EVALUATION OF OPEN HEARTH SLAG AS A HIGHWAY BASE MATERIAL

MICHIGAN
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MICHIGAN DEPARTMENT OF STATE HIGHWAYS

EVALUATION OF OPEN HEARTH SLAG AS A HIGHWAY BASE MATERIAL

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INTRODUCTION

In October 1968 the Research Laboratory began this project for the purpose of determining the feasibility of continuing the use of open hearth and basic-oxygen slags for base and subbase aggregates. The project was initiated at the request of R. L. Greenman after extensive heaving had been observed in slag-base medians recently constructed on the Fisher Freeway (I 75) in Detroit, Control Section 82194 (Fig. 1).

The primary objectives of this study, as stated in the project proposal, are: 1) to determine the cause of heaving, 2) to measure the pressures generated by such expansive activity, and 3) to determine whether or not open hearth slag can be used as subbase under concrete pavements without detrimental effects. Slags from open hearth, basic-oxygen, and electric furnace processes are included in this study because materials from all of these methods were probably used in the problem areas. Unless specific reference is made to other forms of slag, the term "open hearth" will refer to all slags evaluated in this project.

Nature of the Problem

Open hearth slag was used both as selected subbase and for the construction of class AA shoulders for approximately 4.8 miles of the Fisher Freeway (I 75) constructed through Detroit from 1965 to 1968. Difficulties due to the use of this material were first evidenced by differential heaving of the median areas as shown in Figure 2. A similar problem was also observed in an unpaved parking lot at the Detroit Metropolitan Airport (Fig. 3).

The exact time between construction and the start of heaving is not known, and appears to vary with different conditions. Surface distress was observed on the Fisher Freeway three to four months after construction, whereas the same problem was not readily noticed at the parking lot until about a year after construction.

Heaving, in all observed instances, is accompanied by a void beneath a hardened crust of slag as shown in Figure 4. The slag crust always seems to be present to some extent regardless of the amount of heave. No reason for the crust formation has yet been established.

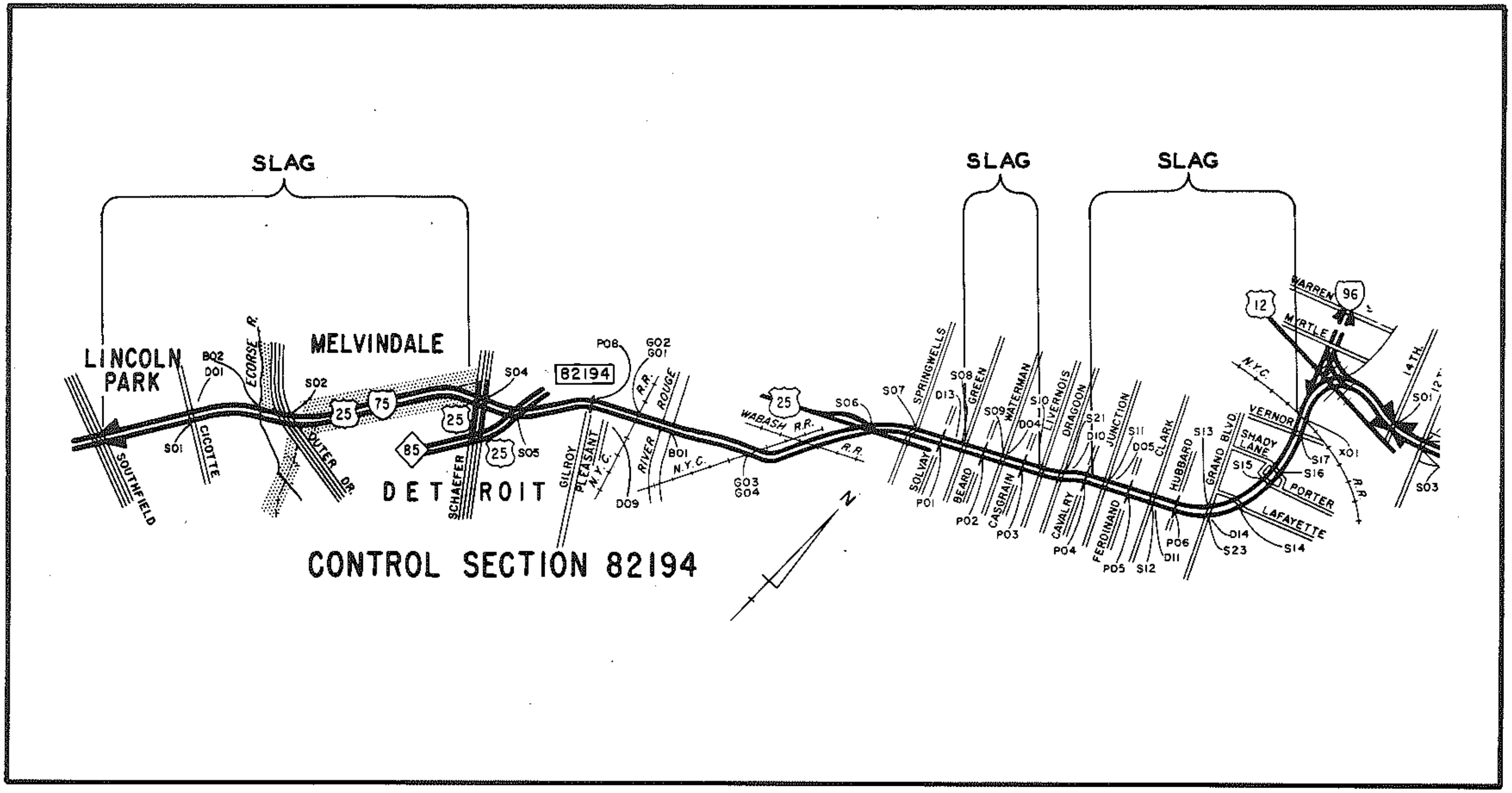
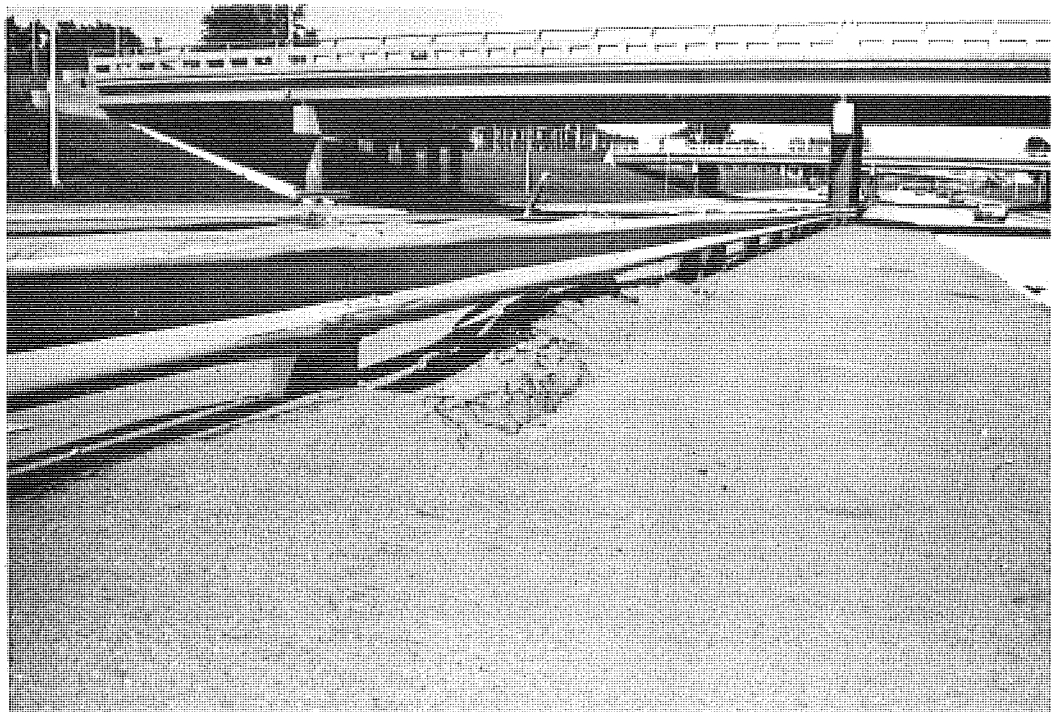


