Geosynthetics reinforcement – limit state approach

Renforcement de la géosynthétique – solution en fonction des états limites

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ABSTRACT: Reinforced soils represent very significant and progressive approach to civil engineering problems. The reinforcement with high tensile strength geosynthetic reinforcing element can add to the earth structure a missing tensile strength and so significantly improve its properties. The main aim of the proposed paper is to discuss and present the approach for safe and effective design and construction of reinforced soils with accordance of limit states design approach which is expressed in EC 7 – Geotechnical design, Part 1 – General rules. The most attention is given to the limit state of overall stability but deformation is also discussed.

RÉSUMÉ: Les sols renforcés représentent une solution trés importante et progressive de problémes du Génie Civil. Le renforcement á l´aide des éléments de renforcement géotechniques ayant une grande résistence á la traction, apporte á la construction la résistence á la traction manquante et, améliore ainsi de la maniére considérable, les qualités de ceux-ci. L´objectif principal de la contribution présentée et de traiter et de présenter l´approche des projets et des constructions surs et effectifs des sols renforcés, tout en étant en accord avec le projet indiquant les états limites, comme l´exige la réglementation générale, partie I, EC 7 – Projet Géotechnique. La plus grande attention est pretée á l´état limite de la stabilité totale, la déromation étant tout de meme discutée.

1 INTRODUCTION

Reinforced earth structures are here for some years, but the design methods are still in the face of development. Some changes are also due to the limit state design which are preferred in an EC 7 - Geotechnical Design, Part 1 - General rules. We know that even for earth structures the basic limit state - limit state of overall stability is in some cases very problematic and not fully accepted yet.

Another problems are connected with the fact that EC 7 emphasizes that in most cases soil improvement and reinforcement should be classified as a third geotechnical category. In this case characteristic input data should be obtained on the base of laboratory or in situ tests and with the following evaluation of these values.

2 LIMIT STATE DESIGN OF OVERALL STABILITY

For classical unreinforced slopes the approach for limit state design of overall stability applied in the Czech code of practice can be defined as follows:

$$\gamma_{sit} \cdot \gamma_n \cdot \psi_c \cdot \Sigma \gamma_{fai} \cdot S_{act,in} \leq \gamma_{stp} \cdot \Sigma \gamma_{fpj} \cdot S_{pas,jn} \quad (1)$$

where $S_{act,in}$ = force influence of design loading values which act on the earth construction or its part above the slip surface to reach the limit state;

$S_{pas,jn}$ = force influence of design effective loading values (friction) and force influence of cohesion by which the earth structure or its part above the slipping surface resists to the limit state overrun;

γ_{fai}, γ_{fpj} = partial reliability factors of the loading which are related to the loading which generate the force influences $S_{act,im}$, $S_{pas,jn}$;

γ_{stp} = partial factor of location stability which is usually taken as 0.9;

γ_n = partial factor of function (significance of earth structure), usually in the range of 1.1 - 1.2;

γ_{sit} = partial factor of design situation;

ψ_c = partial factor of loading combination.

For simplified case is the ratio between the passive and active forces can be defined by:

$$\Sigma S_{pas,jn} / \Sigma S_{act,in} \geq \gamma_n / \gamma_{stp} \quad (2)$$

and when substituting the values on the right side we get:

$$\Sigma S_{pas,jn} / \Sigma S_{act,in} \geq 1.22 - 1.33 \quad (3)$$

Saying very simply when taking into account design values instead of characteristic ones to reach enough slope stability we can accept the safety ratio in the range between 1.22 and 1.33, according to the significance of the earth structure.

2.1 *Design values for reinforced soil*

For the reinforced earth structures the next step is to define the design strength for soils and the design strength for the geosynthetic reinforcing elements. For the design strength of soil we can accept the recommendation of EC 7 - ÈSN P ENV 1997-1:

$$\text{tg}\ \phi_d = \text{tg}\ \phi/1,25 \quad (4)$$

$$c_d' = c'/1,6 \quad (5)$$

$$c_{u,d} = c_u / 1,4 \quad (6)$$

or we can use older recommendations of the ÈSN 73 1001 from the year 1987, where:

$$\phi_d = \phi/\gamma_{m\varphi} \quad (7)$$

where $\gamma_{m\phi} = 1,5$ if $0 < \phi \leq 12°$, or $\gamma_{m\phi} = \phi/\phi$-4° for $\phi > 12°$

$$c_d = c/\gamma_{mc} \quad (8)$$

where $\gamma_{mc} = 2$.

