# Proposed structural and functional evaluation of unpaved roads improved with geosynthetics, reclaimed asphalt pavement and Portland cement

*Luiz Heleno Albuquerque Filho*[1#], *Michéle Dal Toé Casagrande*[2], and *Luís Fernando Martins Ribeiro*[2]

[1]*Brazilian National Department of Transportation Infrastructure (DNIT), Brasília, Brazil*
[2]*University of Brasília, Department of Civil and Environmental Engineering, Brasília, Brazil*
[#]*Corresponding author: luiz.albuquerque@dnit.gov.br*

## ABSTRACT

The cargo transport network in Brazil is highly unbalanced, with a marked concentration of road transport in relation to other modes of transport. As if the flagrant imbalance between modes were not enough, serious distortions are also observed in the distribution of road network coverage. Only 13% of the Brazilian network has coating considered definitive, reinforcing the importance of unpaved roads in the transport network. Despite advances, the design methods for unpaved roads were mostly developed for roads treated with gravel in regions with a temperate climate, which are inconsistent with the nature and behavior of Brazilian tropical soils. They also disregard important soil improvement techniques, such as reinforcement with geosynthetics, incorporating civil construction waste, reclaimed asphalt pavement, mining tailings or chemical stabilization with different additives (hydrated lime, Portland cement, latex polymers, organic additives and asphalt emulsion). Faced with this challenging scenario, this research was designed to monitor the structural and functional conditions of unpaved road test sections in Brazil built with different soil reinforcement and stabilization techniques. The structural condition of the test sections will be evaluated through deflection measurements with the Light Weight Deflectometer (LWD), Benkelman beam, and Falling Weight Deflectometer (FWD), and the functional condition will be evaluated through field inspections for the qualification and quantification of defects. This article aims to present the synthesis of the proposed methodology and the initial results of soil characterization obtained in constructing the first test section located in an unpaved section of the Federal Highway BR-030, in the state of Bahia.

**Keywords:** unpaved roads; soil improvement; test sections.

## 1. Introduction

Important investments in recent decades for the implementation of waterways and railroads were not enough to balance the network of cargo transport in Brazil, and there is still a strong concentration of the road modal in relation to the others.

In addition to the excessive participation of road transport, Brazil's logistical problem is aggravated by the lack of integration between the different modes and the fact that the road network today is mostly made up of roads laid exclusively in natural riverbeds or with some type of coating that is only primary.

On unpaved roads, the characteristics of the materials, mainly the local and foundation soils, the need to reinforce the subgrade, the surface and deep drainage conditions, the thickness of the landfill layer and the average volume of traffic are the factors considered in the project and directly condition the cost of construction. Higher initial construction costs may prove to be relevant not only in the later reduction of maintenance and operating costs, but mainly in guaranteeing the track's good running conditions throughout the year, particularly in the rainy season.

Despite important advances observed, most dimensioning methods are formulated exclusively for the construction of roads treated with gravel in temperate climate regions, which is not always adjusted to the nature and behavior of Brazilian tropical soils.

Restriction of most methods also refers to the non-prediction of alternative materials in the design of unpaved roads, such as civil construction and demolition waste (Amorim 2013 and Fleury 2018), mining tailings, chemical stabilization with polymers (Carneiro 2020, Silva 2020 and Alelvan 2022), geosynthetics (Góngora 2015), among other solutions.

The problem is compounded by the growing environmental and economic restrictions imposed on the extraction of natural resources used in the primary coating of unpaved roads, particularly lateritic gravel.

Faced with this challenging scenario for Brazil's transport infrastructure, this research project was designed to evaluate the structural and functional conditions of the experimental section of unpaved roads built with different soil improvement techniques. In addition to measuring deflection and qualifying and quantifying defects, the project also plans to analyze aspects related to construction, maintenance, and operation costs of the different solutions adopted.

## 2. Transport and Road Network in Brazil

The absence of investments in the railway sector and the prioritization of highways as a vector of development and regional interconnection from the 60s of the last centuries accentuated the imbalance in the network of cargo transport in Brazil. To illustrate, Table 1 presents the participation and distribution of different modes in cargo transport (CNT 2019). When comparing the historical evolution to the idealized planning for 2025 according to the Brazilian National Transport Logistics Plan (PNLT), a State Policy designed to structure Brazil's infrastructure, the imbalance in the transport network is even more evident. That is, from the initial objective of ensuring a more uniform distribution of cargo transport between road, rail and waterway modes, what remains characterized is the little growth in total cargo transport capacity and an even greater concentration of road transport in relation to other modes.

