FROST SUSCEPTIBILITY

OF

ALASKAN BASE COURSES

State of Alaska, Department of Highways
Materials and Research Division
State Materials Laboratory

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I Introduction

This paper summarizes laboratory investigations which included the development of procedures and equipment for the testing of frost heaving soils, and presents the results of heave rate testing on various base course gradations. The greatest portion of the work consisted of efforts to standardize procedures for evaluating base courses by means of unidirectional freezing. The testing apparatus selected is designed to impose on the soil sample the worst possible situation, controlled unidirectional freezing from top down after complete sample saturation, with an unlimited water supply located at the sample base. This study was made to determine whether current State of Alaska specifications for base course materials are providing a material which adequately serves its intended purpose of providing non-frost susceptible support for the overlying pavement structure.

The design of the test equipment and the testing procedures utilized were decided upon after reviewing previous soil heave testing work performed by the Alaska Department of Highways, the University of Alaska Arctic Environmental Engineering Laboratory, recent studies performed by J.H. Zoller of the University of New Hampshire, and by C.W. Kaplar of USA-CRREL.

II Test Equipment

The equipment included a modified Gibson vertical home-type freezer, heave molds, dial length change indicators, thermometers, potentiometers, modified CBR mold, an ASTM compaction hammer, scales, thermocouples, and other miscellaneous standard lab equipment.

Freezing Cabinet

To provide the necessary heave test environment of freezing from the top down, with a constant supply of water at the sample base, a 17 cubic foot upright home freezer was purchased and modified as required. Figure 1 shows an interior diagram of the modified freezer. The first modification was the removal of one of the middle freezer shelves, including its cooling coils, in order to provide space for the samples and related equipment. A 5" high tank of 3/16" thick aluminum was then constructed to the width and depth of the freezer interior, and installed in place of the previously removed freezer shelf. Rubber weather stripping was installed around the edges of the tank to separate the freezer interior into two chambers. The freezing
coils in the chamber beneath the tank were covered with insulation, and two 60-watt light bulbs, connected to a temperature controller, were installed to serve as heaters for maintaining the temperature beneath the tank at +40°F. The original temperature controller for the freezer was replaced by a more accurate "Honeywell" brand controller so the temperature above the tank could be set at any desired temperature in the range of -10°F to +80°F. Small circulating fans were installed in both upper and lower chambers to assure temperature uniformity. Plumbing connections were made through the wall of the freezer so the water level in the tank could be externally controlled at any desired level.

Four dial indicators were mounted on top of the freezing cabinet and were connected by means of extension rods, to the tops of the heave samples inside the cabinet. By this means, the heave of each sample could be observed to the nearest 0.001 inch without opening the cabinet. Remote reading thermometers were installed in upper and lower chambers, and a series of thermocouples was also installed to monitor temperatures at various points in each chamber.

Heave Molds

Sample heave-testing molds consisted of five one inch high plastic rings topped by one ½ inch high ring. These ring molds were lathe-cut from a length of 6 inch diameter by 1/8 inch wall rigid clear plastic tubing. During sample compaction the plastic rings were enclosed and supported by a split 6 inch diameter steel CBR mold, which effectively prevented displacement and damage to the rings. Samples were compacted using a 10 pound rammer with an 18 inch drop, meeting AASHO Specification T-180-70.

After compaction, the samples with rings in place were removed from the CBR mold and placed into the tank inside the heave cabinets on top of six inch diameter by ¼ inch thick porous stones. The samples were topped by six inch diameter by ¼ inch thick aluminum plates, which were weighted with lead to provide a surcharge loading of 0.2 pounds per square inch, equivalent to the weight of roughly 2½ inches of asphalt concrete pavement.

III Sample Preparation

Approximately 800 pounds of aggregate base course material was obtained from the Fairbanks Sand and Gravel Company and was the only soil type tested under this Study. It was felt that heave tests of various particle size gradations prepared from a single source would serve to indicate the general effects of these variations on heave rate and strength after thawing.

Specific procedures for preparation of the samples were as follows.

