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CRREL

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The Determination of Frost Susceptibility of Recycled Crushed Glass-Aggregate Mixtures

by Karen Henry and Susan Hunnewell

Report to the New Hampshire Department of Transportation in fulfillment of the Cooperative Research and Development Agreement dated 12 August, 1992.

I. INTRODUCTION

It is necessary to dispose of or reuse crushed bottle glass which has been rejected for the purpose of recycling. One potential use is as a partial aggregate substitute to extend base course material in road construction. The supply of high quality "select" base course material for road construction in New Hampshire is diminishing; thus, there is added impetus to investigate this use of recycled glass. The glass has been rejected for recycling because of small amounts of contamination (<3%)which is caused by the presence of an unacceptable glass, such as ceramic or plate glass.

The New Hampshire Department of Transportation is considering extending base course material by up to 30% by weight with crushed glass that has been rejected for purposes of recycling. Before this practice begins, it is prudent to consider whether the presence of glass would influence the frost susceptibility of the aggregate.

The glass could potentially worsen the frost susceptibility in one or two ways--1) it could be a source of frost susceptible fines or 2) it could cause the aggregate to wear to finer particles under traffic loading. If the glass contains negligible fines and does not increase the wear rate of the aggregate; it may improve the frost susceptibility of the base course material. If this is the case, it opens the potential for using granular material previously rejected because of too high a fine content.

II. OBJECTIVE

The objective of this research was to estimate the influence of recycled glass on the frost susceptibility of aggregate material. The work was done entirely in the laboratory in two phases. The first phase, carried out by the New Hampshire Department of Transportation, determined the grain size distributions of crushed recycled container glass samples and measured the effect of the glass on the wear of aggregate materials. The second phase, carried out at CRREL, evaluated the frost susceptibility of (a) the crushed glass, (b) typical aggregates used in road construction in New Hampshire and (c) glass-aggregate mixtures (30% by weight of glass).

III. BACKGROUND

Whenever air temperatures fall below freezing for more than a few days, there is a good chance that soil water will freeze. If a soil is frost susceptible and there is an adequate water supply (i.e. a water table within 3 to 8 ft of the surface), water can migrate to the freezing front and generate ice lenses. This ice lens formation causes frost heave. Water contents of heaving soils can increase up to tenfold due to ice lens formation.

The most frost susceptible soils are fine grained, but not highly plastic (i.e. silts); however, there is a wide range of soils prone to frost effects. Gravels containing 1 to 10% of particles of diameter less than 0.02 mm may rate as medium frost susceptible material and gravels containing more than 10% of particles smaller than 0.02 mm may be highly frost susceptible, according to the Corps of Engineers (Berg and Johnson, 1983).

Frost heave is responsible for the infamous mud season that New Hampshire experiences each spring. When frozen soil containing ice lenses begins to melt (from the top down), excess water is trapped above the underlying frozen layers. This results in the highly saturated soil characteristic of mud season. Although damage is done to pavements by frost heave, it is thought that most damage occurs during spring melting when pavement subgrades and sometimes base courses are in an extremely weakened condition. Both types of damage can be prevented by using non-frost susceptible materials in road construction.

The simplest frost susceptibility criteria are based on grain sizes. Chamberlain (1981) conducted a study on the reliability of various grain size methods for determining frost susceptibility. He found that the most reliable criteria was that of the Corps of Engineers, which is reported in Berg and Johnson (1983). This method is conservative in that whereas it always identifies those soils that are frost susceptible, it also predicts that a non-frost susceptible soil is frost susceptible about 33% of the time. According to this method gravels, well-graded sands and silty sands, especially those approaching the theoretical maximum density curve, which contain over 1.5% finer than 0.02 mm particles may be frost-susceptible. Most inorganic soils containing 3% or more by weight of grains finer than 0.02 mm are frost susceptible.

