PROGRESSIVE FAILURE PROPERTIES AND BEARING CAPACITY OF FOUNDATION REINFORCED WITH H-V INCLUSIONS

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Abstract: In conventional reinforced soil, the reinforcements are often laid horizontally in the soil. A new concept of soil reinforced with H-V (horizontal-vertical) geosynthetics was proposed. In the proposed H-V reinforced soil, besides conventional horizontal reinforcements, some vertical reinforcing elements are also placed upon the horizontal ones. A fundamental difference between the H-V reinforcing elements presented in this paper and other forms of inclusions is that the soil enclosed within the H-V orthogonal reinforcing elements will provide passive resistances against shearing that will increase the strength and stability of the reinforced soil. In this paper, a series of model tests of foundations reinforced with H-V inclusions and horizontal elements respectively subjected to strip loading were carried out, and the bearing capacity and the settlement of the reinforced foundation were compared. It was shown that the H-V reinforcement can increase the bearing capacity greatly and reduce the settlement, as compared with the horizontal reinforcements. Moreover, the bearing capacity of sand foundation reinforced with H-V orthogonal elements increases with increasing height of the vertical elements, but decreases with increasing of horizontal spacing between vertical elements. A microscopic measurement was performed to investigate the progressive failure process and failure models. The progressive failure of the sand within foundations reinforced with H-V inclusions was recorded by a digital video camera. Based on the image and graph disposal technique, a model of the initial shear failure and final shear failure was proposed. The failure characteristics and interaction mechanism of foundations reinforced with H-V inclusions were analyzed.

Keywords: H-V reinforcement; reinforced earth structure; laboratory test; bearing capacity; settlement

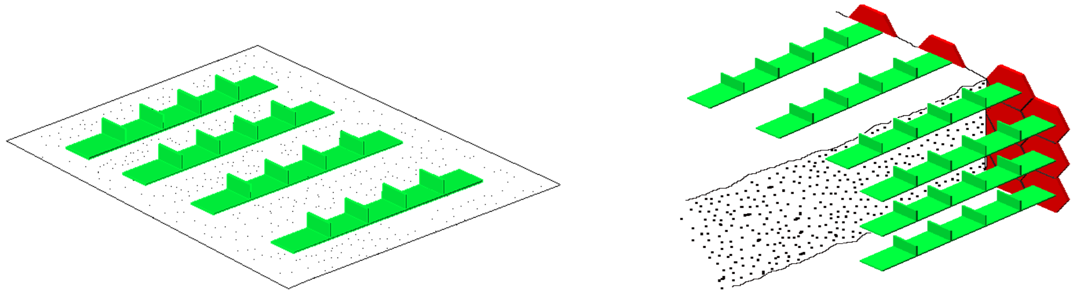
INTRODUCTION

Reinforced foundation is a kind of complex structure with a method of putting one or multi-layered reinforcements into the soil under the foundation, this compound structure can exert the tensile strength of reinforcements, and can redistribute the stress, thus improve the ultimate bearing capacities and reduce the settlement. It is widely used in geotechnical engineering, such as construction of road and railway embankments, stabilization of slopes, and so on. During the past 20 years, the strength mechanism of reinforced foundation was studied by researchers. The commonly accepted ‘wide-slab’ theory was first reported by Binquet and Lee (1975). Yamanouch and Gotoh (1979) investigated the reinforcing efficacy of the reinforced foundation through model tests and proposed the modified-Terzaghi ultimate bearing capacity formula. Jenner (1988) proposed a methodology to calculate the increase in bearing capacity due to the provision of a cellular geocell mattress at the base of the embankment resting on soft soil by means of slip line theory. Zhao (1996) calculated the failure loads on geosynthetic reinforced soil structures by limit equilibrium theory. Taesoon and Siew (2005) verified the effects of the inclusion of short fiber in sandy silt soil on the performance of reinforced walls. Laboratory model test results for the ultimate bearing capacity of a strip foundation supported by multi-layered geogrid-reinforced sand were carried out by Patra et al. (2005). All of these studies have been conducted for conventional horizontal reinforcements. In this paper, a new concept of soil reinforced with H-V geosynthetics was proposed.

In the proposed H-V reinforcements, besides conventional horizontal reinforcements, some vertical reinforcing elements are also glued upon the horizontal ones. The remarkable characteristic is that the placed vertical reinforcements can limit the lateral movement of the soil, and form ‘strengthened zones’. Thus, it can increase the strength and stability of the soil greatly. This paper presents the results of some recent laboratory-model load tests on a strip foundation supported by H-V reinforced sand bed. The behaviour of sand bed reinforced with different H-V reinforcing configurations (including height of vertical reinforcement, length of horizontal reinforcement and space of vertical elements) is studied in terms of progressive failure properties and bearing capacity. Comparison is made between reinforcing effects and bearing capacity of the soil reinforced with horizontal inclusions and with H-V reinforcing elements.

