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Experimental Study on Frost Resistance of Rammed Earth Building Materials

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To study the freezing resistance of rammed earth building materials. Different areas of rammed earth are selected and rammed earth samples are prepared according to relevant provisions of China referring to the relevant literature. Some maintenance measures are taken after the sample preparation to prevent deterioration of rammed earth samples. Afterwards, the relative dynamic elastic modulus of the test specimen with different silane content is tested and the capillary water absorption test is performed. The relative dynamic elastic modulus of samples B, B2 and B4 decreases to 49.07%, 45.46% and 10.88% of the original level respectively under the condition of 100 freeze-thaw cycles. When the number of freeze-thaw cycles is 100, AB=900.2 g/ (m2·h0.5), AB2=640 g/ (m2·h0.5) and AB4=410 g/ (m2·h0.5). The 2% silane content is reasonable and the resistance to water intrusion is enhanced under the condition of fewer freeze-thaw cycles and increased silane emulsion content.

1. Introduction

Different from modern buildings, Chinese traditional dwellings are very particular about site selection, ventilation and drainage. The construction of traditional dwellings pays more attention to the coordination with the surrounding environment and uses nature as the construction standard. The construction of most traditional dwellings in China uses rammed earth as the building material, which has a good adaptability to the environment and topography and also conforms to the concept of energy conservation and emission reduction and ecological development in China. There is a big difference between rammed earth and modern concrete materials. Rammed earth has good thermal insulation, heat insulation and air permeability. The construction of rammed earth buildings in China generally uses ancient rammed earth construction technology, which results in the fact that the form of most traditional Chinese dwelling houses is relatively single with lower floors. Compared with modern high-rise reinforced concrete buildings, most residents in China believe that traditional Chinese dwellings are extremely old-fashioned, moist and dark. Affected by this idea, some rural residents have abandoned the original building technology and blindly pursued the concrete structure, which increases the energy consumption of rural housing construction and is not conducive to the protection of the rural ecological environment.

This paper mainly carries out the experimental study of the freezing resistance of the rammed earth building materials. Different areas of rammed earth are selected and rammed earth samples are prepared according to relevant provisions of China referring to the relevant literature. Some maintenance measures are taken after the sample preparation to prevent deterioration of rammed earth samples. Afterwards, the relative dynamic elastic modulus of the test specimens with different silane content is tested and the capillary water absorption test is performed.

2. Literature review

Since the formation of human society, the raw soil has been one of the main building materials. According to the data, some people in the world live in the earth building (Beckett and Ciancio, 2014). The development and improvement of traditional soil architecture is very important for the improvement of human living conditions. On the other hand, the increasingly serious environmental pollution has become the main factor restricting the development of the global economy. For the third world countries including China, this problem is more prominent. The economic loss caused by pollution and ecological destruction in China is about more than 200 billion yuan per year. The building of raw soil can reduce the damage to the ecosystem, protect and improve the natural environment, and contribute to the sustainable development of the society.

Today, the building of rural and township housing is in the ascendant. It is an important way to eliminate the "urban disease" and to restore the ecological characteristics of the countryside by not blindly copying the high-rise buildings, saving the resources and saving energy, and taking the road of Chinese village and town development. On the one hand, many countries in the world have experienced the development stage of intensive urbanization, enjoying the consequences of disorderly development. On the other hand, many countries still pursue the development of urbanization unrealistically, and even suffer from serious environmental pollution and ecological destruction before they realize the protection. Bui and others pointed out that high-rise buildings were a feature of technical and economic strength, but they did not represent the architectural style of modern Chinese characteristics (Bui et al., 2014). At present, conservation type, resource benefit type, flexible adaptability and style diversity should be the basic characteristics of Chinese rural architecture, and soil building is one of the important forms of residential buildings in the vast rural areas of China.