III. LABORATORY TESTS

1) Test Plan

Phase 1. This phase was carried out by the Department of Transportation and consisted of two parts. One part was to establish the amount of fines in crushed glass by conducting grain size analyses. Grain size analyses were performed on crushed recycled container glass collected from the Hartford, Vermont, recycling facility and the New

London, New Hampshire recycling facility. The crushed glass at Hartford was produced by the JR Engineering Glass Crusher, Model GB 5000 and the crushed glass at New London was produced by the GEW Corporation Glass Crusher.

The second part of this phase was to perform abrasion tests on combined aggregate-glass specimens to determine if the glass caused unacceptable wear on the aggregate. Two aggregates were tested in the abrasion tests. One was representative of 'soft' aggregate, typically found north of Lancaster. It was collected from Perry Stream Pit in Pittsburg. The second aggregate, being representative of higher quality 'hard' material found in the southern part of the state, was a crushed gravel collected from Concord Sand and Gravel. Grain size distribution curves for the aggregates used in this project are contained in Appendix A.

Phase 2. This phase was carried out by CRREL. Laboratory tests were conducted to determine the frost susceptibility of crushed glass, aggregate and glass-aggregate mixtures. CRREL used glass collected from the New London recycling facility and aggregates from the same sources as in Phase 1.

2) Test Procedures

a) Grain Size Distributions

The grain size distribution determinations were carried out according to ASTM Standard D 422, Standard Test Method for Particle-Size Analysis of Soils.

b) Abrasion Tests

The abrasion tests were performed according to AASHTO Designation T 96-87, Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine (L.A. Abrasion).

c) Frost Susceptibility Tests

The frost susceptibility determinations were carried out according to the Draft ASTM procedure for determining the frost susceptibility of soils (Chamberlain, 1987). One modification was made to the procedure in that specimens were not compacted with a Proctor rammer (in order to avoid crushing the glass). Instead, the specimens were prepared by pouring the aggregate, glass or aggregate-glass mixtures into the molds in five layers, hitting the mold with a rubber mallet 24 times (six on each quarter side) after each layer was poured into the mold. The specimens prepared in this way were 81 to 95% of the maximum index density measured according to ASTM procedure D 4253-83. Table B-2 in Appendix B contains dry density information on all of the laboratory samples tested.

The maximum index densities of the glass, glass-aggregate and aggregate samples were determined according to ASTM procedure D 4253-83, which utilizes a vibratory table to determine the maximum density of soils. Two modifications were made to this procedure, which are described in Appendix B. Note that for cohesionless, free-draining material this procedure may result in greater maximum densities than those determined according to the Proctor or modified Proctor methods.

IV. RESULTS

a) Grain Size Distributions

Grain size distribution curves of the crushed glass specimens are shown in Figure 1. There was less than 1% passing the #200 (0.074 mm) sieve for all crushed glass specimens tested. This means that the crushed glass itself is not frost susceptible and that adding it to a material containing fines would decrease the overall percent fines. Due to the similarity of the grain size distributions for the various crushed glass samples, all tests were conducted using the New London mixed crushed glass.

