CENTRIFUGE MODEL TESTING OF LINEAR BAR REINFORCED TOYOURA SAND SLOPE

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I. GENERAL

The construction of roads along mountainous regions usually involves heavy cutting of natural slopes. The increasing concerns over protection of existing environment requires the total width of cutting be minimized by making the slopes as steep as possible based on the technology availability and the in-situ soil condition. The soil nailing technology has proved it as a promising technique to accelerate the construction works with increased safety (even during construction) as compared to the conventional gravity or other types of retaining walls.

The total cost of the soil nailing work is controlled by the total cost of drilling and subsequent grouting work. As the length of the soil nail increases, the cost increases geometrically. While the long nails are considered efficient over the short nails because the part of nail length inside the failure surface is considered as dummy and has no meaning in the current design methods. Thus the contractors usually want to compromise the cost of long nails by having reduced number of soil nails. How far a contractor can optimise the cost of long nails over the cost of number of nails(?) is the main question left unanswered, yet. Meanwhile, if the mechanism of the positive effect or contribution of the nail length (inside the failure surface) and the facing material in developing a pseudo retaining wall effect that increases the overall safety factor of the slope, can be explained, and such effects if introduced in the design, the total cost of the soil nailing may be further reduced.

The present research concentrates on the reinforcing of the natural slopes made of cohesionless frictional soil slopes, named Toyoura Sand. The current research concentrates on the identification of the aforementioned pseudo retraining wall concept through a series of centrifuge model tests on purely frictional soil, Toyoura Sand and explains how the effectiveness of the soil nailing can be alternatively used to reduce the total cost of stabilizing the slope without sacrificing the safety of the soil structures. The model test shows promising results.

II. OUTLINE OF SLOPE MODELS

Toyoura sand was selected as a representative purely frictional soil because of its very high angle of internal friction and zero cohesion upon drying in the oven. The same Toyoura sand can be repeatedly used after drying in the oven accordingly. This soil is extensively used in model studies and full-scale tests at PWRI and is a type of purely frictional sand commonly used in other research laboratories in Japan. The model size and shapes are illustrated in Fig. 1 and the shapes were selected based on the assumption that the model represents medium height soil nailed structures. In the previous year, a series of reinforced soil models were tested on Kanto Loam where the unreinforced slope failed at F=20g, and based on this the size and shape of slope models were fixed. Same slope dimensions were adopted in the case of Toyoura sand, too. So that, the effectiveness of soil nails can be compared between the purely cohesive soil (Kanto Loam) and the purely frictional soil (Toyoura Sand). The results of the centrifuge model testing on Kanto Loam were already published elsewhere (Pokharel et al., 1999).

The basic components in conventional soil nailing method usually consist of three components: (a) soil nail (b) grouting around soil nails and (c) facing material. Sand coated (*equivalent to grouting around soil nail in the real soil nailing works*) metallic reinforcing bars of 5mm diameter were used and 8mm thick acrylic plates were used as facing panels. In the first series of model testing, five panels were placed vertically. The facing panel and reinforcing bar connection was nut bolt type. Considering the rigid joints and enough concrete back filling in typical panel faced soil nailing methods, the next series of model tests were carried out on full height jointless facing panel. It also offered relatively high rigidity against vertical settlement and horizontal deformation, and in the case of Toyoura sand, such full height facing ensured the failure due to leakage of sands, usually, found very difficult to avoid the situation developed in panel facing due to the widening of panel to panel joints.

The dry density of the Toyoura sand in the model slope was fixed in between the maximum dry density ($\gamma_{d,maz}$=1.65 tf/m^3) and the minimum dry density ($\gamma_{d,min}$=1.35 tf/m^3) of the sand, thus, at γ_d=1.5 tf/m^3. The soil in the model apparatus was compacted in such a way that the dry density of γ_d=1.5 tf/m^3 is achieved. To ensure the uniformity of the soil density, the soil mass was divided into 10 layers and soil weight was computed accordingly. Thus, the height of each fill was 23.5 mm and dry density was assumed to be accurate enough and practically acceptable. Few trial models were made with different model conditions, e.g. different foundation material, side friction, the bottom of the panel, the sides against sand leakage, etc. and finally, loaded in the centrifuge machine until failure occur. To reduce the sand-wall interface friction and make it truly plane strain condition, Teflon sheets were pasted and oil was applied to ensure the practically frictionless surfaces, simialarly, the rigid cemented material was used as foundation material to force the critical slip

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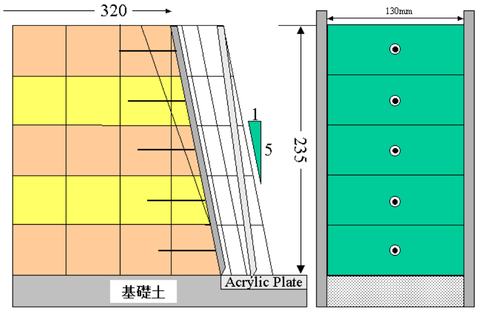
surface pass through the toe of the slope. The bottom surface of the panel was wedge shaped and the surface under the facing up to a distance of 5cm in front of the slope was slightly inclined (1/15) to avoid the resistance against sliding of the slope face, because in conventional design and analysis methods the contribution of panel resistance is not directly accounted.

