Behavior of strip footing on sand slope reinforced with orthogonally H-V inclusions

Zhang, S.
Department of Civil Engineering, Shanghai University, Shanghai, PR China

Zhang, M.
Department of Civil Engineering, Shanghai University, Shanghai, PR China

Tan, G.
Department of Civil Engineering, Shanghai University, Shanghai, PR China

Keywords: sand slope reinforced with orthogonally H-V inclusions; laboratory model test; load-settlement curves; bearing capacity

ABSTRACT: Geosynthetic reinforced soil has come to play an important role in a variety of geotechnical engineering applications. Soil reinforced with horizontal- vertical (H-V) is a new concept of reinforcements. In the soil reinforced with H-V inclusions, besides conventional horizontal reinforcements, some vertical reinforcing elements are also placed upon the horizontal ones. The remarkable function is that the vertical elements can not only restrict the lateral deformation of soil, but also form strengthened zones and provide passive resistances to soil enclosed within the H-V reinforcing elements. It can change the stress distribution and deformation of reinforced soil effectively, that will increase the strength and stability of soil. The interface behavior would be significant to reinforcing mechanism, bearing capability and stability of the soil retaining structure reinforced with orthogonal H-V inclusions. In this paper, a series of laboratory model tests were carried out to study the behavior of strip footing on sand slope reinforced with H-V inclusions. Several parameters including the length and the location of the orthogonal H-V reinforcing elements was varied in the model tests. Comparison was made between sand slope reinforce with conventional reinforcements and H-V elements. The load-settlement curves were observed to study the strength of s strip footing on sand slope reinforced with H-V inclusions. The laboratory model test results indicated that the bearing capacity of the sand slope reinforced with H-V inclusions was increased greatly and the settlement was decreased. The H-V reinforcing element also restricted the lateral deformation of the slope effectively. By comparing the result of slope reinforced with different H-V inclusions in model test, some useful conclusions were founded. The layout of the reinforcements influenced the strength of sand slope evidently. The strength of the H-V reinforced sand slope was increased with increment of the length of reinforce inclusions.

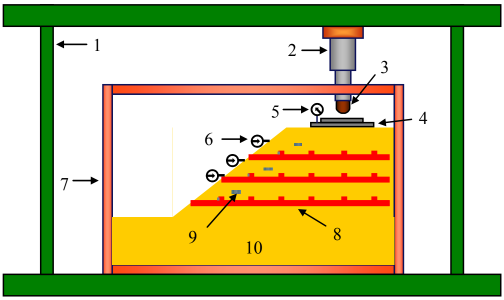
1 INSTRUCTION

The use of reinforced soil has been widely used to increase the stability of various geotechnical structures such as slopes, embankments and foundations, etc. Many investigations on analysis of the reinforced slope or embankments have been carried out, most of them focused on the effect of slope model parameters. The embankment slope degree, horizontal and vertical reinforced ratio, the height of the embankment and the loading strip ratio influenced the capacity of the reinforced soil embankment (El-Naggar & Kennedy, 1997). A series of model tests and numerical simulations were carried out to study the relationship between the bearing capacity behavior of reinforced slope and the layout of the reinforcements, for example, Yoo (2001). This investigation has demonstrated that the bearing capacity of reinforced slope can be improved with the increase of the layers of geogrid, and the magnitude of the bearing capacity increase depends on the reinforcement distribution. A series of model tests on reinforced slope were carried out by El Sawwaf (2007), with different depth of sand layer, footing location and geogrid parameters. These tests conducted that the reinforcements can improve the footing behavior and reduce the depth of replaced sand layer, and the maximum benefit of the geogrid reinforcements was dependent on reinforcement configuration. Besides of the reinforcement parameters, some new reinforcements were also investigated recently. Low tensile strength reinforcements and high strength composite geotextiles were used in full scale test of reinforced embankments by Mannsbart and Oberreiter (2000). Bergado et al (2002) carried out full-scale tests and FEM simulations on embankments reinforced with high-strength geotextile on soft clay. The results showed the high-strength geotextile can reduce the plastic deformations in the underlying foundation soils and increase the collapse height of embankment. Alamshahi and Hataf (2009) investigated the bearing capacity of sand slopes reinforced with geogrid and grid-anchor. The results showed grid-anchors can improve both strength and settlement characteristics of soil slope greatly. Zhang et al (2006), Zhang and Zhou (2008) carried out a series of laboratory triaxial tests and model tests on retaining wall reinforced with H-V (Horizontal-Vertical) reinforcing elements. The traditional reinforcements are only placed horizontally. In H-V reinforcements beside the horizontal elements, some reinforcing inclusions are placed vertically in the soil and have a firmly joint with the horizontal elements. The investigation indicated the effects of H-V reinforcements are better than traditional horizontal inclusions.