TYPE OF SOIL REINFORCED WITH H-V INCLUSIONS

The H-V reinforcement is one specific example of 3D reinforcements. Some kinds of reinforcing structure schemes have been established. A fundamental difference between the H-V reinforcing elements presented in this paper and other forms of 3D inclusions as well as fiber-reinforced soil is that in the presented H-V reinforced soil, the soil enclosed within the H-V reinforcing elements will provide passive resistance against shearing that will increase the strength and stability of the reinforced soil. Typical soil structures reinforced with H-V reinforcing elements for in situ applications are shown in Fig. 1.   H-V inclusions composed of conventional horizontal reinforcing stripes and vertical reinforcing elements (rectangular in shape) are laid within the structures.



(a) Reinforcement used in foundation (b) Reinforcement used in retaining wall

Figure 1. The typical H-V reinforced soil schemes

EXPERIMENTAL PROGRAM

The model tests were conducted in a rectangle-steel tank with a length of 800 mm, width of 400 mm and a height of 700 mm. The four sides of the tank were made of 20mm thick perspex sheet and were braced laterally on the outer surface with mild steel angles to avoid yielding during the tests. The model foundation used for this study had a width of 10mm and a length of 400 mm. It was made of three pieces of steel plate with a thickness of 20 mm. The inside walls of the box must be keep smooth to reduce the influence of friction. For all tests, the average unit weight and the relative density of compaction were kept the same. In conducting a model test, H-V reinforcement was placed in the sand at desired values of depth. The model foundation was placed on the surface in the middle of the tank to simulate plane-strain condition. The load and the settlement were recorded. The configuration of the model test is shown in figure 2. The details of experiment are given in Table 1.

Table 1. Details of laboratory model tests

Test series	Constant parameter	Variable parameter	Variable range
A	L=20cm	H	H=0,0.5,1,1.5,2cm
B	H=1.5cm	L	L=20,40,60cm
C	L=40cm, H=1.5cm	D	D=0,3.3,10cm

Note: L- length of horizontal reinforcement; H- height of vertical elements; D- horizontal spacing of vertical elements.

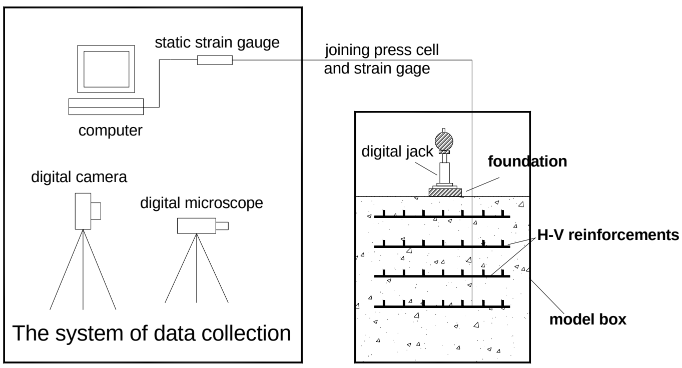


Figure 2. Device of model test

MODEL TEST RESULTS

Fig.3 shows the load per unit area versus settlement of the foundation as determined from the test in series A. From the figure it can be seen that the curves are similar and every curve has a peak value, after the peak value, the ultimate bearing capacity doesn't improve while the settlement becomes bigger. It can also be observed that the effect of H-V reinforcement is much better than horizontal reinforcements. And it becomes better with the increase of the height of vertical reinforcing elements. For example, with the settlement of *S*=20mm, H =0(the conventional horizontal reinforcements), 0.5, 1, 1.5, 2cm cases can improve the ultimate bearing capacity 18.9%, 22.9%, 38.6%, 52.3% and 100% than unreinforced soil respectively, and with the same load *p*=78kPa, the settlement can reduce 32.2%, 43.8%, 61.8%, 68.1%, 71.6% separately, it indicates the higher the vertical elements are the better the effect.

Figs.4 and 5 show the influence of the length of horizontal reinforcement and the spacing of vertical reinforcing elements to the bearing capacity and settlement of H-V reinforced foundation. It shows that with the increase of horizontal length and the decrease of vertical interval, the bearing capacity increases.

