	12.3	NA	12.8
Non-Friable Sandstone	0.2	0.4	0.2	NA	0.3
Friable Sandstone*	0.0	0.0	0.0	NA	0.0
Siltstone*	0.6	0.6	1.6	NA	0.9
Shale*	0.0	0.4	0.5	NA	0.3
Clay Ironstone*	0.3	0.3	0.5	NA	0.4
Chert	5.2	4.0	4.4	NA	4.5
Totals	100.0	100.0	100.0	NA	100.0
Soft* + Chert	6.1	5.3	7.0	NA	6.1

FREEZE-THAW TESTS

Freeze-thaw testing was conducted cooperatively by the Structural Services Unit, Testing Laboratory Section, of the Materials and Technology Laboratory, according to ASTM C 666 Method B "Resistance of Concrete to Rapid Freezing in Air and Thawing in Water" (5), and Michigan Test Methods 113, 114, and 115 (6, 7, 8). In each test, nine 3 by 4 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 the high-durability control dolomite in the No. 4 size fraction. The substitution in the smallest size fraction greatly reduced the sorting time for the aggregate preparation phase of the investigation and produced no detectable beneficiation bias in the freeze-thaw test results.

At the time of the earlier MDOT investigation, the results of freeze-thaw tests were reported 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

TABLE 1

Rock Type	Bulk S.G.	ABS, percent		DF[4]	Pore Index	Equivalent Expansion, percent per 100 cycles
	Dry[1]	24H[2]	VAC[3]			
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						
Carbonates						
Limestone (Quarried)	2.65	0.71	0.80	92	19	0.003
Dolomitic Limestone (Quarried)	2.65	0.77	0.83	81	27	0.008
Dolomite (Quarried)	2.80	0.47	0.71	95	6	0.002
Detrital						
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	>0.103
Siltstone*	2.20	7.56	8.96	2	48	>0.103
Shale*	2.12	5.64	5.87	13	106	0.089
Clay Ironstone (Fossiliferous)*	2.64	6.65	8.13	0	119	>0.103
Clay Ironstone (Laminated/Massive)*	2.37	12.07	14.31	0	423	>0.103
Non-Detrital						
Chert (Dense/Vitreous-Lustered)*	2.56	0.93	0.87	23	30	0.060
Chert (Mottled)*	2.41	3.17	3.75	0	76	>0.103
Chert (Porous)*	2.37	4.15	4.61	0	96	>0.103
Clay Ironstone (Concretion Shells)*	2.49	11.28	12.49	0	304	>0.103
Clay Ironstone (Concretion Centers)*	3.24	1.44	1.53	20	12	0.067

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[1] Bulk specified 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.

* Rock types included as deleterious in MDOT Standard Specifications.

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. The scale of durability represented by the DF numbers ranges from 0 (very low durability) to 100 (very high durability).

Presently, freeze-thaw durability is reported as expansion (or dilation), percent per 100 cycles, resulting in a difficulty in comparing the results of the earlier investigation with the present freeze-thaw data. Comparison of the older freeze-thaw durability factors with the new expansion measurements was made possible by the following conversion 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

$\ln DF$ = natural log of durability factor DF

The correlation is valid only when comparing the average expansion of a nine-beam set of specimens with the equivalent freeze-thaw durability factor.

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. However, durability factors of 10 or less indicate very low durability. According to the 1990 MDOT Standard Specifications for Construction, the maximum allowed expansion (expressed as freeze-thaw dilation, percent per 100 cycles) for coarse aggregates is 0.067, which converts to a freeze-thaw durability factor of 20 (9).

Results of the freeze-thaw tests conducted on the individual gravel lithologies in the earlier investigation are shown in Table 1 for comparison with the results of this investigation. The results are expressed as freeze-thaw durability factors and expansions per 100 cycles of freezing and thawing. Iowa Pore Index test results are also included for comparison.

In Table 1, the gravel lithologies clay ironstone (concretion centers) and chert (dense to vitreous lustered) which recorded marginally acceptable durability factors are included in the deleterious category because of their close relationship to other deleterious subtypes.

The freeze-thaw tests for this investigation were conducted in three separate phases. Phase I included tests of the control aggregates and the evaluation of the carbonates sorted from gravel. Phase II included the evaluation of blending and down-sizing to reduce the deleterious effect of gravel carbonates, and Phase III included the evaluation of blending to reduce the deleterious effect of the chert and soft particle deleterious fractions in gravel.

Results of the freeze-thaw tests conducted on the test mixes for this investigation are shown in Table 2. The results are expressed as freeze-thaw durability factors and expansions per 100 cycles of freezing and thawing. Results of Iowa Pore Index tests are also included for comparison.

TABLE 2

Phase/ Mix	Aggregate	Bulk S.G.	ABS, percent		DF[4]	Pore Index	Equivalent Expansion, percent per 100 cycles
		Dry[1]	24H[2]	VAC[3]			
I/A	Control Dolomite	2.81	0.35	0.55	100	8	-0.001
I/B	Control Gravel	2.71	0.82	1.02	36	*	0.041
I/C	Igneous/Metamorphics	2.73	0.45	0.55	100	7	0.000
I/D	Non-Absorptive Carbonates	2.72	0.76	0.90	38	28	0.038
I/E	Absorptive Carbonates	2.56	2.56	3.37	4	34	0.172
II/A	Dolomite 90% + Carbonates 10%	2.79	0.42	0.59	93	*	0.003
II/B	Dolomite 70% + Carbonates 30%	2.76	0.51	0.90	86	*	0.006
II/C	Dolomite 50% + Carbonates 50%	2.76	0.70	0.73	64	*	0.017
II/D	Carbonates, 6A	2.67	1.20	1.42	33	*	0.044
II/E	Carbonates, 17A	2.68	0.94	1.23	47	*	0.029
III/A	Dolomite 95% + Chert 05%	2.78	0.56	0.71	69	*	0.014
III/B	Dolomite 90% + Chert 10%	2.77	0.51	0.76	10	*	0.103
III/C	Dolomite 85% + Chert 15%	2.75	0.83	0.86	<10	*	0.187
III/D	Dolomite 95% + "Soft" 05%	2.76	0.71	0.97	26	*	0.055
III/E	Dolomite 90% + "Soft" 10%	2.73	1.02	1.26	<10	*	0.315
III/F	Dolomite 85% + "Soft" 15%	2.71	1.34	1.56	<10	*	0.289

[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.
* Pore Index determinations not conducted on composites.

Carbonates in the Phase II mixes are proportioned to contain 80% non-absorptive and 20% absorptive carbonates sorted from gravel.

