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Use of tropical soils as backfill of reinforced soil structures in Brazil

Bueno, B.S. & Vilar, O.M.
Department of Geotechnical Engineering, University of Sao Paulo at Sao Carlos, Sao Paulo, Brazil

Zornberg, J.G.
Civil Engineering Department, The University of Texas at Austin, Texas, USA

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ABSTRACT: Soils with a large percentage of fines (silt and clay) are considered of marginal quality for the purposes of their use as backfill in reinforced soil structures because they exhibit poor drainage capacity. In spite of the significant caution against the use of such soils, reinforced soil structures in Brazil have often been built using soils with a large percentage of fines. Indeed, the reported performance of these structures, many of them with field instrumentation, has shown a very good long-term performance. Most of the fine-grained soils used as backfill material in Brazil are residual soils, and often lateritic soils, which have shown excellent performance in engineered embankments. Accordingly, existing guidelines for reinforced soil construction should be refined as the sole use of grain size distributions to define the adequacy of backfill soils may be oversimplified. This paper presents an overview of Brazilian case histories involving the construction of reinforced walls and steep slopes using poorly draining soils, and documents the basis for their design, aspects of their construction, and their long-term performance. Some of the structures built using poorly draining soils are now over 20 years old and show no signs of distress.

1 INTRODUCTION

Soil reinforcement is now a common design alternative in Brazil for the construction of retaining walls and steep slopes. This is because of reduced costs as well as their excellent long-term behavior when compared to that of conventional retaining structures.

High shear strength and adequate (free) drainage capacity are the typical requirements expected from the soil selected as backfill for reinforced soil structures. Granular soils fully attend these two design requirements regarding strength and drainage. Design guidelines worldwide indicates that most countries that explicitly establish criteria based on grain size distribution end up indicating very stringent requirements regarding the maximum allowable percentage of fine-grained material (Zornberg & Leshchinsky, 2003).

In Brazil and other countries of tropical climate, granular materials are typically not readily available in the vicinity of typical construction sites. Indeed, mixtures of sands, silts and clays cover large areas of the Brazilian territory. Unlike the typical fine-grained soils in countries with temperate climate, most of the fine-grained soil deposits in Brazil are of residual origin, often modified by laterization processes. In spite of their comparatively lower drainage capacity than free-draining granular soils, they present high shear strength and low compressibility, which makes them an excellent backfill material when compared to more conventional clayey soils.

Many reinforced soil structures designed and built in Brazil were constructed using poorly draining backfill soils. Some of these structures have been even instrumented. The overall long-term performance of these structures has been reported to be excellent.

The objective of this paper is to discuss the use of tropical soils as backfill of reinforced soil walls and steep slopes. The good performance of these structures, some of which over 20 years old, can provide significant insight regarding the potential need of introducing design guidelines to take into account the use of tropical soils, traditionally considered as marginal or poor draining soils.

2 TECHNICAL GUIDELINES FOR REINFORCED SOIL STRUCTURES

Three of the most popular design earth reinforcement design guidelines are: (i) the Federal Highway Administration (FHWA) (2002) that indicated that backfill soils for reinforced soil walls should must be free from organic and deleterious materials and should present a maximum of 15% of their fine particles passing sieve 200 (it allows for up to 50% fines with PI up to 20 for reinforced slopes); (ii) the AASHTO Manual (2001) that specifies free drainage backfill and exclude any type of expansible soils. The manual indicates that silts and clays should not be used in permanent structures; (iii) the British Standards, which provide design criteria for permanent reinforced soil backfills. Cohesive soils are not allowed by the British Standards (1995) for structures of categories 2 (retaining walls where the failure could result in a moderated damage) and 3 (bridge abutments, retaining walls that support directly main roads, railroads and dams).

The aforementioned guidelines apply for the design and construction of public projects in the US and the UK. Private projects in these countries typically have fewer restrictions and often specify soils with a larger percentage of fines.

Transportation agencies in Brazil have not issued guidelines regarding the selection of backfill soils for geosynthetic reinforced structures. This has often created controversial situations because Brazilian engineers either follow international recommendations that pose stringent backfill requirements, or follow local experience, which recognize the good mechanical properties of residual soils.

