International Geotechnical Symposium on Theory and Practice of Earth Reinforcement / Fukuoka Japan / 5-7 October 1988

26m height reinforced soil quaywall: Design and full-scale test

Zhongchun Ouyang
Chongqing Institute of Communication, People's Republic of China

ABSTRACT: In this paper the highlights of the design and main results of on-site test on 26m height geosynthetic-fiber reinforced soil quaywall are presented. Author proposes an experimental equation to calculate the tension in the extensible inclusions (geosynthetic-fiber). A reinforcing-tieback system failure plane is also discussed.

1 INTRODUCTION

Chongqing located by the Yangtze river in China is a beautiful mountain city, its topographic form is narrow, and its banks are high and precipitous. There are many tall retaining structures in the city. However what are the design outlines of the geosynthetic-fiber reinforced soil structures in this kind of city? And how to consider the calculating method? Our testing project, Bai Sha Wan reinforced soil quaywall, is an attempt.

Bai Sha Wan reinforced soil wharf is a coal export one. It is located on the north bank of the Yangtze river in Chongqing. The quaywall is 137m in length, the part of reinforced soil is 90m in length, and from 18m to 26m in height. The loading area is 2200m². The quaywall was finished in July, 1985 (Fig. 1), and the loading test has been done (Fig. 2).

2 THE UNITS OF STRUCTURE

Bai Sha Wan wharf is a vertical quay. The units of the structure are as follows (Fig. 3).

1. The facing made of precast reinforced concrete panels measuring 150*50*25cm.

2. The fill consists of sand and gravel. The particle size is shown in Table 1. The unit weight of the fill is 19.6 KN/m³. The angle of internal friction is 36°.

3. The reinforcements are polypropylence strips, 20mm in width, 1.2mm in thickness. The ultimate tension in a piece of strip is greater than 4KN. The elongation at break is 19.2%, and 5% was used in design.

4. The tieback parapet. In order to stabilize the tall reinforced soil structure we have to increase the length of reinforcements, i.e., we have to increase the width of reinforced soil mass. But it is impossible to do on site where the topographic form is narrow and the digging is difficult. And the costs will be increased also. Therefore we set the girt-tieback-parapets separately at the middle and the top of the quay, so that a stability of reinforced soil mass is increased but the length of the reinforcements is not increased. The parapet is 1.5m in height, 0.7m in thickness and 30m in length of segmentation. The parapets are connected with deadman using steel bars. A horizontal space between the bars is 1.0m. The deadman is 50*60*30cm. All deadmans are laid behind the reinforced soil mass.

5. Filter is close to the facing, 1.2m in width. The fill of the filter consists of sand and gravel with elements from 0 to 20mm.

6. Foundation was made of stone masonry or stone concrete, which

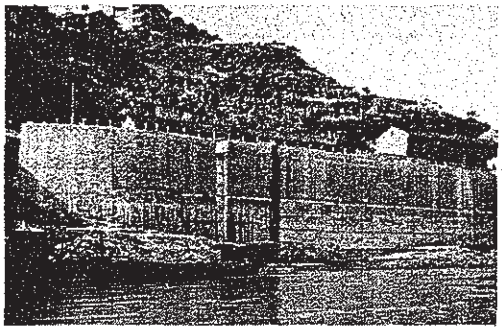


Fig. 1 Bai Sha Wan reinforced soil wharf

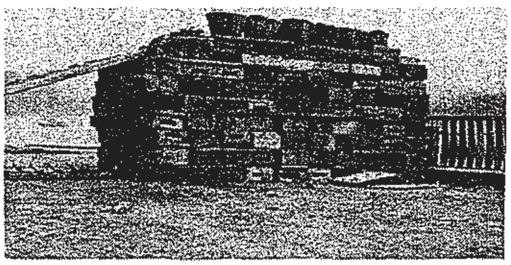
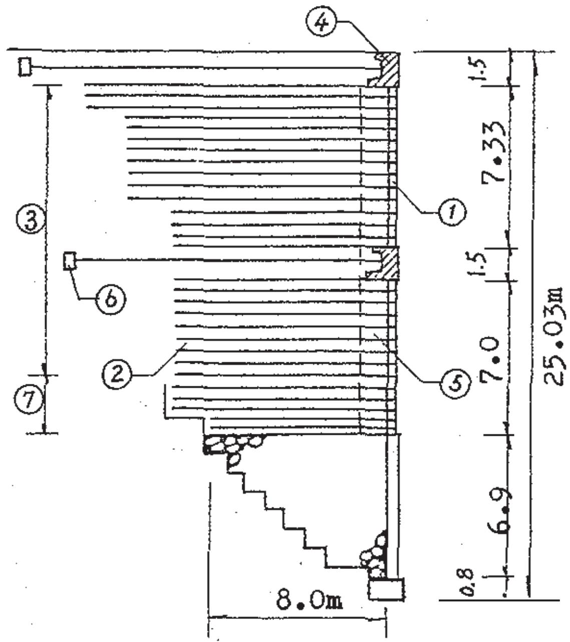


