Journal of Engineering Research

ISSN 2764-1317 vol. 5, n. 8, 2025

ARTICLE 15
Acceptance date: 10/12/2025

STRUCTURAL PERFORMANCE OF EN6 IN MOZAMBIQUE: CHALLENGES FACING CLIMATE CHANGE AND HEAVY TRAFFIC

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Abstract: This study evaluates the structural performance of National Road No. 6 (EN6) in Mozambique under the combined effects of climate change and heavy vehicle traffic. Using measurements with the Heavy Impact Deflectometer (FWD), the study characterizes the bearing capacity of the pavement layers (subgrade, subbase, and base) using the LLI, MLI, and BLI indices. The results reveal marked structural heterogeneity, with progressive degradation in the Beira–Machipanda direction, associated with water saturation, drainage deficiencies, and aging of granular materials. It is observed that the base layer maintains satisfactory stiffness in some segments, while the subbase and subgrade show partial collapse and loss of support, especially in the Mafambisse–Inchope and Vanduzi–Machipanda sections. The study demonstrates the relevance of FWD as a structural diagnostic tool and proposes selective rehabilitation and improved drainage measures, aiming at the resilience and sustainability of road infrastructure.

Keywords: EN6; Pavement; Falling Weight Deflectometer (FWD); LLI, MLI, (BLI) layer index; Climate Change; Road Resilience.

Introduction

The Mozambican road network shows significant signs of aging and degradation, with both functional and structural failures, which compromise the efficiency, safety, and resilience of the road system (Mucavele et al., 2018, p.104) . This fragility becomes even more critical in the face of growing urban pressure and the continuous increase in demand for mobility and logistics. Road transport, the predominant mode of transport in central Mozambique, accounts for approximately 30% of the volume of cargo moved and more than 98% of passenger transport (Nhantumbo et al., 2020, p.89) , and is essential to the socioeconomic development of (INE, 2021) . In this scenario, National Road No. 6 (EN6) plays a strategic role, acting as a link between the Port of Beira, global markets, and neighboring countries, promoting regional and international integration (Simões, 2015; Solidar, 2020) . Mozambique plays a crucial role in regional trade, handling around 70% of the Southern African Development Community (SADC) traffic through its logistics corridors (Dominguez-Torres & Briceno-Garmendia, 2011) . However, the structure of the EN6 reveals marked vulnerabilities, especially in the face of extreme weather events such as heavy rains, floods, cyclones, and tropical storms, which compromise the durability of the pavement and negatively affect both the functional and structural performance of the road (Banú Sultuane Jethá, 2024; Mosca &bLasse, 2023, p.115). Structural performance refers to the pavement's ability to withstand loads without excessive deformation that compromises the integrity of the structure (Huang, 2004, p. 17) . This performance is intrinsically associated with the characteristics of the materials used (subgrade, subbase, base, and pavement), the thickness of the layers, the quality of execution, and the stresses imposed by traffic (Huang & H., 2004) . Structural degradation can manifest itself in the form of cracks, *rutting*, permanent deformations, and loss of bearing capacity as a result of material fatigue due to repeated traffic and adverse environmental conditions (Banú Sultuane Jethá,2024) .These conditions are aggravated by extreme climatic factors, such as water infiltration and large temperature variations, which accelerate the deterioration process (Dawson, 2009; de Abreu et al., 2022) . The functional performance of a pavement is directly related to the quality of the surface in terms of user comfort and safety. Among the main functional performance indicators, the International Roughness Index (IRI) stands out, used to measure driving comfort and operational speed on roads (Sayers & Karamihas, 2025.; Harikrishnan & Gopi, 2017) ; Surface roughness and texture (tire grip and road drainage capacity); the presence of surface defects (potholes, exudation, and loss of aggregates). Functional performance can deteriorate even when the structure still maintains its bearing capacity (Papagiannakis & Masad, 2028, p.425) , which highlights the need for an integrated approach to pavement management. In tropical regions such as Mozambique, where intense cycles of rain and heat predominate and heavy traffic is frequent, this approach is even more necessary (Schweikert et al., 2015; Knott et al., 2019). The National Road N6 (EN6) in the Beira–Machipanda corridor, for example, is particularly vulnerable to extreme weather conditions and international traffic pressure. Although several interventions have been carried out, including a recent rehabilitation financed by the World Bank (2019), extreme events continue to compromise its integrity. A paradigmatic case was Cyclone Idai, which hit the region in 2019 with winds of up to 210 km/h and rainfall exceeding 600 mm in just 48 hours. The impacts on the EN6 were severe: prolonged interruptions (up to 24 days), sections submerged for more than 15 days, and structural damage such as cracks, erosion, and instability of the roadbed, especially in critical areas (Charrua et al., 2021; Maree & Others, 2019; Chirindza & Chimbutane, 2021) . Given the scenario described above, this study aims to evaluate the structural and functional performance of EN6 in Sofala province, considering the combined effects of climate change and heavy vehicle traffic, with a view to supporting strategies for resilience, preventive maintenance, and efficient management of road infrastructure.

