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Design and analysis of geotextile–reinforced soil structures in highway applications in Brazil

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ABSTRACT: The work describes the systematic of the design and construction of great reinforced soil structures using geotextiles that have been implemented in large scale in highway embankments and bridge abutments built in the state of Minas Gerais / Brazil. The procedures of design and the evaluation of the global behavior of the structures are explained for three examples of works that present singular features in terms of dimensions, and nature of the soil and the reinforcement elements. The design and construction of these structures have considered aspects related to the interface strength parameters, to the effects of the confining pressures about the tensile behavior of the geotextiles and to the constructive prescriptions. In addition, the projects have contemplated analyses of stability and mechanisms of deformability under service conditions. These estimates of behavior will be correlated later with results of instrumentation and numerical analyses now in progress.

1 INTRODUCTION

In the state of Minas Gerais/Brazil several works of great size using the technique of soil reinforcement with geosynthetics have been executed in the last few years (Martins, 2000) under jurisdiction of the Highway Department of Roads (DER/MG). The impacts of this technology are very high in these applications considering our accidented relief and the fact that one of the biggest motorway planning of the world is located in Brazil. In this work, three of these works are presented, all using geotextiles as reinforcement elements, characterized by not conventional aspects in terms of dimensions, nature of the soils and low strength of the reinforcement elements. Stability and deformability analyses (Jewell & Milligan, 1989; Leshchinsky & Boedeker, 1989; Zornberg et al. 1998) were implemented in association with results obtained from special tests (Long et al., 1997; Wu & Arabian, 1990).

2. REINFORCED SOIL SLOPE IN THE BR 381

Located in a place known as Variante da Ingá, at km 463.24 of the BR 381, a federal highway that connects São Paulo and Belo Horizonte, two of the main Brazilian cities, this work constitutes the biggest reinforced soil slope already constructed in the country, with 18 m of height and 270m of extension. The solution adopted was imposed by economical reasons and for the impossibility of executing a common embankment, in function of the necessity of an excessive advance of the off-set of the embankment in the limits of one forest reserve in this region.

In the zone between the stations 20+15.00 and 24 +15.00, the reinforced structure reached 18,0m of height, subdivided in three slopes of 6,0m of height and inclination of 1H:2V, with berms of 3,0m of width. A conventional embankment with 10,00m of height and inclination H3:V2 overlaps the reinforced structure (figure 1).

The face consisted of a system in rip-rap, executed in cement-soil bags in the ratio of 1:15, with a disposition in accordance with the inclination of the faces of the structure. The drainage system was projected as a layer with 20 cm of thickness in the base of the structure and extending, under a form of steps, along the contact between the structure and the natural soil.

The reinforced slope was built with residues from an iron mining distant about 1.5 km of the area of implantation of the work. Two different types of residues were used: wastes in the execution of the inferior slope and, in a bigger scale, iron ore tailings (silty sand with pebbles, $G_s = 4.6$; $\phi' = 38.9°$; $c' = 19.6$ kN/m^2 and $\gamma = 20.3$ kN/m^3) for the intermediate and upper slopes. The substitution of wastes for the tailings in a large part of the reinforced slope occurred due to limited availability of the volumes of these materials in the local mining.