Fig. 2 Loading condition in test



① Facing ② Fill ③ Polypropylence strips ④ Parapet ⑤ Filter ⑥ Deadman ⑦ Metal strips

Fig.3 Section of Bai Sha Wan reinforced soil quaywall

Table 1. Particle size of the fill in Bai Sha Wan quaywall

Size (mm)	2	2-20	21-60	60
Content (%)	17.1	21.4	54.7	6.8

was built along the bank slope. The top of the foundation is 8m in width.

3 CONSIDERATION OF THE TENSION IN THE REINFORCEMENT

The calculation of the tension in reinforcement relates not only to the number and the length of reinforcement but also to the internal stability of the reinforced soil. The present methods to calculate the tension in the reinforcement are not suitable for greater than 15m height quaywall reinforced with lower-modulus-extensible inclusions (geosynthetic fiber etc.), e.g., if we adopted the Rankine's equation or the Mayehef's equation to calculate the tension in the course of designing the Bai Sha Wan quaywall, the tension at a node can be more than 40KN, i.e., more than 30 pieces of the geosynthetic strips are laid within 0.5m, which makes it difficult not only to lay the strips but also to limit mobilizing the friction between the strips and the fill. Fig.4 shows that the tensions calculated by Coulomb's equation or by Rankine's equation are less. Because the above equations allowed the fill is at active state of limiting equilibrium in full, which is inclined to disadvantage for the reinforced soil structures over 15m height. Although Fig. 4 shows that the tension diagram calculated by Osman's equation could be approximately accordant with the result in centrifugal model test (Fig. 5), the Osman's tension will be reduced to zero at the foot of wall, which brings about blindness to lay the reinforcements at the foot. In theory it is possible that the lateral earth pressure is equal to zero, in this case $\phi=90$, the cohesion must be large enough. In fact the reinforced soil are mostly cohesionless and the "cohesion" increased by reinforcement is limit-

