Experimental study of the effect of surface net on rock bolt slope stabilization with facing plate

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ABSTRACT

Rock-bolt with individual facing plate (Inoue and Iwasa, 2001) is one of soil nailing methods against relatively shallow sliding failure. Rock-bolts are inserted with grout in a slope, and stiff facing plates are attached at the bolt heads to cover the slope surface with a certain preloading. When slope deformation occurs, additional tensile resistance would be mobilized to stabilize the slope. In this study, dynamic centrifuge tests were conducted to scrutinize the effect of surface geo-net on rock-bolt slope stabilization with facing plate. In this paper, the details of the dynamic centrifuge model test system and the results were described, and the effect of the geo-net to increase the bearing capacity of the facing plates and prevent local surface failure was discussed.

Keywords: soil nailing, slope protection, geo-net, centrifugal model test

1 INTRODUCTION

Rock-bolt with individual facing plate (Inoue and Iwasa, 2001 and Nakamoto et al, 2015) is one of soil nailing methods against relatively shallow sliding failure. Rock-bolts are inserted with grout in a slope, and stiff facing plates are attached at the bolt heads to cover the slope surface with a certain preloading. When slope deformation occurs, additional tensile resistance would be mobilized to stabilize the slope as shown in Fig. 1. To study the reinforcing effect and the resistance force mobilization of this kind of method, many static loading tests have been done using both small scale 1g physical models and centrifuge models (Hayashi et al. 1986, Nakamoto et al., 2018). From the dynamic centrifuge model tests on the reinforced slopes, Nakamoto and Takemura (2017) investigated the effects of plate size, bolt spacing, and bolt installation angles. Nakamoto et al. (2017) also found that plate bearing failure and local surface failure are critical failure mechanisms for the slope with relatively small strength. Therefore increasing the plate bearing capacity and preventing the local failure are considered to increase the seismic stability of the reinforced slope and the placement of geo-net on the slope surface could be one of options for these. In this study, dynamic centrifuge tests were conducted to scrutinize the effect of surface geo-net on rock-bolt slope stabilization with facing plate.

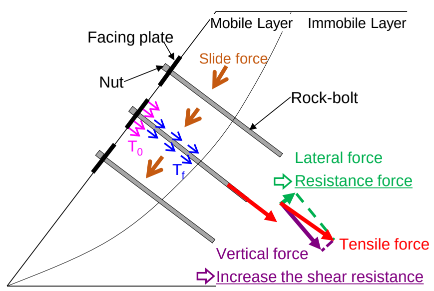

Fig. 1. Reinforcement mechanism of rock-bolt with facing plate

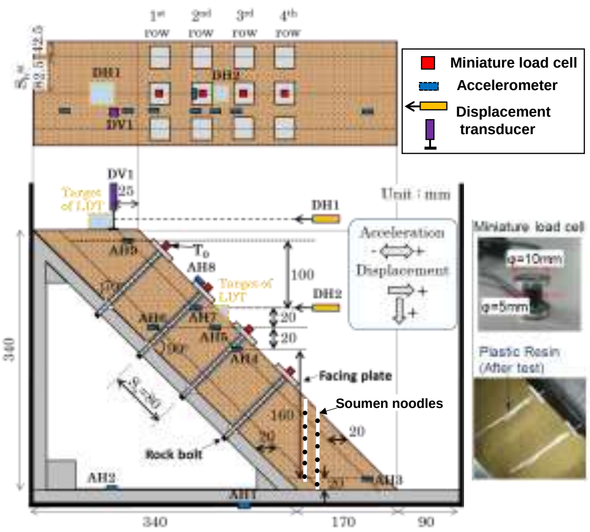

Fig. 2. Model setup, test parameters and locations of sensors.

2 CENTRIFUGE MODEL TESTS

2.1 Model preparation and test conditions

Fig. 2 shows the model setup used in this study. In the tests, a relatively weak mobile layer on a rigid immobile base was modeled. The slope base is an

Table 1. Physical and mechanical properties of sand used for the model slope.