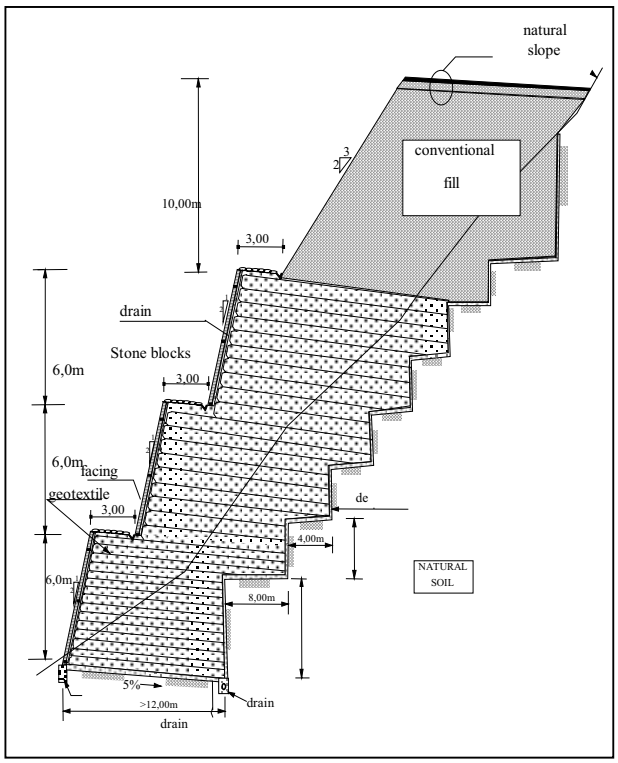

Figure 1. Typical section between stations 20+15.00 and 24+15.00

In the upper part, it was made a sealing with a cohesionless soil, conforming the base of the pavement. Close to the face of the structure, it was used a layer of clay with 50 cm of thickness as sealing material since the mining residues demonstrated to be sufficiently friable and susceptible to the erosive action of the surface percolation.

The compacting of the embankment was made in layers with thickness varying between 20 and 30 cm, using conventional equipment, with light mechanical compaction in the marginal zone of about 70 cm, close to the face of the structure. Two different types of reinforcements were used for evaluation of the deformability of the structure: nonwoven geotextiles of polyester, with 600 g/m^2 and tensile strength of 40 kN/m and woven geotextiles of polypropylene, with 445 g/m^2 and tensile strength of 75 kN/m. Specific tests involving the materials of the real structure were carried out for the determination of the interface strength parameters (table 1) and the effects of the confining pressures about the tensile behavior of the geotextiles (figure 2).

Table 1. Interface strength Parameters for the materials of the reinforced slope of the BR 381

Interfaces	Soil		Interface		coefficients	
	c' kPa	ϕ' (°)	c_g kPa	ϕ_g (°)	adhesion (a)	friction (f)
waste	13.1	48.3	-	-	-	-
waste / WG*	-	-	13.4	28.7	1.02	0.49
tailings	16.7	42.7	-	-	-	-
tailings/NWG*	-	-	9.5	42.5	0.57	0.99

* WG: woven geotextile; NWG: nonwoven geotextile

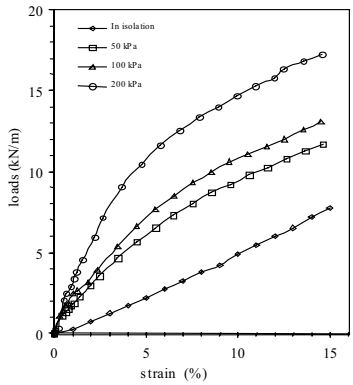

Figure 2. In isolation and in soil load-extension curves of the nonwoven geotextile

The inferior slope was designed with 08 layers of woven geotextiles, equally spaced and with 4.85m in length, corresponding to a demand of 57.60 m^2/m and a factor of safety against global rupture of 1.75. The intermediate and upper slopes were constructed with 16 layers of nonwoven geotextiles equally spaced and with 4.50m in length, for a demand of 109.60 m^2/m and a global factor of safety of 1.52.

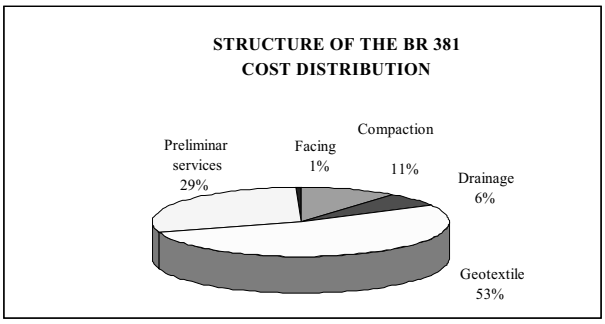

Figure 3. Cost distribution in the reinforced slope of the BR 381

The demand of the geotextiles represented 53% of the total cost of the work (figure 3), and had been used about 21,360 m^2 of woven geotextiles and 72,500 m^2 of nonwoven geotextiles. In figure 4 are represented the estimated horizontal displacements for the facing of the structure considering stiffness parameters in relation to the strains of 1% and 5%, in accordance with the methodology proposal by Jewell and Milligan, 1989. The maximum values were registered in the medium zone of the structure, varying between 16.2 cm and 17.7 cm (respectively, 1,35% and 1,48% of the height of the structure) for reinforcement stiffness to 1% of strain and between 25.3 cm and 27.8 cm (respectively, 2,11% and 2,32% of the height of the structure) for reinforcement stiffness to 5% of strain.

