Laboratory Freeze-Thaw Tests of Portland Cement-Treated Granular Bases

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An Iowa freeze-thaw test is compared to the standard ASTM freeze-thaw test. In the Iowa test, the sample is undisturbed between cycles and is frozen from the top down with water continually available at the base of the specimen. Specimen deterioration is determined by the length changes and unconfined compressive strength after the freeze-thaw cycles.

A comparison of standard Proctor and vibrated compaction specimens was made for both freeze-thaw tests. The vibratory compaction method yields more consistent laboratory densities, produces less particle degradation, is easier to conduct, and is less time consuming than the standard Proctor compaction method.

The Iowa freeze-thaw test is easier to conduct and more nearly duplicates field conditions of freezing and thawing than does the ASTM test. The Iowa test considers strength and length change rather than brushing loss and allows interpolation for a design cement content. The ASTM method often requires additional molding and testing of specimens to pinpoint design cement content since no convenient method of interpolation is apparent.

•CEMENT requirements for soil-cement mixtures are controlled by freeze-thaw tests (ASTM D560-57) and wet-dry tests (ASTM D559-57). Since soil-cement is primarily used in bases rather than in surface courses where wearing ability is an important criteria, the validity of a test where the samples are stiff wire brushed after each cycle of freeze-thaw could be questioned.

A laboratory freeze-thaw test for cement-treated granular base materials that will more nearly duplicate field conditions is compared to the ASTM D560-57 freeze-thaw test in this report. Also, a vibratory method of compaction is compared to the AASHO-ASTM standard compaction method for preparation of all freeze-thaw specimens.

MATERIALS

The crushed limestone materials used in this investigation have previously been described in detail by Ferguson and Hoover (2). Textural classification of the materials is gravelly sandy loam, with AASHO classification in the A-1 grouping. Hereafter the following designations are assigned: Bedford (B series), Garner (G series), and Gilmore (H series). Type I portland cement was used in all specimens prepared and tested in this study.

Specimen Preparation

Sufficient air-dried crushed limestone material to produce two Proctor size specimens plus two 500-g moisture content samples was combined with type I portland cement in the following dry weight proportions: 5 percent for B-5, G-5, and H-5 specimens; 3 percent for B-3, G-3, and H-3 specimens; and 1 percent for B-1, G-1, and H-1 specimens.

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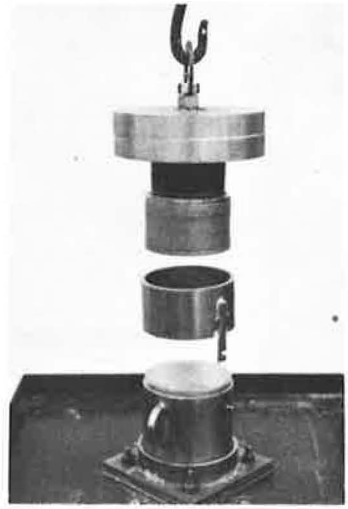

Figure 1. Vibratory compaction apparatus.

The dry materials were thoroughly mixed by hand. Sufficient distilled water, as calculated from the optimum moisture content determined in accordance with ASTM designation D558-57 was added to the sample which was again mixed by hand. The sample was covered with a damp cloth, allowed to stand for 5 min, then remixed. About 500 g were then removed for moisture determination. Two Proctor size specimens were molded, and about 500 g of mix was used for a second moisture content sample. Moisture contents were calculated as the average of the two moisture samples.

Compaction

Two methods of compaction of the freeze-thaw test specimens were used in this study. The first was in accordance with ASTM designation D558-57, hereafter referred to as method A. Since all of the crushed stones passed a ¾-in. U. S. standard sieve, it was not considered necessary to carry out the sample separation and reproportioning process recommended in section 5 of the above ASTM method.

The second method of compaction, hereafter referred to as method B, was accomplished in a Proctor size mold mounted on an electric vibrator table. Following final mixing, a sufficient quantity of material to provide a 4.00-in. diameter by 4.585-in. high cylindrical specimen was weighed and placed in the mold in three equal layers, each layer being rodded 25 times with a ¾-in. diameter tapered-end rod. A 25-lb surcharge was placed on top of the sample and compaction was accomplished for a period of one minute at an amplitude of 0.705 mm and frequency of 3600 cycles per minute. These values were selected as a result of previous compaction studies (4) as being the most desirable in terms of (a) little or no degradation of particle sizes, (b) little or no segregation of particles, and (c) extremely small loss of fines at top or bottom of mold during vibration. Figure 1 illustrates compaction method B.

In compaction method A, the height of specimen was always 4.585 in., or the length of the Proctor cylinder. In compaction method B, the height was determined as the average calibrated Ames dial readings at four points on the specimen, immediately after compaction and prior to removal of the mold. In both methods of compaction the specimen was weighed in the tared mold.

Curing

Each specimen was extruded onto a flat metal plate and cured in a moist room at near 100 percent relative humidity and 75 ±2 F for 24 hr, after which it was sealed in Saran wrap and cured for an additional 6 days in the moist room.

