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A new interpretation on principle of reinforced soil and design of reinforced soil wall with strips

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ABSTRACT: In this paper, the distress of current design concept on reinforced soil wall with strips was pointed out ,and reasonable design concept on reinforced soil wall discussed through investigation on practice and analysis on according to the fundament of reinforced soil wall.

1 INTRODUCTION

Reinforced soil technique has been extensively applying in China since 1980s. Nevertheless, because the reinforced soil is a new technique, the fundamentals of it may not be understood. Hence, there is popular misunderstanding involved in the design of the reinforced soil wall, especially reinforced soil wall with strips. Most designers tend to regard the facing of the wall as a element which suffered entire earth pressure and transferred it to the strips (Fig.1 (a)). So, according to current comprehension, the internal stability of the reinforced soil wall is checked by the theory of tiebacks only.

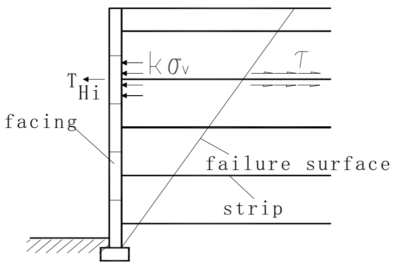

Figure 1a. Tieback theory conventional renforced soil wal with strips

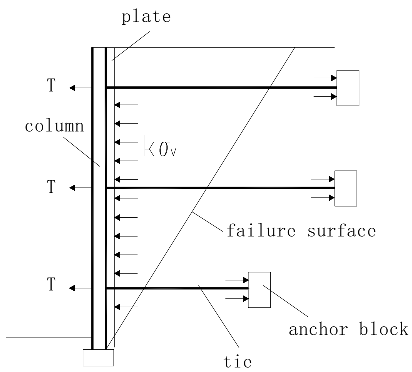

Figure 1b. Transfer of force for tieback structure

In author's opinion, Tieback wall is consist of rigid facing (such as column and plate) which suffered the earth pressure (Fig.1 (b)), but reinforced soil wall does not, so, theory of tiebacks isn't perfectly suitable to the design of the reinforced soil wall, because it disregards the actual reinforcement effect on the soil-reinforcement interface. As a consequence, severe belly-deformation even local collapse of reinforced soil wall with strips occurred during its subsequent performance. On the basis of analyses and experiments of the reinforced soil, we can draw the conclusion that the facing would not be a element which suffered lateral earth pressure. The tieback theory is not employed along, besides the sufficient strength of strips, reinforcement effect must be considered when determine the quantity of strips.

2 FUNDAMENTALS OF REINFORCED SOIL

As well know, the strength of reinforced soil is higher than unreinforced soil, obviously, the reinforced composite mass is better in mechanical characteristics due to the affect of reinforcement. On the viewpoint of soil mechanics, the strength of soil is improved after the applications of reinforcements, which can be demonstrated sufficiently by the triaxial test. In Fig.2, Mohr's envelope of reinforced and unreinforced soil are shown as line M and N respectively, the shear strength is as following based on the Mohr-Coulomb criterion

unreinforced soil $\tau = \sigma \cdot \tan\phi$

reinforced soil $\tau_r = \sigma_r \cdot \tan\phi + C_r$

Obviously, $\tau_r > \tau$

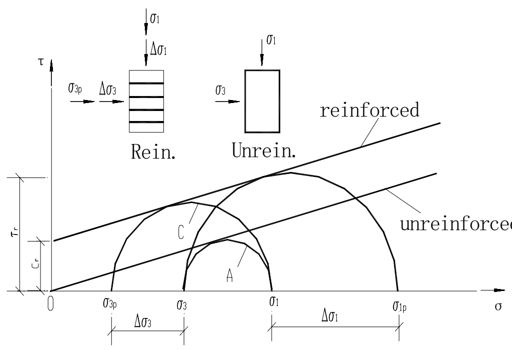

Figure 2. Mohr's circle of stress for reinforced soil

In Fig.2, if σ_3 is kept constant, in order to reach the limit equilibrium of reinforced soil, σ_1 must be increased to σ_{f1} i.e., compared with unreinforced soil, the vertical bearing capacity of reinforced soil is significantly increased,

