Geotechnical Assessment for the Restoration of Garandoya tumulus with the Naked Stone Chamber

Évaluation géotechnique de la restauration du tumulus de Garandoya et grottes en pierres nues

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ABSTRACT: Garandoya Tumulus was constructed on the terrace of Mikuma River and famous for mural paintings. The soil mound that originally covered the stone chamber has been destroyed. Due to instability of the naked stone chamber, it has been decided to restore the tumulus with the construction of round soil mound with a diameter of 25 to 30m. The necessary strength together with the compacted density of the restored mound soils are investigated through various laboratory tests. A series of laboratory test results confirm that the stability of the restored mound is achieved with the possible in-situ density. Water resistant and adiabatic structure is required to protect the mural paintings inside the stone chamber. Based on the chamber model test results, the double-layered earth mound has been introduced for the restored tumulus mound, namely, the well compacted soil with the enough strength to stabilize the restored tumulus mound underlain by the well permeable gravel layer to support the drainage for rainfall water. The heat conduction chamber tests on the mound soils are carried out to investigate the capacity to protect the heat transfer into the chamber. A series of the stability and environmental assessments has successfully assisted to develop the design of the restored tumulus mound.

RÉSUMÉ : Le tumulus de Garandoya, très connu pour ses peintures murales dans ses grottes, est construit sur le banc de la rivière Mikura. Le monticule de terre qui recouvrait les grottes est désormais dénudé, ce qui mène à l'instabilité des pierres nues des grottes, ainsi que la vulnérabilité des peintures murales à l'eau. On propose des travaux de restauration du tumulus en construisant un monticule de forme circulaire de diamètre de 25 à 30m pour le recouvrir. On étudie la résistance du sol compacté et la restitution de la densité in situ en faisant des tests au laboratoire. La texture du sol compacté doit être étanche pour protéger les peintures murales contre l'infiltration des eaux dans la grotte. Les résultats de tests sur un modèle réduit de la grotte préconisent une bi-couche pour restaurer le tumulus, càd une couche de sol compacté recouvrant une sous-couche de gravier pour permettre le drainage. On a aussi fait des tests de conductivité thermique sur le sol compacté pour évaluer l'isolation de la grotte. Des études de la stabilité environnementale du monticule ont aussi fait partie du design de la restauration du tumulus.

KEYWORDS: heritage, tumulus, mound, water retention characteristic, capillary barrier, heat conduction

1 INTRODUCTION

The Garandoya Tumuli, the national heritage are located at Hita city in Oita prefecture (Figure 1) with the mural paintings in the stone chamber. Although three tumuli were discovered, all of them have lost their earth mound and the stone chambers are exposed. The tumuli have been determined to be restored to conserve the stone chamber as well as the colored mural paintings drawn on the surface of the chamber stones. In order to protect the mural paintings from deterioration, the water resistant and adiabatic structure is strongly required because the main factor for the damage of the mural paintings is luxuriant growth of mold due to dew condensation induced by the intruded water by rainfall and the rise in heat by solar radiation.

In the present paper, the geotechnical assessment for the conservation of the tumuli including the mural paintings through the in situ and laboratory tests is reported. The behavior of underground water at the site is investigated through the in situ tests with emphasis on the possibility of suction-induced water intrusion. The necessary drainage function against the rain water is also discussed. The layered structure such as the compacted earth underlain by the permeable coarse gravel for the restored earth mound is proposed considering the assisting effect of capillary barrier at the border of these layers. Discussion is extended to the adiabatic structure of the earth mound, which is expected with the heat conduction characteristics of soils. For the purposes, a series of chamber model tests are conducted.

