Conservation of historical tumulus mounds using geotechnical engineering techniques

La conservation des tumuli historiques à travers les techniques et méthodes d'ingénierie géotechnique

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ABSTRACT: Tumuli are burial mounds constructed more than 1300 years ago in many places in Japan. They have been conserved as historical cultural heritages. However many of them are seriously damaged by precipitation, earthquakes and human activities. The authors have hence been studying damage mechanism and countermeasures against the damage using geotechnical engineering techniques. The damage of tumuli can be divided into three types, namely 1) destruction of earth mounds, 2) water infiltration into stone chambers and 3) deterioration of decorated stone chambers due to hydrothermal environment change. In the present paper, geotechnical investigations into these types of damage are discussed. Rainfall induced slope failures in a tumulus mound is provided as an example of 1) and the instability of the mound is quantitatively explained. As a countermeasure against 2), water shielding by a capillary barrier is successfully introduced to the restoration of a damaged tumulus. Temperature control in stone chambers is required to suppress 3) hence the influence of a tumulus mound on the chamber temperature is evaluated with a basic numerical analysis.

1 INTRODUCTION

Tumuli are burial mounds for ancient members of the imperial family and district rulers constructed in many places in Japan from the middle of 3rd century to the 7th century. A tumulus usually consists of a burial chamber made of stones covered by a compacted earth mound which varies in size and shape. The Daisen Tumulus known as the biggest one has a keyhole shape 480m in length. They have been conserved as vital compernents of Japanese history. However many of them are seriously damaged by precipitation, earthquakes, tomb roberry and urban development. Cooperative actions between archeoloy and fields of science and technology are hence required to conserve the damaged tumuli to the future generation. The authers have been contributing to the restoration of tumuli using geotechnical engineering techniques with respect for their authenticity as cultural heritages. It is required to clarify damage mechanism and develop effective countermeasures against the damage with the least change in the original characteristics of tumuli.

The damage of tumuli can be categorized into three types shown in Fig. 1, namely 1) destruction of earth mounds, 2) water infiltration into stone chambers and 3) deterioration of decorated stone chambers due to hydrothermal environment change. Because earth mounds originally protect the stone chambers from water and heat, destruction of earth mounds directly results in deterioration of stone chambers. Infiltrating rainwater and dew condensation water in stone chambers promote wet-dry cyclic condition and damage the stones. In addition, rich water and temperature change in stone chambers activate propagation of fungi, which gives serious damage particularly to stone chambers with decorations such as mural paintings. The objectives in the restoration of damaged tumuli are shown in Fig. 1. In the present paper, geotechnical investigations to achieve these objectives are discussed.

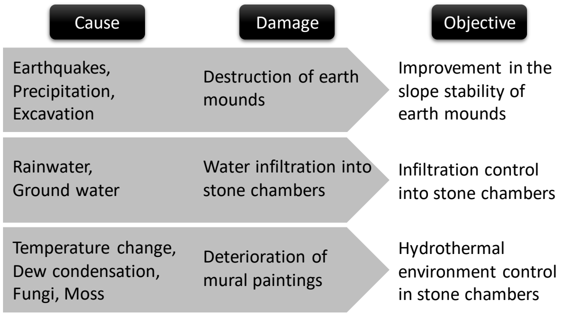

Figure 1. Three types of damage of tumuli and objectives in restoration.

2 INVESTIGATION OF THE RAINFALL INDUCED INSTABLITY OF A TUMULUS MOUND

For the restoration of destructed tumulus mounds, investigation of the destruction mechanism is essential. Here, rainfall induced slope failure in the Kengoshizuka Tumulus in Asuka village, Nara (Fig. 2(a)) is discussed as an example.

The tumulus has a dense compacted earth mound in an octagonal shape 22m in length. However, the surface where the slope failure occurred has many cracks and pores. The rainfall infiltration and stability of the mound are quantitatively evaluated using a numerical model shown in Fig.2(b). The

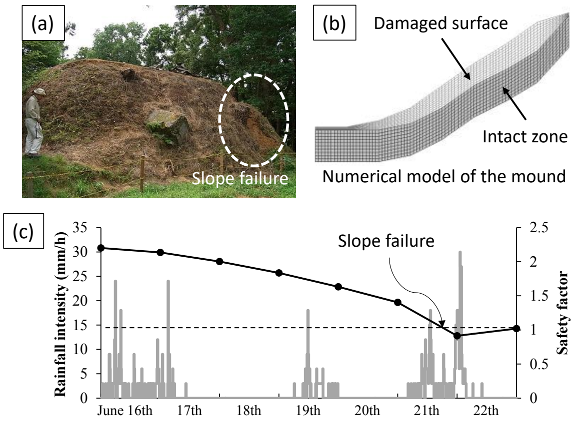

Figure 2. (a)The Kengoshizuka Tumulus, (b)A numerical model of the mound, (c) The calculated slope stability of the mound.

mound is modeled based on S wave velocity obtained by elastic wave exploration conducted on the mound. The strength parameters and hydraulic properties of the mound are determined by non-destructive in-situ tests and laboratory tests using the excavated soil produced by archeological investigation. The details of the developed evaluation method for the instability of the mound are found in Sawada et al. 2015.

