令和元年度土木学会全国大会第74回年次学術講演会

SURFACE MOVEMENTS OF AN UNDERCUT SLOPE STUDIED BY CENTRIFUGE MODEL

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1. INTRODUCTION

Surface movements can occur any time on the slope. Several factors could cause the significant surface movement leading to slope failure, such as gravity, geological activity, hydrological influence and excavation orders of slopes. These factors affect different movement configurations and modes of failure. Slope instabilities definitely involve surface movements. Previous researchers have carried out some studies on deformation of undercut slope model and presented by displacement vectors (Khosravi et al. (2012, 2013)). As displacement vectors show only accumulative movements at each time interval of snap shot before the failure; however, this measurement might not be effective enough to track the onset of slope failure. Therefore, the measurement using velocity vectors is alternatively studied. The physical model of an undercut slope made of Edosaki sand resting on a Teflon plate with fixed excavation width in centrifuge model. Increasing gravitational acceleration until the failure is observed. The movement distributions of the slope surface were recorded through a high-speed VDO camera and analyzed using the image processing software (Flow Expert). This study reveals the sequences of surface movements of an undercut slope in the centrifuge model as well as discussing the comparison of characteristics between velocity vectors and displacement vectors.

2. METHODOLOGY

The physical model was made of Edosaki sand. Basic properties of Edosaki sand are shown in Table 1. The model was divided into two parts as shown in Fig.1, the basal support, and slope part; each of which was compacted to the bulk unit weight 15.3 kN/m^3. The 20 cm wide, 17.5 cm long and 5 cm thick basal support was placed on sandpaper while the 20 cm wide, 22.5 cm long, 5 cm thick slope part was inclined by angle 40°on a Teflon plate for simulating the low friction interface plane. After finishing basal support and slope preparation, the trapezoidal trench was excavated through the basal support to have a base width of 10 cm and a top width of 12 cm as shown in Fig.2. Then, the marking lines were drawn on the surface every 5 cm from the bottom of the slope part for clear observation. High-speed VDO camera was installed above and perpendicular to the model to observe the movements of an undercut slope. Finally, slope deformation was monitored and analyzed using image processing software called Flow Expert; however, the limitation of this software is only 2D analysis. Therefore, the deformation in depth direction and the displacement of sand inside surface cannot be observed.

Table 1 Basic properties of Edosaki sand (*Values from Khosravi et al. (2016))

Water content (w)	10%
Bulk unit weight (γ)	15.3 kN/m^3
Unconfined compressive strength (σ_c)	14.7 kN/m^2 *
Interface friction angle (ϕ_i)	17.5° *
Apparent adhesion (c_i)	0 kN/m^2 *
Internal friction angle (ϕ)	40.9°