3 TROPICAL SOILS

In tropical environment, weathering processes give rise to the formation of deep profiles of residual soils. Depending on the degree of alteration, some formed materials do not keep features of the parent rock, while others are strongly influenced by relict structures inherited from the parent rock. So the profile of residual soils shows different materials with different properties. The more superficial horizons of residual soils are subjected to pedogenetic processes that give rise to lateritic materials (laterites and lateritic soils). In Southwest Brazil, sometimes the residual soil is covered by transported material, such as colluvium, which is also subjected to laterization processes. Under a geotechnical point of view a tropical soil profile (that formed under conditions typical of tropical environment) can be separated as composed by lateritic and saprolitic materials. Both classes of materials have been used as construction materials in Brazil, even when they do not conform to the conventional standards stipulated for sedimentary soils. Although compacted saprolitic soils can sometimes show properties similar of corresponding material formed in temperate environment, there is no doubt that the lateritic soils have properties superior than that of similar materials from temperate climates. For instance, it is known that many lateritic materials can achieve very large dry unit weight (above 20 kN/m^3) when compacted at maximum dry density and optimum water content. Corresponding shear strengths are accordingly high, Table 1, and saturated hydraulic conductivity is relatively low (lower than 10^{-5} cm/s). These relatively low permeabilities could suggest that construction pore water pressures would be high, what is not confirmed by test results and field data.

Another feature of tropical soils is that they do not swell appreciably even when of predominantly clay nature as laterization process lead to the formation of more stable clay minerals, such as kaolinite, and sesquioxides of iron and aluminum, known by its low activity. The low permeability poses other advantage to these compacted materials as it controls infiltration process as will be discussed ahead.

Among the various attempts to establish an appropriate classification for tropical soils, Nogami and Villibor (*1981*) developed the MCT classification to attend the geotechnical peculiarities of tropical compacted soils. This classification takes into account, in addition to the grain size distribution, aspects such as workability of the soil and its mineralogical and structural characteristics.

4 PORE WATER PRESSURES IN REINFORCED SOIL BACKFILLS

The most serious concerns related to the use of fine soils is associated with the potential development of pore water pressures or loss of strength due to wetting within the reinforced fill mass. Three identified adverse conditions of pore water pressure generation and/or loss of strength due to wetting are as follows:

- *Construction pore water pressures.* Excess pore water pressure can develop during compaction of fine grained, poorly draining soils (particularly if placed wet of optimum moisture) and under subsequent loading and surcharging.
- *Wetting front due to infiltration*. The loss of strength due to post-construction infiltration could be expected, even if no positive pore water pressures are generated during construction and no seepage flow configuration is established within the fill.
- *Seepage configuration established within the reinforced fill*. Seepage flow may occur either during rainy or spring thaw seasons. Water level fluctuations and rapid draw down conditions can also induce seepage forces in structures subjected to flooding or constructed adjacent to or within bodies of water.

The pore water pressures generated during construction have been evaluated for the case of tropical soils using the parameter $\overline{\mathbf{B}}$, which relates the pore water pressures and the vertical total stress. Cruz (1996) summarizes the values of $\overline{\mathbf{B}}_{opt}$ ($\overline{\mathbf{B}}$ at optimum moisture content for standard Proctor test) from various soils from southeastern areas of Brazil (Table 1). As can be observed by inspection of these values, with exception of clays, average values of $\overline{\mathbf{B}}$ at optimum moisture content are comparatively small.

Table 1. Shear strength and pore pressure parameters of residual soils (Cruz, 1996).

Soil (parent rock)	ø (°)	c′(kPa)	$\overline{\mathbf{B}}_{\text{opt}}$ (%)
Sandy soils (sandstone)	30-35	0-20	5-20 (5-10 usual)
Silts/clays (granite/gneiss)	26-32 (30-32 usual)	0-40	6-10 (silt) 20-45 (clay)
Silts/clays (filite/siltstone/ claystone)	23-29	0-25	5-10 (silt) 8-25 (clay)
Clays (Basalts)	24-31	10-70	16-35

At the dry side of compaction curve, most soils show strong variation of $\overline{\mathbf{B}}$ values with the increase in moisture content. However, with few exceptions (basalt plastic clays) values of $\overline{\mathbf{B}}$ are very small (generally less than 0.1) if the backfill soils are compacted dry of optimum. In some situation this value can even be negative.

