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The limit equilibrium of geotextile reinforced structures

Y.Zhang
Ministry of Water Resources, People's Republic of China
E.Schwing
University of Karlsruhe, FR Germany

ABSTRACT: The global stability of geotextile reinforced retaining structures is usually determined without any consideration of the deformation properties of the composite building material soil-geotextile. For practical design the orientation of the geotextile reinforcement towards potential slip surfaces is investigated using a simple equilibrium analysis. It is shown that safety increases reaching the limit state with the appearence of local deformations.

1 INTRODUCTION

The stability analysis for geotextile reinforced walls is still done the same way as for conventional retaining walls. A substantial difference however is that the slip surfaces can penetrate the supporting body of geotextile in the limit state. More accurate studies on stability analysis of geotextile reinforced retaining structures are presented in [1]. It is shown in the analysis of stability that one important difference between geotextile reinforced walls and classical retaining walls (such as gravity walls) is, that tensile forces are variable in direction and magnitude. Under these circumstances the classical elastic theory can not be directly used.

In practice, changes occur in relation to the direction and magnitude of tensile forces to the effect that the stability tends to increase at the initial state of slip in geotextile reinforced walls. Such tendency stops only when slip deformation reaches a certain degree (figure 1c). This phenomenon is a result of the limit state of geotextile reinforced walls.

The present paper aims at finding out the limit state of geotextile reinforced walls through a theoretical investigation of the influence of the tensile force inclinations on geotextile reinforced wall stability. The limit state can be expressed in a simple equation of limit equilibrium which therefore is very practical.

The adopted approach and part of the drawn conclusions are considered to be of general significance.

2 LIMIT STATE AND LIMIT EQUILIBRIUM

For inner stability of geotextile reinforced walls the factor of safety is defined as:

$$F = \frac{\sum_{i=1}^{n} \vec{R}_i}{\sum_{i=1}^{n} \vec{T}_i} = \frac{R}{E} \qquad (1)$$

with (figure 1)
$\vec{R}_i$: pull out resistance force of the i – layer,
$R : \sum_{i=1}^{n} \vec{R}_i$
$\vec{T}_i$: actual tensile force of the i – layer geotextile acting on the slip surface, $E = \sum_{i=1}^{n} \vec{T}_i$
E : active earth pressure
n : number of layers

The tensile forces are always horizontal, providing that no deformation occurs in the reinforced soil (geotextiles are built in horizontally). When slip occurs inside geotextile reinforced walls, $\vec{R}_i$ and $\vec{T}_i$ are sure to incline, leading to a corresponding change of F (figure 1 a,b,c).

As safety factors always refer to limit state equilibrium it may seem conservative to obtain a safety factor with $\theta=0$ as limit state (all forms of safety expressions lead to the same conclusion). Therefore it is of primary importance to determine the limit state.

2.1 Equation of equilibrium for local forces

The forces acting in the i-layer geotextile around the slip surface (figure 1d) can be expressed as follows:
a) from equilibrium of the horizontal forces

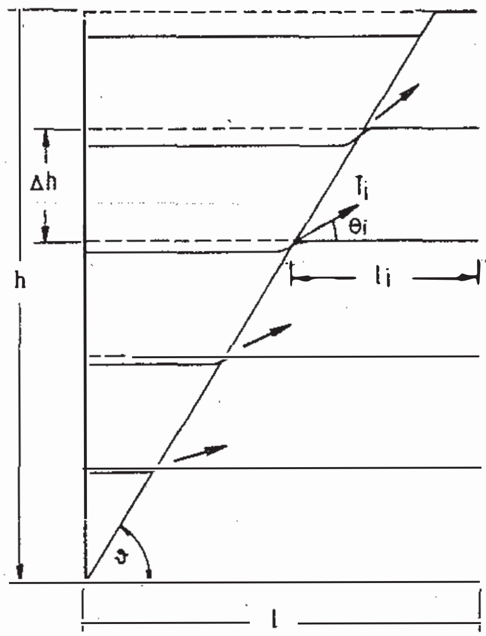
$$q_i \tan\beta r_i \sin\theta_i - q_i r_i (1-\cos\theta_i) + T'_i - T_i \cos\theta_i = 0 \quad (2)$$