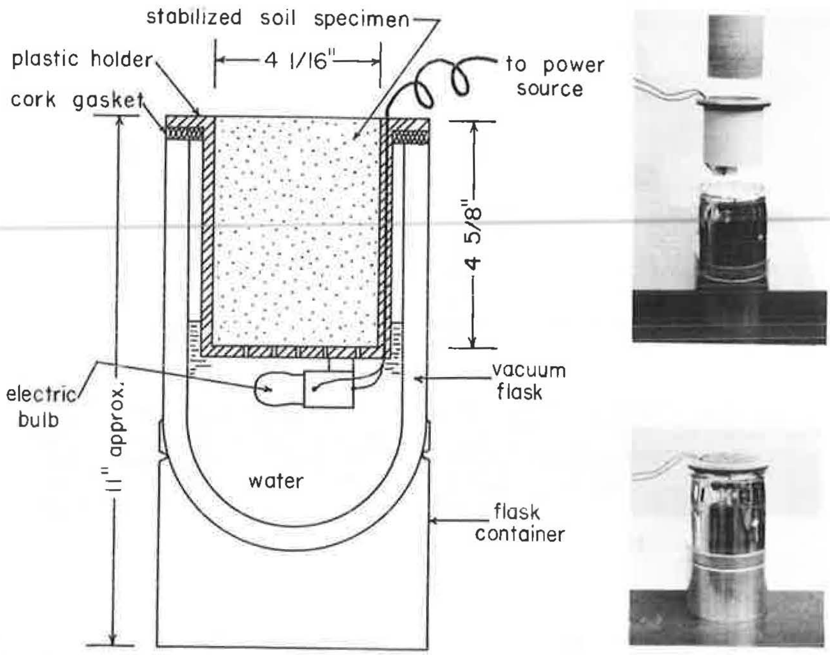

Figure 2. Iowa freeze-thaw test apparatus.

METHOD OF TEST

ASTM Freeze-Thaw Test

Specimens compacted by both methods A and B were subjected to 12 cycles of freezing and thawing in accordance with ASTM designation D560-57 with the exception that no volume change measurements were made. Instead, the height of specimen (referred to as the volume change specimen in ASTM D560-57) was recorded after molding, curing, and each full cycle of freeze-thaw.

Iowa Freeze-Thaw Test

The Iowa freeze-thaw test was conducted in accordance with the methods developed by George and Davidson (5) with the following exceptions: (a) Proctor size specimens were used rather than 2.0-in. diameter by 2.0-in. high cylinders, and (b) compaction was as previously described in this report, using both methods A and B. The freeze-thaw test apparatus is illustrated in Figure 2. Essentially, the test consists of freezing the specimens from the top, with free water at about 35 F available at the bottom. Ten cycles of freeze-thaw constitute a full test.

During the freeze-thaw test, identical specimens remained immersed in distilled water. At the end of ten cycles both the control (immersed) specimens and the freeze-thaw specimens were tested in unconfined compression. Loading rate during compression testing was 35 to 50 psi per minute. All portions of each specimen were retained for moisture content determination immediately after the unconfined compression test.

Time-temperature relationships for the Iowa freeze-thaw test were obtained from recorder tracings of thermocouples in the freezer, vacuum flash water, and molded into three locations within one of the test specimens.

RESULTS

Comparison of Compaction Methods

Table 1 summarizes the moisture-density values for two conditions: as designed, and as achieved by both methods of compaction. Design densities were determined from moisture-density plots of each of the nine series, run in accordance with ASTM Designation D558-57.

According to ASTM Designation D560-57, all acceptable freeze-thaw test specimens should be molded at moisture contents within 1.0 percent of optimum and 3.0 pcf of maximum dry density. This criterion was met with all specimens except the G series method A specimens and the H series method B specimens. With the latter, average densities were higher and moisture contents lower than as originally designed. Discontinuities of the former were with lower densities than as designed. In general, densities obtained with method A were slightly lower, while densities obtained with method B were slightly higher than initial design.

Prior research indicated Bedford specimens compacted by method A had nearly 7 percent reduction in gravel size fraction and about 5 percent increase in minus No. 200 sieve sizes (4). Similar Bedford specimens compacted by method B indicated negligible change in all particle size fractions (4).

Reproducibility of densities by the two compaction methods are of significant interest. Specimens compacted by method A showed an overall average standard deviation in density of 1.25 pcf and a coefficient of variation of 0.95 percent. Specimens compacted by method B had an average standard deviation of 0.55 pcf in density and a coefficient of variation of 0.40 percent. A summary of these results is shown in Table 2. Vibratory compaction yielded more uniform densities than the standard drop-hammer process. In addition, the vibratory technique produced negligible amounts of degradation of particle sizes.

ASTM Freeze-Thaw Test

Brushing Loss—The Portland Cement Association (PCA) recommends that soil-cement brushing losses for A-1 AASHO classified soils be not greater than 14.0 percent by dry soil weight following 12 cycles of freeze-thaw (6).

