New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)

Surface holding conditions of reinforced slope and slope stability

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ABSTRACT: A series of the direct sheer tests and model slope failure tests performed to investigate the surface holding effect of reinforced slope on the slope stability. As the results, it was confirmed that the shear force increased gradually as improving surface holding condition, and the bending and tensile strains of rock bolts increased as increasing the holding effect of slope surface. The shallow slope failure can be restrained by increasing holding effect of slope surface. The proposed reinforced earth method with the holding effect of slope surface was effective to stabilize the slope.

1 INTRODUCTION

In recent years, various reinforced earth methods for natural and cut slopes are proposed (e.g. Kusumi et al., 2002). The authors also proposed a new reinforced earth method which was composed of five items such as rock bolts, cup plates, pressure plates, steel wing plates and tie rods as shown in Figure 1. The rock bolts are used to stabilize a slope, and cup plates are used to fix rock bolts on the slope. Four steel wing plates are connected with a cup plate and put on the surface by a pressure plate. Tie rods connected the top of rock bolts. By combining these items, this reinforced earth method has a holding effect of slope surface, which is an advantage of the proposed reinforced earth method. However, the surface holding effect on the slope stability has not been fully clarified.

In this paper, a series of the direct sheer tests and model slope failure tests are performed to investigate the surface holding effect of reinforced slope on the slope stability. Direct shear tests are performed to investigate the reinforcing mechanism of the proposed reinforced earth method. Model slope failure tests are performed to investigate controllability of the shallow slope failure by the proposed method. The holding effect of slope surface on slope stability is discussed through the both test results.

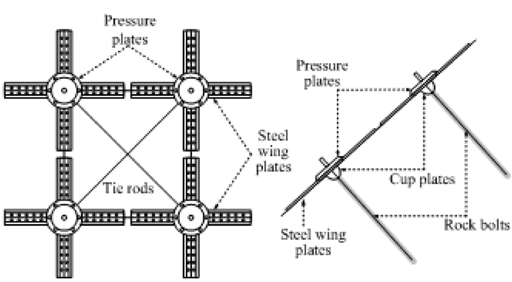


Figure 1. Schematic illustration of the proposed reinforced earth method.

2 DIRECT SHEAR TEST

2.1 *Test procedures of direct shear test*

The authors carried out a series of direct shear test to investigate the role of every items used in the proposed method. Figure 2 shows shear test apparatus used in this study. The soil box is formed by 20 steel frames. The inner size of soil box is 300 mm in length, 300 mm in width, and 410 mm in depth. Tooura sand was used as test sample to make model ground, and the model ground was prepared for the relative density of about 75%. In the direct shear tests, middle part of the soil box is sheared and the shear area is 100 mm between 145 mm and 245 mm from the surface as shown in Figure 2, and pushed out with 1.0 mm/min. Main items of the proposed method were truthfully modeled in the shear test. Rock bolts were modeled by brass bars, the diameter is 3.0 mm and the length is 320 mm, steel wing plates by acrylic boards which have 100 mm × 100 mm in length, 20 mm in width and thickness of 2 mm, and tie rods by brass bars, the diameter is 2.0 mm. And the model rock bolts have the screwed heads. Edges of a tie rod are equipped with

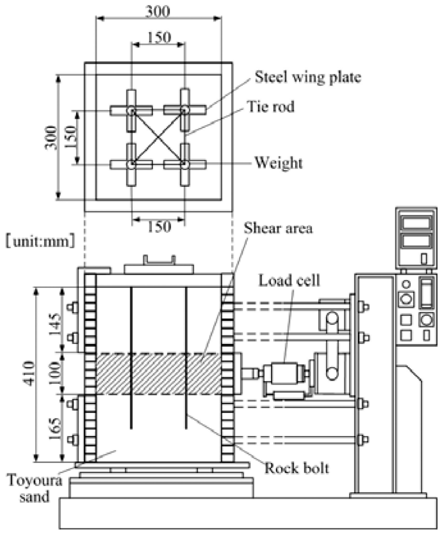


Figure 2. Direct shear test apparatus.

