FURTHER EVALUATION OF OPEN HEARTH SLAG AS A HIGHWAY BASE MATERIAL

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INTRODUCTION

This project was initiated by the Soils and Aggregates Unit of the Re- +1
search Laboratory in October 1968 at the request of R. L. Greenman, to +3
determine whether the use of open hearth and basic-oxygen slags should +6
continue to be permitted in base and subbase construction. Use of such +7
materials had resulted in extensive heaving of finished surfaces, partic- +4
ularly noticeable on confined median strips of the Fisher Freeway in Detroit. -8

The primary objectives of this study were to determine the cause of +5
heaving, measure pressures generated by such expansive activity, and de- -2
cide whether open hearth slag could be safely used as subbase under con- +2
crete pavements.

The first report concerning this project (1), published in May 1970, +6
described the background of the work, methods for producing and handling 0
open hearth slag, and laboratory testing methods used to identify slag com- -4
ponents and measure the swelling characteristics of the materials; and an +1
evaluation of the producer's method (acid treatment) for reducing expan- +4
sion of the slag. General conclusions of this report were:

1) Heaving of median areas where open hearth slag had been used were -5
quite general. In one area of I 75 (Control Section 82194) 80 percent of the -2
median exhibited extensive heaving.

2) Laboratory tests showed that open hearth slag was subject to ex- +4
pansive volume changes which continued for more than three months.

3) Acid treatment of the slag did not prevent expansion under labora- 0
tory test conditions.

4) Mineralogical identification by X-ray diffraction and microscopic +3
analysis indicated a very complex and variable mixture of compounds in +6
the slag. Because of the high variability and lack of control in slag pro- +4
duction, further study in this area was not considered to be of value.

5) A potential frost heave problem was indicated for the slag mixtures. -5

As a result of this phase of the study, it was recommended that the use -4
of open hearth slag be restricted to those areas where expansion would not -1
be detrimental.

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This report presents the results of studies made subsequent to the pre- -5
paration of Research Report No. R-739 and concerns primarily the results -2
of:

1) Laboratory and field studies of environmental factors affecting open -4
hearth slag bases.

2) Further condition and performance surveys of pavements supported -3
by open hearth slag bases.

3) Experiences of other agencies who have used open hearth slag.

This project has been substantially completed except for long-term +7
evaluation of pavement construction and possible supplemental laboratory +1
tests.

ENVIRONMENTAL EXPOSURE TESTS

Environmental exposure tests, as included in this study, were primarily -8
concerned with volume change of samples due to chemical action of the slab -4
in the presence of moisture, and with the effects of frost action on the sam- -5
ples. Each of these factors was tested in the laboratory and in the field +6
using samples of slag obtained from production stockpiles produced to meet -4
Departmental specifications for graded aggregate 22A.

Non-Freezing Volume Change

In the initial phase of this study, laboratory volume change tests were -1
usually concluded after a 28-day exposure period. This period allowed rel- -5
ative volume changes to be determined and the performance of a larger +8
number of tests. To correlate laboratory results with those of field ex- +5
posure, however, laboratory testing time for five samples was extended +5
to approximately eight weeks--the time used for field exposure. Figure 1 0
shows the general set-up for measuring volume change of 2-in. diameter +3
by 4-in. high test cylinders in the laboratory. All slag samples used in +6
this testing phase were obtained from production stockpiles and scalped to 0
pass the No. 4 sieve in order to better fit the 2-in. diameter molds.

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Six field exposure samples, placed at an outdoor storage area of the +4
Grand Ledge Maintenance Garage, consisted of rectangular strips 6 in. +8
wide, 4-1/2 in. deep, and 4 ft long (Fig. 2). The strips were compacted +3
to a design density of 160 lb per cu ft, on a base of compacted granular +8
material, and surfaced with 1-1/2-in. bituminous aggregate. During sum- -3
mer 1970, changes in surface elevations were measured as shown in Fig- +1
ure 3. Later, when freezing weather began, these same samples were +8
used for frost action study. A top size of 3/4 in. was used for these slag +2
samples.

Figure 4 shows the volume change of three identical, freshly produced -2
samples when tested under laboratory and field exposure conditions. These -5
tests indicate that volume changes due to field exposure are generally +12
greater than those developed under laboratory conditions and that field re- -1
sults are more variable than those obtained in the laboratory. Field meas- -4
urements, however, were not made to the same degree of accuracy as those -6
used in the laboratory tests (Figs. 1 and 3). For comparison, the maxi- +3
mum laboratory expansion of one three-year old sample taken from a median -8
strip is shown. Less volume change is apparent in the seasoned slag.

Frost Susceptibility

Laboratory tests presented in the initial report indicated open hearth +2
slag to be frost susceptible and that acid treatment made this condition +9
worse (Fig. 5). A top size of 3/4 in. was used for the laboratory frost +7
effects testing. Supplementing these laboratory tests were field test strips, -5
described above, which were allowed to weather during a freezing season +2
with volume change measurements made weekly.