The structural performance assessment focuses on estimating the rate of pavement deterioration, i.e., the speed at which structural deformations arise and evolve. This deterioration depends on variables such as load geometry, traffic intensity, tire pressure, and measurement point positioning (Huang, 2004). The structural capacity of a pavement is linked to its ability to withstand repeated loads, accumulating elastic and plastic deformations in the layers (Bernucci et al., 2007). The most widely used technique for structural assessment is the measurement of deflections caused by simulated loads, using the Full-Wheel Deflectometer (FWD), which reproduces actual traffic loads through the controlled drop of weights onto the pavement surface (Makwana, 2023; Domitrović et al., 2021). The impact is measured by a flexible circular plate (150 mm radius), with the load measured by a cell located under the drop assembly (Pandya et al., 2024)including the pavement layer thickness, elastic modulus, and subgrade strength, and to identify pavement areas that may require maintenance or rehabilitation. Despite the widespread use of the FWD, there are some concerns regarding the consistency and reliability of FWD test results. These inconsistencies have led to the need for a comprehensive evaluation of the current state of practice of FWD testing. The overall goal of this study was to conduct a comprehensive review of the literature and

DOI https://doi.org/10.22533/at.ed.3175825011015

synthesize the best practices and areas of inconsistency in FWD testing for rehabilitation applications. This review will also allow for developing a robust FWD testing procedure across the states. Different agencies nationwide employ similar yet different FWD testing procedures, mainly in sensor configuration, load sequences, test plans, and data processing. Reviewing these testing procedures highlighted the similarities and differences and identified the potential items to improve. These potential items include but are not limited to sensor configuration, load sequences, test frequency, test spacing, and temperature measurements. This study will help state highway agencies and the industry identify best practices, improve consistency, enhance data comparability, increase efficiency, and improve decision-making for nationwide road construction and maintenance (or rehabilitation . The sensors (usually seven) capture deflections at different distances from the point of impact, with the data being transmitted for analysis on a computer(Wang et al., 2023) . The application of FWD has proven to be efficient in the structural characterization of pavements, providing essential data for decisions related to road maintenance and rehabilitation (Pandya et al., 2024). Several studies highlight its relevance, as demonstrated by Visser and Tetley (2021), Horak et al. (2015), Makwana (2023), and Mehta & Roque (2003). A practical example of this application is the study conducted in South Africa along Highway P21-1 in the province of KwaZulu-Natal. In this comparative study, the structural capacity of two flexible pavements, one in good condition and the other in poor condition, was evaluated using both the FWD. The FWD, in this context, was used to measure surface deflection from a static vertical impact load. However, the authors point out that this method differs from operational reality, where wheel loads are applied dynamically, and the pavement behavior assumes viscoelastic characteristics in response to vertical and horizontal stresses (Visser & Tetley, 2021) . Nevertheless, this method is still widely used and produces satisfactory results.

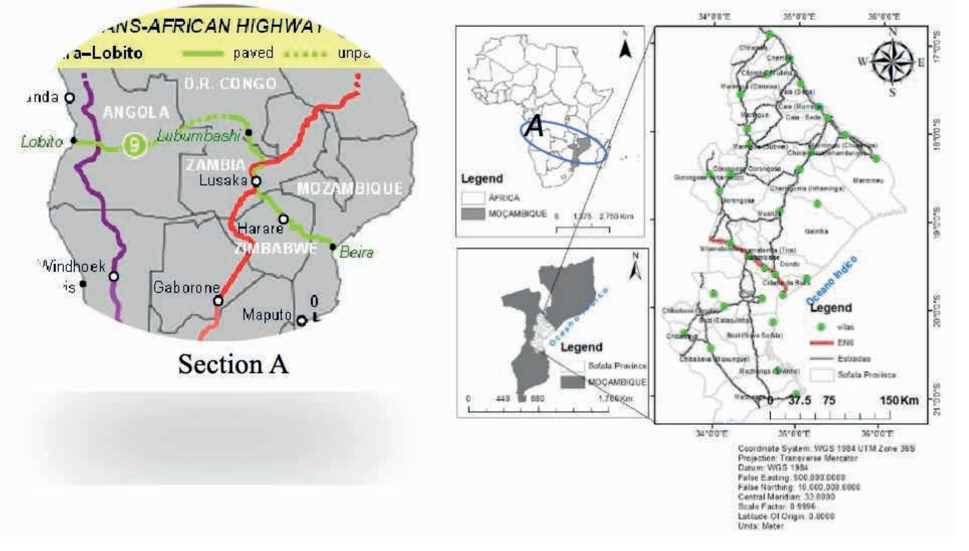

Figure1 : Geographic location of Sofala and route of the EN6(Rexparry Sydney, 2007)

Geoclimatic Context of EN6

EN6 establishes a strategic west-east link between the port city of Beira (capital of Sofala province) and the Machipanda border post in Manica province, near Zimbabwe. Covering approximately 287 km in Mozambican territory, it crosses the districts of Beira, Dondo, Nhamatanda, Gorongosa, Vanduzi, and Manica, passing through dense urban, peri-urban, and rural and mountainous areas with significant geomorphological and geometric variations along the route. This road was designed for mixed traffic, including heavy international freight vehicles, integrating the Beira Corridor, which connects the Indian Ocean to inland countries such as Zimbabwe, Zambia, the Democratic Republic of Congo, and Angola.