Figure 1. Location of Garandoya tumulus

2 GENERAL VIEW OF THE RESTORATION PROJECT

2.1 Restoration plan

In order to keep the preferable environment for the mural paintings on the chamber stones as well as to enable general public presentation of the stone chamber, the Hita Municipal Board of Education has determined to construct the shelter building which covers the stone chamber covered by the restored earth mound as shown in Figure 2. The shelter building

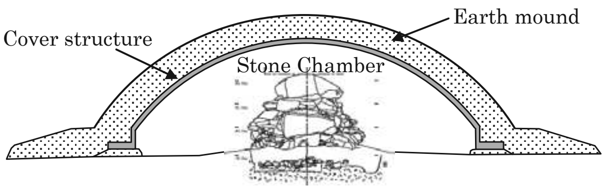


Figure 2. Schematic view of the restoration plan for the Garandoya Tumulus

whose diameter and height is 18 m and 6 m respectively. The restored earth mound will be constructed with a diameter of about 25 m based on the archaeological knowledge.

2.2 Examination subjects

Degradation of the colored paintings drawn on the surface of the chamber stone is most greatly subject to the influence of moisture. Development of the water resistant structure is required to prevent dew condensation and intrusion of water into the stone chamber. The possible phenomena to be considered are 1) the underground water exudation from the foundation, 2) the leakage of water from the joint of the reinforced concrete panel of the shelter building, 3) the inflow from surrounding ground. Technical procedures to overcome the above-mentioned problems have to be discussed together with the control of the temperature inside the stone chamber caused by the solar radiation.

3 INVESTIGATIONS OF MOISTURE IN THE GROUND

In order to consider the seepage of groundwater from the ground, the condition of groundwater was investigated in the observation well that is made from a vinyl chloride pipe with outer diameter 60 mm and inner diameter 52mm (Figure 3) currently installed in the nearest to the tumulus. The inserted type RI densimeter and moistmeter of the shape of a pillar stick of 42.7 mm in diameter and about 1000 mm in length is applied to detect the moisture content as well as the density of the ground. The RI densimeter and moistmeter is inserted to the bottom of the well at the depth of 9 m from the ground surface followed by conducting the scanning logging by pulling up at the rate of 1 m/min. Investigation was conducted in a rainy season when the groundwater level heightens due to sufficient rainfall as well as in a dry season when the groundwater level

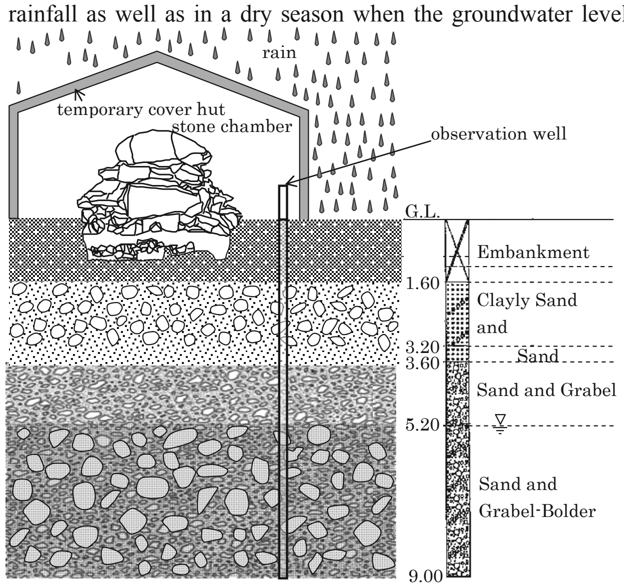


Figure.3 Cross section of the foundation of the Garandoya Tumulus

lowers. As far as the condition at the investigation is concerned, the temporary shelter structure was equipped to cover the stone chamber to avoid rainfall. The stone chamber was however not completely free from the infiltration of water through the surrounding ground.

According to the boring log, the subsurface condition of the Grandoya Tumuli is as follows: The artificial fill consisting of fine grained soil with gravel appears from the ground surface to GL-1.6 m underlain by the clayey sand with gravel and boulder from GL.-1.6 m to -3.2 m. The sand layer is found from GL-3.2 m to -3.6 m underlain by the sand and gravel from GL.-3.6 m to -5.2 m. Then the gravel and boulder deposit appears from GL-5.2 m to -9.0 m. Because the clayey sand above GL-3.2 m is expected to have a low permeability enough to hinder infiltration into the ground, the water by rainfall is expected to exude inside the stone chamber.

