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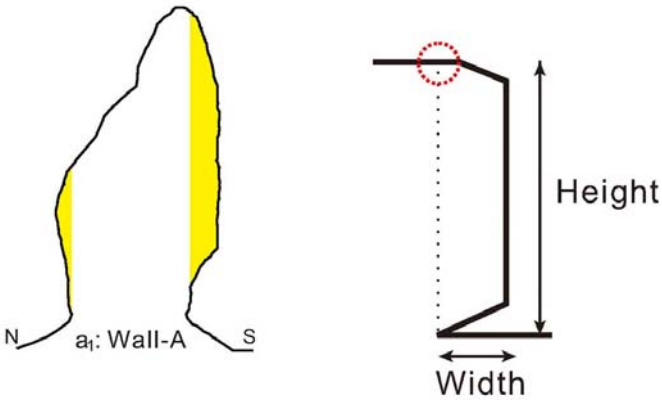
A study related to stability for the earthen archaeological site in central Asia

Yukiyasu Fujii[1*], WATANABE Kunio[2], Enrico Fodde[3]

[1]Fukada Geological Institute, [2]Geosphere Research Institute, Saitama U., [3]University of Bath

Historical heritage has been deteriorated by the main cause, for instance, rheological (water-flow and soluble salts) damage, vegetation & animal damage, and man-made damage. Geo-engineers and geo-technicians have potential to contribute to such works, especially for rheological damage, with the knowledge of rock mechanics, rock weathering, and the related technique.



In the field of geo-engineer and civil engineer, there are many studies for stability of natural rock slope and the prediction of rock failure. Fujii et al. (2009) report that salt attack caused the erosion of the basal part of the walls, thinning the walls and causing the upper and middle parts to collapse due to the loss of structural support from the underlying basal part. In order to better conservation works and safety use of earthen materials, it is important to clarify the mechanism and cause of the collapse. In this study we introduce the study of collapse using results from application of digital stereo-photogrammetry.

The Buddhist monastery of Ajina Tepa is one of the most significant sites in central Asia, as it was fully excavated by employing updated archaeological methods and extensive documentation in 1960s'. Much information was manifested not only in the Russian and English monographs (Litvinskij and Zejmal, 2004), but also in the extensive archival material. The site is manly constructed by mud brick (adobe). After the archeological excavation, no adequate preservation work has been carried out. Therefore, the site is much decayed and the reconstruction of original shape of the walls is rendered difficult. The Preservation of the Buddhist Monastery of Ajina Tepa, Tajikistan (Heritage of the Ancient Silk Roads) has been performed as a project of the UNESCO/Japan Trust Fund for world heritage since 2005. In this project, some earthen structures were documented by photogrammetry in three-dimension. In addition, one of the structures was collapsed and post-collapse structure was also documented in the project.

Left figure shows the section of pre-collapse structure. The basal part of structure was eroded, and it was similar to the overhanging cliff. Therefore, it can be assumed as the cantilever deformation with its own load (right figure). On the top of the structure, the maximum tensile stress can be calculated as $T_x = 3W^2pg/H$, in which H is the height of structure, W is the depth of erosion, p is density of mud brick, and g is gravity . According to the observation on fracture surfaces, the fracture started as tensile, and proceeded to shear fracture.

It can be inferred that the main causes of collapse are following three phenomena. First, the basal part of the structure was eroded and W reached the finite length. For an example of left figure with assumption of $p = 2.2 kg/m^3$, $T_x$can be calculated as about $10 kN/m^2$. This value is much lower than the strength of mud brick in dry situation. However, the strength of mud brick decreases with

increasing moisture in it. Therefore, it will be possible to collapse in the winter rainy season in Tajikistan. Second is crack proceeding from the top of structure. Progress development of crack decreases H in the above equation, and $T_x$will increase to the strength of mud brick. In addition, intrusion of rain water into crack might cause the weakening the crack -tip. Third Phenomena might be earthquake. There are many earthquakes in Tajikistan, which is located west of the Pamir Mountains. During earthquake, gravity might be twice or more than ordinary one. It will be the trigger for collapse.

Keywords: photogrammetry, earthen structure, weathering, collapse, conservation