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EFFECT OF LABORATORY TESTS WITH WATER ON SAMPLES OF COMPACTED LATERITIC SOIL

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Abstract

This article presents a study of compacted fine lateritic soil for use on the unpaved shoulders of low-traffic roads and on the earthen inspection walkway of railway tracks, in a subtropical Brazilian climate area with high rainfall. The study included laboratory tests using lateritic sandy silt soil from the surface horizon of the subgrade of the experimental field located at University of Campinas – UNICAMP, in Brazil. The UNICAMP has unpaved roads with this soil exposed to traffic, which produces some compaction, resulting in a slippery surface with erosion at the edges of the road after rain. The objective of the study was to evaluate the behavior of compacted fine lateritic soil from UNICAMP through laboratory tests under different water action conditions: partial immersion, total immersion, capillarity rise, and surface runoff of rainwater, according to Brazilian and international road specifications. Additionally, the study investigated the decrease in the soil's residual UCS after water tests. Proctor cylindrical specimens compacted at densities corresponding to 100% of the Modified and Intermediate (Brazilian criterion, which corresponds to 50% of the Modified energy) efforts were used. In both water immersion tests, the part exposed to water disintegrated, at both compaction efforts studied. In the capillary action test with a constant 1 cm water layer, the capillary rise was 100% in the samples, but which maintained their shape. In the surface water runoff test, like rain, the lateral surface of the sample exposed to water suffered erosion. Only the capillary test allowed the determination of the residual UCS. The results obtained confirmed the conditions observed on the roads at UNICAMP. The use of this soil exposed to weathering is only possible by using modified effort to meet a minimum resistance to the vertical loading of vehicles, but the adequate compaction alone does not allow for a durable surface.

Keywords: lateritic soil, erosion, residual mechanical strength, low-traffic roads, rail tracks

1 Introduction

Global warming and the increasing frequency of extreme weather events are altering precipitation patterns, posing significant challenges to road infrastructure. Water is a key factor affecting subgrade performance, influencing road quality and safety through surface erosion and groundwater damage. However, traditional soil subgrades are also prone to stability degradation under wet-dry cycles, where repeated moisture fluctuations induce microstructural damage and consequently reduce soil strength [1]. Laboratory capillary rise tests are being used to quantify water absorption in soils due to moisture fluctuations and, primarily, to assess the adequacy of hydrophobic soil treatment in mitigating the degradation of wetting stability [2-5]. Similarly, tests using rainfall simulation equipment are being used to quantify soil erosion [6, 7].

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The authors [7] indicated that soil loss showed a positive correlation with rainfall intensity and that initial soil moisture is an important factor in mass loss due to wetting. In this context, the article presents a study of compacted fine lateritic soil for use on the unpaved shoulder of low-traffic roads and on the earthen inspection walkway of rail tracks exposed to weathering, in an application in a Brazilian subtropical climate area with high rainfall (1,500-2,000 mm/year) and with seasons marked by periods of intense rain. These uses are common in Brazil on existing roads (figure 1), and, if this soil has low resistance to surface runoff of rainwater, any pedestrian or vehicular traffic can cause permanent vertical deformation.

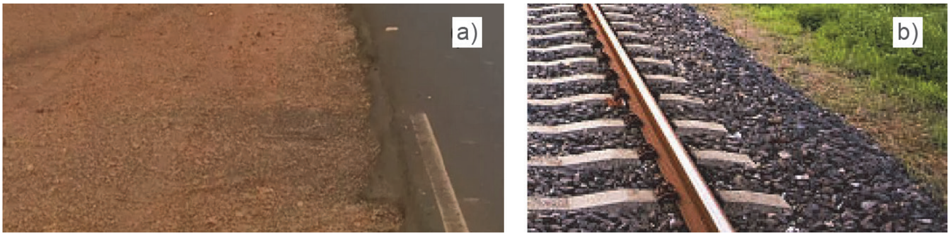

Figure 1 a) Paved road with earthen shoulders and b) Existing railway with earthen inspection walkway

The study included conducting laboratory tests using lateritic sandy silty soil from the surface horizon of the subgrade of the experimental field of the Faculty of Civil Engineering, Architecture and Urbanism of the State University of Campinas – FECFAU UNICAMP, located in the city of Campinas (a Brazilian municipality in the interior of the state of São Paulo, Southeast Region of Brazil). The UNICAMP campus has unpaved roads with this soil exposed to traffic, which produces some compaction, and its surface is smooth and eroded at the edges of the road after rain.