Figure 6 shows that the rate of change in elevation of the exposed sam- -4
ples increased rapidly with the beginning of the freezing season, indicating -2
a substantial increase in volume change due to frost action. This is verified -7
by points on the same figure showing the results of laboratory frost suscep- -5
tibility tests. For both laboratory and field tests the volume change was +4
much greater when the samples were subjected to freezing than when al- +4
lowed to expand by chemical action alone. Figure 7 shows the heaved and +1
cracked test strip at the end of the eight-week weathering period.

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Drainage Characteristics

Another problem with open hearth slag became apparent from a study +1
of certain underdrains at the Detroit Metropolitan Airport. Perforated +8
metal edge drains and appurtenant catch basins were found to contain de- +3
posits of carbonate scale after only one year of service, despite the fact +5
that natural aggregate filter material was used. Drainability tests per- +6
formed by the Department's Testing Laboratory (2) confirmed that water +4
flowing through the slag base course had clogged the underlying layers of +3
filter material. Detailed laboratory analyses (3) conducted by independent -1
laboratories for the Wayne County Road Commission indicated the same +6
cause. As a result, Wayne County has recommended a full-scale field +9
evaluation to study this problem and check the producer's suggested method -4
of correction by treating the slag with carbon dioxide.

PERFORMANCE OF SLAG BASES

Current Condition

At the start of this project it was felt that volume change problems +8
were limited to those slags produced during certain time periods and which -3
had been used only in those areas where extreme heaving had been first +7
noticed. Initially, sampling, volume change testing, and compositional +7
analyses were planned around this premise. Subsequent condition surveys, -3
however, show that all slag medians constructed between 1965 and 1968 +7
experienced heaving to some degree (Control Section 82194C, 12-14, 21-24, -5
28, 29, and 31). Furthermore, cracking and surface distress are apparent -4
in extensive areas of outside shoulders where the slag base had been thought -6
to be satisfactory. Figure 8 shows such shoulder distress observed during -3
1970 in the Porter St area.

Measurements of medians constructed in 1968 have continued to show +1
additional heaving (Fig. 9) although samples of seasoned slag, obtained +8
from median bases exhibit only a slight residual volume change potential +4
when tested in the laboratory (Fig. 4). Continued median movement after +1
seasoning, therefore, probably is due to frost action rather than to chemical -7
activity of the slag.

Typical transverse cracking of a 71-ft slab of conventionally reinforced -5
pavement on the Jeffries Freeway (82194K) is shown in Figure 10. The +7
two lanes, which merge with and become part of the Fisher Freeway, were -3

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constructed under the same contract as a portion of the Fisher. A total of -1
46 of these slabs were constructed as part of this contract and all exhibited -3
the same transverse cracking pattern, generally three or four cracks per +1
slab, prior to being opened to traffic. However, the adjoining project, +9
paved the following year and also supported by open hearth slag as the +11
selected subbase, shows no cracking to date.

In order to detect possible slab displacement due to expansion of slag +1
in the selected subbase, elevations were measured at six locations--50 ft +2
apart--paved over freshly placed slag in a section of the continuously rein- -3
forced concrete pavement in the vicinity of Michigan Ave on the Fisher +9
Freeway (Control Section 82194C). At each location or section, elevations -2
were read immediately after construction in July and periodically until the -1
road was opened in September. Average elevation changes for the six sec- -3
tions, measured at the edges of each of the three slabs across the pave- +5
ment, are shown in Figure 11, with previous results of laboratory volume 0
change tests for comparison. Even though pavement movement was greater -5
than laboratory values would indicate, it was not large, and relative move- -3
ment between adjacent sections was not significant. It is expected that only -4
long-term pavement performance evaluations will reveal whether or not the -4
slag selected subbase is detrimental to the pavement structure.

Although not a factor in this particular study, it was noted that on these -5
projects in the Detroit area, the cost of open hearth slag varied from $3.50 -4
to $4.60 per cu yd as compared with $3.75 to $4.75 per cu yd for normal +3
specification aggregates.

Long-Term Studies

Even though laboratory tests and pavement elevation measurements +6
show that slag can expand beneath a pavement, damaging effects have not +3
been proven. Adjoining sections of continuously reinforced pavement, con- -4
structed over both natural aggregate and slag selected subbases have been 0
selected for observations to obtain a long-term performance comparison. +2
Pavement roughness of these sections will be measured twice a year, for +2
a minimum period of five years, using the Rapid Travel Profilometer. Re- -5
sults will be compared yearly for pairs of adjacent sections and this infor- -3
mation will allow us to predict the long-term rate of deterioration for each XX -2
type of base.