For the design tensile strength of geosynthetic reinforcing element there are different approaches, but very often they are similar (e.g. Viezee et al. (1990), BS 8006). The simple version expressed Gourc (1996):

$$T_d = \frac{1}{F_{tc}} \cdot \frac{1}{F_{comp}} \cdot \frac{1}{F_{env}} \cdot T_f \quad (9)$$

where T_f is maximum tensile strength according to EN-ISO 10319 - high-speed test;

F_{tc} - partial safety factor for creep, depends on geosynthetic material and construction performance. For polyester F_{tc} = 1.5 (for short term structure - 7 years) or 2.25 (for long term structure - 70 years) or for polypropylene and polyethylene F_{tc} = 3.0 or 4.5;

F_{comp} - partial safety factor for compacting effect, ranging between 1.1 and 1.5 as a function of soil and geosynthetic types, upper value 1.5 is recommended for crushed gravel with high sharpness and for geosynthetics from polyester;

F_{env} - partial safety factor for environment, recommended values are: F_{env} = 1 for temporary earthworks and F_{env} = 1.1 for definitive earthworks. This range is valid for pH between 4 and 9 and good protection against UV radiation, for more alkaline environment polyester can degrade.

It is useful to compare the design value T_d with relative deformation for tensile loading.

Relative deformation ε_d for this design value T_d is usually recommended between 2 and 6 percent, according to the sensitivity of the structure to the deformation. This condition can be used for the selection of the right reinforcing element material.

The development of the strength in soil and the development of the tensile strength in reinforcing element depend on the relative deformation (tensile strain, shear strain) and by the applying of partial factors of safety we are not sure that the design values are reached for the same deformation. Jewell (1990) use for this optimum design the expression equilibrium strain - see Figure 2.

Instead of using partial safety factor for creep from recommended values, the more precise way is to use cluster of

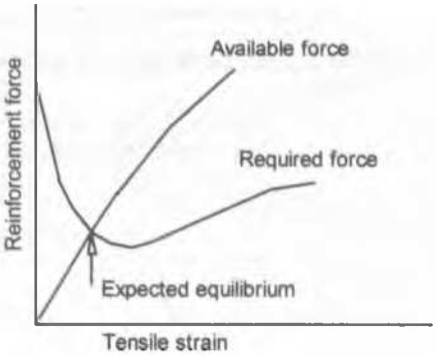

Figure 2. The compatibility curve for determining the equilibrium in reinforced soil by Jewell (1990).

tensile test curves obtained for different rate of loading (EN ISO 13431).

From this cluster the curve for expected service life can be easily selected.

2.2 *Slope stability methods*

For the classical slope stability methods, like Bishop one, the reinforcing element can be applied by two different ways. One opportunity is to include the reinforcing element as an additional horizontal force acting in the direction of reinforcement or as an additional force action in the direction of the slip surface. For this uncertainties we have recommended to apply the reinforcement as an additional horizontal inter-slice force.

Due to this assumption the method of Janbu (1973) was used for the calculation of the reinforced slope Vanίèek,I. & Škopek (1989), Vanièek,M. (2000). Janbu's method, which is adopted