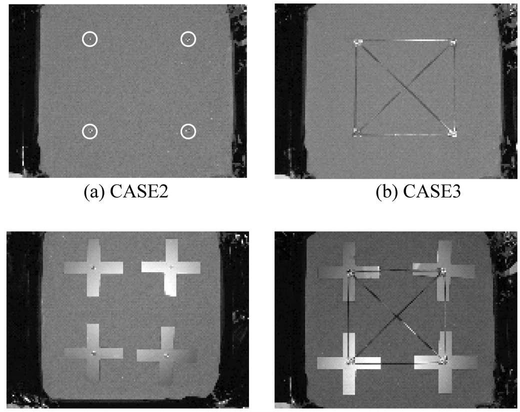
rings by which the heads of rock bolts can be connected. Details of the direct shear test are referable in the references (Kawajiri et al., 2005; Kawajiri et al., 2006).

2.2 *Test cases and test conditions*

Five cases of shear tests are performed, CASE1 is performed without any reinforcements, CASE2 is with rock bolts which are located in the white circles in Figure 3. CASE3 is with rock bolts and tie rods, CASE4 is with rock bolts and four steel plates, CASE5 is with rock bolts, tie rods, and four steel plates. Figure 5 shows appearances CASE2 to CASE5 in the model ground. Figure 4 shows a cross-sectional view of the model ground in the soil box. In CASE4 and CASE5, the weight of 200 g was put on every model steel plates to press down the ground surface. In addition, six strain gages are installed on rock bolts to measure tensile and bending strain. The direct shear test in this study was selected because the difference of surface condition on the shear test results was clearer than conventional direct shear test (Kawajiri et al., 2005).

2.3 *Test results*

Figure 5 shows relationship between shear force and displacement in all cases. As shown in this figure, the shear force in CASE2 to CASE5 is much bigger than that in CASE1. It is confirmed that the shear force increased by combining every items. In particular, the shear force in CASE5 is the biggest in all cases, and twice as big as that in CASE1 at the displacement of 20 mm. Thus, holding effect by combining every items contributes to an increase in shear force.



(a) CASE2 (b) CASE3

(c) CASE4 (d) CASE5

Figure 3. Appearance of direct shear tests in CASE2 to CASE5.

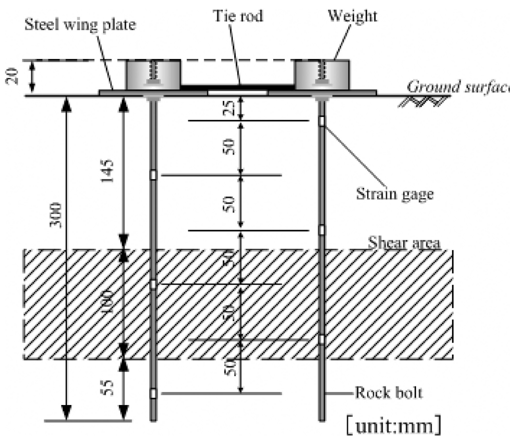


Figure 4. Cross-sectional view of the model ground.

Figure 6 shows the distribution of the tensile strains in CASE2 to CASE5 at the displacement of 20 mm. As shown in this figure, the tensile strains increase in the shear area. The tensile strain at 225 mm from ground surface in CASE4 obviously increase, it means that rock bolts with steel plates effectively work as reinforcements. While the tensile strain at the same position in CASE5 is smaller than that in CASE4, it attributes that tie rods distribute and average the load to all rock bolts. In addition, the tensile strain in CASE2 did not increase around surface area, although those in CASE3 to CASE5 increase. This is because holding effect by combining all items contributes to the increase in surface area. Figure 7 shows the distribution of the bending strains in CASE2 to CASE5 at the displacement of 20 mm. As shown in this figure, the bending strains increase in the shear area. And

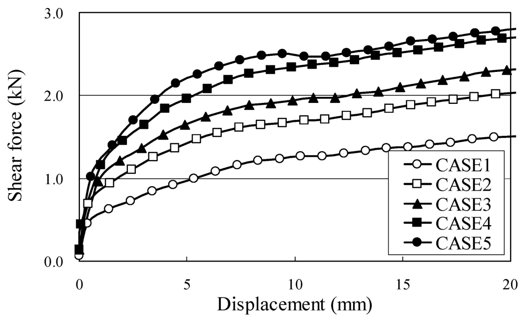


Figure 5. Relationship between shear force and displacement.

