Comparative study on the reinforced earth retaining walls design methods

Etude comparative des méthodes de conception des murs de soutènement renforcés

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ABSTRACT: As an assessment of internal stability, the methods of designing these types of structures have been constantly developing in the course of time, from the requirement to transpose the interaction of the reinforced earth in the retaining structures as accurately as possible. Thus, if the external stability of the mechanically stabilized earth walls is evaluated in the same manner as for the classical retaining walls, for the internal stability the main methods used are: methods based on the static equilibrium analysis of the active area, methods based on the limit equilibrium along the failure surface and numerical methods applied to reinforced soil structure – supported massive. The available range of geosynthetics, facing panels and granulometric composition of the embankment soil, although wide, greatly controls internal stability once the calculation method used includes the relevant interactions between the elements of the reinforced soil. In the attempt to evaluate the most rele-vant dimensioning method, that assure the criteria of safety at acceptable costs, based on the analysis of the methods, as means of determining the forces involved in equilibrium, followed by a case study on a mechanically stabilized earth wall, using the methods mentioned before, a comparative study was carried out, having as results the quantitative and graphical evolution of the values of tensile forces in the reinforcements of the considered structures, depending on the different hypothesis considered and the variation of the different influence factors.

RÉSUMÉ : En tant qu'évaluation de la stabilité interne, les méthodes de conception de ces types de structures ont constamment évolué au fil du temps, de l'exigence de transposer l'interaction du sol renforcée dans les murs de soutènement de la manière la plus précise possible. Ainsi, si la stabilité externe des murs de terre renforcée est évaluée de la même manière que pour les murs de soutènement classiques, les principales méthodes utilisées pour la stabilité interne sont les suivantes : méthodes basées sur l'analyse statique de la zone active, celles basées sur l'équilibre limite à long de la surface de rupture et les méthodes numériques appliquées à l'ansamble sol renforcé – massive soutenu. La gamme disponible de géosynthétiques, les panneaux de parement et la composition granulométrique du sol de remblai, bien qu'étendue, contrôlent grandement la stabilité interne une fois que la méthode de calcul utilisée comprend les interactions pertinentes parmi les éléments du sol renforcé. Dans le but d'évaluer la méthode de dimensionnement la plus pertinente, qui assure les critères de sécurité à des coûts acceptables, basés sur l'analyse des méthodes, comme moyen de déterminer les forces en équilibre, suivi d'une étude de cas sur un mur du sol renforcée, en utilisant les méthodes mentionnées précédemment, une étude comparative a été réalisée, ayant pour résultat l'évolution quantitative et graphique des valeurs des forces de traction dans les renforts des structures considérées, en fonction des différentes hypothèses considérées et de la variation des différents facteurs d'influence.

KEYWORDS: reinforced soil, design methods, reinforcement, geosynthetics

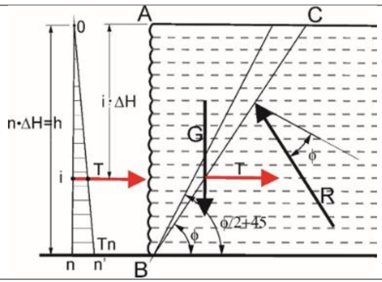
1 INTRODUCTION.