Phase I completed the evaluation of the major gravel lithologies originally included in the earlier MDOT investigation. The Phase I freeze-thaw tests included a control dolomite to establish a base durability value for the comparison of the effects of blending to improve freeze-thaw durability. Composite gravel was tested for comparison with the durability values obtained for the individual gravel lithologies analyzed in the earlier investigation. The igneous/metamorphic gravel fraction was tested as a composite, based upon the results of the earlier investigation which indicated that the individual rock types in the igneous and metamorphic classes all had high freeze-thaw durability. The gravel carbonates were tested in two categories — non-absorptive, and absorptive — which were separated by pressure-saturation in the Iowa Pore Index test chamber, followed by examination in the "saturated surface dry" state. Phase I included the following mixes:

		Coarse Aggregate
Phase I:	A)	Control Dolomite
	B)	Control Gravel, Composite of 2 Sources
	C)	Igneous/Metamorphic Gravel Fraction
	D)	Non-Absorptive Carbonate Gravel Fraction
	E)	Absorptive Carbonate Gravel Fraction

Phase I freeze-thaw tests conducted on the control dolomite and the composite igneous/metamorphic gravel fraction produced expansion values of -0.001 (DF 100) and 0.000 (DF 100), both indicating the highest measurable freeze-thaw durability. The composite gravel produced an expansion value of 0.041 (DF 35), typical of a low to intermediate durability aggregate. The non-absorptive gravel carbonates produced an expansion value of 0.038 (DF 38), whereas the absorptive carbonate fraction produced a high expansion of 0.172 (DF <10) indicating that the carbonate fraction of glacial gravel contains material which contributes to poor freeze-thaw durability, as suspected.

Phase II included freeze-thaw tests of three blends of the control dolomite with gravel carbonates to determine the beneficiation effect of dilution on the carbonate gravel fraction. Gravel carbonates for blending were composited to contain 80 percent non-absorptive, and 20 percent absorptive particles, as determined from petrographic analyses conducted on gravel from 31 sources submitted to the MDOT Testing Laboratory for freeze-thaw durability tests (10).

Down-sizing to improve freeze-thaw durability was also investigated in Phase II. The gravel carbonate fraction was used as coarse aggregate in mixes prepared as standard MDOT 6A gradation containing 1-in. to 3/4-in. top size, and as MDOT 17A gradation containing 3/4-in. to 1/2-in. size. Phase II included the following mixes:

Coarse Aggregate

Phase II:
A) Control Dol. 90%+80/20 Composite Gravel Carbonates 10%
B) Control Dol. 70%+80/20 Composite Gravel Carbonates 30%
C) Control Dol. 50%+80/20 Composite Gravel Carbonates 50%
D) 6A 80/20 Composite Gravel Carbonates
E) 17A 80/20 Composite Gravel Carbonates

The Phase II freeze-thaw tests of the control dolomite blends with gravel carbonates produced results that indicate decreasing durability with increasing amounts of gravel carbonates in the concrete. The blend with 10 percent gravel carbonates produced an expansion of 0.003 (DF 93), and the blend with 30 percent gravel carbonates produced an expansion of 0.006 (DF 86). The blend with 50 percent gravel carbonates produced an expansion of 0.017 (DF 64). This is comparable to some glacial gravels containing a similar carbonate component and only a small amount of chert and soft particle deleterious material to account for the lowered durability.

The mixes containing 3/4 in. vs. 1/2 in. 80/20 composite gravel carbonate coarse aggregate produced expansions of 0.44 (DF 33) and 0.029 (DF 47), respectively, indicating a moderate improvement in freeze-thaw durability attributed to down-sizing, from MDOT 6A to 17A gradation.

Phase III included freeze-thaw tests of three blends of the control dolomite with gravel chert to determine the beneficiation effect of smaller quantities of the chert gravel fraction. Chert is a major deleterious constituent in many Michigan gravels. The Phase III freeze-thaw tests also included three blends of the control dolomite with the MDOT "soft particle" deleterious gravel fraction to determine the beneficiation effect of smaller quantities of this category. The soft particle fraction for blending was composited to contain equal amounts of the constituents friable sandstone, siltstone, shale, and clay ironstone, stated as deleterious in the MDOT Standard Specifications for Construction. All of the soft particle lithologies produced low freeze-thaw durabilities in the earlier MDOT investigation.

Phase III included the following mixes:

		Coarse Aggregate
Phase III:	A)	Control Dolomite 95% + Gravel Chert 05%
	B)	Control Dolomite 90% + Gravel Chert 10%
	C)	Control Dolomite 85% + Gravel Chert 15%
	D)	Control Dolomite 95% + Gravel "Soft" 05%
	E)	Control Dolomite 90% + Gravel "Soft" 10%
	F)	Control Dolomite 85% + Gravel "Soft" 15%

The Phase III freeze-thaw tests of the control dolomite blends with chert produced results that indicate large reductions in durability with increasing amounts of chert in the concrete. The blend with 5 percent chert produced an expansion of 0.014 (DF 69). Whereas, the blend with 10 percent chert produced an expansion of 0.103 (DF 10), and the blend with 15 percent chert produced an expansion of 0.187 (DF <10).

The Phase III freeze-thaw tests of the control dolomite blended with the MDOT soft deleterious gravel fraction produced results similar to the blends containing chert. The blend with 5 percent soft deleterious fraction produced an expansion of 0.055 (DF 26). Whereas, the blend with 10 percent soft deleterious fraction produced an expansion of 0.122 (DF <10), and the blend with 15 percent soft deleterious fraction produced an expansion of 0.289 (DF <10).

The similar results of the blends with chert and soft deleterious fraction indicate that blending to dilute the harmful effects of chert and the soft deleterious material requires a reduction of the amounts of these gravel constituents in an aggregate to 5 percent or less to achieve satisfactory freeze-thaw durability. The additive harmful effect of absorptive carbonates in the gravel would require, for some deposits, a lower allowable amount of the total deleterious (chert combined with soft) material to achieve improved freeze-thaw durability.

Examination of the concrete freeze-thaw beams after testing revealed numerous pop-outs and cracks in the specimens containing the absorptive carbonates, chert blends, and soft particle deleterious blends with increasing surface expression of distress related to increasing amounts of deleterious material in the concrete.

The range of expansion values was noted to increase with increased amounts of deleterious material in the beams. In such cases, the chance placement of deleterious particles also was noted to affect the performance of the concrete. Several deleterious particles clustered in a small area often produced severe localized distress. In the blends containing lower amounts of deleterious particles surface distress was usually limited to isolated pop-outs, less likely to occur in critical locations affecting the expansion of the beams.

