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Experimental study of remoulded soil properties based on freezing and thawing cycle

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Abstract. The experiments were carried out on the remolded soil to study the change law of the soil properties with the numbers of freezing and thawing cycles. It aims at simulating the effect of natural environmental factors on the mechanical performances artificial filling roadbed in Songbei region. After the soil sample was compacted in the optimum moisture content, and undergone limited numbers of freezing and thawing cycles, physical and mechanical properties were measured respectively. The experimental results indicated distinct change trend on physical and mechanical properties of soil after limited numbers of freeze-thaw cycle to confirm that the fillings was susceptible of temperature and moisture in this region.

Introduction

The stability and durability of roadbed depends directly on the strength the deformation characteristics of soil, and the moisture and temperature is the key factor to determine the mechanical properties of soil. One hand, the temperature is the premise which cause phase change of the water in the soil, and on the other hand, moisture acting as the carrier of temperature change will lead to the frost heaving and thaw collapse of the soil mass[1,2]. The existing research data shows that diseases of roadbed in permafrost and seasonally frozen ground areas is mainly caused by frost heaving and thaw collapse. Strength characteristics have great difference in frozen and thawing state, internal microstructure and strength of the soil will change through repeated freezing and thawing cycle. The study about properties change of the soil based on the freezing and thawing cycle mainly reflects the two respects: physical property and mechanical property. The former focus on the change in water content and density etc, and the latter emphasizes the change in shear strength of the soil.

At present, the research about the change of modulus of resilience under different water content after repeated freezing and thawing is very few. In this paper, take the compacted soil under the optimum water content state as the research object, perform geotechnical test to understand the change of soil property under different freezing and thawing cycle conditions, in order to announce the law of influence on the properties of soil caused by freezing and thawing cycles.

The test design

The basic characteristic of test specimen. Songbei region is located in the north shore of the Songhua River section of the Harbin city, four distinctive seasons, the free-thaw action in this region roadbed filling obviously, widespread cohesive soil is the research object in this test. Determine the initial physical property parameters according to the specification [3]. Using WX-2 type photoelectric liquid and plastic limit combined tester to obtain the liquid limit and plastic limit of the soil is 32.2% and 21.8% respectively. According to classification standard of soil group, the test specimen is silty clay. Employ the optimum moisture content and the maximum dry density is 14.4% and 1.85g/cm3 respectively through standard compaction test.

The testing program. In the practical construction, constructors compact the fillings in the optimum water content state so as to reach the maximum degree of density. Whereas the accomplished roadbed exposed to atmospheric environment, the soil mass will undergo periodical freezing and thawing action caused by the change of climate, atmospheric precipitation, surface water and underground water, then the strength of roadbed should be changed subsequently. This experiment simulates the field working state of artificial filling roadbed, mixes the soil in the optimum moisture content state at the moment of preparing the test specimen, then infiltrate for 24 hours. The static manner was applied to make it model one time. The models were put into plastic film so as to the predetermined moisture content by drying or humidifying respectively, then enclosed and placed in the constant humidity cabinet to uniform the moisture content.

When select the cold junction temperature, two factors were considered mainly in the test procedures according to the maximum frozen depth range in Songbei region. One is the freezing temperature of water through the soil; another is the performance of the selected test instrument. Above factors were taken into account, set -15℃±1℃ as the final selected cold junction temperature. The test specimen was prepared according to the optimal water content, and then compacted to determine the initial parameters including the height, weight and water content. Next then both the test specimen and compaction mould were put into the temperature adjustable freezer then taken out after 24 hours. They were placed in an environment where the temperature is remained to 20℃±2℃ all the time so as to melt the soil naturally. After the above two procedures were completed regarded to one freezing and thawing cycle.

Bearing plate testing was applied for understanding the resilient modulus of the soil with LOD-2 roadbed and pavement material strength test system. The maximum specific pressure used in prepressing was 100KPa twice for 1min each time in the test. The predetermined maximum pressure was divided into 6 portions equally as the load per level during 1min, and then unloaded during 1min. The final result was determined by the average of the datum from 3 parallel tests.