The EN6 in Sofala crosses a humid tropical climate with two distinct seasons: rainy and hot (November–April) and dry and relatively cool (May–October). Rainfall is heaviest on the coast, decreasing inland, with annual precipitation between 800 and 1,500 mm and average temperatures of 24°C to 27°C. In recent years, the province has been increasingly affected by extreme weather events, intensified by climate change, causing recurrent damage to roads (see Table 1). (Banú Sultuane Jethá, 2024). The province of Sofala is part of the Mozambique Sedimentary Basin, composed of sedimentary formations dating back to the Upper Jurassic, Cretaceous, and Cenozoic periods, superimposed on the Karoo basalts. It exhibits two main cycles of erosion: the Zumbo Cycle, from the middle plateaus (GTK CONSORTIUM, 2006) , and the Congo Cycle, from the coastal plain. These flattened areas connected by eroded escarpments create a "staircase" landscape. Geomorphologically, it can be divided into five subunits: (i) the Inhaminga/Cheringoma plateau (continental Cretaceous); (ii) the

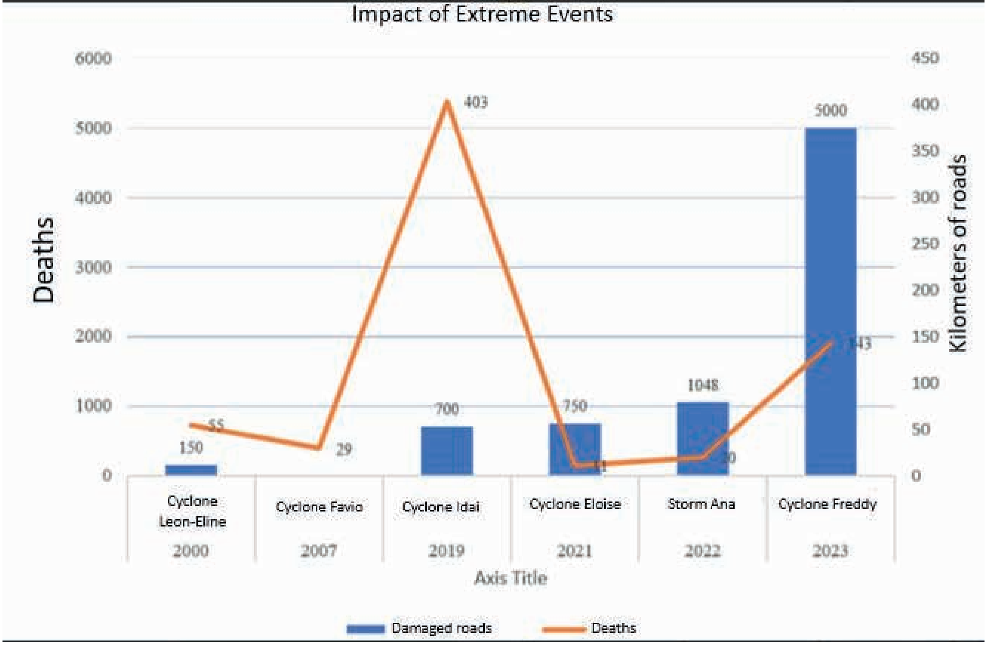

Figure 2 : History of damage recorded to road infrastructure in Sofala from 2000 to 2023. Adapted from (Banú Sultuane Jethá, 2024).

Zungué and Macua river valleys (Urema Rift graben); (iii) sandy transition plains; (iv) the extensive Quaternary Zambezi delta plain; and (v) ancient dunes and coastal ridges parallel to the coast . For example, the Cheringoma Plateau, located in Sofala, is composed of sandy soils derived from the conglomeratic sandstones of the Mazamba Formation (Miocene–Pliocene), overlaid by marine limestones of the Cheringoma Formation (Eocene), which form escarpments and karstic cavities (Oliveira et al., 2020; Pacheco.;2014) . However, studies carried out at the Mafambisse Administrative Post (municipality of Dondo) indicate that the local soils (gravel) are predominantly silty sand (SM type), classified in group A-2(4), with excellent to good load-bearing capacity (CBR ~70-80%) for paving and earthworks when properly compacted. On the other hand, in the city of Beira, there is a variety of tropical soils, including alluvial (fluvial, lacustrine, and marine), litholic, fersialitic, and hydromorphic soils, distributed according to the topography (soil catena) and local pedogenic factors (Pacheco, 2014). The coastal plains are dominated by recent sandy soils, with permeability decreasing as one moves inland, where more clayey deposits predominate (Pacheco, 2014). These are fundamental characteristics for the planning and evaluation of infrastructure structural performance, especially in areas subject to flooding and coastal erosion.

