Sensitivity Analysis of Flexural Strength Characteristics of Artificial Frozen Soil

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Abstract. In subway engineering, artificial frozen soil wall is often used as temporary supporting curtain for underground connecting passage, which bears the effect of upper pressure and lateral earth pressure. In the actual subway tunnel project, artificial frozen soil is generally under both compression and bending. Therefore, to evaluate the soil strength, both compressive strength index and tensile and bending strength index of frozen soil are required. The tensile strength index of frozen soil has a great influence on the design and construction of frozen soil engineering, so it is of great significance to study the tensile strength by testing the flexural strength of frozen soil.

1. Introduction

At present, scholars have carried out relevant researches on the tensile strength of frozen soil by using different test methods[1]. The test methods of tensile strength of artificial frozen soil include uniaxial tension, conventional triaxial tension, axial splitting and three-point loading bending, but these test methods all have certain defects[2]. The ideal direct tensile test requires uniform tensile stress to be applied in the axial direction of the test piece, and the clamps fixing the two ends of the test piece are difficult to manufacture, which may cause certain damage to the test piece, and cannot eliminate the influence of microcracks and other defects[3]. Conventional triaxial tests have high requirements on test equipment, and when the soil sample undergoes axial splitting, the fracture surface is difficult to control[4, 5]. When loading at three points, the fracture failure surface is not necessarily at the maximum bending moment, which will lead to distortion of calculation results.

Based on the frozen soil uniaxial test equipment, this test has designed and developed a double-point supporting and double-point loading test equipment[6]. Compared with the traditional test method, the equipment greatly reduces the test deviation[7]. The flexural strength test of frozen soil is carried out by using independently developed test equipment, and the flexural strength of different soils and different water contents at different freezing temperatures is studied, so as to study the influence relationship between freezing temperature and water content on flexural strength, and provide certain reference for selecting parameters in engineering design and construction.
2. Bending test

The sample size is 200 mm× 50 mm× 50 mm. As shown in figure 1, the undisturbed soil samples are opened and cut to make samples.

![Figure 1. Cutting process of undisturbed soil](image1)

Seal the prepared sample with plastic film. Set at preset temperature (-10 °C, -15°C, -20°C). Freezing for more than 24 hours in a thermostatic oven at -20°C ensures that the temperatures inside and outside the test piece are consistent.

![Figure 2. Sample preservation](image2)

The testing instrument for this test is WDW-D50 microcomputer controlled frozen soil testing machine. Three control temperatures of-10 c, -15 c and-20 c are used. The flexural strength of undisturbed soil samples and remoulded soil samples at different freezing temperatures are tested, and the flexural strength indexes of samples with different soil properties at different freezing temperatures are obtained through the tests.

During the test, the sample is placed on the bearing head with a spacing of 15cm. The loading device is a two-point steel pressure head with a spacing of 5cm, so that the two trisection points of the beam are simultaneously subjected to concentrated loads with the same size. In view of the fact that both the bearing head and the pressure head are steel and their hardness is much higher than that of the soil sample, the bearing head and the pressure head contacting with the soil sample are processed into arcs and can rotate, thus ensuring good contact with the soil sample and preventing the bearing or the pressure head from falling into the soil sample, causing distortion of test results and even the test cannot be carried out.

After the test starts, switch on the power supply and start the testing machine to make the pressure head drop gradually close to the soil sample. When the pressure head drops close to the sample, fine-tune the pressure head and the support to make the two contact evenly. The pressure head is controlled by a computer to be slowly loaded at a speed of 60N/s to avoid impact. The testing machine is controlled by software, which can automatically record the stress and strain values until the sample is damaged. If the position of the support is misaligned during the sample process, the test shall be
stopped, and the failure load shall be the load value recorded by the software when the misalignment occurs. After the test, the pressure head is operated to lift it, the testing machine is opened to take out the sample, and the damage of the sample is observed and recorded.

Figure 3. Sample loading and data acquisition process

During the test, the test average value of the three samples is taken as the test result. If the difference between the maximum value or the minimum value and the intermediate value in the three test results exceeds 15% of the intermediate value, this set of tests shall be repeated.