1. A quantity of 600 pounds of aggregate base was obtained, dried, and screened into sizes falling between the specification sieve sizes.
Interior Diagram of Heave Test Cabinet
2. All aggregate portions larger than the No. 200 sieve in size were washed and agitated several times to assure that all adherent fines were removed. All materials were again dried at 140°F.

3. Each aggregate fraction was accurately weighed and combined with other size fractions, in the amounts needed to make up the test gradations shown by Table 1.

4. The first three gradations represent the lower, mid-range and upper specification limits for D-1 grading aggregate base, except that all materials used were smaller than the 3/4" sieve rather than the 1" maximum size permitted by the specifications. This change was made to minimize damage to the plastic heave molds, which increases with particle size. The last two gradations were identical to Grading C except for excessive fines contents. Table 1 also shows the size distribution of the fines from hydrometer analysis of samples after completion of heave rate testing.

5. The aggregate fractions were combined in clean, sealable polyethylene hags, and dry mixed manually. These containers were used to prevent loss of any fines in the form of dust.

6. Water was added as necessary to condition each sample to a moisture content of 4.0%, the optimum moisture for compaction of a mid-specification gradation as determined by AASHO Test Method T-180-D. Mixing with the water was again done in the plastic sacks to eliminate the possibility of fines and moisture losses.

7. Samples were compacted into the six plastic heave mold rings as discussed under "heave molds" above. The samples were compacted in five layers with the compactive effort varied as necessary to attain approximately 95% of the maximum density as determined by AASHO Test Method T-180-D. Each layer was lightly scarified to eliminate stratification prior to placement of the following layer. Samples not falling in the range of 95 to 96% compaction were removed and recompacted until the proper density was achieved.

IV Testing Procedures

After placing the compacted samples into the tank inside the freezing cabinet, seating the top plates, and connecting the heave dial indicators, the freezing cabinet was closed and the water tank surrounding the samples was filled with water to an elevation at 1/4 inch from the tops of the heave samples. The samples were permitted to saturate for a period of about 16 hours, and were also cooled to +40°F during this time.

At the end of the saturation period, the water level around the samples was lowered to 1/4 inch above the bottom of the tank, a level just at the
<table>
<thead>
<tr>
<th>Sample Designation</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
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<tr>
<td><strong>Particle Size</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3/4&quot;</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<td>3/8&quot;</td>
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<td>10</td>
<td>20</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>#200</td>
<td>3</td>
<td>6.5</td>
<td>10</td>
<td>12.5</td>
<td>15</td>
</tr>
<tr>
<td>.02 mm</td>
<td>0.9</td>
<td>2.0</td>
<td>3.0</td>
<td>3.8</td>
<td>5.2</td>
</tr>
<tr>
<td>.005 mm</td>
<td>0.3</td>
<td>0.3</td>
<td>0.5</td>
<td>0.7</td>
<td>0.8</td>
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<tr>
<td>.002 mm</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>
contact between the bottom of the samples and the underlying porous stones. This assured that the bottom of the samples would have a continuing supply of water during freezing. After lowering the water level, the space in the tank around the sides of the samples was filled with loose fill bead-type polystyrene insulation. This was done to insulate the sides of the samples against heat loss and provide for vertical freezing only.

Sample freezing and heaving were started by setting the temperature control for the upper chamber, to which the tops of the samples were exposed, at +150°F, while maintaining the chamber beneath the sample tank at +40°F. These temperature conditions were maintained for a period of 96 hours. The height changes resulting from frost heaving of each sample were recorded hourly during working hours, with occasional additional readings made late in the evenings. In each test run, one sample was also compacted into a tapered heave mold instrumented with thermocouples at 0.5 inch intervals, to determine the depths and rate of penetration of the 32°F isotherm. This tapered heave mold, 6 inches in height and varying from 5½ inches in diameter at the bottom to 5 3/4 inch at the top, is similar to molds previously used in heave rate testing at the State Materials Laboratory. The taper in the mold was provided to minimize side friction as freezing and heaving occurred. Heave rate comparisons between identical samples tested side by side in the segmented and tapered molds showed the heave magnitudes and rates were generally from two to three times higher in the segmented molds than they were in the tapered molds. Maximum depths of frost penetration were similar between the two mold types, and averaged approximately half of the total sample height of six inches.