Table 3 presents the brushing loss data for each of the cement-treated stones and compaction methods used. Each entry in the table is the average of at least two specimen tests. Economical design cement contents can be assigned only to the H series

TABLE 1

COMPARISON OF AVERAGE VALUES OF MOISTURE CONTENT AND DENSITY

Series Designation	Design		Compaction Method A[a]		Compaction Method B[b]	
	Optimum Moisture Content (%)	Maximum Dry Density (pcf)	Average Moisture Content (%)	Average Dry Density (pcf)	Average Moisture Content (%)	Average Dry Density (pcf)
B-5	9.5	128.6	9.8	126.5	9.4	128.6
B-3	11.1	125.6	10.9	124.1	10.7	125.2
B-1	10.5	125.4	11.0	123.5	10.3	127.7
G-5	6.3	143.3	6.7	138.7	6.5	144.5
G-3	6.4	142.8	7.3	138.3	6.6	143.3
G-1	7.4	141.2	8.3	138.1	7.3	143.2
H-5	8.7	134.8	8.3	132.7	7.8	137.7
H-3	9.2	133.5	8.4	130.8	7.7	137.7
H-1	9.6	131.5	8.2	130.5	8.1	134.8

[a] Each value noted is the average of 8 specimens.
[b] Each value noted is the average of 12 specimens.

TABLE 2

STANDARD DEVIATION AND COEFFICIENT OF VARIATION OF DENSITIES OF SPECIMENS

Series Designation	Compaction Method A[a]		Compaction Method B[b]	
	Standard Deviation (pcf)	Coefficient of Variation (%)	Standard Deviation (pcf)	Coefficient of Variation (%)
B-5	0.93	0.73	1.14	0.89
B-3	0.61	0.49	0.39	0.31
B-1	1.28	1.03	0.38	0.30
Bedford average[c]	0.94	0.75	0.64	0.50
G-5	1.13	0.82	0.67	0.46
G-3	0.99	0.72	0.75	0.52
G-1	1.25	0.91	0.37	0.26
Garner average[c]	1.12	0.81	0.60	0.41
H-5	1.04	0.78	0.29	0.21
H-3	2.65	2.03	0.36	0.26
H-1	1.35	1.03	0.56	0.42
Gilmore average[c]	1.68	1.28	0.40	0.30
Overall average	1.25	0.95	0.55	0.40

[a]Each value computed from a series of 8 specimens.
[b]Each value computed from a series of 12 specimens.
[c]Each value is average of the preceding 3 standard deviations or coefficients of variation.

compacted by method A and the G series, method B; the only series having brushing losses near 14.0 percent. Additional specimens for the G series, method A, would have to be freeze-thaw tested at (a) 2 percent cement to obtain a design cement content to the nearest 1 percent, or (b) 1.5, 2.0, and 2.5 percent cement to obtain a design cement content to the nearest 0.5 percent. Likewise the B series, methods A and B, and the H series, method B, would have to be retested at 4.0 percent or 3.5, 4.0, and 4.5 percent cement contents, depending on whether design cement requirements are desired to the nearest 1.0 or 0.5 percent, respectively.

It was not possible to adequately graph soil-cement brushing losses vs percent cement and interpolate a design cement content since end of test conditions were not

TABLE 3

RELATION OF SOIL-CEMENT BRUSHING LOSS AND LENGTH CHANGE TO CEMENT CONTENT

Series Designation	Compaction Method A			Compaction Method B		
	Length Change (%)	Soil-Cement Loss (%)	Number F-T Cycles	Length Change (%)	Soil-Cement Loss (%)	Number F-T Cycles
B-5	-0.10	2.3	12	-0.03	0.7	12
B-3	Failed	100	6	Failed	100	10
B-1	Failed	100	2	Failed	100	4
G-5	-0.28	1.4	12	-0.14	0.5	12
G-3	+0.34	11.3	12	-0.14	1.4	12
G-1	Failed	100	3	Failed	100	6
H-5	+0.78	3.0	12	+0.06	0.4	12
H-3	Failed	100	5	Failed	13.2	12
H-1	Failed	100	1	Failed	100	5

equivalent. From the above considerations, a range of design cement contents to the nearest 0.5 percent might be indicated as follows:

1. B series—3.5 to 5 percent cement, for both compaction methods A and B.
2. G series—3 percent and 1.5 to 3 percent cement for method B.
3. H series—3.5 to 5 percent cement for method A and 3 percent cement for method B.

It is apparent from Table 3 and the preceding statements, that method of compaction affects the quantity of cement needed to satisfy PCA mix design criteria for the G and H series stones. Compaction method B indicated lower design cement contents than did compaction method A; part of this inconsistency may be due to the slight variations in densities of the mixes noted previously (Table 2). It is possible also that variations may be due to increase in fines content by the drop hammer method A. The additional fractured surfaces created during compaction would not be in intimate contact with cement particles, resulting in specimens having a lower durability.

