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The construction of improved foundation using geosynthetic materials

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ABSTRACT: Many construction projects require to be found on fill material. The paper presents a soil reinforcement method based on the realisation of successive strata of soil being reinforced with geotextile. This paper describes the method in two parts: first the first part – describes the theoretical basis and, the second part – presents the technology for execution.

1 INTRODUCTION

The action of man and nature continuously modifies the landscape of the earth surface and changes the nature of the crust zone materials where constructions works are founded.

Furthermore, areas with thick fill layers have been formed from diverse materials made by man (concrete blocks, bricks, metals, etc.).

It is often necesarsary the necessity to build foundations on fill for which the following essential stages should be followed:

- Stratigraphic column in the geolithological context;
- Making trial pits for the identification of the materials;
- Establishing the consolidation method for the foundation ground, considering the terrain stratigraphy and the nature of the material.

The preliminary geotechnical report, made in conformity with "Guidelines for construction geotechnical documentation", indicative GT 035/2002 and "Normative on the principles, requirements and geotechnical study methods of the foundation ground", indicative Np 074/2002, will establish the thickness and the nature of fill deposits (concrete blocks, bricks, these will be removed during the foundation excavation).

For stabilizing the fill and establishing a good foundation a procedure based on laying successive layers of geosynthetic and soil can be considered.

2 THEORETICAL BASE OF PROCEDURE

The reinforcing effect of the materials (especially geosynthetics) depends on the tensile capacity of the foundation ground.

This is the result of shear stress (ϕ, c) mobilised at the soil and geotextile interface.

The interaction of soil and geosynthetic produces a tensile stress in the reinforcement which reduces the lateral stress in the adjacent soil, giving an increase of apparent "soil cohesion".

The value of the apparent cohesion depends on the strength on the magnitude of the soi/geotextile interaction.

The strengths mobilised in this Geocomposite material (Fig. 1) is:

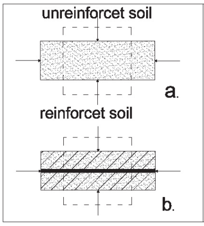
$$\tau = \tau_s + D \cdot T \tag{1}$$

where τ is the strength mobilised in the composite soil, τ_s is the strength on the interface soil/reinforcement, d is the distance between reinforcements, $D = 1/d$ is the frequency of the reinforcement and T is the resistance force of the reinforcement elements.

Taking into account that for the same elongation (ε) the ratio of the resistance mobilized in the soil ($m_r = \tau/\tau_{fr} = 1/F_{sr}$) is different from that in the reinforcement ($m_r = \tau/\tau_{fr} = 1/F_{sr}$).

The relation mentioned above becomes:

$$\begin{aligned}\tau &= m_s \cdot \tau_{sf} + D \cdot m_r \cdot T_f \\ &= m_s\left[(\sigma \cdot tg\phi + c) + \left(D \cdot \frac{m_r}{m_s} \cdot T_f\right)\right] \\ &= m_s(\sigma \cdot tg\phi + c + \Delta c) \end{aligned} \tag{2}$$



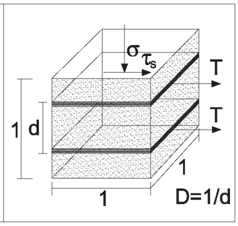


Figure 1. Definition of the additional cohesion.

Figure 2. Reinforcement of the earth element.

where the supplementary cohesion cohesion is:

$$\Delta c = D\frac{m_r}{m_s}T_f \tag{3}$$

When the soil fails first ($m_s = 1$) the supplementary cohesion becomes:

$$\Delta c_s = D \times m_s \times T_f \tag{4}$$

or:

$$\Delta c_s = D \times T \tag{5}$$

and it is proportional to the reinforcement density D and to the force T, developed in the reinforcement (Fig. 3).

When the reinforcement fails first ($m_r = 1$)

$$\tau = m_s \cdot \tau_{sf} + D \cdot T_f = \tau_{s\varepsilon} + D \cdot T_f$$
$$= \sigma \cdot tg\phi_\varepsilon + c_\varepsilon + D \cdot T_f = m_s\,(\sigma \cdot tg\phi_\varepsilon + c_\varepsilon + \Delta c_r) \tag{6}$$

Additional cohesion becomes:

$$\Delta c_r = \frac{D \times T_f}{m_s} \tag{7}$$

and it is added to the cohesion developed for an elongation (ε_r) that corresponds to the failure of the reinforcement (Fig. 3). The position of two families of lines Δc_s and Δc_r allows to the inner "intrinsic lines" to be obtained corresponding to different

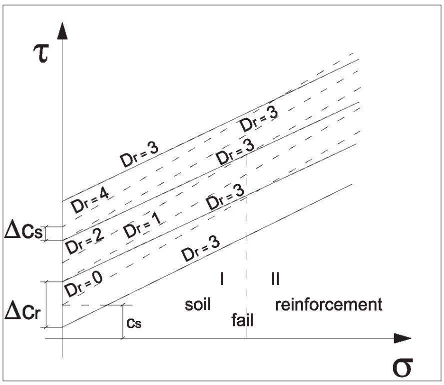


Figure 3. Intrinsic lines for soil and different frequency D_r of reinforcement.

densities or reinforcement $D = 1, 2$ … For example for Figure 2 it is obvious that for $D = 1$ the "elastic domain" is limited by a single line. (corresponding to the soil failure), while for $D = 2$ the elastic zone is limited by two lines corresponding to the soil failure (I) and soil failure (II) (Fig. 3).