Figure 1. Location of open hearth slag sections - Fisher Freeway (I 75).



Heaving and buckling of bituminous surface

Bulging and cracking of bituminous surface

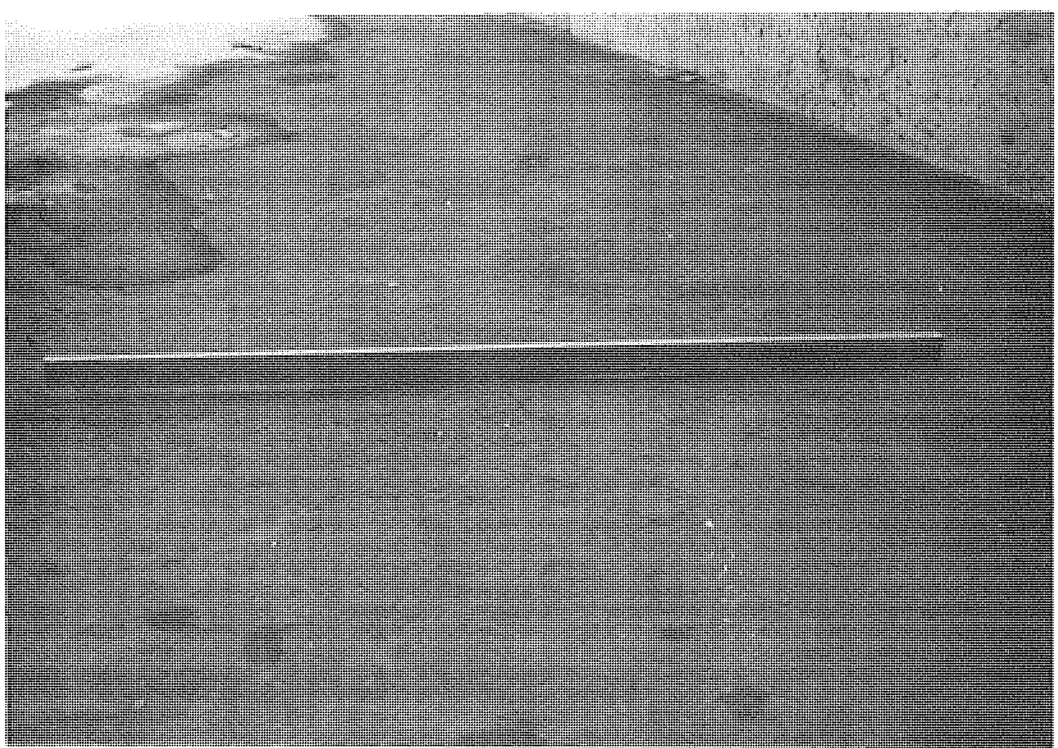
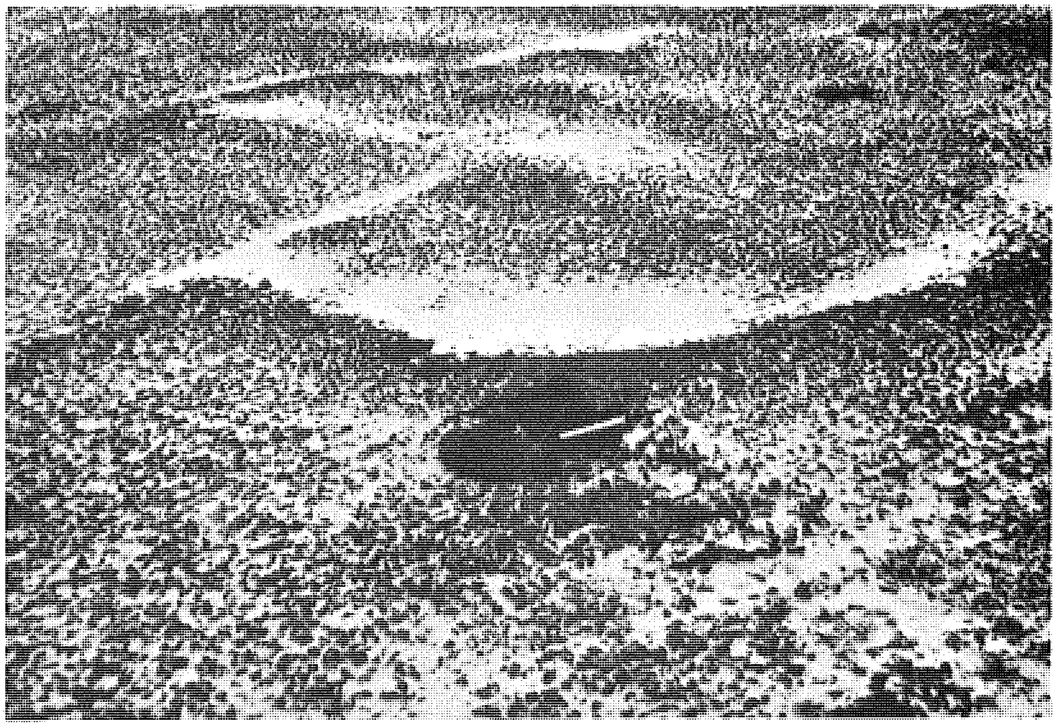


Figure 2. Median heaving along the Fisher Freeway.