Specific gravity: G_s	2.72
Mean grain diameter: D_{50}	0.27mm
Uniformity coefficient: U_C	28
Bulk density: ρ_t	1.7-1.76g/cm^3
Water content : w	14.5-17.4 %
Degree of compaction: D_c	85-90 %
Friction angle*: φ'	36 - 37º
Cohesion*: c'	2.8 - 3.3kPa

*: Drained triaxial compression (σ_3=25–100kPa)

Table 2. Model test conditions (prototype scale).

Test case	Facing plate width	Bolt Placing	Geo-net	Copm. Degree	Maximum Input Amplitude
Case1	—	—	—	—	11.1g (444 gal)
Case2	20mm (0.5m)	80mm (2m),	No	85%	12.3g (492 gal)
Case3	20mm (0.5m)	80mm (2m)	No	90%	17.6g (704 gal)
Case4	20mm (0.5m)	80mm (2m)	Lattice	85%	17.8g (713 gal)
Case5	20mm (0.5m)	80mm (2m)	Whole Surface	90%	14.4g (575gal)
Case6	30mm (0.75m)	80mm (2m)	No	85%	19.0g (760 gal)

aluminum box with 45 degrees slope angle, which has 16 tapered holes with 80mm and 160mm interval on the slope surface. The base was fixed in an aluminum made model container with inner dimensions of 400mm in depth, 600mm in length and 250mm in width. Silica sand No.6 was pasted on the slope base surface to create a rough condition. In the preparation of the mobile slope soil layer, Edosaki-sand sand (Table 1) was compacted horizontally from the bottom of the container layer by layer. After the compaction, the front and back walls were detached and then the compacted soil was cut to the slope with 45 degree inclination angle using a template. After soumen-noodles were placed on the front slope surface for the visual observation of the slope displacement, the walls were attached to the model container. In the cases with reinforcement, 3 mm holes were augured in the normal direction to the slope surface to the tapered hope in the base and then model rock bolts were inserted in the hole. The model rock bolts was 3mm diameter brass screw rods with plastic resin pated on the surface to simulate grouting used in the real case. 2mm thick aluminum made model facing plates were placed on the top of the bolts and the both ends of the bolts were fixed by nuts. Miniature load cells were fixed at the top of four bolts to measure the facing plate resistance. Details of model preparation is explained in Naokamoto et al, (2017). The rock bolt were installed in a square alignment of spacing about 40mm. Geo-net placements (elongation stiffness of 500N/m (12.5kN/m in prototype scale) with lattice pattern and whole surface were modeled as shown in Fig.3. The conditions for the six tests presented in this report are summarized in Table 2. It should be noted that due to the disconnection of the geo-net to the front and back wall of the model container, tensile forces could not be modeled in the geo-net at the both ends (broken line circles in the figure). Furthermore, the facing plates cannot be provided at the lower portion of the slope (slide line circle) due to the difficulty in installing the bolts (See Fig.2). These conditions deteriorate the reinforcement effect.

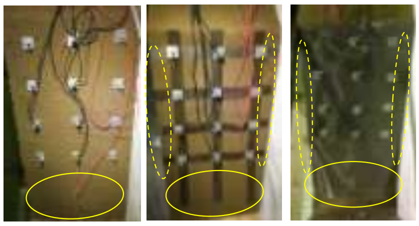

Fig.3. Reinforced slope surface (facing plate and geo-net)

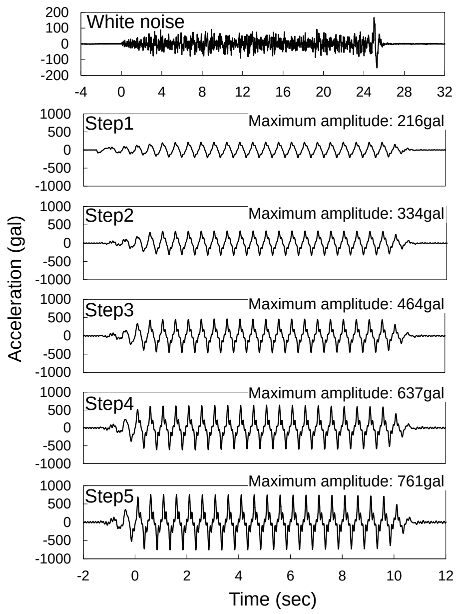

Fig. 4. Example of input waves.

