

# Engineering-Geological Evaluation of Salaito Road, Santiago de Cuba

## Evaluación Ingeniero-geológica del Vial Salaíto, Santiago de Cuba

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**Abstract:** The geotechnical deterioration causes of Salaito Road are evaluated in this study. That roadway provides access to Cementos Moncada S.A. factory in Santiago de Cuba and is subjected to heavy traffic loads. A review of the state of the art on road deterioration was conducted, along with a specific analysis of the road, including the physical and mechanical properties of the base and subbase soils. Five main lithologies were identified as contributors to problems such as subsidence and cracking, manifested on the asphalt layer as crocodile skin cracking, subsidence, longitudinal and cross cracks, and rutting. The findings provide a strong basis to carry out corrective measures and enhancements to the design and maintenance of road infrastructure.

**Keywords:** heavy-load road, road deterioration, technified embankment

**Resumen:** Se evaluaron las causas geotécnicas del deterioro del vial Salaíto, acceso a la fábrica Cementos Moncada S.A. en Santiago de Cuba, una vía sometida a alto tránsito de cargas pesadas. Se realizó una revisión del estado del arte sobre el deterioro de viales y un análisis específico del vial, incluyendo las propiedades físico-mecánicas de los suelos de base y subbase. Se identificaron cinco litologías principales que contribuyen a problemas como hundimientos y agrietamientos, manifestándose en la capa asfáltica como piel de cocodrilo, hundimientos, grietas longitudinales y transversales, y ahuellamiento. Los resultados proporcionan una base sólida para implementar medidas correctivas y mejoras en el diseño y mantenimiento de la infraestructura vial.

**Palabras claves:** carretera de alta carga, deterioro vial, terraplén tecnificado

**Introduction**

Roadway infrastructure plays a vital role in the economic development of any country (Dorado-Zaldívar, 2021; Vásquez Rodríguez, 2022; Huamaní, Rimayhuaman & Tito, 2022; Olaya-Reyes, 2023; Pedraza, Camacho & Porras, 2024). Road construction and maintenance require special attention from the government. Well-planned roadworks reduces vehicle operating costs, transport time, and environmental pollution, thereby contributing to the effective territorial planning and socio-economic development of a nation (Novela, 2017; Tobar-Insuasty, 2024). Road durability depends on proper design and effective maintenance (Huamán-Cortés *et al.*, 2023).

This research was aimed to conduct an engineering-geological study of Salaito road, which provides acces to Cementos Moncada S.A. factory in Santiago de Cuba. This heavy-load road, despite being recently constructed, has shown a fast deterioration affecting its safety and stability. To carry out this study, geological mapping, soil and rock analysis, and geotechnical modeling techniques were used to assess the actual condition of the road.

The study area is located at Abel Santamaría neighborhood, in Santiago de Cuba province. The road´s alignment intercepts Siboney road 3.37 km west San Juan River bridge, extending 1440 m south the entrance of the residential neighborhood identified as Petrocasas, wich is located in Micro III (Figure 1).