Surface crust

Heaving

Figure 3. Unpaved parking lot at Detroit-Wayne Metropolitan airport.

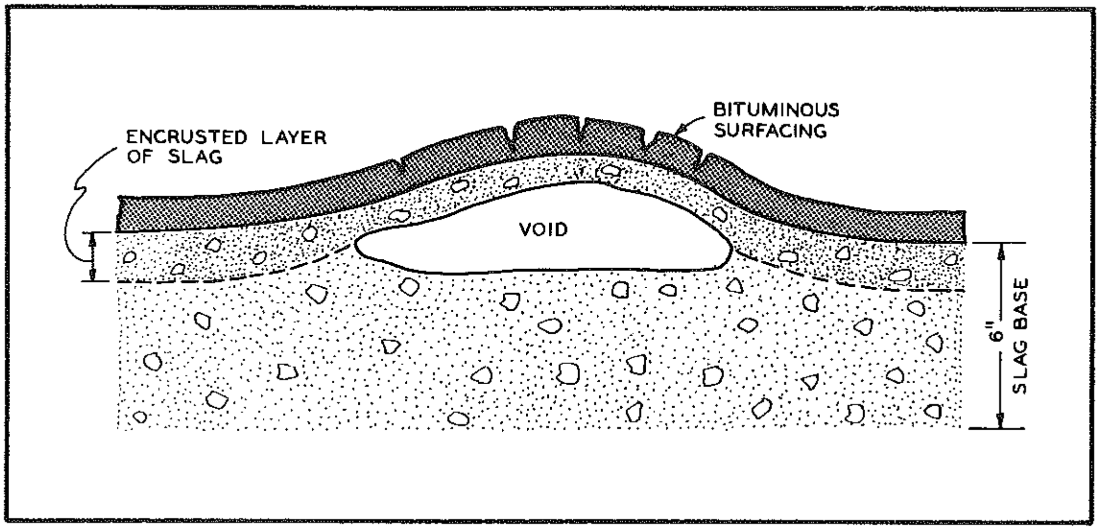


Figure 4. Typical heave of open hearth slag base.

Slag Aggregate Production

The slag aggregate used on Departmental projects was produced in the E. C. Levy Co. plant No. 3 (Westfield plant) located in Ecorse, Michigan. The slag produced at this plant is a byproduct of both open hearth and basic-oxygen process steel producing furnaces, located in the adjacent Great Lakes Steel Corp. mill. A schematic plant layout and flow chart of slag aggregate production are shown in Figure 5. The processed slag aggregate is loaded directly from the production pile when sold, rather than being stockpiled as normally required for base course aggregate.

Solidified open hearth slag is hauled from the mill by trucks and dumped near the plant input. In addition to slag, this material may contain unprocessed steel scrap, furnace brick, and raw lime, ranging in size from a foot or more to a powder.

Basic-oxygen slag, as a molten liquid, is delivered to the quenching area in specially designed steel kettles. In the bottom of each kettle is a solidified mass of slag, above which is the molten slag, capped with nearly a foot of hardened slag that serves as a protective crust, restraining the molten portion and preventing dangerous spillage during transport. Although open hearth production is expected to decrease in the future, slag processed at the Westfield plant still is comprised of nearly equal amounts of open hearth and basic-oxygen materials but with daily production of both types varying considerably.