Examples of the effects of deleterious particle content in the concrete are shown graphically in Figure 1 which includes plots of the individual beam expansions recorded for the Phase III mixes containing the control dolomite with gravel chert. The plots show the effects of increasing deleterious material, and the increasing range of expansions with increasing deleterious material in the concrete. The blend containing 5 percent chert, for example, showed a very small range in the expansion data for the nine beams tested. Whereas, the blends containing 10 and 15 percent chert showed a large range due to the chance placement of deleterious particles in the test beams. It would seem entirely reasonable to expect these same types of groupings to occur in actual concrete in the field, with similar deleterious effects.

The mixes containing the control dolomite, gravel igneous/metamorphics, non-absorptive carbonates, and blends of high-durability dolomite with 5 percent chert, and 5 percent soft particle deleterious gravel fraction all recorded similar small range in the expansion results for the individual test beams. In contrast, the mixes containing greater amounts of deleterious material recorded increased ranges similar to the plots of the blends with 10 and 15 percent chert.

Statistical procedures to discard suspect high expansion measurements, based upon outlier criteria, do not appear to be appropriate for the analysis of the expansion data, since the distress caused by the deleterious particles is evident, and can occur similarly in pavements and structures. The range displayed by such expansion measurements is an inherent characteristic of the freeze-thaw procedure that signals the presence of disruptive particles in the aggregate, and should not be regarded as a lack of control in the test.

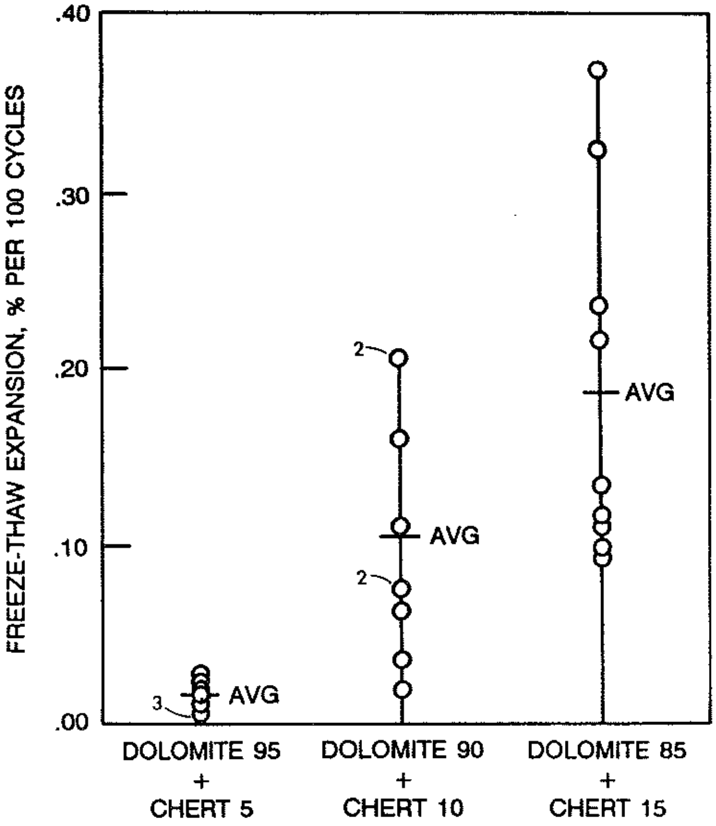


Figure 1. Expansions of individual beams of dolomite-chert blends.

SPECIFIC GRAVITY AND ABSORPTION DETERMINATIONS

Specific gravity and absorption determinations were conducted on all of the coarse aggregates for preparation of the freeze-thaw mixes. The gravel lithologies display a direct correlation between bulk specific gravity and freeze-thaw durability, as shown in Tables 1 and 2. The rock types with bulk specific gravity greater than 2.56, with the exception of two clay ironstone subtypes, were found to have acceptably high freeze-thaw durability according to the present MDOT specifications.

The absorption characteristics of the gravel constituents also indicate a direct correlation between absorption and freeze-thaw durability. The rock types with 24 hour absorption above two percent are shown to exhibit considerably lower resistance to freezing and thawing than those that are less absorptive.

As indicated by the specific gravity and absorption determinations shown in Tables 1 and 2, a heavy media separation process maintained at a specific gravity greater than 2.56 should remove most of the low-gravity, absorptive constituents from the gravel.

The high-gravity clay ironstone subtypes usually are present in small amounts in most gravel deposits, and can be removed by other beneficiation processes involving crushing or fractionation if necessary.

IOWA PORE INDEX TESTS

In 1981 an evaluation of the Iowa Pore Index test was initiated at the Materials and Technology Laboratory to determine if the test could be used as a screening procedure for aggregates submitted to the laboratory for freeze-thaw testing. The pore index test is a rapid procedure that measures the absorption of an oven-dried 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. According to Meyers and Dubberke, a pore index number greater than 27 has been correlated with D-cracking susceptibility in Iowa's carbonate aggregates (11).

As part of the evaluation of the Iowa Pore Index test, quantities of the individual gravel lithologies sorted for the earlier MDOT investigation were tested for comparison with the results of freeze-thaw tests conducted on the gravel constituents. Pore index determinations were also conducted on the control dolomite and gravel constituents sorted for the Phase I, II, and III freeze-thaw tests of this project. The igneous/metamorphic gravel lithologies were tested as a composite, and the gravel carbonates were tested as non-absorptive and absorptive fractions separated by appearance when "saturated surface dry" after pressure-saturation in the pore index chamber.

Results of the pore index tests conducted on the gravel lithologies are included in Table 3. The table also includes the comparative results of freeze-thaw tests, expressed as freeze-thaw durability factors. Aggregate numbers were assigned for reference.

Pore index tests conducted on the indidivual lithologies of the igneous and metamorphic rock classes produced similar results when tested as a composite igneous/metamorphic gravel fraction. The pore index numbers were considerably below the 27 criterion for D-cracking susceptibility. The aggregates also produced high freeze-thaw durability.

Pore index tests conducted on the quarried high-durability carbonates produced similar results. The quarried carbonates, with exception of dolomitic limestone, produced low pore index numbers which were associated with high freeze-thaw durability. Dolomitic limestone produced a pore index number of 27, the separation value for D-cracking susceptibility.

