D204

Bearing capacity failure of a foundation near the crest of a slope in centrifugal model test

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1. Introduction

Meyerhof [1] proposed a method for determining the ultimate bearing capacity for continuous foundations on the top of a slope based on foundation failure. While many theories were developed after it [2], experimental verification was relatively rare. Thus, a centrifugal model test was conducted to study its effectiveness.

2. Centrifuge test

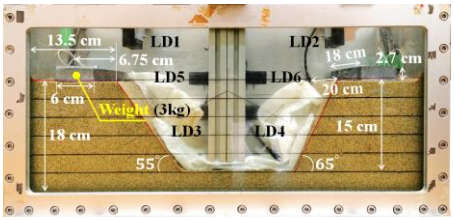


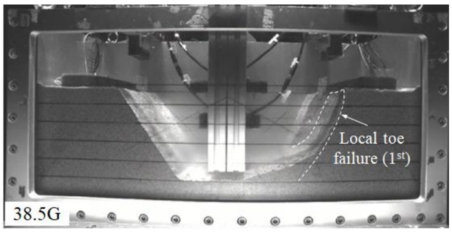
Fig. 1 Photograph of the slope model

The configuration of the centrifugal model in the model scale before the first loading is shown in Fig. 1 above. It consisted of two slope models with the same height (15 cm) and different slope angle (left slope: 55°, right slope: 65°). A single strip weight block was placed near the top edge of each slope, functioning as a continuous shallow foundation. The block was 2.7 cm high and 6 cm wide and had a mass of 3 kg. Its length was 18 cm, smaller than the width of the slope model (20 cm), to avoid additional resisting force caused by the soil chamber at both ends. The distance from the center of the block to the slope crest was 6.75 cm. Six laser transducers were arranged to measure the displacement of the slope. The material used in this test is called Hiroshima sand under 80% compaction degree (optimum density is $1.747 g/cm^3$) with a water content of 8%. It has an internal friction angle $\phi = 31.7^{\circ}$ and an effective cohesion $c' = 3.8\ kPa$.

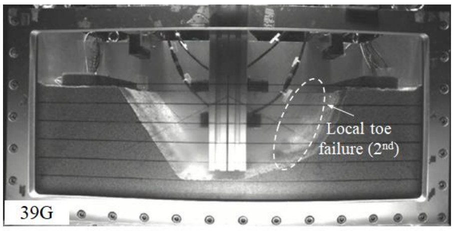
Firstly, steadily increasing centrifugal loading was applied to the model until slope failure. Then, the weight blocks on the failed side were removed and the centrifuge was restarted to induce failure in another slope. If sliding did not occur until 50G, the process was repeated with an increasing number of blocks.

3. Test results

3.1 First loading



(a) First failure on the right-hand side slope



(b) Second failure on the right-hand side slope

Fig. 2 Local toe failures on the right-hand side slope

The slope models remained stable until 38.5G when a local toe failure happened on the right slope near the glass side (as shown in Fig. 2(a)), followed by another local toe failure on the remaining part (Fig. 2(b)). These were not bearing capacity failures because the shallow foundation did not rotate and the sliding surface was in the front of it. This indicates that foundation failure cannot occur if the weight of the foundation is insufficient, and the slope is too steep.

3.2 Second and third loading

As shown in Fig. 3, an additional block was placed on the left slope before the second loading. However, no failure happened until 50G.