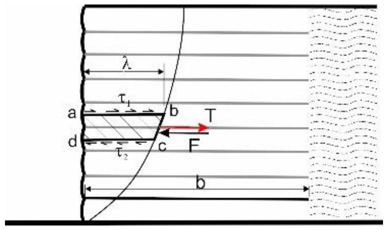
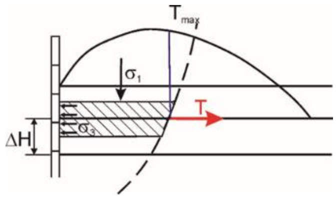
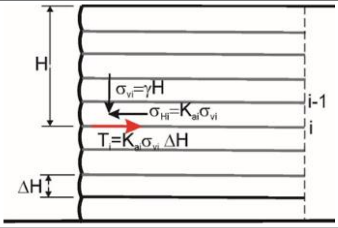
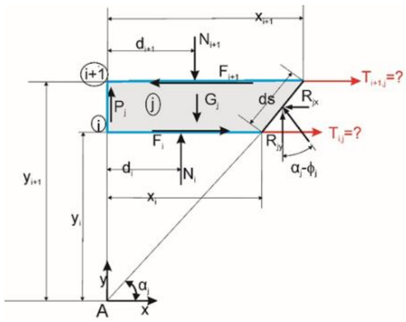
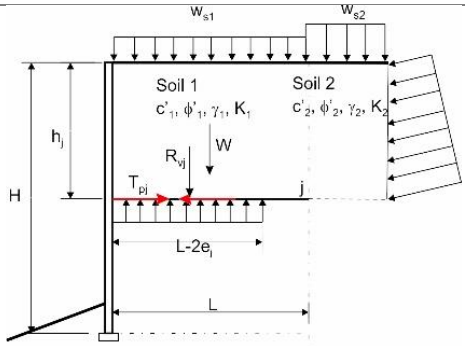
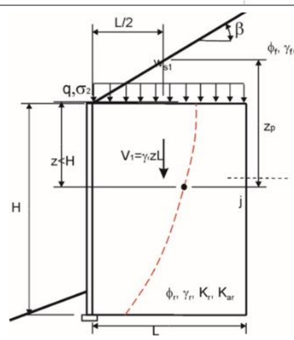
Since the first use of the reinforced soil retaining structures in 1963, their analysis has been an important concern of designers and researchers, having the main objective to achieve economic structures and to understand their mechanical behaviour by developing new theories for estimating internal stability. The "reinforced soil" structural system has been studied in laboratory on small scale models, as well as on-site on the executed structures in order to carry out a design as appropriate as possible, in terms of mechanical behaviour. Stability analysis of reinforced soil retaining structure involves two problems (Schlosser & Vidal, 1969), (Stanciu, 1981): in-ternal and external stability.

If, for external stability the checking is similar with the analysis of the classical retaining walls (gravity or flexible retaining walls, in the case of internal stability, two types of failure should be considered (Schlosser & Vidal, 1969), (Silion, 1980): tension failure and pull-out failure.

Over the time, in order to determine the internal stability of the reinforced soil retaining structures, various methods have been developed in the attempt to follow as closely as possible the interaction between the soil and the reinforcement. A brief presentation of the most common methods is presented in Table 1.

Table 1 Methods to evaluate the internal forces in the reinforced soil retaining structures

Method	General principles	Model
Vidal's method (Vidal, 1966) -two equations for static equilibr ium	-plane failure surface - tension failure - static equilibrium of the active zone $$T_i = \frac{i}{n(n+1)} \cdot K_a \cdot \gamma \cdot H^2$$	

Method	General principles	Model
Schlosser – Long method (Schlosser & Long, 1974) -only one equation for static equilibrium	- cylindrical failure surface - tension failure - static equilibrium of the active zone $T = K_a \cdot \gamma \cdot h \cdot \Delta H \cdot \left(1 - \frac{\lambda \cdot f^*}{K_a \cdot h}\right)$	
Local equilibrium method (Segrestin, 1979) (Schlosser & Segrestin, 1979) -only one equation for static equilibrium	- polyline failure surface - tension failure - limit equilibrium - variable friction angle on the height (Schlosser mobilisation) $T_M = \sigma_3 \cdot \Delta H \cdot 1$ cu $\sigma_3 = \sigma_1 \cdot K$	
L.C.P.C. Method (Schlosser, 1972) -only one equation for static equilibrium	-plane failure surface - tension failure - limit equilibrium $T_i = \sigma_{vi} \cdot K_a \cdot \Delta H = i \cdot K_a \cdot \gamma \cdot \left(\Delta H\right)^2$	
MCR (Calculation to breakage method) (Stanciu, 1981) (Donciu, 2014) -three equations for static equilibrium	- plane or cylindrical (circle, ellipse, parabola, logarithmic spiral) failure surface - tension failure - limit equilibrium - takes into account the interaction between the soil and the reinforcement, the reaction on the failure plane, the friction between the soil and the front side of the wall	
Tie back wedge method (Mitchell & Villet, 1987) (Christopher, 1989) -only one equation for static equilibrium	- plane failure surface - tension failure or pull-out failure - limit equilibrium $T_{pj} = K_1 \cdot \sigma_{vj} \cdot s_{vj}$ $P_j \ge \frac{T_{pj}}{\mu \cdot L_{ej} + c \cdot L_{ej}}$	
Simplified Coherent gravity method (FHWA-NHI-00-043, 2001) -only one equation for static equilibrium	- cylindrical circular failure surface - tension failure - limit equilibrium - variable friction angle on the height $T_{pj} = K_1 \cdot \sigma_{vj} \cdot s_{vj}$	