The control dolomite used for blending produced a low pore index number of 8 and a high durability factor of 100. In comparison, the non-absorptive gravel carbonate fraction produced a marginal pore index number of 26

TABLE 3
RESULTS OF IOWA PORE INDEX AND FREEZE-THAW TESTS

Aggregate	Agg No.	Freeze-Thaw DF	Iowa Pore Index Values, ml	
			Primary Load	Secondary Load, Pore Index
Igneous:				
Granite	I1	94	34	9
Gabbro	I2	98	25	4
Basalt	I3	98	36	10
Felsite	I4	96	46	21
Metamorphic:				
Quartzite	M1	95	32	8
Tillite	M2	99	23	4
Metasediments	M3	98	30	8
Schists	M4	76	55	51
Composite IG/Meta[1]	IM	100	24	7
Sedimentary:				
Carbonates				
Dolomite[2]	C1	95	34	6
Dolomitic Limestone	C2	81	44	27
Limestone[2]	C3	92	42	19
Control Dolomite[2]	C4	100	33	8
Non-Absorptive Carbonate[3]	C5	38	43	28
Absorptive Carbonate[3]	C6	4	150	34
Detrital				
Crag	S1	30	132	19
Non-Friable Sandstone	S2	22	174	36
Friable Sandstone*	S3	4	324	17
Siltstone*	S4	2	321	48
Shale*	S5	13	87	106
Clay Ironstone (foss.)*	S6	0	260	119
Clay Ironstone (lam./mas.)*	S7	0	262	423
Non-Detrital				
Chert (dense./vitreous)*	S8	23	37	30
Chert (mottled)*	S9	0	108	76
Chert (porous)*	S10	0	106	96
Clay Ironstone (shells)*	S11	0	245	304
Clay Ironstone (centers)*	S12	20	31	12

[1] Composite sorted from gravel.

[2] Quarried bedrock.

[3] Sorted from gravel.

* Rock types included as deleterious in the MDOT Standard Specifications for Construction.

and an intermediate freeze-thaw durability factor of 38, and the absorptive gravel carbonate fraction produced a pore index number of 34 — above the 27 limit for D-cracking susceptibility — and a very low freeze-thaw durability factor of 4.

Results of the Iowa Pore Index tests conducted on the gravel lithologies and quarried carbonates indicated a relationship between the pore index measurements and the freeze-thaw durability of aggregates. The gravel lithologies chert and clay ironstone produced very high pore index numbers and very low freeze-thaw durability factors, indicating poor durability in concrete. The two rock types produce most of the pop-outs observed on Michigan pavements.

Similar findings were reported by Shakoor and Scholer in an investigation comparing the measurement of aggregate pore characteristics as measured by the mercury intrusion porosimeter and Iowa Pore Index tests (12). Results of their findings state that the Iowa Pore Index test could be used to predict the freeze-thaw durability of coarse aggregate, in particular the potential for producing pitting and pop-outs in concrete.

The relationship between the Iowa Pore Index number and the MDOT freeze-thaw durability factor is shown in Figure 2. Results of the freeze-thaw tests are expressed as durability factors. The figure shows that the minimum MDOT durability limit, expressed as DF 20, and the Iowa Pore Index limit of 27 both separate the high-durability aggregates from the low-durability aggregates.

The figure shows a few apparent exceptions. Aggregate M4 (schist) is a foliated, absorptive aggregate which has been found to cause spalling and pop-outs when highly weathered. Aggregate S2 (non-friable sandstone) is an absorptive aggregate having relatively low physical strength which poorly resists freezing and thawing when in a critically saturated condition. Aggregate S3 (friable sandstone) is an absorptive, weakly cemented aggregate which, because of its open pores, produces low pore index values. Due to weak cementation, the aggregate has poor freeze-thaw durability. Such aggregates are readily identified by the high primary load recorded during the Iowa Pore Index determination.

Aggregate S8 (dense to vitreous-lustered chert) is a relatively minor constituent in most gravels, and can be highly variable in porosity, often grading into more porous forms of chert. This aggregate is readily identified by petrographic examination.

The differences in the absorption characteristics of the gravel lithologies are shown graphically by absorption curves generated by plots of the absorption measurements obtained during the pore index determinations. The curves, included in Figures 3 through 8, demonstrate the great range of absorptivity present in the gravel lithologies.