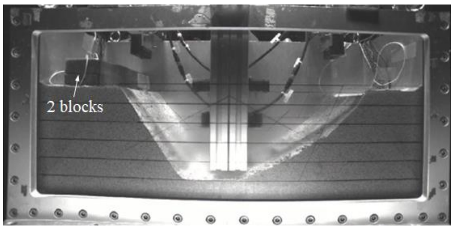


Fig. 3 Model configuration before the second loading

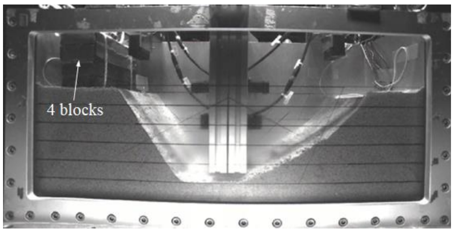


Fig. 4 Model configuration before the third loading

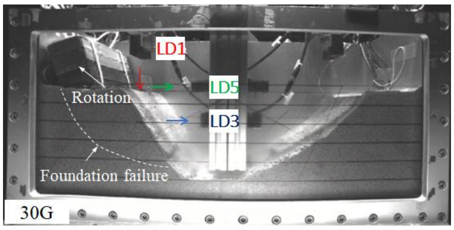


Fig. 5 Foundation failure on the right-hand side slope

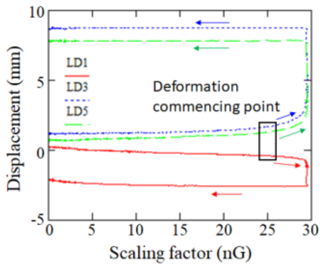


Fig. 6 Displacement of the left-hand side slope

During the third loading, four weight blocks were placed, as shown in Fig. 4. Foundation failure occurred, accompanied by the rotation of the foundation at 30G as shown in Fig. 5. The displacement of the left slope measured by LD1, LD3 and LD5 is illustrated in Fig. 6. Positive and negative values mean that the target point is moving toward or away from the laser sensor, respectively. Slow deformation commenced at 25G. Then, a sudden change happened at 30G for all values, indicating the occurrence of foundation failure.

4. Evaluation the theory of Meyerhof

The equation suggested by Meyerhof [1] is shown in Eq. (1), where γ is the unit weight of the soil and B is the width of the foundation. Two coefficients N_{cq} and $N_{\gamma q}$ can be defined by charts [1]. Here, $N_{cq} = 4.5$, $N_{\gamma q} = 4.8$ and $N_{cq} = 4.1$, $N_{\gamma q} = 2$ for the left slope and right slope, respectively. Foundation failure can happen if the ultimate bearing capacity q_u is smaller than the applied load q by the shallow foundation.

$$q_u = c' N_{cq} + \frac{1}{2}\gamma B N_{\gamma q} \qquad (1)$$

In the centrifuge test, γ in the above equation is multiplied by n (scaling factor) and q can be calculated as $q = nW/A$, where W is the weight of the weight blocks and A is the contact area.

The theoretical predictions are presented in the diagram below for the left slope with four weight blocks (2G) and the right slope with one block (8G), which are significantly smaller than the experimental results. This could be caused by the additional lateral resistance on the two sides of the slope, which is not considered in the classical theory using 2D analysis.

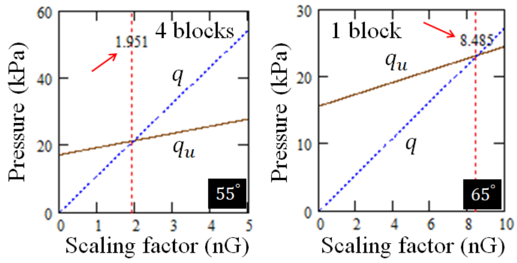


Fig. 7 Predictions by Meyerhof’s theory

5. Conclusion

A gentle slope with a sufficiently heavy foundation on the top is more susceptible to foundation failure, whereas the toe failure dominates in a steep slope. Meyerhof’s theory on foundation failure is proven to be conservative because the slope can withstand a greater load in the centrifuge model than predicted.

Reference

[1] Meyerhof, G. G (1957). The ultimate bearing capacity of foundations on slopes. In *Proc., 4th Int. Conf. on Soil Mechanics and Foundation Engineering*, 1: 384-386.

[2] Kusakabe, Osamu, Tsutomu Kimura, and Hakuju Yamaguchi (1981). Bearing capacity of slopes under strip loads on the top surfaces. *Soils and foundations* 21(4): 29-40.