In consideration of the completion of the whole test processes is entirely indoor and the structure damage, there would be many cracks on the test specimen surface so as not to employ triaxial shear testing to study the shear strength of the soil, so the direct shear testing was applied. In order to avoid disturbing the test samples, the quick shear testing was more suitable for understanding the change law of shear strength before and after the soil sample freezing and thawing. In other words, the internal friction angle and cohesion were considered mainly.

The test results and resultant analysis

The change law of physical properties. When one cycle was accomplished, aforementioned physical parameters were determined again for further experimental study the change law of the soil properties including the physical and mechanical properties. The moisture content and the density of the soil were taken into account about the former, while the resilient modulus and shear strength were mainly focused on about the latter. Through calculation and comparison, the change law of the moisture content and density could be obtained after the limited numbers of freeze-thaw cycle shown in Fig1 and Fig2 respectively.

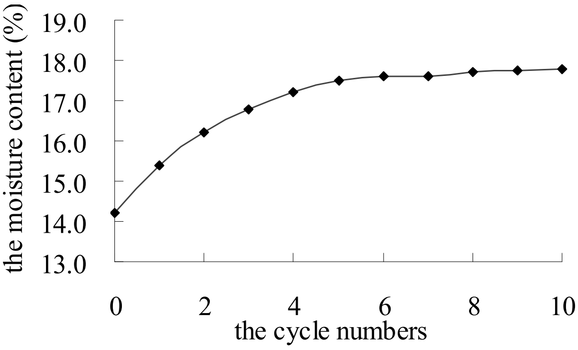

Fig.1. The curve of moisture content corresponding to the cycle numbers

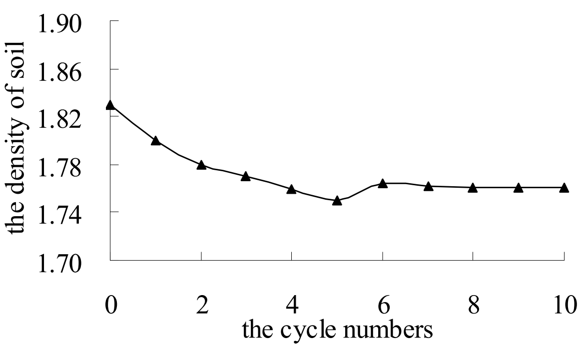

Fig.2. The curve of density corresponding to the cycle numbers

The test datum indicated that the moisture content of the soil increased with the cycle number and the growth rate faster within the initial several cycles, and then leveled off step by step. Investigate its reason, the growth of the moisture content during the cycle proceeding stem from the migration of environmental moisture to freezing frontal surface. Due to the test were carried out in semi-closed space, where water recharging was from moisture in the air, consequently the amount of moisture growth is not so enormous. Additionally, the density of the soil sample decreased with the cycle numbers, and the biggest drop occurred after the first cycle, then the reduction became smaller and smaller, finally leveled off after 6 cycles finished. The cause of this phenomenon is the freeze of the moisture in the soil resulting in the soil volume expansion.

The change law of mechanical properties. The test specimen compacted in the optimum moisture content was varied the characters after drying and humidifying, which induced the change of soil structure and caused the change of mechanical properties of the soil.

The resilient modulus. The modulus is the greatest concerned parameter in the geotechnical engineering, and must be used in analysis of the deformation and stability, so there were many investigators working on this issue. Lee had found out that the change of resilient modulus would exceed 50% for unfrozen soil which resilient modulus more than 100KPa after freezing and thawing [4]. Simonsen had pointed out that the modulus would vary with the soil classification and the more percentage of fine-grained soil the sharper variation [5]. In a word, the reduction of the resilient modulus was realized conformably.

The p-l curves of soil with cycle numbers can be obtained after bearing plate test in the optimum water content, shown in the Fig3. The gradient of the p-l curves were used for reflecting the necessary unit pressure corresponding to unit radius deformation, i.e. the resilient modulus. The gradient is greater, the bigger the modulus. The curve of resilient modulus of soil corresponding to freeze-thaw cycle could be obtained by calculating according to the datum shown in Fig3, and shown in Fig4.

