Centrifugal modelling of seepage-induced failure in undercut slope

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The technique of geotechnical centrifuge modelling is used to evaluate the stability of undercut slopes subjected to groundwater seepage conditions. Physical models of undercut slope with a shallow depth resting a Teflon plate were carried out with different pre-excavation width and seepage condition for which a water supply system controls. The results show that higher seepage along the bedding plane can induce whole failure of slope and arch-shaped failure. Arching failures involving stress transition from active condition to passive condition during seepage were observed by the change of earth pressure. In addition, the maximum excavation width in undercut slope subjected to seepage is checked and the effect of unconfined compressive strength with different degree of saturation is discussed.

1. Introduction

In the classical trap-door test (Terzaghi, 1936), the percolation of the water through the saturated sand did not seem to interfere with soil arching. In extension to the previous works regarding slope with groundwater seepage conditions (Take et al., 2004), the stability of unsaturated undercut slope involving arching effect subjected to seepage was investigated by centrifugal modelling in this study.

2. Experimental setup and physical modelling

According to some preliminary tests, Edosaki sand with 10 % water content was chosen as material of the model. Edosaki sand which is well-graded sand, thus water leakage in high centrifugal acceleration can be prevented. The model configuration and all sensors are shown in Fig. 1. Dimension of the model (length: 22.5 cm in slope part and 17.5 cm in base part, width: 20 cm, thickness: 5 cm) was set for a size of model container and a slope structure model with suitable capacity of miniature gauges and an applicable range of displacement monitoring using laser sensors.

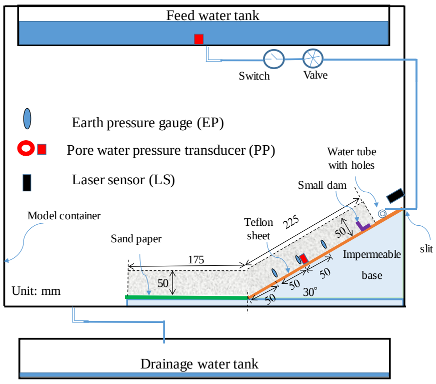
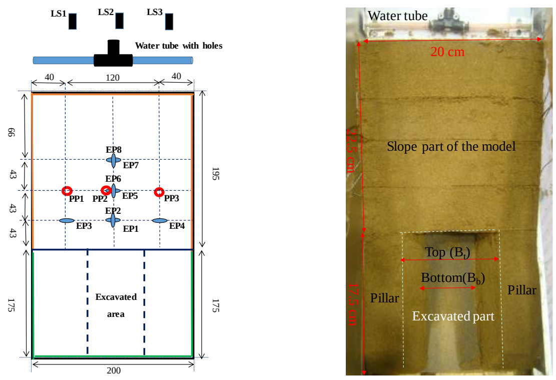


Fig. 1 Model configuration in prototype scale

In the model, 8 earth pressure gauges, 3 pore water pressure transducers and 3 laser sensors were used in order to monitor the stress change and slope movement during seepage (See Fig. 2(a)). A water tank and a tube simulated groundwater seepage from the top of slope by a remote control system. The slope model after preparation is shown in Fig. 2(b) and the experimental conditions are outlined in Table 1.

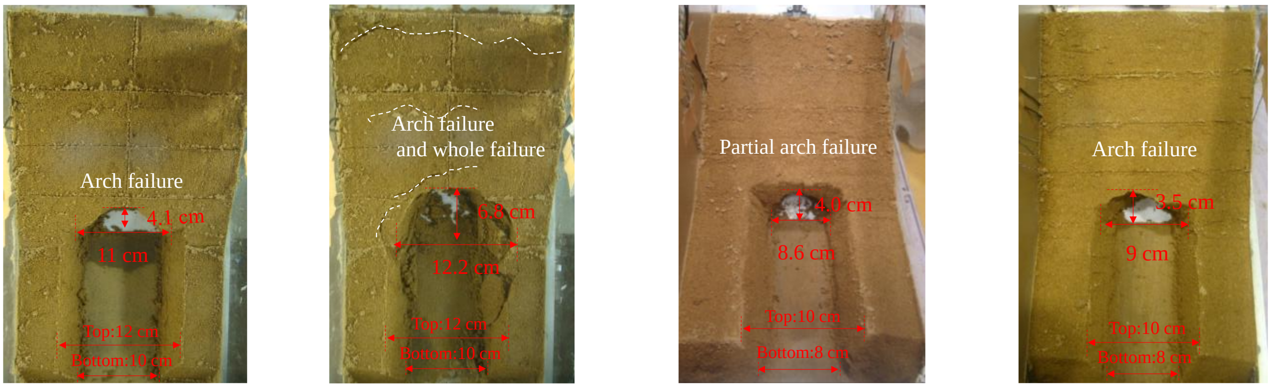


(a) Location of the instrumentations (b) Physical model after preparation

Fig. 2 Slope model with instrumentations

3. Results and theoretical analysis

In Fig. 3, the different failure modes namely, arch failure and whole failure were observed in undercut slope model with different water supply rates and pre-undercut spans, especially the appearance of partial arch failure like a hollow in Test 2 with



