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Some considerations about the calculus of earth retaining structures reinforced with geosynthetics

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ABSTRACT: The paper points out that the usual calculus methods for earth retaining structures with geosynthetics are based on the limit equilibrium analysis. As a consequence the strain field between active and passive state are not taken into account. The authors propose the transformation of the retaining work problem into a stability analysis problem together with the stress strain relationships for soil and for soil-geosinthetics interplay. First of all the method leads to find the relative displacements of the retaining structure according to the geosynthetics material deformation. In this way the compatibility of soil - geosynthetics system is accomplished. The described method has an iterative calculus model using secant moduli for both the soil and the geosynthetics material.
A study case is presented and a good fitting between FEM analysis and the new proposed method results was obtained (errors under 10%).

1 INTRODUCTION

The design of retaining structures reinforced with geosynthetic materials is usually based on the limit equilibrium methods (LEM).

The main advantage of this method is the easiness of determining the force system, based on the analogy with the classic retaining structures. Initially, these methods were adapted for the calculus of the reinforced soil with metallic isolated elements.

In order to quantify the lateral confining effect on the earth thrust (specific for two directions reinforcement), several tests were performed on reduced scale models of reinforced earth. Based on the experimental research done by Yasufuku et all in 2002 were determined the confining parameters and its effects (fig 1 and fig 2). In fig. 3 it is showed the way that the confining effect is materialized within the forces system.

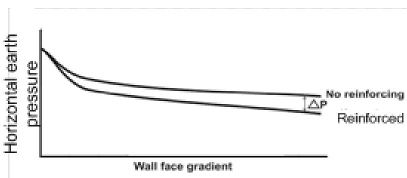

Figure 1. Confining parameters definition.

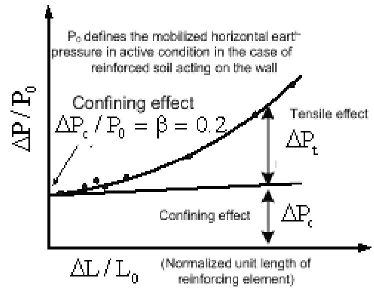

Figure 2. Confining effect vs. reinforced normalized unit length.

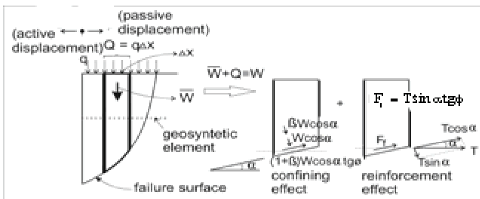

Figure 3. Modified forces system.

In this way the design of retaining structures with geosynthetic material becomes more rational.

Another category of more precise calculation methods used for the calculation of geosynthetic armed earth are the numerical methods such as the FEM methods. For exemplification the figures 4 and 5 are presenting the results of a study made by the Turkish researchers Guler and Hamderi (2002). They have modeled a vertical retaining wall 9 m high with geosynthetic facing elements. On the figure 4 the failure surface is presented as a shear band which respects the Coulomb theory also used in LEM. In fig 5 the displacement distribution can be observed for this case study. A total displacement of 15 mm has been computed. A big advantage of this category of methods consists in the possibility of utilization of different behavior models for both the soil and the reinforcement material. This category of methods requires unfortunately very precise input, powerful computers and specialized algorithms.

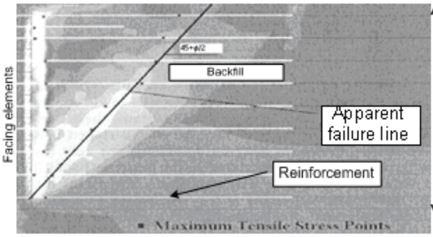

Figure 4. Failure surface obtained as a shear band.

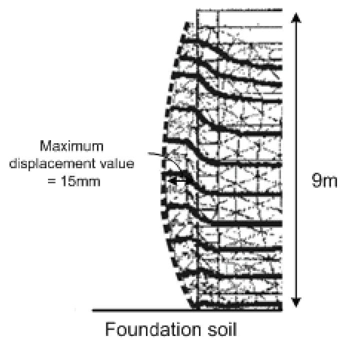

Figure 5. Displacements distribution for FEM model (max displacement 15 mm).

