Research on the Characteristics of Moisture, Temperature and Deformation in the Process of Frost Heaving and Thawing Settlement

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Abstract: In order to understand the rule of water, temperature and deformation in the process of frost heaving and thawing settlement, carry out the soil column model experiment, record the change of temperature, moisture and deformation during the experiment, draw the line chart and analyze the process of soil column freezing and thawing. By analyzing the curve of freezing depth and freezing rate over time in soil column, the freezing process of soil column can be divided into three stages: rapid freezing, transition freezing and stable freezing. And according to the curve of the deformation and the moisture with time during freezing, it is concluded that when the soil column is in the transitional freezing stage, it will produce a large deformation of frost heaving. By analyzing the deformation curve during the melting process, it can be divided into three stages: rapid deformation stage, slow deformation stage and stable stage.

1. Introduction

With the development of China's economy, roads need to be built in cold regions. However, due to the influence of severe weather, the highway in cold regions is easily affected by frost heaving, thawing settlement, salivary flow ice, slope collapse and other disasters. [1] A large number of engineering practice shows that the uneven subsidence of subgrade, the seasonal freezing and the non-uniform deformation of the roadbed have become important reasons for the early failure of cement concrete pavement structure. In the permafrost regions, as the temperature drops, the internal temperature of the soil decreases, and the soil begins to freeze. The water in the soil frozen, which increases the volume of the soil and causes the frost heaving. During the Spring Festival, as the temperature rises, the ice in soils begins to thaw, which leading to the carrying capacity of the road decreases, and uneven settlement. [2]-[5] In this experiment, soil column model is used to simulate the actual working state of roadbed in freezing process, using refrigerating plant and Markov bottles to simulate cooling processes and groundwater recharge. Measuring the temperature and moisture content in the soil column model and analyzing the influence of moisture and temperature on the soil freezing process. Then providing advices of protection and treatment of the road in the permafrost area.

The soil column model test system mainly includes deformation acquisition system, temperature acquisition system, temperature control system, moisture acquisition system, moisture control system and cylindrical model cylinder. The diagram is shown in Fig. 1 below.

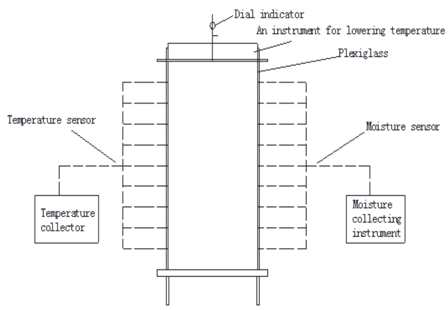

Fig. 1 Hydrothermal synthesis experimental system.

2. Moisture, temperature and deformation characteristics during freezing.

The freezing of soil is the result of the combined action of water, temperature and force. Therefore, the analysis of the moisture, temperature and deformation characteristics of the frozen heaving and thawing settlement is helpful to understanding the mechanism of frost heaving and thawing settlement

2.1 Temperature characteristics during freezing.

It can be seen from Fig. 2, because, the refrigeration unit is applied to the top of the soil, the temperature of the upper part of the model decreases rapidly. As the height decreases, the cooling rate decreases gradually. Due to the initial temperature gradient, the overall cooling rate of the first 24h is rapid. Especially within 20cm range from the top. When the experiment was conducted between 24h and 192h, the water in the soil began to freeze. After 192h, the temperature of the top of the soil column is close to that of the refrigeration unit, temperature gradient reduced, the cooling rate in the soil column is slowed down. The freezing depth is almost no longer changed and the soil temperature tends to be stable.

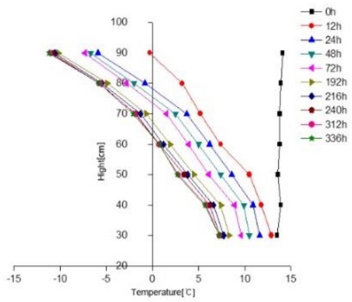

Fig. 2 The temperature in different height during the freezing process.