(a) Arch failure due to centrifugal force in Test 1

(b) Whole failure due to seepage in Test 1

(c) Partial arch failure due to seepage in Test 2

(d) Arch failure due to seepage in Test 3

Fig. 3 Different failure models in undercut slope models

Table 1 Test conditions of the physical model

Model Test		Test 1	Test 2	Test 3
Water supply rate (mL/min)		299	160	301
Centrifugal acceleration (m/s^2)		30g	30g	30g
Undercut span B(cm)	Top (B_t)	12	10	10
	Bottom (B_b)	10	8	8
	Average	11	9	9

a lower water supply. Based on the results of earth pressure and pore water pressure, the transformation stress condition from active condition to passive condition in undercut slope due to groundwater seepage was observed as shown in Fig. 4. Pipatpongsa et al. (2016) derived the maximum excavation width in undercut slope subjected to full parallel seepage based on arch action. With the fully saturated condition, the maximum width is expressed as follow.

$$B_f = \frac{1}{sin\alpha - (1 - \gamma_w/\gamma_{sat})tan\phi_i cos\alpha} \cdot \frac{\sigma_c}{\gamma_{sat}}$$

Where, σ_c: unconfined compressive strength of sand; γ_{sat}, γ_w: unit weight of saturated sand and water, respectively; B_f: the maximum undercut span in base; ϕ_i: interface friction angle between sand and bedding plane; α: slope angle.

From the equation, the decrease of unconfined compressive strength and the increase of unit weight of sand in saturated condition cause the decrease of maximum width in undercut slope. In addition, the unconfined compressive strength of sand also decreases as the increase of the degree of saturation as shown in Fig. 5.

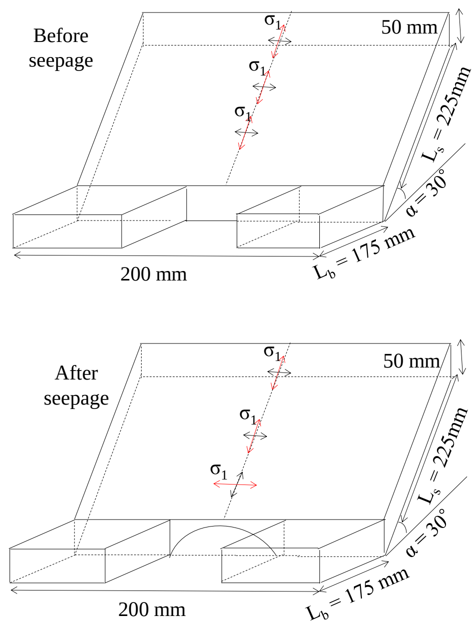


Fig. 4 Stress transformation in slope model (Test 2)

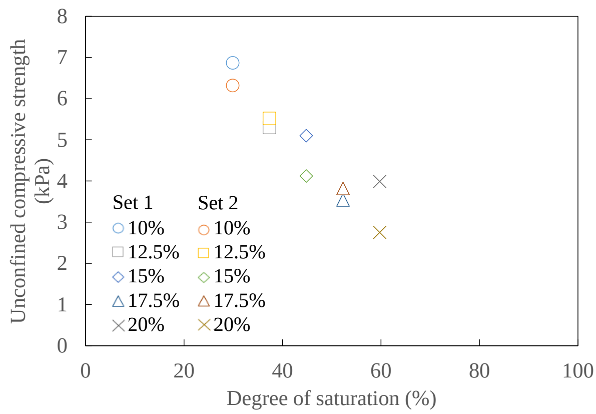


Fig. 5. Unconfined compressive strength of Edosaki sand with different degree of saturation

Reference

Pipatpongsa T, Khosravi MH, Takemura J, Leelasukseree C and Doncommul P (2016) Modelling concepts of passive arch action in undercut slopes. Australian Centre for Geomechanics.