The measured results of the density and moisture logging are shown in Fig. 4. The groundwater level is found to change at G.L. -5.04 m in the rainy season and G.L.-8.45 m in the dry season. It is natural that the degree of saturation is kept almost

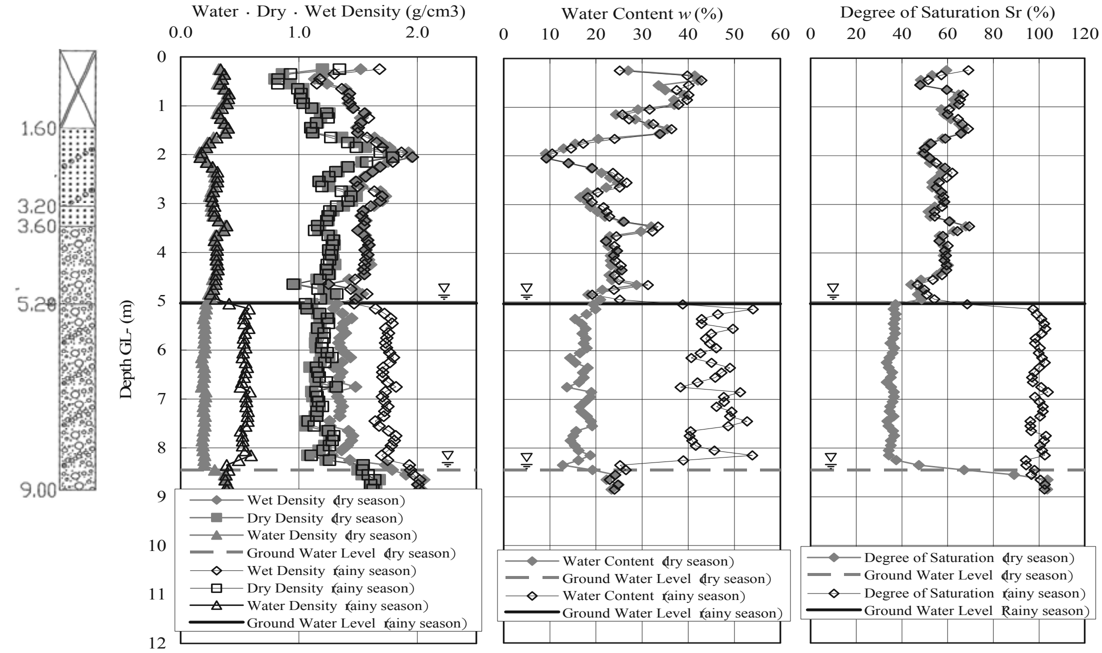


Figure 4 Measured results of the density and moisture content of the foundation ground at the Garandoya Tumulus

100 % and when the underground water level lowers in the dry season, the degree of saturation from G.L. -5.04 m to – 9.0 m significantly drops to about 35%. On the contrary, the degree of saturation above G.L. -5.04 m is about 60% in the rainy season, and it is noteworthy that the degree of saturation in the layers above the groundwater level of does not change at all irrespective of the underground water level. From these results, the seepage of the water to the layers above the groundwater level due to suction can be ruled out. It is hence not necessary to consider the problem of exudation of the underground water into the stone chamber from its base.