**Table 1.** Historical evolution of participation by mode in cargo transport in Brazil (CNT 2019)

| | 1950 | 1970 | 1988 | 2005 | 2018 | PNLT (2025) |
|---|---|---|---|---|---|---|
| **Road** | 49.5 | 70.4 | 56.5 | 58.0 | 60.0 | 33.0 |
| **Rail** | 23.8 | 17.2 | 22.5 | 25.0 | 23.3 | 32.0 |
| **Waterway** | 26.4 | 12.1 | 17.0 | 13.0 | 13.2 | 29.0 |
| **Airway** | 0.3 | 0.3 | 0.3 | 0.4 | 0.1 | 1.0 |
| **Pipeline** | - | - | 3.7 | 4.2 | 3.4 | 5.0 |

Because of this historical concentration of road transport in cargo transport, the Brazilian network today consists of approximately 1,720,700.0 kilometers of highways and rural roads, excluding planned roads, under the jurisdiction of the Union, States, and Municipalities, which qualifies it as one of the most extensive road networks among all nations in the world.

However, despite the total extension of the road network in Brazil, second only to that of the United States, and its reasonable distribution throughout all its geographic regions, only 213,453.0 kilometers of these roads have a definitive coating, whether flexible, rigid or semi-rigid, which represents a share of only 12.4% of paved roads in the road network, as detailed in Table 2 (CNT 2019). That is, worryingly, 87.6% of the road network in Brazil today is made up of highways and rural roads laid exclusively in natural roadbeds or with some type of surface treatment that is only primary.

**Table 2.** Road network in Brazil by jurisdiction and coating condition (CNT 2019)

| | Unpaved road (km) | Paved road (km) | Total (km) |
|---|---|---|---|
| **Federal** | 55,067.2 | 65,513.3 | 120,580.5 |
| **State and Municipal** | 1,452,179.8 | 147,939.7 | 1,600,119.5 |
| **Total (km)** | 1,507,247.0 | 213,453.0 | 1,720,700.0 |

## 3. Characteristics of Unpaved Roads

The unpaved roads are formed by roads of different characteristics and range from side roads to agroways and rural roads. They constitute the main connection between the rural properties and the neighboring villages (urban area), and serve as access to the main roads. This group should also include roads intended exclusively for the internal movement of rural properties, whose main function is to allow the transit and flow of residents, machinery, equipment, and agricultural products to the neighboring roads.

Unpaved roads normally have a low volume of traffic and are mostly made of local materials that have been shaped or are only expected to be treated primarily. Due to their implementation being associated with the use of pre-existing trails and paths, geometric layouts are usually characterized by ramps and more pronounced horizontal curves in relation to paved road projects.

Degradation of the pavement of an unpaved road can occur in two ways, namely: superficial or structural. Surface degradations are those that interfere with the behavior of the surface, resulting in reduced safety and riding conditions for users. Degradations considered structural are related to the lack of support capacity of the foundation soil or the rupture of the constituent materials of the road structure.

The main and most frequent defects that contribute to surface or structural deterioration of unpaved roads are:

- Potholes - Small depressions in the running surface, usually in the form of a basin, one or more centimeters deep, resulting from excessive humidity, the absence or deficiency of binder particles in the wear layer, the occurrence of poorly drained platforms and without slope transversal, or a combination of these factors;
- Loss of aggregates - The passage of vehicles can cause the segregation of the coarse fraction of the wear layer of unpaved roads, which results in the accumulation of aggregates along the wheel tracks and in areas close to the edges of the road;
- Corrugations - Irregularities on the surface of unpaved roads, especially those made of poorly cohesive materials. They are characterized by the occurrence of a series of medianly spaced grooves at regular intervals, always perpendicular to the direction of traffic;
- Ruts or whell track - Depressions formed on the surface, which always appear in the direction of passage of vehicle tires, that is, longitudinally to the road axis. It originates from the permanent deformation of the subgrade or any upper layer and results from the compressibility and/or low support capacity of the soil, the action of repeated vehicle loads and poor drainage conditions;
- Dust - The formation of dust on the surface is related to the loss of the fine fraction of the sub-base or wear or rolling layers. Its occurrence, aggravated by long periods of drought, is the result of the passage of vehicles that generate an abrasive action on the road, causing the particles of binding soil to detach from the running surface.

