International Geotechnical Symposium on Theory and Practice of Earth Reinforcement / Fukuoka Japan / 5-7 October 1988
 ISBN 90 6191 820 0

The earth reinforcement effects of steel bar truss set in embankment

H.Yokota, T.Nakazawa & H.Fujimoto
Miyazaki University, Miyazaki, Japan

Y.Ono
Sumitomo Construction Co., Ltd, Tokyo, Japan

ABSTRACT: We investigated the reinforcing effects of full-size steel bar truss, which was welded to a steel band, on banking soil by pull-out and settlement tests in a soil chamber. The experimental results show that the pull-out resistance of the steel bar truss is more than 2.5 times approximately as large as one of the steel band plate used in Terre Armée and give the soil more effective stiffness.

1 INTRODUCTION

Recently, metal materials such as steel bar and steel band plate have been utilized (see Hashimoto(1979), Cartier and Gigan (1983) and Marczal(1983)) to increase the shearing strength of banking soil and to reduce the subsidence of embankment. The increase of shearing strength is caused by the pull-out resistance of these reinforcing materials. The resistance largely depend upon the friction and interlocking between reinforcing materials and soil. The subsidence of embankment may be reduced in the case that reinforcing materials and soil behave in one and the composite made of these two materials has large stiffness. It would be very meaningful to develop the reinforcing material, which has high pull-out resistance and gives large stiffness to soil.

We propose a steel bar truss welded to a steel band plate as the reinforcing material with these mechanical characteristics. This paper describes their mechanical characteristics in embankment, obtained from pull-out and deflection tests, and we investigate their reinforcing effects by comparing with ones of a steel band plate used in Terre Armée method.

2 EXPERIMENTAL METHOD

2.1 Reinforcing materials

Fig.1 shows the form of the reinforcing material used in the experiments and expresses the full size used in banking. The band plate has the dimensional shape of 0.32cm × 10cm × 280cm (thickness × width × length). A truss of 5cm in height, made of steel bars of 6mm in diameter, was assembled at 20 cm pitch on the steel band plate. We use hereinafter the abbreviated word, PT, about this steel band plate mounted space truss of steel bars.

We made an experiment on the steel band plate used in Terre Armée method in order to obtain the reinforcing effects. This steel band plate (hereinafter abbreviated as TA) has the same shape as one of the PT. These reinforcing materials were set in a following soil chamber.

2.2 Soil chamber

A soil chamber is made of stiffened steel and has the dimensional shape of 3.0m × 3.0m × 0.3m as shown in Fig.2. We loaded to the reinforcing materials in soil as follows. A movable loading wall, to which reinforcing materials are attached, was pulled out horizontally by hydraulic

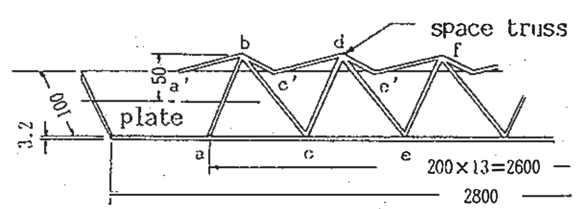


Fig.1 Form of reinforcing material (mm)

jacks. In the case of deflection tests, we used concrete blocks and H-section steel beams as surcharge load, which is transmitted through a loading plate to the reinforcing materials in the soil.