Following the freezing period, samples were removed from the molds and separated at the frozen-thawed interface. After recording the depth of freezing, the frozen and thawed sample portions were oven dried to determine the final moisture contents.

Discussion

Heave testing using the equipment and procedures described above gave very good repeatability between duplicate samples, and clearly differentiated between the heave rates of different sample gradations. Three identical samples, tested at the same time, showed a difference in heave between all three samples of only 5%. A total freezing period of 96 hours was used for all tests under this study. Figure 2 shows a plot of frost penetration and heave versus freezing time. This pattern of freezing and heaving is very similar to the tests on other samples. The frost penetration rate steadily decreases with time. For the freezing chamber temperatures of +150°F and +40°F used in this test it is estimated that frost penetration equilibrium would be reached after six days, with approximately two thirds of the sample being frozen at equilibrium.

Results of heave tests on the five aggregate base material gradations used in this study are shown by Figure 3. Freezing of the samples did not
Heave vs. Frost Depth
Sample Grading E
15% - #200 sieve

Figure 2
Sample Heave vs. Elapsed Time
Samples in Segmented Ring Molds

- 15% - 200 (Sample E)
- 12.5% - 200 (Sample D)
- 10% - 200 (Sample C)
- 6.5% - 200 (Sample B)
- 3% - 200 (Sample A)

ELAPSED TIME

Figure 3
begin until approximately eight hours after the upper chamber temperature
was reset from +40°F to +15°F. The time of resetting is used as the zero
reference hour, on Figure 3. Reliable indications of the differences in heave
potential between the various gradations did not develop until after roughly
24 hours of cooling. Test times longer than 72 hours do not appear to have
any value.

It was generally noted that by the end of the freezing period a layer
of white crystalline ice had formed between the tops of the samples and the
bottoms of overlying surcharge plates. This ice layer was often on the
order of 1/16 inch in thickness, and probably resulted from condensation
and freezing of vapor phase moisture drawn from the underlying samples.
Because these ice layers caused a physical separation between the samples
and the top plates, their formation was the cause of a portion of the ob-
served heave, and was probably the major factor in the observed heaves
during the first twelve to twenty-four hours of the test.

The results of heave testing can be evaluated in several different
ways. These include comparing heave rates over a set period or at a set
freezing rate, comparing total heave magnitudes, comparing final moisture
contents of the frozen soils, and evaluating soil strengths after thawing
without drainage of excess moisture. For the testing procedures used in
this study, any of these methods would appear to differentiate between the
various gradations tested. Heave data from the first 24 hours should be con-
considered as a temperature stabilization period only, and not included in
the final evaluations. As shown by Figure 2, the freezing rates were
roughly 2.0, 1.0, 0.5, and 0.3 inches per day for the first through fourth
days of testing, respectively.

The only semi-standardized test for frost heave potential, reported by
Kaplar (1), is used by CRREL and the Corps of Engineers and is based on a
controlled rate of frost Penetration of $\frac{1}{2} \pm \frac{1}{4}$ inch per day. Samples are com-
pacted into 6" high tapered heave molds similar to the thermocouple instrumented
mold used in this study for frost depth determinations.

The CRREL heave susceptibility classification under this system is as
follows:

<table>
<thead>
<tr>
<th>Avg. Heave Rate (mm/day)</th>
<th>Heave Susceptibility Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.5</td>
<td>Negligible</td>
</tr>
<tr>
<td>0.5 - 1.0</td>
<td>Very Low</td>
</tr>
<tr>
<td>1.0 - 2.0</td>
<td>Low</td>
</tr>
<tr>
<td>2.0 - 4.0</td>
<td>Medium</td>
</tr>
<tr>
<td>4.0 - 8.0</td>
<td>High</td>
</tr>
<tr>
<td>Greater than 8.0</td>
<td>Very High</td>
</tr>
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</table>
The freezing rates under this study best approximate the \( \frac{1}{2} \) inch per day freeze rate requirement during the third day of testing. However, as mentioned previously, the heave of samples tested in the tapered mold was only about 40% of the heave of similar samples tested in segmented ring molds. During the third test day, heave rates observed in this study were as shown by Table 2, with CRREL heave rates and classifications based on 40% of the observed heave rates.