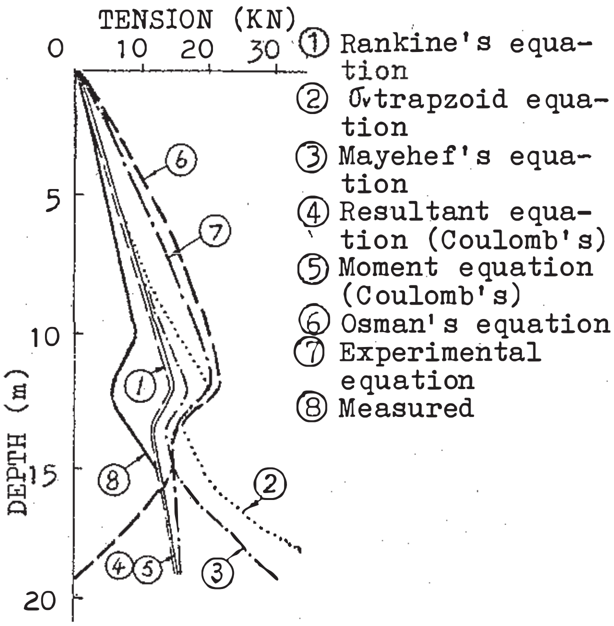


Fig.4 Tension measurements and comparison

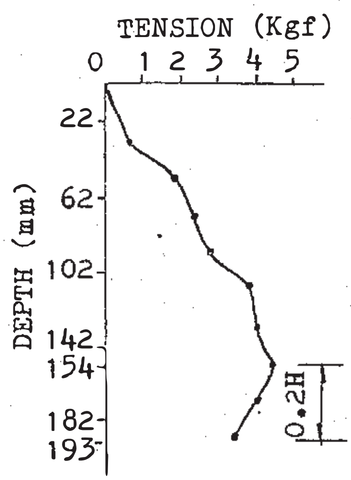


Fig.5 Peak tensions at 63g in centrifugal model

ed. Thus it is impossible that the lateral earth pressure is zero at the toe, then the tension can't be also reduced to zero. Based on the practice of the Bai Sha Wan quay-wall the author suggested an experimental equation to calculate the tension in geosynthetic fiber reinforcements.

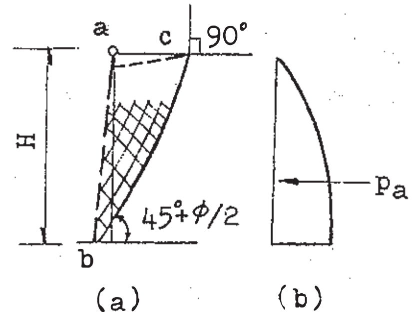


Fig.6 When a wall rotates around the top (a) failure plane (b) earth pressure distribution

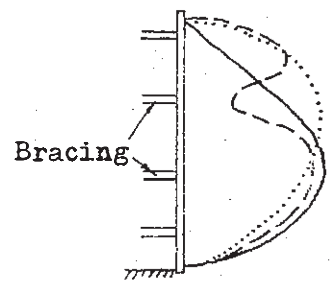


Fig.7 Earth pressure measurements with bracing in excavation

4 THE EXPERIMENTAL EQUATION

The tension in the reinforcement is determined in terms of the lateral earth pressure. The tension distribution along the height of the wall should be fit in with the lateral earth pressure. A lot of measurement as well as investigation of Terzaghi and Peck showed that the earth pressure distribution is such as shown in Fig. 6(b) and Fig. 7 when the wall rotates around the top. The earth pressure distribution measured from installation of bracing as the excavation proceeded had the shape of curve. In general the Terzaghi's and Peck's "apparent-earth-pressure" diagram was used to design a retaining wall and the Schnabel's "apparent-earth-pressure" diagram was used to design a tied-back wall, which have performed successfully also (Fig. 8).

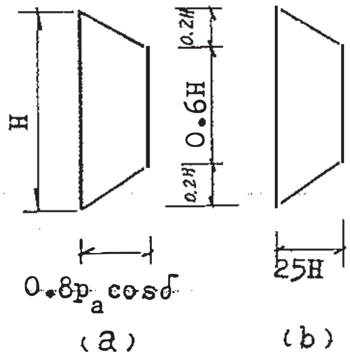


Fig.8 "Apparent-earth-pressure" envelope: (a) Terzaghi and Peck (b) Schnabel

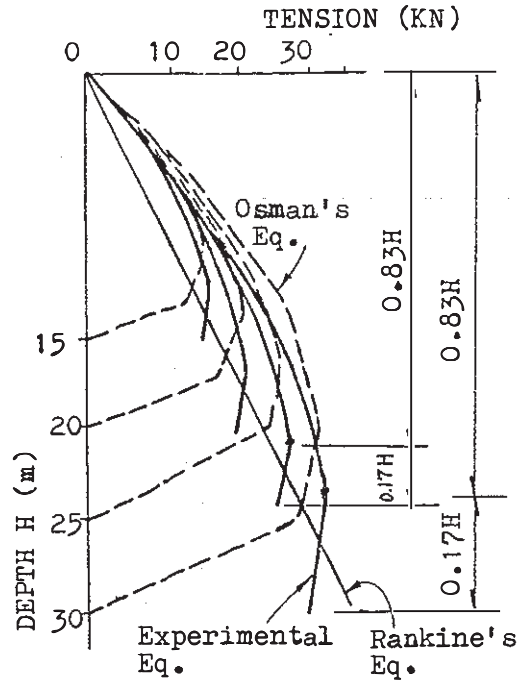


Fig.9 Experimental equation is compared with other equation

The acting force of the reinforced soil with geosynthetic-fiber strips is similar to that of the bracing wall and the tied-back wall in some ways. The bracing apply a thrust on the wall along the depth of the excavation, and the reinforced soil or tied-back wall apply an anchoring force on the wall behind the facing. Both of them are the horizontal supporting force. Therefore the diagram of the tension in reinforcements should be also similar to earth pressure distribution of the bracing wall and the Schnabel "tied-back wall", i.e. it has the shape of firstly-in creased and laterly-reduced curve which has been demonstrated by Bolton's results from the centrifugal model test as shown in Fig. 5.