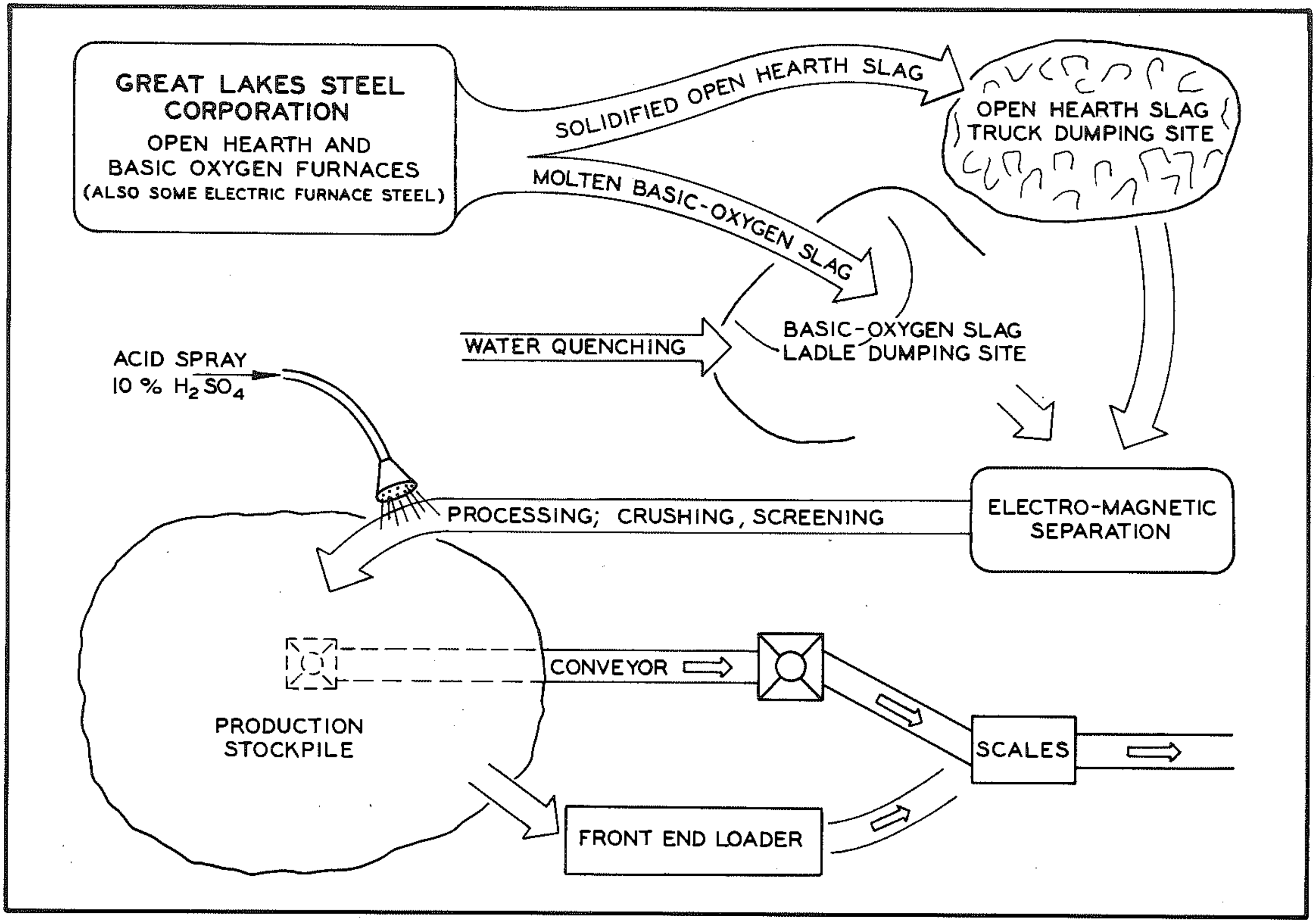


Figure 5. Schematic of slag aggregate processing plant.

In the dumping areas, the slag is quenched with a water spray and pushed into the processing plant with a bulldozer. During this stage, larger pieces of iron and steel are removed with a crane operated electromagnet. The slag is then crushed, screened, and--after additional iron is removed--routed to the proper stockpile via conveyor. Mixing of open hearth and basic-oxygen slags takes place throughout the process with no particular control of proportioning.

In the spring of 1969 the Levy Company, in an effort to reduce the volume change characteristics of their product, began experimental treatment of the slag with a 10 percent sulfuric acid solution, wasted from the steel descaling process. Production treatment of the processed slag began on a full-time basis at the Westfield plant in September 1969 with the acid applied by a spray bar at the end of the conveyor carrying the slag to the stockpile.

Past Performance of Open Hearth Slag

Until recently, no thorough investigation of specific causes of heaving has been conducted, although literature and correspondence during the past 14 years have described several projects where heaving of open hearth slag did occur (1). Such projects consisted of parking lots, city streets, and an airport runway, all consisting of six inches or more of open hearth slag base topped with two to three inches of bituminous surfacing.

The only instance found in the literature where a chemical analysis of the slag was made concerned a recent case involving damage to a building (2). Concrete floor slabs, placed over open hearth slag backfill, heaved from one to three inches (approximately 9 percent) with slag ranging in depth from nearly one foot to three feet. X-ray diffraction analysis revealed the presence of calcium oxide and magnesium oxide (periclase). Hydration expansion of calcium oxide was thought to occur within a few weeks, but the magnesium oxide reaction required as long as several years.

Potential problems with open hearth slag were considered by the Department in 1960 ("Open Hearth Slag," Research Project 60 A-20), resulting in the recommendation that the material not be used until an unbiased record of satisfactory performance in a variety of applications had been established (3).

The scope of the present study of open hearth slag includes X-ray diffraction analysis to identify mineral phases present, laboratory swell tests, frost susceptibility tests, and observation of in-service performance.

LABORATORY STUDIES

Minerological Analysis

Representative samples of the slag material were obtained for X-ray diffraction analysis from two locations on the Fisher Freeway median and from two distinct sources of slag within the Westfield processing plant as follows:

Sample No.	Description
68-5	Basic oxygen slag obtained while open hearth furnaces were shut down
68-10	Road sample, non-heaved area, Dearborn St island
68-11	Road sample, heaved area, Dearborn St island
68-12	Road sample, I 75 Sta. 1214+30 SB, heaved area
68-13	Road sample, I 75 Sta. 1213+85 SB, non-heaved area
69-1	Open hearth truck sample

An attempt was made to obtain samples in pairs from both heaved and adjacent non-heaved areas. Subsequent inspection of the entire median area in which slag was used as a base, however, indicated that most all of the slag had potential heaving characteristics.

These samples were submitted to Dr. T. A. Vogel of the Geology Department at Michigan State University for X-ray analysis.

Results of this minerological analysis show the major portion of the slag to consist of eight minerals. Two of these, periclase (MgO) and pseudowollastonite ($CaSiO_3$) are known to be unstable and to expand during hydration. Pseudowollastonite was found in three samples including one from an unheaved area, and periclase was found in all samples with the exception of those obtained from the open hearth truck sample. Three of the other minerals, fayalite (Fe_2SiO_4), anorthite ($CaO{:}Al_2O_32SiO_2$) and olivine ($(Mg, Fc)_2SiO_4$), are known to be stable. The remaining minerals, $Mg_2Al_4Si_5O_{18}$ (indiolite), $Ca_2Fe_2O_5$, and Ca_3SiO_5 require a literature search to determine their stability characteristics (4).

In order to supplement the information provided by the X-ray analysis, individual pieces of slag were submitted to N. Wingard, Research Laboratory Geologist, for examination by optical means. Nine different pieces of slag in the 1- to 1-1/2-in. size range were selected on the basis of appearance as representing the variety of slag particles to be found in the aggregate material. From each of the nine specimens a thin slice, a few thousandths of an inch thick, was cut, mounted on glass and polished to a thin section which is translucent to a light source when observed under a microscope. The degree to which light passes through the slide depends on the optical properties of the minerals present. Under magnification of X100, individual mineral crystals can be distinguished and individual optical properties can be measured.

These optical properties along with visual appearance can be compared with descriptions found in minerological reference texts as a means of sample identification. Color photographic slides have been made of each of the thin sections for future reference. This phase of the project is now approximately 50 percent complete.

Volume Change Tests

Beginning in September 1968 slag samples were obtained from the Westfield plant on a routine basis and tested in the Laboratory to measure volume change potential. To date 34 samples have been tested including 19 samples of the acid treated slag.

Cylindrical samples of the slag aggregate were formed in the laboratory by static compression to maximum density. The samples were 2 in. in diameter by 4 in. high and composed of the portion of the slag aggregate passing the No. 4 sieve. Throughout the test, the base of the samples remained on a porous plate in contact with a free water surface and the samples were allowed to expand vertically under surcharges equivalent to: a) the weight of 10 in. of concrete as shown in Figure 6, and b) the weight of 2 in. of bituminous surfacing. Samples composed of the entire gradation (1 in. top size) when similarly tested in 6-in. molds, yielded results comparable to those obtained from the 2- by 4-in. samples; therefore, the smaller samples were used in subsequent tests for ease in preparation and testing.