Length Change—As previously noted, the volume change determinations of ASTM Designation D56-57 were not made. Studies by Packard and Chapman (7) have indicated the volume change techniques specified in the standard ASTM freeze-thaw test are not a sensitive measure of deterioration of all cement-treated soils. Instead, precise length change measurements are considered to be a very sensitive and direct measure of deterioration (7).

Because of these studies, each specimen length was determined as the average length, to the nearest 0.001 in., taken at three previously marked locations immediately following the thaw cycle. Average length change was expressed as a percentage of the cured length of the specimen, and is given in Table 3 for the various number of cycles noted. Plots of length change versus F-T cycles showed that the treated B and G series for both compaction methods fluctuated through length increases and decreases prior to completion of 12 cycles or failure.

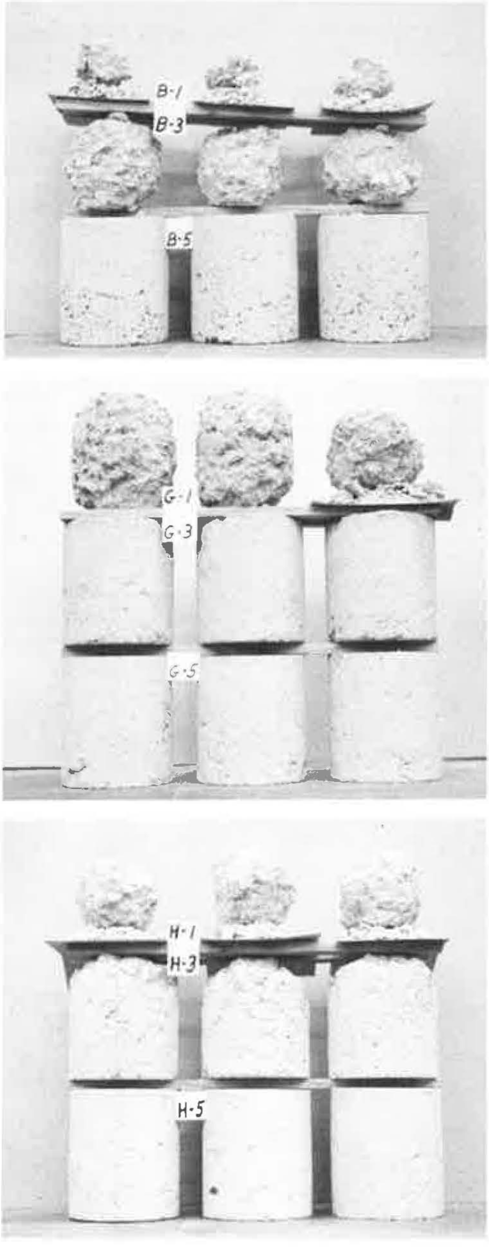

Figure 3. ASTM freeze-thaw test specimens.

Materials adequately cement stabilized for resistance to freeze-thaw deterioration will have minimal length change. If cement content is insufficient, expansion should occur due to formation of ice lenses forcing the particles apart. If cement content is greater than that required for freeze-thaw durability either little or no length change will be noticed or decrease in length will occur due to normal shrinkage during continued curing in a moist atmosphere. Though no standard criterion of length change

TABLE 4

RESULTS OF IOWA FREEZE-THAW TEST AFTER TEN CYCLES

Series Designation	Cement Content (%)	Compaction Method A[a]				Compaction Method B[a]			
		P_c (psi)	P_f (psi)	R_f (%)	Length Change Following Freezing (%)	P_c (psi)	P_f (psi)	R_f (%)	Length Change Following Freezing (%)
B-5	5	757	770	95	0.0	969	951	98	0.0
B-3	3	338	170	50	3.4	317	281	69	2.6
B-1	1	134	41	31	5.7	227	109	48	7.4
G-5	5	1640	1595	97	0.0	2210	2010	91	0.2
G-3	3	845	815	96	-0.4	1100	993	90	0.0
G-1	1	190	117	62	2.4	374	245	66	2.5
H-5	5	702	668	95	-0.1	1315	1190	90	0.1
H-3	3	280	231	83	1.1	813	660	81	0.3
H-1	1	86	50	58	2.2	227	97	43	2.8

[a]Each value noted is the average of at least two specimen tests.