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EXPERIENCE OF OTHER AGENCIES

Wayne County and Detroit

In addition to the previously mentioned drainage problem encountered 0
by the Wayne County Road Commission, a report by the City of Detroit in +2
1967 (4) indicated pavement damage due to the frost susceptible nature of +3
open hearth slag. Laboratory tests reported by the City of Detroit resulted -4
in volume changes ranging from 6.69 to 16.25 percent using open hearth +5
slag at 6 percent moisture content. Changes in gradation specifications of -1
open hearth slag were recommended in order to reduce capillary potential, -2
increase permeability, and thus reduce the possibility of swelling upon +9
freezing.

Pennsylvania

The use of approved open hearth slag has been permitted since 1957 +5
by the State of Pennsylvania for certain subbase, surfacing, and stabilized -1
shoulders. Specifications (5) require that the slag be seasoned in a control- -6
led stockpile for a minimum of six months, with provision for keeping the +1
material in a damp condition. Research studies (6) showed expansion to +5
continue after 17 months of seasoning, with the finer portions (passing the 0
3/4-in. sieve) being more expansive than the larger fractions. Recom- +6
mendations resulting from these studies include: 12-month stockpiling +9
prior to use with a definite arrangement for watering; periodical inspection -3
of the piles; and wasting the upper 2 to 3 ft of slag in each pile. Pennsylvania -10
research recommendations also caution against a possible lack of adhesion -2
of slag to asphalt if open hearth slag is used in bituminous concrete. Ex- +1
perimental construction projects, using open hearth slag aggregate in bitu- -3
minous concrete, aggregate-cement bases, and shoulder construction, are -2
being evaluated in Pennsylvania.

In contrast to the stockpiling requirements of Pennsylvania, open hearth -7
slag used in the Detroit area is taken directly from production piles, a pro- -5
cedure not conforming with Michigan's aggregate handling specifications. +3
Operations are such that no stockpile can be inspected as a unit nor can an -1
estimate of material age be made with any confidence.

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CONCLUSIONS

Pending the completion of long-term studies of the performance of +9
pavements supported by open hearth slag selected subbases, the following +1
conclusions are presented based on available test data.

1) Open hearth slag is subject to volume change due to chemical re- +3
action in the presence of moisture; is frost susceptible and, due to leaching -5
of calcium carbonate from the slag, can cause blockage of drainage filters. -3

2) Acid treatment of slag, proposed as a corrective measure by the +4
producer, does not alleviate volume change caused by chemical action and 0
appears to increase susceptibility to frost action.

3) It is indicated that seasoned slag (taken from approximately three- -1
year old median strips) has less than half the volume change due to chemical -7
action as does freshly produced slag.

4) Due to age, chemical composition, and possibly other factors, open -4
hearth slag sources are extremely variable and their performance unpre- +1
dictable. It is recommended that the Department prohibit the use of this +4
material for highway construction until it first can be evaluated by the Re- -1
search Laboratory for the particular use intended.

5) Volume change of a particular sample of open hearth slag under +7
field conditions can be successfully predicted by laboratory procedures +8
used in this study. However, the effect that such volume change might have -5
on the performance of pavement surfaces can be determined only by an +9
evaluation of test pavements now being studied. A five-year observation
period is planned.

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3. Ross, B. A., "Evaluation of Carbon Dioxide Treated Open Hearth Slag as a Subbase Aggregate," Report to Wayne County (Mich.) Road Commissioners, Decmeber 1968. 0 -2

4. City of Detroit, Inspection Bureau Report, December 8, 1967.

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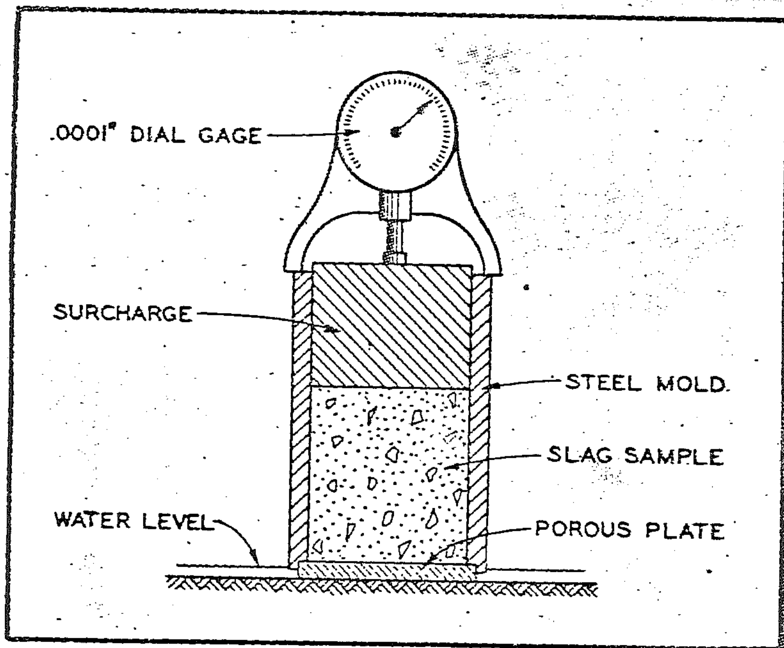
6. Kandhal, P. S., et al, "Expansive Characteristics of Open Hearth Slag," Pennsylvania Department of Transportation, October 1970. -1



~~Figure 1.~~ Section through volume change sample.