Throughout the 28-day test, the vertical expansion of each sample was measured daily with a dial gage as shown in Figure 7. Average expansion values for one, seven, fourteen, and twenty-eight day durations are shown in Figure 8. The solid line represents the average expansion of non-treated slag and the heavy dashed line the average values for acid treated slag. The shaded band enclosing these lines is two standard deviations wide and shows the degree of expansion variability to be expected from this material. Tests performed by the Ann Arbor Testing Laboratory show expansive activity even after 3 months as shown in Figure 9, taken from reference (5).

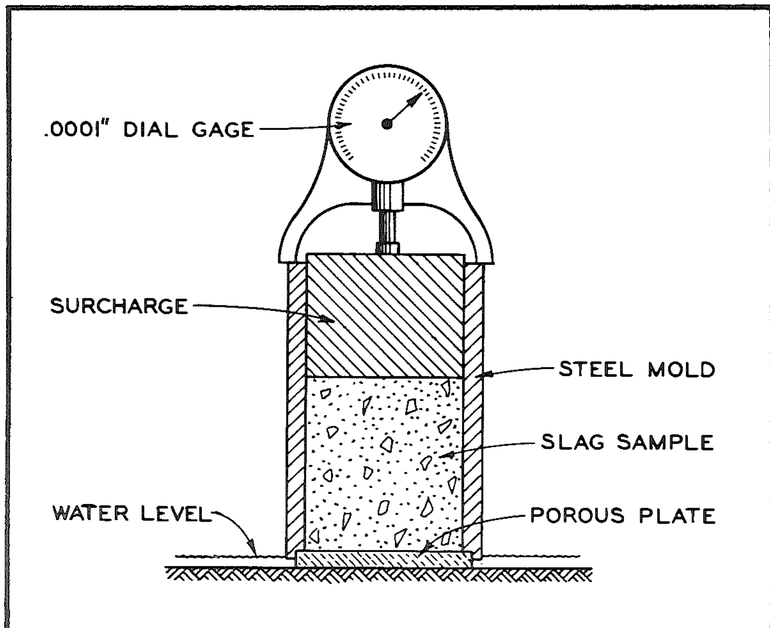


Figure 6. Section through volume change sample.

Figure 7. Laboratory volume change measurements on 2- by 4-in. samples.