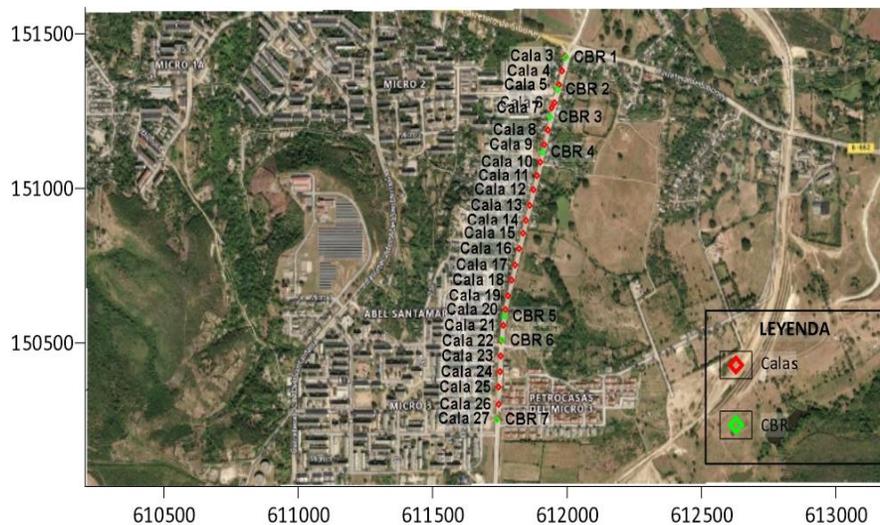


Figure 1. Location map of Salaito roadwork area, Santiago de Cuba.

The area is located in San Juan River basin, which consists of a surface and a subsurface basin, where the main tributary is San Juan River with a 30.3 hm<sup>3</sup> flow. The historical accumulated precipitation is characterized by values ranging from 700 to 1,600 mm (Salmo Cuspinera *et al.*, 2023).

The area is dominated by Tejar and Santiago Members of La Cruz Formation, presenting biotrititic limestones alternations, sometimes silty or clayey, subordinately marl and marly matrix calcarenites, conglomerates, polymictic sandstones, and silestones with calcareous cement, formed mainly by volcanics. To a lesser extent, smectitic clays insertions appear. Coloration is greenish-gray to mottled brownish in terrigenous horizons and whitish and creamy in carbonaceous ones. There are very fossiliferous horizons. The silestones on the SE edge of Santiago de Cuba Bay appear slightly phosphatized. Its Quintero member lies discordantly over El Cobre (undifferentiated part) and the granitoid bodies. This formation is discordantly covered by Jaimanitas and Río Maya formations (Instituto de Geología y Paleontología, 2013).

## **Materials and Methods**

The research was divided into three stages:

Preliminary stage: Bibliographic review of studies and methodologies to assess road damage. Road construction historical background was analyzed, from Trésaguet (1775), Telford (1821), and McAdam (1816) methods, to current standards such as those of AASHTO (2020).

Specific study of the road: A topographic survey, an engineering-geological survey of the alignment, a hydrogeological and hydrological analysis, construction materials identification, and an engineering-geological investigation were carried out. 64.35 m were drilled with the Spanish-made Rolatec 45 machine, distributed over 24 test pits out of 27 planned, using the percussion with a split Terzaghi spoon and Bx cleaner method; additionally, 7 test pits were executed for sampling and performing in situ CBR. 77 laboratory tests were performed, divided into 17 granulometry analyses, 13 Atterberg limits tests, 17 specific weighting of soils, 15 density tests, and 15 moisture content tests.

Desk stage: This stage ran simultaneously with the others to ensure correct decision-making during the research process as new information emerged on the analyzed

variables. Cuban standards NC 59 (2000), NC 157 (2002), and NC 334 (2004) were used to determine the parameters and variables to be studied for heavy-load roads.

## Results and Discussion

### Geological Survey

The geological survey revealed that the main damages observed on the road corresponded to potholes, longitudinal and cross cracks, patching works, subsidence, aggregate stripping, rutting, crocodile skin cracking, bumps, cracking, and exudation (Figures 2 and 3). Most of these deficiencies were found in areas where water and sewer works had been installed after the construction of the road's technified embankment, which compromised the strength of the embankment and its ability to deal with water in those areas.



Figure 2. a), b), c) Potholes. d) Patching, subsidence s. e) Patching, pothole and cross crack in concrete slab. f) Concrete pouring on the roadway, aggregate stripping. g) Cross cracks, concrete patch and subsidence. h) Crocodile skin cracking and patching.



Figure 3. a) Subsidence. b) Concrete pouring on the roadway, aggregate stripping and potholes. c) Aggregate stripping. d) Crocodile skin cracking. e) Bump, subsidence and rutting. f) Bumping, subsidence, rutting and exudation. g) Bumping and subsidence. h) Block cracking.