From R-739

~~Figure 2. Laboratory~~ Volume change measurements on 2- by 4-in. samples, subjected to capillary moisture absorption.

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Fig 1 Method of Measuring Non-freezing Volume Change of Laboratory Test [illegible]

Fig. 2. FIELD TEST SECTIONS OF ACID-TREATED SLAG AT START OF EXPOSURE.

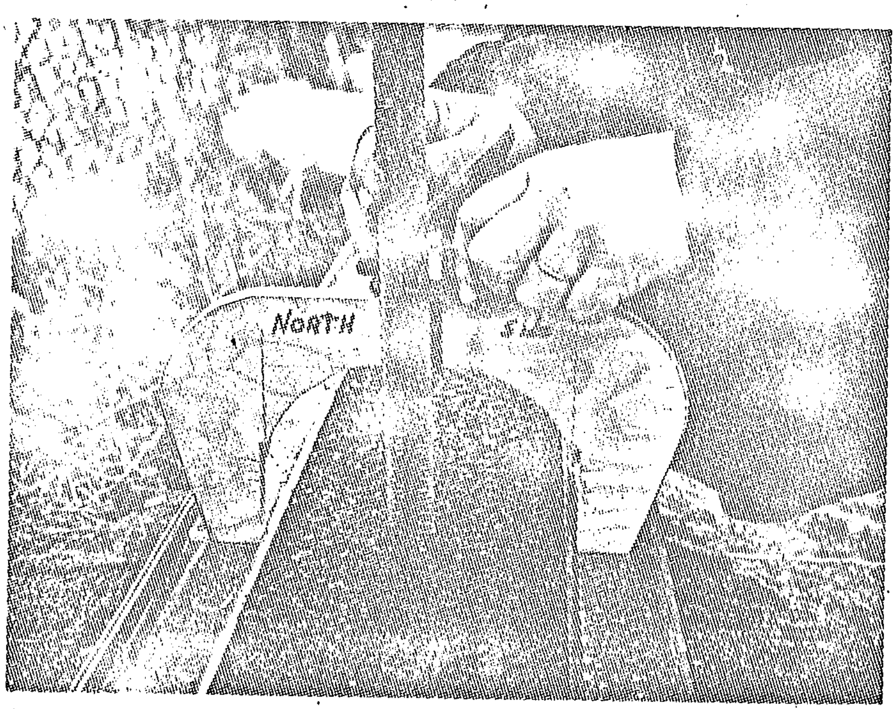

FIG. 3. PERIODIC MEASUREMENT OF ELEVATION CHANGE DURING EXPOSURE. (AVERAGE OF FIVE VALUES USED FOR EACH MEASUREMENT)