Based on the above considerations the following conclusions can be drawn:

1. The tensile distribution in the reinforcements has the shape of firstly-increased and laterly-reduced curve as shown in Fig. 5.
2. The maximum tension acts at an approximate distance of 0.2H above the bottom of the wall.

Therefore the author suggested an experimental equation to calculate the tension by means of the curve fitting as follow:

$$T_i = \sqrt{6K_a^{2.8}(H - 0.8h)/L} \quad rhS_xS_y$$

where $K = K_o(1-h/6)+K_a$ when $h \leq 6m$

$K = K_a$ when $h > 6m$

K_o=coefficient of earth pressure at rest; $K_a = \tan(45° - \phi/2)$; h=the depth at the ith layer; L= a strip length; r=density of soil; S_x= a horizontal spacing between the joint, and S_y= a vertical spacing; H=wall height; T_i= a tension in the reinforcement one joint at i layer.

Fig. 9 shows the comparison between the experimental equation and other equations. By comparison it is found that experimental equation diagram is close to the Osman's equation diagram above distance of 0.17H from the bottom of the wall, but within 0.17H distance the tension is slightly less than that of Rankine's equation, and it is not zero at the bottom, which just satisfied designing reinforced soil wall. The maximum tension of the experimental equation is at a distance of 0.17H from the bottom. The experimental equation diagram is also similar to Fig. 5, and it is also satisfactory for designing Bai Sha Wan quaywall.

In addition the experimental equation diagram was similar to the measurement of the earth pressure in Bai Sha Wan quaywall, which demonstrates the tension distribution

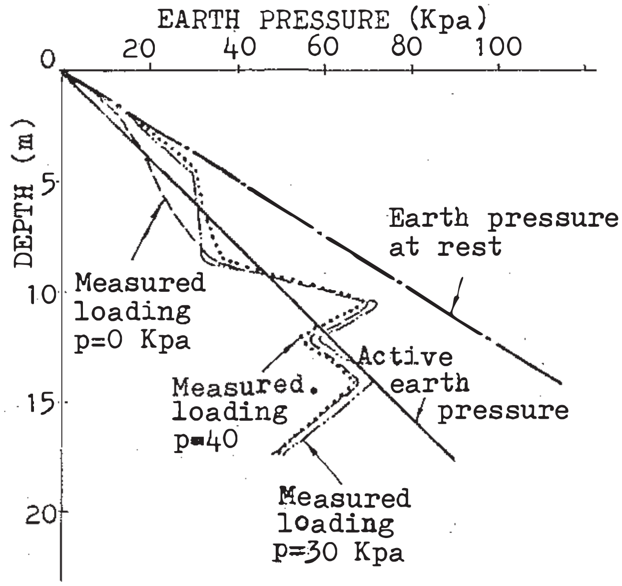


Fig.10 Measurement of the earth pressure in Bai Sha Wan quaywall

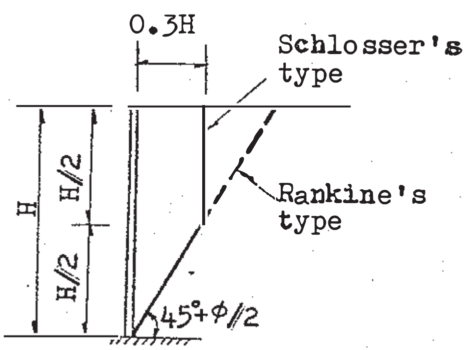


Fig.11 Typical failure planes of reinforced soil

along the height of the wall calculated by the experimental equation coincides with the earth pressure distribution (Fig. 10). Therefore the experimental equation is also satisfactory for designing Bai Sha Wan quaywall.