## 4. Unpaved Roads Project

The pavement structure of an unpaved road can be divided into four basic layers: the wear layer (bearing surface), the base layer, the subbase layer, and the foundation layer (subgrade), as shown in Figure 1. However, it is common for the layers to be treated as a single element and made up of the same material, especially when the volume of traffic is low and the foundation has good support capacity.

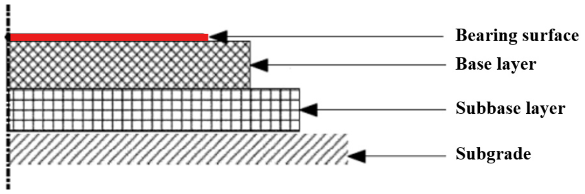


**Figure 1.** Typical pavement structure of an unpaved road

The determination of the thickness of the layers of unpaved roads has been carried out through knowledge of the properties of resistance and deformability of the foundation and of the materials of the layers, mainly the California Bearing Ratio (CBR), of the need to reinforce the subgrade, notably geosynthetics, surface and deep drainage conditions, characteristics and frequency of local traffic and even local climatic conditions.

Despite the recognized advances in its formulation, most of the design methods for unpaved roads in the world were developed exclusively for the construction of gravel roads, respecting local definitions regarding the granulometry of the materials and the criteria used for evaluation and recomposition of the surface material.

In the United States of America, approximately 35% of its extensive road network consists of unpaved roads, most of which are treated with gravel. Thus, the surface damage sizing and evaluation methods proposed by leading technical organizations, such as the United States Army Corps of Engineers (USACE), Federal Highway and Transportation Officials (FHWA), American Association of State Highway and Transportation Officials (AASHTO) and United States Forest Service (USFS), respect this concept.

In the United Kingdom, the Transport and Road Research Laboratory (TRRL) has developed design methods for unpaved roads based on investment experiences in countries in Africa and Asia. These methods were based only on the bearing capacity of the foundation soils and on the standard axis repetitions and observed traffic characteristics.

In Australia and New Zealand, desert and forest areas predominate, which is why unpaved roads are important and represent 60% of their road networks. Since the 1990s, these countries have jointly studied unpaved roads' construction and maintenance design.

Despite having important technical regulations related to the maintenance of unpaved roads, such as those of the Brazilian National Department of Transportation Infrastructure (DNIT) and the municipal and state highway departments, Brazil does not have a method for sizing and classifying surface conditions of unpaved roads consistent with the nature and lateritic behavior of local soils, where imported and adapted methods are normally used.

## 5. Proposed Methodology

Due to the importance of unpaved roads in Brazil's transport network, the growing environmental restrictions on the extraction of natural resources and the diversification of technical solutions for soil improvement, the experimental program of this research was designed to answer two important questions:

- Is it possible to monitor and identify differences in the parameters of the functional and structural of test sections built with different soil reinforcement and stabilization techniques on unpaved roads that present topographic, geological and traffic uniformity?
- How can this knowledge contribute to the qualification of design solutions increase operational safety, and reduce maintenance costs on Brazilian unpaved roads?

The degradation of an unpaved road occurs simultaneously due to functional and structural defects. Thus, the experimental research program foresees the construction of segments with different soil improvement techniques and the routine performance of deflection measurements and field inspections for the quantification and qualification of defects.

### 5.1. Assessment of functional condition

The functional assessment of unpaved roads is carried out by observing the comfort conditions, the defects found and their respective degree of severity. This assessment is directly influenced by bearing capacity, road deterioration level, and user perception.

Methods for assessing the functional condition of unpaved roads can be divided into two main areas: subjective and objective.

The subjective assessment is based on the premise of investigating the condition of the road surface from the exclusive perspective of the users. Despite its importance, the assessment of road usefulness is not an isolated action by road agencies. The most common procedure consists of associating this subjective assessment with other criteria and methods that also incorporate the identification of defects and pathologies on the roads, even if qualitatively and not quantitatively.

The objective assessment or survey of surface defects is based on data collection by proven methods of measuring existing defects or pathologies on the road: the type of defect, severity and density. After field collection, consolidation of information takes place to define the functional condition of the road section.