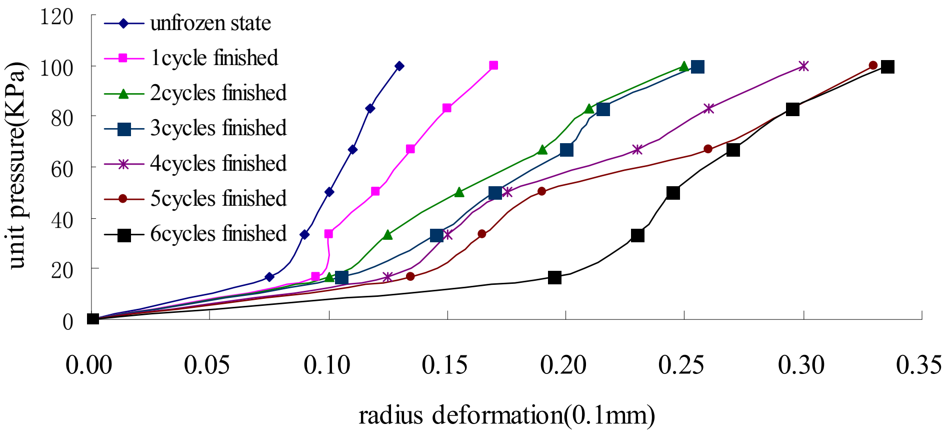

Fig.3. The p-l curves of soil with cycle numbers

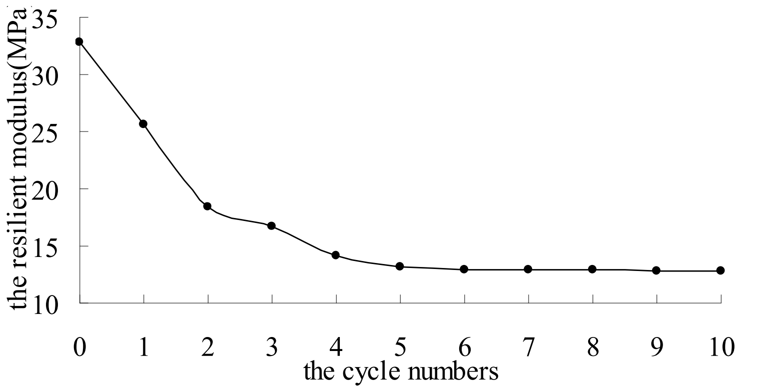

Fig.4. The curve of resilient modulus of soil corresponding to freeze-thaw cycle

We could find out that the resilient modulus of soil reduced greatly in the initial 4cycles, leveled off gradually during the 8cycles. The intrinsic structure of soil was varied by freezing and thawing action. When the test specimen was frozen in the cold air, freezing in situ could be available because of the small specimen size and great rate of temperature reduction so as to moisture migration too late. The void in soil increased due to the 9% addition in the volume when water changed to ice. While the increased void reverted to the original state vanishingly, resulting in the reduction of binding strength between soil particles leading to the decrease of the resilient modulus. After several cycles, the void in soil leveled off so that the soil reached to rebalance, as a result the reduction of the resilient modulus flatted out.

The shear strength. The shear strength is one of the most concerned mechanical properties in the geotechnical engineering. Considering the change of strength parameter merely is easier than understanding the change law of mechanical properties roundly. While there were many differences among the results. Most researches indicated the reduction of shear strength with the freeze-thaw cycle [6, 7], while another displayed invariant even increased [8, 9, 10]. The change law of shear strength was attributed to the variation in soil structure caused by freeze-thaw action on one side, and related to the soil state and test conditions. Direct shear testing was applied for studying the change law of shear strength and the relevant strength parameters. The finial result was shown in Fig5, Fig6 and Fig7 respectively.