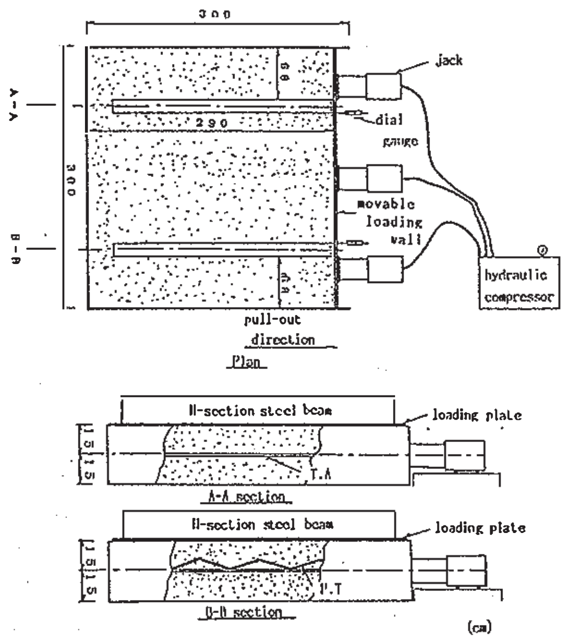


Fig.2 Soil chamber and reinforcing material in soil

2.3 Banking soil

In the experiments, we used the disturbed Shirasu(sandy volcanic ash soil found in Southern Kyushu), having grain size accumulation curve as shown in Fig.3. Characteristics of the Shirasu are as follows. The specific gravity Gs=2.46, the optimum moisture content w_{opt}=26.8% and the maximum dry density ρ_{dmax}=1.27 g/cm^3. The density shows the variation of ρ=1.16-1.25g/cm^3, though the Shirasu was compacted by tamping and watering.

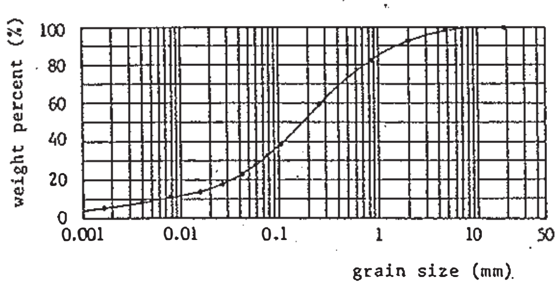


Fig.3 Grain size accumulation

2.4 Method of pull-out tests

The reinforcing materials PT and TA were placed in the soil chamber with the spacing of 1.5m each other, and were arranged in parallel in depth of 15cm from the soil surface as shown in Fig.2. Under vertical load of 1.15tf, we pulled out the reinforcing materials at the horizontal displacement speed of 2 mm/min.

In this case, we enable the attachment portion of the steel band plate to move correspondingly to the settlement of reinforcing materials, caused by soil compaction as in the case of actual construction works.

We measured the strains of steel band plates and obtained the pull-out force from the strains of the attached portion of the steel band plate to the movable loading wall.

2.5 Method of settlement tests

The reinforced soil has larger stiffness than soil itself and it is desirable that the reinforcing materials behave with soil in a body. We examined these stiffness increase and behavior in a body by two experiments.

We arranged the reinforcing materials PT and TA through the same procedure as in the pull-out tests. The reinforcing materials was placed in depth of 0cm, 10cm and 15cm from soil surface. We measured deflection of the reinforcing materials under the loads of 300-1500kgf. And we investigated the stiffness increase of the composite beams made of PT and soil cement by loading tests.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Pull-out tests

Fig.4 shows the relation between the pull-out forces(F) and the horizontal displacements(δ). The pull-out force of TA shows peak value (F_{TA}) to small displacements. While, in the case of PT, the peak of the pull-out force (F_{PT}) occurs in the region of relatively large displacements. These peak values F_{TA} and F_{PT} are shown in Fig.5. It can be seen from this figure that F_{PT} is more than three times in maximum and 2.5 times in average as large as F_{TA}.

Fig.6 shows the axial strain distributions of TA and PT when their pull-out forces reached peak values. We consider that these distributions were obtained under same experimental conditions, though there was a little amount of scatter in the unit weight of soil.

We can consider from Fig.6 that the strain distribution of PT is expressed linearly as TA, and that, in other words, the shearing stress between PT and soil distributes uniformly along longitudinal axis of PT. Though the shearing stress at top and bottom sides are different from each other in the case of PT, we deal with the sum of the shearing stress at both sides, which distributes uniformly. Therefore, we propose the following apparent frictional coefficient f^* in the same way as TA,

$$f^* = \frac{F_{PT}}{2b\,\sigma_v L_e}$$

where

b: width of reinforcing material PT,

σ_v: average vertical stress acting on reinforcing material PT,

L_e: length of reinforcing material PT.

Fig.7 shows the f^* values of PT and TA. It is reasonable that the value of TA is between 2 and 5. This may suggest the reliability of the f^* value about PT.