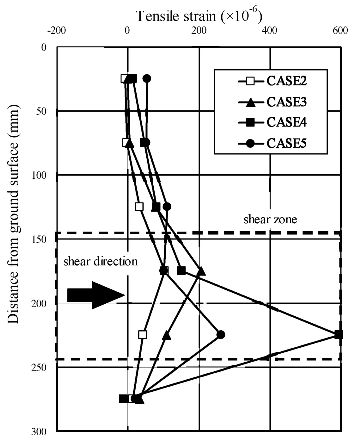


Figure 6. Tensile strains at displacement of 20 mm in CASE2 to CASE5.

in the shear area, the bending strains in CASE3 to CASE5 almost equal to that in CASE2, but in surface area, those in CASE3 to CASE5 are markedly smaller than that in CASE2. It seemed to be the holding effect of surface area by tie rods and steel plates. Thus, the holding effect of slope surface contributes to stabilize the slope judging from the behavior of bending strain.

3 SLOPE FAILURE TESTS

3.1 *Test procedures of slope failure test*

The surface holding condition was recognized as important factor to stabilize slope failure. The authors are carried out to investigate failure pattern of reinforced slope with and/or without surface holding effect.

In this study, the decomposed granite soil was used as test sample. The model slope with 1202 mm high, 1600 mm wide and 1700 mm long was constructed in

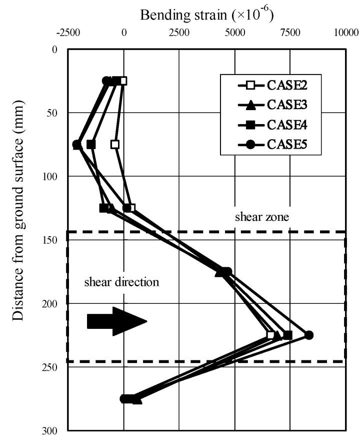


Figure 7. Bending strains at displacement of 20 mm in CASE2 to CASE5.

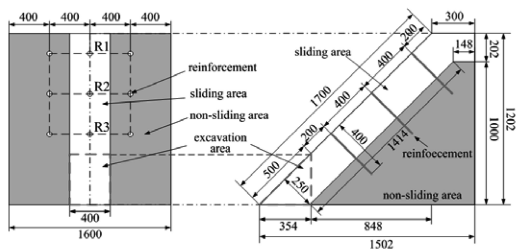
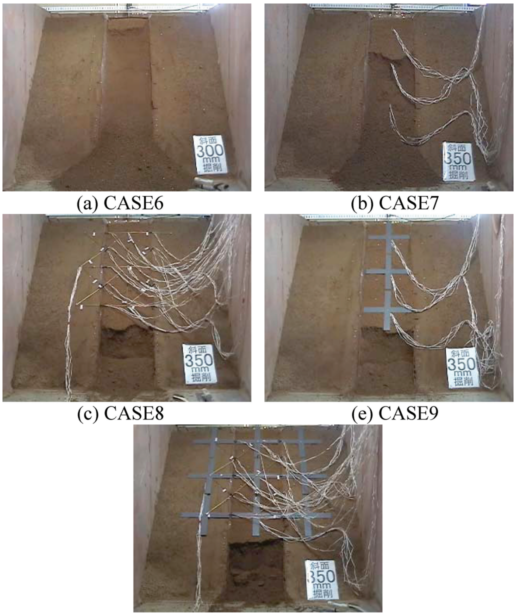


Figure 8. Appearance and schematic diagram of the model slope failure test.

the wooden box. Chloroethylene sheets were stuck on the wooden box to prevent absorption of water and thin rubber sheets and silicon grease were used as the lubrication. Figure 8 show the appearance and schematic diagram of the model slope, respectively. The model slope was divided into two areas, which were sliding area and non-sliding area. Thin Chloroethylene sheet was laid between two areas and the soil mass in the sliding area slid on the sheet. Decomposed granite soil in the non-sliding area was compacted to about 1.80 g/cm^3 of wet density with water content of about 14% which was the optimum water content. While decomposed granite soil in the sliding area was compacted to around 1.35 g/cm^3 of wet density with water content of about 7.5%.

3.2 *Test cases and test conditions*

In the model slope failure tests, a 1/5 model slope was made by a step construction method. Shallow slope failure was demonstrated by the excavation of the slope toe in the sliding area. The excavation area in the sliding area was shown in Figure 8 and every 50 mm



(a) CASE6 (b) CASE7

(c) CASE8 (e) CASE9

(e) CASE10

Figure 9. Slope failure pattern in CASE6 to CASE10.

of slope was excavated until 500 mm. Main items in the proposed method were modeled as faithfully as possible. Rock bolts were modeled by brass bars, which diameter is 3.0 mm and the length is 400 mm, steel plates by iron cross-shaped boards which have 380 mm × 380 mm in length, 50 mm in width and thickness of 2 mm, and tie rods by brass bars which diameter were 2.0 mm.