Methodology

The study was based on deflectometric surveys carried out using FWD on National Road No. 6 (EN6) over a total length of 287 km, whose geometric configuration varies along its route. In urban sections, such as in the cities of Beira, Dondo, and Chimoio, the infrastructure has two lanes in each direction, separated by a central divider, while in interurban segments it has two simple bidirectional lanes. The road has an asphalt concrete surface and supports an average daily traffic of approximately 1,600 heavy vehicles, being classified as T5 equivalent traffic(ANE, 2019, p.63) , and an annual traffic growth rate of 5%. The structural performance of the road was assessed on the rightmost lane of each carriageway. This lane is technically recognized as the one that supports most of the heavy and low-speed traffic and is subject to more intense structural stresses. This choice is in accordance with the recommendations established by ASTM D4694-09 (ASTM, 2009) and the guidelines of *the World Road Association* (PIARC, 2004), which recommend that

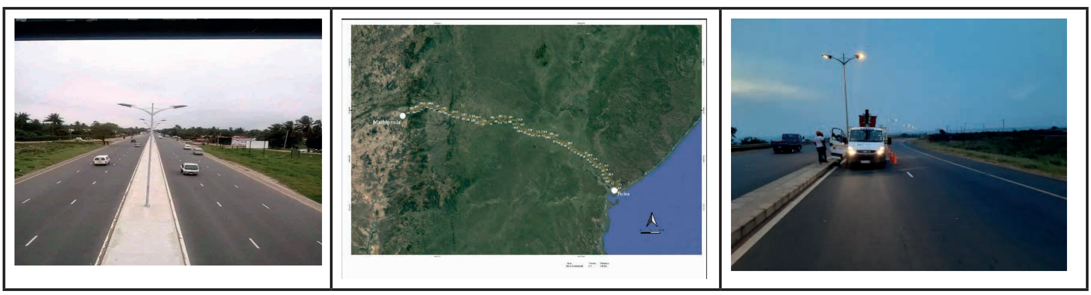

Figure 3 . Route of the EN6, from Porto da Beira to the Machipanda border: two carriageways, three lanes in each direction, separated by a simple concrete central divider. Photos by the author, image from Google Earth.

DOI https://doi.org/10.22533/at.ed.3175825011015

structural tests be carried out preferably on the lanes most subject to dynamic loads (ASTM, 2009; PIARC, 2004). The study was requested by REVIMO (Mozambique Road Network) and carried out between 2015 (start) and 2018 (completion).

The FWD test was performed with a nominal load of 65 kN, applied by means of a circular plate with a radius of 150 mm, with controlled contact pressure of 560 kPa. Vertical deflections were measured with sensors distributed radially from the center of load application, covering the range from 0 mm to 900 mm (including the point under the load). To reduce the thermal influence on the behavior of the bituminous pavement, the deflection records were corrected to a reference temperature of 35 °C(ANE, 2019) . The distance between test points along the alignment was 100 m, ensuring representative sampling of the section. Based on the specific deflection results, a deflection bowl was constructed (Fig. 3), which represents the structural response of the pavement to the applied load. This bowl was defined by the maximum deflection ($Y(_{max})$) under the load (D_0) and by the deflections at increasing distances, for the purpose of characterizing the overall stiffness of the system (pavement, granular layers, and subgrade); Identification of local asymmetries or anomalies in support; Support the back analysis of elastic modules and the structural classification of sections for maintenance and/or reinforcement prioritization.

Based on the guidelines proposed by Horak (2008), the structural indices used in pavement evaluation were determined, which allow the mechanical performance of the different layers that compose it to be characterized. The maximum deflection (γ_max), measured directly under the load applied by the Falling Weight Deflectometer (FWD), represents the overall stiffness of the pavement layer system. High γ_max values indicate lower structural capacity, while low values reflect a more rigid and resistant system (ANE, 2019) . The Base Layer Index (BLI) assesses the structural strength of the base layer in the radial range from 0 mm to 300 mm from the center of load application. The Middle Layer Index (MLI) is associated with the performance of the subbase and selected layers, corresponding to the range of 300 mm to 600 mm. In turn, the Lower Layer Index (LLI) quantifies the stiffness of the subgrade and the selected lower layer, in the range of 600 mm to 900 mm. The results were interpreted according to three levels of structural criticality, represented by a color code: green (good structural condition), yellow (moderate condition), and red (critical condition), as shown in Table 1.

Determination of homogeneous subsections

In the structural analysis of EN6, homogeneous subsections were delimited along the four sections, with the aim of identifying segments with uniform structural behavior. The method applied was cumulative sums (CUSUM) (Lisboa et al., 2024) , which is based on calculating the average of the maximum deflections measured by the FWD, determining the differences between the observed values and the average, and then graphically representing these sums (Figure 4).