2 THE NEW PROPOSED METHOD

The major disadvantage of LEM pointed out by the numerical model method results (see figure 4) is that it only takes into consideration displacements domain corresponding only for the active earth pressure or passive earth pressure mobilization (see figure 6). Intermediate displacements field is not utilized. In order to consider the progressive mobilization of the shear strength one proposes the retaining work problem transformation into a stability analysis one (figure 7).

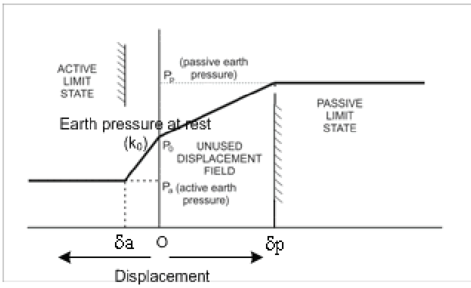

Figure 6. Displacement domains for the active and passive limit state

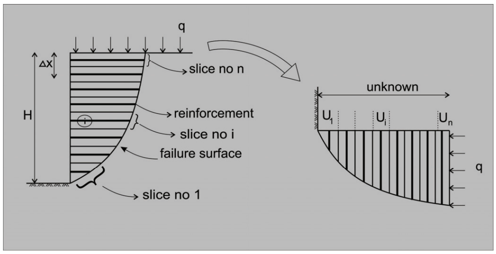

Figure 7. Transformation of the sustaining work problem into a stability analysis problem

The reinforced earth volume is divided in calculus slices. The loads which act on the slide "i" are presented in the figure 8.

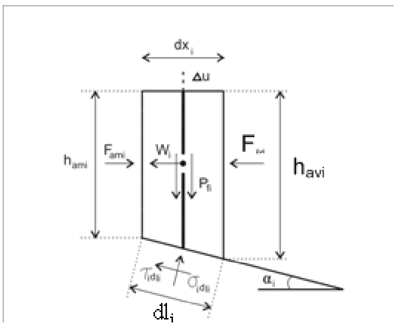

Figure 8. The loads system acting on the calculus slice “i”

The soil mechanical properties are considered by the secant modulus G found on the stress – strain graphical relation. It is known the numerical correlation between G and E moduli by the Poisson coefficient ν. In the following equilibrium relations appear also the pull out strength for the geosynthetic material represented by the modulus E_f. By considering the horizontal and vertical equilibrium equations one can write:

$$W_i - F_{ami} + F_{avi} - \tau_i \cdot dli \cdot \cos\alpha_i + \sigma_i \cdot dli \cdot \sin\alpha_i + Q_i = 0 \quad (1)$$

$$P_{fi} - \sigma_i \cdot dli \cdot \cos\alpha_i - \tau_i \cdot dli \cdot \sin\alpha_i = 0 \quad (2)$$

with

$$W_i = \left(\frac{h_{ami} + h_{avi}}{2}\right) dx_i \cdot 1 \cdot \gamma \quad (3)$$

$$Q_i = q \cdot h_{avi}$$

From the relation number (2) it is possible to obtain:

$$\sigma_i \cdot dli = \frac{P_{fi}}{\cos\alpha_i} - \frac{\tau_i dl_i \sin\alpha_i}{\cos\alpha_i} \quad (4)$$

If (4) is replaced in (1) one obtains:

$$W_i - F_{ami} + F_{avi} - \tau_i dx_i - \tau_i dx_i tg^2\alpha_i + P_f \cdot tg\alpha_i + Q_i = 0 \quad (5)$$

The lateral forces will be calculated using the following calculus relations:

$$F_{ami} = \frac{(u_i - u_{i-1}) ctg\alpha_i}{dx_i} \cdot \frac{(E_i + E_{i-1})}{2} \cdot h_{ami}$$

$$Favi = \frac{(u_{i+1} - u_i)}{dx_i} ctg\alpha_i \frac{(E_i + E_{i+1})}{2} \cdot h_{avi} \quad (6)$$