Based on some of the presented methods algorithms and computer programmes were developed. For different types of reinforced soil structures (ex. reinforced soil retaining walls, reinforced slopes) there are programmes that al-low the design by taking into account the types of reinforcements to be used, the loads and, the most important, different norms from different countries (Donciu, 2014).

2 COMPARATIVE STUDY

Starting from the analysis of the methods used to determinate the forces in the reinforcements of the reinforced soil retaining structures and the factors influencing the values of these forces, a comparative study of the results obtained using these methods was performed. In order to carry out this study a reinforced soil retaining structure was considered in different loading and re-inforcement situations: with and without over-load with equal interspaces between reinforcements (65cm); with and without overload and different interspaces between reinforcements - 32.5cm at the lower part and 65cm at the upper part (Figure 1).

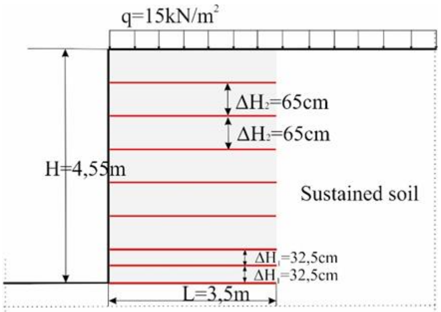


Figure 1. Reinforced soil retaining structure: differ-ent interspaces between reinforcements and overload.

In this comparative study the influence of the geotechnical characteristics of the sustained soil, the foundation soil and the soil between the reinforcements was not analysed. In order to establish the characteristics of the soil, a reinforced earth retaining wall, made in France in 2006 was taken as case study (Donciu, 2014). The geotechnical characteristics of the soils were: unit weight 20kN/m3, internal friction angle: 37°, cohesion 0 kPa for foundation soil; 20 kN/m3, the internal friction angle 30°, for the sustained soil. For the soil between the reinforcements a 0/80 mm shredded gravel was used: unit weight 20 km/m3 and the internal friction angle 32°.

2.1 *Calculation of tensile forces in reinforcements using different theoretical methods*

In order to take into account the overload and different interspaces between reinforcement's new expressions were rewritten for the Vidal, LCPC, and local equilibrium methods. In the case of Schlosser-Long method, that does not give a position of the failure surface, according to the practical results (Amidou, 1995), (Rimoldi, et al., 2013), (Leshchinsky, 2013), a cylindrical surface (with abscissa at the top of H/3) was considered. The medium value of the friction coefficient at the reinforcement's level was considered as a percentage of the internal friction angle of the soil between the reinforcements for which a Schlosser mobilization on the height was taken into account (Schlosser, et al., 1974/2; Segrestin, 1979; Schlosser & Segrestin, 1979).

With respect to MCR (Calculation to break-age method), two types of failure surfaces were considered: cylindrical surface with circular di-rectory (centre at 2H from the structure base, passing through the base and the H/3 from the top); and a plane surface, inclined at 45+φ/2 related to the horizontal, surface that is usually used in the design for this type of structures.

Following the calculations, the values of tensile forces in the analysed structure reinforcements were obtained, for different calculation methods and hypotheses. Based on these data, graphs with the evolution on the height of the tensile forces values in the structure reinforcements were plotted for each case (Figure 2, 3 and 4).