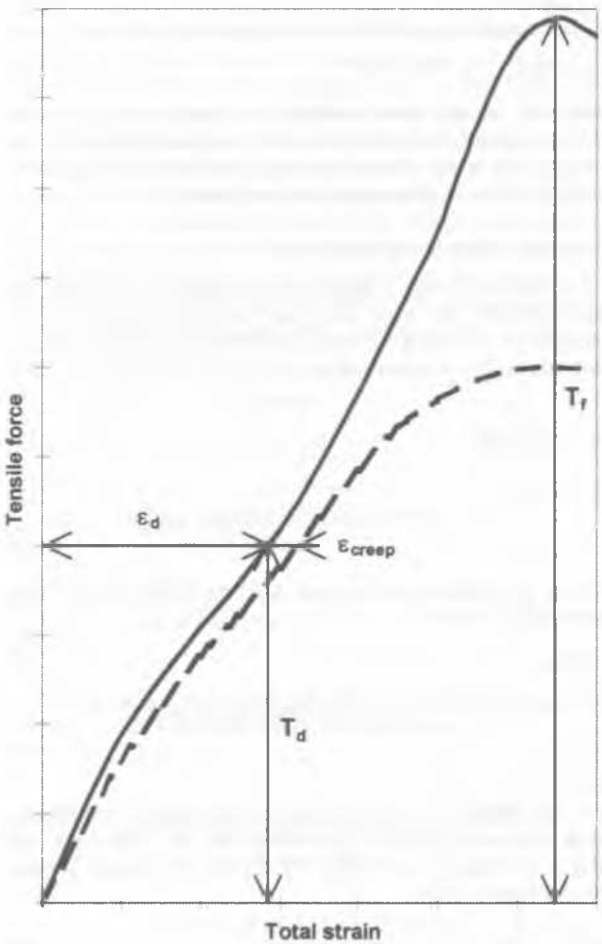

Figure 1. Typical working diagram for tensile test.

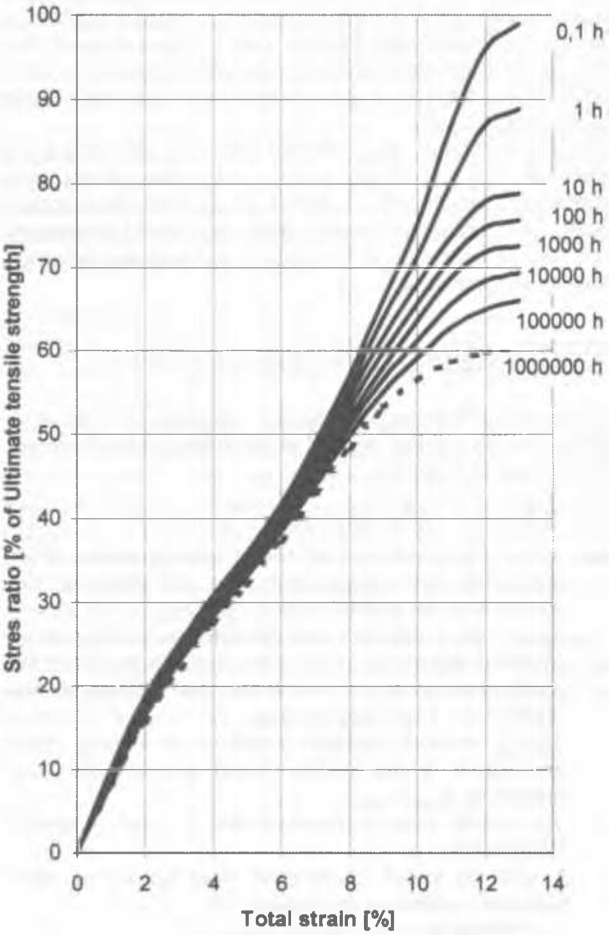

Figure 3. Isochronous curves of polyester woven geogrid Fortrac.