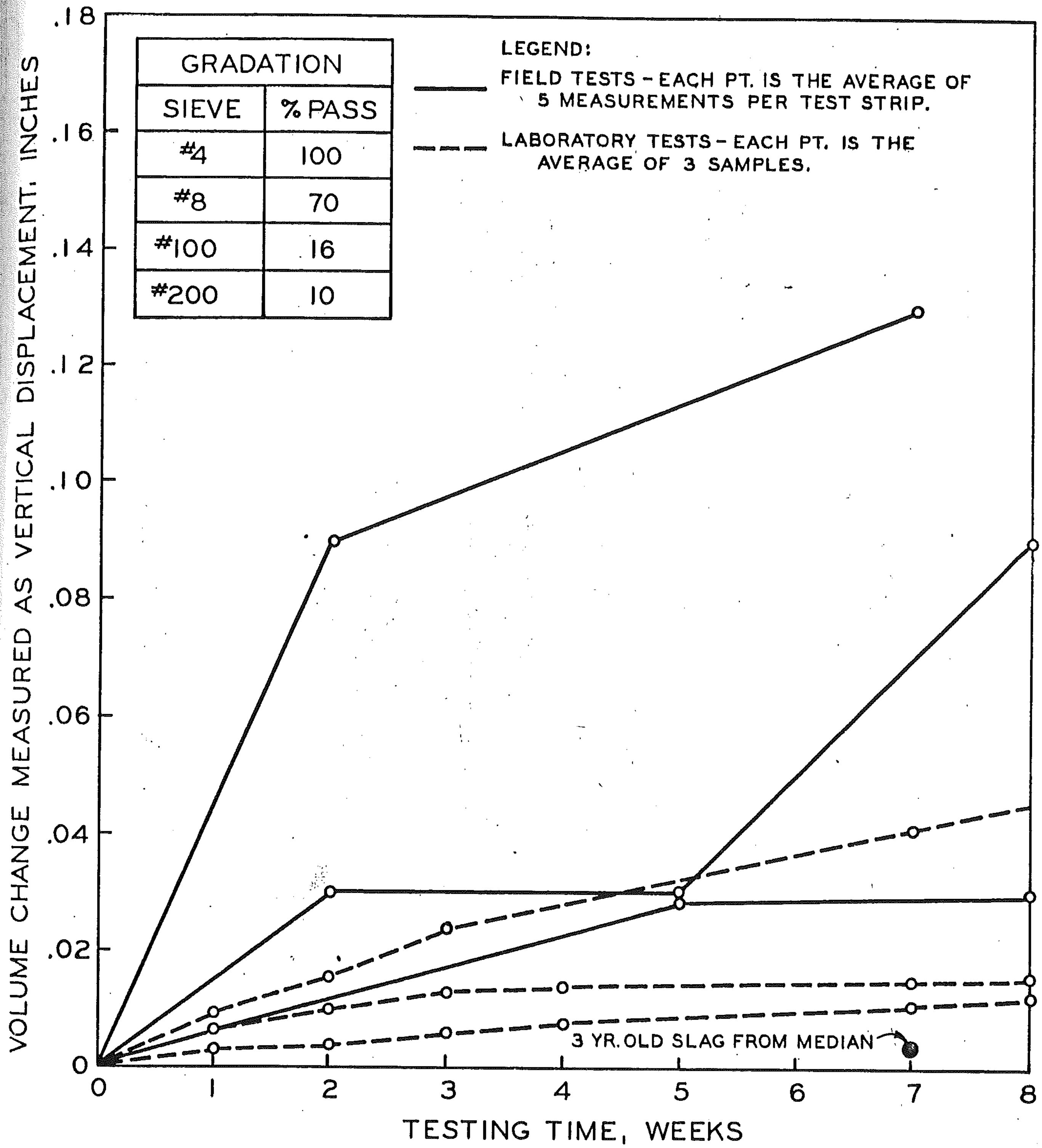

Figure 4. Comparison of field and laboratory exposure tests under non-freezing conditions using samples of acid treated slag with 2-in. bituminous surcharge (Newly produced samples).

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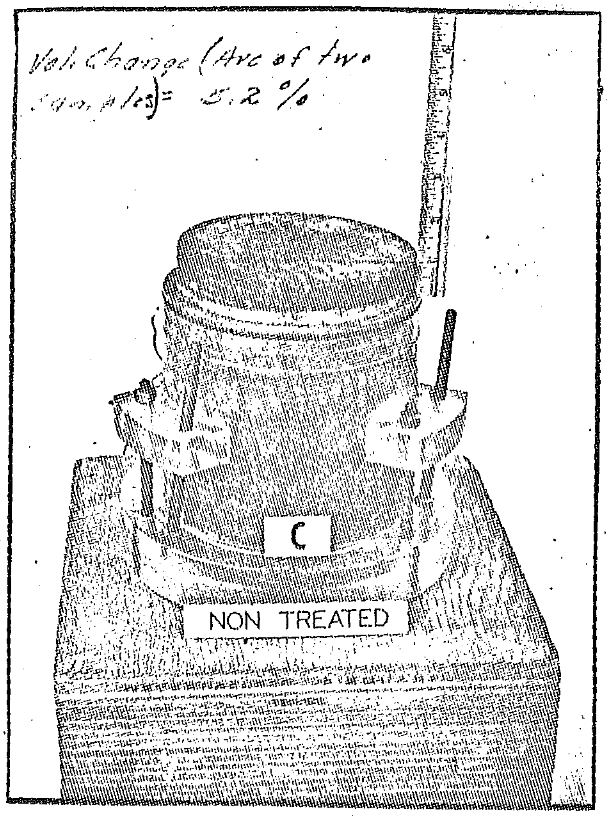
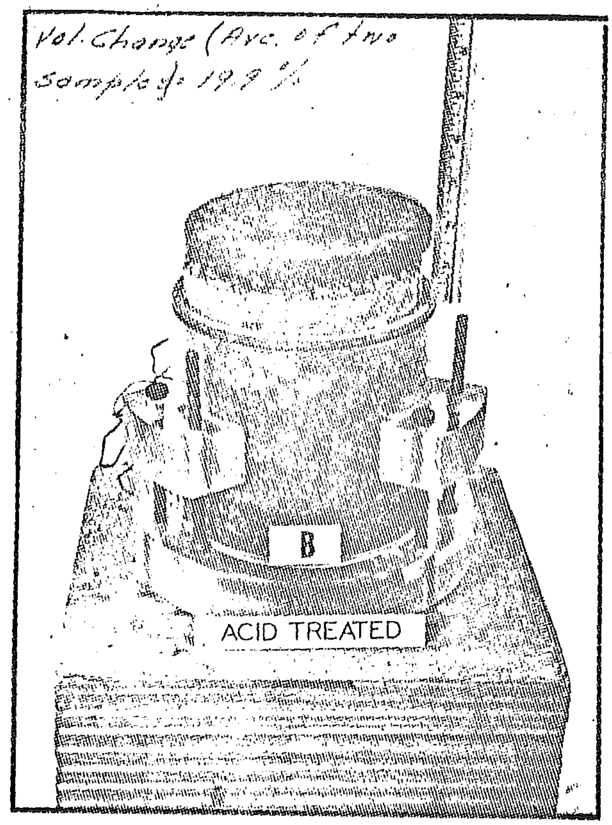




Note: Ave Vol. Change of 22-A natural aggregate ~ 2.7%

Fig. 5 Volume Change of Non-treated and Acid-Treated Slag Samples at Conclusion of Laboratory Frost Susceptibility Tests.