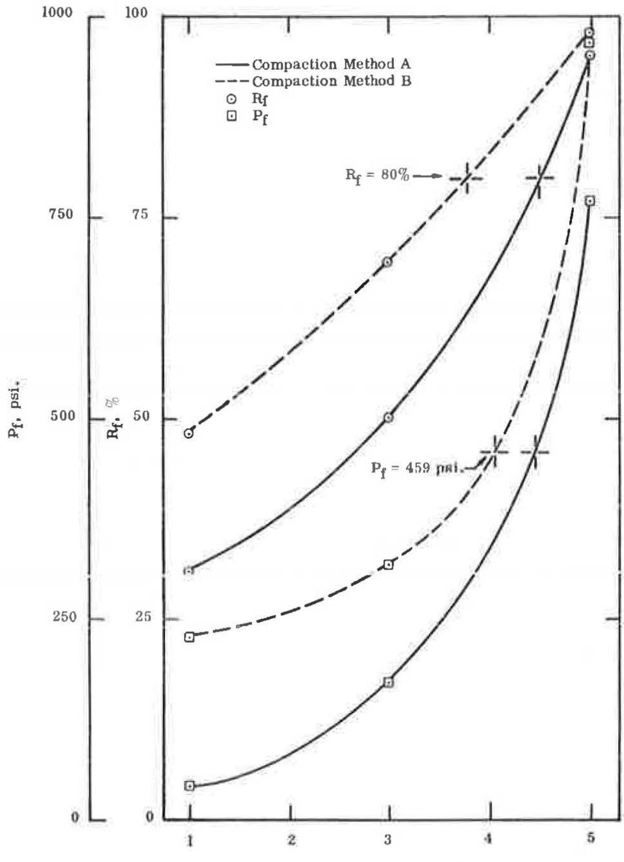

Figure 4. Relationship of cement content to index of resistance to freezing, R_f, and unconfined compressive strength, P_f, of B series freeze-thaw test specimens for compaction methods A and B.

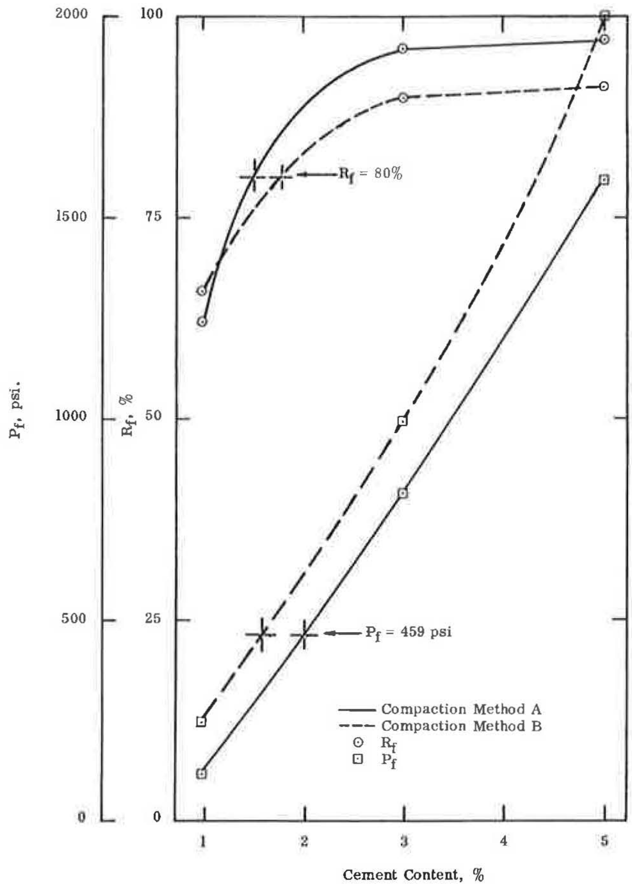

Figure 5. Relationship of cement content to index of resistance to freezing, R_f, and unconfined compressive strength, P_f, of G series freeze-thaw test specimens for compaction methods A and B.

vs design cement content has been established, it was believed that cement requirements based only on a minimization of length change might be arbitrarily assumed for comparative purposes only. Thus, for compaction method A, Table 3 indicates about 5 percent cement might be required for the B series, 3 to 5 percent for G series, and something in excess of 5 percent for the H series stone. For compaction method B, about 5 percent cement might be required for the B series, 3 percent for G series, and 5 percent for the H series stone.

Iowa Freeze-Thaw Test

Index of Resistance—The ratio of average unconfined compressive strength of freeze-thaw specimens (P_f) to that of control specimens (P_c) is the index of resistance to effect of freezing (R_f) in the Iowa freeze-thaw test. Tentative criteria for freeze-thaw durability by the Iowa test as developed by George and Davidson (5) suggest a minimum P_f of 459 ± 41 psi and R_f of 80 percent. Table 4 gives the major results of the Iowa test following ten cycles of freeze-thaw. Variation of unconfined compressive strengths P_c and P_f due to materials, cement contents, and compaction methods are obvious. In general the treated G series stone shows the highest strength values while the B series is lowest. Also the vibratory compaction method B produced higher strengths than the standard compaction method A and may be due to the higher densities of the method B specimens and/or lack of intimate contact of cement particles with newly fractured surfaces created by compaction method A.