Fig. 2(c) shows the slope stability calculated with limited equilibrium method assuming the slope failure occurs at the boundary of the surface and intact zone of the mound. The value of the safety factor goes down below 1.0 on the day with the maximum rainfall when the actual slope failure probably occurred. This indicates that the developed method for evaluation of the instability of the mound successfully explains the slope failure.

3 INFILTRATION CONTROL INTO A DAMAGED TUMULUS USING A CAPILALLY BARRIER

Controlling infiltration into tumulus mounds is indispensable to avoid rainfall induced slope failure and deterioration of stone chambers. A capillary barrier which works as a water shielding system is one of the feasible countermeasures. A capillary barrier functions at the interface between coarser and finer grained soil layers. Infiltrating water is diverted at the interface and cannot enter the underlying coarser grained soil layer due to the difference of the hydraulic properties of the two layers.

Model chamber tests were conducted to investigate the mechanism of water shielding by a capillary barrier and evaluate the diversion capacity to introduce a capillary barrier effectively for the restoration of tumuli. Using the apparatus shown in Fig. 3(a), infiltration in the double-layered ground model under constant precipitation was observed. Numerical analyses were also conducted to simulate a series of the model chamber tests. The analyses have indicated that water diversion occurs when the unsaturated hydraulic conductivity of the coarser soil layer is negligibly low compared to that of the finer soil layer. The diversion capacity is controlled by the inclination of the soil interface, the thickness of the finer grained soil layer and rain intensity (Sawada et al. 2016).

A capillary barrier has been successfully introduced in the restoration of the Garandoya Tumulus in Hita City, Oita which is famous for its mural painting in the stone chamber. The mural painting had been deteriorated because the chamber stones had been exposed due to loss of the covering earth mound. A concrete building was hence constructed above the tumulus and a double-layered earth mound which formed a capillary barrier was applied to cover around it (Fig. 3(b)). The earth mound is reported to effectively restrict infiltration into the building and also keep the temperature in the building stable.

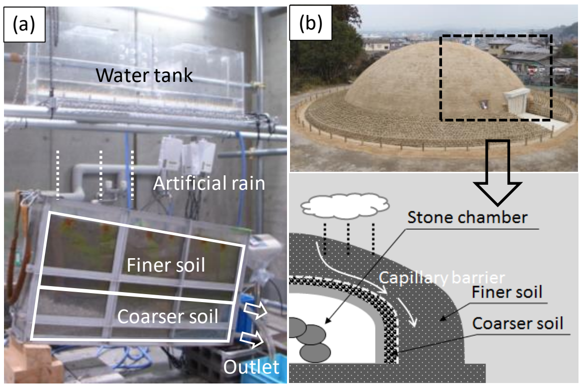

Figure 3. (a)The model chamber test for observation of a capillary barrier, (b)The reconstructed tumulus using a capillary barrier.

4 EVALUATION OF THE INFLUENCE OF A TUMULUS MOUND ON THE CHAMBER TEMPERATURE

The hydrothermal environment in a stone chamber is originally stable because the earth mound restricts heat conduction to the stone chamber. The stable environment is, however, vulnarable to change because of global warming and the degradation of heat protection due to the destruction of the earth mound. Subtle temperture change generates dew condensation because the humidity in the stone chamber is usually almost saturated, which negatively affects on its decorations.

Reconstruction of damaged earth mounds is effective to control the temperature change in stone chambers. The influence of an earth mound on the chamber temperature is evaluated using one dimensional equation of heat conduction. The applicability of the analysis method has been checked by comparing the calculated and measured temperature of a stone chamber (Sawada and Mimura 2016). Fig. 4 describes the influence of the thickness of the earth mound on the chamber temperature. The temperature calculation is also conducted to evaluate the influence of the density and degree of saturation of the earth mound.

The calculated performance shows that the thickness of the earth mound is a main controlling factor of the chamber temperature, on the other hand the density and degree of saturation do not practically affect the chamber temperature (Sawada and Mimura 2016). It indicates that destruction of earth mounds strongly affects the chamber temperature and the thickness of earth mounds is a key factor for reconstruction in terms of temperature control in stone chambers.

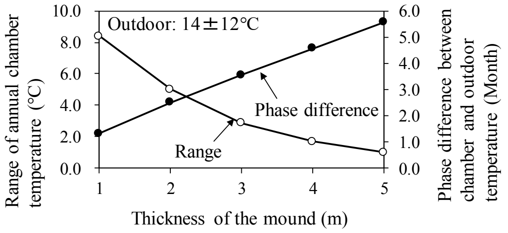

Figure 4. The influence of the thickness of the mound on the chamber temperature assessed by a numerical analysis.

5 CONCLUSION

In the present paper, geotechnical investigations into the three types of damage of tumili were reported. 1) The rainfall induced instability of the tumulus mound was evaluated and successfuly explained the slope failure. 2) A capillary barrier functions when the unsaturated hydraulic conductivity of the coarser and finer soil layers is contrasting, which controls rainfall infiltration into tumuli. 3) The thickness of tumulus mound strongly affects the chamber temperature. Hence, it is a key factor for the temperature control in stone chambers.

6 REFERENCES

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