The inflection points in the graphs indicated the boundaries between homogeneous subsections (Molenaar et al., 2003) . This procedure, inspired by methodologies used in Southern Africa, especially in the

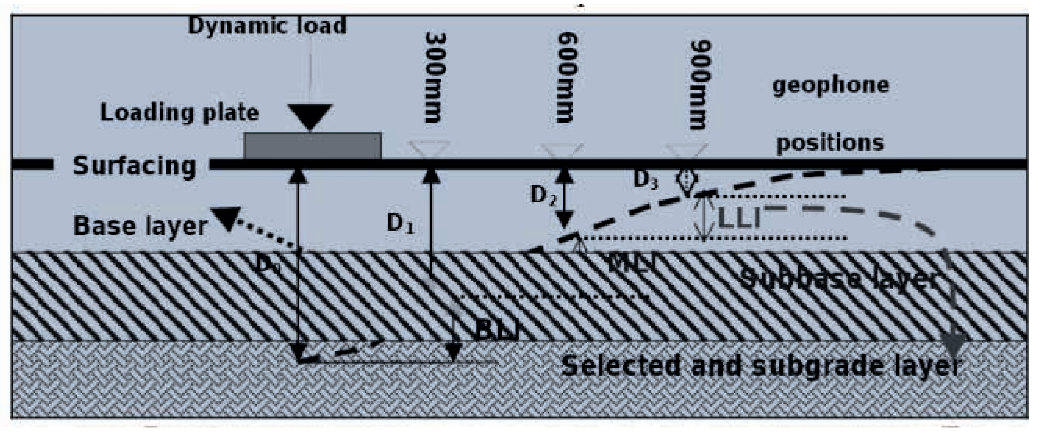

Figure 4 : Deflection basin parameters and their associations with pavement structure()

Structural condition classification	DEFLECTION BASIN PARAMETERS				
	γ_{max} (μ_m)	RoC (m)	BLI (μ_m) $D_0 - D_{300}$	MLI (μ_m) $D_{300} - D_{600}$	LLI (μ_m) $D_{600} - D_{900}$
Good	<200	>150	<100	<50	<40
Moderate	200-400	80-150	100-300	50-100	40
Critical	>400	<80	>300	>100	>80

Table 1 : Deflection measured at a certain distance from the point of load application(Horak, Emile and Emery, 2006)

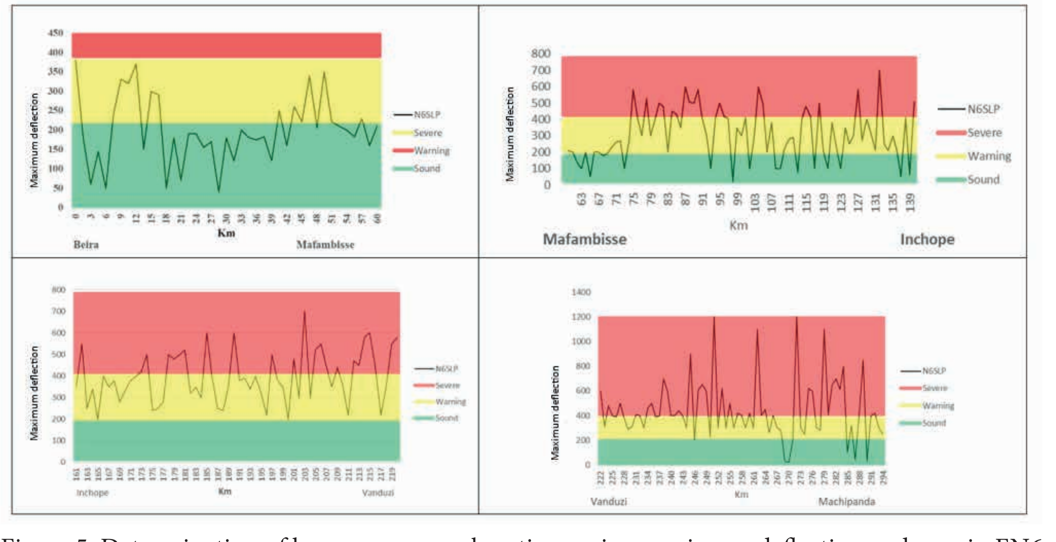

Figure 5: Determination of homogeneous subsections using maximum deflection and sum in EN6

Republic of South Africa(Jordaan & De-Bruin, 2003) , proved effective in characterizing pavement performance based on deflection basin parameters. After excluding areas of discontinuity such as bridges, at least seven homogeneous subsections were identified, showing variations in structural capacity along the first section of Beira-Mafambisse, as illustrated in Table 1.

The table shows that Subsection 1 has high dispersion (CV = 35%), resulting in a marked characteristic deflection. In contrast, Subsections 3, 5, and 7 show good homogeneity, with low coefficients of variation and characteristic deflections close to the mean. Sub-sections 2 and 4 show greater structural vulnerability , reflected in lower averages and relatively high CV values. Overall, the results point to significant structural variation along the EN6 route. On the other hand, the Mafambisse–Inchope section (Table 3) shows high heterogeneity in most subsections (CV > 40%), with only subsections 1, 3, and 4 showing relatively homogeneous behavior.

This condition highlights the existence of critical areas in the subgrade and foundation layer, associated with structural capacity limitations. The situation is aggravated by frequent heavy rains, floods, and flooding, which cause saturation of the foundation soils, reduce mechanical resistance, and accelerate pavement degradation processes. Together, these factors make rehabilitation interventions essential, aimed not only at restoring structural capacity, but also at improving drainage and increasing the resilience of the road system in the face of extreme hydrometeorological events.

In section 3, corresponding to Inchope–Vanduzi (Table 4), the analysis resulted in the division into six sections with ten stations each, with subsections 3 and 6 standing out as critical, given that they presented a coefficient of variation greater than 30%.