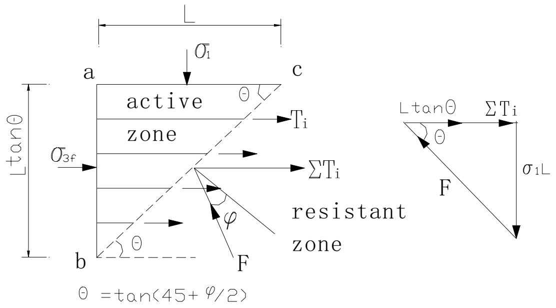

Figure 3. Failure wedge of reinforced soil

the increased value is $\triangle\sigma_1$; If σ_1 is kept constant, the circle C is a Mohr's circle of limiting stress for reinforced soil. In comparison with circle C, circle A is at state of elastic equilibrium, i.e., specimen of reinforced soil is not at state of failure under the same condition (σ_1, σ_3 and dimensions are the same), because the lateral restrain force was increased by $\triangle\sigma_3$. Following analyses indicate $\triangle\sigma_3$ is made from reinforcements. To calculate $\triangle\sigma_3$, we take out a failure wedge of specimen (Fig.3) as a working member *abc* and analyze its static equilibrium according to Mohr-Coulomb criterion. F is a resultant against the failure surface, according to the force polygon, we get

$$F=\frac{\sigma_1 L}{\sin\theta} \quad (1)$$

σ_1 in Eq. (1) can be obtained by Eq. (2) under the condition of soil's limit equilibrium.

$$\sigma_1=\sigma_{3f}\cdot\tan^2\theta+2C_r\cdot\tan\theta \quad (2)$$

According to $\sum X=0$, the force system exerted upon the working member *abc* that should be satisfied with following equation, see Fig.3.

$$L\cdot\tan\theta\cdot\sigma_{3f}+\sum T_i-F\cos\theta=0 \quad (3)$$

Inserting Eqs. (1) and (2) into Eq. (3), we get

$$C_r=\frac{\sum T_i}{\tau\cdot L} \quad (4)$$

On the other hand, C_r can be indicated by $\triangle\sigma_3$ in Eq. (5) according to the theory of pseudo-cohesion.

$$C_r=\frac{\Delta\sigma_3\cdot\tan\theta}{\tau} \quad (5)$$

Let Eq. (4) equal to Eq. (5), the lateral restraining stress $\triangle\sigma_3$ applied to overall height wall can be obtained

$$\Delta\sigma_3=\frac{\sum T_i}{L\cdot\tan\theta}=\frac{\sum T_i}{H} \quad (6)$$

$\sum T_i$ is a resultant pullout resistance that was made from soil-reinforcement interaction in resistant zone. Hence

$$\sum T_i=\tau\cdot\sum S_{ip} \quad (7)$$

Where

τ is the pullout resistance of shearing friction between soil and reinforcement

$\sum S_{ip}$ is the sum of the reinforcement surface area substituting Eq. (7) into Eq. (6), we get:

$$\Delta\sigma_3=\frac{\tau\cdot\sum S_{ip}}{H} \quad (8)$$

Eq. (8) shows that the lateral restrain was made from friction between soil and reinforcement and was in proportion to the surface area of the reinforcement.

In addition, as the soil mass in active zone is at state of active limiting equilibrium that the soil mass would be moved outward. The outward force is equal to the active earth pressure.

$$T_H=E_H=\frac{\gamma\cdot H^2\cdot K}{2} \quad (9)$$

Author conducted a experiment of 3-meter-high non-facing reinforced soil wall at Colorado University in U.S.A in 1993. Under loading, the soil on the wall face was merely stripped in local rather than collapse of the wall. The result indicated the facing would not be a take-force element of retaining wall. In other words, the earth pressure was transferred to the reinforcement by soil-reinforcement interface instead of facing of the wall (Fig.4). The result, which produced a tension T_{Hi} in reinforcement, Hence

$$E_H=\frac{\gamma\cdot H^2\cdot K}{2}=\tau\cdot\sum S_{ia}=T_H$$

$$\sum S_{ia}=\frac{\gamma\cdot H^2\cdot K}{2\tau} \quad (10)$$

Where

$\sum S_{ia}$ is the sum of reinforcement surface area in active zone

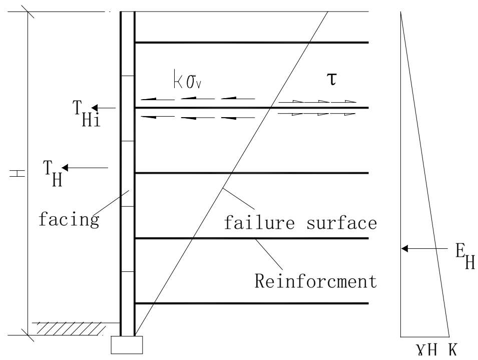

Figure 4. Transfer of force reinforced soil

Eq. (10) indicated that enough soil-reinforcement interface should be guaranteed so that the tension of the reinforcement would be produced and the facing would not be suffered earth pressure, the reinforced soil wall was at stability, which is the reinforcement effect. The above is a basic mechanism of the reinforced soil wall. But the above mechanism was neglected in current design of the reinforced soil wall with strips.