PT is composed of the portions of mountain and valley. The former is the "acba'c'" or "cedc'e'" and the latter is "bcdc'" or "defe'" in Fig.1. The soil

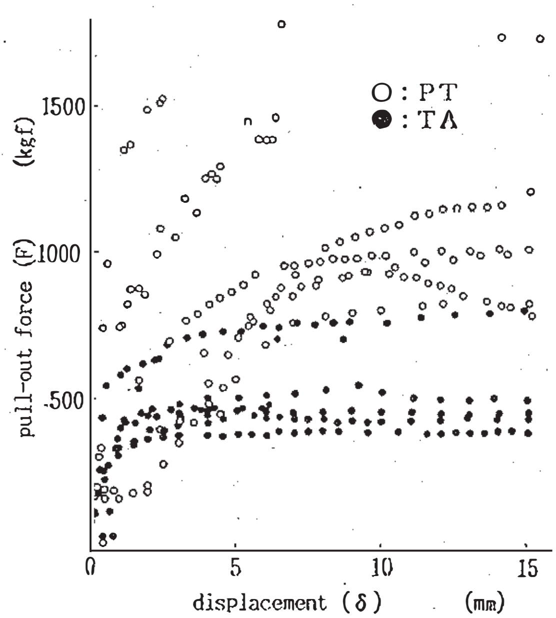


Fig.4 Relation between pull-out force and displacement

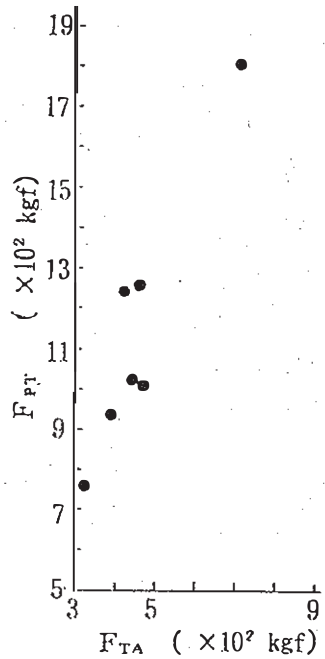


Fig.5 Pull-out resistance F_{PT} and F_{TA}

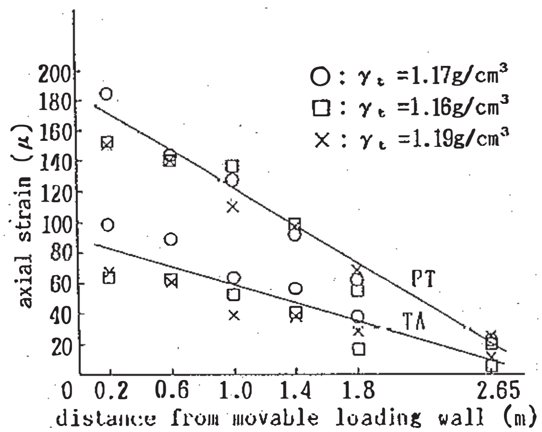


Fig.6 Axial strain distribution

filled in the portion of mountain, for example "acba'c'", resists a pull-out force with the shearing strength of soil on the plane "abc" and "a'bc'". The portion of the valley, "bcdc'", contributes to the resistance with the shearing strength on the horizontal plane containing bd-line. The pull-out resistance of PT is caused by these shearing strength except for the frictional force between the steel band plate and the soil.

3.2 Deflection tests

Fig.8 shows the deflections produced at the center of PT and TA set in a soil, where the preceding load P is applied on the ground surface just above the center of PT and TA.