In section 4 Vanduzi–Machipanda (Table 5), analysis of the coefficient of variation (CV) values showed significant differences in the structural behavior of the sections. All sections had a CV of less than 30%, indicating an acceptable level of homogeneity and, therefore, being representative for structural characterization. These results reinforce the need for careful analysis of the critical points identified, which may require localized interventions, and the prioritization of preventive maintenance measures in homogeneous areas, in order to ensure greater durability and performance of the pavement over time.

Results and Discussion

Subgrade Evaluation (LLI)

The subgrade layer is the fundamental basis of the pavement's bearing capacity, responsible for distributing loads from the upper layers and traffic. The degradation of this layer directly compromises the overall durability of the road, especially in tropical contexts, where the combination of heavy traffic and humidity variations accelerates the processes of deformation and loss of stiffness (Yang H. Huang, 2004) (Bernucci et al., 2008) (Horak, 2008) . Therefore, statistical analysis of this lower layer (Sub-Bed), based on the Lower Layer Index (LLI), shows a picture of high structural degradation in the four sections analyzed, as illustrated in Figure 5. Referring to the deflection basins.

On the Beira–Mafambisse section, the analysis revealed a structurally critical situa-

DOI https://doi.org/10.22533/at.ed.3175825011015

Subsec-tion	Stations (points)	No. of points	$\overline{X}$ (μm)	S-Standard Deviation (µm)	CV (%)	(γ_max) (µm)
1	1 – 2	2	280	141	35.0	562
2	3 – 6	4	124	40	32.3	204
3	7 – 11	5	322	29	9.0	380
4	12–19	8	131	43	32.8	217
5	20–26	7	165	29	17.7	223
6	27 – 33	7	255	63	24.7	381
7	34–41	8	202	23	11.4	248

Table 2 : Analysis and division into homogeneous sections in Section 1: Beira–Mafambisse.

Subsec-tion	Stations (points)	No. Points	$\overline{X}$ (μm)	S-Standard Deviation (μm)	CV (%)	(γ_max) (μm)
1	1–5	5	170	44	26	258
2	6–15	10	190	69	36	328
3	16–23	8	435	93	21	621
4	24–33	10	433	119	27	671
5	34–43	10	302	138	46	578
6	44–55	12	290	148	51	586
7	56–63	8	301	153	51	607
8	64–73	10	348	159	46	666
9	74–81	8	250	147	59	544

Table 3 : Analysis and division into homogeneous sections in Section 2: Mafambisse-Inchope

Subsection	No. Points	$\overline{X}$ (μm)	Standard Deviation (μm)	CV (%)	γ_max (μm)
1	12	303.3	49.3	16.3	352.6
2	12	456.7	49.7	10.9	506.4
3	9	581.1	17.0	2.9	598.1
4	10	239.0	33.1	13.8	272.1

Table 4 : Analysis and division into homogeneous sections in Section 3: Inchope-Vanduzi

Subsection	Stations (Points)	No. Points	$\overline{X}$ (μm)	S-Deviation Standard (μm)	CV (%)	(γ_max) (μm))
1	1 – 23	23	424.35	103.78	24.46	631.92
2	24	1	900.00	0	0	900.00
3	25	1	200.00	0	0.00	200.00
4	26 – 28	3	620.00	26.46	4.27	672.92
5	29	1	230.00	0.00	0.00	230.00

Table 5: Analysis and division into homogeneous sections in Section 3: Vanduzi-Machipanda