<table>
<thead>
<tr>
<th>Sample Grading</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
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<tr>
<td>% Passing #200 Sieve</td>
<td>3.0</td>
<td>6.5</td>
<td>10.0</td>
<td>12.5</td>
<td>15.0</td>
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<tr>
<td>Observed Heave Rate (mm/day)</td>
<td>.18</td>
<td>.43</td>
<td>1.09</td>
<td>1.90</td>
<td>3.81</td>
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<tr>
<td>Estimated CRREL Heave Rate</td>
<td>.07</td>
<td>.17</td>
<td>.44</td>
<td>.76</td>
<td>1.52</td>
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<tr>
<td>CRREL Heave Classification</td>
<td>Neg.</td>
<td>Neg.</td>
<td>Neg.</td>
<td>Very Low</td>
<td>Low</td>
</tr>
<tr>
<td>Moisture After Freezing, %</td>
<td>5.8</td>
<td>3.4</td>
<td>12.0</td>
<td>13.3</td>
<td>14.7</td>
</tr>
<tr>
<td>Unfrozen Moisture Content, %</td>
<td>5.4</td>
<td>6.2</td>
<td>7.2</td>
<td>6.9</td>
<td>7.6</td>
</tr>
<tr>
<td>Moisture Content Increase, %</td>
<td>0.4</td>
<td>3.2</td>
<td>4.4</td>
<td>6.4</td>
<td>7.7</td>
</tr>
</tbody>
</table>
At the end of the 4 day freezing period, the heave samples were separated at the frozen-thawed interface and both frozen and unfrozen portions were oven dried to determine the final moisture contents. It was noted that all samples except those of Grading A developed significant ice lenses at various depths during freezing. The thickest lenses, approaching 1/4 inch, were found in the Grading A sample tests (15% #200). Changes in final moisture contents between the frozen and unfrozen sample portions are shown by Figure 4. From a typical zero air voids plot for the aggregate used in this test, with a specific gravity of 2.70, it is apparent that full saturation will be reached at about 7% moisture when compacted to 100% of the AASHO T-180 maximum density, and at 9% moisture when at 95% of maximum density. All tested gradations except Grading A, with 3% passing the #200 sieve, increased in moisture upon freezing to the point where some drainage of excess moisture must occur after thawing, before the sample can regain its former density. Under traffic loadings, the base course layer will probably reattain a density somewhat above 95% of the T-180 maximum, making similar base course aggregates unstable upon thawing, until drainage of the excess water occurs, whenever the frozen moisture content exceeds 8% by weight of the dry aggregate. In the case of Grading E, with 15% passing the number 200 sieve, the sample after freezing contained more than one gallon of excess water per cubic foot of soil.

It is realized in this discussion that the actual field heave and moisture content increase of a soil layer will depend on several factors not considered in this study; such as distance to the water table, freezing rate, actual density, and physical properties of the soil particles finer than the #200 sieve. The conditions used in this testing are probably the most severe that can be imposed, and do not represent the field condition except for the extreme case of a very high ground water table.

Apparently no reliable means of predicting the frost heave rate from any combination of soil particle parameters has yet been developed(6). The laboratory heave rate test is considered the most reliable means of predicting a soil's response to frost heaving conditions(6). Previous reports, particularly those of A. Cassagrande, have indicated that the .02 mm particle size is the most significant size in determining the frost susceptibility of a given soil, although many other factors must also be considered.