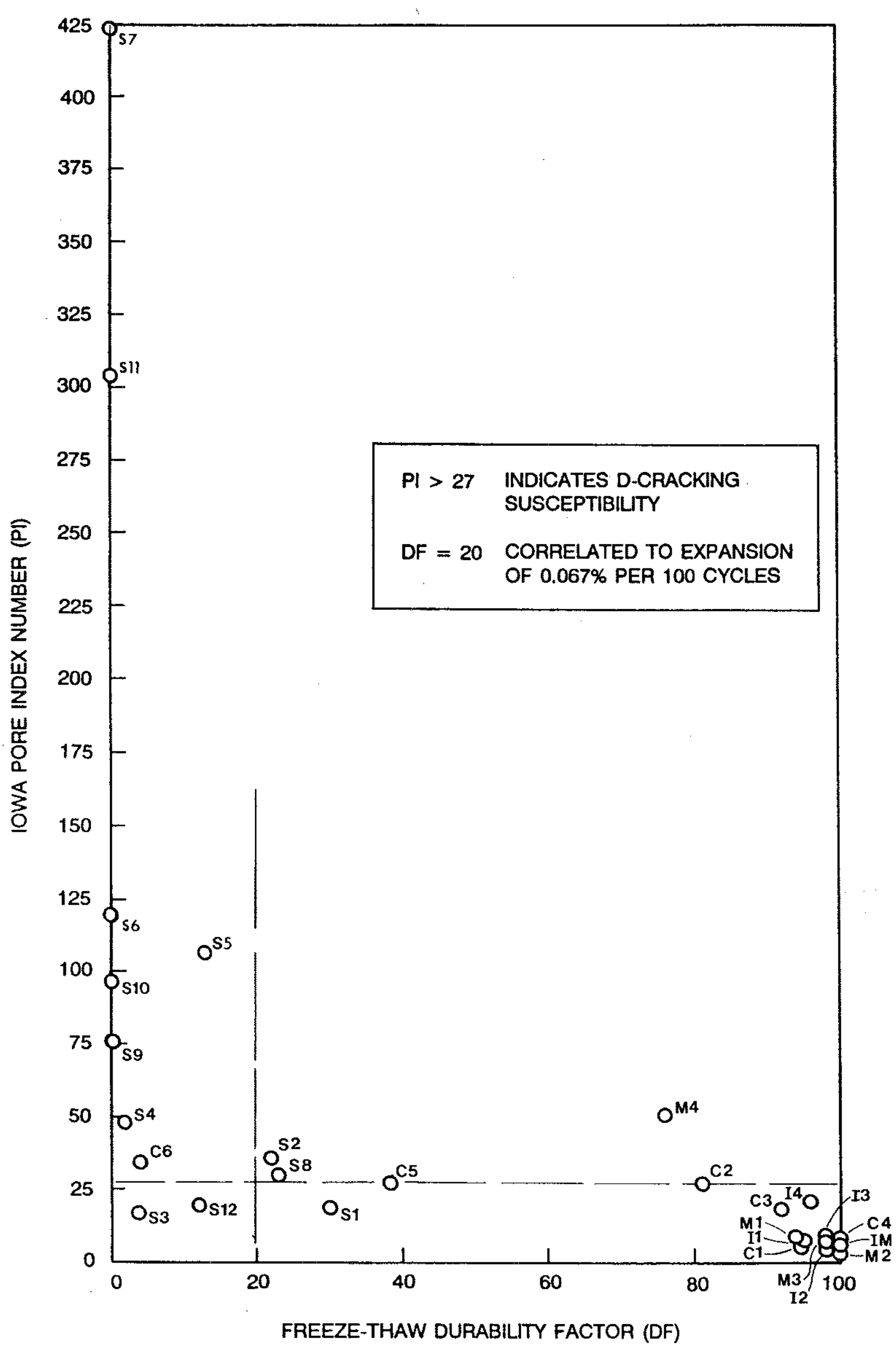
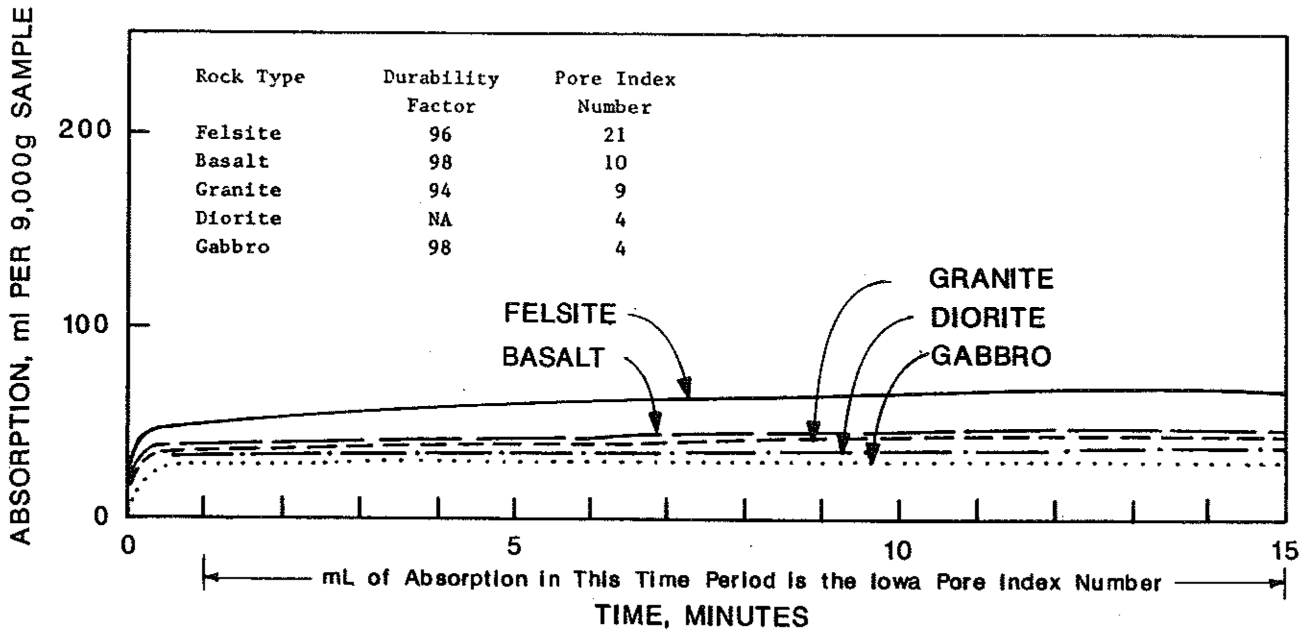


Figure 2. Relationship between MDOT durability factor and Iowa Pore Index number.

Dense, impermeable aggregates such as granite, quartzite, and the control dolomite take up a small amount of water, primarily during the initial minute, due to the slight absorption into shallow surface weathering or pits.

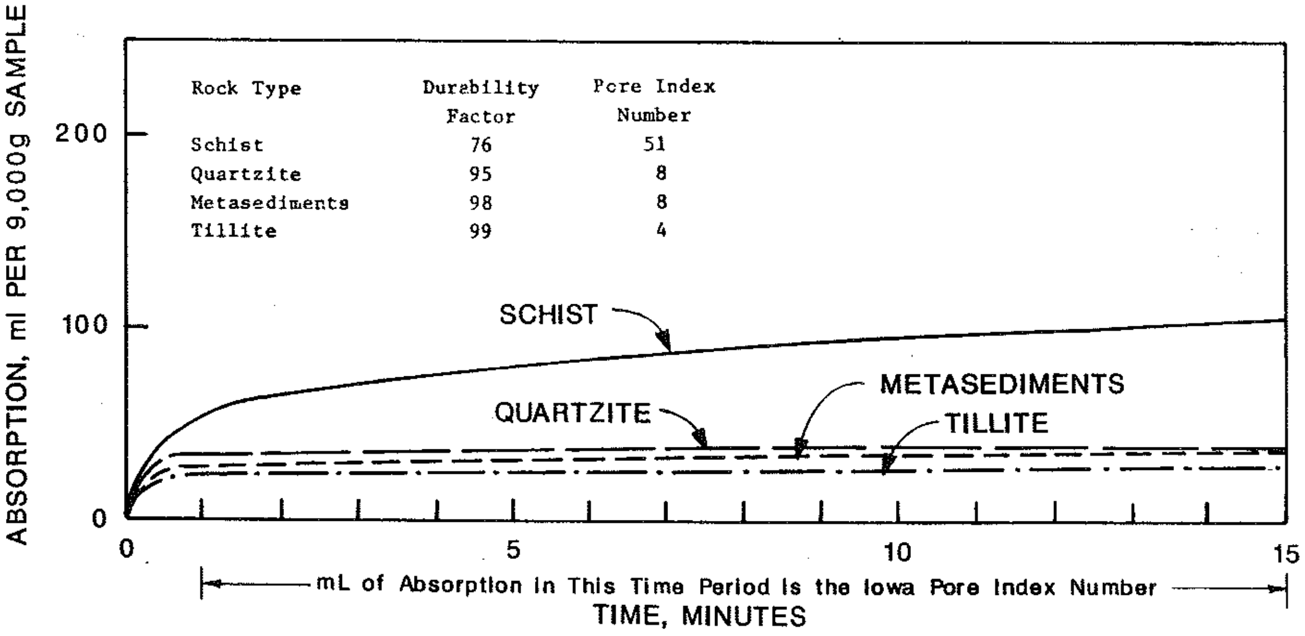
Aggregates with large, open voids such as crag and friable sandstone take up a large amount of water during the initial minute, followed by little or no additional absorption during the remaining 14 minutes of the test.