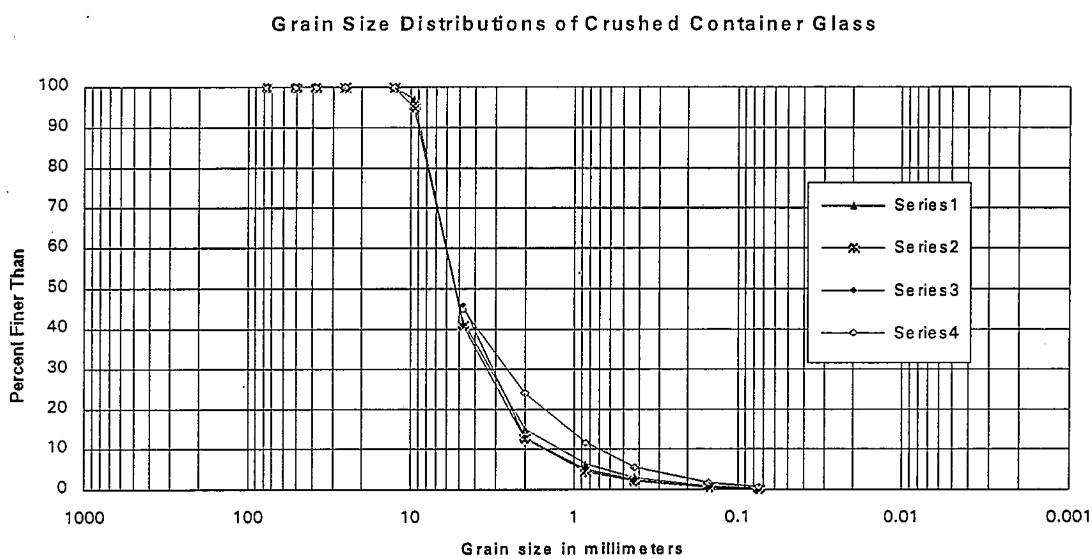

Figure 1 Legend:

Series 1: Brown crushed glass (Hartford, Vermont)

Series 2: Green crushed glass (Hartford, Vermont)

Series 3: Clear crushed glass (Hartford, Vermont)

Series 4: Mixed crushed glass (New London, NH)

b) Abrasion Tests

The results of the L.A. Abrasion tests conducted on both the 70% by weight aggregate-30% by weight mixed crushed glass and the aggregate-only specimens are contained in Table 1. The glass did not worsen the wear of either the 'soft' aggregate (Perry Stream gravel) or the 'hard' aggregate (Concord crushed gravel).

Table 1: Percent wear at 500 revolutions.

Material	Percent Wear
PSG	52.3
PSG	29.9
PSG (70%), Glass (30%)	31.2
CG (70%),Glass(30%)	25.3
CG	33.0

PSG = Perry Stream gravel CG = Concord crushed gravel

c) Frost Susceptibility Tests

Frost heave rates after 8 hours of freezing for two consecutive freeze cycles and the California Bearing Ratio after two freeze-thaw cycles are the indices used to establish the frost susceptibility of the soil (Chamberlain, 1987). Table 2 contains the frost susceptibility classification results for all of the freezing tests performed. The crushed glass had negligible to low frost susceptibility. The frost susceptibility of the glass and glass-aggregate specimens was always less than or equal to that of the aggregate specimens. Thus, the addition of glass did not worsen the frost susceptibility of aggregates. Note the relatively low CBR values for the glass only specimens, indicating that glass may have been crushed in this test.

Table 2: Frost susceptibility classification of glass, aggregate and glass-aggregate mixtures.

Test/sample	Material	First Freeze heave rate (mm/hr)	Second Freeze heave rate (mm/hr)	CBR	Frost Susceptibilty
1/3	glass	0.08	0.07	6.3	negligible
2/3	glass	0.74	1.73	6.0	very low
1/1	PSG	3.44	4.49	12.7	medium-low
3/1	PSG	4.91	5.44	15.0	medium
1/2	PSG-glass	1.55	2.26	10.7	low
2/4	PSG-glass	1.42	3.78	10.0	low
3/4	PSG-glass	2.62	2.68	14.0	low
2/1	CG	2.38	2.81	26.0	low-v.low
3/2	CG	2.22	2.11	25.0	low-v.low
1/4	CG-glass	0.16	3.08	20.0	low-v.low
2/2	CG-glass	0.35	2.39	21.9	very low
3/3	CG-glass	0.88	1.05	29.3	very low

PSG = Perry Stream Gravel CG = Concord Crushed Gravel

V. DISCUSSION

Figure 2 is a bar graph showing the range of (maximum) frost heave rates reached in the freezing tests for each material tested. The addition of glass to the Perry Stream Gravel apparently results in a lower frost heave rate. This is further evidenced by the fact that the PSG-glass samples were compacted to lower percentages of maximum densities than the Perry Stream Gravel only samples. The frost heave rates of the Concord gravel, which are already low, are not affected by the addition of glass.