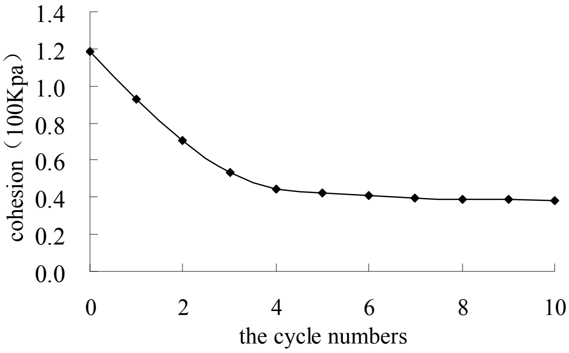

Fig.5. The curve of cohesion with freezing and thawing cycle

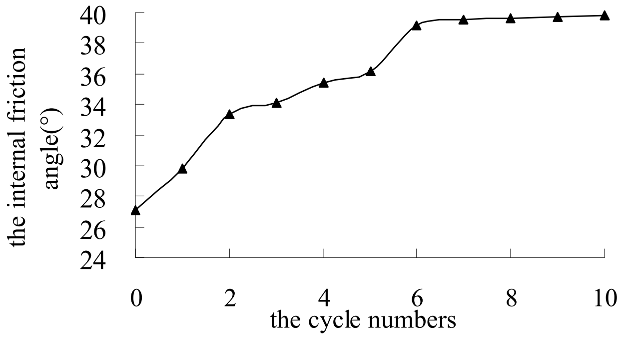

Fig.6. The curve of internal friction angle with freezing and thawing cycle

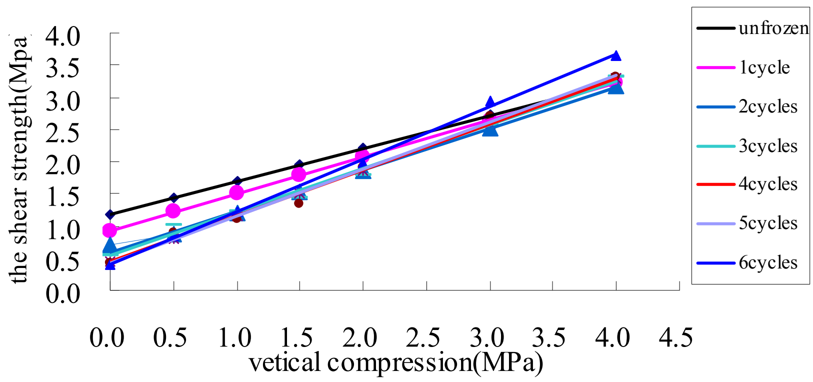

Fig.7. The curve of shear strength with freezing and thawing cycle

Above datum indicated the reduction of cohesion from 118.49KPa to 38.02Kpa after 6cycles, while the slight increase of internal friction angle from original 27.1° to the final 39.8° for the roadbed fillings in Songbei region. Comprehensively, the reduction of shear strength could be obtained with the numbers of freezing and thawing cycle.

The freeze-thaw action would result in the increase of moisture content and the reduction of density leading to smaller space between particles and water film deeper, so that the electric molecular attraction between particles reduced so as to the lose of the original cohesion. Furthermore, the soil structure was damaged by freezing and thawing cycle so that the cured cohesion disappeared. The great increase of the cohesion though the slight reduction of internal friction angle was the critical affect factor in changing of shear strength.

Conclusions

Temperature and moisture are the critical factors on inducing the change of strength and stability. The soil microstructure will change under the freezing and thawing action leading to the change of mechanical properties of soil. The experiments were carried out on the remolded soil compacted in the optimal moisture content from Songbei region to study the change law of the soil properties with the numbers of freezing and thawing cycles, the conclusions can be obtained as following:

The datum indicated that the first change of the soil physical properties caused by freezing and thawing cycle is the critical factor to affect the soil mechanical properties for the compacted soil in the optimum moisture content. After the limited numbers of cycles, the moisture content of the soil increased and the density decreased with the cycle times. In terms of the change of the mechanical properties, as a result of the degree of density reducing caused by freezing and thawing action, the resilient modulus of the soil decreased continuously, the cohesion decreased severely, while the internal friction angle increased slightly, generally speaking, the shear strength of the soil decreased. Sharp change trend occurs within the initial several cycles usually. Nevertheless, both the physical and mechanical properties of the soil will be stable within the limited numbers of freezing and thawing cycles. It confirmed the soil in this region vulnerable to the influence of the temperature and moisture change.

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