Among the methods for assessing the functional condition of unsurfaced roads, the so-called Unsurfaced Road Condition Index (URCI) deserves special mention. Proposed by Eaton et. al. (1987) and compatible with the Pavement Condition Index (PCI), the URCI Method consists of a classification proposal and a field manual for evaluating the surface condition and the drainage system of unpaved roads.

The URCI index is obtained by subjectively and objectively evaluating the defects observed and classified by their respective degrees of severity. The severity is defined as a function of the dimensions of the defects in relation to the total dimensions of the sample unit. For each defect, specific classifications are proposed which, together with severity graphs and measurement methods, allow the determination of the index per sample unit, according to the criteria presented in Table 3.

**Table 3.** Description of defects and measurement criteria of the URCI Method (Eaton et al. 1987)

| Defects | Measurement Criteria |
|---|---|
| **Improper Cross Section** | Length (meter) |
| **Inadequate Roadside Drainage** | Length (meter) |
| **Potholes** | Number |
| **Loss of Aggregates** | Length (meter) |
| **Corrugations** | Area |
| **Ruts** | Area |
| **Dust** | Height and density |

## 5.2. Assessment of structural condition

The structural assessment of a road is associated with the concept of load capacity, the design of the structure and its dimensioning. Structural defects result from repeated loads, mainly from heavy vehicles, and are linked to elastic or recoverable and plastic or permanent deformations (Bernucci et al. 2006). In evaluating unpaved roads, the only defects that can be considered essentially structural, although with functional implications in the wear layer, are related to the formation of potholes and wheel tracks. The other defects observed on the road, and previously presented, are classified as purely functional.

The evaluation of the structural condition can be performed by destructive, semi-destructive or non-destructive methods. Destructive methods assess the structural condition of the layers by opening trenches or drilling holes, which allows the collection of samples of each material up to the subgrade and the consequent carrying out of load capacity tests. By their very nature, destructive methods can only be used at a few points and selected as representative of each segment.

Semi-destructive methods consist of drilling holes that allow the use of small portable instruments, such as dynamic penetration cones (DCP). This equipment is intended to evaluate the resistance to penetration into the soil or the load capacity, both in the compacted layers and in the soil in its natural state (subgrade).

For the evaluation of the structural condition in large extensions of lanes and with the need to perform numerous repetitions at the same point, in order to follow the variation of the load capacity over time, non-destructive methods are normally used that measure the deflections of the layers (Bernucci et al. 2006). The non-destructive evaluation can be carried out using quasi-static loading equipment (Benkelman beam), vibrating loading, or impact loading (FWD and LWD). In this research, the LWD owned by DNIT will be used.

## 5.3. Costs analysis

The construction and maintenance costs of each soil improvement technique adopted in the experimental sections will be defined according to the quantities of services, equipment and materials used, depending on inspection field measurements and unit prices of the Reference Costs System for Works - SICRO, the official price reference of the Federal Government of Brazil for contracting transport infrastructure services. Operating costs of the unpaved road and the vehicles that travel along it will be estimated based on the HDM-4 program, a tool widely used worldwide for pavement management.

The different soil improvement techniques will be economically evaluated in possession of the cost surveys and the results of the functional and structural parameters of the test sections. Among the quantitative methods, the Cost Benefit Analysis is the most used tool for evaluating road projects as it allows monetizing aspects considered objective. Due to the need for a comparative evaluation of the different soil improvement techniques, Cost-Effectiveness Analysis, Cost-Utility Analysis, and Life Cycle Analysis will also be used.

The Cost-Benefit Analysis consists of a project evaluation method that aggregates all the relevant criteria of a project in a single measure: money. All these criteria are distributed through a cash flow that respects the useful life of the project (direct or indirect benefits).

Direct benefits are the quantifiable advantages arising from the construction or improvement of a highway, which are particularly reflected in transport costs (reduction in operating costs, the number of accidents and travel time). In addition, these benefits are considered direct because they affect road users. On the other hand, indirect benefits are reflected in the entire community or just in some of its members in terms of economic development in the region under the influence of the highway in a given project.

The Cost-Effectiveness Analysis consists of a microeconomic evaluation based on the comparison of alternative courses of action, both in terms of costs and consequences. That is, the difference in costs (incremental cost) is compared with the difference in consequences, in the form of a ratio between the first and second, always admitting a choice between interventions and assuming the scarcity of resources.

