A consideration on some reinforcing effects of small diameter steel pipes with blades on stabilization of cover soil on embankment slope

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ABSTRACT

For the widening and slope surface repair of the embankment, cover soil is placed on the existing embankment slope. To stabilize the cover soil, the slope stabilization method we have developed for existing embankments using small diameter steel pipes with blades is adopted. Since the pipes are perforated in order to provide drainage function, the pipes are installed laterally. In this study, to verify reinforcing effects of laterally installed steel pipes into the embankment, unloading experiments are carried out in the geotechnical centrifuge and on an actual embankment.

Keywords: slope stability, steel pipes with blades, reinforcing effect, unloading experiment

1 INTRODUCTION

When cover soil is placed on an existing embankment slope to widen and repair the embankment, it is required to stabilize the slope surface and to improve the drainage performance. The authors have developed a slope stabilization method using the small diameter perforated steel pipes with blades as shown in Fig. 1. (Hereinafter, referred to as steel pipes.) These are installed in lateral not only to reinforce the slope but also to provide drainage to the slope.

In this study, to examine reinforcing effects of the laterally installed steel pipes on stabilization of the cover soil, we carried out the centrifuge model tests and field test on the actual embankment.

Fig 1. Steel pipe with blades and strainers.

2 REINFORCING EFFECTS AND ITS MECHANISM

Tatsuoka and Hamada (1984) observed the strain distribution in the model embankment during loading tests and proposed effective arrangement of the reinforcing materials. Jewell and Pedly (1990) showed a variety of design models of reinforcing materials. Muramatsu et al. (1995) examined the reinforcing effects by unloading experiments on the model embankment and concluded that (a) the pull-out resistance of reinforcement and (b) slope protection method by either bearing plate or slope frame influence each other.

Conventional preventive pile for landslide is installed vertically and bending stiffness of the steel pile contributes to pining of the slip plane. Its design method (PWRI, 2007) has been established and its reinforcing effects have been well studied. Mochida et al. (2015) pointed out that the bearing plate and steel pipe restrain the movement of the soil below the reinforcement, leading to increase in confining pressure near the reinforcement and hence increase of the resistance against sliding at the interface between cover soil and original embankment. Figure 2 shows expected reinforcing effects of the steel pipes except drainage function. Since no pre-stress is given to the reinforcement in this method, displacement of the cover soil is needed to mobilize the resistance of pipe against sliding. When the pull-out resistance of the pipes is mobilized, factor of safety against sliding, $F_s$, can be expressed by the Equation (1) based on the limit equilibrium method. When the cover soil displacement becomes large, the steel pipes in the cover soil is bent downward with increasing the confining pressure of the soil below the pipe. At this time, since the shear resistance of pipes and increase of frictional resistance at the cover soil-original embankment interface due to increase in the confining pressure (tightening effect), the factor of safety can be expressed by Equation (2).

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second and third rows from the bottom, the model bearing plate made with aluminum plate was attached. Aluminum block was placed at the toe of the slope and the block was connected to the jack inside a steel strong box. Slope failure starting from the slope toe was modeled by pulling the block outwards under the centrifugal acceleration of 40G.

3.2 Results and discussions

Two tests were carried out; Case SF with the size of the bearing plate of 10×10mm (400mm) and Case LF with the size of 20×20mm (800mm). Figure 4 shows the front view of the slope at the time of slope failure. In Case SF, the cover soil slipped through between the reinforcing bars H and I. On the other hand, in the Case LF, such a local failure could not be observed.
4   SLOPE UNLOADING EXPERIMENT ON ACTUAL EMBANKMENT

4.1   Experiment outline

Test embankment shown in Fig. 8 was constructed with installing actual steel pipes. In the test, instability of the slope starting from the slope toe was modeled by excavating the slope below the steel pipes. The embankment height was 8m, the slope was 1V:1.33H, and the slope was covered with silty soil in a thickness of 0.6-1.0m on the original embankment. The original embankment mainly consisted of gravel-mixed sandy soil. Properties of these soils are shown in Table 2. The cover soil was divided into the reinforced area with installation of steel pipes and no reinforced area by partition plates. The steel pipe diameter was 76.3mm, blade outer diameter was 176mm and length of pipe was 5.8m. These pipes were installed in the lower half of the slope in three rows arranged in a staggered pattern at 2m interval, and the two steel pipes for the measurement were installed in just above the area to be excavated at unloading experiment (GL+1.5m) at an elevation angle 5 degree.

