Experimental Research on Compressive Performance of Modified Rammed Soil Based on Highland Barley Straw Fibers and Rubbles

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Abstract. In order to find a green, low-cost and high-performance modified raw soil method, samples were made from highland barley straw and gravel, which are unique in Qinghai-Tibet Plateau. The failure phenomenon, compressive strength, deformation capacity and load-displacement curve of different samples were studied, and the action mechanism and influence law of compressive strength of modified soil with different admixtures were analyzed and discussed. The test results show that when 0.25% highland barley straw and 20% gravel are mixed, the specimen has a smooth surface without dry shrinkage cracks, and its compressive strength and deformability are increased by 2.1 times and 30% respectively compared with that of plain soil. This content can be used as the best mixture ratio of this modified raw soil method.

Keywords: Highland barley straw; rubble; modified rammed earth; compressive strength; optimum mix proportion.

1. Introduction

The researchers used organic and inorganic materials as admixtures to alter the rammed earth material. The modified rammed earth material not only increases the properties of the rammed earth but also conforms to the green building concept and ecologically sustainable development concept of Chinese villages and towns. Mixing rubble and cement in rammed earth can increase the compressive strength by 1.16~3.55 times and improve its deformability[1], while river sand with a certain amount of rubble and good gradation can also greatly improve the compressive ability of rammed earth[2]. Wheat straw has good anti-corrosion properties and is a natural reinforced material that can be seen everywhere in the countryside. Adding it to rammed earth the shear resistance, deformation ability, and ultimate bearing capacity of rammed earth could be improved[3-6]. Sisal fiber and synthetic fiber can increase the strength and stiffness of the soil, and it is also a good reinforced material[7-9].

People in the Qinghai-Tibet Plateau region of China are affected by the limitations of natural economic conditions and the influence of traditional ideas. There are still many rammed earth buildings in the local rural areas, and this form of construction will not disappear for a while. In this paper, highland barley straw peculiar to Qinghai-Tibet Plateau and rubble are used as an admixture to carry out green, low-cost, and low-energy physical modification on soil materials. Then studies the
modification effect of the highland barley straw and rubble on rammed soil to provide a theoretical basis for the inheritance and development of traditional rammed earth buildings.

2. Materials and Experiment Process

2.1. Materials
The experiment soil samples were taken from the northern suburbs of Xining City, Qinghai Province, China. The loess silty clay with an initial moisture content of 15.2%, optimal moisture content of the 15.8%, and a maximum dry density of 1.72 g/cm³ was used as soil sample. To remove impurities from the soil sample, it is baked in the baking box to dry and sieved through a standard sieve with a diameter of 5 mm.

Highland barley is the largest food crop in the Tibetan Plateau which belongs to the family of Gramineae or Poaceae known as grasses. Highland barley straw is a kind of agricultural waste after the harvest of highland barley crop. The crude fiber content in the highland barley straw is up to 47%. The original length of the straw is about 800 mm~1200 mm, the diameter is 2.5 mm~4 mm, and the hollow stalk has 4~8 stem nodes. Peeled straw of highland barley gives a smooth stalk rich in fiber and cut into lengths of 30 mm~50 mm and rolled several times makes it a suitable shape for usage. The addition of highland barley straw to rammed earth material can play the role of consolidating soil.

The rubbles used in this research are general construction concrete rubbles with a particle size of 5 mm~10 mm, 10 mm~15 mm, and 15 mm~20 mm [10]. The rough surface of the rubble has a good compressive property. As an aggregate, it can make the soil more closely combined and beneficial to the cooperative stress with the soil to make the rammed earth material obtain better compressive properties, so the rubble is used as one of the modified materials.