2 EXPERIMENTAL PROGRAM

2.1 *Model box*

The laboratory model test apparatus was made by steel beam and toughened glass, as shown in Fig.1. The inside dimensions of the test box are 700×1400×1100 mm (width×depth×height).



1 - Reaction frame for loading
2 - Oil jack
3 - Pressure pickup
4 - Model footing
5 - Displacement pickup
6 - Displacement pickup for collecting lateral displacement
7 - Model casing
8 - Reinforcing element
9 - Earth pressure cells
10 - Filling

Fig.1 The model test apparatus

2.2 *Test material*

The soil used in the model tests was locally available. The properties of this soil are given in Tab.1. The strength parameters of the sand are obtained by the laboratory triaxial tests. The triaxial tests and the model tests were carried out in a same test condition.

Tab.1. Properties of soil used in model tests

Internal friction angle (°)	31.62
Cohesion of soil (*kPa*)	21.31
Specific gravity	2.712
Maximum dry unit weights (kN/m^3)	18.7
Minimum dry unit weights (kN/m^3)	16.9

The particle size distribution was determined by using dry sieving method and the result are shown in Fig.2.

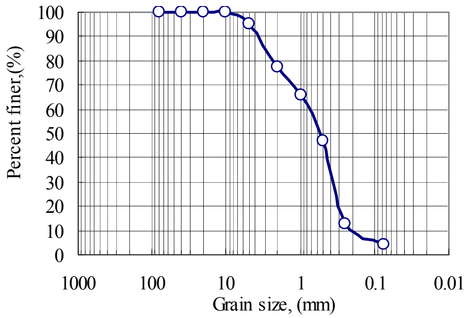


Fig.2 Grain size distribution of the soil

Besides of traditional horizontal reinforcements, H-V inclusions were also used in model tests, as shown in Fig.3. All the reinforcing elements were made of perspex. In H-V reinforcing elements, the vertical inclusions were glue on the horizontal ones firmly with chloroform ($CHCl_3$). The height of the vertical inclusion is 15mm in H-V reinforcement.

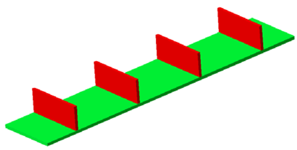


Fig. 3 H-V reinforcing element used in tests

2.3 *Model tests program*

The soil was set up to form a slope of 3(H):2(V). The soil slope was accumulated by raining technique. Layers of reinforcing elements were placed in the filling at predetermined depth. The geometry of the soil slope is shown in Fig.4. There were 3 series of model tests program: tests on non reinforced slope, tests on slope reinforced with horizontal inclusions and H-V inclusions. In model tests, the lengths of the H-V inclusions are same with horizontal ones.

