Effect of shear pin arrangement in undercut slope model using pencil leads

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ABSTRACT

In order to increase the maximum width to which the slope can be undercut, slope stabilization by shear pins is required. In this study, two layout patterns of pencil leads, 2 mm in diameter, were placed into physical models of undercut slope made of a confined block of humid silica sand No.6 resting a Teflon plate. The soil pressure and slope movements during which the slope was undercut from the center line until reaching the failure were monitored by a set of pressure gauges, a digital camera and a high-speed VDO camera. The experimental results revealed that for a given similar number of pencil leads, the layout in vertical row has a relatively higher influence on the stability than that in horizontal row.

Keywords: undercut slope, slope stability, shear pin, physical model, excavation

1 INTRODUCTION

Stabilizing piles are a reinforcement technique that has been applied to improve the stability of slopes [1,2,9]. Design criteria of stabilizing piles are depended on the stage in life cycle at which the slope is excavated; therefore, permanent slopes would require more reinforcement than temporary slopes. Excavation in open-pit mining generally forms unprotected temporary slopes. As the mining process could take many years to complete before in-pit dumping, it becomes essential to reduce the potential risk of slope failure that could impede the mining schedule and cause personal casualty. One type of stabilizing piles known as shear pins is suitable for such temporary slopes due to cost effectiveness and simple construction process. In order to increase the maximum width to which the slope can be undercut, slope stabilization by shear pins is required. However, utilization of shear pins to strengthen undercut slope in surface mining has not been well studied in the past researches [3,7,8]. This study aims to increase knowledge about the failure mechanisms of undercut slope reinforced by shear pins using 1g physical models as well as the influence of shear pin alignment that can assure the maintenance-free performance of undercut slope where excavation is undertaken at the slope toe.

The preliminary experiments [6] have been conducted to optimize the setup of testing procedure and selection of materials. In contrast to the previous study to which screw bolts representing the stiff behavior of piles is employed, pencil leads were chosen to model the brittle behaviors of piles in this study. Experimental procedures established in Kitakata [5] are adopted to examine the influence of shear pins arrangement corresponding to the given number of shear pins. The maximum width of the undercut slope is confirmed by carrying out a certain number of model tests. Different layout patterns of pencil leads, 2 mm in diameter, are placed into physical models of undercut slope made of a confined block of humid silica sand No.6 resting a Teflon plate. Measurements recorded by pressure gauges, digital camera and high-speed VDO camera for particular cases of the model test using the vertical row of 5 pencil leads and the horizontal row of 5 pencil leads are reported in this study. The result of this research might be able to suggest the optimized stabilization in undercut slope by minimizing the necessary number of shear pins at mining sites.

2 PHYSICAL MODELS TEST

2.1 Overview of soil block with pencil leads

The necessary material properties of soils have been investigated thoroughly by Khosravi et al. [4]. The soil pressure and slope movements during which the slope was undercut from the center line until reaching the failure were monitored by a set of pressure gauges, a digital camera and a high-speed VDO camera. Figure 1
schematically shows a typical physical model of a confined block of humid silica sand No.6 resting on Teflon plate that has a low interface fiction stabilized by a number of shear pins. For a case without shear pin, the maximum width mainly depends on the property of silica sand No.6, the interface fiction between the sand and the Teflon plate as well as the property of pencil leads. The model test was built by silica sand No.6 whose basic properties are shown in Table 1 after keeping constant water content and compacting with same method in every test. The humid sand No.6 with the given conditions was compacted on Teflon sheet. According to the direct shear test, the interface friction was 18.5° and adhesion 0.1 KPa. The physical model of undercut slope is divided generally into two parts, the base part (0.8 m × 1.3 m) and slope part (0.4 m × 1.3 m). After tampering the calculated volume of sand in the base and the slope part with a constant thickness of 6 cm, the marking lines were drawn on the surface of sand of both parts every 50 mm as shown in Fig.1. Figure 2 shows a typical position of five shear pins inserted into the slope part after compaction in either horizontal row or vertical row with the equal interval 10 cm.

Table 1. Properties of silica sand No.6

| Parameter                        | Value       |
|----------------------------------|-------------|
| Water content (W)                | 10%         |
| Bulk unit weight (γ)             | 13.68 kN/m³|
| Unconfined compressive strength  | 1.59 kN/m²  |
| Internal fiction angle (ϕ)       | 41.5°       |

Finally, the process of excavation using a blade is initiated form the central line in the base part and gradually extends leftward and rightward in a symmetrical manner until the slope failure happen (see Fig.3). During the excavation, photographs are taken constantly by a digital camera installed above the slope. Once the pencil lead is broken, the light bulb connected with pencil leads by electric wires to the lamp box (see Fig.4) is off; thus the position of broken pencil leads can be observed during excavation. Observations of slope and lamp box at the moment of failure are captured by a high-speed camera.

2.2 Instrumentation in model tests

In order to investigate the changes of stress in the slope part during the excavation, a set of pressure gauges were embedded inside the slope at the designated locations during the stage of slope preparation. In this study, a total number of 10 miniature sensors were installed as shown in Fig.5. Different directions of pressure gauges were inserted in the specified locations to monitor the changes of earth pressure in the slope part with respective to excavation sequences. The digital camera and high-speed VDO camera were installed in front of the slope. Furthermore, particle image velocimetry (PIV) using GeoPIV [10] and image processing software (Flow Expert) were employed to analyze the movements, as shown in Fig.6.
3 RESULTS AND DISCUSSIONS

3.1 The width of excavation

Generally, there are two types of failure occurred during the excavation. The first failure involves local failures and the final failure involves a total collapse of slope. The results of model test are reported in Table 2 and in Figs.7 and 8, showing the first failure and the final failure for cases of 5 shear pins. Comparison between model tests indicates that the span widths of first failure and final failure for slopes reinforced by pencil leads in a vertical row were wider than those in a horizontal row. The final failure width in a vertical row increased around 18.4% than that in a horizontal row. Since a vertical row of pencil leads allows double arch action, the slope is more stable. By observation of lamp box, breakage of a whole pencil leads happened in the first failure of a slope reinforced with a horizontal row of pencil leads. However, two pencil leads were not broken after the final failure of slope reinforced with a vertical row of pencil leads.

