A statistical approach for detection of the formation of slip planes in a dip slope using particle image velocimetry

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Abstract

A physical model is created to understand geotechnical behavior and failure mechanism. For the slope model, the formation of the slip plane is important for the slope failure mechanism. In this research, the slip line on slope models along with the bedding plane was considered by using a statistical approach and particle image velocimetry (PIV) analysis.

Introduction

In general, a high-speed camera is utilized in centrifuge modeling tests to observe movements. The recorded video from the high-speed camera can be calculated to velocity vectors by using particle image velocimetry (PIV). This study aims to apply PIV analysis to the slope model under surcharge loading along with bedding plane and present a statistical approach to detect the formation of slip planes.

Materials and Methods

For the slope stability experiment, the slope models were made of silica sand no.6 and constructed by using the compaction method. Acrylic plates were installed as bedding plane and lateral supports (see Fig. 1). In addition, toe support was launched to prevent movement at the bottom part of the slope. The basic properties of silica sand no.6 and interface properties on acrylic plates are shown in Table 1(Pipatpongsa et al., 2022). For the geometry of the slope model, the angle of the slope, the thickness, the breadth, and the length of the slope were 30°, 60 mm, 209 mm, and 300 mm, respectively. When the slope model was completed, a surcharge load cart would be installed on top of the slope. The weight of the surcharge was gradually increased by adding metal weight until the slope collapsed. In the experiment, the high-speed camera was used to record the movement from the side of the slope model during the loading process. The perspective of high-speed camera video recording before loading is illustrated in Fig.2 Moreover, videos from the high-speed camera were recorded at 200 fps.

Table 1 Basic properties of Silica sand no.6

Bulk density (γ)	13.68 kN/m^3
Water content (w)	10.0%
Friction angle (ϕ)	33.2°
Apparent cohesion (c)	0.57 kPa
Friction angle of roller cart (ϕ_r)	6.1°
Interface friction angle of humid sand on acrylic plate (ϕ_i)	29.4°
Interface adhesion of humid sand on acrylic plate (c_i)	0.26 kPa

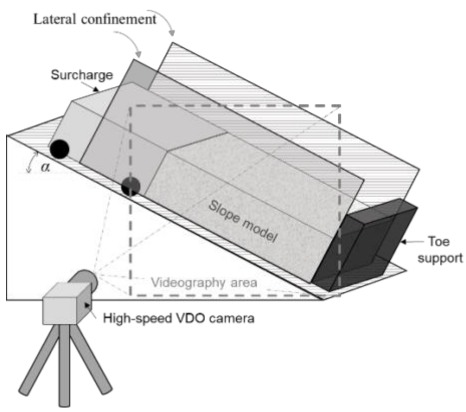

Fig. 1 Installation high-speed VDO camera

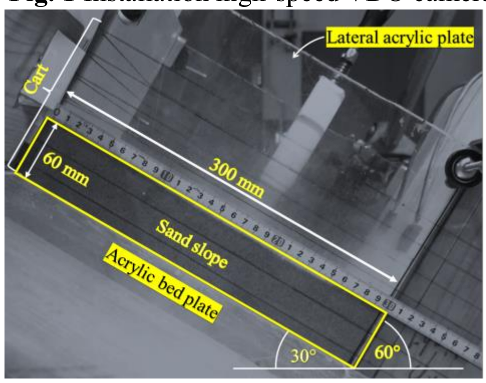

Fig. 2 Slope model compacted on bedding plane and being confined by two lateral supports.