4 ASSESSMENT OF WATER RESISTANT STRUCTURE

The shelter building is planned to be constructed for the conservation of the naked stone chamber of the Garandoya Tumulus. It is true the intruded rain water is intercepted by the shelter building but it is preferable that the intruded water does not reach the surface of the shelter building to avoid possible leakage due to loss of function of the waterproof processing equipped among the concrete panels of the shelter building. The earth mound has been selected to cover the shelter building to reproduce the original shape of the tumulus together with the consideration of the adiabatic effect. The layered structure, namely the well compacted soil underlain by the well permeable coarse gravel has been adopted for the restored earth mound in order to provide a good drainage function. The adopted layered earth mound structure consequently give a possible function of a capillary barrier at the border of the compacted soil and gravel layers due to the different capacity of suction in those layers.
A series of the chamber tests on the layered foundation is carried out to confirm the occurrence of capillary barrier at the border of the upper compacted soil layer and the underlying coarse gravel layer. The model chamber is shown in Figure 5. The selected parameters for this chamber test are the inclination angle of the foundations and the intensity if precipitation. The size of the model chamber is 1100 mm in length, 600 mm in height, and 120 mm in width. The equipment for precipitation has eight hypodermic needles per 100 cm^2 at the bottom of the tank, and can give the raindrop from the needle tip to the surface of the model foundation. Intensity of precipitation is adjusted by the hydrostatic pressure in terms of the level of water in the tank that can be controlled by the Marriott siphon.
The soil with which the present experiment is conducted is the candidate material of the tumulus restoration that is the graded grain material extracted from the quarry in the proximity of the tumulus. The coarse gravel is also extracted from the same quarry. The particle size distribution of the materials is shown in Figure 6. The candidate material is a well-graded sandy soil. The initial water content of soil was adjusted as natural water