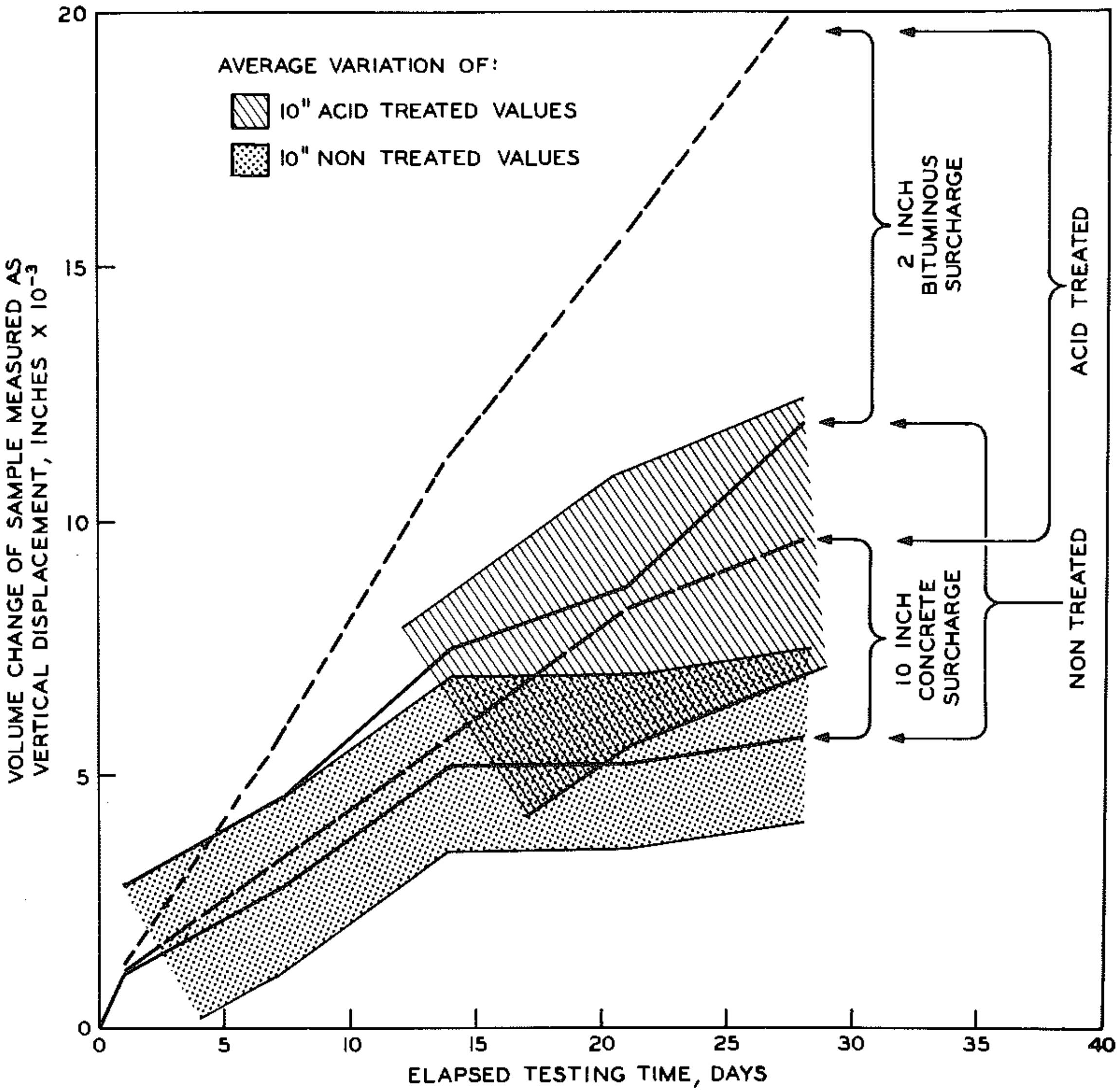
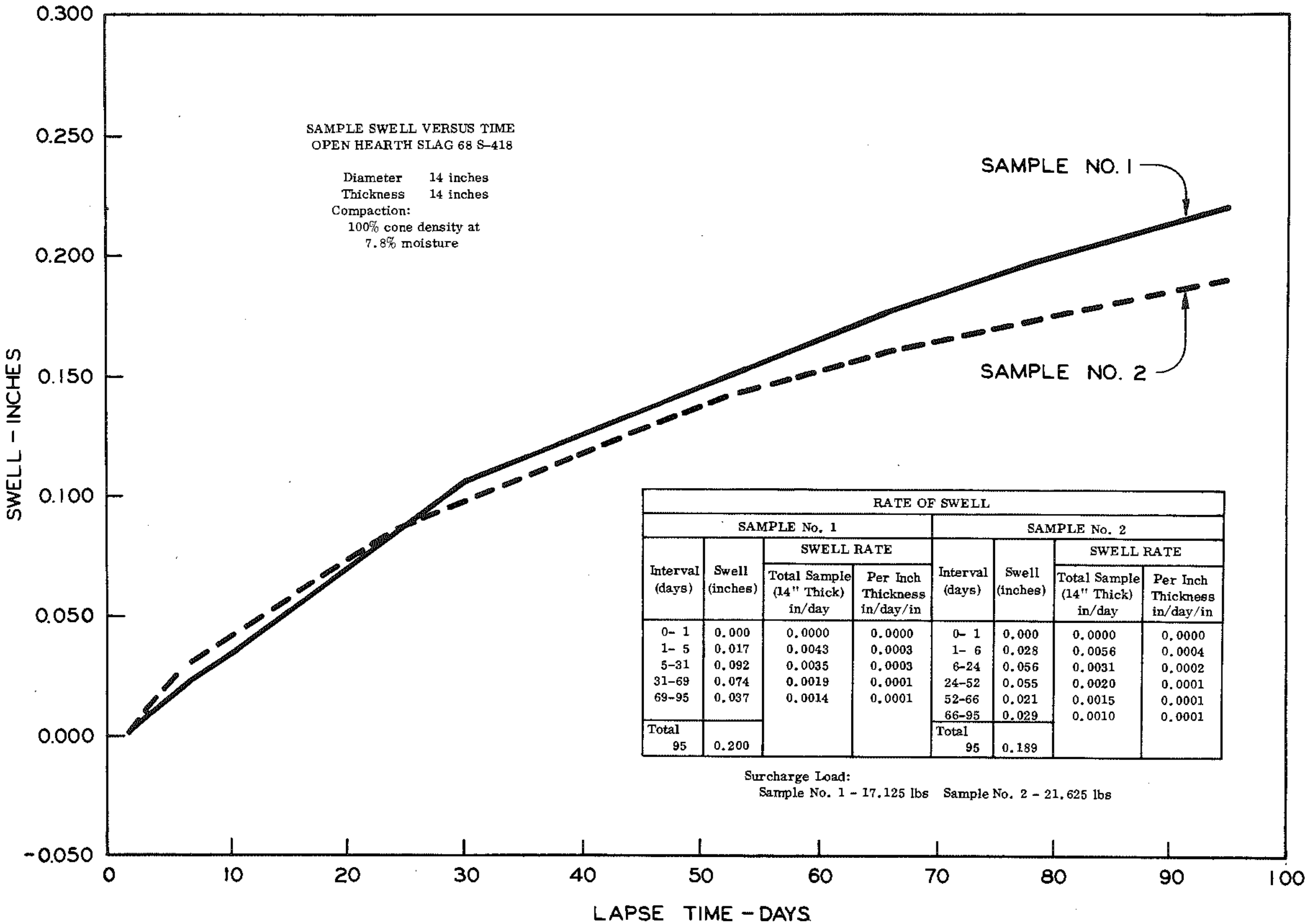


Figure 8. Volume change performance on open hearth slag.



RATE OF SWELL							
SAMPLE No. 1				SAMPLE No. 2			
		SWELL RATE				SWELL RATE	
Interval (days)	Swell (inches)	Total Sample (14" Thick) in/day	Per Inch Thickness in/day/in	Interval (days)	Swell (inches)	Total Sample (14" Thick) in/day	Per Inch Thickness in/day/in
0- 1	0.000	0.0000	0.0000	0- 1	0.000	0.0000	0.0000
1- 5	0.017	0.0043	0.0003	1- 6	0.028	0.0056	0.0004
5-31	0.092	0.0035	0.0003	6-24	0.056	0.0031	0.0002
31-69	0.074	0.0019	0.0001	24-52	0.055	0.0020	0.0001
69-95	0.037	0.0014	0.0001	52-66	0.021	0.0015	0.0001
				66-95	0.029	0.0010	0.0001
Total 95	0.200			Total 95	0.189		

Surcharge Load:
Sample No. 1 - 17.125 lbs Sample No. 2 - 21.625 lbs

Figure 9. Long-term volume change of open hearth slag.

Frost Susceptibility

Frost susceptibility tests were performed on four samples of compacted slag following procedures developed by the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL) (6). In this test, two samples of acid treated slag and two samples of non-treated slag were tested.

The test procedure consists of compacting the slag in 6-in. diameter by 6-in. high molds at maximum unit weight, and freezing the sample from the top surface downward at a rate of 1/4 to 1/2 in. per day. A free water surface is provided at the base of each sample at 38 F with an insulating medium laterally surrounding the sample and a below-freezing ambient temperature maintained over the samples' surface. A 0.5 psi surcharge on the sample surface simulates the pavement weight and the amount of heaving due to freezing is measured with a dial gage. Figure 10 shows the cross section of a typical sample in testing position with thermocouples in place for temperature measurement as well as the placement of the four samples in the environmental chamber where the test was performed.