Based on the obtained results, respectively the graphs, it can be said that:

1. The highest values of the tensile forces in the reinforcements resulted for the tie back wedge method and the LCPC method, while the lowest values resulted for MCR, comparable to both the simplified coherent gravity method and the Vidal method (methods that had already proven there applicability);
2. For each method, the presence of the over-load on top caused an increase of about 25% in the total tensile force in the reinforcements, differently distributed on the structure height, the largest increases (45-50%) were in the upper reinforcements.
3. The use of smaller interspaces between reinforcements or intermediate reinforcements determined a decrease of the tensile forces values in the reinforcements, the sum of all the tension forces in the reinforcements remaining un-changed.

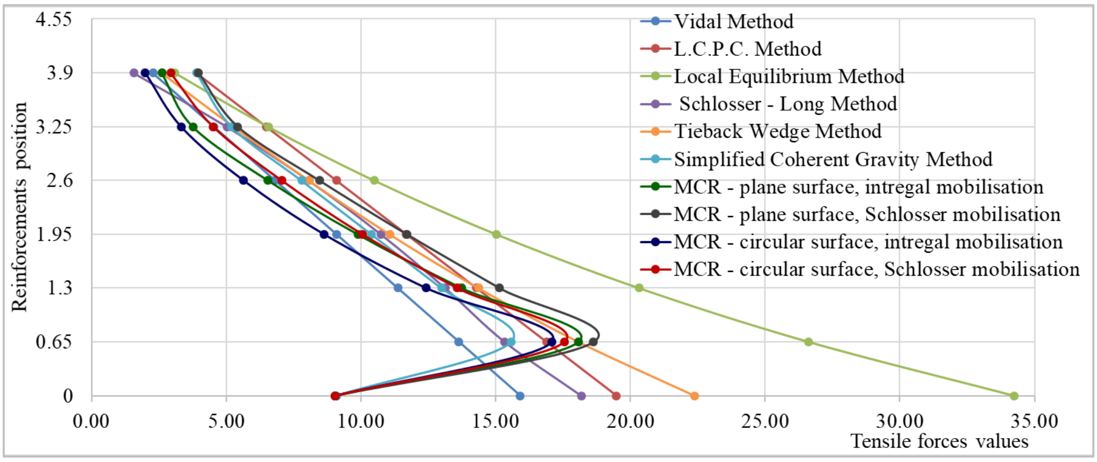


Figure 2 – Evolution of the tensile forces in the reinforcements – equal interspecies between the reinforcements (65cm) without overload

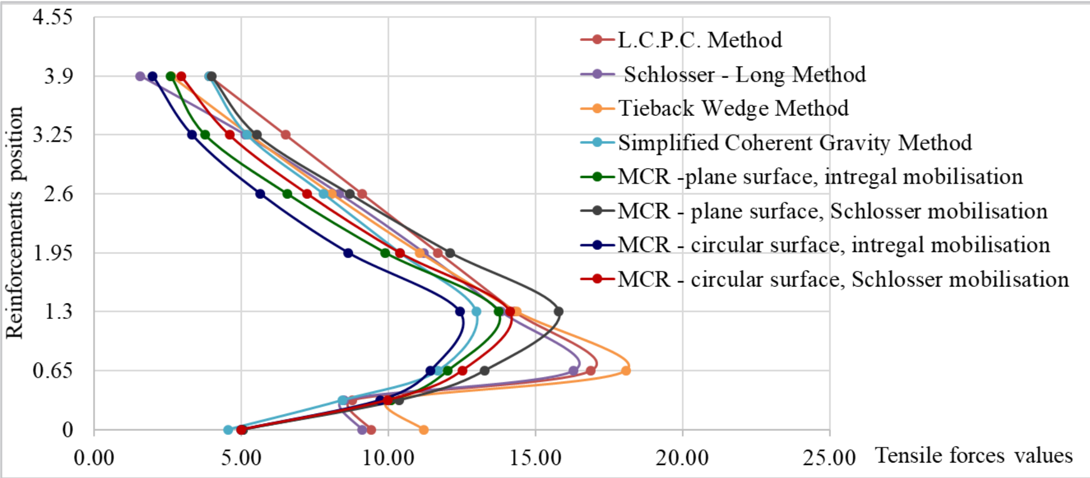


Figure 3 - Evolution of the tensile forces in the reinforcements – different interspecies between the reinforcements (32.5cm at the lower part, 65cm at the upper part) without overload

2.2 *Calculation of tensile forces in reinforcements using different practical methods*

The comparative study continued with the anal-ysis and evaluation of the results obtained fol-lowing the calculation according to different norms from different countries, taking into ac-count both the specific safety factors and the ex-ternal stability. The calculation was performed manually and with computer programmes as well.