The objective of the study was to evaluate the behavior of the compacted fine lateritic soil of UNICAMP through laboratory tests under different water action conditions. Based on the literature review, it was possible to better define the laboratory testing program, which aimed to: (i) analyze mass loss by immersion of compacted soil at OMC [8] and water absorption by immersion [9], capillary rise of water [10], and mass loss by water runoff (similar to rain) [11] of compacted soil as a function of the process and efficiency of test specimen drying, and (ii) analyze the decrease in residual unconfined compressive strength (residual UCS) of the tested specimens. The results of the laboratory tests demonstrated that: (i) the drying temperature of the test specimen produced different values of initial residual moisture content, but it was not a very sensitive variable, and (ii) for the test specimens in the capillary rise test, there was a clear pattern of decline in residual UCS compared to sample after compaction, in which the moisture content and, secondarily, the compaction effort affected the degradation of residual UCS. Therefore, the results obtained confirmed the conditions observed on the unpaved roads existing at UNICAMP. The use of this soil meets the minimum resistance to vertical vehicle loading (CBR › 20%) only when applying higher compaction energies (which requires the use of heavy machinery), but it does not allow for long-term use against the action of water, requiring chemical stabilization treatment.

2 Materials end methods

2.1 Material

The supporting material for this study was silty-clayey sandy soil, which presents small undeveloped clods from a concretionary point of view. This provides some porosity in its natural state, but this porosity is reduced in the compacted state. Table 1 summarizes the main properties of these soils and is therefore simply referred to as fine soil (FS).

The CBR test results showed that the soil meets the minimum acceptable CBR value igual a 20% (Brazilian criterion estimated for soil layer exposed to traffic and climate without surfacing or chemical stabilization) within the moisture content tolerance range of -2 to +1 percentage point of OMC for MP compaction, and -1.5 to +0.5 percentage point of OMC for IP (figure 2).

Table 1 Characteristics of untreated FS

Soil characteristic		MP(2)	IP(3)
Particle size [12]	Sand [%]	45	
	Silt [%]	28	
	Clay [%]	27	
Atterberg limits [13]	Liquid limit (LL) [%]	40	
	Plastic limit (PL) [%]	30	
Classification	USCS [14]	ML	
	AAHTO	A-4	
	MCT(1)[15]	LG'	
Optimum moisture content (OMC) [%]		21 [16]	23 [18]
Maximum dry density (MDD) [kN/m^3]		17, 2 [16]	16, 6 [18]
California bearing ratio (CBR) [%]		26 [17]	24 [19]
Unconfined compressive Strength (UCS) [MPa] [20]		0, 59	0, 33

(1)Classification of fine-grained tropical soils for road construction purposes (2)Modified Proctor compaction effort (3)Intermediate Proctor compaction effort - Brazilian criterion, which corresponds to 50% of the Modified Proctor compaction effort

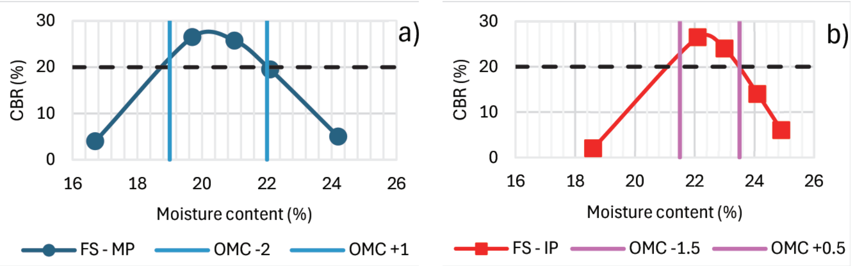

Figure 2 OMC tolerance range of the compacted FS at (a) MP and (b) IP

2.2 Test specimens preparation

Triplicate cylindrical test specimens (Proctor cylinder) of FS compacted to OMC and MDD of MP and IP were prepared for each test group and drying temperature. As a tolerance criterion, the compacted test specimen that met the following requirements were accepted as suitable for testing: a) degree of compaction between 100% ±2 and b) molding moisture content in the OMC tolerance range of the compacted FS sample at MP and IP (figure 2).

2.3 Testing program

2.3.1 Mass loss test by immersion in water

According to the Brazilian standard [8], after the compaction process (figure 2), 10% of the height of the test specimen was exposed outside the compaction cylinder and then immersed the test specimen in water for 24h in a horizontal position. After this 24h period, the portion of soil that detached was collected and its dry mass was determined. The mass loss by immersion is calculated as the percentage of dry mass detached in relation to the originally exposed part of the test specimen.

2.3.2 Water absorption test by immersion

The water absorption test by immersion was performed after the test specimen was oven-dried to constant mass at 60°C, and then the dried test specimen was immersed in water for 24h in a vertical position. Water absorption by immersion is calculated as the percentage of mass gain by wetting. In addition to the standard value of the drying temperature (60°C), the test was performed for test specimens air-dried at 28°C and oven-dried at 80°C.