Regarding the condition involving infiltration of moisture, it should be noted that there is only small amount of reliable data on water infiltration in natural or compacted slopes in Brazil. Piezometer data available from the few instrumented reinforced backfills built across the country show very small pore pressure variations throughout the year, some of these readings have been even negative. Compacted soils usually are non-saturated and the coefficient of hydraulic conductivity of such soils can reduce by two or three orders of magnitude depending on the suction acting on the soil. This is of foremost importance to control the infiltration. Santos & Vilar (2004) have analyzed the pore water pressures that develop in some profiles of unsaturated soils when subjected to a rain of 20 mm/h of intensity that is larger than the saturated hydraulic conductivity (k_s) of the analyzed soils. Figure 1 shows that for the soil A (soil water retention typical of sands and k_s = 5.10^{-6} m/s), the soil saturates only in the uppermost part and that past 70h of precipitation, the wetting front reaches about only 1,5 m depth. For soil B (soil water retention typical of clayey silt and $k_s = 10^{-8}$ m/s), wetting is quicker than for soil A, however the soil do not saturate and keep appreciable values of suction. Finally, for soil C (soil water retention typical of clayey sand and $k_s = 10^{-6}$ m/s) it can be observe that the wetting front reaches about 2 m depth only after 50h of continuous precipitation. These simulations show an interesting point that is the conditions at which the soil suction is maintained in a soil under rainfall. This is very interesting for the benefits that non saturation introduces on shear strength. In clay soils displaying hydraulic conductivity above 10^{-07} m/s, water infiltration concentrates at the topmost 2 m of the slope even for an intense rain with duration of 50 hours

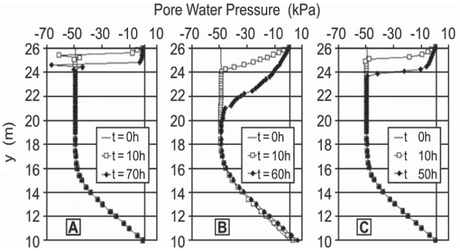

Figure 1. Infiltration profiles for three different soils (Santos & Vilar, 2004).

5 BRAZILIAN HYSTORY CASES OF REINFORCED WALLS AND STEEP SLOPES

To give an overview of history cases, data of 80 different reinforced walls and steep slopes published at Brazilian conferences have been gathered (Azambuja et al., 2003; Strauss, 2003; Bueno, 2005; Meneses, 2005). The collected data were organized in terms of (a) height of the structure; (b) type of soil used as reinforced backfill and (c) type of geosynthetic inclusion used. Because a large percentage of the published data does not describe with sufficient details all three mentioned aspects, Figure 2 shows the variations of these three parameters with the percentage rather with number of occurrences. Only reinforced structures over 4m in height were considered.

As can be seen, Figure 2a, most of the reinforced structures are less than 10 m high although in the last years, with more intense use of geogrids, data of several structures with heights above 10 to 15 m have been published.

The use of fine grained soils, especially of lateritic and saprolitic origin, has been intense, Figure 2b. The reasons and advantages of using such soils were given above.

In recent years, the use of geogrids has intensified throughout the country although the use of geotextile, either nonwoven and woven, is still large in some parts of the country, especially because of local successful experiences.

6 FINAL REMARKS

A summary is provided of Brazilian practice with the design and construction of reinforced soil structures with backfills of fine grained soils. The success of these experiences rests on the peculiar behavior of tropical soils regarding mechanical and hydraulic properties. So, any fine grained soil adequate for the

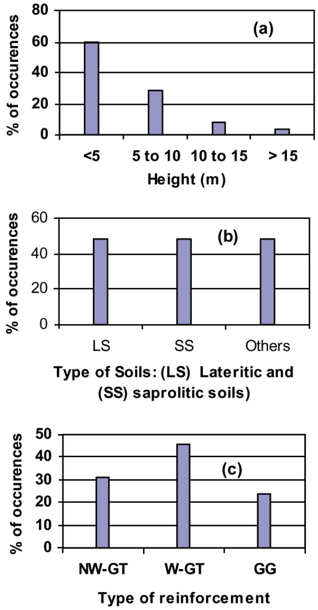

Figure 2. (a) Height of the d structures; (b) type of soil used as reinforced backfill and (c) type of geosynthetic inclusion.

construction of unreinforced slope can be used as backfill of reinforced soil structure.

The published data on reinforced structures reflect an experience of twenty years of soil reinforcement construction. The vast majority of the reported works has been behaving adequately with no sigh of distress of any sort.

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