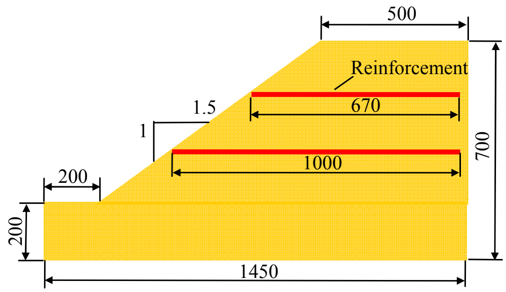


Fig.4 Geometric parameters of soil slope model

3 TEST RESULTS AND DISCUSSIONS

3.1 *Bearing capacity behavior*

Fig.5 illustrates the relationship of footing pressure and settlement obtained from the model tests on soil slope reinforced with different inclusions. In this paper, the ultimate bearing capacities of the soil slope were determined from the load-settlement curves as the peaks, after which the footing collapsed. The measured ultimate bearing load of soil slope reinforced with horizontal inclusions and H-V reinforcing elements are 79.97 and 106.47 kPa.

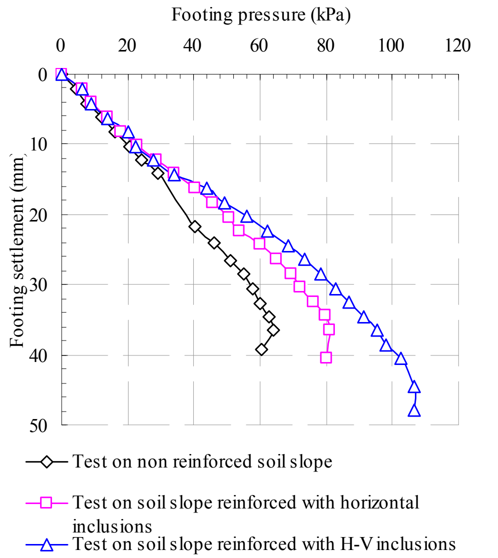
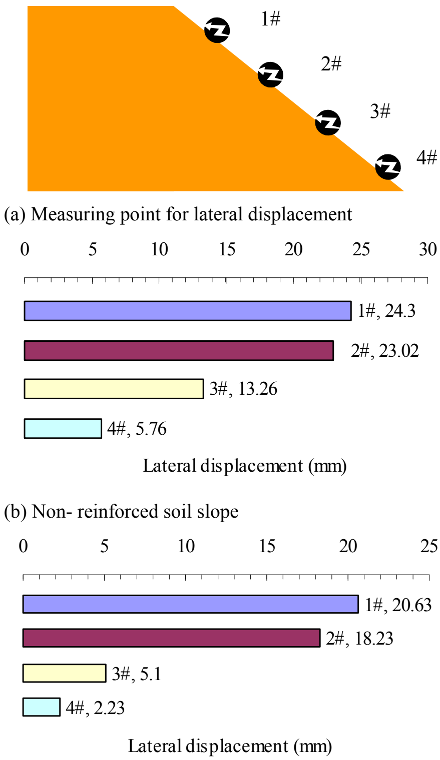


Fig.5 The relationship between footing pressure and settlement

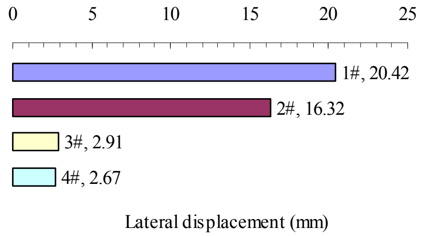
The result clearly showed that the effect of H-V reinforcing elements was better than traditional horizontal ones. In initial stage of loading, the effect of the reinforcing elements is not obviously. The frictions between soil particles and reinforcing element increase with load, and it can be found that the bearing capacities of the reinforced slope are remarkably higher than non-reinforced ones. When slope reinforced with H-V inclusions is under loading, besides the friction between horizontal reinforcement, the vertical inclusions provide resistance force to the soil. It is well illustrated that the ultimate bearing capacity of the slope reinforced with H-V inclusions is approximately 33.14% greater than that of traditional horizontal reinforcing elements.