2.2 Dynamic Centrifuge tests

Having completed the model setup, 40G centrifugal acceleration was once applied to the model slope and then sopped as the preloading process to secure certain facing plate loads. After applying the preload, the centrifugal acceleration was again increased up to 25G, which is called G-up process in this study. Under 25 g, using a hydraulic type shaking table, a several input motions were applied to the model as shown in Fig. 4. Firstly small amplitude white noise wave was imputed and then 50 Hz sinusoidal waves were applied with the amplitudes, which were increased waves by waves until a large deformation observed on the slope. During the tests, the accelerations and displacements of the model slope, and the resistance force of the facing plate and rock bolt were measured at the locations as shown in Fig. 2. Furthermore, the slope deformation was monitored by a video camera. The maximum amplitudes of the sinusoidal waves applied to the slope

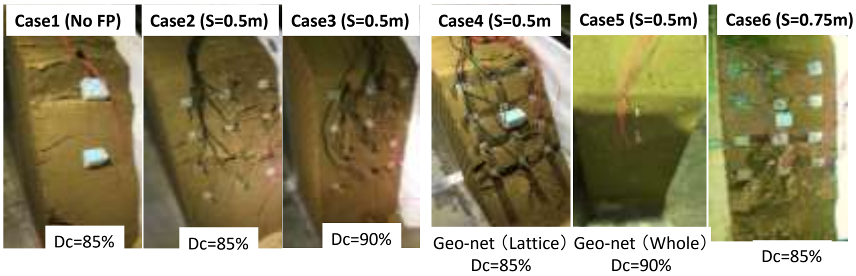

Fig.5. Observed failures of the slope surface.

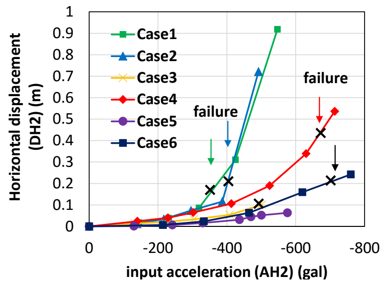

Fig.6. Horizontal displacement of the slope.

are shown in Table 2. In Figure 4 and the following section, the results are shown in prototype scales.

3 TEST RESULTS AND DISCUSSIONS

3.1 Slope deformation and failure

Top views of the slopes observed after the tests are shown in Fig. 5. Large block type failure tool place in the slope without reinforcement (Case 1). In the cases with B=0.5m facing plates and without geo-net (Cases3, 4 and 5), plate bearing failures take occurred at all plates and local surface failure took place the upper slope. While in Case4 (B=0.5m with lattice pattern geo-net) and Case 6 (B=0.75m without geo-net) the surface failure took place at the lower slope. In the both case the plates penetrated into the soils at the upper portion, geo-net and large facing plate could prevent the local failure in the upper portion. In Case5 (Dc=90% with whole geo-net), no visible damage could be seen in the slope.