Cost-Utility Analysis aims to compare costs and benefits associated with the impacts of alternative strategies in terms of their monetary values. The method is based on the premise that each indicator has an absolute weight, and the benefits of the analyzed alternatives are evaluated with weights for each indicator. Results are calculated for each option, representing a weighted average for all these criteria.

Life Cycle Analysis is a technique that involves the assessment of environmental aspects and potential impacts (positive and negative) throughout the life of a product or service, from raw material extraction to the destination. That is, the evaluation of all the steps necessary for a product or service to be developed or designed, fulfill its function and reach the stage of disposal, recycling, or reuse.

# 6. Experimental Program

## 6.1. Localization of the test section

The first test section will be built on the federal highway BR-030, part of the DNIT network, in the segment between the junction with the BA-001 highway and the district of Campinho, near the city of Maraú, on the cost of the state of Bahia, as shown in Figure 2. This segment of the highway is in an unpaved condition, and there is no forecast for the application of a definitive coating within the research monitoring interval.

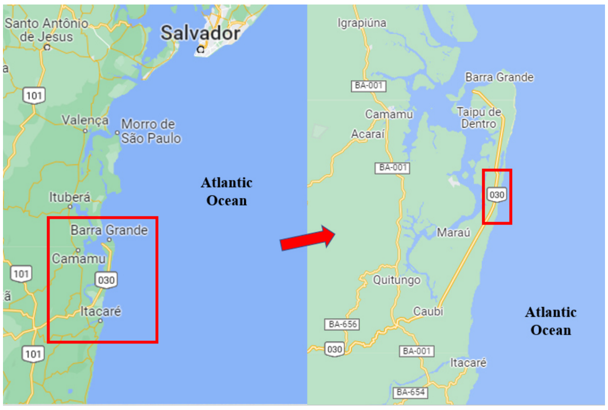


**Figure 2.** Localization of the first test section of the research

Another important requirement for defining the region for implementing the test section is topographic and geological uniformity (Figure 3). Compliance with this requirement aims to ensure that the distribution of loads arising from heavy vehicle traffic occurs uniformly in all segments with the incorporation of soil improvement techniques.

**Figure 3.** Frontal view of the region where the test section will be implemented on the BR-030/BA highway

## 6.2. Site characterization

### 6.2.1. Relief

The Maraú Península has altitudes that vary from sea level to 55 meters, located from the coastal zone to the relief of hills and mountains in the western portion of the area. Figure 4 presents the hypsometry distribution of the area with classification defined according to four altitude intervals. The class between 0 and 10 meters represents the altitudes distributed preferentially in the coastal zone, including coastal sandy deposits and mangroves. The class with altitudes between 10 and 30 meters represents elevations associated with the occurrence of Mesozoic sediments in the Camamu Basin (Waldburger 2014). These are the dominant classes in the area of the future test section of the BR-030/BA highway.

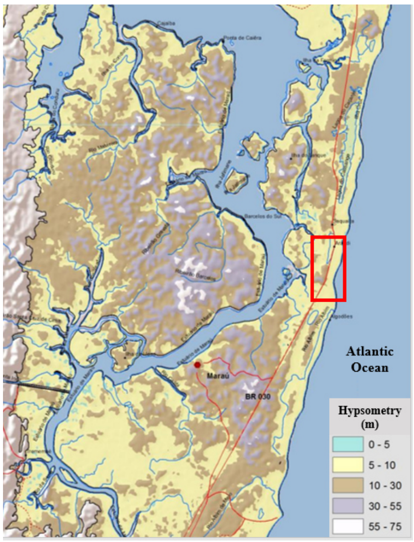


**Figure 4.** Distribution of hypsometry classes in the region of the test section (modified from Waldburger 2014)

### 6.2.2. Climate

The climate in the Peninsula de Maraú region is Tropical Super-Humid, without a pronounced dry season, common on the south-central coast, extending from the Reconcavo to the extreme south of the state of Bahia.

This region has high rainfall, normally exceeding 2,000.0 mm annually and distributed throughout the year. The greatest rainfall occurs in the months of April and May and the lowest in the months of September and October. Figure 5 presents the consolidated monthly rainfall averages from January 2012 to October 2022, according to results extracted from the Maraú Station of the Brazilian National Institute of Meteorology (INMET). The average annual temperature in the region of test sections presents an annual temperature range oscillating between 21 and 25°C.