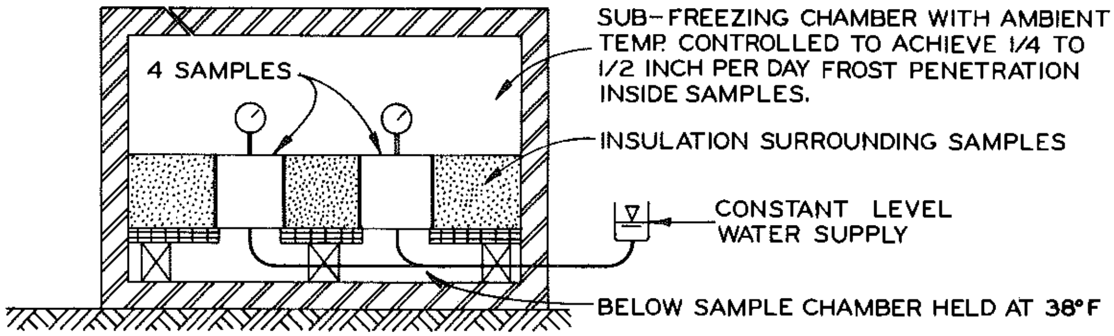
Duration of the frost susceptibility tests on the slag was 23 days. Acid treated samples heaved 1.2 in. whereas the samples of non-treated slag heaved only 0.3 in. (average), as shown in Figure 11, corresponding to 20 and 5 percent, respectively.

Current Condition of Field Areas

An inspection of the Fisher Freeway between Vernor and Outer Drive (Control Section 82194) in December 1969 showed approximately 80 percent of the slag-based median paving to be heaved. Magnitudes of the distress range from slight surface cracking and bulging to buckling and rupture of the bituminous surface similar to that already shown in Figure 2. Samples of slag obtained from the base in these areas show a slight residual expansive activity when subjected to the laboratory's volume change tests.

Drainage Characteristics

In August 1968 the Testing Laboratory performed tests relative to the drainage characteristics of open hearth slag at the request of J. S. Gooding, District Soils Engineer for the Detroit Metropolitan District. Results of these tests (5) showed open hearth slag to have good drainability and that the material met specifications for Granular Material, Class II Modified. In addition, permeability tests were performed on a layer of Ottawa sand that had been placed beneath the slag sample so that the water passing through the



Frost susceptibility samples in environmental chamber.

Detail of frost susceptibility sample.

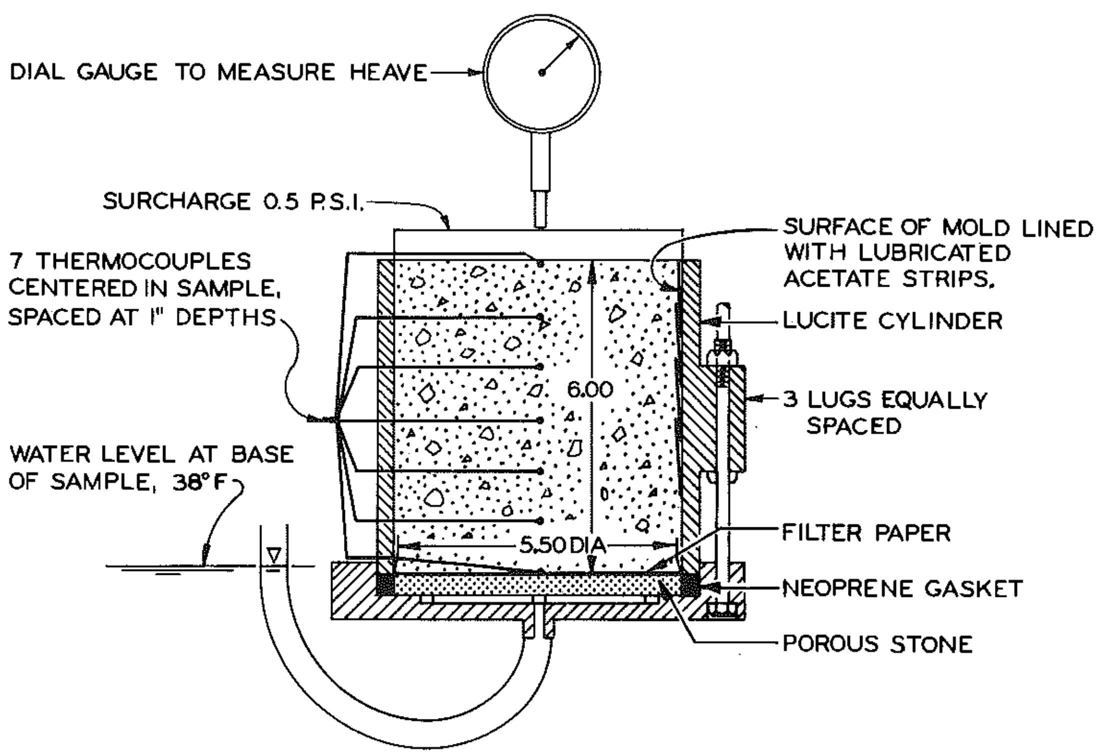


Figure 10. Frost susceptibility samples and environmental chamber.