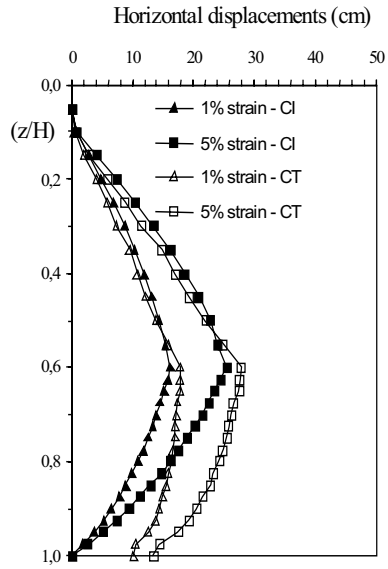

Figure 4. Horizontal displacements of the facing of the BR 381 reinforced structure

3. REINFORCED SOIL SLOPE IN THE MG 030

The retaining wall constructed along the km 16 of MG 030, the highway that connects the cities of Belo Horizonte and Nova Lima in the state of Minas Gerais / Brazil, consisted of one reinforced soil structure with vertical face and maximum height of 9,2m to attend to the local conditions (figure 4).

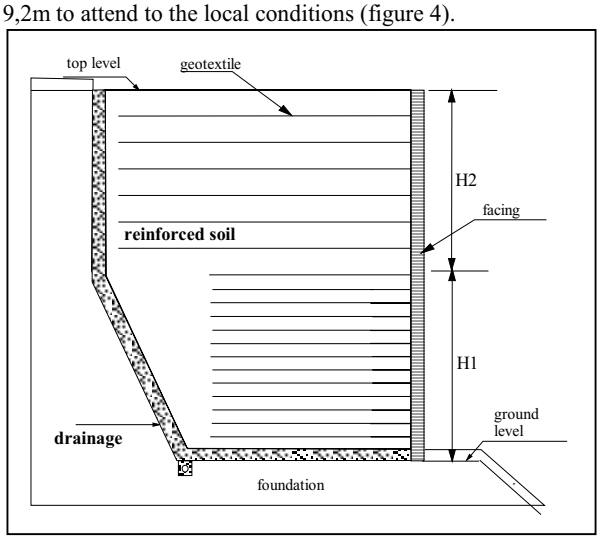

Figure 5. The cross section of the reinforced wall in km 16 of the MG 030

A singular feature of this work consisted on the direct use of a local soil, constituted for a residual soil from itabirite, with 71.2% of fines. There were used reinforcements of woven geotextiles of polypropylene of 250 g/m^2 and tensile strength of 42 kN/m. Similarly to the previous work, specific tests involving the materials of the structure were carried out for the determination of the interface strength parameters (table 2) and the effects of the confining pressures about the tensile behavior of the geotextiles (figure 6).

The compacting process was similar to the work described previously, using, however, a soil-cement mixture in a zone of 70 cm of width close to the facing, in order to guarantee one adequate verticality of the structure. A shotcrete lining constituted the facing of the structure. The internal drainage system was projected as a draining mattress with 20cm of thickness and peripherical to the reinforced soil.

Table 2. Interface strength Parameters for the materials of the reinforced slope of the MG 030.

	Soil		Interface		coefficients	
Interfaces	c' kPa	ϕ' (°)	c_g kPa	ϕ_g (°)	adhesion (a)	friction (f)
soil / soil*	24.3	48.4	-	-	-	-
soil/WG/soil*	-	-	15.3	36.9	0.63	0.67
soil/WG/base*	-	-	0	36.6	0	0.66

* residual soil of itabirite; WG: woven geotextile; smooth base

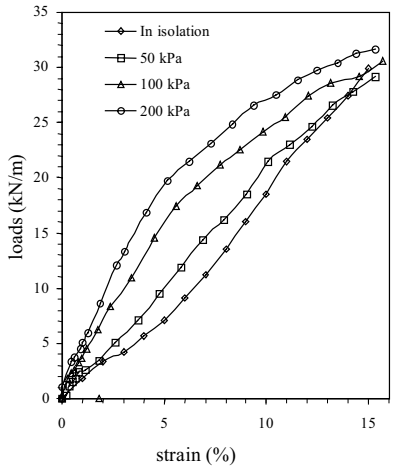

Figure 6. In isolation and in soil load-extension curves of the adopted geotextile

The distribution of the costs associated to the structure built in the MG 030 is presented in figure 7. It is verified that the acquisition of the synthetic material represented 61% of the total cost of the executed work, having been used about 50,000 m^2 of woven geotextiles as reinforcement elements.