2.3.3 Capillary rise test

The capillary rise test was performed according to the Australian standard [10]. The test was performed after the compacted test specimen was oven-dried to constant mass at 60°C, and then the dried test specimen was immersed in standing water of a 1cm height for 24h, in a vertical position. The relative capillary rise (CR) is calculated as the percentage of capillary rise at wetting relative to the original height of the test specimen. A maximum CR of 25% over a 24h period is acceptable, without any swelling [10]. In addition to the standard value of the drying temperature (60°C), the test was performed for test specimens air-dried at 28°C and oven-dried at 80°C.

2.3.4 Mass loss due to water runoff

The test was performed after the test specimen was oven-dried to constant mass at 60°C, and then the dried test specimen was subjected to 5-minutes of water runoff at a constant water head of 1 m. Excess water should be allowed to drain for a further 5-minutes, after which the test specimen is removed from the apparatus and oven-dried to constant mass at 60°C. Mass loss is expressed as the percentage of dry mass loss of the test specimen. A maximum mass loss of 9% for a 5-minute water runoff is acceptable [11]. In addition to the standard value of the drying temperature (60°C), the test was performed for test specimens air-dried at 28°C and to 15-minutes of water runoff.

2.3.5 UCS testing

The degradation of the strength of the test specimens that maintained their shape or showed acceptable mass loss after exposure to wetting was measured in the UCS test.

3 Results and discussion

3.1 Mass loss test by immersion in water

Compacted soil does not exhibit resistance to erosion under immersion in water; it is noteworthy that the mass loss reached the remaining interior of the test specimen not exposed to water (Pi › 100%) for both compaction efforts.

3.2 Water absorption test by immersion

All samples failed immediately upon exposure to water. Therefore, the test specimens showed the same performance as in the previous mass loss by immersion test, with the test specimens at OMC (section 3.1). Analyzing the variation of the average value of the moisture content of the test specimens during the test (figure 3): 1) the efficiency of the drying process was greater the higher the temperature, with the total loss of moisture content occurring at 80°C. For temperatures of 60 and 28°C, there was residual moisture; 2) it was not possible to obtain absorption by immersion because the test specimens failed to wet. Then, the tendency was for the total moisture content (initial remaining + absorbed) to exceed the LL value of the FS (LL > 40) (table 1).

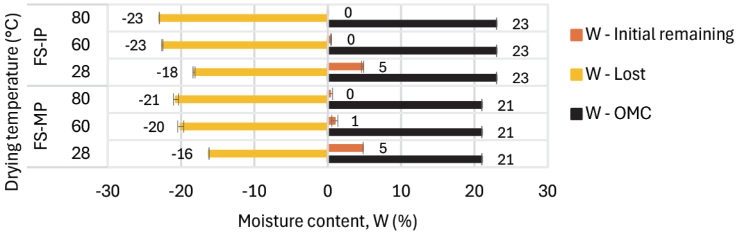

Figure 3 Variation in the average moisture content value as a function of the drying temperature of the compacted FS test specimen at MP and IP

3.3 Capillary rise test

All samples failed to meet the capillary performance suggested by Austroads [10] (a maximum CR of 25% over a 24h period). The capillary rise was equal to the height of the samples (CR = 100%); however, the samples did not show swelling at the bottom in contact with water. Analyzing the variation of the average value of the moisture content of the test specimens during the test (figure 4): 1) the result of the drying process was the same as described in the immersion absorption test (figure 3); 2) in the wetting process, the previous drying temperature of the test specimen (and the respective initial remaining moisture) was not a very significant variable, and the trend was water absorption on the order of the OMC (OMC ±1). Resulting in a total moisture content (initial remaining + absorbed) varying up to above the upper tolerance limit for OMC of compacted FS sample at MP and IP (figure 2); however, it is noteworthy that this excess total moisture did not cause the softening of the test specimens.

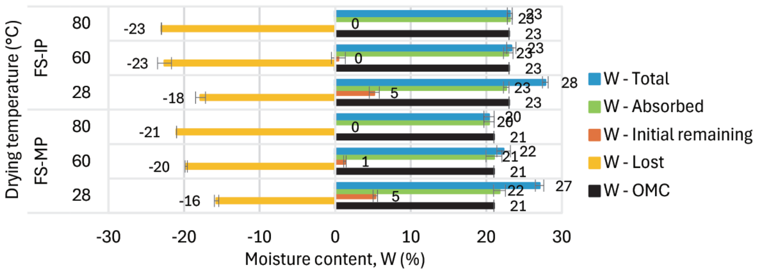

Figure 4 Variation in the average moisture content value as a function of the drying temperature of the compacted FS test specimen at MP and IP