This report presents heave rate correlations based on the #200 sieve size since this size is controlled by Alaska Department of Highways materials specifications, while the .02 mm size is not. In all samples the ratio of the .02 mm to the #200 sizes was approximately 0.3:1. Much higher .02 mm to #200 size ratios could occur in field samples, and would presumably result in much higher heave rates while still indicating specification conformance. Further heave rate testing is recommended, to evaluate the effects of varying the .02 mm size, while holding the #200 size constant.

The determination of "strengths" representative of these various aggregate gradations after thawing could not be adequately evaluated, because of the difficulty in controlling the drainage and re-densification of the samples.
during thawing. Strength gains require that the excess water be permitted to drain away from the soil prior to or during loading. Drainage may not occur in the field in cases where the roadway pavement seals the top of the base course, downward drainage is prevented by underlying frozen layers, and lateral drainage is restricted by still frozen soils beneath snow covered side slopes. With no drainage, the gradations tested with inure than 6.5% passing the #200 sieve acted as a heavy fluid due to the excessive moisture content.

Review of the data indicates that similar conclusions regarding the frost susceptibility of the subject base course gradations could have been obtained more simply. The periodic heave and frost penetration observations could be eliminated, and the moisture content increase from the thawed to frozen zones used as the criteria for determining frost susceptibility, after controlling the test conditions of upper and lower chamber temperatures and using uniform saturation and base water level procedures. A three day freezing period would be adequate to freeze the upper half of the sample.

Summary and Conclusions

The test equipment utilized in this study consisted of a freezer modified to provide a +150°F temperature at the top of the heave test samples, and a sample base temperature of +40°F. Samples were compacted into 5.5 inch high segmented ring molds, saturated prior to testing, and provided with a water supply at their bases during freezing. Heave magnitudes and frost depths were observed periodically over a four day freezing period.

The samples tested in this study were made up to various crushed aggregate base course gradations and were from the Fairbanks Sand and Gravel commercial aggregate source. Results showed excellent repeatability between duplicate test runs, and consistent increases in heave rate with increasing percentages of particles finer than the #200 sieve. For the test conditions, samples with more than 6.5% passing the #200 sieve accumulated excess moisture during freezing, and required drainage of this excess moisture before they could be re-compacted to the original densities. The soil samples with 3% passing the #200 sieve were the only samples which did not heave significantly after the first 24 hours of freezing, or gain significant amounts of moisture upon freezing. Samples with 15% passing the #200 gained in excess of one gallon of water per cubic foot of soil due to ice segregation during freezing.

Recommendations:

Based on the results of this study, consideration should be given to reducing the maximum allowable fines contents in base and subbase layers, or to use cement treatment for slightly heave susceptible materials, which has been shown to prevent frost heaving by it's bonding action(4). Because only one material was used and only base course gradations were tested, further heave testing should be done to cover the heave susceptibility of our specified Sub-base and Select Materials, and to evaluate the effects of different materials sources having similar gradations.
Bibliography


### Appendix A

**Sample Heave Observations**

<table>
<thead>
<tr>
<th>Run A</th>
<th>3% - 200</th>
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<tr>
<td></td>
<td>Heave</td>
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<tr>
<td>No.</td>
<td>in.</td>
</tr>
<tr>
<td>1</td>
<td>0.090</td>
</tr>
<tr>
<td>2</td>
<td>0.003</td>
</tr>
<tr>
<td>3</td>
<td>H$_2$O</td>
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<tr>
<td>4</td>
<td>0.058</td>
</tr>
<tr>
<td>5</td>
<td>0.060</td>
</tr>
<tr>
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<td>0.060</td>
</tr>
<tr>
<td>7</td>
<td>0.061</td>
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<td>8</td>
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<tr>
<td>9</td>
<td>H$_8$O</td>
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<tr>
<td>10</td>
<td>0.079</td>
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</table>

\[ E \text{ Elapse Time} \times \text{Heave Rate} = \frac{28.53}{E} \text{ Elapse Time} - 24 = \text{Heave Rate} 1.19 \text{ mm/day}. \]  
This avg. heave rate from 20% total heave to 80% total heave very closely approximates a \( Y = mX + b \) best fit curve.
Run B  6.5% -200