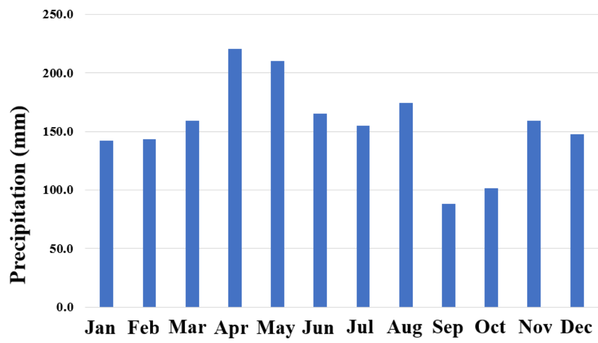


**Figure 5.** Monthly rainfall averages at the Meteorological Station of Maraú-BA (INMET 2022)

### 6.2.3. Geology

In an extract of interest to the Map of the Coastal Quaternary of the State of Bahia (Waldburger 2014), it is observed that the rocky substrate of the region where the experimental section will be implanted is characterized by the interspersed occurrence of three different classes, with the predominance of the first, namely:

- Holocene sandy terraces - Well-selected coastal sands characterized by remarkably developed cord ridges. These ridges can be easily distinguished from other transgressions by being thinner and closely packed together;

- Alluvial fan deposits - Poorly sorted sands containing pebbles found in different locations along the coast. They normally occur at the foot of elevations and with tops located 15 to 20 meters above sea level;
- Barriers Group - Unconsolidated tertiary sedimentary deposits composed of sands, clays, and gravels. They occur in trays arranged on rocks of the crystalline complex or Mesozoic sediments of the Camamu Basin.

Figure 6 shows an extract from the soil distribution map of the Maraú Peninsula (Waldburger 2014).

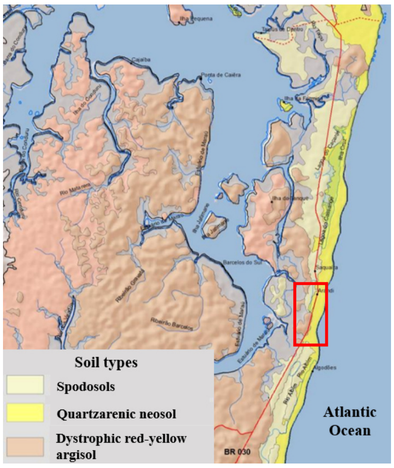


**Figure 6.** Soil types distribution in the region of the first test section (modified from Waldburger 2014)

Due to the spatial distribution of rocky substrates and pedological processes specific to the region, the region of the future experimental section is characterized by the occurrence of the following soil classes:

- Quartzarenic neosol - They are associated with sandy terraces and are characterized by frank sand over at least 2 meters in depth. They are soils made up essentially of quartz grains, that is, practically devoid of primary minerals that are not very resistant to weathering;
- Spodosols - They are distributed in the areas where deposits of alluvial fans occur. They are characterized by the presence of spodic B horizon, constituted by the concentration of organic matter;
- Dystrophic red-yellow argisol - They occur in areas where the unconsolidated sediments of the Barreiras Group emerge. These are deep to shallow soils, moderately to well-drained, with highly variable granulometry, although a certain predominance of a medium texture on the surface and more clayey in the subsurface, with or without the presence of gravel, is identified.

### 6.2.4. Hydrology

The most granular texture of the sedimented deposits in the region of the experimental section confers moderate to high drainage to the soil extracts.

The underground water level varies between 3 and 5 meters in depth in the areas of the sandy coastal zone and outcrops in marshy lowlands. In the substrate of the Barreiras Group and in Mesozoic sediments, the depth of the water level increases due to the influence of the relief of greater amplitude.

## 6.3. Construction of the first test section

The segments of the first test section will be 8 meters wide and 100 meters long. Between each segment with soil improvement, control sections will be executed, also 100 meters long and with the same solution originally adopted on the rest of the unpaved road (primary coating with lateritic gravel), according to the location of the test section segments shown in Figure 7.