According to Fig. 3, the whole soil column freezing process can be divided into three stages: rapid freezing stage, transition freezing stage, and stable freezing stage. The period of 0-24h of cold bath is rapid freezing. At this stage, the temperature gradient is large and the freezing rate is faster. As the temperature gradient decreases, the freezing rate decreases sharply, but the minimum freezing rate is still above 0.1cm/h. The period of 24h - 192h is the transitional freezing stage. At this stage, the freezing rate is lower, the rate is reduced, and the freezing rate is no more than 0.1m/h, and the rate of the frozen depth increases slowly. After 192h, at the stable frozen stage, the freezing rate and the depth of foundation are not changed.

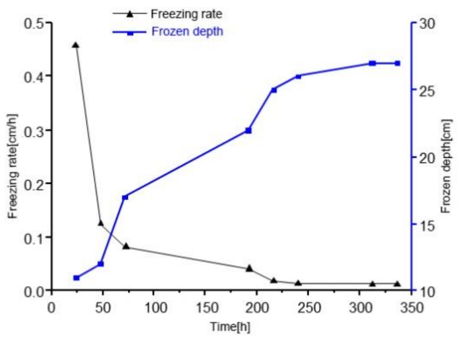

Fig. 3 The curve of freezing depth and freezing rate over time

2.2 Moisture content characteristics during freezing

We can see from Fig. 4, within 24h, the moisture content within the top 20cm of the soil column decreased rapidly. This time period is the rapid freezing stage. The moisture content in the soil is quickly frozen, and the moisture sensor cannot measure the moisture content of the ice, which leads to the rapid decrease of moisture content in this time period. From Fig.6, the frozen surface barely moved. Therefore, it appears that the three moisture content curves in Fig. 4almost coincide. After 72h, the frozen surface begins to move down, so, the water content of 72h - 192h period and 63-78cm is explained rationally. In 192h—336h, the moisture content of each measurement is basically coincident, and the moisture content of the whole soil column is no longer changed and tends to be stable.

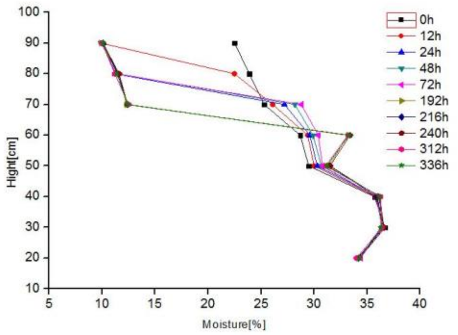

Fig. 4The moisture content varies with time during freezing

2.3 Deformation characteristics during freezing

As can be seen from Fig. 5, the deformation of soil column is -0.3mm due to simulating groundwater recharge and self-weight increase. After 48h, in the rapid freezing stage, the freezing rate and the freezing depth began to increase rapidly. Water cannot be moved to a frozen area. Only water in the original pore is frozen in situ, so frost heave deformation is small, it corresponds to the slow deformation phase of the Fig. 5. In 48h—192h, the freezing rate decreases and the freezing depth increases slowly. Follows a side moving from one side of the high potential to the lower potential energy, the Water is transferred from an unfrozen layer to a frozen surface. So, in this time period, the deformation of soil column is large. Corresponds to the rapid development stage of deformation in Fig. 5.After 192h, the freezing depth of soil column no longer increases, the temperature tends to stabilize, and the frost heaving tends to be stable.

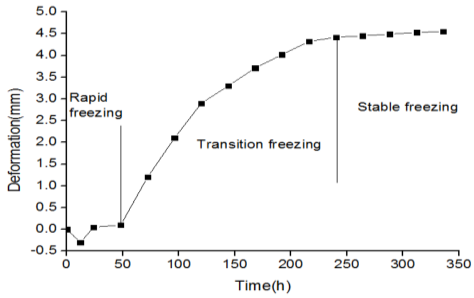

Fig. 5 Frost heave deformation curve

3. Moisture content, temperature and deformation characteristics during thawing settlement

The melting causes the volume of the soil to shrink and sink, and the carrying capacity decreases. Under the repeated action of the automobile load, the uneven subsidence of the foundation will be produced, which will seriously affect the safety and comfort of the driving. The temperature, water and deformation characteristics of soil column model were analyzed on the following paragraph. The purpose of this study is to find out the change characteristics of moisture content, temperature and deformation characteristics in melting process.