In this comparative study the MCR (Calculation to breakage method) was included by ap-plying the appropriate partial safety factors. The results obtained, the values of the tensile forces in each reinforcements, were centralized in tables and graph for each norms/computer pro-gramme considering three distinct design situations: equal interspaces between reinforcements (65cm) with the minimum required reinforcement length resulted from the design; different spaces between reinforcements (32.5cm at the lower part and 65cm at the superior part) with minimum length required; different spaces be-tween reinforcements (32.5cm at the lower part and 65cm at the upper part) with 3.5m imposed length (Figure 1).

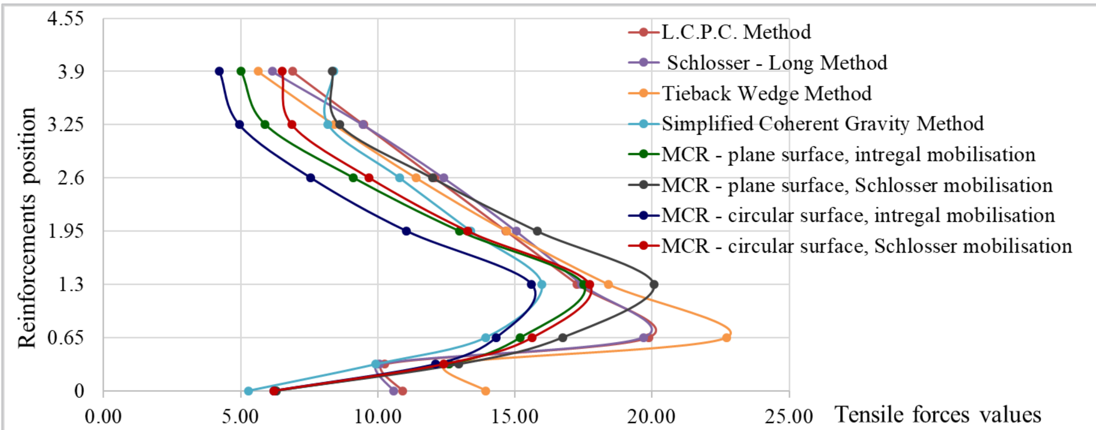


Figure 4. Evolution of the tensile forces in the reinforcements – different interspecies between the reinforcements (32.5cm at the lower part, 65cm at the upper part) with overload

Figure 5 illustrates the chart obtained for the third case considered. Analysing these results, it can be said that:

1. For the case with equal interspaces, rein-forcements with ultimate tensile strength of 100kN/m were necessary and the minimum re-quired reinforcement length was different for each norms or programme used. From this point of view, the values of the minimum required re-inforcement length determine results higher in the manual design than the computer pro-grammes design for each norm considered. The necessary length, in each case is determined by the external stability.

2. Analysing the results obtained with the Miraslope and Geo5 programmes, according to the considered norms, the calculation showed that for both programmes the most conservative design rule is the German norm, EB-GEO - for which the necessary reinforcements resulted the longest, followed by BS 8006-2010 (British norm) and GP063-006 (Romanian norm), while the least conservative, is FHWA-NH-00-043 / 2001, the American norm. From the point of view of the tensile forces in the reinforcements the lowest the lowest values resulted also for FHWA-NH-00-043 / 2001, similar results with the analysis of Alex Galindo, (Galindo, 2013).

The same result is also observed in the case of manual design according to British norm (BS 8006-2010), Romanian norm (GP 063-20060 and American norm (FHWA-NHI-00-043) where both the minimum length and the tensile forces in the reinforcements were lower in the calculation with the American norm.