<table>
<thead>
<tr>
<th>No.</th>
<th>Tilt</th>
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<th>Time</th>
<th>Elapse Time</th>
<th>Between Readings Heave Rate mm/day</th>
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<tr>
<td>1</td>
<td>0.000</td>
<td>0.000</td>
<td>6</td>
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<td>0.003</td>
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<td>10</td>
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<tr>
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<td>H20</td>
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<td>3.8</td>
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<td>8</td>
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<td>0.113</td>
<td>57.8</td>
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<td>14</td>
<td>0.132</td>
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<td>76</td>
<td>18.2</td>
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<td>15</td>
<td>0.142</td>
<td>0.142</td>
<td>96</td>
<td>20</td>
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Heave Rate H20 to H80 = 1.18 mm/day
Run C 10%, -200

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<th>No.</th>
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<th>hr. Time (clock)</th>
<th>Elapse Time</th>
<th>Between Readings Heave Rates</th>
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<td>6</td>
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<td></td>
</tr>
<tr>
<td>3</td>
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<td>10</td>
<td>3</td>
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<td>0.023</td>
<td>14</td>
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<td>H₂O</td>
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Heave Rate H₂O to H₈₀ - 1.92 mm/day
Run D) 12.5% -200

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<th>(clock) Time</th>
<th>Elapse Time</th>
<th>Between Readings Heave Rates</th>
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Heave Rate H₂O to H₈₀ = 2.83 mm/day
Run E 15% -200

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Heave Rate H2O to H80 = 4.01 mm/day
**LAB REPORT**

**STATE OF ALASKA**

**DEPARTMENT OF HIGHWAYS**

**PROJECT NAME:** Construction Overhead

**LOCATION:** Mile Richardson Highway

**SOURCE:** Stockpiles

**SAMPLED FROM:** Fairbanks Sand & Gravel

**SUBMITTED BY:** Bowen-Yocum

**FIELD NO.:** 728-38

**DATE:** March 3, 1972

---

**SPECIMEN DESCRIPTION:**

**Aggregate Source:**

**Project No:** N00400

**Construction Overhead**

**Sampled From:** Fairbanks Sand & Gravel

**Submitted By:** Bowen-Yocum

**Field No.:** 728-38

**Date:** March 3, 1972

**Date Sampled:** 2/08/72

**Date Received:** 2/09/72

---

**DETERIORIOUS MATERIALS:**

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<tr>
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<th>Spec.</th>
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**OPTIMUM MOISTURE:**

**MAX. DRY DENSITY:**

**MAX. DENSITY NUMBER:**

**COMPACTED DENSITY:**

**FIELD DENSITY:**

**FIELD MOISTURE:**

**% COMPACTION:**

**% + 1/2":**

**% + NO. 4:**

**AASHO 11800:**

**ALASKA T-12:**

---

**DETERIORIOUS MATERIALS:**

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>%</th>
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<tr>
<td>CLAY LUMPS</td>
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<td>STICKS &amp; ROOTS</td>
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<td>FRIABLE PARTICLES</td>
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<td>MORTAR COMPRESSION STRENGTH:</td>
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**DENSITY - POUNDS / FT.?**

**MOISTURE - PERCENT:**

**FOR ROAD MATERIALS LABORATORY USE ONLY**

**WELL PROCESSED TO CONFORM TO GRADING REQUIREMENTS. THIS MATERIAL IS SATISFACTORY FOR:**

Subbase, Base, Bituminous Surfacing, Fine and Coarse Concrete Aggregate

---

**DESCRIPTION OF MATERIALS:**

**REMARKS:**

*Light weight particles include sticks and roots. Not possible to differentiate.*

**CONFORMS TO SPECIFICATIONS:**

**YES** | **NO** | **N.A.**

**SIGNATURE:**

**TITLE:** D. C. Esch, Engr. of Tests

---

**DATE:** 2/09/72