### Lithology of the area

According to the performed drillings, the presence of five lithologies was determined in the study area.

**Asphalt Concrete (AC):** Sometimes damaged with a thickness ranging between 0.08 and 0.06 m.

**Hydraulic Concrete (HC):** Massive concrete slab in good technical condition, with a 0.25 m thickness. It appears in test pits 8 (Sta. 30+4.60) and 25 (Sta. 116+4.00).

**Fill (F):** Clayey gravel with sand (GC): gravel 50%, small and angular; sand 28%, medium to fine grain; fines 22%, LL = 26%, PI = 8%, low plasticity; hard consistency; slightly moist, light-yellow coloration. This layer appears in all drilled test pits with thicknesses ranging from 0.25 up to 1.25 m.

**Soil 1:** Sandy high-plasticity clay (CH): fines 65%, LL = 57%, PI = 33%, highly plastic; sand 30%, fine grain; gravel 5%, small and angular; medium to soft consistency; moist, dark gray to black coloration. This layer appears in test pits drilled in the alignment's low area (3, 4, 7, 9, 10, and 11) and in test pit 26 with thicknesses ranging from 0.25 m up to 2.00 m.

**Rock (Ls):** Marly limestone, severely weathered, highly fragmented, hard, light-yellow coloration. It was cut in most of the drilled test pits.

### Physical-Mechanical Properties

To determine the physical-mechanical properties, soil and rock samples taken from mechanical probing were used, the results of which are presented in Table 1.

Table 1. Physical-mechanical properties of the materials forming the study section 's base and subbase earth structure.

Properties	Layer F	Layer 1
Number of blows /30 cm NSTP	40	22
Liquid Limit (LL) %	26	56
Plastic Limit (LP) %	18	23
Plasticity Index (IP) %	8	33
Consistency Index (Ic) s/d	1.97	1.20
Specific Weight ( $\gamma_s$ ) kg/m <sup>3</sup>	2.72	2.70
Natural Moisture (Wn) %	10.19	16.32
Moist Density ( $\gamma_f$ ) g/cm <sup>3</sup>	2109	1964
Dry Density ( $\gamma_d$ ) g/cm <sup>3</sup>	1913	1689
Porosity Fraction (e) s/d	0.42	0.60
Saturation (S) %	66	73
Cohesion (C) kPa	17	30
Internal Friction Angle ( $\phi$ ) <sup>o</sup>	22	11
Deformation Module E0 kPa	26000	15000
Elastic Module E Kpa	35000	22000
Controlled Swelling	-	200 kPa
Poisson's Ratio ( $\mu$ ) a/d	0.25	0.35
Gravel %	20	6
Sand %	41	30
Fines %	39	64
USCS Classification	GC	CH
HRB Classification	A-2-4(0)	A-7-6(20)

For the filling soil layer, according to the SPT test, it classifies as a very dense soil, with very high compactness, low plasticity, and a high consistency index, being a very hard clayey soil. The porosity fraction classifies it as a compact soil with a 66 % of saturation, a factor that makes it a moist soil. The material is classified as clayey gravel with sand on the basis of the Cuban standard NC-59 (2000), and transportation standard 63 (2000) classifies it as an A-2-4<sub>(0)</sub> soil, which exhibits an excellent-to-good behavior for its use in subgrade construction.

On the other hand, Layer 1 is a high plasticity clay which, based on its saturation degree, is considered moist, dense, of high compactness and plasticity, half compact, and of a

very hard consistency. For its use as a subgrade layer, it shows a fair-to-poor behavior as it falls into the A-7-6 subgroup.

This subgroup includes those materials having a high plasticity index in relation to the liquid limit and are subjected to extremely large volume changes. This explains the high value of controlled swelling.