3. Regarding the evolution on the height of the tension forces in the reinforcements, there were noticed two tendencies. So in the design according to GP 063-2006, BS 8006 -2010 (manually or programme design) and Miraslope the most loaded reinforcement is the lower one (for the case with equal

interspaces). On the other side, similar with the experimental and theoretical studies (Khalifa, 2012) were methods that gave a decrease of the tensile forces values in the lower reinforcements: GEO5, American norms and including MCR.

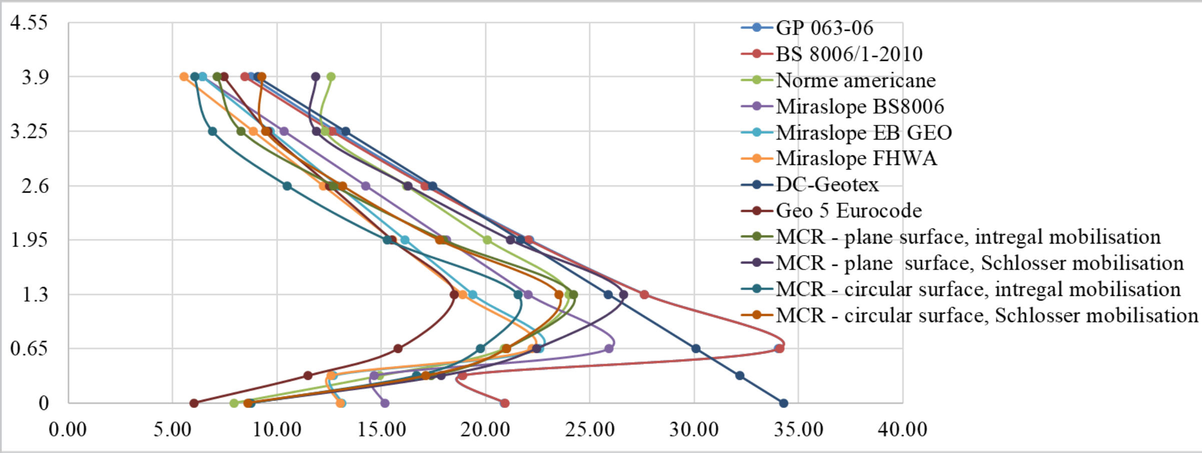


Figure 5. Evolution of the tensile forces in the reinforcements – different interspecies between the reinforce-ments (32.5cm at the lower part, 65cm at the upper part) with overload and 3.5m reinforcements length

4. Regarding MCR, it is observed that the tensile forces values in the reinforcements are similar to those obtained through the pro-grammes design. Thus, considering the MCR with Schlosser mobilization of the internal fric-ion angle on the height of the reinforced soil retaining structure gives similar results to those obtained from the calculation with the Geo5 programme.

Also close values to the manual calculation after Ameri can norms FHWA-NH-00-043 / 2001 (FHWA, 2001) were obtained by using MCR, with the plane failure surface and the integral mobilization of the internal friction angle.

4 CONCLUSIONS

From the point of view of the analysed norms, the higher values of the tensile forces in the reinforcements resulted for the Romanian norm (GP 063-2006), followed closely by the British norm (BS 8006-2010), norms based on the same theoretical calculation method, and the least conservative, the lowest values for the tensile forces resulting for American normative, which gives values quite close to those resulting from design using computer programmes.

In this respect it can be said that for a competitive manually design for the reinforced soil retaining structure, with the computer pro-grammes design, especially in the absence of such programmes, it is necessary to adopt a de-sign method, which considered all the factors that can influence the interaction between the soil and the reinforcements, to ensure a correct evaluation of the tensile forces.

Analysing the factors that determine lower values of the tensile forces in the reinforcements, it can be said that the MCR hypothesis (with the three equilibrium equations) takes into account all the factors that influence the interaction between the soil and the reinforcements, factors that were also evaluated in the experimental studies. The advantages of this method also derive from the possibility of considering the cohesion of the soil between the reinforcements as well as the possibility of using this method for inclined face retaining walls.

The results obtained from the MCR calculation justify the idea of using this method in the future for a more economical design, by providing an optimal quality/price ratio.:

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