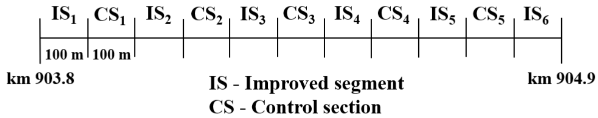


**Figure 7.** Location of the first test section segments.

As shown in the previous figure, in this first moment of the development of the research, 6 segments will be built with the following soil improvement techniques:

- Reinforcement with woven geotextile;
- Reinforcement with non-woven geotextile;
- Reinforcement with geogrid;
- Reinforcement with geocell;
- Granulometric stabilization with the incorporation of reclaimed asphalt pavement (RAP);
- Granulometric and chemical stabilization with the incorporation of RAP and Portland cement.

In a later stage, the test section will be expanded through the construction of improved segments with the incorporation of civil construction waste and natural fibers and chemical stabilization with hydrated lime, latex polymers and organic additives.

## 6.4. Sample collection and sand cone method

Dimensioning the layers of the segments with soil improvement requires knowledge of the geotechnical properties of the foundation soil and of the materials used in the primary coating of the unpaved road.

Soil samples from the primary coating and subgrade (1.5 meters deep) were collected at the midpoint of each improved segment and control section, as shown in Figure 8. The samples were used for granulometric characterization and determination of consistency limits and resistance parameters (compaction and CBR tests).

**Figure 8.** Collection of soil samples in the test section

The collection was carried out alternately on the axis and on the left and right edges of the road in order to expand the investigation of the area of application of the stresses. At these points, in addition to collecting soil samples, tests were carried out on the surface and in-depth to determine the relative density in situ using the sand cone method, as shown in Figure 9.

**Figure 9.** The sand cone method was performed on the primary coating in the test section

Evaluation of the relative density in situ was motivated by the need to identify the compaction energy to be applied in the laboratory tests to determine the resistance and expansion parameters. Results obtained in the field indicated the suitability of the energy of the standard Proctor for the subgrade and of the intermediate Proctor for the layers with surface lateritic gravel.

Granulometric characterization tests, determination of consistency limits, mechanical strength and soil expansion indices are being carried out at the Paving Laboratory of the Federal University of Reconcavo da Bahia, a partner in the development of this research.

### 6.5. Granulometry and consistency limits

Figure 10 shows the granulometric distribution curve of the subgrade soil in the region where the future test section will be implemented. According to the textural classification proposed by the Brazilian Association of Technical Standards (ABNT), the soil is made up of 10% gravel, 61% sand, 12% silt, and 17% clay.

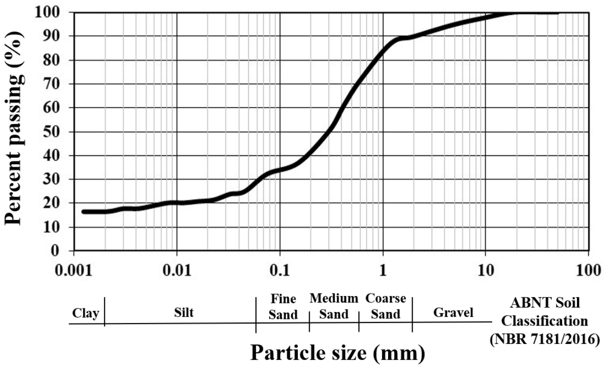


**Figure 10.** Particle size distribution curve of the subgrade sample (1.5 meters deep) in Improved Segment 1 (spot 903.8)

Tests indicated a liquid limit of 25%, a plasticity limit of 19% and a plasticity index of 6% for the soil subgrade. According to Unified Soil Classification System (USCS), the subgrade soil is classified as SM. According to the Transportation Research Board (TRB) classification, the sampled soil is classified as A-2-4, which predicts satisfactory behavior as a subgrade.

Figure 11 shows the granulometric distribution curve of the primary coating soil (lateritic gravel) in the region of the future test section. According to the textural classification proposed by ABNT (2016), the soil is made up of 25% gravel, 53% sand, 13% silt, and 9% clay.