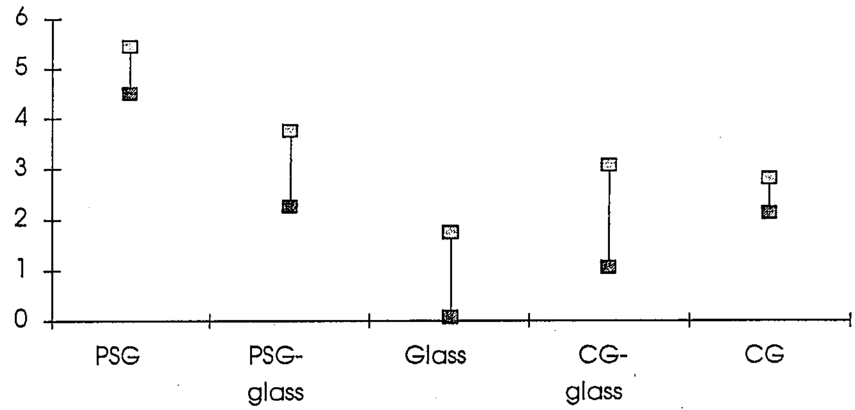

Figure 2: Range of lowest to highest maximum frost heave rates for each material tested.

Because the two aggregates perform differently when glass is added to them, they cannot be placed in one group to compare the frost heave of aggregate with the frost heave of aggregate-glass samples. This leaves too few tests available to perform reliable statistical analyses for each aggregate individually. Therefore, it should not be concluded that adding crushed glass will improve frost resistance when added to Perry Stream Gravel.

Even if the effect of glass on the Perry Stream gravel were verified in the laboratory with further testing, it would have to be observed and documented in a field application. Past experience has shown that frost effects observed in laboratory tests can be quite different from those observed in the field due to the inherently more complicated heat and moisture flow and material variability in nature than in carefully controlled laboratory tests (e.g. Henry and Christopher, 1993). These results merely suggest a possible beneficial effect.

There is no explanation for the observation that the second frost heave cycle resulted in apparently greater heave rate than the first one for the glass-aggregate specimens, while the aggregate-only specimens had approximately the same frost heave rate for both cycles.

The low CBR values of the glass-only specimens suggest that the glass was further crushed during the procedure. This may warrant further investigation if the State were to consider constructing with a much higher than 30% glass content for all or part of a base course. The CBR values for glass-aggregate samples were comparable to the aggregate-only specimens.

VI. Conclusion

The addition of crushed recycled container glass to aggregate used for road construction in New Hampshire, in the amount of 30% by weight, did not increase the wear or the frost susceptibility of either of the aggregates as determined by the procedures described in this report.

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AASHTO Designation T 96-87, "Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine",

ASTM Standard D 422, "Standard Test Method for Particle-Size Analysis of Soils", ASTM 1916 Race St., Philadelphia, PA 19103

ASTM Standard D 698-91, "Test Method for Laboratory Compaction Characteristic of Soil Using Standard Effort", ASTM 1916 Race St., Philadelphia, PA 19103

ASTM Standard D 1557-91, "Test Method for Laboratory Compaction Characteristic of Soil Using Modified Effort", ASTM 1916 Race St., Philadelphia, PA 19103

ASTM Standard D 4253-91, "Standard Tests Method for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table", ASTM 1916 Race St., Philadelphia, PA 19103