The raw soil building includes rammed soil building, adobe building, soil cover building, and so on. Among them, rammed soil building is one of the important achievements in the history of Chinese ancient architectural technology, which has a long history and is widely used. The so-called rammed soil wall is commonly known as the punching wall, that is, the "Legends of Mencius". Its significance is the building of the wall, and the building of the walls on both sides of the formwork. In the building, the soil in the template is rammed. After demolishing the formwork, beat the newly built and dry soil wall vigorously, so as to make it strong. In addition to convenient, economical and practical purpose, rammed soil has certain bearing capacity, strong integrity, superior thermal performance and complete set of ramming technology. So far, traditional ramming soil technology is still used in many rural residents to build soil houses. From the history of rammed soil architecture, rammed soil houses existed as early as the Shang Dynasty. From the archaeological excavation, the most ancient example of this ramming technology in China is called the Bai yingzi in Tangyin County, Henan province. It is the site at the end of the Neolithic period seven thousand or eight thousand years ago (Tripura and Singh, 2016). In the era of the great Yu king more than four thousand years ago, not only did we use this technology to build palaces in cities, but also used to repair dams and control floods. At present, the palace ruins of Henan City three thousand years ago, such as Anyang and Zhengzhou, are built by ramming technology. As the Han nationality moved south, the ramming and building technology of Fujian, Guangdong and Jiangxi began to develop gradually from the Tang Dynasty. In the Ming Dynasty, the mountainous rural areas in the southwest of Fujian were built with clay as the main building material and built with Rammed Soil technology. The ramming soil technology has reached the peak level and the building buildings are generally three or four floors, up to five or six layers, and some are more than 20 meters high. In Fujian, most of the soil buildings, built in the Ming and Qing Dynasties, are the technical crystallization of the consolidation technology of the Central Plains after thousands of years and the highest achievement of tamping earth civilization. The technical level of the rammed soil wall has reached the height and width of 25:1, which is a great tribute to the ancient rammed soil technology. No wonder Mr. Fukushima Toshi of University of the Ryukyus in Japan called it "edifice built with special materials and wonderful methods" (Bui et al., 2014).

The so-called soil modification is to add the modified material to the soil at normal temperature and apply a certain external force to cement the soil by a series of physical and chemical reactions that occur in the soil, so as to change the original structure and properties of the soil, and to enhance the durability and mechanical properties of the soil. In the early twentieth Century, some developed countries, due to the needs of new roads, ports, airports and other projects, used lime and cement to modify the soil, and achieved good results (Maria et al., 2014). In 1970s, the United States, Japan, Canada, South Africa and other countries carried out the deep development of soil modification technology and the technical level made great progress. The materials of the modified soil are upgraded from single lime, cement and fly ash to the modified new material - the soil modifier (Miccoli et al., 2015). This is a kind of composite material with excellent performance. It has some characteristics that cement does not have. The object is all kinds of soil, which realizes people's dream of "soil changes to stone". After the product is put into the market, it is widely used in engineering rapidly. The United States called this one of the great inventions in twentieth Century, and Japan called it a new material in twenty-first Century (Ciancio et al., 2014). In these countries, soil solidifying agents are made by specialized enterprises as a brand of goods, such as the solidified enzyme of Palma Company in the United States, and Soil modified materials of Roadbond, Roadgood, UKC of Japan, Japan Century East Emergency Industry Corporation, Sumitomo Company of Japan, and so on (Khadka and Shakya, 2016).

In China, many institutions have carried out the development and research of curing agent, and have used in the soft soil treatment and water conservancy building of highway subgrade. However, the research of this technology is different for different application fields of soil materials, and has different adaptability. Rammed soil building, as a building method, has a long history and is widely distributed. Because of the different use environment, the transformation technology is also different, and the scale, size and volume are different, and especially the variety and cost of the modified materials determine the validity of the ramming soil building field. From the point of view of durability of the soil, it has the properties of water resistance, frost resistance and so on, all of which depend on the modification of the soil. Therefore, it is a new problem how to improve the strength and durability of the rammed soil wall by modifying the environment and size specifications of the rammed soil wall.