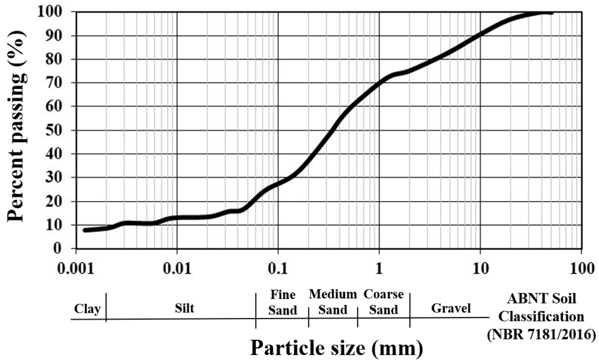


**Figure 11.** Particle size distribution curve of the primary coating sample in Improved Segment 1 (spot 903.8).

Tests indicated the non-plastic behavior of the materials used in the primary road surfacing. Despite greater participation of gravel in the matrix, primary coating has the same classification according to the USCS and TRB methodologies. However, in-depth, the subgrade presents some compressibility.

This similar textural observed may be associated with the influence of embankments carried out during the implementation of the road platform and mainly the continuous cycles of surface material recomposition in maintenance operations.

### 6.6. Compaction and CBR Tests

Table 4 presents the results of the compaction and California Bearing Ratio (CBR) tests carried out on some subgrade and primary coating samples.

**Table 4.** Initial results of compaction and CBR tests

| Spot | Layer | Dry specific weight (kN/m$^3$) | Optimal moisture content (%) | CBR Index (%) | Exp. (%) |
|---|---|---|---|---|---|
| 903.8 | Subgrade | 18.54 | 13.5 | 10.0 | 0.0 |
| 903.8 | Primary coating | 21.23 | 8.6 | 37.0 | 0.0 |
| 903.9 | Subgrade | 18.93 | 11.9 | 8.4 | 0.0 |
| 904.0 | Subgrade | 18.72 | 12.1 | 14.6 | 0.0 |
| 904.0 | Primary coating | 21.03 | 8.8 | 38.3 | 0.0 |

Results indicate that the granulometric similarity previously observed between the layers does not appear when analyzing the maximum dry specific weight and the mechanical strength parameters.

High values of dry specific weight of the primary coating may be associated with the lateritic nature of the gravel used as the base and wear surface of the unpaved road. The subgrade dry specific weight values are consistent with sandy-silt soils in natural conditions.

Figure 12 shows MCT (Miniature, Compacted, Tropical) methodology's result for classifying tropical soils to the primary coating material. This systematic divided tropical soils into seven groups and two main classes: soils with non-lateritic behavior and soils with lateritic behavior (Nogami & Villibor, 1981).

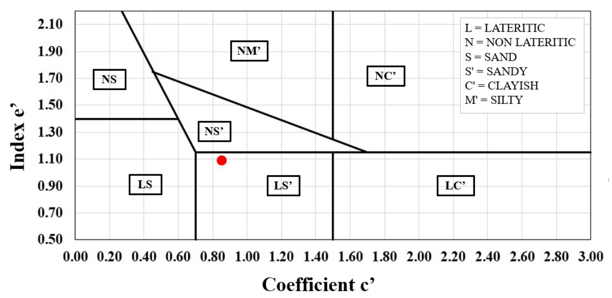


**Figure 12.** Brazilian MCT classification of the primary coating sample in Improved Segment 1 (spot 903.8)

According to the MCT classification, the primary coating soil of the test section is classified as lateritic sandy (LS'), but at the limit of the line that defines the lateritic behavior of the soils. This observation requires the enlargement of the tests to better characterize the material that makes up the base and the wear layer, over and with which all soil reinforcement and stabilization techniques will be performed in the test sections of the unpaved road under investigation.

## 7. Conclusions

Results of the laboratory tests of granulometric and mechanical characterization preliminarily indicated the adequacy of the soils of the segment in research of the federal highway BR-030/BA. However, the increase in the weight of loads on the road due to the accelerated real estate expansion of Praia de Barra Grande, considered the new tourist frontier in Bahia, and the local conditions have resulted in increasingly shorter maintenance cycles and greater use of lateritic gravel for the primary coating.

The surroundings of this BR-030/BA highway segment have several areas of environmental preservation of the Atlantic Forest and the search for new deposits for lateritic gravel exploration shows a trend of growth in average transport distances.

Thus, it is essential to evaluate other soil improvement techniques that can guarantee functionality and safety to users of this unpaved road, with a reduction in maintenance costs, which justifies the continuity of research and monitoring of the functional and structural parameters of the test sections.

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