b) from equilibrium of the vertical forces

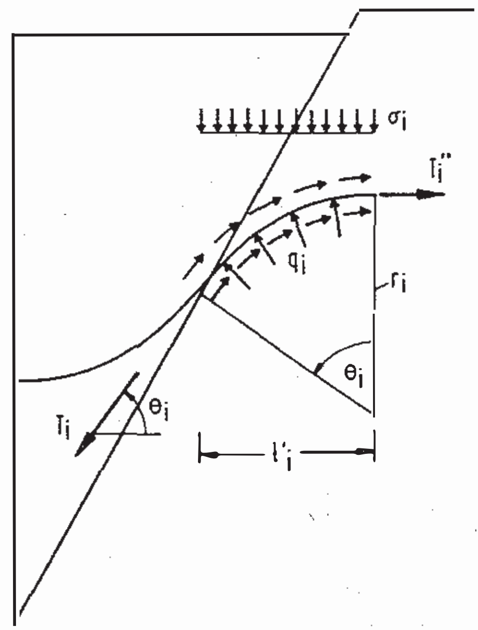
$$q_i \tan\beta r_i (1-\cos\theta_i) + q_i r_i \sin\theta_i - T_i \sin\theta_i = 0 \quad (3)$$

with
T'_i, T_i : tensile forces; $T'_i = T''_i + 2\, l'_i\, \sigma_i \tan\beta$
$\tan\beta$: coefficient of friction between earth and geo textile.

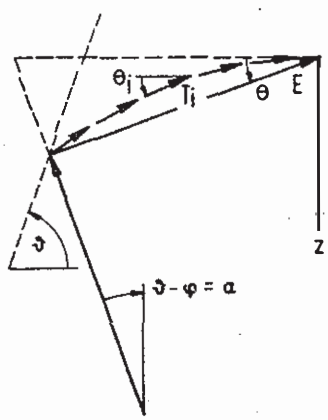
Thus (2) and (3) yield



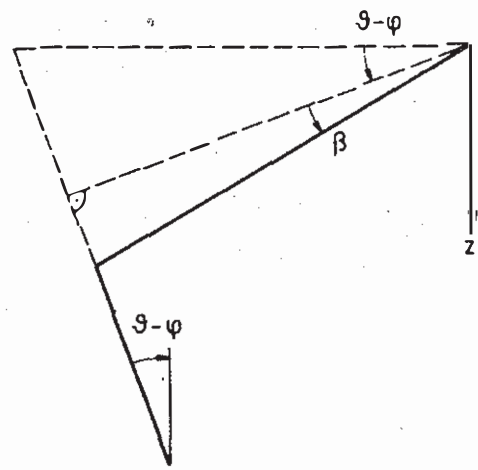
a) System



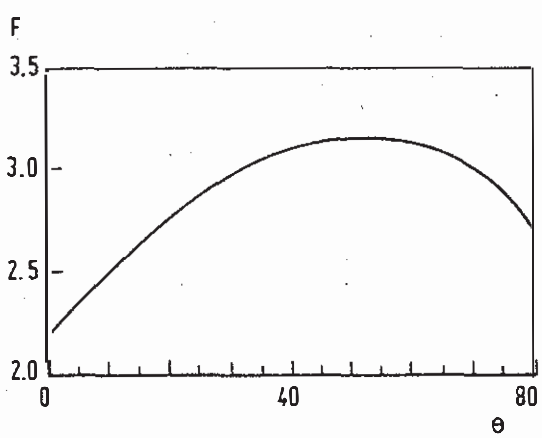
d) Local forces



b) Polygon of forces



e) Significance of limit state



c) Effect of θ on F(ϑ=const.)

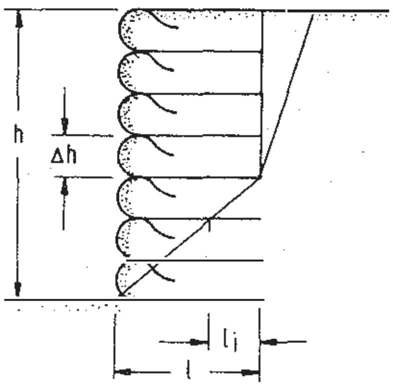
Fig.1. General description

$$T_i = T_i' \frac{\cos(\beta - \theta_i/2)}{\cos(\beta + \theta_i/2)} \qquad (4)$$