3. Test results

According to the deflection-pressure curves of different samples, the samples show typical brittle failure, i.e. the failure strain is very small. After the experiment started, the strain was very small, the stress rose rapidly, and the curve was close to a straight line. When the stress reached the ultimate strength, it broke immediately and could no longer bear any stress. There is no trace of viscoplastic flow or gradual stress reduction process. For this type of failure, the properties of the material can be considered to be mainly controlled by elasticity.

Comparing the flexural strength with the uniaxial compressive strength, it is found that the flexural strength of frozen soil is obviously less than its compressive strength, and its deformation capacity is far less than its compressive deformation capacity. The reason for this is that the lower part of frozen soil sample is pulled. Tretovitch believes that the frozen soil is a multi-component and multi-fabric anisotropic body, in which the anisotropy of ice crystals has a great influence on the strength of frozen soil. In addition, due to the stress concentration in the air holes, cracks will expand rapidly and cause brittle fracture when frozen soil is under tension. However, when compressed, cracks or cavities tend to be exhausted and are not easy to cause cracking. Therefore, the tensile strength of frozen soil is generally lower than its compressive strength.

This characteristic of frozen soil flexural strength is related to the change of unfrozen water content in the soil, which affects the negative temperature of the soil. When the temperature begins to drop, the unfrozen water content in the soil decreases sharply, which increases the frozen soil strength significantly. However, when the temperature drops to a certain extent, most of the water in the soil has already frozen, and the temperature has less and less influence on the strength. When the temperature is lower than -15°C, the influence of unfrozen water will gradually stabilize with the further decrease of temperature, and then the ice matrix will melt under the double action of stress and heat generated by deformation energy under the action of higher increased stress. This in turn increases the unfrozen water content in frozen soil to some extent. This is why the tensile strength of frozen soil decreases at lower temperatures and at higher deformation rates.

Remolded soil samples with different water content and dry density can be prepared by controlling the quality of water and dry soil. The volume of the mold used to make the sample is constant, and the quality of water and dry soil required for samples with different water contents are calculated in advance, so that different samples with constant dry density and saturation from low to high can be
made. When the soil sample reaches saturation, the remolded soil sample with higher water content can be made by reducing the compaction degree of the soil sample, thus obtaining the variation rule of the flexural strength of artificial frozen soil with water content.

The following points can be seen from the experimental results:

1) The flexural strength increases with the increase of water content, but when the water content increases to a certain extent, the flexural strength decreases with the increase of water content, which is more prominent in silty sand samples. This is because when there is too much water, the performance index of the soil is close to water, and the load and deformation are nonlinear. However, when the water content is low, the frozen soil may undergo linear brittle fracture, which should be paid attention to in actual construction.

2) Under bending, frozen soil samples with different soil properties may be fractured, and one side of the beam is in tension at this time. Both tensile and bending failure modes of frozen soil are fracture failure. Therefore, a larger safety factor should be selected in design to ensure sufficient bearing capacity and avoid accidents.

4. Conclusion

It is completely feasible to use double-point support and double-point loading test equipment for the flexural strength test of artificial frozen soil in this test, which is a new test method that can conveniently and accurately measure the flexural strength of frozen soil. For frozen soil samples with different soil properties, brittle fracture can occur under bending conditions, with little strain to break, which is worthy of attention in engineering construction. The reason for the failure is that one side of the beam reaches the limit of tension and breaks. Therefore, in the construction design, it is necessary to ensure sufficient bearing capacity, and the bending structure should take a larger safety factor to avoid accidents. The flexural strength of frozen soil is obviously less than its compressive strength. This is because ice crystals in frozen soil are anisotropic, and the essence of compressive strength and tensile strength are shear failure and tensile failure respectively, which are quite different. Under the action of tensile force, pore cracks in frozen soil will expand rapidly and become larger, resulting in brittle fracture. However, under the action of pressure, cracks in soil tend to close and are not easy to crack. Within a certain range, the flexural strength of frozen soil increases with the decrease of freezing temperature, but the rate of increase is different under different negative temperatures, and the strength increases faster at higher temperatures (-15℃). With the increase of water content, the flexural strength of frozen soil increases first and then decreases, which basically conforms to the quadratic curve rule. When the water content is low, the flexural strength increases with the increase of water content. When the water content is high, the flexural strength decreases with the increase of water content, which is related to the relative content of soil particles and ice crystals in frozen soil.

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