Establishing "The domain of elastic state" for different composite materials permits the selection of the adequate material. At the same time considering the "concept of equivalent material" it is possible to introduce a more dense reinforcement in the critical zones. Using this kind of reinforcement the soil becomes nonhomogenous.

The main principle propose for the design of the soil reinforcement is the "elastic state" (before failure) the strain, $\varepsilon_s = \varepsilon_r$, of the two components are equal. This interaction between soil and reinforcement is expressed by a diagram which allows us to follow simultaneously the parameters of soil mobilisation (Φ_ε, c_ε) and the tension in the reinforcement T for the same deformation ε.

Such a diagram obtained by direct shear test and tensile strength test of the reinforcement is presented in Figure 4. The same diagram shows the mobilisation parameters Φ_ε and c_ε at the interface of the geotextile, as they result from the direct shear test made upon a soil with geotextile inserted in the shear plane; Φ_ε and c_ε correspond to the different strains $\varepsilon(\%)$ during shear test.

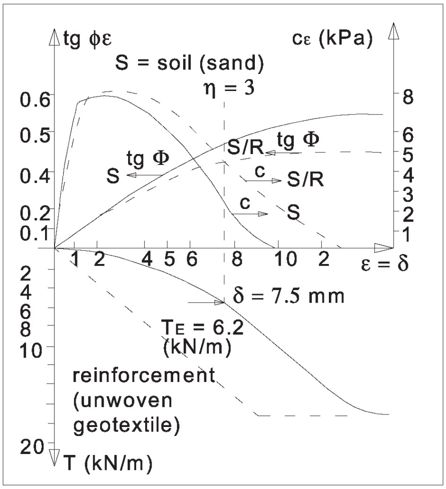


Figure 4. The interaction diagram (S/R = Soil/Reinforcement).

It is interesting to note that for soil the mobilisation of cohesion c_ε is more rapid than that of the internal sliding angle Φ_ε. These facts disclaim the hypothesis of simultaneous mobilisation of the two parameters, taken into consideration by the usual methods of stability analysis.

When the shear strength of soil is determined by triaxial testing (Fig. 5a) one can notice that for the same load there is a linear correlation between:

$pi = (\sigma_1 + \sigma_3)/2$ and $q_i = (\sigma_1 - \sigma_3)/2$

by type $q_i = p_i \cdot tg\ \beta_i + b_{i\varepsilon}$ (8)

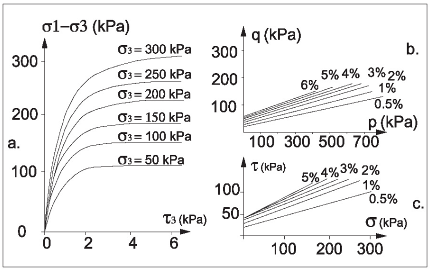


Figure 5. "Intrinsic lines" corresponding to the soil deformation triaxial test.

These parameters are correlated with the intrinsic line parameters for the same deformation ε_1 (Fig. 5c):

$$\tau_m = \sigma_m \cdot tg\ \theta_{\varepsilon 1} + c_{\varepsilon 1} \quad (9)$$

by the relations:

$$tg\beta = \sin\theta_i = \frac{n\sum p_i \cdot q_i - \sum p_i \cdot \sum q_i}{n\sum p_i^2 - (\sum p_i)^2} \quad (10)$$

$$h_i = c_a \cdot \cos\theta_i = \frac{\sum p_i^2 \cdot \sum q_i - \sum p_i \cdot \sum p_i q_i}{n\sum p_i^2 - (\sum p_i)^2} \quad (11)$$

where $n > 6$ is the number of triaxial tests.

For the triaxial test, in order to obtain the interaction diagram (Fig. 6) it is supposed that the deformation ε_3 is equal with those in the reinforcement

$$\varepsilon_r\text{: } \varepsilon_3 = \varepsilon_r \quad (12)$$

Using the above mentioned relations (8)–(12) we can obtain the mobilisation curves of for shear strength parameters tg Φ_n and c (Fig. 6) so that, from the correlation $T = T_f/n$, we can determine the pseudo cohesion:

$$\Delta c = DT$$

and to chart representthe intrinsic lines for the different densities of reinforcement (Fig. 7).

Generally the acceptable deformation is determined by taking into account the post-elastic deformation on the designed life of reinforcement corresponding to the accepted loss of tension in the reinforcement: $T = T_f/n$ (13) where T_f is the maximum strength of reinforcement and $n = 3$ is the safety factor.