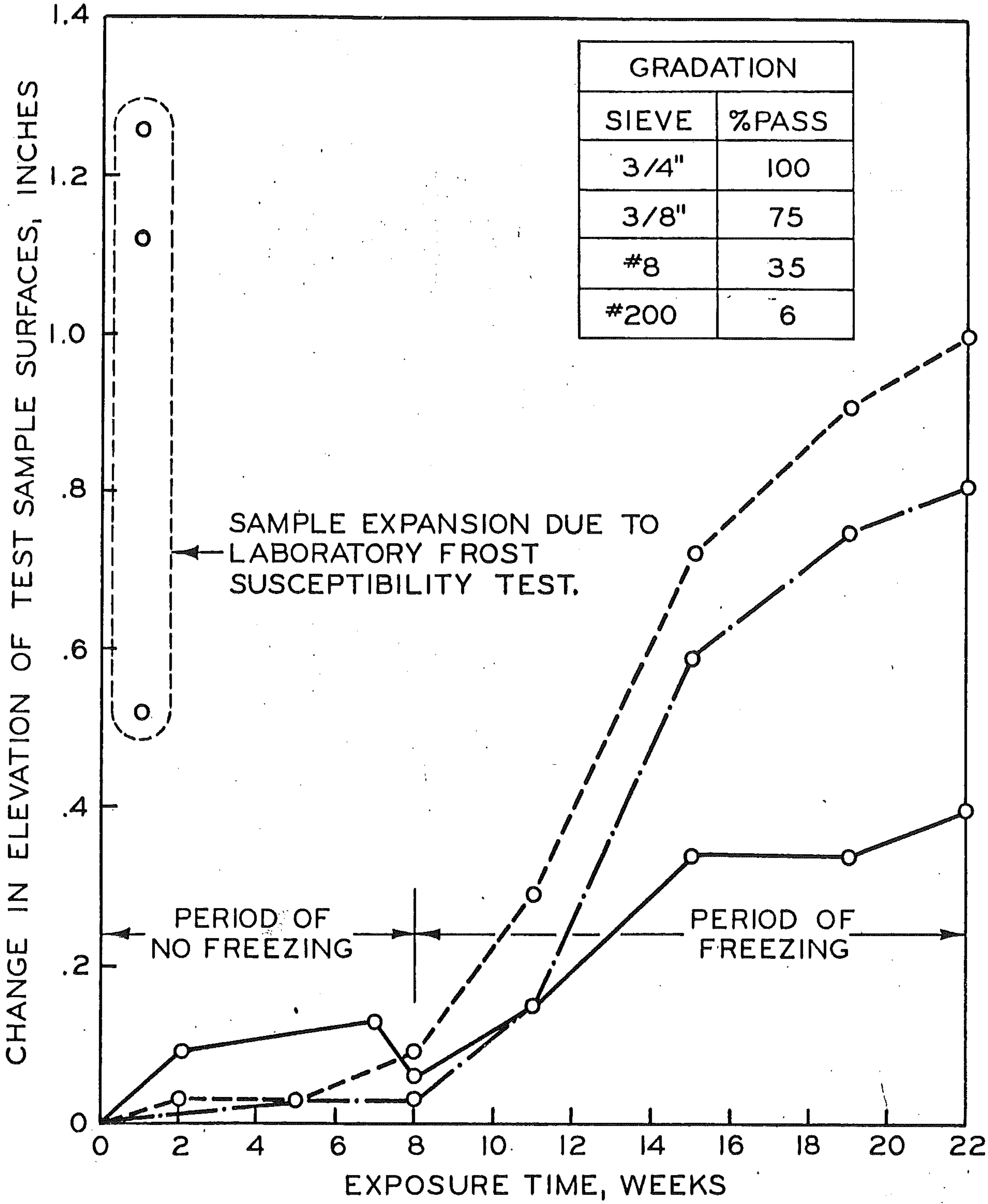


Figure 6. Effect of freezing on expansion of field test sections and comparison with laboratory frost testing results (Acid-treated slag).