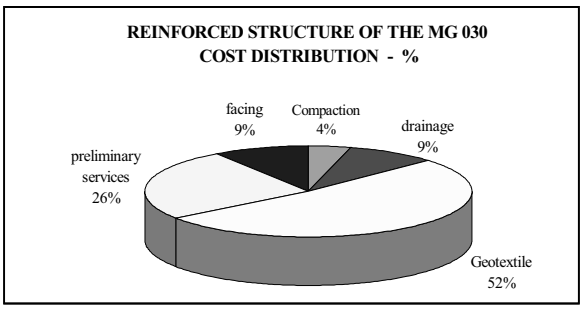

Figure 7. Cost distribution in the reinforced structure of the MG 030

Additionally predictions of the displacements of the facing of the structures under the service loadings were established, based on the methodology proposal for Jewell & Milligan, 1989. Figure 8 shows the distribution obtained for the reinforcements stiffness corresponding to the strains of 1% and 5%. The maximum horizontal movements of the facing vary between 5.7 cm and 6.0 cm (respectively, 0,62% and 0,65% of the height of the structure) and between 5,8 cm and 6,9 cm (respectively, 0,63% and 0,75% of the height of the reinforced wall), for the stiffness to 1% and to 5% of strain, respectively, under the actual pressures in the field

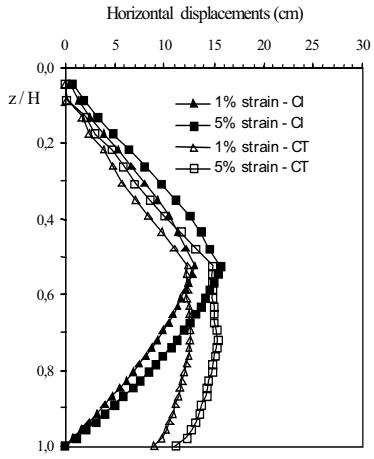

Figure 8. Horizontal displacements of the facing of the MG 030 reinforced structure

4. REINFORCED BRIDGE ABUTMENTS IN THE MG 123

At km 12 of the motorway MG 123, that connects the cities of Rio Piracicaba and Alvinópolis in the state of Minas Gerais/Brazil, there is a transposition of the motorway about the Victoria – Minas railroad. In this place, it was executed, then, a viaduct of great dimensions, with abutments in reinforced soil with geotextiles.

The structure was executed on both sides of the viaduct, with the height of 11,0m on the left side and inclination of 1H:5V, subdivided in two slopes and a height of 12.0 m on the right side with an inclination of 1H: 11V in one unique slope (figure 9). The spacing adopted varied between 0.30m and 0.60 m in the abutment on the left side and between 0.20 and 0.40 m in the abutment on the right side.

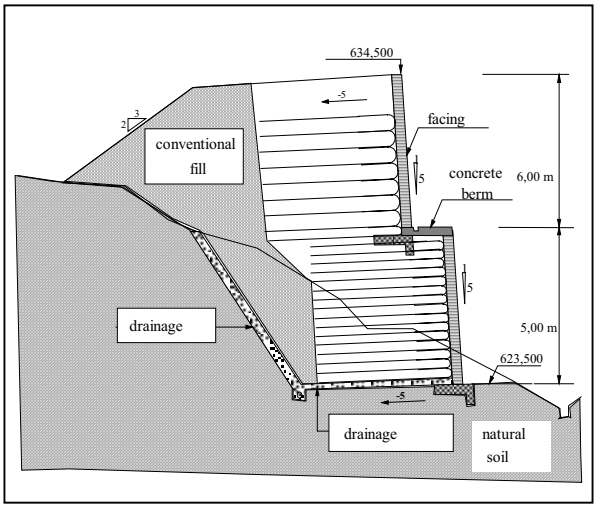

Figure 9. The cross section of the reinforced abutment on the left side in km 12 of the MG 123 motorway.