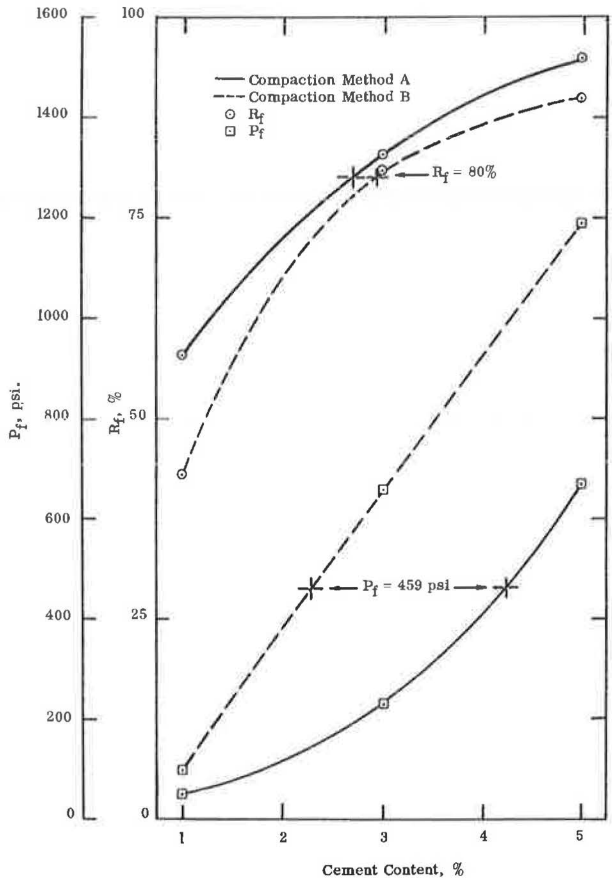

Figure 6. Relationship of cement content to index of resistance to freezing, R_f, and unconfined compressive strength, P_f, of H series freeze-thaw test specimens for compaction methods A and B.

Values of P_f and R_f vs cement content are ploted in Figures 4, 5, and 6 for convenient selection of cement requirements as based on the above criteria. (Each plotted point in Figures 4 through 9 is the average of at least two specimen tests.) Application of the criteria to the treated B series stone indicate the same values of cement content, i. e., 4. 5 and 4 percent for compaction methods A and B, respectively. R_f and P_f criteria indicate cement contents for compaction method A, G series, as 1. 5 and 2. 0 percent, while G series method B content would be 2. 0 percent. Cement requirements for the H series treated stone as based on the P_f criterion indicate 4 and 2. 5 percent for compaction methods A and B, respectively, while the R_f criterion indicates 3 percent cement is required for both compaction methods.

Length Change—Specimen lengths were determined as the average length, to the nearest 0. 001 in., taken at three previously marked locations. Since the specimens were left in their plastic holders, accurate length measurements could be made after the freeze cycle as well as after the thaw cycle with negligible specimen disturbance.

Graphs of length change vs cement content following 10 cycles of freeze-thaw in the Iowa test are shown in Figures 7, 8, and 9. Cement requirements to the nearest 0. 1 as determined from the index of resistance (R_f) and unconfined compressive strength after freeze-thaw (P_f) previously shown in Figures 4, 5, and 6 were transferred to Figures 7, 8, and 9. Corresponding length changes for R_f and P_f criteria can be read from Figures 7, 8, and 9 and are summarized in Table 5. Based on Table 5, suggested

TABLE 5

MAXIMUM ALLOWABLE PERCENTAGE LENGTH CHANGE AS PREDICTED FROM R_f AND P_f CRITERIA IN THE IOWA FREEZE-THAW TEST

Series Designation	Following Thaw Cycle				Following Freeze Cycle			
	Method A		Method B		Method A		Method B	
	R_f	P_f	R_f	P_f	R_f	P_f	R_f	P_f
B series	0.9	1.0	0.8	0.7	0.9	1.1	1.3	1.2
G series	-0.1	-0.3	0.4	0.5	1.0	0.3	0.8	1.0
H series	0.8	0.6	0.2	0.4	1.4	0.6	0.4	0.6

TABLE 6

SUGGESTED DESIGN CEMENT CONTENTS BASED ON INTERPOLATION OF LENGTH CHANGE DATA IN THE IOWA FREEZE-THAW TEST

Series Designation	Following Thaw Cycle		Following Freeze Cycle	
	Method A	Method B	Method A	Method B
B series	5.0	4.5	4.5	4.0
G series	1.0	2.0	2.0	2.0
H series	4.5	2.0	3.5	2.0

TABLE 7

COMPARISON OF CEMENT CONTENTS OBTAINED WITH EACH DURABILITY CRITERION FREEZE-THAW TEST PROCEDURE, AND COMPACTION METHOD

Series Designation	ASTM Freeze-Thaw Test				Iowa Freeze-Thaw Test			
	Brushing Loss		Length Change		Index of Resistance, R_f		P_f	
	A	B	A	B	A	B	A	B
B series	3.5-5	3.5-5	5	5	4.5	4	4.5	4
G series	3	1.5-3	3-5	3	1.5	2	2	2
H series	3.5-5	3	>5	5	3	3	4	2.5

maximum length changes are 1.0 percent following the last freeze cycle or 0.5 percent following the last thaw cycle. If these criteria are applied to Figures 7, 8, and 9, design cement contents, to the nearest 0.5 percent, based on length change are as shown in Table 6 and agree within 0.5 percent of those determined by the R_f and P_f criteria summarized in Table 7.