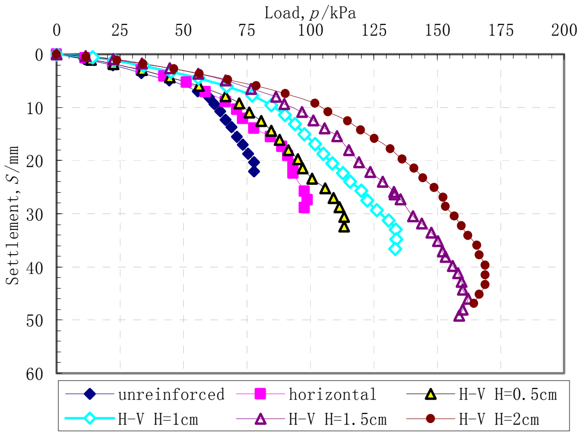


Figure 3. The curves of *p* versus *S* under different heights of vertical elements

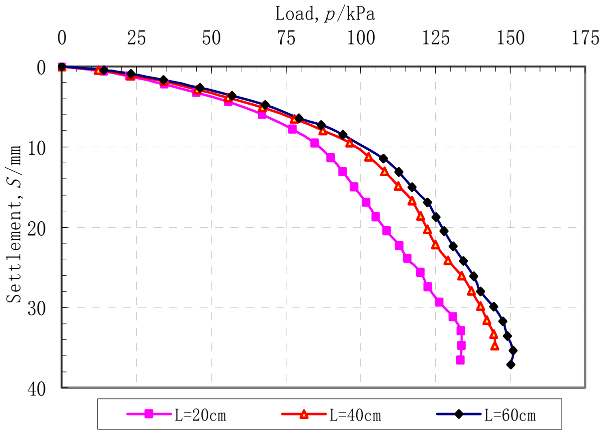


Figure 4. The curves of *p* versus *S* under different length of horizontal reinforcements

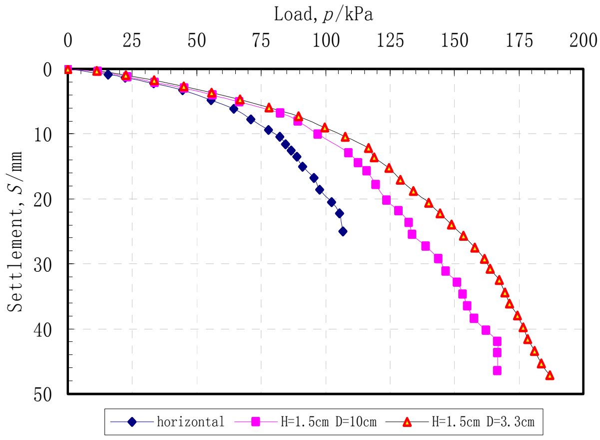


Figure 5. The curves of *p* versus *S* under different spacing of vertical elements

PROGRESSIVE FAILURE PROPERTIES

Fig.6 shows the deformation status of H-V reinforced foundation in the process of loading. In order to observe the movement of sand, a layer of black coal ash was placed in the front of perspex sheet every 5cm in depth. The deformation curves were obtained.

In the latter period of loading, when the load reach the ultimate bearing capacity, the surface of the sand bed on all sides of foundation heaved. The progressive failure process is shown in Fig.6. The horizontal black coal ash lines became curved, a failure surface approximately in circular arc-shape was formed, and the soil above the failure surface moved upward along the unloaded surface.

(a) Prior to loading

(b) The first loading stage

(c) The second loading stage

(d) The failure stage

Figure 6. The process of progressive failure

CONCLUSIONS

A comprehensive set of laboratory model tests were carried out on sand foundation reinforced with H-V reinforcements, in order to study the progressive failure properties and ultimate bearing capacity of reinforced foundations subjected to strip loading. The following conclusions can be drawn from the results of this study:

(1) Compared with conventional horizontal reinforcements, the H-V reinforcements can increase the ultimate bearing capacity and decrease settlement much more.

(2) The effect of reinforcing becomes better with increasing height of the vertical elements and length of horizontal reinforcements, but decreases with increasing of horizontal spacing between vertical elements.

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REFERENCES

Binquet, J., & Lee, K L. 1975. Bearing capacity analysis of reinforced earth slabs. Journal of Geotechnical Engineering, Div. ASCE, 101(GT12), 1257-1276.

Jenner, C. G., Basset, R. H., & Bush D. I., 1988. The use of slip line fields to asses the improvement in bearing capacity of soft ground given by cellular foundation mattress installed at the base of an embankment. In: Proceedings of International Geotechnical Symposium on Theory and Practice of Earth Reinforcement. Balkema, Rotterdam, 209–214.

Patra, C. R., Das, B. M., & Atalar, C. 2005. Bearing capacity of embedded strip foundation on geogrid-reinforced sand. Geotextiles and Geomembranes, 23(5), 454-462.

Taesoon, P., & Siew, A. T. 2005. Enhanced performance of reinforced soil walls by the inclusion of short fiber. Geotextiles and Geomembrances, 23(4), 348-361.

Yamanouch, T., & Gotoh, K. 1979. A proposed practical formula of bearing capacity for earth work method on soft clay ground using a resinous mesh, Technology Report of Kyushu University, 52 (3), 201-207.

Zhao, A. 1996. Failure loads on geosynthetic reinforced soil structures. Geotextiles and Geomembrances, 14(6), 289-300.