A series of slope failure test was carried out in conjunction with direct shear tests. Normal shallow slope failure without any reinforcements was demonstrated in CASE6, slope failure with rock bolts in CASE7, slope failure with rock bolts and tie rods in CASE8, slope failure with rock bolts and steel plates in CASE9 and slope failure with proposed method in CASE10.

Schematic arrangement of rock bolts in the slope failure test was also shown in Figure 8. Rock bolts were installed into non-sliding area. The settlement at the slope top and deformation of slope were measured at every excavation stages.

3.3 *Test results*

Figure 9 shows slope failure pattern of each case at the final excavation stages in which final excavation length were 300 mm in CASE6 and 350 mm in other cases. Whole slope failure was occurred in case B-1 and not occurred in other cases. It was clear that whole slope failure can be inhibited by reinforcements by

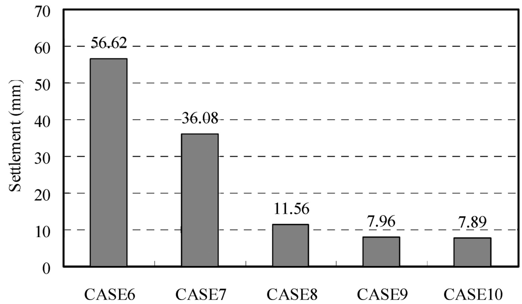


Figure 10. Final settlement at top of slope at final excavation stages.

comparing CASE6 and CASE7, because slope failure was limited at the middle and low part of slope in CASE7. In addition, surface slope can be hold by members of tie rods, steel plates and both combination as shown in CASE8, CASE9 and CASE10.

Figure 10 shows the final settlement at top of the slope at the final excavation stages. As mention above, final excavation length was 300 mm in CASE6 and 350 mm in other cases. The final settlement in CASE7 was much smaller than that in CASE6, which was due to confliction effect of reinforcements. In addition, the settlement in CASE7 was much bigger than that in CASE8, CASE9 and CASE10. It was due to the surface holding effect of members such as tie rods, steel plates and their combination. From view point of surface holding effect, the slope stability increases as increasing the surface holding effect.

4 SURFACE HOLDING CONDITIONS AND SLOPE STABILITY

It was confirmed through the direct shear tests and model slope failure tests that surface holding conditions have a clear relationship between slope stability.

It was observed that shear force, tensile and bending strains increased as increasing surface holding effect in the direct shear tests and shallow slope failure could be controlled by changing the surface holding conditions in the model slope failure tests. Judging from both test results, shallow slope failure, which often becomes a trigger of whole slope failure, can be restrained by increasing holding effect of slope surface. Therefore, the proposed reinforced earth method with the holding effect of slope surface was effective to stabilize the slope.

5 CONCLUSIONS

In this paper, we proposed a new reinforced earth method, and performed a series of direct shear tests and model slope failure tests to investigate the holding effect of slope surface and the role of each part.

As the results, it was confirmed that the shear force increased gradually as combining each item. The tensile and bending strains of rock bolts increased as increasing the holding effect of slope surface. The shallow slope failure can be restrained by increasing holding effect of slope surface. Judging from both test results, the shear force and the holding effect of slope surface were increased by combining all items. The proposed reinforced earth method with the holding effect of slope surface was effective to stabilize the slope.

REFERENCES

Kusumi, H., Iwai, S., Fukumasa, T. and Kitamura, Y. (2002): Fundamental research on slope stability method of the natural slope considered the landscape and tree, Proceeding of 11th Japan Rock Mechanics Symposium, I-08.

Kawajiri, Y., Nabeshima, Y. and Kigoshi, S. (2005): Experimental study on a reinforced earth method with holding effect of slop surface, Proceedings of the 4th Korea/Japan Joint Seminar on Geotechnical Engineering, 153–158.

Kawajiri, Y., Nabeshima, Y., Tokida, K. and Kigoshi, S. (2006): Variation of reinforcing efficiency due to changing the surface holding conditions, Proceeding of 41st Annual Meeting of Japanese Society, 677–678.