Comparison of Freeze-Thaw Tests

Table 7 presents a comparison of cement contents obtained using the ASTM-PCA and Iowa test criteria for both methods of compaction. Of primary importance in this comparison are the cement contents obtained by criteria of PCA brushing loss, index of resistance, R_f, and compressive strength after freezing, P_f. In general, the Iowa test indicates a reduction in required cement content ranging from 0.0 to 1.5 percent. Variation of compaction method is most pronounced in the brushing loss test and least in the index to resistance criteria, indicating an element of validity of this test method regardless of the method of lab compaction and potentially of field compaction processes.

Graphs of ASTM brushing loss and length change vs percentage cement could not be made as all specimens did not withstand the full 12 freeze-thaw cycles. Therefore,

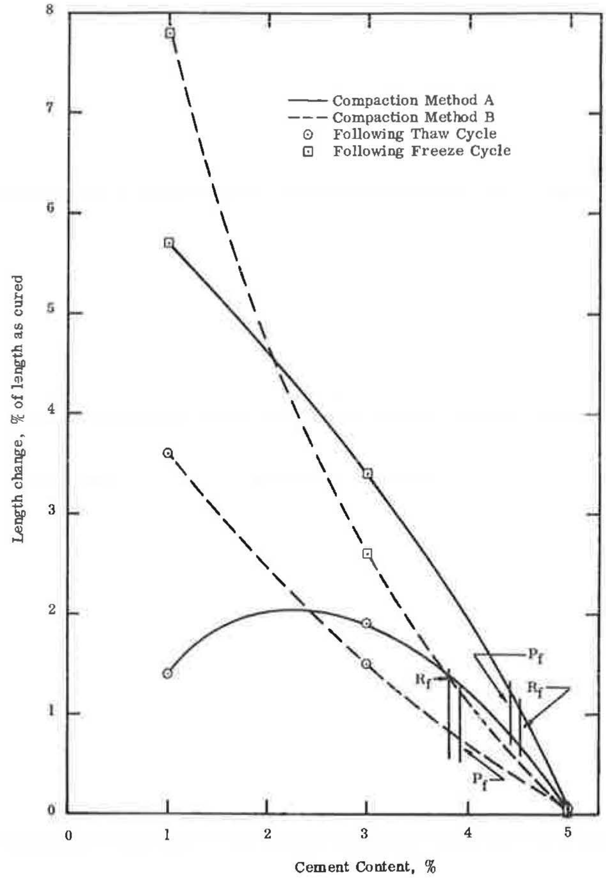

Figure 7. Relationship of cement content to percentage length change of B series test specimens following 10 Iowa freeze-thaw cycles.

interpolation of design cement content was not possible and those contents shown in Table 7 are expressed either to the next highest content tested, or as a possible range.

Data for R_f, P_f, and length change in the Iowa freeze-thaw test could be graphed and design cement contents interpolated therefrom; this was possible since all specimens could be tested throughout the full 10 freeze-thaw cycles. The interpolated design cement contents are shown in Table 7 for the R_f and P_f criteria and in Table 6 for the length change criterion. Neither the ASTM nor Iowa freeze-thaw tests have a standardized procedure for selection cement content based only on length change. The easy method of interpolation of design cement contents in the Iowa freeze-thaw test may encourage the standardization of cement content design as based on length change.

CONCLUSIONS

1. Relatively small additions of Type I portland cement can increase durability and compressive strength and decrease potential volume change upon freezing of compacted crushed stone bases in Iowa.
2. The vibratory method of compaction yields more consistent laboratory densities than does the ASTM compaction method. In addition the vibratory process is less time consuming, and produces less degradation of particles during compaction.
3. The Iowa freeze-thaw test is easier to conduct and more nearly duplicates actual field conditions of freezing and thawing than does the ASTM test.

4. The Iowa freeze-thaw test allows considerations of strength and length change as well as durability of cement-treated granular base materials.

5. The Iowa freeze-thaw test facilitates obtaining a design cement requirement by a simple plot of index of resistance to freezing, R_f, and unconfined compressive strength after test, P_f, vs cement content. The ASTM method often requires additional molding and testing of specimens to pinpoint the design cement content since no convenient method of interpolation is apparent.

6. Cement content by measurement of length change in the Iowa test appears to be more suitable (probably due to less actual handling of the specimens) and more closely associated with other criteria in the test than does length change measurements of ASTM specimens with the brushing loss test.

7. Accurate length measurements after the freeze cycle can be obtained in the Iowa freeze-thaw test but due to recommended procedure cannot be obtained in the ASTM freeze-thaw test.

8. Percentage of length change of Iowa test specimens is generally greater than that of ASTM specimens, and may be indicative of the severity of the test process through greater water attraction and adsorption during freezing.

9. Comparison of cement contents by PCA brushing loss and Iowa P_f, indicated variations of 0.5 to 1.0 percent cement. Comparison of brushing loss and R_f indicated variations of 0.5 to 2.0 percent cement. In each comparison, Iowa criteria indicated less cement content was required.