Where E is the elasticity modulus which is linked by the shear modulus G by Poisson coefficient ν:

$$E_i = 2Gi(1 + \nu) \quad (7)$$

If (6) and (7) calculus relations are replaced in (5) it will be generate the following recurrent relation

$$a_i u_{i-1} + b_i u_i + c_i u_{i+1} + d_i = 0 \quad (8)$$

where: $a_i = \frac{h_{ami} ctg\alpha_i (1 + \nu)(G_i + G_{i-1})}{dx_i}$

$$b_i = E_{fi} \cdot tg\alpha_i - \frac{2G_i dx_i (1 + tg^2\alpha_i)}{(h_{ami} + h_{avi})} - \frac{(G_i + G_{i+1})(1+\nu) h_{avi} \cdot ctg\alpha_i}{dx_i} - \frac{(G_i + G_{i+1})(1+\nu) \cdot h_{ami} \cdot ctg\alpha_i}{dx_i}$$

$$c_i = \frac{h_{avi} \cdot ctg\alpha_i (1 + \nu)(G_{i+1} + G_i)}{dx_i} \quad (9)$$

$$d_i = \left(\frac{h_{ami} + h_{avi}}{2}\right) dx_i + q \cdot h_{avi}$$

For computing the unknown u_i an iterative process is followed for both the soil and geosynthetic material (see figure no 9). This process is finished when the difference between the calculated and the effective stress on the experimental given curves are less than a given tolerance.

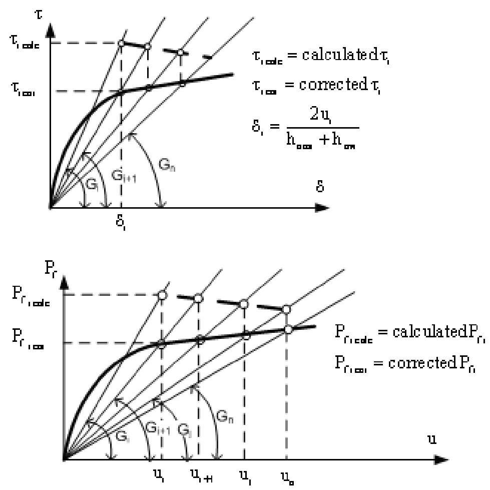

Figure 9. Iterative process which model the progressive mobilization of soil shear strength and pull out force for geosynthetic material (Athanasiu and Chirica, 1982)

3 COMPARATIVE ANALYSIS

In order to have a checking-out of the proposed method some case studies were analyzed. It is about some retaining structures made by reinforced earth with geotextiles or geosynthetics materials.

For example, on the figure 10 there are presented the stress-strain relation for soil pull out force displacement curve for the geosynthetic material.

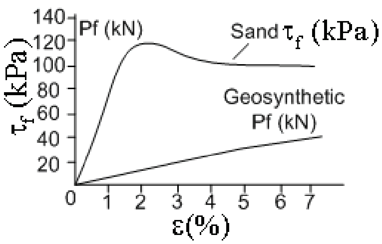

Figure 10. Stress strain curve for the soil and geosynthetic strength mobilization

For the study case described in the figure 5 the new proposed method was used and as it is possible to see in the figure 11 a good fitting of results was obtained.

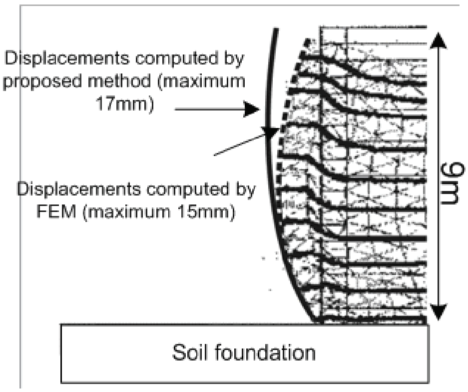

Figure 11. Comparison between the results obtained by FEM analysis and the new method for a study case

4 CONCLUSIONS

The authors propose the transformation of a retaining work problem into a stability analysis problem in order to elaborate a new method for the reinforced earth with geosynthetics calculus. By using the experimental relation between shear strength and displacements for soil and pull out force and displacement of geosynthetics interacting with soil the total displacement compatibility is accomplished. The mechanical model adapted for this method is presented in the figure 12.

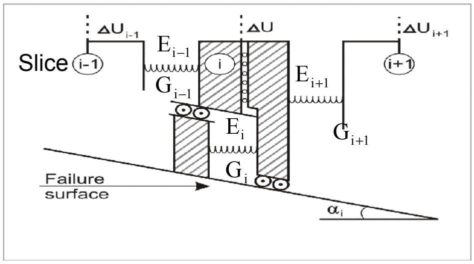

Figure 12. Mechanical model for the new method

The calculus simplicity of the new method and the good correlation with the results of FEM analysis for a case history point out the proposed method efficiency.

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