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Experimental Study on Frost heave of Silty Clay in Seasonally Frost Soil Regions

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Abstract

A new instrument for freezing-thawing test was developed by Cold and Arid Regions Environmental and engineering research institute (CAREERI), Chinese academy of sciences. By using this device, silty clay of different water content and dry density were frozen under different conditions of temperature gradients in seasonally frost soil regions. By doing so, the regularity of frost heave amount, water content and dry density in seasonally frost soil regions were illuminated. The test results show that the final frost heave amount enhances with the increase of the water content and dry density. The results may provide some technical and theoretical references for the application of artificial ground freezing in the seasonally frost soil regions.

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Keywords: seasonally frost soil regions; silty clay; frost heave amount; frost heave ratio

1. Introduction

During soil freezing process, the water content of unfrozen regions migrated continuously to the freezing front, agglomerated and crystallized ice lens, the volume of soil will increase by 9% when the water in soil becomes into ice[1], and the soil mass formed unequal frost heave. As we know, the engineering damage is caused by soil mass unequal frost heave in seasonally frost soil regions [2-4]. Consequently, we should make frost heave sensitivity analysis and evaluation for soil mass before engineering construction, to find some valid safety measure to make engineering safe. CAREERI is a authority institution on frost soil in china, there many peole studied in permafrost for many years, got a large amount of achievement from scientific research and experience formula, and a lot of problems are solved on permafrost. However, research on seasonal frozen soil is a little relatively. In China, especially, seasonally frozen ground regions is account 53% for the total area of land, and the depth of seasonal free-

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zining layer is different from several centimeters to several meters in North Area [5-8], the Central Committee adopted a decision on reform of the water conservancy structure in 2011, large number of water conservancy project will be born in this excellent situation. To ensure the safety of water conservancy project, it is necessary for us to further research forst heave sensitivity on forst soil in seasonally frost soil regions. which will not only satisfy the water conservancy engineering construction need and also provide intellectual support for economic development in these regions [9].

2. Physical and mechanical properties of silty clay

According to the test requiremen, the experiments were carried out, soil samples came from Heilongjiang Province Hydraulic Research Institute Wanjia forst soil testing ground, site in Northeast China. To ensure samples uniform, sampling depth is between 1.0 ~ 1.5m within the maximum frost depth, the physical and mechanical properties of silty clay are showed in Table 1.

Table 1. The basic physical and mechanical properties of silty clay

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Composition of grains (％)</th>
<th>Specific gravity g/cm³</th>
<th>Liquid Limit ／%</th>
<th>Plastic Limit ／%</th>
<th>Plasticity index</th>
<th>Dry density g/cm³</th>
<th>Initialb water content/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silty caly</td>
<td>2<del>0.5 0.5</del>0.25 0.25<del>0.075 0.075</del>0.005 ＜0.005</td>
<td>82.44 17.66 2.66 33.6 21.8 11.8 1.71 17.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Experiments

3.1. Experiment requirements

In order to study the law of frost soil more really in seasonally frost soil regions, we used testing equipment which was developed by CAREERI, Chinese academy of sciences to do tests, and finished all the tests on engineering frost soil laboratory of Heilongjiang Province Hydraulic Research Institute. Experimental requirements are composed of temperature control system and data acquisition system, as shown in Fig1.

Three components of temperature control system are freeze-thaw-cycle thermostat , type XT5201 low constant temperature trough and XTCOM temperature measure and control software. Freeze-thaw-cycle thermostat can regulate and control temperature range from -40℃ to 90℃ and the maximum error is ±0.1℃, and the system can put cylindrical sample which diameter is 10cm height is 15cm. XT5201 low constant temperature trough equipped with RS232/485 communication interface, the resolution of display
is 0.1°C. XTCOM temperature measure and control software can set and plot curves automatically. Data collection system adopts data taker 515 which have 30 data acquisition channel and imported from foreign country. It can change electrical signal from transducer into data, using software delogger 4 to export data and plot curve.

3.2. Experiments design

These experiments are all of one single dimension freeze in a closed system. Changing of ground temperature is complex because it is stochastic in nature. It is difficult for us to simulate the changing accurately in laboratory. Therefore, we set cold terminal temperature to be a series of constant negatives which can form different temperature gradient between cold and warm ends, when silty clay freeze under the conditions there will appear frost heave. We refer to ground temperature data measured during 2006 ~ 2007, as shown in Fig.2. We choose -2°C, -6°C, -10°C and 12°C as control temperature, the temperature of test box and top board were control at 1.0°C. Water content is another important factors which directly affect frost heave, research indicates that not all silty clay can produce frost heave, only water content exceed starting-frost heave water content can frost heave emerge. We choose starting-frost heave water content from minimum, Gradient of water content is 2%, the maximum water content is 24%. The compactness of silty clay can influence frost heave, for non-saturated soil, density change can cause to soil pore a transformation, the dry density is 85%~95% maximum dry density when soil mass have the maximum frost heave, consequently, we choose different dry density, the test scheme was shown in Tab.2.