The aggregates that display D-cracking susceptibility, such as absorptive carbonates and the deleterious sedimentary lithologies, display a more gradual, continuous absorption through the 15 minute duration of the test. The more gradual absorption indicates that the predominant size of the pores in such rock types is very small, requiring greater time for absorption.



Rock Type	Durability Factor	Pore Index Number
Felsite	96	21
Basalt	98	10
Granite	94	9
Diorite	NA	4
Gabbro	98	4

Figure 3. Absorption curves of the igneous gravel lithologies.



Rock Type	Durability Factor	Pore Index Number
Schist	76	51
Quartzite	95	8
Metasediments	98	8
Tillite	99	4

Figure 4. Absorption curves of the metamorphic gravel lithologies.

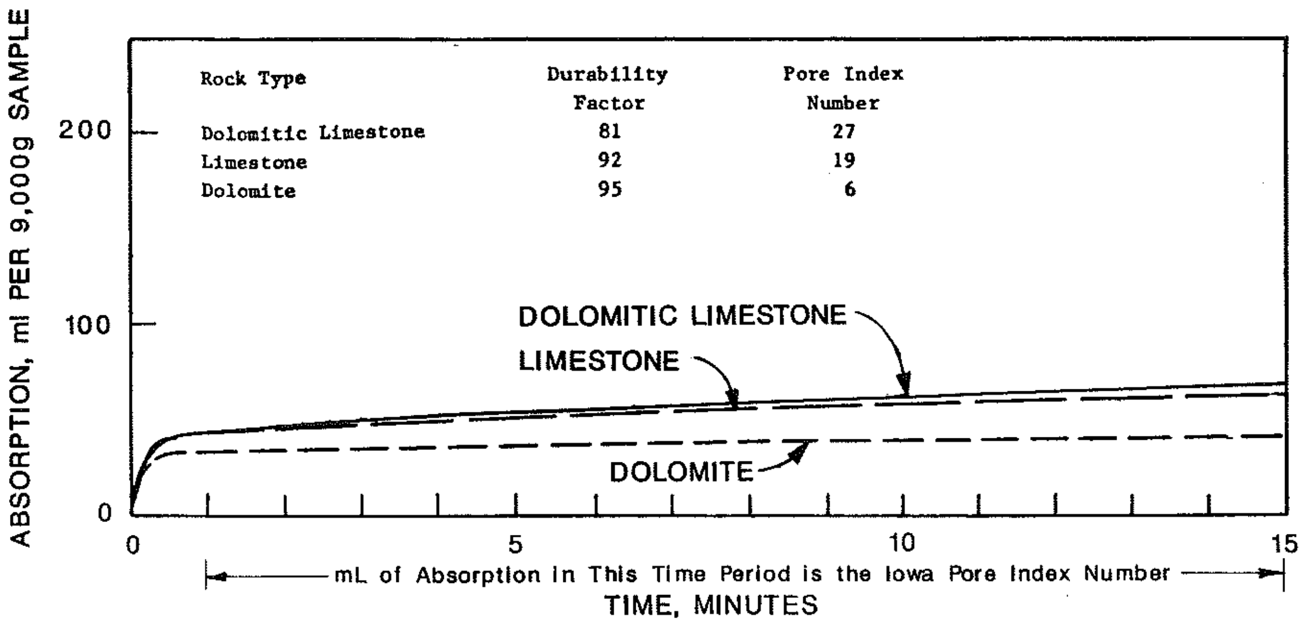


Figure 5. Absorption curves of the sedimentary northern Michigan carbonates (representative quarried material).