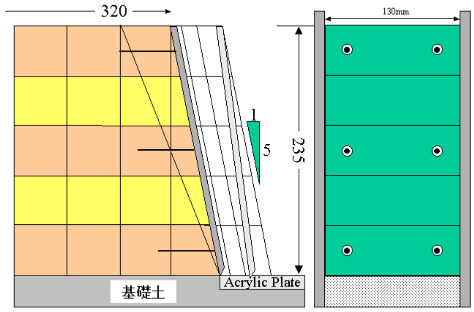
III. RESULTS AND DISCUSSIONS

In this paper, the results of a typical set of models are presented. The set consists of (1) 1bar per layer, total five layers, thus, total 5 bars reinforced soil slope (Fig. 1.a), (2) 2bars per layer, total 3 layers, thus, total 6 bars reinforced soil slope (Fig. 1.b), (3) 2bars per layer, total 5 layers, thus, total 15 bars reinforced soil slope (Fig. 1.c) and (4) 2bars per layer, total 9 layers, thus, total 18 bars reinforced soil slope (Fig. 1.d). As the objective of current research is to illustrate the effect of the number of reinforcing bars in failure mode, and how the increase in the spacing and number of bars changes the failure mode from pull-out failure mode to pseudo retaining wall mode.

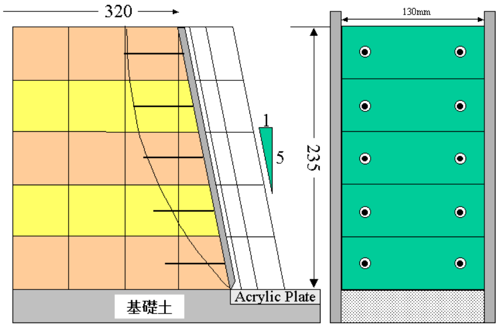
As the number of bar per layer was increased (decrease in lateral spacing) and increase in the number of bars in vertical direction (decrease in vertical spacing), the centrifugal load that results the failure of the model slope was gradually increased. The failure mode in Case 1 and Case 2 remained almost practically same (i.e. Coulomb's triangular failure mode), while the Case 2 to Case 3 showed the changes in failure mode to the pseudo retaining wall. It must be due to the overlapping of the influence zone of the neighbouring soil nails. Thus, the closed spacing of the soil nails may change the failure mode to the pseudo retaining wall and the conventional retaining wall design concept may be used to design the such soil nailed structures and the cost of the soil structures may be considerably decreased.



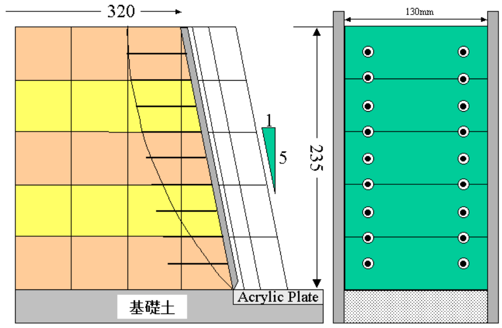
(a) Model TS-SRW-15: 5.5cm long bars (Total 1b/Lx5L=5bars).
Failed at Centrifugal Force, **F < 5G** (Pull-out Failure Mode).



(b) Model TS-SRW-16: 5.5cm long bars (Total 2b/Lx3L=6bars).
Failed at Centrifugal Force, F=35G (Pull-out Failure Mode).



(c) Model TS-SRW-19: 5.5cm long bars (Total 2b/Lx5L=10bars).
Failed at Centrifugal Force, F=50G (Pseudo Retaining Wall Mode).



(d) Model TS-SRW-18: 5.5cm long bars (Total 2b/Lx9L=18bars).
Failed at Centrifugal Force, F=90G (Pseudo Retaining Wall Mode).

Figure 1. Slip surface and deformations observed at the end of model tests (*5.5cm long bars*)

IV. CONCLUSIONS

The decrease in the lateral and vertical spacing changes the mode of failure from pull-out type to pseudo retaining wall mechanism. The pseudo retaining wall mechanism can be attributed to the overlapping of influence areas of neighbouring soil nails similar to the group pile effect in closely spaced pile foundations. These failure patterns could be explained only through the self weight loading and the centrifuge model testing method is very much promising in this perspective.

REFERENCES:

Pokharel, Fujii and Miki (1999): *Centrifuge Model Testing of Reinforced Soil Slopes in the Perspective of Kanto Loam*, Slope Stability Engineering, IS Shikoku 99, Matsuyama, pp.985-989, Balkema Publishers, Netherlands.