3 CURRENT MISUNDERSTANDING TO DESIGN OF REINFORCED SOIL WALL

According to Eqs. (8) and (10), in order to reflect the basic theory of reinforcement soil, the sufficient contact area of soil-reinforcement must be ensured to bring the effect of soil-reinforcement mechanics into full play. More sufficient the effect is, more lateral restraining force is, the better self-stability of retaining wall is, otherwise, it's unbelievable that the thin flexible build-up wall plates could maintain the stability of retaining wall up to more than 10 meters high. Nevertheless, we usually pay little attention to above basic theory in design of reinforced soil wall, especially higher walls.

So far, for the internal stability checking computation of the wall, the surface area and the embedment length of strips were calculated according to the Eqs. (11) and (12) only.

$$A_i = \frac{T_i \cdot 10^3}{K[\sigma_L]} \cdot \quad (11)$$

$$L_1 = \frac{[K_f]T_i}{2f^{'} \cdot b_i \cdot \gamma_i \cdot Z_i} \quad (12)$$

Where

T_i is pull force applied to reinforcement

$[\sigma_L]$ is allowable tension stress of strip

L_i is the length of strip

$f^{'}$ is coefficient of friction between soil and strip

b_i is width of strip at a node

z_i is distance from top of the wall to ith layer

Obviously, by equation (11), the strength of the strip was emphasized, the section area of strips (i.e., the quantity of strips) depends on the strip's allowable strength instead of reinforcement effect. If the allowable strength is high, the quantity of strips is little. Although considering the pulling stability as well, equation (12) prefers to emphasize the embedment length of strip by the theory of tiebacks. So, the reinforcement effect is neglected in current design of reinforced soil wall and poor reinforcement effect result in high lateral earth pressure applied to the thin flexible plates of the wall. Therefore, the hazard, such as belly-deformation of wall is inevitable. Hence, it's unreasonable to employ strength theory of tiebacks only to determine the quantity of strips.

4 MODIFICATION OF CURRENT DESIGN OF THE REINFORCED SOIL WALL

Reasonable design of reinforced soil wall should express the reinforcement effect besides satisfaction of the pullout resistance. In author's opinion, current design of the reinforced soil wall should be modified as follow:

1. The quantity of reinforcements is calculated according to the reinforcement effect (i.e., Eqs. (8) and (10)), besides which, the pullout and strength of reinforcement are checked according to tieback theory (i.e., Eqs. (11) and Eq. (12)).
2. Geogrid or geotextile must be used giving full play to the reinforcement effect.
3. The design height of reinforced soil wall with strips should be restricted within 6m and the strips can't be bundled to connect the facing.

5 CONCLUSION

It is unreasonable that the quantity of strips is calculated by strength theory of tiebacks only. Because the tiebacks theory could not express the reinforcement effect but strength only, the lateral deformation (such as belly-deformation) is inevitable especially for higher walls. To avoid the misunderstanding, the quantity of reinforcements should be determined by Eqs. (8) and (10), furthermore, arrangement of strips, type of the reinforcements are improved properly.

6 REFERENCES

Bengt B.Broms, Fabric reinforced retaining walls, Theory and Practice of Earth Reinforcement. Balkema 1988

K.Nakamura & Y.Tamura, Role of facing in reinforcing steep clay slopes with a non-woven geotextile. Balkema 1988

Department of communications of P.R.China Specifications for Design of Highway Reinforced Earth Engineering. Jiaotong Public House 1991

Zongyao Liu, Manual of application for geosynthetical engineering. China Jianzhu Public House 2000

Zhongchun-Ouyang, Modern technique of reinforced soil. Renmin Jiaotong Public House 1990

P.J.Sabatini etc. Earth Retaining Systems. FHWA-SA-96-038 U.S.A 1997