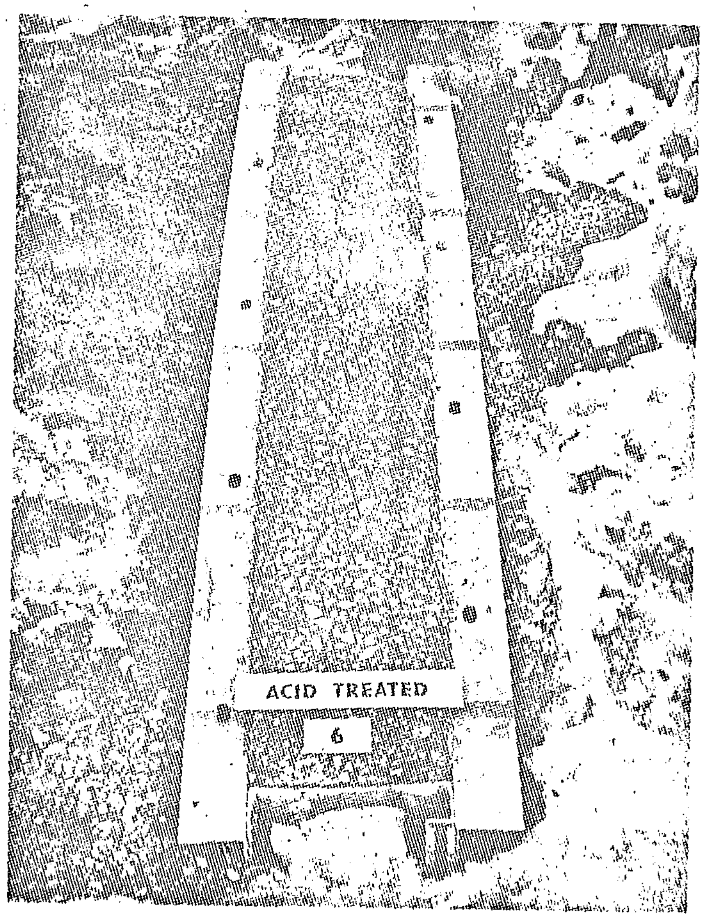
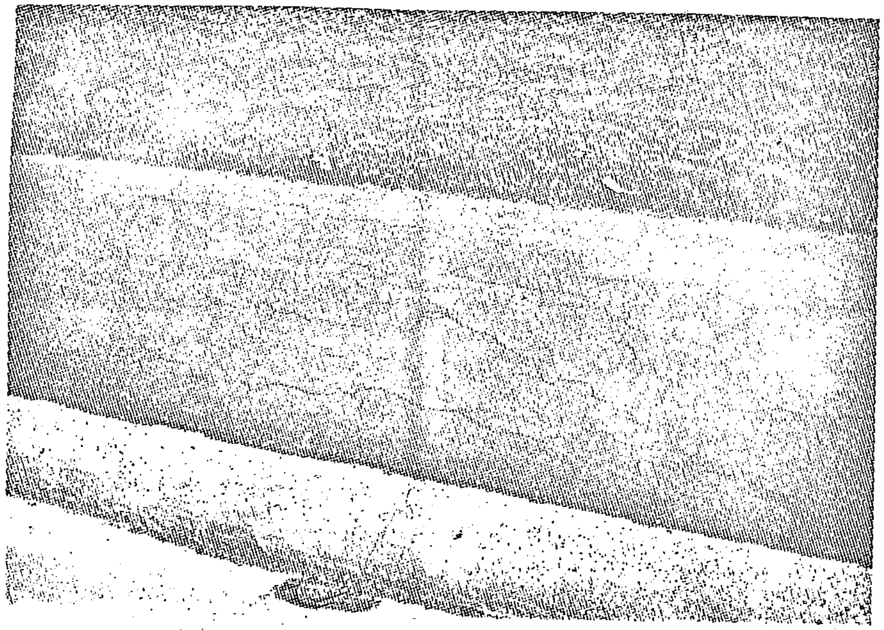


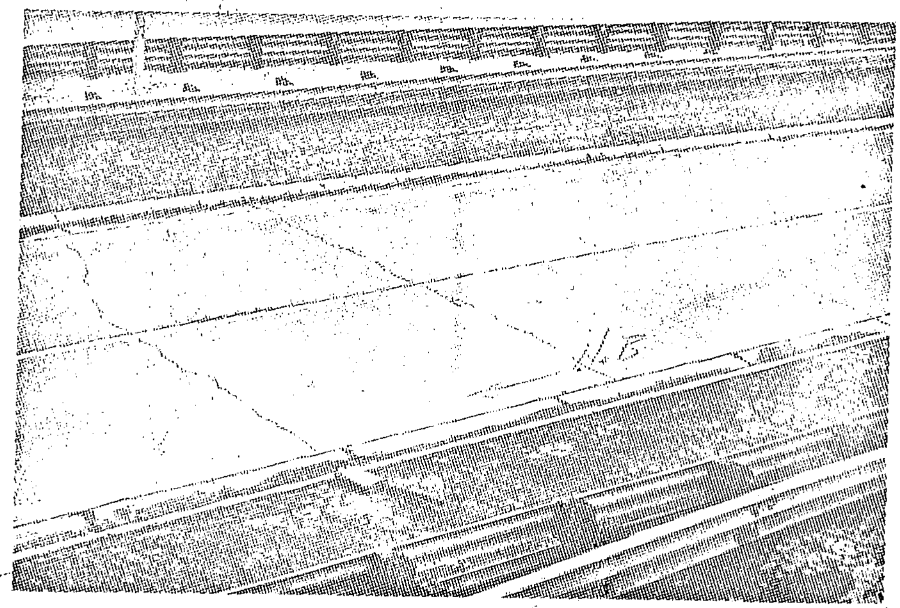
Fig 7. Heaved and Cracked Test Section
After 8-Weeks Field Exposure