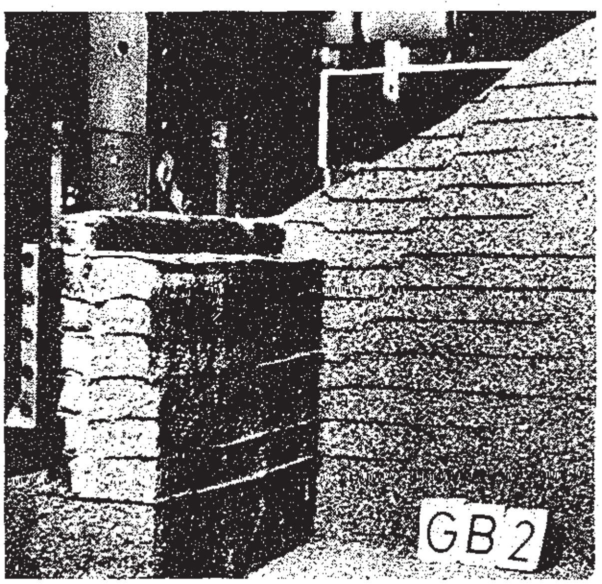
Equ.(4) denotes the increase of tensile forces due to local pressures.

2.2 Limit state

It is shown in figure 1c, that in the course of deformation the tensile force inclines with the result of F,



a) System



b) Model tests

Fig.2. Two-wedge failure system

increasing at the initial stage of deformation till θ reaches a certain degree. In other words, the maximum value of $F(\theta)$ corresponds to the limit state of geotextile reinforced walls. In this paper the cause of the inclination of θ (or θ_i) is of little importance. That geotextile reinforced soil is able to deform is all that matters.

From formula (1) ensues:

$$F = \frac{R}{E} = \frac{\sum_{i=1}^{n} R_i \cos(\theta - \theta_i)}{E_h \cos\alpha} \cos(\alpha - \theta) \qquad (5)$$

with

$E_h = E|_{\theta=0} = E\frac{\cos(\alpha-\theta)}{\cos\alpha}$

(See figure 1 for characters used)

From $\delta F/\delta\theta_i = 0$, $R = R_i'\frac{\cos(\beta-\theta_i/2)}{\cos(\beta+\theta_i/2)}$,

$\Delta\theta/\Delta\theta_i = R_i/R$:

$$R_i \sin(\alpha - \theta) + \cos(\alpha - \theta)[R_i \sin(\theta - \theta_i) + R_i \frac{\sin 2\beta \cos(\theta - \theta_i)}{\cos 2\beta + \cos\theta_i}] = 0 \qquad (6)$$

Adding all $\delta F/\delta\theta_i = 0$:

$$\sum_{i=1}^{n} R_i \sin(\alpha - \theta) + \sin 2\beta \cos(\alpha - \theta) \sum_{i=1}^{n} R_i \frac{\cos(\theta - \theta_i)}{\cos 2\beta + \cos\theta_i} = 0 \qquad (7)$$

Within the range of $0 \leq \theta \leq \vartheta$, the solution of formula (7) is always equal to or slightly larger then $\alpha + \beta$. Therefore it is on the safe side. Limit state is expressed as:

$$\theta = \alpha + \beta \qquad (0 \leq \theta \leq \vartheta) \qquad (8)$$

with $\alpha = \vartheta - \varphi$; (φ : angle of internal friction)

2.3 Equation for limit state equilibrium

From (1) and (8), the equation for limit state equilibrium is :

$$F = \frac{\sum_{i=1}^{n} R_i' \cos(\beta - \theta_i/2)/\cos(\beta + \theta_i/2)}{E_h \cos\alpha} \cdot \cos(\alpha - \theta) \qquad (9)$$

with

$R_i' = 2\sigma_i l_i \tan\beta$: pull out resistance

l_i : anchor length behind the slip surface

σ_i : normal pressure on the geotextile

Though θ is uncertain in formula (9), the following formula is obtained from $0 \leq \theta \leq \vartheta$:

$$\frac{\sum_{i=1}^{n} R_i' \cos(\beta - \vartheta/2)\cos(\alpha - \theta)}{E_h \cos(\theta + \beta - \vartheta/2)\cos\alpha} \leq F \leq \frac{\sum_{i=1}^{n} R_i' \cos(\beta - \theta/2)\cos(\alpha - \theta)}{E_h \cos(\beta + \theta/2)\cos\alpha} \qquad (10)$$