### ***In situ* CBR**

The in situ CBR values were taken on the filling layer. The results range between 15% and 54%. The CBR 1 values are the lowest of all (Table 2). This behavior may be due to the low compaction shown by the ground, as it was performed in an area with considerable subsidence accompanied by crocodile skin cracking. This area has also the presence of the water table and a highly-saturated plastic clay layer.

Table 2. *In situ* CBR values

Test	Station	X (m)	Y (m)	Z (m)	Value (%)
CBR-1	Sta: 5+7.36	611998.03	151414.29	37.87	15
CBR-2	Sta: 16+8.95	611967.42	151310.06	39.20	53
CBR-3	Sta: 26+0.00	611939.37	151220.91	42.37	22
CBR-4	Sta: 38+0.00	611912.10	151107.89	47.20	54
CBR-5	Sta: 92+9.73	611770.19	150577.11	75.60	24

CBR values 2, 3, and 5 fall within the range reached by materials classified as A-2-4 by NC-63 (2000).

CBR 6 (station 100+8.42) and 7 (station 126+00) were not performed because, at the time of the test, these test pits were flooded with water coming from the water and sewer pipes that cross the road.

### **Current Characteristics of the Pavement Structure**

The drilling revealed that the wearing course rests directly on a 2.00 m average thickness technified embankment, which has characteristics that make it useful as a subbase material. Although its plasticity index is higher than required by the Cuban standard, it may be permissible according to other international standards, leaving its use to the discretion of the project managers by taking into consideration the economic feasibility and the fact that the ground water is not present along most of the alignment.

However, the requirements established for a material to be considered as a base course for heavy traffic, under good drainage conditions like the ones the road presents along most of its alignment, are more demanding, and the layer in question does not meet these standards (Tables 3 and 4).

Table 3. Comparison of Layer F for using as subbase (NC 334, 2004)

Parameter as Subbase	NC 344	Layer F	Status
Liquid Limit (LL)	≤ 35%	26%	Complies
CBR	80% - 100%	42%	Complies
Plasticity Index (IP)	≤ 6	8	Does Not Comply
Sand Equivalent	-	41	Complies

Table 4. Depth to disregard saturation in roads (NC 334, 2004)

Parameter for Base	NC 344	Layer F	Status
Liquid Limit (LL)	≤ 25%	26%	Does Not Comply
CBR	80% - 100%	42%	Does Not Comply
Plasticity Index (PI)	≤ 6	8	Does Not Comply
Sand Equivalent	≥ 50%	41	Does Not Comply

In test pit three, the presence of the water table was detected at a 1.80 m depth, and it was detected that sandy clay is the material composing the subgrade in that area, classifying it as unsaturated (Table 5). Despite this, it is recommended to consider this zone as saturated because, at the time study was carried out, there was a severe drought in the area, which could have influenced the water table height. As demonstrated by CBR 1, the high moisture values are already affecting the embankment's characteristics.

Table 5. Depth to disregard saturation in roads (NC 334, 2004)

Type of Subgrade Soil	Plasticity Index	Depth of WT from the subgrade (m)
Sands	NP	≥ 1.00
Sandy Clays	≤ 10	≥ 1.5
Silty Clays	20-30	≥ 2.5

## Conclusions

The pavement structure of Salaito road consists of an asphalt concrete layer with a thickness between 0.08 m and 0.06 m; hydraulic concrete (HC) slabs up to 0.25 m thick present only in some sections; a fill layer (F) that appears in all test pits, with variable thicknesses ranging from 0.25 m up to 1.25 m, and forms the technified embankment; a high plasticity sandy clay layer, in a dark gray to black color, which usually appears in low

areas; and marly limestone (Ls) severely weathered, highly fragmented, in a light-yellow color.

The embankment supporting the wearing course suffered significant damage during the installation and repair of water and sewer lines.

The technified embankment supporting the wearing course does not meet the specific requirements for that task in a heavy traffic design.

The deterioration of Salaito road is the result of a combination of inadequate materials, alterations in the embankment's compaction, and the constant presence of water within it.

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