5 THE FAILURE PLANE

The present typical failure plane of the reinforced earth are two types, i.e., the Rankine's type and the Schlosser's type (Fig. 11). The Rankine's type required the length of the reinforcement to be 0.8H. It is obvious that this length may be impossible for the great height reinforced earth wall in the mountain area; and the Schlosser's type required the length of the reinforcement to be 0.3H enough, it is obvious that this length may be too shorter for the great high wall. From this reason we set separately the tieback parapet which is like the girt at the middle and the top of the quaywall to increase the stability of the quaywall rather than to increase the length of reinforcement. Owing to the restrained action of the tieback parapet a lateral displacement of the upper part of the quaywall might be developed difficultly, which forms the condition to turn about the top of the wall. Terzaghi and Peck considered that the failure plane corresponding to the above condition should be like Fig. 6(a), i.e., the failure plane which starts from b made an angle of $(45°+\phi/2)$ with the horizontal (Fig. 6), and then the failure plane is orthogonal gradually to the fill surface. That means before the foot of the failure wedge arrives at the state of plastic equilibrium the upper part of the wedge is still at the state of elastic equilibrium, i.e., the upper fill in the wedge is settlement rather than shear failure. Thus when the lower part of the reinforced fill is firstly unsteady, the failure plane will be developed, the fill behind the parapet will be still at state of the elastic equilibrium (vertical settlement). In consequence of settlement the point of the maximum tension in reinforcement behind the parapet moves towards to the facing and the reinforcement must be cut at M (Fig.12). Therefore the failure plane of the reinforced soil quaywall which has a tieback parapet may be simplified as shown in Fig. 13.

6 CONCLUSION

1. For the reinforced soil structure over 15m height the experimental equation presented in this paper might be adopted to calculate the tension in the geosynthetic-

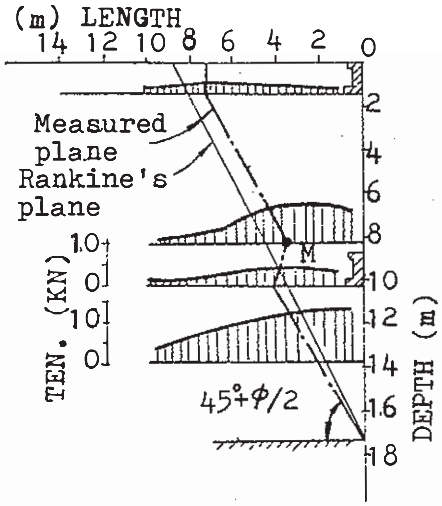


Fig.12 Measurements of the tension along the length of the strip

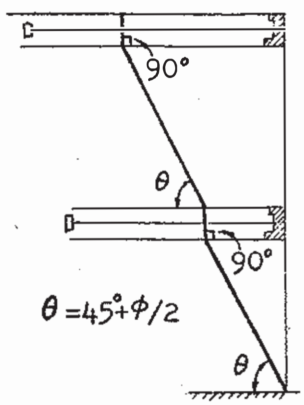


Fig.13 Reinforcing-tieback system failure plane

fiber reinforcement, which can obtain the satisfactory results.

2. For reinforced soil structure with a tieback parapet, the simplified failure plane presented in the paper can be used to determine the length of the reinforcement. The girt-tieback-parapet is set in the great height reinforced soil structures, which can reduce the length of the reinforcement as well as increase the stability of a structure.

REFERENCES

Bolton, M.D. & Pang, P.L.R. 1982. Collapse limit states of reinforced earth retaining walls. Geotechnique 4: 349-367.

Harry Schnabel, Jr. 1982. Tiebacks in foundation engineering and construction: 129-149, Mcgraw-Hill, Inc.

Lee, Kenneth L., Adams, Bobby Dean and Vagneron, Jean-Marie. 1973. Reinforced earth retaining walls. Journal of the Soil Mechanics and Foundation Division, Vol. 99, No. SM10:745-764.

Ouyang Zhongchun, 1986. Design and test of reinforced soil structure over 15m height. Proceeding of CCES 3rd convention: 387-398.

Terzaghi and Peck, 1948. Soil mechanics in engineering practice. New York.