3.4 Mass loss due to water runoff

Air-dried test specimens failed the standard 5-minute water runoff for both compaction efforts. For the oven-dried test specimens, the standard 5-minute water runoff resulted in a mass loss below the maximum limit of 9% [11]; however, after drying following wetting, the test specimens were brittle to the touch. Mass loss increased significantly (on average > 70%) for 15-minute water runoff. Analyzing the variation of the average value of the moisture content of the test specimens during the test (figure 5):

- the result of the drying process at 60°C was the same as described in the immersion absorption test (figure 3)
- for the standard 5-minute water runoff, the tendency was lower water infiltration than the OMC
- in the drying process after wetting (standardized procedure for determining PM), the tendency was for the test specimens to lose moisture on the order of that infiltrated, resulting in a final remaining moisture content on the order of the initial remaining moisture.

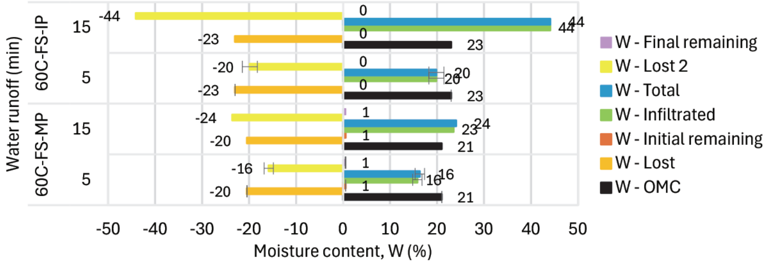

Figure 5 Variation in the average moisture content value of the compacted FS test specimen at MP and IP as a function of the water runoff time

3.5 Effect of wetting on residual UCS

All samples from the capillary rise test showed a decrease in compressive strength compared to the sample after compaction (figure 6), where the moisture content and, secondarily, the compaction effort affected the degradation of the compressive strength. It is noteworthy that the test specimens with moisture content on the order of OMC and without visible degradation also showed loss of RCS, which suggests that the oven drying and capillary wetting process caused stress in the test specimen. Therefore, the drying temperature of the test specimen (and the respective initial remaining moisture) was not a variable for capillary rise (figure 4), but it did affect the degradation of residual RCS through the total moisture content.

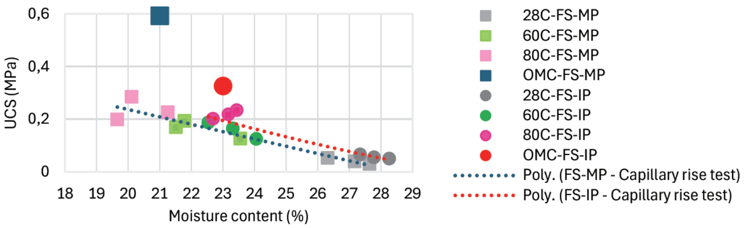

Figure 6 Variation in the residual RCS value of the compacted FS test specimen at MP and IP wetted by capillarity

For the test specimens compacted at MP that showed a mass loss of 7% in the standard 5-minute surface runoff (figure 5), the average residual RCS was equal to 0.18 MPa. Therefore, the maximum erosion limit of 9% [11] should be lower for untreated FS.

4 Conclusion

In Brazil, there are over 1 million km of unpaved rural roads without any treatment of the roadbed, which receive heavy traffic during agricultural harvest periods. The study developed allowed for the analysis of the performance of these road platforms when exposed to rain, which has proven to be more intense and prolonged in this current context of climate change. Depressions are very frequent in platforms of fine, uncompacted soils and facilitate the formation of puddles of water after rain (figure 7a). The immersion test, which resulted in the failure of the compacted soil test specimens, and the capillary rise test, which demonstrated the ability of water to infiltrate laterally and vertically, explain the evolution to deep depressions and potholes and, consequently, the formation of mud (figure 7b). Finally, the erosion resulting from the laminar flow of water over the compacted soil could be estimated. Therefore, carrying out various laboratory tests with water on compacted soil specimens was useful for the accurate understanding of the phenomena that occur in a compacted layer exposed to rain.

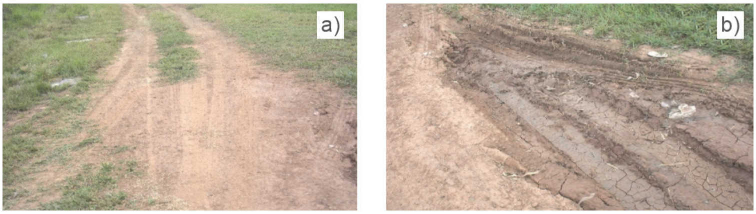

Figure 7 a) Unpaved access road to UNICAMP, b) deep depression on the side of the same road

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