Fig. 6 shows the relationships between the input acceleration amplitude at the slope base AH2 and the horizontal displacement of slope (DH2) measured after each shaking. In the figure, the points of surface failure initiation are also indicated. For relatively soft soil (Dc=85%), the reinforcement with B=0.5m and S=2m could decrease the slope and increase the stability against the dynamic loads, but the reinforcement effect is not so eminent. But the addition of lattice pattern placement of geo-net with the same width of the facing plate could significantly increase the seismic stability of the slope with large redundancy. The reinforcement effect are slightly smaller than that of Case6. However as explained in 2. (1), the effect of geo-net of the model with discontinuity in the slope transverse direction was less than the actual case where the net is placed in the wide area of the slope. Therefore the combined effects of the rock bolt with facing place of B=0.5m and lattice geo-net the displacements could be more than the observation and almost equivalent to that of B=0.75m without the geo-net. For Case5, input acceleration was not enough to cause a large deformation, the effectiveness of large area covering can be seen in the figure.

3.2 Dynamic responses of the slope and mobilization of facing plate resistance

Fig. 7 show the time histories of the input and slope response accelerations (AH2, AH5), and the horizontal slope displacement (DH2) in the last shakings and one before the last, for Case2 and Case4. As the valley side direction is taken as positive in this study (Fig. 2), the negative acceleration corresponds to the inertia force destabilizing the slope. In the shakings without failure, the acceleration responses were quite stable and slope accelerations are amplified. Additional plate resistance

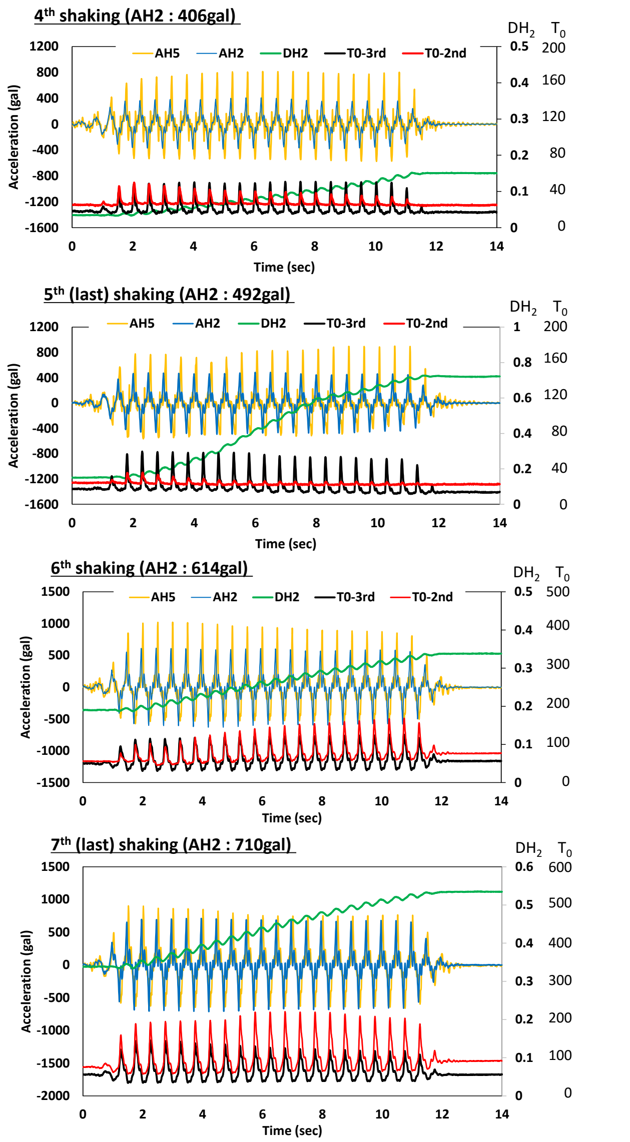

Fig.7. Time histories of the input acceleration (AH2) and surface response acceleration (AH5), and the horizontal displacement (DH2), and facing plate resistances ($T_{0\_2nd\ \&\ 3rd}$).

was mobilized in limited time of each cycle when relatively large destabilizing inertia force acting on the slope. In 6th shake of Case4, the displacement increased with time and the mobilized resistance gradually increased with increasing displacement. While in 4th shake of Case2, shakings, the mobilized facing plate resistance against the dynamic loading turned to decrease at 2nd row t~5sec, resulting in the displacement rate increment. The decrease of resistance could be seen at the 3rd row in 7th shake of Case4 t~2secs. Considering the fact the local surface failure occurred at the upper and lower part of the slope for Case2 and Case4, respectively, these decrease of plate resistance could be also attributed to the local surface adjacent to the plate. These observations imply that the gradual increase of plate resistance could prevent the large slope deformation, but the local surface failure leaded the reduction of plate resistance, resulting the slope failure.