3.1 Temperature characteristics during melting

As shown in the Fig .6 below, the upper temperature of soil column model increases rapidly when the soil melts. The reason for the above phenomenon is that the upper part of the specimen is near the cold bath, and the temperature is the lowest, after the cold bath is stopped, the temperature gradient between the upper part of the specimen and room temperature is the maximum. As time goes on, the upper and lower ends of the soil column model were first heated to room temperature due to the large contact area with air, and there was a lag process in the middle of the soil column model.

During the period of 0-120h, the change of soil temperature was severe; during the period of

120h240h, the change of soil temperature was slow; during the period of 240h-316h, the soil temperature is basically stable.

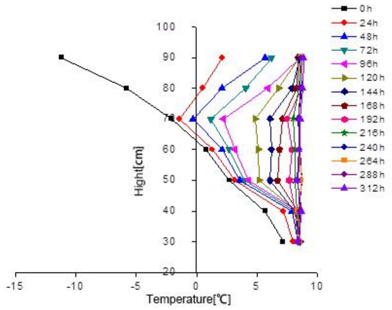

Fig. 6 The temperature in different height during freezing

3.2 Moisture content characteristics during melting

As is shown in Fig. 7, the process can be divided into three stages: rapid thawing settlement stage, transition thawing settlement stage and stable freezing stage. In the first 72h, the slope of the curve is large, and the deformation is relatively rapid. The reason of it is that, in this period, the temperature rises quickly and the water in the soil melts rapidly. On the one hand, ice in the soil melts, resulting in a decrease in volume; on the other hand, the moisture content of soil is high, which leads to insufficient carrying capacity, leading to large deformation and settlement. After 72h, the soil slowly sinks under its weight, the thawing settlement rate becomes slow. After 240h, the deformation of soil has reached a stable stage, and there is no large deformation settlement.

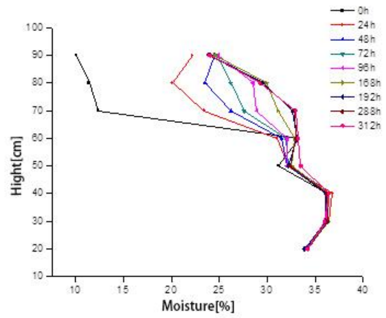

Fig. 7 The moisture content varies with time during thawing

4. Analysis of the mechanism of frost heaving and thaw settlement

The temperature in soil dropped below 0℃,and the water in the soil frozen, the volume of soil increase, which resulting in frost heaving. When the heat released by the freezing of pore water is equivalent to the cooling air from the top, the frozen surface stabilizes in a certain position. In this time, the ice crystals adsorb nearby moisture through their own adsorption, forming new ice crystals. The water is continuously migrating from the lower part of the soil to the freezing area. When the temperature reducing slowly, water in freezing areas can be replenished continuously, which will result in severe frost heaving deformation. When the temperature decreases rapidly, the water supply channel between the soil particles is frozen, so, the water can’t continuously migrate from the lower part of the soil to the freezing area. So, the deformation of frost heaving is small.

There are many reasons for the thawing settlement of the soil. On the one hand, the outside temperature increases, the permafrost began to melt, the ice in the soil thawed, which leading to the volume of soil decreases, the surface of the soil drops. One the other hand, as the water begins to infiltrate, the drainage consolidation settlement occurs. The following is also the cause of the thawing settlement. As the outside temperature increases, the frost heaving force of soil particles disappears, then the frozen soils produced compression and settlement displacement.

5. Conclusion

1. By analyzing the curve of freezing depth and freezing rate over time in soil column, the freezing process of soil column can be divided into three stages: rapid freezing, transition freezing and stable freezing. The freezing rate of the rapid freezing stage (0-24h) was very fast, the freezing rate of the transition freezing stage (24-196h) levelled off, the freezing rate of the stable frozen stage (192-336h) was almost zero.

2. The freezing rate influences the change of moisture content in soil, and the two factors influence the frost heaving deformation of soil. When the freezing rate is slower, moisture content decreases more slowly. The water keeps moving to the freezing region, which can cause the frost heave deformation of the soil. When the freezing rate is faster, the moisture content decreases rapidly. The water can't move to the freezing zone, resulting in a smaller frost heave deformation.

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