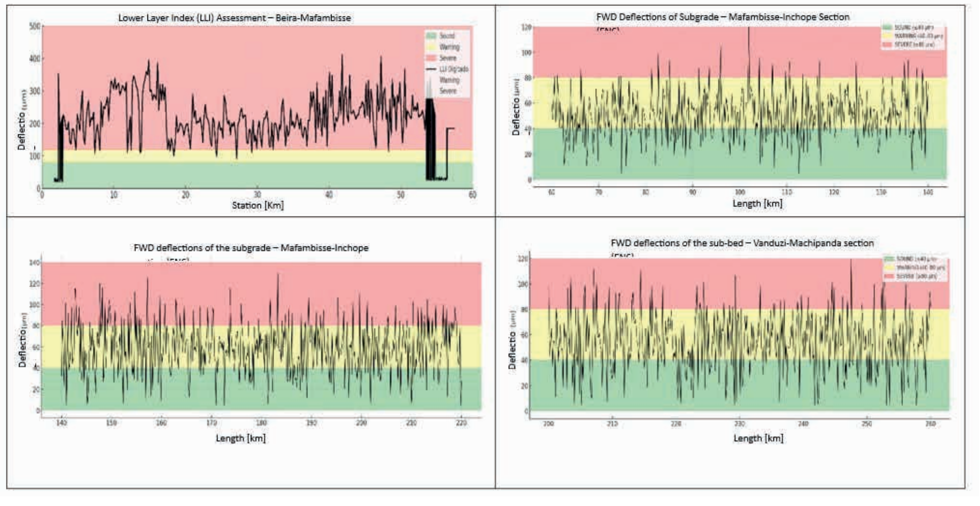

Figure 6 : Deflection basins of the Sub-Bed layer (LLI) along the EN6

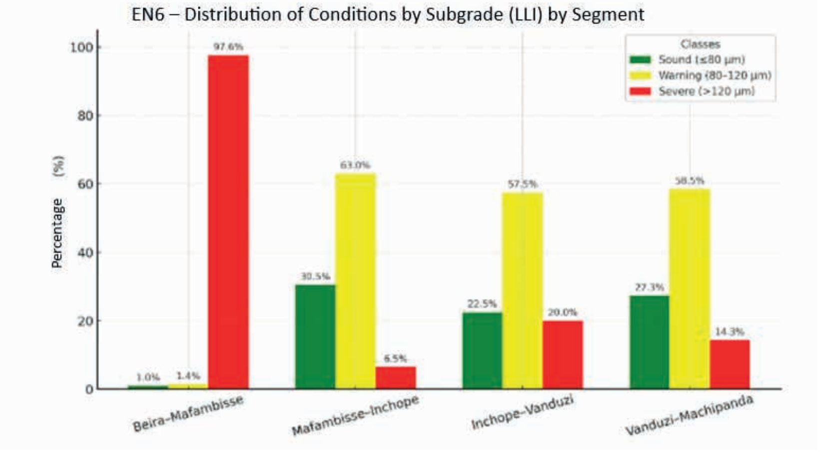

Figure 7 : Distribution of LLI Subgrade Structural Condition in the four sections

tion, with 97.6% of points above the critical limit (> 120 μm) and an average deflection of 231 *μm* (σ = 59.1 μm). Only 1% of points showed behavior considered "normal" (≤ 80 μm). These results reflect a generalized loss of subgrade stiffness, associated with differential settlement, water saturation, and degradation of the lower granular structure, factors that are recurrent in areas subject to flooding. From a technical point of view, the section requires extensive rehabilitation, with removal and replacement of the foundation and implementation of effective longitudinal and transverse drainage. In the Mafambisse – Inchope section, approximately 30.5% of the length has adequate support, 63% is weakened, and 6.5% is in poor condition. This distribution shows moderate structural heterogeneity, suggesting the presence of partially degraded lateritic materials and areas with insufficient drainage. This can be improved with techniques such as selective stabilization (Hossain et al., 2012) and localized reconstruction, but further on, the Inchope – Vanduzi section was found to be in a structurally moderate and heterogeneous condition, with 22.5% in good condition, 57.5% on alert, and 20.0% in critical condition. The average deflections (59.07 μm) and standard deviation (24.56 μm) show localized variations associated with geotechnical differences and high moisture levels. For this segment, the need for complementary surveys (CBR, DCP, field sampling) was noted; for localized structural reinforcement with granular material with a higher resilience modulus according to FHWA (2016) and the SAPEM manual (2014), which provide for localized reinforcement in areas with subgrades < 80 MPa. Finally, in the last section, Vanduzi–Machipanda, about 27.3% of foundations are in stable condition, 58.5% are on alert, and 14.3% are in poor condition, reflecting a trend of progressive loss of rigidity towards the border. The increase in the percentage of critical points (more than double that observed in Mafambisse–Inchope) is possibly linked to heavy international traffic pressure and deficiencies in the drai nage system. The graph.

Sub-Base Evaluation (MLI)

The Middle Layer Index (MLI) values were calculated along the axis and plotted by extension of EN6 (Figure 7). The reading of the FWD deflection basins shows that deflection peaks and wide basins (with amplitudes ≥ 150 μm) are concentrated in the same sections previously identified as problematic in the subgrade analysis, evidencing loss of subbase stiffness and direct influence of the lower support. In operational terms, the following thresholds were adopted: *Sound* ≤ 80 μm, *Warning* 80–150 μm, and *Severe* ≥ 150 μm; the frequency of occurrences in the *Warning* and *Severe* classes follows the zones with rapid variation in D_0 and "widening" of the basin, typical of high humidity, fine/plastic materials, and heterogeneous compaction (Horak, 2000) .

The coincidence between the MLI and LLI anomalies indicates that, in addition to the sub-base, the underlying layers (selected and subgrade) contribute to the lack of support, promoting permanent deformations and pumping of fines. This reading is consistent with the classic interpretation of the FWD deflection basin: high amplitudes (peak D0D_0D0) and a "wide" basin denote low stiffness and/or high moisture content in the lower layers (Horak, 2008; FHWA, 2016). The interpretation is further corroborated by visual evidence (not detailed in this document): cracking and split-