Based on the above research situation, this paper mainly studies the frost resistance of rammed soil building materials.

3. Method

The rammed earth building material is a type of building material, which means the void in the soil is squeezed through the ramming action to make the soil stronger. It is a solid building material in soil materials and it was commonly used as a building material for city walls and palaces in ancient times. In China, the technology of rammed earth could be traced back to Longshan culture. The city walls and platforms in ancient Chinese were often built by rammed earth. The rammed earth is compacted in layers and has a compact structure, which is generally harder than immature soil and the soil color is not as uniform as immature soil. It also contains ancient relics and the most obvious feature is that it can be layered. The plane between the upper and lower layer, is called ram surface and ram pits can be seen on the surface. There are often fine sand particles on the surface of the ram pit.

3.1 Test soil samples

The study adopts the soil sample of the graveyard tomb in Yoshinogariiseki (referred to as graveyard soil in the paper), which was sampled in 1993 and has been placed in the road and site engineering research room of Saga University. Table 1 shows the physical property of the graveyard soil used in the experiment. The real sand is the silty soil widely distributed in the Kyushu region of Japan and the real sand used in this test is collected from Seven Hills Village in Saga Prefecture. According to the relevant provisions of the frost resistance test and the capillary water absorption in the GB/T50082-2009 "Test methods for long-term performance and durability of ordinary concrete", the formed test specimens are divided into two types: 100mm*q00mm*400mm frost test specimens and 100mm*100mm*100mm capillary water absorption test specimens. In order to prevent the influence of the release agent on the frost resistance of the test specimen, the release agent is not used when casting the test specimen.

After 24 hours, the specimens are demolded and then placed in a standard curing room (temperature (20±3) °C and relative humidity greater than 90%) for curing for 24 days.

3.2 Test methods

When the water-frozen test specimen reaches the 24th age, it shall be taken out of the curing room and soaked in clean water for 4 days. After that, it is put into a rubber tube of the freeze-thaw tank and clean water is put in the tube; the salt-frozen test specimen shall be soaked in the 3% sodium chloride solution for 4 days and then it is placed in the 3% sodium chloride rubber tube in the freeze-thaw tank to start the freeze-thaw test. The frost resistance instrument used in the test is the TDR-3 automatic concrete quick freezing and thawing equipment and the freeze-thaw environment and parameter settings are in compliance with the current national standards.

When the number of freeze-thaw cycles is 0, 25, 50, 75 and 100, the frost resistance test specimen is taken out and the horizontal fundamental frequency of the 100mm*100mm*400mm test specimen is measured. The scum on the surface of the test specimen should be cleaned before measurement and the surface moisture shall be dried. The external damage shall be checked and the weight of the test specimen shall be measured. After the measurement, it is put back in the freeze-thaw chamber to continue the freeze-thaw test.

The cubic specimen with freeze-thaw cycle of 0, 50 and 100 cycles is taken out and the stone cutter is used to cut the specimen into two test blocks with 50 mm thickness. To ensure that the capillary water absorption test block is sufficiently dry, the test block is placed in an electric blast oven to dry at a temperature of 75 °C for 72 hours. Finally, the other four surfaces of the dried block is sealed with paraffin except for the water absorption and cut surface. The capillary water absorption test is performed in the flat bottom container shown in Figure 1. When the concrete test specimen is in contact with water, the timer is started. The test specimen is taken out from the container when the water absorption time is 0, 0.5, 1, 2, 4, 8 and 24 hours. The clear water on the surface of the test specimen is wiped off with a damp cloth and then weigh the mass. After recording the weight, immediately put the test block back to its original position. The entire capillary water absorption test lasts for 24 hours. Figure 2 shows the tools used in the sample preparation for this study. The prepared sample is cured in the thermostatic chamber for a predetermined period of time before the experiment. Figure 3 is a photograph of the sample during curing.