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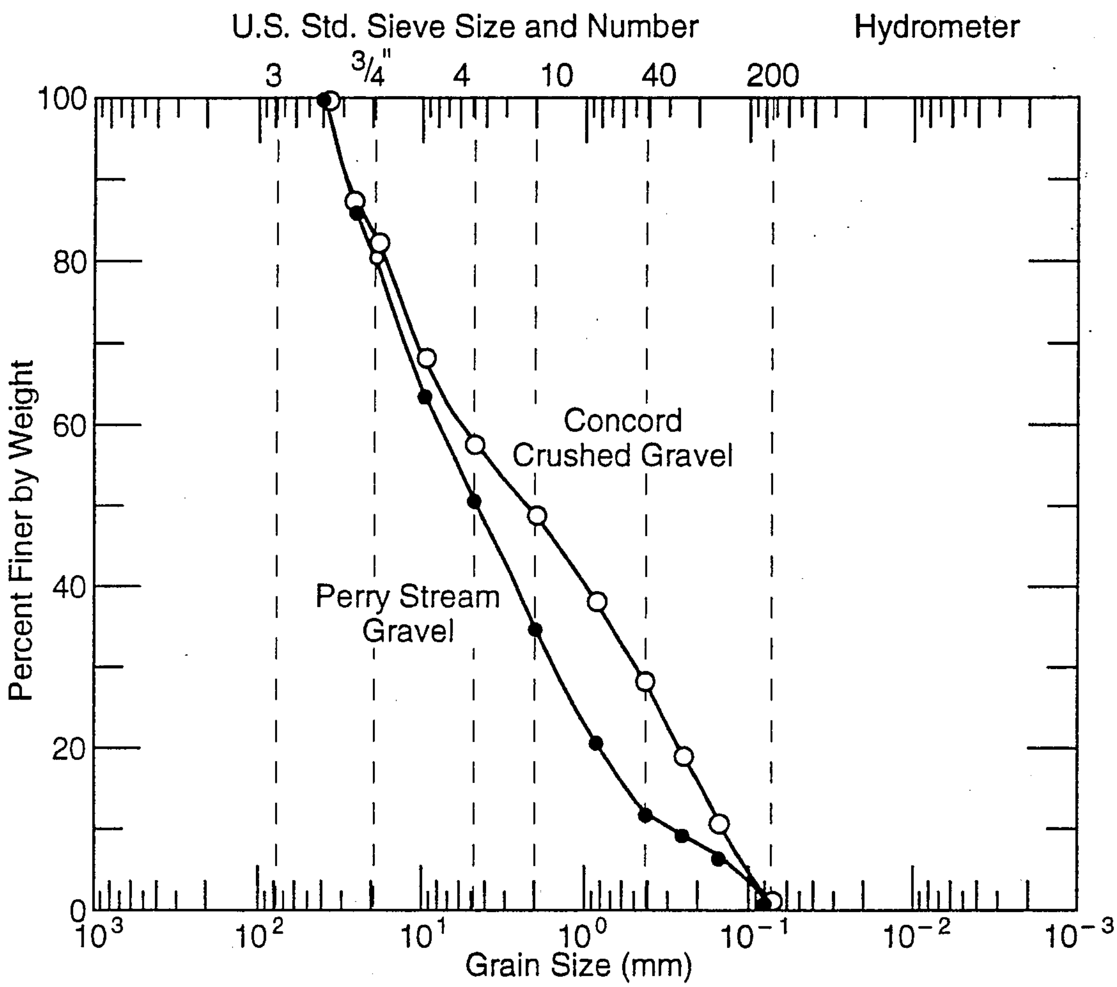
Appendix A: Grain size distribution curves for Perry Stream Gravel and Concord Crushed Gravel



Cobbles	Gravel		Sand			Silt or Clay
	C'rse	Fine	C'rse	Med.	Fine	

Legend:

○ Concord Crushed Gravel

• Perry Stream Gravel

Appendix B: Determination of the Maximum Density of Crushed Glass, Aggregate and Glass-Aggregate Specimens

The maximum density of the material was determined according to ASTM Standard D 4253-83 using a vibratory table. Method 1.A was followed using a 0.500 cubic foot mold. One modification to the procedure was that the glass and aggregate samples were not oven dried as they were already air dried.

Another modification concerns the double amplitude of vertical vibration. The vibrating table used was a FMC Corporation Syntron table, Model VP86C1. It had never been calibrated; but the manufacturer suggested that the amplitude gage be set at 100 (its maximum setting). To test for the proper setting, four tests were run with crushed glass and crushed aggregate, one for each material with the gage set at 100 and one for each material with the gage set at 90 for 8 minutes each. Results of these tests showed that the maximum density of the material was achieved when the amplitude gage was set at 100.