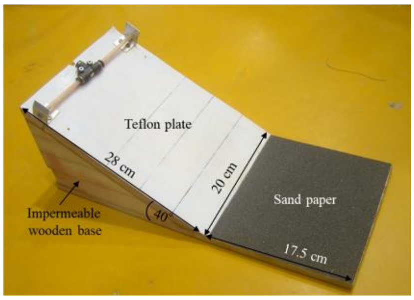

Fig.1 Slope model configuration

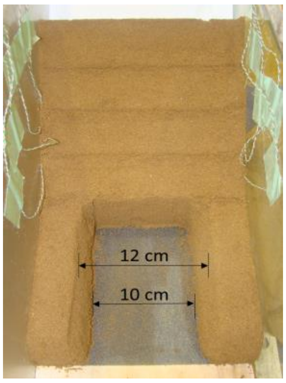

Fig.2 Physical model of undercut slope

Fig.3 Mode of failure

Keywords: Slope stability, Undercut slope, Centrifuge model, Surface movement, Velocity vector
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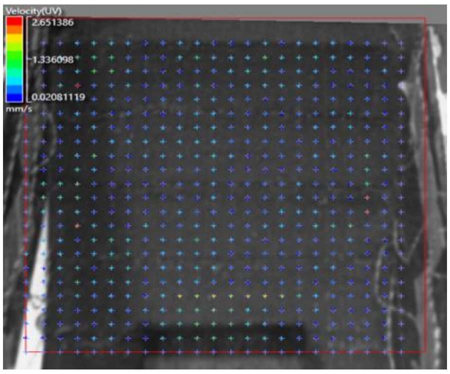
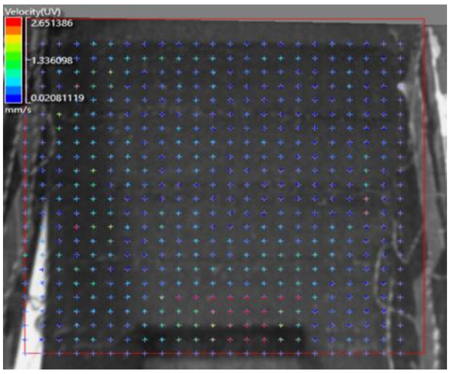
3. RESULTS AND DISCUSSIONS

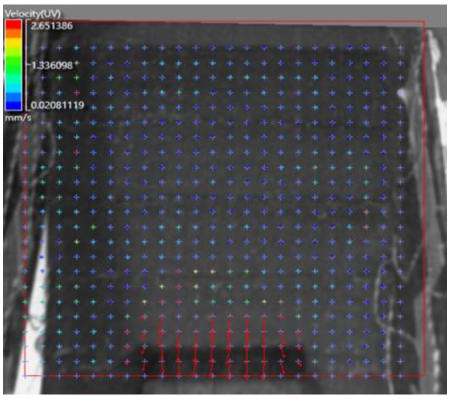
After using the centrifuge model test, failure was observed at 31.4g like an arch failure as shown in Fig.3. Results of image processing software (Flow Expert) observed by a high-speed VDO camera are shown in Fig.4 in the form of velocity vectors. Fig. 4 show the velocity vectors from when the movements were started until a failure observed on the slope. Where t_0 represents the starting time of movement triggering to failure. From Flow Expert, the increasing velocity vectors start from the central part of the slope located above the excavated area of basal support (Fig.4(b)) and spread to the adjacent part until reaching the excavated width (Fig.4(c)). The side supports restrict the model from lateral movement, resulting in symmetrically downward movement. The movements of the detached arch at the center are faster than the lateral part of the arch corresponding to the failure by relative displacement. The stability of the stable scarp in this model could be explained by arch action under the passive condition; the lateral compression is greater than the inclined compression (Khosravi et al. (2013)). The movements of velocity vectors at the central part are straight downward with similar magnitude due to gravity as rigid body motion. The characteristic of velocity vectors is different from the displacement vectors which show the accumulative movement of the slope part. Therefore, the maximum displacement was at the center of the slope above the excavated part. Lateral displacement vectors moved to approach to the epicenter (Khosravi et al. (2012)). After 0.39 s, the detached arch completely failed from stable part (Fig.4(d)).



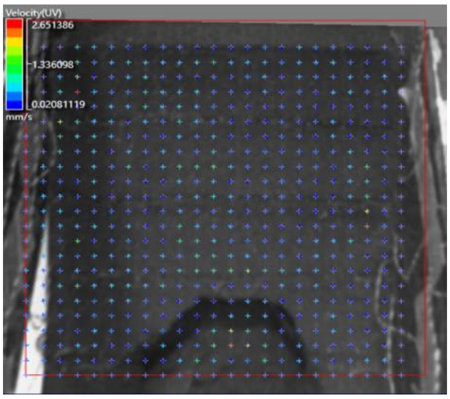
(a) Velocity vectors before failure ($t=t_0$)



(b) Velocity vectors before failure ($t=t_0+0.05$ s)



(c) Velocity vectors before failure ($t=t_0+0.09$ s)



(d) Velocity vectors after failure ($t=t_0+0.39$ s)

Fig.4 Velocity vectors of slope surface in undercut slope

4. CONCLUSIONS

The movements of the slope surface were recorded and analyzed by the image processing software. The velocity vectors start to move downward with the same magnitude from the center and expand to the adjacent part until reaching the excavated width. Although the velocity vectors have partially different in amount and direction from displacement vectors, both measurements show the similar tendency by which the onset of failure can be interpreted.

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