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Tropical soils for highway construction: Peculiarities and considerations

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ABSTRACT

Tropical soils have properties and behavior that are different from sedimentary soils due to the diversity of environments of formation. The focus of this paper is to identify peculiarities that depend on the formation conditions of the soils and the location of highways. It discusses the use of tropical soils in highway construction, making use of physical and soil structure models to facilitate a better understanding of soil properties and behavior. The paper presents aspects ranging from deposit exploitation (borrow areas) for highway construction purposes to issues related to behavior of these soils. To do this, data from several research sources on Brazilian soils were used, noting that climate, geological, geomorphological, and biological peculiarities cause different results not only from one country or continent to another but also between micro regions and even over weathering profiles close to one another. It was found that chemical, mineralogical, physical characteristics change and soil structure depending on the type of tropical soil studied and these characteristics have a direct influence on their behavior. Consequently, for pavement design, non-conventional tests should be done to define field procedures to be used during construction. In particular, some questions related to the soil water characteristic curves and compaction of fine tropical soils are highlighted.

Introduction

In the case of tropical soils, transported or otherwise, the formation process is more than simple rock decomposition, as tropical weathering involves decomposition and chemical–mineralogical and structural transformation. This gives these soils different properties and behavior from other soils formed in temperate and cold climate regions.

A diagram presented by Gidigasu (1976) from Strakhov (1967) concerning depth variation and products derived from the variation of a section studied from the equator to the polar region leads to an understanding on a macro scale of the importance of climate, temperature, precipitation, and surface coverage on soil formation. It must be understood, however, that there is an interdependency between climate, soil formation, surface coverage and vegetation coverage, in particular. In tropical soil formations, aspects such as geomorphology, direction and duration of exposure to weathering, and wind direction and intensity

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have to be considered because they interfere in the interaction between the soil or rock and the atmosphere.

It is also necessary to consider physical–chemical alterations and mineralogical–structural alterations of rocks and soils where anthropological activities lead to relatively quick modifications, implying the necessity of a change in the engineering perception of time scale for consideration of the properties and analysis of the behavior of soils and rocks. In engineering, properties and behavior are generally treated as static factors on a time scale. Lima (2003) studied linear erosion on profiles of tropical soils in the Federal District, Brazil. The author showed that alterations of soil properties and behavior near slopes could occur over short periods of time, e.g., 10, 20, or 30 years, changing their stability. It is worth mentioning that such slopes are similar to those present in the highway design context.

From this brief introduction, it is clear that the study and use of tropical soils in highway construction requires a broader view than the one specified by traditional standards and established knowledge based on studies of cold and temperate climate soils. In tropical regions, highway design is faced with the need to study and understand tropical soils not only with respect to pavement structure itself but also with respect to cuts, embankments, tunnels, and foundations for bridges and viaducts.

An example of the importance of a better understanding of tropical soils in highway construction is shown in Fig. 1, which depicts a section of a trunk road on the Urucu Oil Basin in Amazonas state, Brazil, that deteriorated after a short period of time in use. In this case, deterioration did not occur because of a structural-design problem, but because of soil-atmosphere interaction. This interaction generated longitudinal cracks in the embankment, due to soil swelling in periods of intense rainfall, and transverse cracks in sections slightly above natural soil level where only earthworks were present. These cracks were generated by contraction stress in drought periods. In cases like this one, it is necessary to know more about suction effects on tropical soil behavior as some classical solutions such as chemical stabilization procedures do not always solve the problem (Pessoa, 2004). This type of problem, related to the tensile strength of materials, can be solved by fiber incorporation as indicated in results presented by Sales (2011) with natural fiber use. Thus, there is a need for more specific and detailed studies for deep, fine, weathered tropical soils and laterite soils such as granular laterites.

Fig. 1. Trunk road, Urucu, Amazonas state, Brazil (spring 2007).

Laterization can be explained by the presence of cementation due to iron or aluminum oxides, which typically form metastable structures and high porosity due to particle migration and soluble chemical compounds in the unsaturated zone, resulting in collapsible behavior in the case of soil (Benatti and Miguel, 2013). Many laterites maintain rock-like characteristics, but as soils they are composed of granular elements whose stability depends on the cementation formed between the minerals, internal porosity, water content, and external energy to which they are submitted. These lateralized materials, both fine and granular soils, can be used for subbase, base (Younoussa et al., 2008), and asphalt concrete pavement construction (Moizinho, 2007).

Apart from the conventional use of fine-grained and granular tropical soils for highway construction, there are also mixtures of fine-grained soil with granular materials such as those recycled from construction and demolition (CDW) (Oliveira, 2007), those derived from crushed rock (Rezende and Camapum de Carvalho, 2003; Rezende et al., 2014), and raw material for cement production (limestone and clay) partially calcinated (cement kiln dust) (Amadi, 2014). Fine soils can still be improved for subbase and base layers by applying granulometric stabilization, physical and chemical stabilizers such as lime or cement, asphalt emulsion (Pessoa, 2004), and biological activity by adding nutrients to the soil so that native bacteria can be cemented by the biomineralization process (Valencia et al., 2012). Studies made by Rezende (1999, 2003) and Riccio et al. (2014) showed that it is possible to use fine grained tropical soils reinforced with geosynthetics. All these contexts of use or interaction with tropical soils in highway design show the need for a broader comprehension of their properties and behavior.

This paper highlights relevant points for the study and use of tropical soils in highway construction. Relevant aspects related to the study of borrow areas and subgrade, as well as the importance of geomorphology in field works, are considered. Chemical, mineralogical, structural, and physical characteristics of tropical soils are also presented. The behavior of this type of soil in terms of soil water characteristic (retention) curves and compaction are also analyzed.

Study of borrow areas, subgrade, and geomorphology

In highway design, after defining areas with potential materials to be used based on preliminary studies and field inspections, it is common to make a study of physical properties by sampling using a regular grid without many concentrated points for classification purposes only. These studies are generally made by dividing the soil profile into layers based on color and visual–tactile texture. From this point, there is a need for a different approach when addressing tropical soil profiles; although these two aspects are relevant, they cannot separate layers that