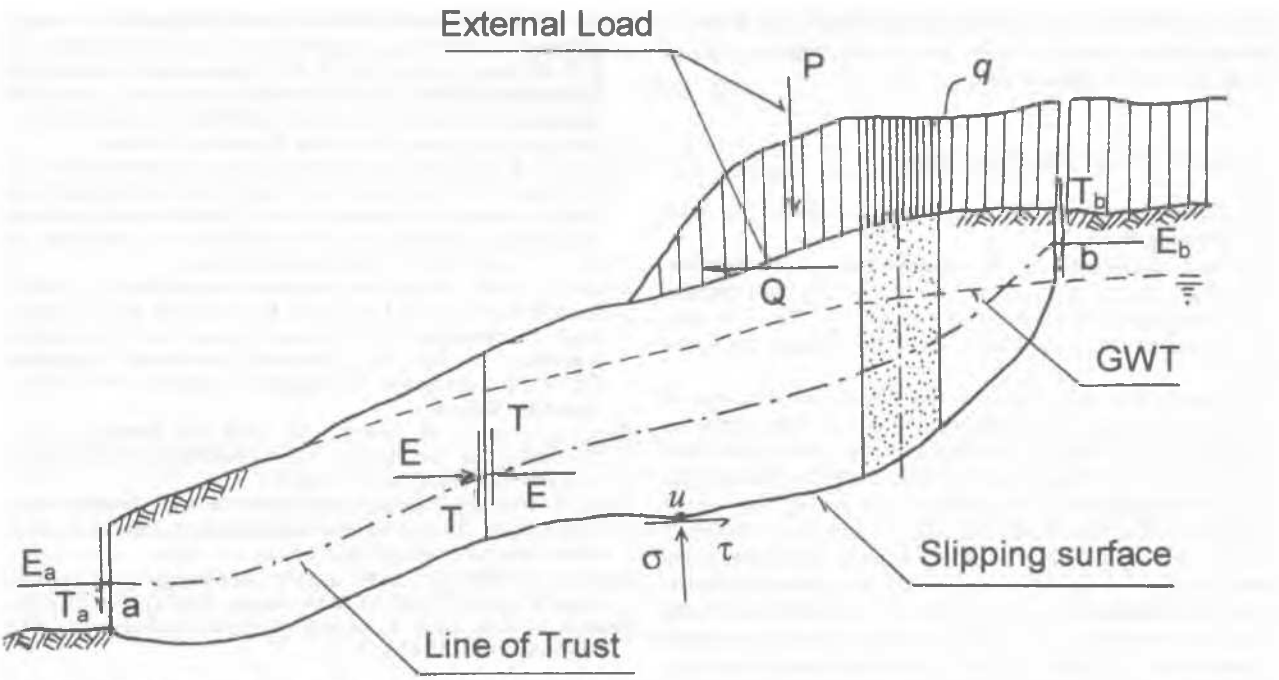

Figure 4. General slope with marked basic terminology and quantities

uses on each slice, to which the whole slope is divided, equilibrium equation in horizontal and vertical directions and momentum one. This approach is complex and accommodates all the forces, which act on each slice (see figure 5). This method solves the safety ratio F by following equation:

$$F = \frac{\sum_{i=1}^{n} \tau_{fi} \cdot \Delta x_i \cdot \left(1 + \tan^2 \alpha_i\right)}{E_a - E_b + \sum_{i=1}^{n} \left[\Delta Q_i + \left(T_i - T_{i+1} + W_i\right) \tan \alpha_i\right]} \tag{10}$$

where the meaning of symbols is explained on Figure 4 and Figure 5. And the shear strength τ_f is for effective stress analysis defined as:

$$\tau_{fi} = \frac{c_{ef} + \left(\frac{T_i - T_{i+1} + W_i}{\Delta x_i} - u_i\right) \cdot \tan \varphi_{ef}}{1 + \frac{\tan \varphi_{ef} \cdot \tan \alpha_i}{F}} \tag{11}$$

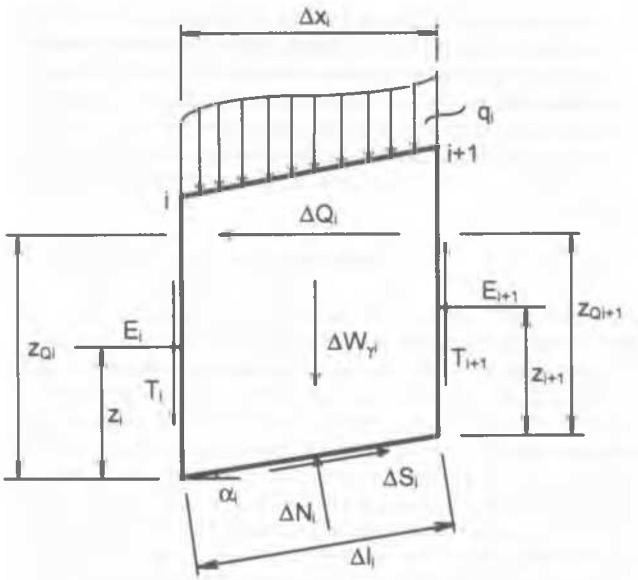

Figure 5. Scheme of forces, which are acting on slice i, and with marked geometric quantities

where c_{ef} is design effective cohesion, φ_{ef} is design effective angle of internal friction. Looking on the equations it can be easily seen that the calculation is iterative.