Movement analysis

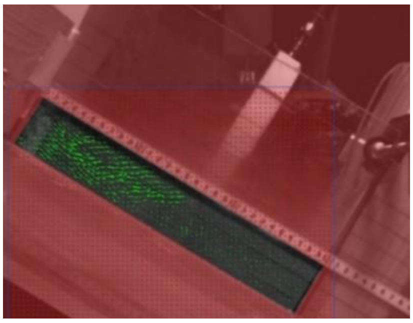

Fig. 3 Velocity vectors ($t=t_0+0.325s$)

The slope movement was calculated from the recorded video by particle image velocimetry (PIV). The movement of the slope model during the loading process is shown in Fig. 3. The green arrows represent velocity vectors that define direction and magnitude. The vectors represent movement in 1 frame(t=0.005s). According to Fig. 3, the PIV result can indicate large movement on the upper part and minor deformations on the lower part. These two parts may be easily distinguished by observation.

$$\Delta r_k = \sqrt{\Delta x_k^2 + \Delta y_k^2} \quad (1)$$

$$\mu = \frac{1}{N}\sum_{k=1}^{N} \Delta r_k \quad (2)$$

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{k=1}^{N}(\Delta r_k - \mu)^2} \quad (3)$$

$$\Delta\mu = \frac{1}{N_U}\sum_{k=1}^{N_U} \Delta r_k - \frac{1}{N_L}\sum_{k=1}^{N_L} \Delta r_k \quad (4)$$

$$\sigma_{UL} = \sqrt{\frac{\sum_{k=1}^{N_U}(\Delta r_k - \mu_U)^2 + \sum_{k=1}^{N_L}(\Delta r_k - \mu_L)^2}{N_U + N_L - 2}} \quad (5)$$

$$CV = \frac{\sigma_{UL}}{\Delta\mu} \quad (6)$$

Where

k position of vector in x-y coordinate

N number of vectors

In this research, a minimum coefficient of variation (CV) is proposed as a statistical approach to detect the formation of slip planes in these slope models by using velocity vectors from PIV analysis. Firstly, the velocity vectors are transformed to deformation in horizontal (Δx) and vertical directions (Δy). Next, Δx and Δy are gathered to deformation magnitude (Δr) as Eq. (1). Mean (μ) and standard deviation (σ) in Eqs. (2) and (3), respectively, are the main component for CV calculation. Mean and standard deviation are separated into two groups due to two different deformations. Different mean and standard deviation are determined by Eq. (4) and Eq. (5). Therefore, the minimum of CV can be calculated as Eq. (6.) In the computation process, nodes A and B are created to separate two groups and find the minimum CV. Thus, the green line between nodes A and B is represented as the slip line and angle (º) (see Fig. 4). According to PIV result provided movement in 1 frame, minimum CV can detect the slip line in each frame.

Result and conclusion

Fig. 5 illustrate the example of calculation for t_0+0.325s (t_0 = time at start moving). The minimum CV shows slip angle of 31.1º. In conclusion, using a video high-speed camera with PIV analysis would be helpful for monitoring the deformation of the slope model. The minimum coefficient of variation (CV) can use to separate two different deformations and can detect slip formation for the slope model in each frame.

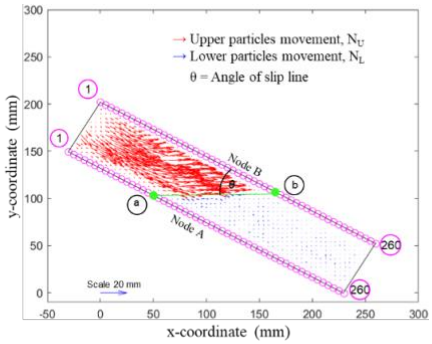

Fig. 4 A detection of the formation of slip planes

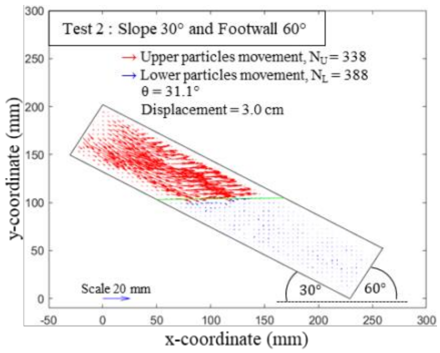

Fig. 5 A result of detection of the formation of slip planes ($t = t_0$+0.325s).

Reference

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2. 加納 武司(2020): 斜面の下盤付近における破壊機構の 研 究 , Bachelor thesis, Department of Urban Management, Kyoto University