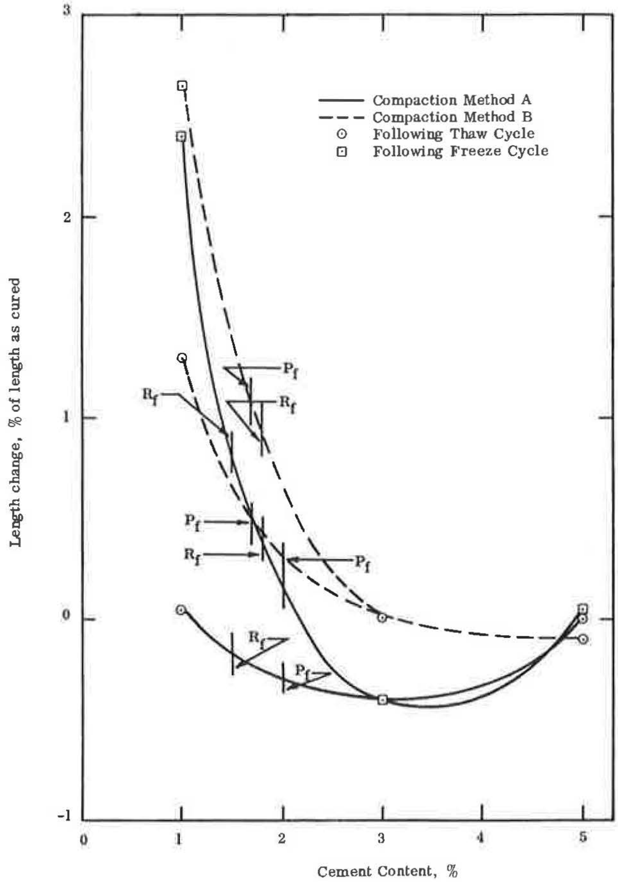

Figure 8. Relationship of cement content to percentage length change of G series test specimens following 10 Iowa freeze-thaw cycles.

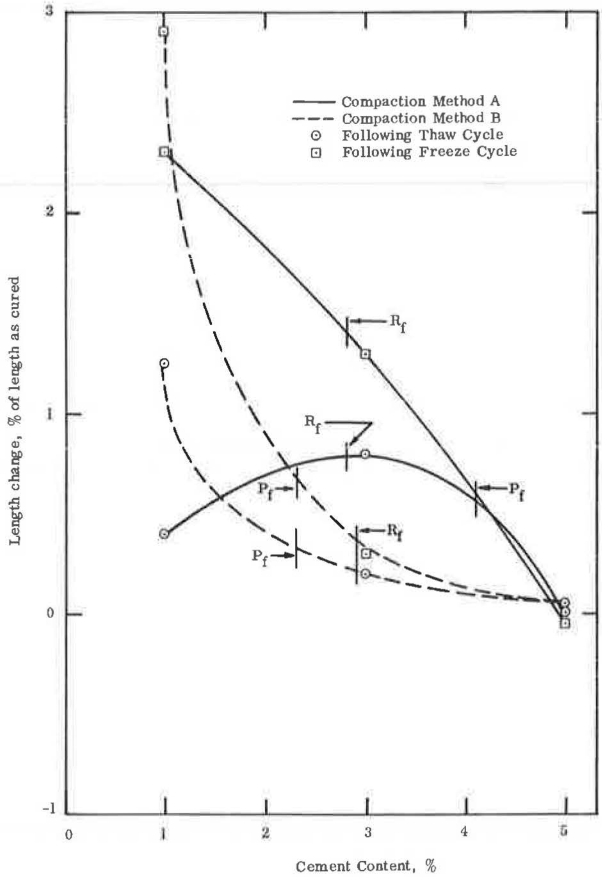

Figure 9. Relationship of cement content to percentage length change of H series test sepcimens following 10 Iowa freeze-thaw cycles.

10. Vibratory compaction usually resulted in slightly lower design cement contents than did the ASTM compaction method.

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REFERENCES

1. 1965 Book of ASTM Standards, Part II. American Society for Testing and Materials, Philadelphia, 1965.
2. Ferguson, E. G., and Hoover, J. M. Effect of Portland Cement Treatment of Crushed Stone Base Materials as Observed from Triaxial Shear Tests. Presented at 47th Annual Meeting and Published in this RECORD.
3. Best, T. W., and Hoover, J. M. Stability of Granular Base Course Mixes Compacted to Modified Density. Special Report, Iowa Highway Research Board,

Project HR-99. Contribution 66-15 of the Soil Research Laboratory, Eng. Research Inst., Iowa State Univ., 1966.

4. Hoover, J. M. Factors Influencing Stability of Granular Base Course Mixes: Final Report. Contribution 65-4 of the Soil Research Laboratory, Eng. Research Inst., Iowa State Univ., 1965.
5. George, K. P., and Davidson, D. T. Development of a Freeze-Thaw Test for Design of Soil-Cement. Highway Research Record 36, pp. 77-96, 1963.
6. Soil-Cement Laboratory Handbook. Portland Cement Assn., Chicago, 1958.
7. Packard, R. G., and Chapman, G. A. Developments in Durability Testing of Soil-Cement Mixtures. Highway Research Record 36, pp. 97-122, 1963.