From our own experience the biggest influence on the stability and calculation result is the position of horizontal inter-slice forces, which are in this calculation method assumed as known. These forces are acting on so called „line of trust", which should be in about 1/3 of the slice height.

Due to the fact that the calculation of this way modified Janbu's method is rather long for hand calculations and for the determination of the most dangerous slip surface with minimum factor of safety, a computer program SVARG (Slope Reinforced by Geosynthetics) was developed. The program can almost immediately solve safety ratio for selected slipping surface or in very short time to find the worst slipping surface. The slipping surface can be general. This program also automatically checks the anchorage length of the reinforcement with the expression:

$$L_k = \frac{3 \cdot T_d}{2 \cdot \left(\gamma \cdot h \cdot tg\varphi_{gs} + a\right)} \tag{12}$$

where φ_{gs} = angle of internal friction between soil and reinforcing element;
a = adhesion between soil and reinforcing element;
h = depth of the reinforcing element bellow the surface;
T_d = design tensile strength of the reinforcing element.

The assumption of the redistribution of the tensile force in the reinforcing element (see figure 6) is adequate for the anchorage part and for the part to the slope face only if the face is without rigid elements. For the retaining structures, where the rigid ele-

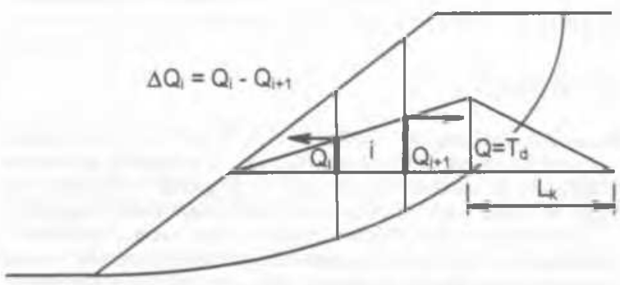

Figure 6. Force introduction from reinforcing element

ments on the face are used, the distribution of the force in the reinforcing element should have on face a value between 0.3 and 0.5 from the design tensile force.

3 LIMIT STATE OF DEFORMATION

Practical approach to the settlement calculation can have some following forms:

a. Without calculation, e.g. for reinforced slope, the deformation is not so important, usually it is satisfied by the condition of acceptable deformation when selecting T_d. The limit state of surface erosion in this case should be checked very carefully.
b. For steep, practically vertical facing, the deformation can be calculated in three steps. Deformation during construction as a soil massive without reinforcement, especially for very flexible facing. Similarly can be calculated second step when the reinforced structure is loaded on the surface, e.g. bridge abutment. And finally we can solve horizontal movement from the creep deformation of the reinforcement during the service life of construction (fig. 2). This additional deformation can be taken from the Figure 3, as an additional strain between short-time test and the test for expected life-time of construction. To hold this value on an acceptable level e.g. BS 8006 defines that the ε_{creep} should be lover than 1% for retaining walls and lover than 0.5% for bridge abutments. This very strict condition can be usually fulfilled by polyester reinforcement, because polyester from this point of view has best performance from the up to now used polymers.
c. Deformation estimation on the base of the laboratory model test (e.g. physical model, centrifuge model).
d. Deformation determination on the base of FEM. The biggest problem when studying reinforced soil by FEM is the great difference in properties and geometry between soil and the reinforcing element, which usually has very small thickness. Two types of connection between soil and reinforcement are usually used for simulation. The first type is simulated by spring elements (normal and shear springs) - Haji Ali & Tee (1990), while the second type uses an interface element, which has zero thickness, e.g. Gens et al. (1988). The reinforcement is treated as a structural membrane with axial stiffness in tension and negligible flexural rigidity.

4 CONCLUSION

For the limit state design of reinforced earth structures as are reinforced slopes, retaining walls and bridge abutments it was shown, that the first limit state of overall stability is dealing with design values for soils and reinforcing elements. For these design values exist methods of their calculations which are defined in many national or European codes of practice.

For the stability calculation the modified Janbu's method was shown, where the reinforcing element act as an inter-slice horizontal force.

Limit state of deformation can be fulfilled by the appropriate selection of reinforcing product. For more important cases modeling in laboratory or numerical one (especially FEM) is recommended.

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