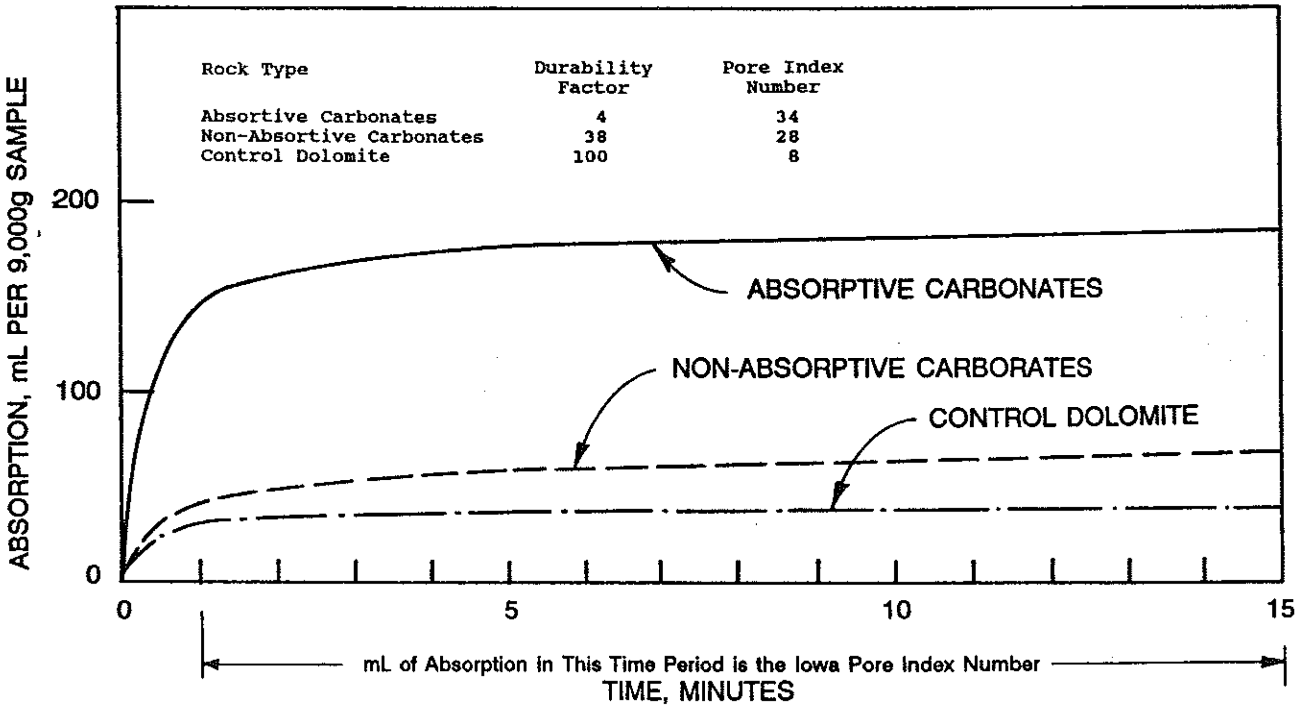
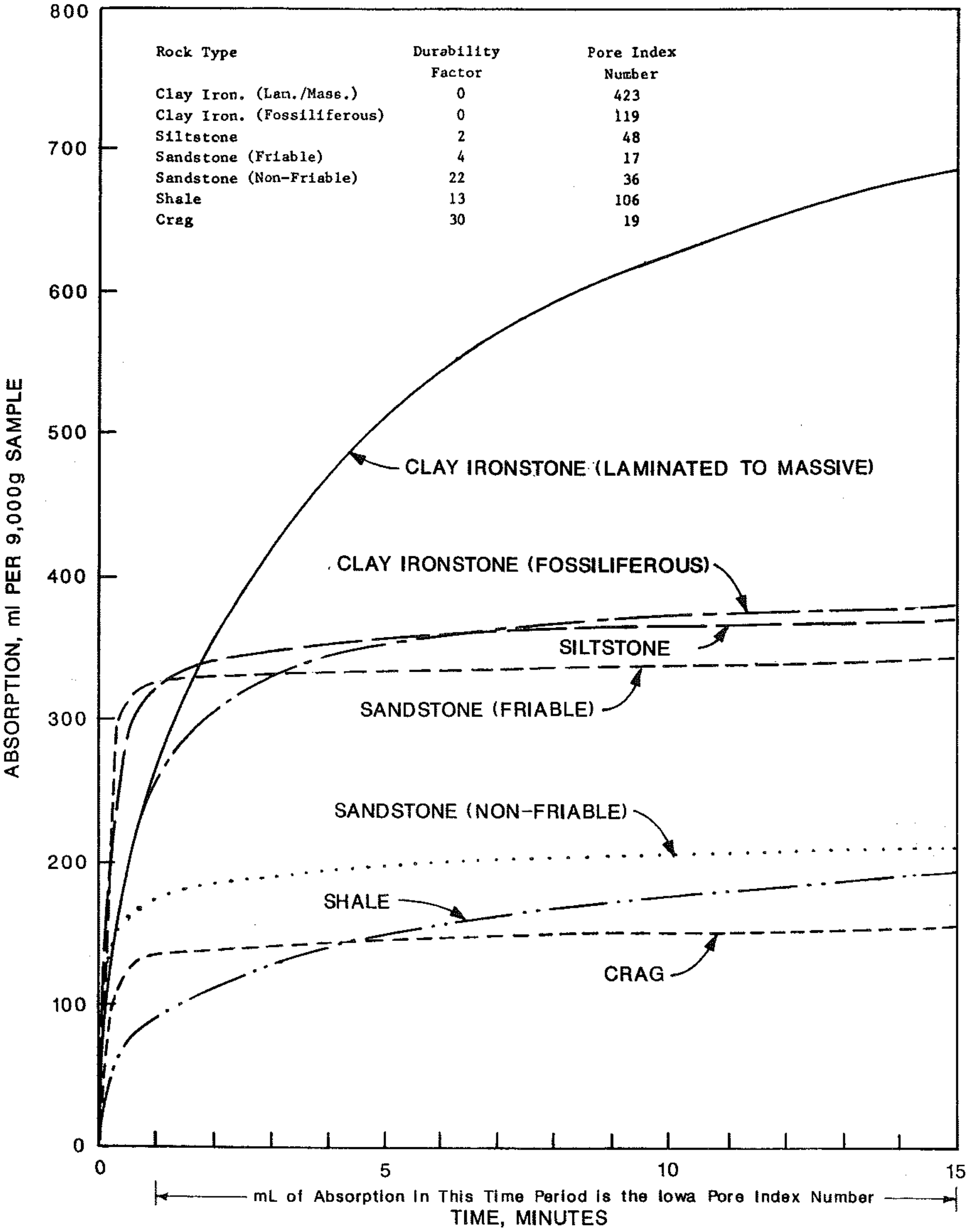
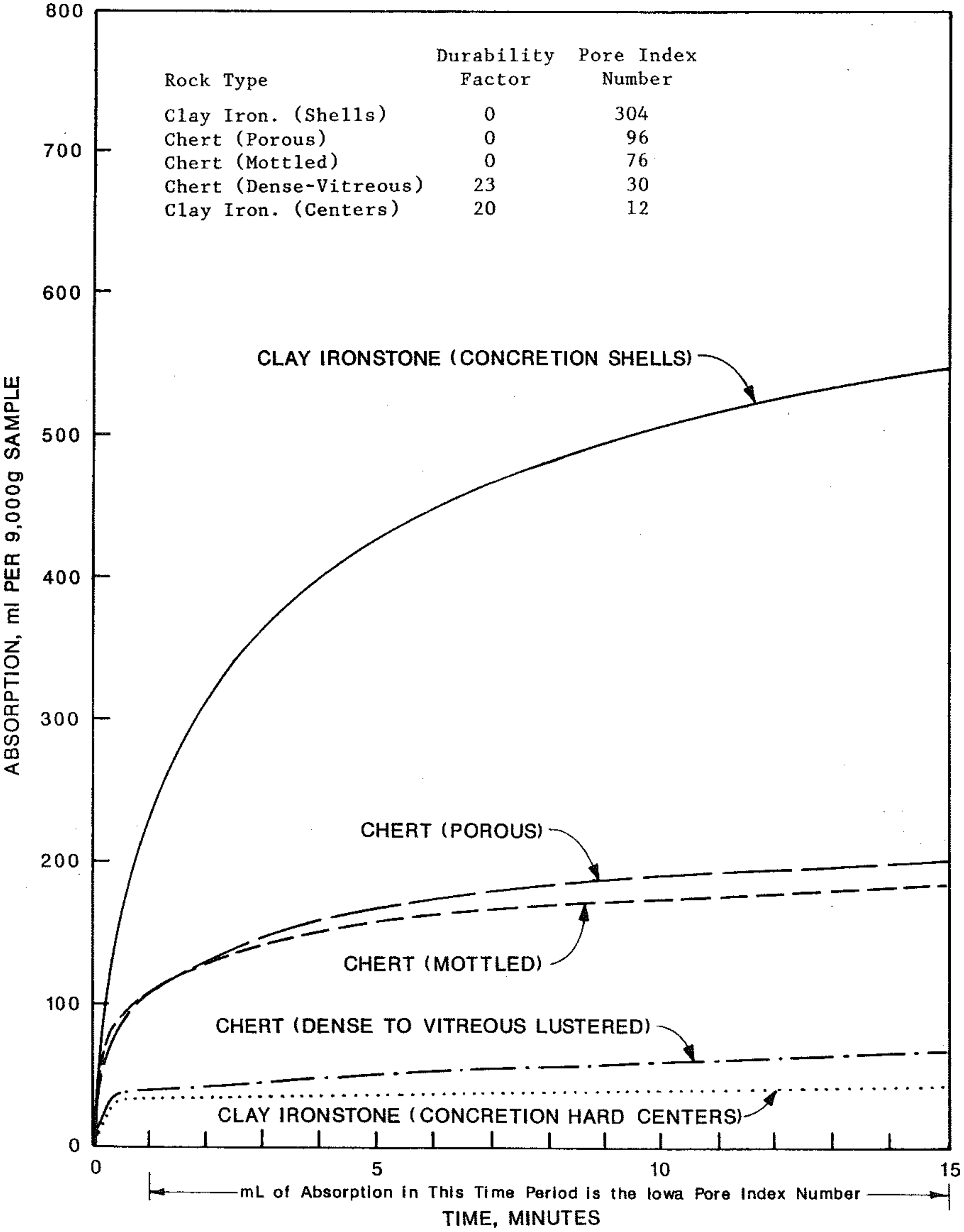