The mobilized plate resistances of the case with geo-net are much larger than those without geo-net. Relationship between maximum facing plate resistance during each shaking and slope horizontal displacement are depicted in Fig. 8. The displacement measured by the slope shoulder (DH1) is used for the place of 1st row, while for the others the slope displacement (DH2) is used in the horizontal axis. The plate resistances of Case 6 were mobilized larger than the other cases. This is due to the larger bearing resistance of the large plate as shown in Fig. 9. The mobilized resistances against dynamic load for the cases without geo-net maximum were limited slightly larger than the static bearing capacity (60kN) even for the large displacement. However, Case4 shows large resistance increase for the relatively large displacement at the upper rows (1st and 2nd). These large resistances are a clear evidence of the apparent effects of geo-net placement with the combination of facing plate nailing. The resistance decrease at 4th row of Case4 indicate the significance of un-reinforced area to maximize the combined effects or importance of avoiding the week port in the reinforced slope.

4 CONCLUSION

In this study, a series of dynamic centrifuge model tests was conducted to the model slope reinforced by rock bolts with facing plate. Special focus was paid on the effect of geo-net placement to enhance the reinforcement effect for the conditions with relatively weak soil and small facing plate size. From the test results, the following conclusions can be derived.

- Geo-net placement could impose the additional effect to suppress slope deformation and to prevent occurrence of local failure.

- By the geo-net, the bearing capacity can be increased and the local surface failure can be prevented.

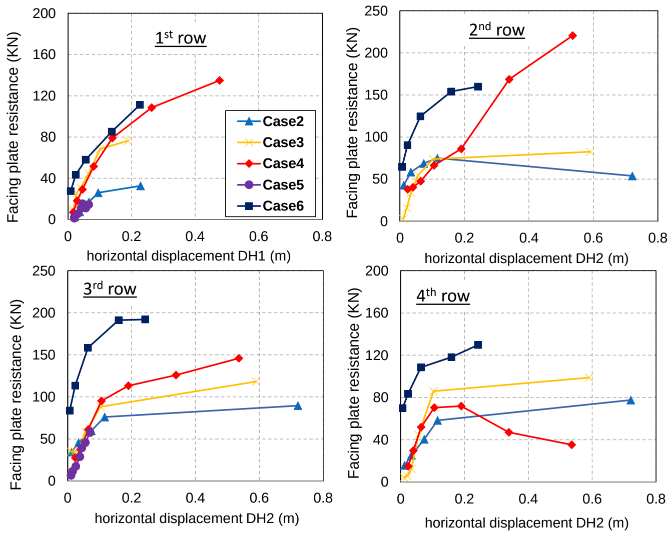

Fig.8. Maximum facing plate resistance vs horizontal slope displacement

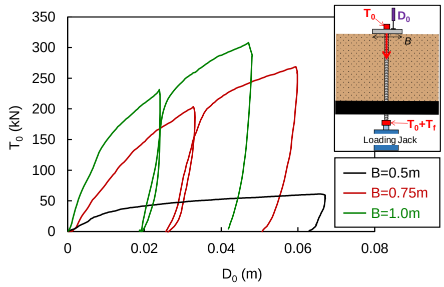

Fig.9. Facing plate resistance measured in the plate loading tests under 25g (Okamoto et al. 2016)

As a result, for the conditions used in the tests, lattice pattern net placement with B=0.5m and S=2m could provide similar effect as facing plate of B=0.75, S=2m without the net.

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