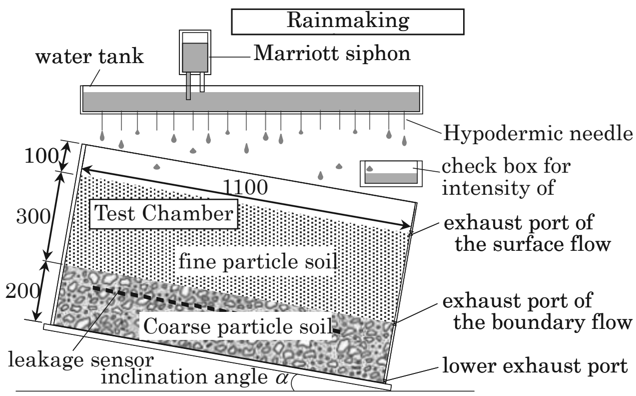


Figure.5 Schematic view of the model chamber of the test for capillary barrier

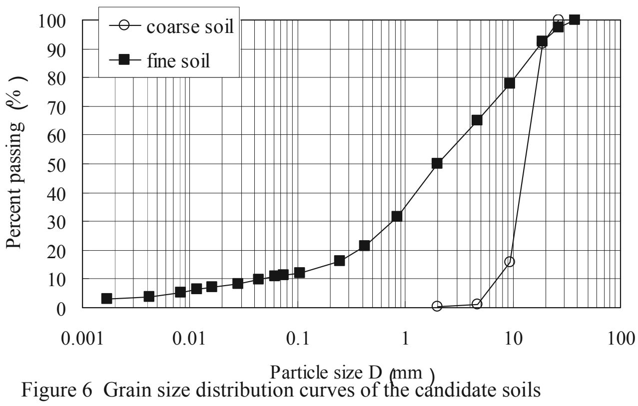


Figure 6 Grain size distribution curves of the candidate soils

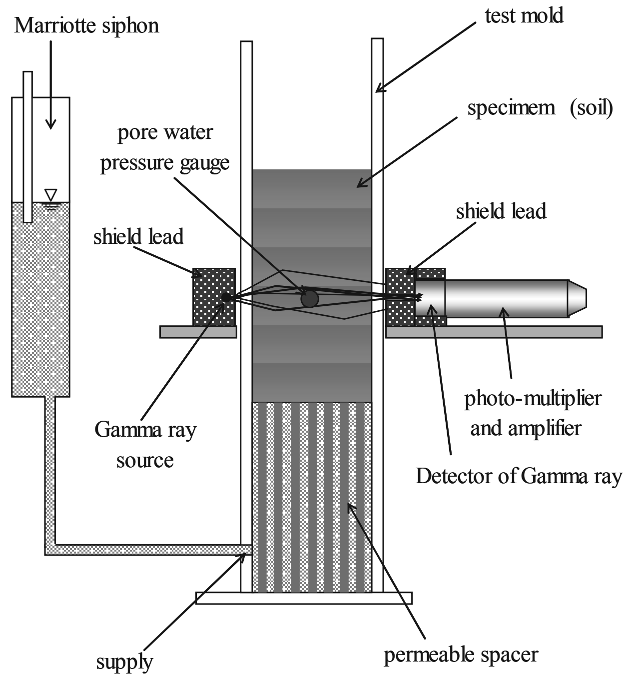


Figure 7 Schematic view of the unsaturated seepage test device

content equivalent to the one for the actual restoration. A series of compaction tests is conducted with the different compaction energy on the material under the natural water content. Based on the experimental results, the density of the soil for the chamber test is determined by supposing the compaction energy at the construction of restored earth mound. The relation of the moisture content by volume and the suction is separately investigated from the unsaturated seepage test. The adopted testing apparatus for the unsaturated seepage test with the radioisotope system is shown in Figure 7.
Figure 8 shows the experimental results between the tangent of the inclination angle of the foundation and the limit length L that denotes the resistant distance for the capillary barrier under the prescribed intensity of precipitation of 3.6 mm/hr. In the present study, the thickness of the compacted earth mound is 300mm. A set of electric sensors to detect water is put at the top of the underlying coarse gravel layer. When infiltrated water leaks to the gravel layer, we can detect the location of the breaking point of capillary barrier by the occurrence of short-circuit. As shown in the figure, there is a definite linear relationship between the limit length L and the inclination angle of the foundation in terms of tanα. It is found that the water resistant structure with capillary barrier at the border of the layered earth mound is expected to function under the condition of the inclined foundation such as tumulus mound.

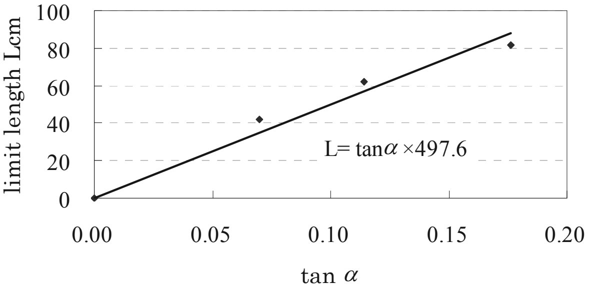
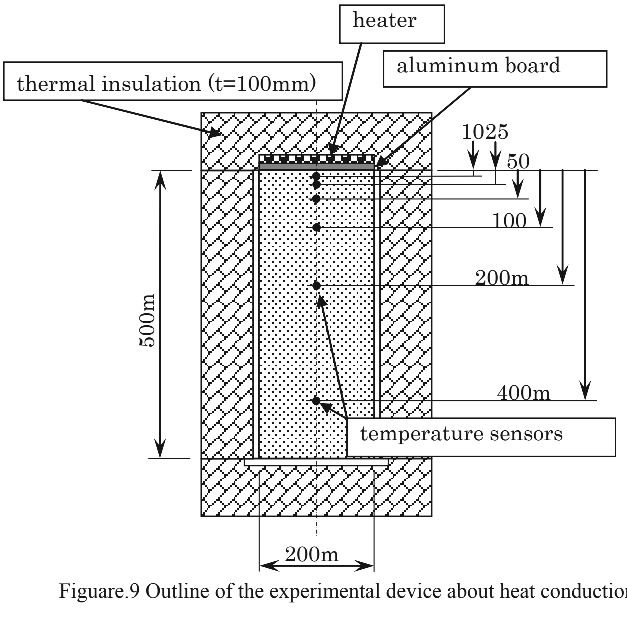


Figure 8 Relation of the inclination angle of the foundation α and the limit length L for capillary barrier