Interlocking modular concrete units were used as the facing for the reinforced structure, with the purpose to guarantee the alignment and control wall facing batter during construction. The wall was constructed by a stepped face that results in a facing batter of 7 degrees. A drainage system, along the contact between the structure and the natural soil, complements the project. On the boards of the abutments was placed a clayey soil and made planting of grass.

The soil used consisted of a residual micaceous sand (G_s = 2.7; ϕ' = 36.7°), found in large areas in this region, reinforced with needle punched polypropylene of low fabric weight (140 g/m^2) and low tensile strength (20 kN/m). The constructive procedures were essentially similar to the previous works, with light mechanical compaction next to the boards (approximately 70cm) of the abutments. Additionally, specific tests were carried out for the determination of the interface strength parameters (friction parameter close to 1.0) and the influence of the confining pressures about the tensile behavior of the geotextile (figure 10).

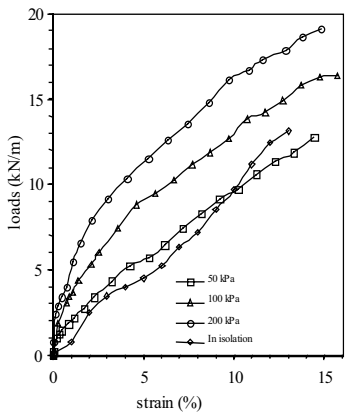

Figure 10. In isolation and in soil load-extension curves of the adopted geotextile

Based on these results, the abutments were designed as reinforced walls resulting in 15 layers of reinforcements with 5.40 m in length on the left side (118.40 m^2/m) and 27 layers with 6.10m on the right side (demand of 221,80 m^2/m of geotextiles). The corresponding cost distribution is showed in figure 11. It is verified that the demand of the geotextiles represented 65% of the total cost of the work, having been used about 23,000 m^2 in the structure.

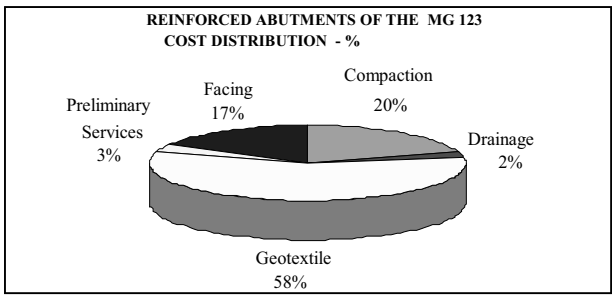

Figure 11. Cost distribution in the reinforced structure of the MG 123

The profile of the predicted displacements for the facing along the height of the structure is indicated in figure 12. In this case the movement of the facing is initiated well next to the top to the structure, with maximum values of the order of 30 cm (2,5% of the height of the structure) for stiffness corresponding to 1% of strain. For stiffness to 5% of strain, the foreseen maximum values were of 48.6 cm (or 4,05% of the height of the structure).

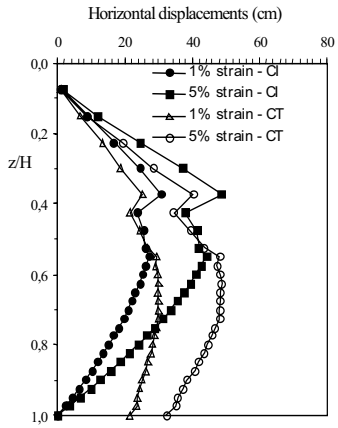

Figure 12. Horizontal displacements of the facing of the MG 03(reinforced structure

5 CONCLUSIONS

The systematic of the design and construction of very larg reinforced soil structures using geosynthetics, that have bee implemented in large scale in highway embankments and bridg abutments built in the state of Minas Gerais / Brazil demonstrat the potential of the technique and the significant contribution o the quantitative ones of the textiles reinforcements in relation t the global cost of the works. These aspects ratified the relevanc of a criterious program of specific studies and constructiv procedures, with particular emphasis in the determination of th interface strength parameters and the effects of the confinin pressures about the tensile behavior of the geotextiles, under th service conditions.

These studies have allowed projects much more elaborate with substantial reductions in the overall cost of construction. I the case of the reinforced structure in the BR 381, this econom reached 35,5% in relation to original design. These estimates o behavior are being correlated with results of instrumentation an numerical analyses now in progress and the observations of th field up to the moment, indicate movements and deformabilit considerably less than the foreseen values.

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