Fig.8. Test embankment overview.

Table 2. Properties of soil in test embankment.

|                     | Original embankment | Cover soil |
|---------------------|---------------------|------------|
| Soil particle density | $\rho_s=2.72\text{g/cm}^3$ | $\rho_s=2.51\text{g/cm}^3$ |
| Wet density         | $\rho_t=1.57\text{g/cm}^3$ | $w=38.1\%$ |
| Cohesion            | $c_d=39.3\text{kN/m}^2$ | $c_u=17.1\text{kN/m}^2$ |
| Internal friction angle | $\phi=39.2\text{degree}$ | $\phi=35.6\%$ |

Fig.6. Bending moment.

Fig.7. Change of reaction at slope toe.

Figures 5 and 6 show change of the axial force and bending moment per unit width with the block movement. The values are in prototype scale. In both cases, axial forces increases from the start of the block movement, while bending moments starts increasing from the block movement of about 20-30 mm, only in Case SF. The relationship between the reaction at the toe and block movement is shown in Fig. 7. The initial reaction at the toe was 26kN/m in both cases. With block movement, reaction increases in Case SF, while it decreases down to 10kN/m in Case LF. In this experiment, since the cover soil could not be self-standing, i.e., the cover soil slipped in the case without reinforcement, decrease in reaction at the toe in Case LF indicates that the steel pipes and bearing plate resist against sliding of the cover soil. For example, when the block displacement is 88mm, the resistance provided by the reinforcement is $\Delta R_f=15\text{kN/m}$. Using the Equations (1) and (2), if the cover soil weight $W$ is constant and $c=0$, the resistance provided by the reinforcement can be obtained as follows:

$$-\Delta R_f\cos \theta + \Delta R_s\sin \theta \tan \phi + \Delta R_c \cos \theta + \Delta R_s \sin \theta + \Delta R_t \tan \phi$$

At this moment, as the change in axial force and estimated shear force are $\Delta R_c=3.7\text{kN/m}$ and $\Delta R_s=1.7\text{kN/m}$, the resistance due to the tightening effects can be estimated as $\Delta R_f=3.6\text{kN/m}$.

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4.2 Results and discussions

In the experiment, the slope toe below GL+1.2m was excavated to overhang using a backhoe and movement of the targets on the slope were measured. Figure 9 shows the slope immediately after the overhang excavation. The cover soil at unreinforced area collapsed immediately after the overhang excavation, while the cutting surface of the cover soil at reinforced area was self-standing. At this moment, tensile force obtained from the strain gauges was 0.08kN and maximum bending moment was 0.04kN·m in the steel pipe in the reinforced area, which are very smaller than the predicted value.

Based on the failure mechanism of the slope in the unreinforced area, collapse mechanism of the slope is assumed as shown in Fig. 10. Since the length of slip surface was 1.5m and \( c \) was 17kN/m\(^2\) in the laboratory test, estimated resistance against falling off of the overhanging portion \( (W = 13.3kN/m) \) was \( 1.5 \times 17 = 25.5kN/m \). Despite the sufficient resistance of the cohesive cover soil against falling off of the overhang portion, the overhang portion was collapsed in the unreinforced area.

Possible reason for this is that moment induced by overhanging of the soil mass caused cracking from the slope surface and sufficient resistance could not be provided. On the other hand, in the reinforced area, the overhang portion was self-standing because formation of crack was prevented by tensile resistance of the steel pipes.

5 CONCLUSIONS

In this study, to examine some reinforcing effects of the laterally installed steel pipes on slope stabilization of the cover soil, centrifugal centrifuge model tests and field test on an actual embankment were carried out. Findings obtained from this study are as follows:

- Centrifuge model tests confirms that resistances provided by steel pipes, namely pull-out resistance, shear resistance and tightening effect caused by downward displacement of the steel pipe and bearing plate are mobilized when the cover soil on the embankment slope is displaced.
- Slope unloading experiment on the actual embankment reveals that laterally installed steel pipes minimize formation of cracks on the slope surface even without bearing plate.

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