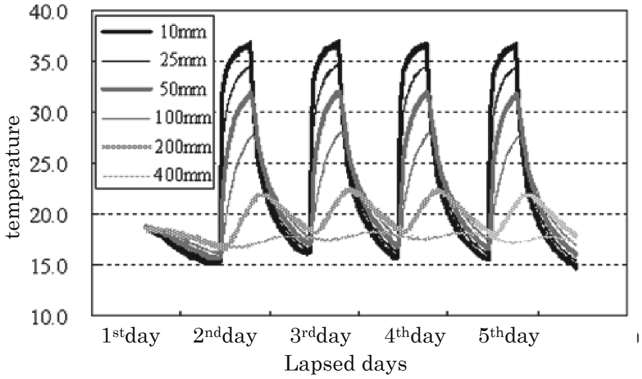
5 ASSESSMENT FOR HEAT CONDUCTIVITY OF SOILS

Subterranean preservation of food using the adiabatic effect of the ground is widely performed from ancient times. The shelter building for the Garandoya Tumulus has hence been covered with soils to ease the temperature change in the tumulus because the variation in temperature has a harmful influence on the conservation of the mural paintings in the stone chamber. The chamber model test is carried out in order to derive the characteristics of the heat conductivity of the soil that is used for the restoration of the tumulus. The schematic view of the experimental device is shown in Figure 9. The soil is prepared by compacting to 50mm per layer and the specimen of ten-layer structure is developed. Then, the specimen is prepared with 200 mm in diameter and 500 mm in height in the cylindrical container of acrylics covered by the thermal insulated styrene foam with a thickness of 100 mm. As is shown in the figure, the temperature sensors have been arranged at the prescribed depth in the specimen. The heat source of aluminum board is set at the top of the container.

The sequence of heat supply is set to provide 40°C of heat for 8 hours from the top of the specimen followed by removal of heat for 16 hours (1-day cycle model). During the time without heat supply, the temperature of the specimen surface is falling to the one of the room (about 15°C). Figure 10 shows the experimental results of the heat conductivity on the soil used for the restoration of the tumulus. The setup condition is equivalent to the prescribed one for the restoration of the tumulus. As shown in Figure 10, 4 cycles of heat supply and removal are conducted. The increasing rate of temperature tends to be higher in inverse proportion to the distance from the heat source. The absolute value of temperature is so high that it is close to the heat source, and there is the tendency for time to reach the



Figuare.9 Outline of the experimental device about heat conduction



Fiigure.10 Experimental results on variation of temperature in the soil

maximum to be overdue in proportion to the distance from the heat source. It is shown that the heat conduction inside the specimen is accompanied by a time lag and attenuation. The one-dimensional equation of heat conduction is solved by the finite difference method. By fitting these data, the coefficient of heat conduction κ=8.04x10^{-5} (J/ms°C) is obtained. On the basis of the heat conductivity chamber test results, the candidate soil for the restored mound is found to have a sufficient capacity as an adiabatic material.

6 CONCLUSIONS

Geotechnical assessment was conducted to conserve the Garandoya Tumulus with the naked stone chamber in which the colored mural paintings are drawn. The preferable environment in the stone chamber is found to be achieved by equipping the shelter building covered by the earth mound. The seasonal change of the underground level that is interlocked with the river level has been monitored. The rise of the water content in the capillary zone above the groundwater level was not detected irrespective of the season. Underground water hence does not infiltrate into the stone chamber from the ground. The layered structure of the restored mound, namely the drained gravel layer overlain by the compacted earth is expected to provide the capillary barrier at the border of the layers. The chamber model test results showed the linear relationship between the limit length, L and the tangent of the inclination angle of the soil layers. Capillary barrier effect is found to possibly assist for the water resistant structure of the tumulus mound. The adiabatic effect by the restored earth mound is experimentally confirmed through the one-dimensional heat conductivity chamber test. On the basis of the experimental results, the necessary thickness of the restored earth mound has been proposed to maintain the desirable thermal environment in the stone chamber.

7 REFERENCES

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