The following maximum densities were obtained using this procedure:

Table B-1: Maximum Index densities of materials used in frost susceptibility tests.

Material	Maximum density (lb./ft^3)	
Glass	102	
Glass	99.8	(Average: 102.3)
Glass	105	
PSG	140	
PSG	149	(Average: 144.5)
CG	151	
CG	154	(Average: 152.5)
PSG-glass	140	
CG-glass	139	

PSG = Perry Stream gravel CG = Concord crushed gravel

It is noted that the maximum index densities obtained according to this procedure for cohesionless soils can be greater than maximum dry densities determined by laboratory compaction methods such as the Proctor method (ASTM D 698) or the modified Proctor method (ASTM D 1557-91).

Table B-2: Dry densities of laboratory samples before freezing.

Test/Sample	Material	δ_d initial	% Maximum Index Density
1/3	Glass	93.7	91.6
2/3	Glass	96.7	94.5
1/1	PSG	126.6	87.6
3/1	PSG	130.3	90.2
1/2	PSG-glass	117.2	83.7
2/4	PSG-glass	113.8	81.3
3/4	PSG-glass	120.3	85.9
2/1	CG	132.1	86.6
3/2	CG	131.2	86.0
1/4	CG-glass	124	89.2
2/2	CG-glass	122.9	88.4
3/3	CG-glass	126.0	90.6

PSG = Perry Stream Gravel   CG = Concord Crushed Gravel

Appendix C: Graphs of frost heave vs. time of laboratory samples

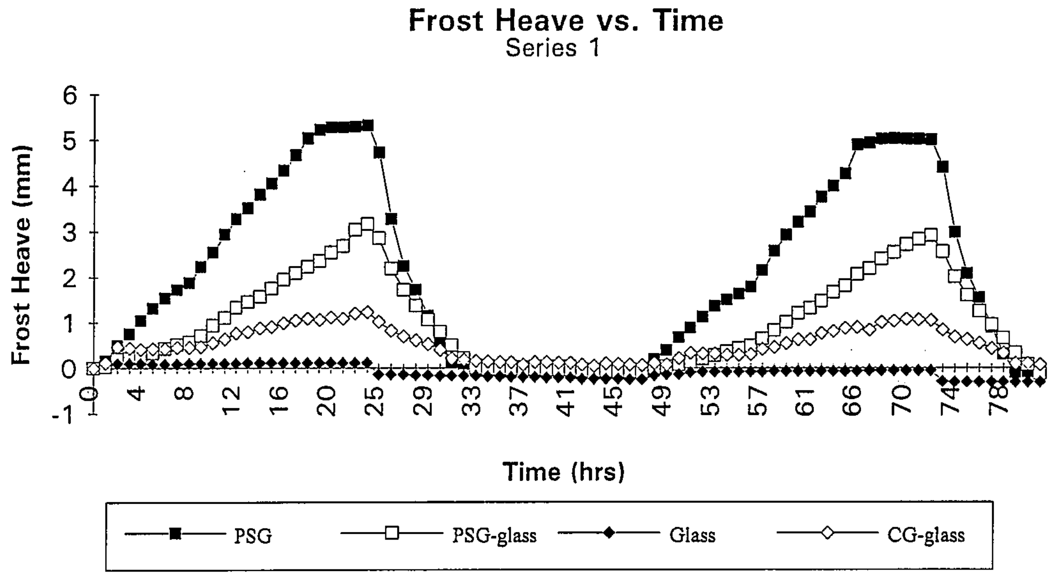


Figure 4: Frost heave vs. time graph for Series 1.