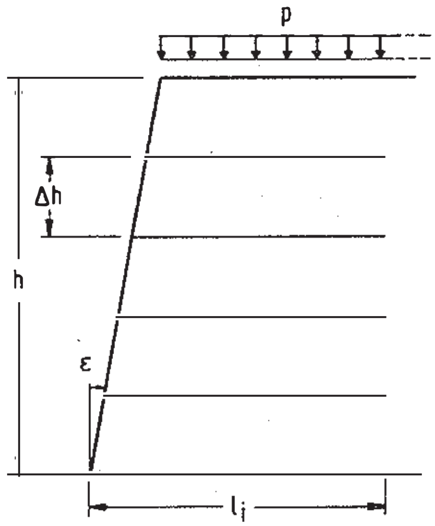
with, if $\theta_i = \theta$ (i=1,2,...n) is true

$$F = \frac{\sum_{i=1}^{n} R_i'(\cos\beta - \theta/2)\cos(\alpha - \theta)}{Z_h \cos(\beta + \theta/2)\cos\alpha} \qquad (11)$$

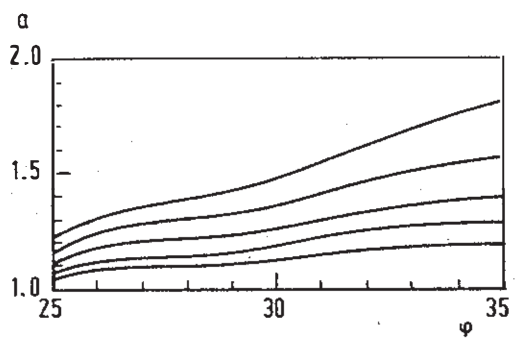
Generally, biased towards the lower safety bound of F, it is suggested, that :

$$F = \frac{\sum_{i=1}^{n} R_i' \cos(\beta - \vartheta/2)\cos(\alpha - \theta)}{Z_h \cos(\theta + \beta - \vartheta/2)\cos\alpha} \qquad (12)$$

where ϑ is obtained corresponding to the minimum value of F.



a) System; ε=10, l/h=1.0, Δh/h=0.2, p/γ_h=0.4



b) Inclination of $a = F_{\theta=\alpha+\beta} \mid_{F_{\theta=0}}$

Fig.3. Effect of tensile forces

3 DISCUSSION

As limit state refers to the whole structure, resultant θ is used in formulas (8), (11), and (12) rather than θ_i for the purpose of clearness. It is true that θ_i sometimes provides more accurate results, but it complicates the expression of formulas (θ_i, q_i and r_i result from the distribution of earth pressure, mechanical characteristics of soil and geotextile and other factors). Actually the difference between F's upper and lower bound ((11),(12)) is relatively very small, so a somewhat accurate solution is of little significance.

. If for example friction by lower pressure is neglected ($R_i = R_i'$ with $\beta = 0$ (4)), maximum F is conditioned by $\theta = \alpha$ (E=mini., R=const.). It can be seen in figure 1e, where E, vertical to a side of the polygon, has the shortest distance. Correspondingly:

$$F = \frac{\sum_{i=1}^{n} R_i' \cos(\alpha - \theta)}{E_h \cos \alpha} = \frac{\sum_{i=1}^{n} R_i'}{E_h \cos \alpha} \qquad (13)$$

Obviously θ_i is irrelevant for the results, here. Formula (13) may also be considered as lower bound of F, when β/φ is smaller (eg. $\beta/\varphi < 0.4$).

Model tests (IBF, Univ. Karlsruhe) show that, if the slip surface extends into non-reinforced soil, two slip bodies emerge (figure 2a,b). Calculations in this paper are all done along this line. Calculation results for figure 3 indicate the influence of tensile force inclinations on the increase of the safety factor, which (though not always so obvious) is comparatively observable when θ becomes larger. It is demonstrated through calculation, that θ seems to be little affected by surcharge.

In general ϑ is smaller when tensile force inclination is considered.

So far, attention has been directed at a plain slip surface; formulas (8) and (12) can also be applied to a curved slip surface and other geo/soil structures, providing that the polygon of forces is in analogy to the one indicated in figure 1b.

4 CONCLUSION

A certain degree of slip deformation is favorable to the stability of geotextile reinforced walls, with the result that F increases.

Affected by tensile force inclination, the limit state of a geotextile reinforced wall is:

$$\theta = \alpha + \beta \qquad (0 \leq \theta \leq \vartheta),$$

which is corresponding to the maximum F (for a given ϑ)

The difference between the lower and the upper bound solution of F is relatively very small.

REFERENCES

Gudehus, G. & Schwing, E. (1986) : Standsicherheit kunststoffbewehrter Erdbauwerke an Geländesprüngen. Baugrundtagung, Nürnberg 1986, 129 - 147.

Proceedings of the 3rd symposium of the international conference on geotextiles. Vol. I – V, Vienna, 1986.