OUTSIDE SHOULDER

MEDIAN SHOULDER

FIG. 8 CONDITION OF SLAG BASE SHOULDERS
I-75 AT "PETER STREET" 1970



REMOVE

FIG. 10 TRANSVERSE CRACKING OF REINFORCED CONCRETE SLAB SUPPORTED BY SLAG BASE (STA. 1224 N.B. JEFFRIES FREEWAY)

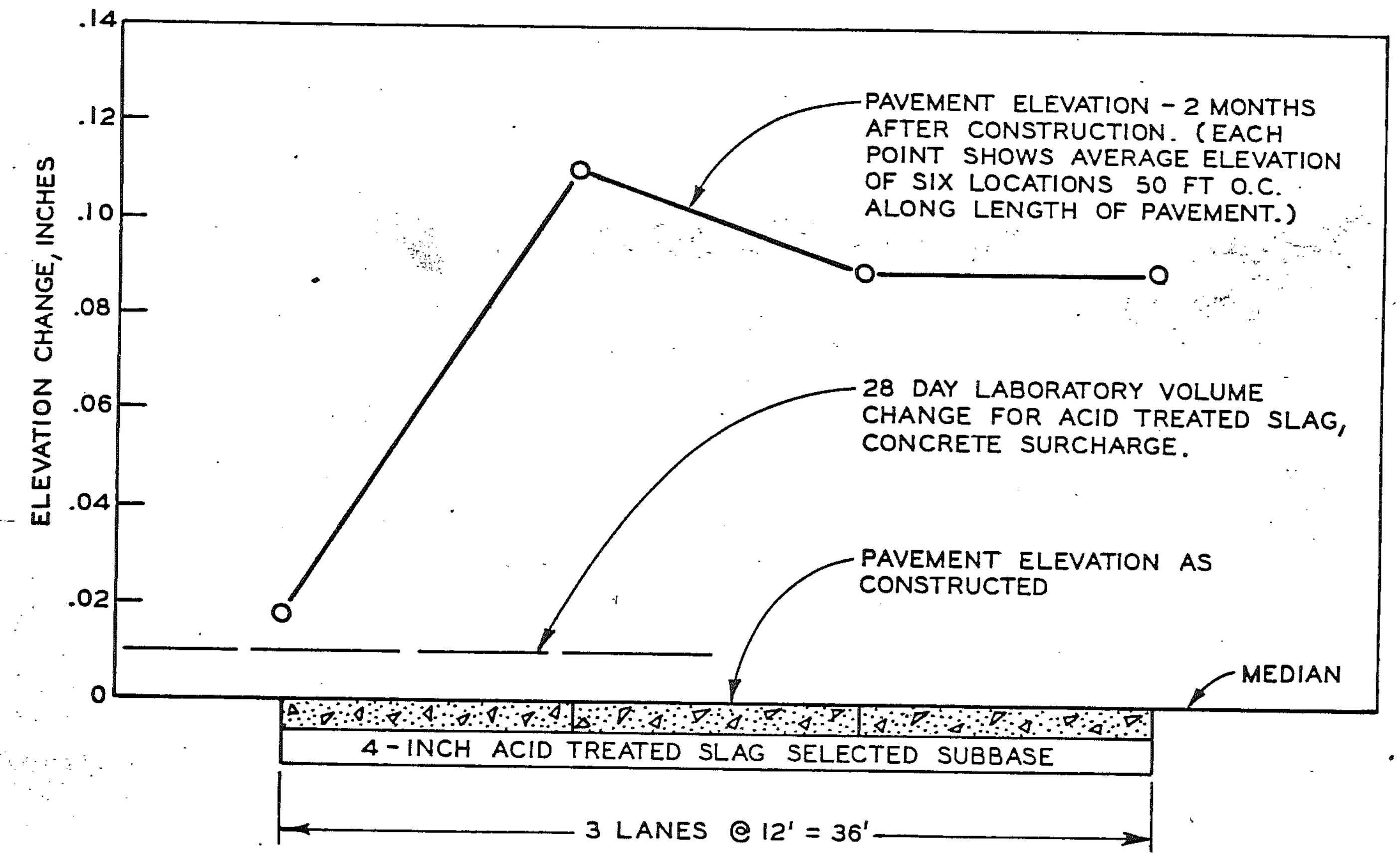


Figure 11. Change in elevations of concrete pavement placed over 4-in. slag selected subbase - two months after construction.