Using this method of homogenisation of the composite soil/geotextile material simplifies the design method for earthworks in the sense that usual soil mechanics methods can be applied.

For establishing the foundation stratum obtained with the proposed method the procedures from STAS 3300/2-85 for choosing the conventional allowable bearing capacity ($\overline{p}_{\text{conv}}$) for direct foundation will be used.

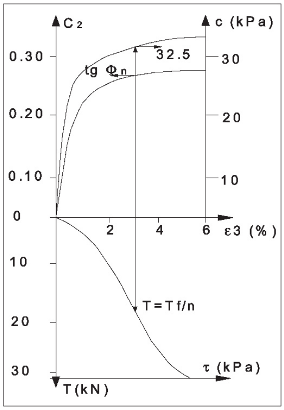


Figure 6. The interaction diagram resulting from triaxial compression test and the tensile test of the reinforcement and the mobilisation corresponding to the parameters of shear strength of soil.

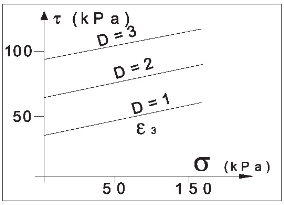


Figure 7. Intrinsic line for reinforced soil.

3 TECHNOLOGY OF EXECUTION

Before starting the earthworks the soil profiles at all parts of the site need to be established.

3.1 *Preparing the soil*

The excavation of the fill material will be carried out until the natural soil are exposed.

All debris with sharp edges (bricks, concrete blocks, iron pieces, knobs, stubs etc.) will be removed from the soil surface at the excavation level, so that there will be no unevenness greater than 2-3 cm.

The surface thus cleared will be leveled with a bulldozer for the desired evenness.

The prepared ground will be compacted with a vibrating roller to give a dence formation, which will be checked using in situ tests.

3.2 *Installing of geotextile material*

Before laying the geotextile remove any water, mud or leaves from the surface.

The geotextile is laid to cover the whole area with adjacent pieces overlapping by 20 cm (the laps can be sewn or bonded)

The first layer of geotextile, taking into account the site conditions can be doubled on the base by another geosyntetic material on the whole formation surface including the lateral walls. (Fig. 8)

Placing the fill material can follow immediately.

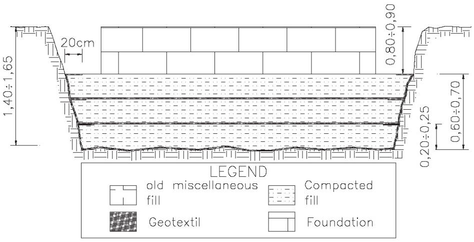


Figure 8. The arrangement of getextile material.

3.3 *Execution of fill*

The source of material is soil obtained from the excavation of the trench for the foundation of the structure. All debris with sharp edges, all deleterious material is removed to be consistent with the material tested in the laboratory (see geotechnical study).

Filling is not allowed on snow or during wet weather conditions.

The fill is placed in successive horizontal layers, to fill the excavation.

The fill material, supplied from the excavation, is spread and leveled over the whole area in one layer. Unacceptable or unsuitable materials will be removed. The thickness of bulk material is determined by formula:

$$H_a = \frac{H_c \frac{D}{100} \rho_{d \cdot \max}}{\rho_{d0}}$$

Where:
H_a – the thickness of bulk material (cm);
H_c – the thickness of compacted layer (cm);
D – requested compaction degree (%)
ρ_d – dry density (g/cm^3)
ρ_{d0} – initial dry density in loose state.

After the spreading, the moisture (w) of deposited material will be determined and it will be compared with the optimum compaction moisture resulted from standard PROCTOR tests 2.5 kg rammer.

If:

a If $w \pm 4\% = w_{opt}$, than begin layer compaction;
b If $w \pm 4\% > w_{opt}$, than wait or ventilate material strata till the excess of water will evaporate:
c If $w \pm 4\% < w_{opt}$, than spray with water all the material surface till $w \pm 4\% = w_{opt}$.

3.4 *Compaction control*

After compaction of each layer, take samples from the compacted layer with a core cutter from a depth of 10-15 cm for determination of the compaction by comparing bulk/dry density ρ and ρ_{dmax} with the Proctor test results.

The layer is considered compacted if the dry density is in the range 95-98% of the maximum dry density.

If the result of the test shows that the density is within the specified range then proceed with the next reinforced layer.

If the result of the tests show that the density has not been achieved the compaction should be repeated with a smooth drum roller.

At the foundation level layer it is possible to check the bearing capacity by plate bearing test or Benkelman test.

A competent person should supervise the execution of the works.

4 CONCLUSIONS

This technology was used for preparing foundations of a large number of houses and civil constructions in Bucharest. Measurements for subsidence monitoring have shown very little settlements all of which are acceptable.

In conclusion, the use of geotextile materials has a large field of application for founding structures on fill considering that these types of synthetic materials help the separation, drainage and reinforcement of soils in which they are incorporated.

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