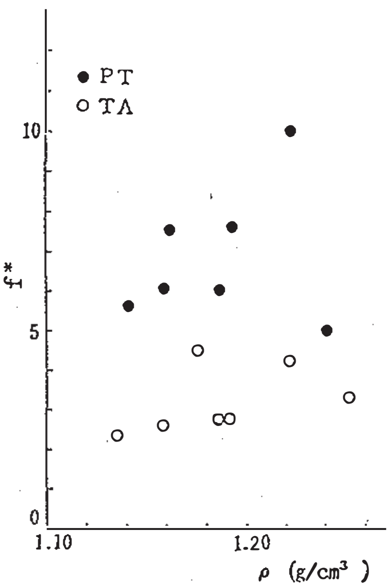


Fig.7 Apparent frictional coefficient

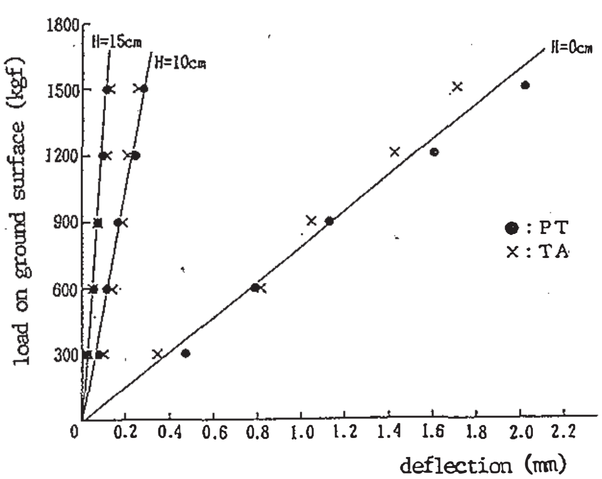


Fig.8 Deflections of reinforcing material

It is seen that the two reinforcing materials show same deflective behavior for each depth H in which the reinforcing materials are set, though PT has larger flexural rigidity than TA. Fig.8 may represent that PT behave with soil in a body, while we should consider that PT can not reduce the subsidence of embankment. The subsidence, however, may be reduced in the case that the volume ratio of PT to soil is larger than one in this experiment and soil is compacted more densely.

The composite beams, made of PT and soil cement (hereinafter abbreviated as CB), were tested to investigate the above mentioned subsidence problems. The soil-cement was made by mixing Shirasu with normal portland cement. The mixing rate of cement c_m is 5, 10 and 25 per cent of the dry weight of Shirasu, respectively. TA and PT beams, and soil-cement beam (hereinafter abbreviated as SB) were also tested to compare with the test results of CB.

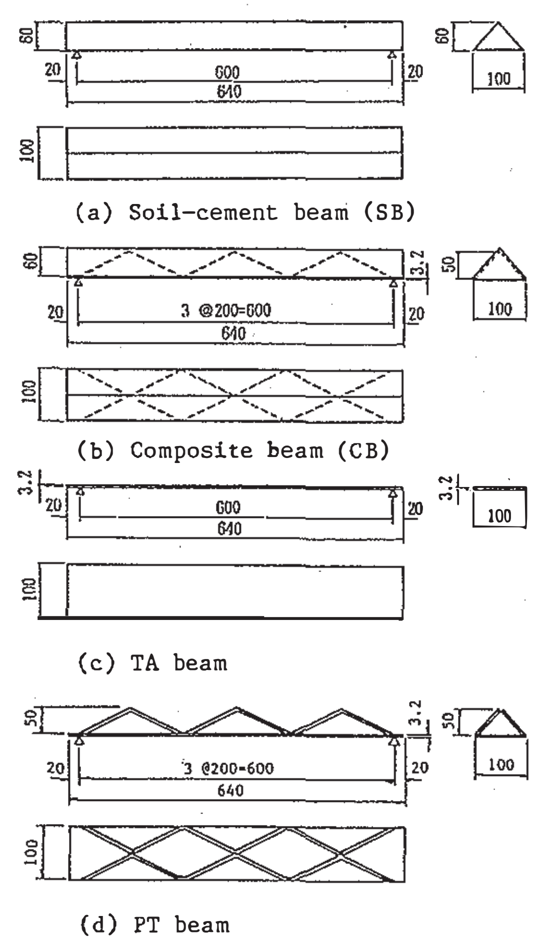


Fig.9 Dimensions of beam specimens (mm)

In these tests, the deflection was measured at the middle point of the beams when the concentrated load acted on the midpoint of the beam span. The configuration and dimension of these beam specimens are shown in Fig.9.