2.2. Preparation of Test Specimen
Referring to the compaction test in "Standard for Geotechnical Test Methods" [11] and the existing research results [12], a sample preparation instrument is made by using jacks, C45 concrete and 100 mm cubic concrete molds, and cubic specimens with a size of 100 mm are made. This size of the test specimen can not only reflect the actual state of stress of the rammed soil material in actual work, but also reduce the consumption of test materials. The test soil sample was added to the optimal moisture content and covered with fresh-keeping film wrap to seal wetting for 24 hours. According to the maximum dry density of the soil sample, the optimal water content of the soil sample and the volume of the test specimen, the total mass of the test specimen was inversely calculated, and the soil material was packed into a mold in three layers to be compacted layer by layer. Each layer was compacted by a jack, while before compacting each following layer 3 minutes for unloading pressure and adding soil material are needed. The made test specimen was naturally cured in 28 days in the room. After curing, the strength and moisture content of the specimens tended to be gentle, the changes were small, the test results had low dispersion and high reliability, and showed better mechanical properties [13]. Considering the large discreteness of the test data of rammed earth materials, a total of 17 groups of cube specimens were made (Table 1). The rubbles with the particle sizes of 5 mm~10 mm, 10 mm~15 mm, and 15 mm~20 mm each account for 1/3 of the mass.

| Group | Description of cube test specimen | % of additives in the rammed soil |
|-------|-----------------------------------|----------------------------------|
| S     | experimental control group (100% plain soil) | - |
| J-1   | with single-doped highland barley straw | 0.25% highland barley straw |
| J-2   | with single-doped highland barley straw | 0.5% highland barley straw |
| J-3   | with single-doped highland barley straw | 0.75% highland barley straw |
| J-4   | with single-doped highland barley straw | 1% highland barley straw |
| SZ-1  | With single-doped rubbles | 10% rubbles |
| SZ-2  | With single-doped rubbles | 15% rubbles |
| SZ-3  | With single-doped rubbles | 20% rubbles |
| JS-1  | With highland barley straw and rubbles admixture | 0.25% highland barley + 10% rubbles |
| JS-2  | With highland barley straw and rubbles admixture | 0.25% highland barley + 15% rubbles |
According to the "Standard for Test Methods of Mechanical Properties of General Concrete"s\[14\], the electro-hydraulic servo pressure tester controlled by YAW4306 microcomputer was used for loading and unconfined compression strength test. The load-displacement curve of the test specimen during the test was recorded, and then the compressive strength of the test specimen according to the material compressive strength formula (1) was calculated as well as the average value of the compressive strength of each group of test specimen which represented the compressive strength of the group.

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f = \frac{F}{A}
\]

Where: \( f \) is the axial compressive strength (MPa) of the specimen, \( F \) is the peak load (N) in the loading process of the specimen, \( A \) is the compression surface area (mm\(^2\)) of the test specimen.

3. Test Phenomenon and Compressive Strength

3.1. Test Phenomenon

With the gradual increase of load, slight cracks appear on the top and the bottom bearing surfaces of the specimen, and the cracks develop slowly and become reticular. When the peak load is reached, there is no through vertical crack on the surface of the specimen, but there are obvious reticular cracks. After the peak load is reached, the load continues to increase, and the soil on the surface of the reticular cracks begins to fall off. During the loading process of the highland barley straw specimen, the sound of continuous breaking of highland barley straw can be heard. After the end of the test, the unloaded soil material was not completely scattered and the tying effect of highland barley straw caused damage.
3.2. Compressive Strength

The compressive strength of the modified specimens with different contents of highland barley straw rammed soil is known (Table 2). When 0.25%, 0.5%, 0.75% or 1% of highland barley straw was added to the rammed soil, the compressive strength was 0.66MPa, 0.85MPa, 1.16MPa and 1.40MPa, respectively. This indicates that the compressive strength of the test specimen also increases with the increase of added highland barley straw. When the content of the highland barley straw in soil reaches 1%, the compressive strength can reach 2.62 times that of the plain soil test specimen.

The compressive strength of the modified rammed soil specimen is greatly improved compared with the plain soil specimen when the specimen is mixed with 10%, 15%, and 20% rubbles. Respectively reached 2.38, 2.22, and 2.18 times of the plain soil specimens. However, with the increase of the rubble content, the compressive strength of the rammed earth modified specimens with single rubbles showed a downward trend. The compressive strength of the specimens with 20% rubble content was reduced by about 10% compared with the specimens with 10% rubble content.

The compressive strength of the modified rammed soil specimens has been greatly improved when mixed with high-quality highland barley straws and rubbles, which can be increased to 2.4 to 3.4 times that of plain soil specimens. There is no obvious rule for the increase of compressive strength and the ratio of admixture.