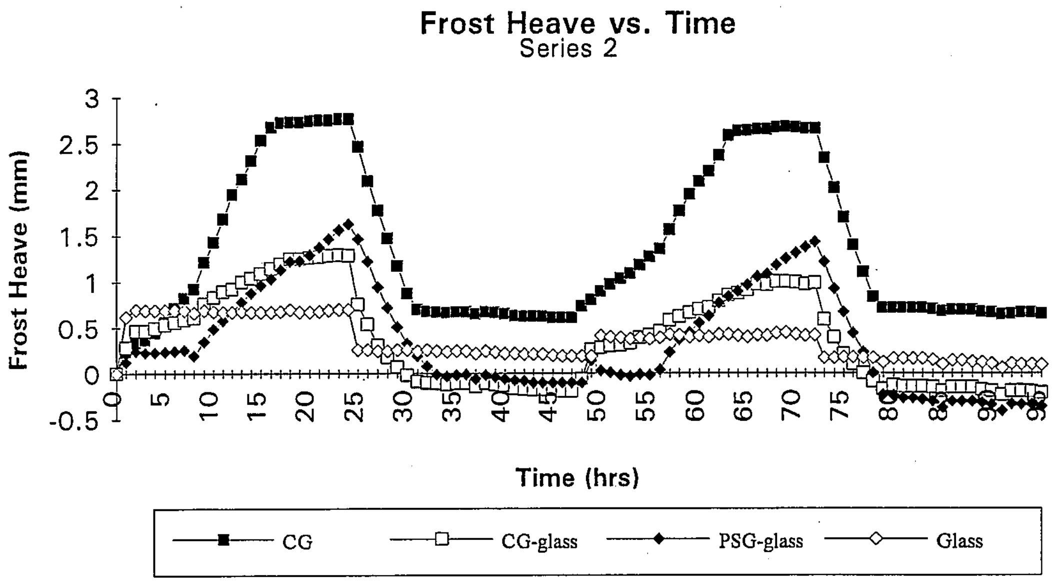


Figure 5: Frost heave vs. time graph for Series 2.

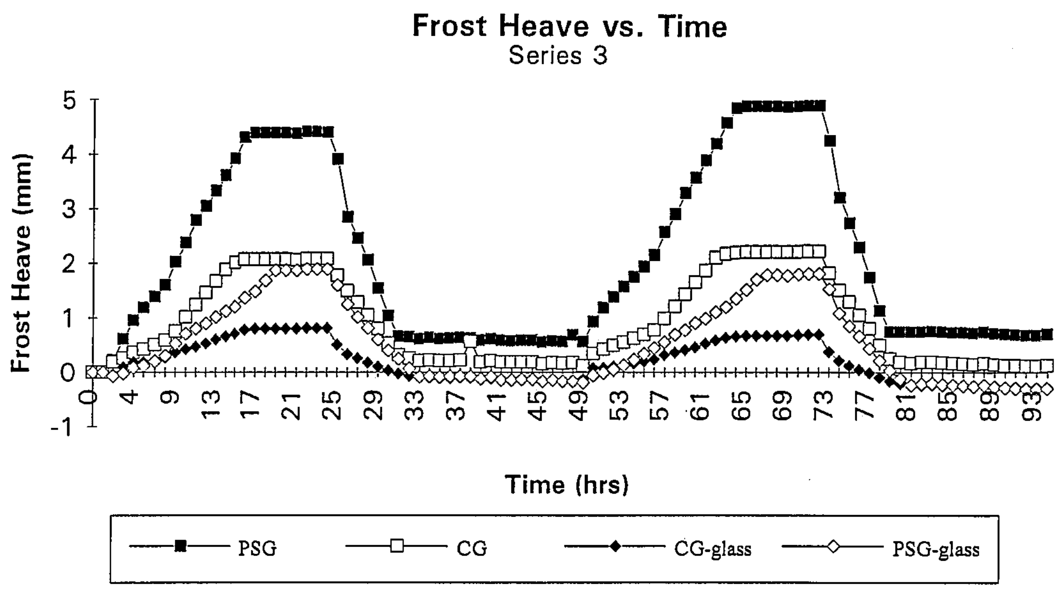


Figure 6: Frost heave vs. time graph for Series 3.

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