Compressive strength of soil-cement was obtained as follows;

$36.5 kgf/cm^2$ (c_m is equal to 25%)
$6.4 kgf/cm^2$ (c_m is equal to 10%)
$2.1 kgf/cm^2$ (c_m is equal to 5%)

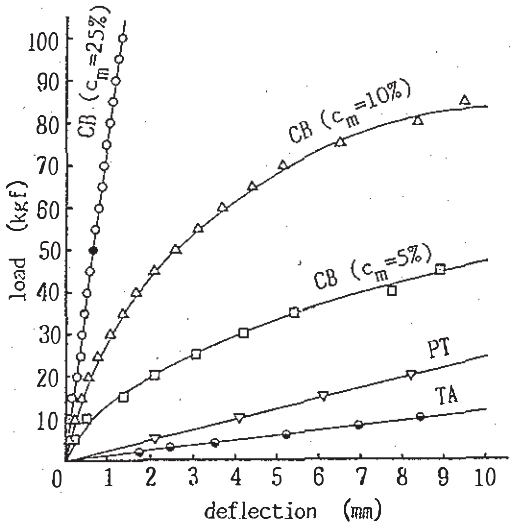
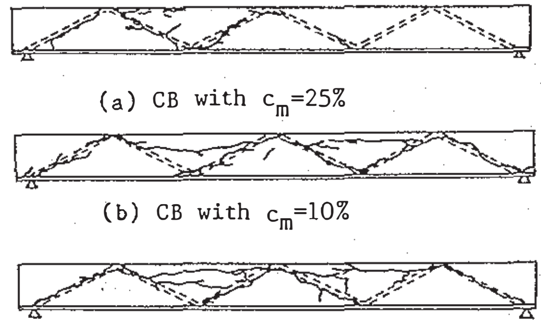


Fig.10 Load-deflection curves

The experimental load-deflection curves of the beams are shown in Fig.10. In this figure, blacken round symbol denotes the deflection when the soil cement beam of c_m =25% was broken in two. It can be seen that the flexural rigidity of the PT beam is two times as large as one of the TA beam. Then, it was found that the flexural rigidity of the CB of c_m=25% was about 50 times as large as one of the TA beam, and that the flexural rigidity of CB increased as c_m increased. For example, when load of 20kgf was placed on CB of c_m= 5,10 and 25%, it was estimated that the flexural rigidities of CB are in the ratio 4:13:26 if the one of PT beam was standardized.As seen from the results in the case of c_m=25%, the flexural rigidity of CB was nearly equal to one of SB for reason of small flexural rigidity of PT beam. The effect of composite beam appeared largely on increasing the failure load.

As it is clear from Fig.11 which shows the crack condition of CB at the ultimate state, only diagonal cracks appear along truss element. This may be due to the truss effect and the valley portions might play a role of compressive chord in the truss structure. This is the reason that



(a) CB with c_m=25%
(b) CB with c_m=10%
(c) CB with c_m=5%

Fig.11 Cracking patterns for CB with different mixing rate of cement

the toughness of CB is far larger than the total one of the PT beam and soil-cement beam. PT may be effective to reduce the subsidence of embankment, if this mechanism is made full use.

4 CONCLUSION

We proposed a reinforcing material which has high pull-out resistance and gives large stiffness to soil. The following characteristics became evident after examining the results of pull-out and deflection tests.

1. The pull-out resistance of the reinforcing material was more than 2.5 times as large as one of Terre Armée method.
2. The relatively large pull-out resistance was dependent upon the shearing stress of soil adjacent to the reinforcing material.
3. The reinforcing material deformed with soil in a body in spite of its relatively high flexural rigidity.
4. The experimental results of composite beam made of the reinforcing material and soil cement suggested that the soil filled in the valley portions of the reinforcing material might play a role of compressive chord in truss structure. This mechanism may be useful for examining the reduction of embankment subsidence by the reinforcing material PT.

ACKNOWLEDGMENT

The authors gratefully acknowledge the advice of Prof. Toshiaki Ohta of Kyushu University in the execution of this research. Thanks are extended to Mr. Shinsuke Kawano and Mr. Tamio Itoh of Miyazaki

University who provided assistance in the conduct of this experiment.

REFERENCES

Hashimoto,Y 1979. Behavior of reinforced earth embankment constructed with Kanto loam. International conference on soil reinforcement. Vol.2, pp.545-550.

Cartier,G & Gigan,J.P 1983. Experiments and observation on soil nailing structure. 8th European conference SMFE, Helsinki. Vol.2, pp. 473-476.

Marczal,L 1983. Measurements on reinforced soil structure. 8th European conference SMFE, Vol.2, pp.525-526.