Figure 6. Absorption curves of the sedimentary gravel carbonates and quarried control dolomite.



Rock Type	Durability Factor	Pore Index Number
Clay Iron. (Lam./Mass.)	0	423
Clay Iron. (Fossiliferous)	0	119
Siltstone	2	48
Sandstone (Friable)	4	17
Sandstone (Non-Friable)	22	36
Shale	13	106
Crag	30	19

Figure 7. Absorption curves of the sedimentary detrital gravel lithologies.



Rock Type	Durability Factor	Pore Index Number
Clay Iron. (Shells)	0	304
Chert (Porous)	0	96
Chert (Mottled)	0	76
Chert (Dense-Vitreous)	23	30
Clay Iron. (Centers)	20	12

Figure 8. Absorption curves of the sedimentary non-detrital gravel lithologies.

CONCLUSIONS

The following conclusions resulted from the combined findings of the earlier MDOT investigation and this investigation:

1) Results of the freeze-thaw tests conducted on the individual gravel lithologies show that the rock types designated as deleterious in the MDOT Standard Specifications for Construction produce low freeze-thaw durability in concrete.

2) Durable rock types show no ill effects from vacuum saturation pre-treatment for freeze-thaw testing in concrete.

3) The carbonate rock components in Michigan glacial gravels contain absorptive constituents that produce low freeze-thaw durability in concrete and have pore characteristics that indicate D-cracking susceptibility (disintegration under repeated freeze-thaw cycles).

4) The rock types included in the MDOT soft particle deleterious category — friable sandstone, siltstone, shale, and clay ironstone — were as harmful as chert in the blends tested with the high-durability dolomite.

5) Down-sizing and blending to increase the freeze-thaw durability of the gravel carbonates resulted in a moderate improvement.

6) Blending to improve the freeze-thaw durability of gravel required a dilution of the deleterious aggregate fractions to 5 percent to achieve a substantial increase in freeze-thaw durability.

7) Variability in the freeze-thaw expansion measurements of the nine-beam sets increased with increasing amounts of deleterious particles in the test aggregates. The presence of a large range in the freeze-thaw expansions was found to be an indicator of disruptive particles in the test aggregate.

8) Specific gravity and absorption data indicate that most of the deleterious lithological components in Michigan glacial gravel can be removed by heavy media beneficiation.

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

10) The Iowa Pore Index test showed a good correlation with the freeze-thaw durability of the individual gravel constituents.

RECOMMENDATIONS

The following recommendations are made based upon the findings of the earlier MDOT investigation and this investigation:

1) Retain the deleterious particle classification for gravel coarse aggregate stated in the MDOT Standard Specifications for Construction.

2) Conduct an investigation to determine more closely the maximum allowable amount of chert plus soft particles for coarse aggregates stated in the MDOT Standard Specifications for Construction.

3) Develop methodology to identify and quantify the deleterious carbonate fraction in glacial gravel to be included in the deleterious particle category in the MDOT specifications.

4) Consider the blending of high-durability aggregates with gravel in the larger grade sizes to improve the freeze-thaw durability of the gravel. This would provide the needed coarse aggregate interlock in pavement concrete, and would result in the down-sizing and dilution of the deleterious constituents in the gravel.

5) Investigate alternative concrete mix designs, including types of cement, additives, and other constituents to develop a pavement concrete that is more impervious to moisture, resulting in protection of the aggregate from freeze-thaw action and other detrimental moisture-related effects. A more impervious pavement concrete could possibly result in satisfactory performance from aggregates that are disruptive in conventional pavement concrete.

REFERENCES

1. Schwartz, Donald R., "D-Cracking of Concrete Pavement," NCHRP Synthesis 134, October 1987.

2. Swenson, E. G., "A Reactive Aggregate Undetected by ASTM Tests," ASTM Bulletin 226, pp 48-50, December 1957.

3. Muethel, R. W., "Freeze-Thaw Evaluation of Selected Rock Types from a Composite Sample of Michigan Gravel," Michigan Department of Transportation Research Report No. R-1301, August 1989.

4. "Practice for Petrographic Analysis of Aggregates," Michigan Test Method MTM 104, Michigan Department of Transportation, Lansing, Michigan.

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

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

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

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

9. "1990 Standard Specifications for Construction," Michigan Department of Transportation, Lansing, Michigan.

10. Records of Freeze-Thaw Test Reports from 1954 to 1990, Materials and Technology Division, Michigan Department of Transportation, Lansing, Michigan.

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

12. Shakoor, A., and Schoeler, C. F., "Comparison of Aggregate Pore Characteristics as Measured by Mercury Instrusion Porosimeter and Iowa Pore Index Tests," ACI Journal, July/August 1985.