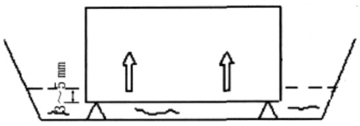


Figure 1: Schematic diagram of water invasion and capillary water absorption test

Figure 2: Sample preparation tool   *Figure 3 Photo at the time of sample conservation*

4. Results and discussion

The relative dynamic elastic modulus of test specimens with different silane content in different freeze-thaw cycles are tested. The test results are shown in Figure 4 and Figure 5.

As it can be seen from Figure 4, under freezing conditions, when the number of freeze-thaw cycles is 100, the relative dynamic elastic modulus of the three comparative specimens B, B2 and B4 reduces to 49.07%, 45.46% and 10.88% of the original level respectively, which is due to the existence of the silane emulsion. It slows down the hydration rate of the experimental rammed earth and decreases the strength of the rammed earth. As a result, the frost resistance of rammed earth test specimen with silane content is poorer than that of the blank rammed earth test specimen. Also, the frost resistance property of the rammed earth decrease with the increase of silane content.

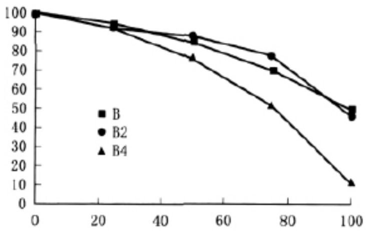


Figure 4: Relative dynamic elastic modulus of concrete under water freezing cycle

As it can be seen from Figure 5, under the salt-frozen test condition of 3% sodium chloride solution, when the freeze-thaw cycle is 100, the relative dynamic elastic modulus of the blank test specimen B reduces to 53.63% of the original level; the relative dynamic elastic modulus of rammed earth test specimen B2 and B4 with silane content of 2% and 4% decrease to 46.23% and 16.46% respectively of the original level. On one hand, the hydrostatic pressure caused by the volume expansion of freezing and the osmotic pressure caused by ice water vapor pressure difference and saline solution difference aggravate the stress expansion inside the test specimen, which leads to fatigue failure and accelerates the peeling of the test specimen. On the other hand, due to the existence of saline solution, the freezing point of the solution drops from 0 °C to -2 °C, which is beneficial for rammed earth. Under the effect of the above two conditions, it can be seen that the salt resistance and frost resistance property of the three types of samples have been improved moderately. However, due to the role of saline solution, the greater the silane content, the more serious the loss of the quality of test specimens. .

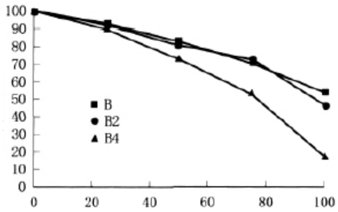


Figure 5: Relative dynamic elastic modulus of concrete under salt-thaw cycle

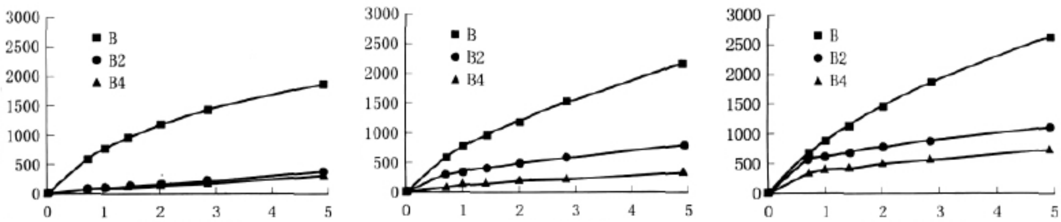
When the surface of rammed earth is in contact with aqueous solution, the water is adsorbed on the surface layer through the capillary action of rammed earth and further penetrates into the interior of rammed earth. Among them, the water-soluble harmful substances such as chloride ions and sulfate ions are infiltrated into the voids of rammed earth, which brings a serious risk of corrosion to the internal structure of rammed earth. Therefore, the water absorption of rammed earth is gradually regarded as an important index to evaluate its erosion resistance.