### Table 2. Compressive strength of specimen.

| Group | average value (MPa) | standard deviation | variable coefficient | Group | average value (MPa) | standard deviation | variable coefficient |
|-------|---------------------|---------------------|----------------------|-------|---------------------|---------------------|----------------------|
| S     | 0.534               | 0.018 9             | 0.035 3              | JS-2  | 1.605               | 0.064 2             | 0.040 0              |
| J-1   | 0.656               | 0.039 4             | 0.060 0              | JS-3  | 1.638               | 0.078 6             | 0.048 0              |
| J-2   | 0.849               | 0.087 1             | 0.102 6              | JS-4  | 1.546               | 0.080 6             | 0.052 1              |
| J-3   | 1.158               | 0.084 3             | 0.072 8              | JS-5  | 1.283               | 0.058 1             | 0.045 3              |
| J-4   | 1.400               | 0.237 4             | 0.169 6              | JS-6  | 1.619               | 0.274 3             | 0.169 4              |
| SZ-1  | 1.272               | 0.085 3             | 0.067 1              | JS-7  | 1.811               | 0.310 4             | 0.171 4              |
| SZ-2  | 1.186               | 0.095 5             | 0.080 5              | JS-8  | 1.393               | 0.068 2             | 0.049 0              |
| SZ-3  | 1.164               | 0.125 8             | 0.108 1              | JS-9  | 1.414               | 0.118 0             | 0.083 5              |
| JS-1  | 1.447               | 0.080 1             | 0.055 4              |       |                     |                     |                      |

4. Analysis on Deformation Performance and Optimum Mix Proportion

4.1. Deformation Analysis

The load-displacement curve of some analyzed test specimen is shown in Fig.1. The analysis of the load-displacement curve shows that the load-displacement curve of the modified rammed earth specimens mixed with highland barley straw and the modified rammed earth specimens with a high content of highland barley straw is relatively gentle in the rising and falling stages, and the peak load corresponds to the highest displacement can be increased by about 40%. It shows that the deformation of the specimen from loading to failure is larger than that of other types of specimens, and the deformation duration is relatively long, showing a certain plastic deformation ability. After reaching the peak load, the specimen will not lose its bearing capacity in a short period. It can maintain a high bearing capacity for a long period, and its deformation capacity in the later stage is relatively strong. This property of modified rammed earth materials can improve the seismic resistance of rammed earth buildings. In actual work, the destruction of rammed earth buildings can be observed, leaving people with time to react. After the rammed earth building destruction does not collapse and protects people's lives and property security.
4.2. Analysis of Optimum Mix Proportion

Comparative analysis of the shape, test phenomenon, compressive strength, standard deviation, coefficient of variation, and deformation ability of the highland barley straw and rubble modified rammed earth specimens with different ratio was done. The compressive strength of modified samples with the ratio of 0.25% highland barley straw and 20% gravel can be increased to more than 3 times that of plain soil, and the standard deviation and coefficient of variation are small. The outer surface of the modified specimen is relatively smooth with less damage, no shrinkage cracks after curing, bare highland barley straw, complete edges and corners, tight connection of soil at delamination, no obvious delamination marks, plastic damage during compression test, and good resistance to deformation. It has the best comprehensive performance, and should be used as the best mixture ratio for compound mixing.

5. Conclusions

Using highland barley straw and rubbles as a modified admixture of raw soil can significantly improve the compressive strength and denaturation ability of rammed earth materials. Highland barley straw is an agricultural waste with low environmental protection costs and is in line with the concept of sustainable development;

(1) Mixed with highland barley straw rubbles can improve the compressive strength of the modified specimen to between 2.4 and 3.4 times the plain soil specimen. The combination of the highland barley straw and rubble together resists external forces, so that the modified specimen has both high compression resistance and good deformability.

(2) The overall performance of modified specimens with 0.25% highland barley straw + 20% gravel ratio was found by comparing the appearance, test phenomena, compressive strength, standard deviation, coefficient of variation, and deformability of different high ratio barley straw rubble specimens. The best, it should be used as the best mix ratio.
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