<table>
<thead>
<tr>
<th>Test NO.</th>
<th>Freezing temperature /°C</th>
<th>Initial water Content/%</th>
<th>Dry density/g/cm³</th>
<th>Impact Factors</th>
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<th>Initial water Content/%</th>
<th>Dry density/g/cm³</th>
<th>Impact Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-2</td>
<td>22</td>
<td>1.54</td>
<td>Temperatures</td>
<td>7</td>
<td>-6</td>
<td>22</td>
<td>1.50</td>
<td>Content</td>
</tr>
<tr>
<td>2</td>
<td>-6</td>
<td>22</td>
<td>1.54</td>
<td>Temperatures</td>
<td>8</td>
<td>-6</td>
<td>24</td>
<td>1.50</td>
<td>Dry density</td>
</tr>
<tr>
<td>3</td>
<td>-10</td>
<td>22</td>
<td>1.54</td>
<td>Temperatures</td>
<td>9</td>
<td>-6</td>
<td>22</td>
<td>1.45</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>-12</td>
<td>22</td>
<td>1.54</td>
<td>Temperatures</td>
<td>10</td>
<td>-6</td>
<td>22</td>
<td>1.54</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-6</td>
<td>18</td>
<td>1.50</td>
<td>Water</td>
<td>11</td>
<td>-6</td>
<td>22</td>
<td>1.59</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>-6</td>
<td>20</td>
<td>1.50</td>
<td>Water</td>
<td>11</td>
<td>-6</td>
<td>22</td>
<td>1.59</td>
<td></td>
</tr>
</tbody>
</table>

4. Results and discussion

4.1. Frost heave amount

The relationships between frost heave amount and time are shown in fig.3, fig.4 and fig.5, from the fig.3 we get that frost heave amount increased as freezing temperature decreased at very beginning, the lower the freezing temperature is, the function of chromatography ice is more intense and the speed of water from liquid to ice is more faster. When freezing becoming stable, the final frost heave amount of soil mass reduced as the freezing temperature decrease, the lower the freezing temperature is, the faster rate of freezing is. Conversely, the higher the freezing temperature is, the slower speed of freezing is, the slower freezing speed makes freezing frontal downward mobile slowly and the moisture in unfrozen soil will transport to freezing frontal which will be helpful for the formation of segregated ice. As the time goes on, migration and accumulation of water are increasing and have produce a huge strength on segregated ice, eventually it forms a large frost heave amount.
Fig.3. Soil frost heaving evolution regulation under different freezing temperature (left)
Fig.4. Soil frost heaving evolution regulation under different moisture content (middle)
Fig.5. Soil frost heaving evolution regulation under different dry density (right)

From fig.4, we know that in a closed system, final frost heave amount grow with increase of moisture content when freezing soil is stable. But when moisture content is 18%, the soil has not happened frost heaving and performed for the cold shrink. Only when the water content of the soil is higher than the starting frost heaving water content can it produce frost heave. From fig.5, we can see, as time goes by, the final frost heave amount grow with the increase of dry density in a closed system. On one hand, for unsaturated soil, the smaller dry density is, the looser of properties and the greater pore space of the soil has. The proportion of the expansion volume which the water freezes into ice will be occupy smaller pore space. displacement generated by soil particle is smaller. While dry density becomes bigger, the pore space is smaller in soil, water filling degree will increase. Soil particle will have a great displacement when water freezes into ice with volume expansion, and which performs as the soil frost heaving deformation increase. On the other hand, the greater soil dry density is, the denser the soil will becomes, so the effective contact area of soil particles will become greater. The pore space change to smaller and smaller, and it is benefit for forming channel for loosely bound water migration, which induces ice lens or ice thickness of the interlayer increasing, and leads to frost heave amount increasing eventually.

4.2. Temperature field and water migration

As shown in Figs.6, in different environmental temperature, soil has the similar changing patterns in different depths during process of one-way freezing, it divided into temperature falls rapidly stage, temperature drops slowly stage and temperature reaches stable stage. during freezing process, negative temperature pass to soil sample from top surface, it makes the temperature of the top of the soil sample fall rapidly. Under the action of heat conduction in the soil, the cold quantity is passing down gradually, when the soil in soil sample close to the top surface, temperature arriving stable state will take shorter time to let. Conversely, with more and more distant from the top surface, it will take longer time for temperature reaching stable stage. We can see whole temperature gradient changing process from fig.7,
temperature is increasing at first at every point in soil, and then decreasing, until becoming stable eventually. The closer of the distance from the top surface is, the greater temperature gradient changes, With the increase of depth of soil layer, the temperature gradient changing will be very gentle especially near the bottom of the sample.

This test measures water content of the soil sample after frozen. Each group of soil samples have been cut as a sample along its height every 2cm, variation of water content is shown in fig.8. The soil samples are freeze with the top surface temperature from -2℃ to -12℃, the water in three different freezing samples was redistributed by the driving power from temperature gradient between top to bottom. There obviously exists water accumulation phenomenon.

5. Conclusion

The conclusions of this research cay are summarized as follows:

(1) Soil mass with different water content and dry density is frozen under different conditions of temperature gradients, variation of temperature gradients with time are in substantial agreement. They are increasing at first, and then decreasing, finally reaching a fixed value, and the bigger temperature gradients is closer to the top surface of sample. The impact of freezing temperature is greater than water content and dry density.

(2) For a closed system, frost heave amount and frost-heave ratio of soil mass with same water content and dry density increased as freezing temperature increased. Similarly, frost heave amount and frost-heave ratio of soil mass with same freezing temperature and dry density increased as water content increased, and the soil mass was not frozen when water content below 83.3% of plastic limit; frost heave amount of soil mass with same freezing temperature and water content increased as the dry density, but frozen-heave ratio was in adverse.

(3) With increase of freezing temperature, moistur concentration amount of soil mass are larger, which can be observed more clearly. Conversely, water accumulation phenomenon are inapparent as the decrease of freezing temperature.

References