Studies by foreign scholars have pointed out that the adsorbing capacity of water in the initial water absorption time basically conforms to the “law of time evolution”, which is:

$$i = A\sqrt{t} \tag{1}$$

In the formula: i is the water absorption capacity of the alumina in the time t and the unit is $g/(m^2 \cdot h^{0.5})$; t is the absorption time and h is the unit; A is the water absorption coefficient of rammed earth.

Assuming that the concrete is isotropic and is in an ideal state without considering the chemical reaction between the internal components of the concrete matrix and the water, A is considered a constant. The concrete test specimens with freeze-thaw cycles of 0, 50, and 100 are taken and the relation curve between the capillary water absorption of concrete test specimens with different silane content and the water absorption time under different freeze-thaw damages are tested, as is shown in Figure 6.



(a) 0 times *(b) 50 times* *(c) 100 times*

Figure 6 : Curve of the capillary water absorption of concrete under water freezing cycle versus time

It can be seen from Figure 6(a) that the capillary water absorption coefficient of the blank rammed earth test specimen B is AB=785.2g/(m2·h0.5) when not damaged by freezing and thawing; the capillary water absorption coefficient of the concrete test specimen B2 with 2% silane emulsion reduces to AB2=96.5g/(m2·h0.5), which is about 1/8 of the blank test specimen; he capillary water absorption coefficient of the concrete test specimen with 4% silane emulsion reduces to AB2=96.5g/(m2·h0.5), which is about 1/9 of the blank test specimen. In summary, the overall waterproof rammed earth prepared with the silane emulsion has good resistance to water intrusion without freeze-thaw damage. However, the resistance to water intrusion has not been significantly improved with the increase of silane emulsion, indicating that 2% silane is a reasonable figure.

It can be seen from Figure 6(b) that when the number of water freeze-thaw cycle is 50, the water absorption capacity and the water absorption coefficient of rammed earth increase significantly. Compared with the experimental data of the capillary water absorption without the freeze-thaw damage, the total water absorption capacity of the concrete test specimens B, B2 and B4 increase by 303g/m2, 419g/m2 15g/m2 respectively within 24 hours. Due to the existence of the silane emulsion, on the one hand, a water-repellent film is formed to resist the water intrusion because of a series of chemical reactions in rammed earth; on the other hand, the hydration reaction of rammed earth is slowed down and the strength of the test specimen is reduced so that the impact of freeze-thaw damage is relatively large on the rammed earth test specimen with silane emulsion content. However, it still has better resistance to water intrusion than that of the blank rammed earth and the resistance to water intrusion is better with the increase of silane content.

Figure 6 (c) shows that when the number of water freeze-thaw cycles is 100, the resistance of water intrusion of the test specimens increases with the silane content. The capillary water absorption coefficient of the concrete samples B, B2 and B4 are AB=900.2g/(m2·h0.5), AB2=640g/(m2·h0.5) and AB4=410g/(m2·h0.5) respectively. It can be seen from the comparison of the capillary water absorption coefficient of rammed earth test specimens B, B2, and B4 under 100 of water freeze-thaw cycle that the resistance of water intrusion of concrete increases with the silane emulsion content; at the same time, it can be seen from the comparison of the data of 0, 50 and 100 freeze-thaw cycles that the damage of the freeze-thaw cycle on the overall waterproof rammed earth prepared with silane emulsion content is more severe compared with blank test specimens and the capillary water absorption coefficient of rammed earth test specimen with silane emulsion content increases dramatically with the number of cycles.

5. Conclusion

The frost resistance of rammed earth is largely afftected by the nature of rammed earth itself and the selection of rammed earth is particularly critical before conducting the frost resistance experiment of the rammed earth building materials. Due to the limitation of experimental conditions, the rammed earth samples selected in this experiment are limited. In the follow-up work, it is necessary to further study the soil texture of rammed earth throughout the country.

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