Fig. 5. The location and the direction of pressure gauges in an undercut slope (dimension in mm)

Fig. 6. The location of high-speed VDO camera and PIV camera in front of the model test

Fig. 7. The failures of undercut slope with the horizontal row of 5 pencil leads

Fig. 8. The failures of undercut slope with the vertical row of 5 pencil leads
3.2 Stress distribution

By using the 10 pressure gauges, the changes of earth pressures for cases of a vertical and a horizontal pencil leads are shown in Figure 9. In the figures, the horizontal axis represents the undercut widths (B) in the base part and the vertical axis represents the earth pressure measured by each pressure gauge scaled by a product of unit weight (p) and the thickness of the slope (T). The initial scaling pressures before starting the excavation are associated with B=0 mm. By symmetrical removals of soil slice from the base part with a constant rate, the magnitudes of earth pressures changes gradually. The measurements on the pressure gauges located on the two sides of slope (P1, P3, P4, P6) increased slightly from the beginning before showing substantial changes before failure. Generally, P1 and P3 were greater than P4 and P6; however, P1 should be similar to P3 and so do P4 and P6 due to the symmetrical location; non-uniform compaction of slope would cause some initial difference. While the middle and lower part, P2 and P5 decreased immediately after excavation, especially for the P2. P8 implied that excavation has no influence to the direction perpendicular to the slope. It is worth noting that the intersection of the decreasing P5 and the increasing P7 indicates passive arch action as reported by Khosravi [4], but no intersection between P9 and P10; hence arch action is not undergone to the upper part of the slope. Comparison with the slope without shear pins, the undercut width corresponding to the intersection between P5 and P7 is wider than that with shear pins, especially for the vertical arrangement of shear pins. Note that once P2 decreased to the lowest value, further increasing in value can be ignored as P2 was detached from the slope after the first (local) failure.

![Graph](image1)

Fig. 9. Changes of earth pressure in Test 2 and Test 3

3.3 Deformation and velocity at failure

The results of particle image velocimetry (PIV) for analyzing deformation by Geo-PIV [10] are shown in Figs. 10 and 11, where B represents the undercut width of each test. The displacement vectors show the accumulative movements of slope in the stage of excavation just before the failure of the slope of both the first (local) failure and the final failure (total collapse). Both slopes with a horizontal row of pencil leads and a vertical row of pencil leads, the central part of slope above excavated part had moved downward before the first failure. While the two sides had a relatively small movement induced by the excavation; therefore, the loads form the mobilized part of slope as well as the top part of the slope were transferred to the two sides, promoting the arching effect. The slope movements observed in a slope with a horizontal row of pencil leads were obviously larger than those observed in a slope with a vertical row of pencil leads during the excavation process in the middle part of the slope. Unlike a slope with a horizontal row of pencil leads, the slope movements in a slope with a vertical row of pencil leads were separated into two parts before the final failure; therefore, the maximum movement was not at the middle but either the middle of those separated parts. This condition of double arch action is supposed to improve the stability of undercut slope.

![Graph](image2)
of an undercut slope reinforced with pencil leads in a horizontal row and a vertical row, where $t_0$ represents the starting time of failure. The open circles marked in the figures indicate the broken pencil leads that are observed from the lamp box placing on the top of the slope model. The velocity of slope clearly represented the effect of arch action during the first failure. The movement velocity in a detaching arch was relative faster than that in the lateral part of the arch.

In a slope with a horizontal row of pencil leads, the pencil leads had already been broken before the substantial movements of the slope. In order to prevent the reinforcing effect of the broken pencil leads, the broken pencil leads should be moved away but the period of time for failure was so short. After 0.42 s, the detached arch part was thoroughly failed without any pencil leads protecting the undercut slope. However, 5 pencil leads kept stable in a slope with a vertical row of pencil leads before the first failure. Two pencil leads were broken just before the detachment of the leftward arch after 0.48 s; therefore, these two pencil lead helped refrain the movement of the slope. Another observation is that the failure of two pencil leads immediately changed a double arch action to a single arch action with the elapsed time 0.20 s after two pencil leads had broken. Even after the first failure, there were still 3 unbroken pencil leads on the slope, leading to a good explanation for the wider width of final failure than a slope with a horizontal row of pencil leads.

Figures 12 and 13 show the velocity vectors observed by a high-speed VDO camera with image processing technique at the stage during the first failure.
4 CONCLUSIONS

In this paper, stabilizing effects of pencil leads in vertical and horizontal arrangement on the sand slope resting on a low interface Teflon plane was investigated by physical models. The pressures changes and velocity of the slope were recorded by 10 different positions of pressure gauges and high-speed VDO camera, respectively. The PIV technique was also used to monitor the movements of the slope.

By excavation at the central part of the base slope, both excavation widths corresponding to the first failure and the final failure of slope reinforced by pencil leads is much wider the slope without pencil leads. Besides, the vertical arrangement of pencil leads shows more effective ability of protecting the slope than that of the horizontal one.

According to results of stress distribution, movement and velocity of the slope, it is evident that the slope becomes stronger as the pencil leads prevent the sand block form slipping down in some extents and the enhance the effect of arch action.

In summary, installing shear pins is considered to be a useful technique for increasing the stability of undercut slope, especially in the vertical arrangement.

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