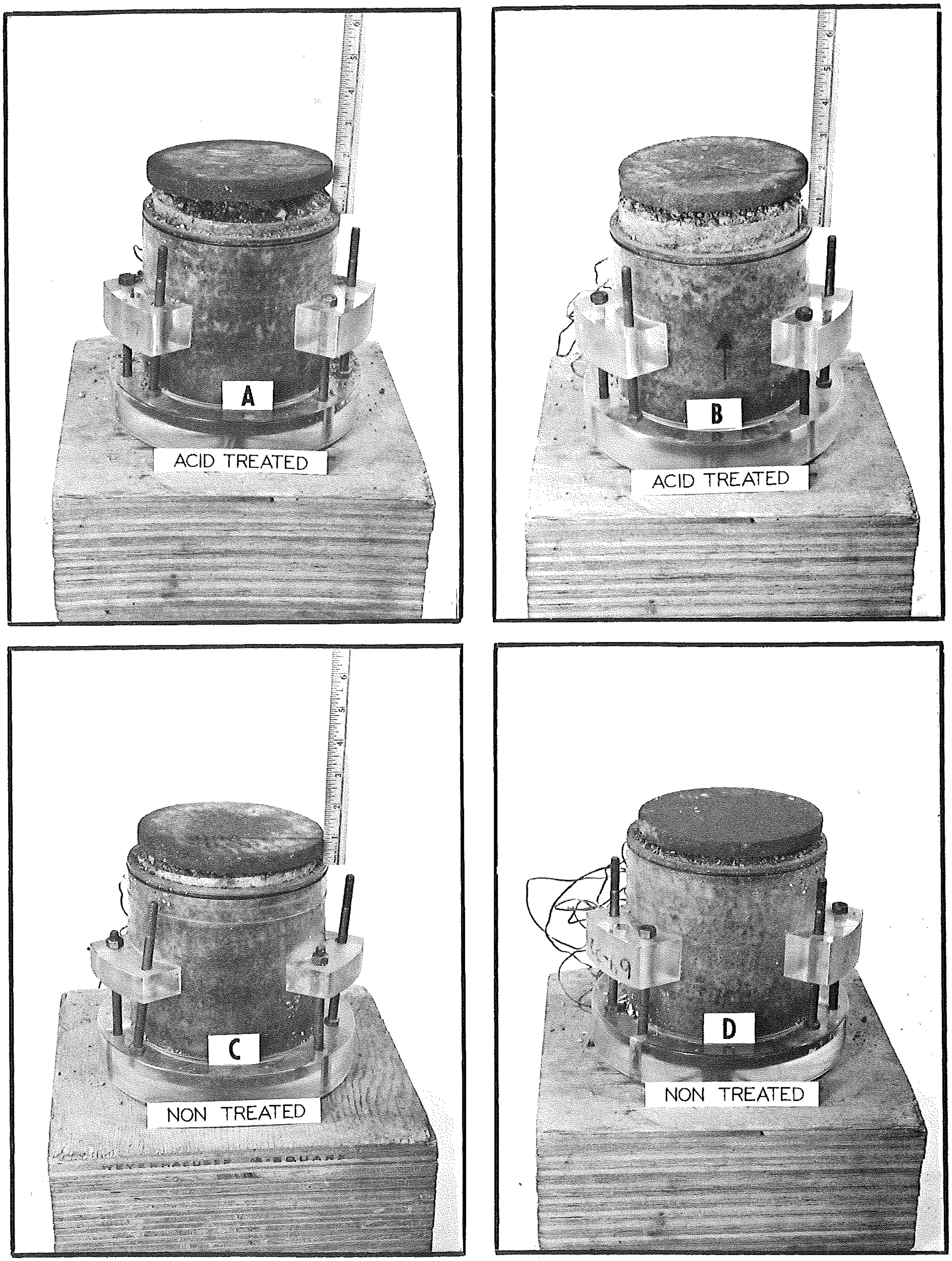


Figure 11. Frost susceptibility test samples.

slag also flowed through the sand. Although the permeability of the sand was slightly reduced, by migration of slag fines, the change was not significant.

DISCUSSION

Volume changes measured in laboratory tests were not equal in magnitude to the more severe vertical heaves observed along the freeway median. The explanation for this seems to be the different manner in which volume changes can manifest themselves in the two situations. Laboratory samples are permitted to expand only in a vertical direction whereas the encrusted layer of slag found immediately beneath the bituminous surfacing, expanding horizontally at the same linear rate, must accommodate it's increased length and apparently does so by buckling. Volume changes measured in the laboratory as linear expansion are of sufficient magnitude to create the buckling or heaving observed in the median. For example a 0.2 percent elongation (average 28-day value) would cause the crusty layer to increase in length by 0.04 feet in the 20-ft median width. A triangular shaped heave having a base width of one foot would therefore raise 1-3/4 in. measured at the apex, assuming that the entire change in length was relieved by the buckling with no internal crushing of the encrusted slag. Ninety-day values of elongation taken from Figure 9, however, would yield a vertical movement of nearly 5 in. by the same computations.

As previously mentioned in this report, more than 80 percent of the slag-based median shows distress of varying amounts with vertical movements ranging from fractions of an inch to nearly a foot. Variations obtained in the laboratory volume change tests along with both field and laboratory measurements show volume change activity after many months, thus indicating that laboratory values and median heaves are not necessarily inconsistent.

In order to firmly correlate laboratory volume change results with surface buckling, test strips will be constructed and exposed to normal weathering for several months with periodic measurement of surface elevations as a measure of buckling. The test strips will be 4 ft long by six in. deep and 6 in. wide, topped with 1-1/2 in. of bituminous surfacing. Samples of slag placed in each strip will also be tested for volume change in the laboratory in the manner previously described. Results of this test are expected to show the validity of the laboratory tests as indicators of potential field problems with open hearth slag, thereby establishing the laboratory volume change test as a means of inspecting slag material for potential problems if used in the future.

Regarding evaluation of acid treatment as a volume change inhibitor, it seems that although the magnitude of volume change measured in the laboratory was not as great as the more apparent median surface distress, acid treated slag experienced greater volume change than non-treated slag in the laboratory tests. It would seem reasonable to expect similar results at larger magnitudes and it is expected that the buckling test strips will verify this.

The volume change tests reported were made with vertical sample movement restrained only by the surcharge and mold friction. One sample, however, has been tested to measure the pressure generated under complete vertical as well as lateral restraint. The 6-in. diameter by 6-in. high sample exerted a pressure of 20 psi after 72 hours. Further testing is planned to extend over longer durations and to measure the variability of these pressure values.

CONCLUSIONS

1. Heaving of open hearth slag is not an occasional occurrance but has happened in varying degrees to more than 80 percent of the median area constructed on a slag base in Control Section 82194.

2. Samples tested for expansion in the Research Laboratory show no improvement due to the acid treatment, the method proposed by the producer to eliminate expansion of the slag.

3. In Laboratory tests, slag expanded vertically under a surcharge load equivalent to the weight of a 10-in. thick concrete pavement. Elongation averaged 0.2 percent for acid treated samples surcharged for 10 in. of concrete and 0.3 percent for the samples surcharged for 2 in. of bituminous paving at the end of the 28-day test. Expansion was found to continue for more than three months, however, so that these values do not depict the total volume change potential. No estimate of how such expansion would effect pavement performance can be made from these data.

4. Minerological identification of slag samples by X-ray diffraction analysis indicate two compounds as possible sources of trouble: periclase (MgO) and pseudowollastonite ($CaSiO_3$). Optical analysis of thin sections under a power microscope showed a hetrogeneous mixture of minerals within each piece of slag and the slag varying greatly in composition from sample to sample. Much additional study, using these techniques, would be required before specific compositional solutions to the heaving problem might be found. Since slag composition is a function of steel production requirements, and cannot be controlled by the slag aggregate producers or the Department, the value of further study of this factor is questionable.

5. No heaving has been observed where open hearth slag has been used in unconfined areas such as outside shoulders.

6. A limited number of frost susceptibility tests indicate a potential heave problem when using open hearth slag. Further frost susceptibility tests should be performed to evaluate this.

RECOMMENDATIONS

Open hearth slag should be used only where expansion would not be detrimental. The effect on pavement performance in which open hearth slag has been used for the base would require additional study and evaluation.

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