3.2 *Displacement of slope model*

H-V reinforcing elements not only improve the bearing capacity of the soil slope, but also reduce the vertical settlements of the footing. It can be observed from Fig.5 that the vertical settlements of slope reinforced with H-V inclusions are obviously smaller than that of slope reinforced only horizontal reinforcing elements. For example, the settlement of the H-V reinforced slope is about 29.3 mm at the footing pressure 80 kPa, and that of traditional reinforced soil is about 36.2 mm. The Fig.6 shows the lateral displacements of the soil slope models at their failure pressures.



(c) Slope reinforced with only horizontal inclusions



(d) Slope reinforced with H-V inclusions

Fig.6 Lateral displacements of soil slope

Generally the maximum lateral displacement occurred at the top layer of the slope, the minimum at the slope toe. Due to the friction between the soil particles and reinforcements, the lateral displacements of reinforced soil are smaller than that of non-reinforced soil slope. The Maximum lateral displacements of non-reinforced soil is 24.3mm, the traditional reinforced slope is 20.63mm, and the H-V reinforced one is 20.42mm It can be found from Fig.6 that the H-V reinforcing elements can restrict the lateral displacements of the soil particles because the vertical inclusions can provide extra resistance force to the soil.

4 CONCLUSIONS

A series of model test on soil slope were carried out to investigate the bearing capacity and displacement of the reinforced soil slope. A few conclusions can be concluded from the results of the model tests:

(1) Reinforcements can increase the ultimate bearing capacity of the soil slope greatly. The ultimate bearing capacity of the slope reinforced with H-V inclusions is approximately 33.14% greater than that of traditional horizontal reinforcing elements, 66.7% greater than that of non-reinforced soil. The effect of H-V reinforcing elements is better than that of traditional horizontal ones.

(2) The vertical settlements of soil slope reinforced with H-V inclusions are smaller than that of slope reinforced with only horizontal inclusions at same degree of loading. The settlement of the H-V reinforced slope is 19% smaller than that of traditional reinforced slope.

(3) The maximum lateral displacement occurred at the top of the slope, the minimum at the slope toe. Reinforcements can restrict the lateral displacements of the slope effectively. The lateral displacement lope reinforced with only horizontal inclusions is 15% smaller than non-reinforced slope, and the H-V reinforced slope is 16% smaller than non-reinforced slope.

ACKNOWLEDGMENT

The financial assistance from the National Natural Science Foundation of China (NSFC) under Grant No. 50678100 is herein much acknowledged. The authors would like to express their appreciation to the financial assistance.

REFERENCES

Alamshahi, S. & Hataf, N. 2009. Bearing capacity of strip footing on sand slopes reinforced with geogrid an grid-anchor. *Geotextiles and Geomembranes*, Vol.27(3), pp.217-225.

Bergado, D.T., Long, P.V. & Murthy, B.R.S. 2002. A case study of geotextile-reinforced embankment on soft ground. *Geotextiles and Geomemranes*, Vol.20(6), pp.343-365.

El-Naggar, M.E. & Kennedy, J.B. 1997. New design method for reinforced sloped embankements. *Engineering Structures*, Vol. 19(1), pp. 28-36.

El Sawwaf, M.A. 2007. Behavior of strip footing on geogrid-reinforced sand over a soft clay slope. *Geotextiles and Geomembranes*, Vol.25(1), pp.50-60.

Mannsbart, G. & Oberreiter, K. 2000. Geosynthetic reinforced full scale test embankment on soft soil. *Soft Ground Technology, Proceedings of the Soft Ground Technology Conference*, pp.237-245.

Yoo,C. 2001. Laboratory investigation of bearing capacity behavior of strip footing on geogrid-reinforced sand slope. *Geotextiles and Geomembranes*, Vol.19(5), pp.279-298.

Zhang, M.X., Javadi, A.A. & Min, X. Triaxial tests of sand reinforced with 3D inclusions. *Geotextiles and Geomembranes*, Vol.24(8), pp.201-209.

Zhang, M.X. & Zhou, H. 2008. Model test on sand retaining wall reinforced with denti-strip inclusions. *Science in China Series E: Technological Sciences*, Vol.51(12), pp. 2269-2279.