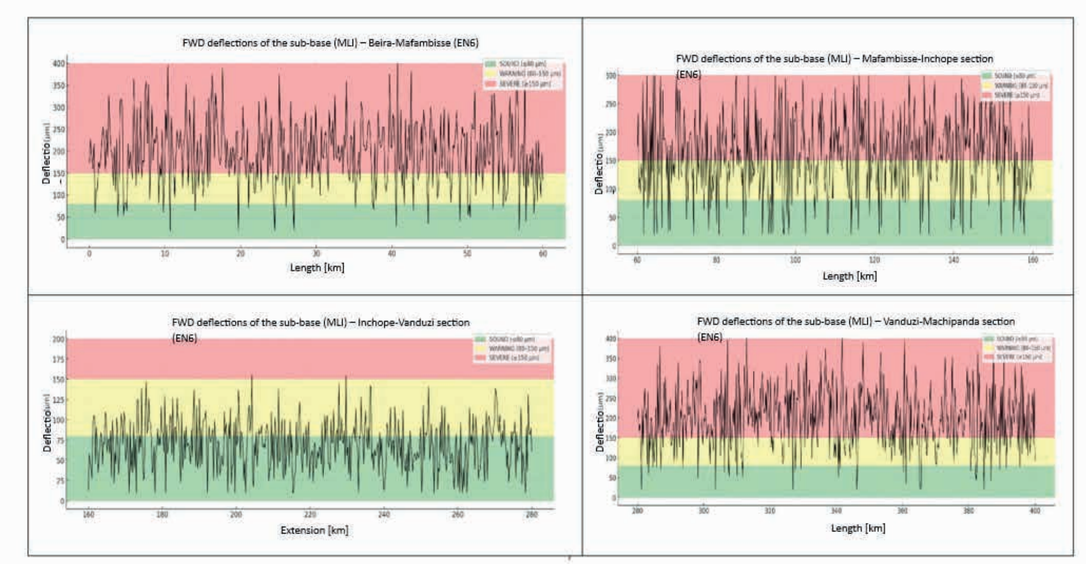

Figure 8 : Deflection basins of the sub-base layer (MLI) along the EN6

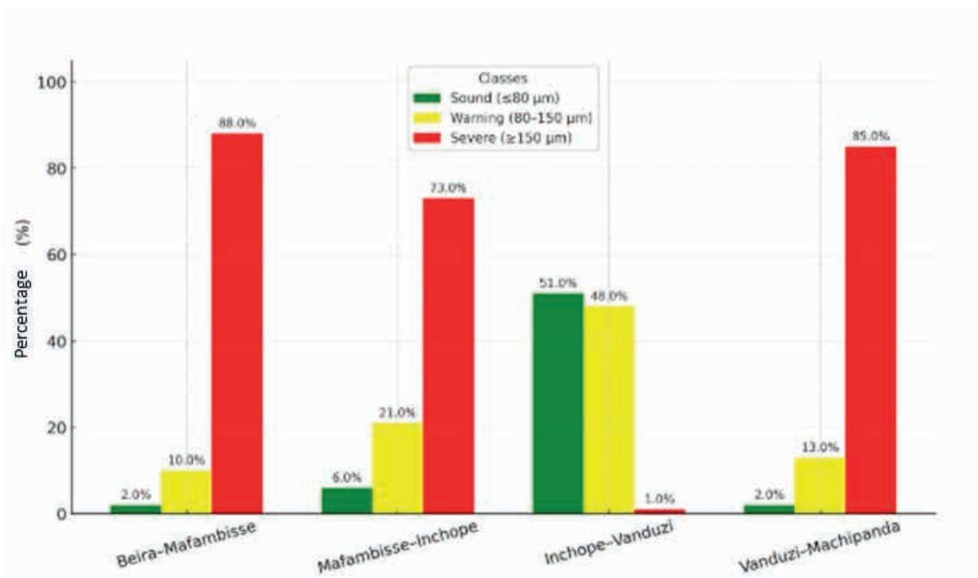

Figure 9 : Distribution of Structural Condition of Sub-base (MLI) in the four sections

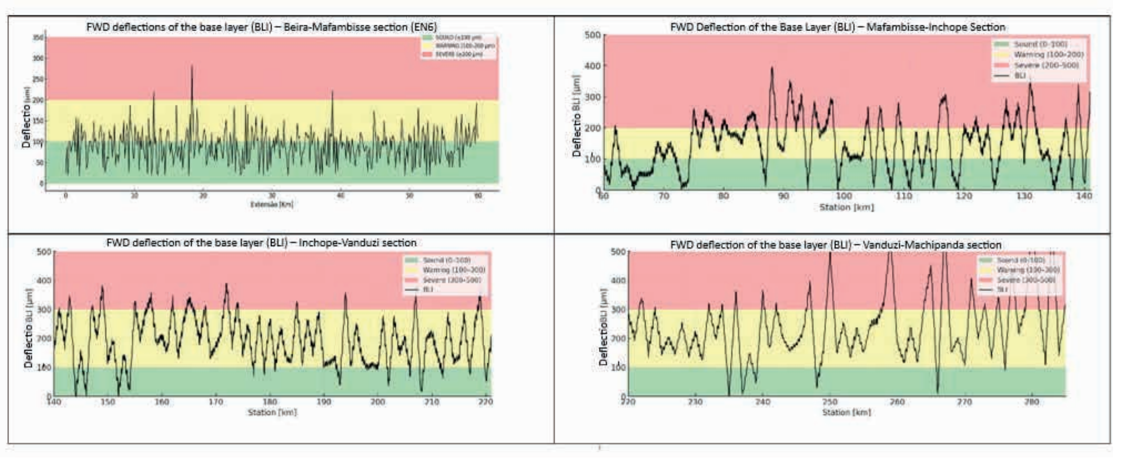

Figure 10: Base layer (BLI) deflection basins along the EN6

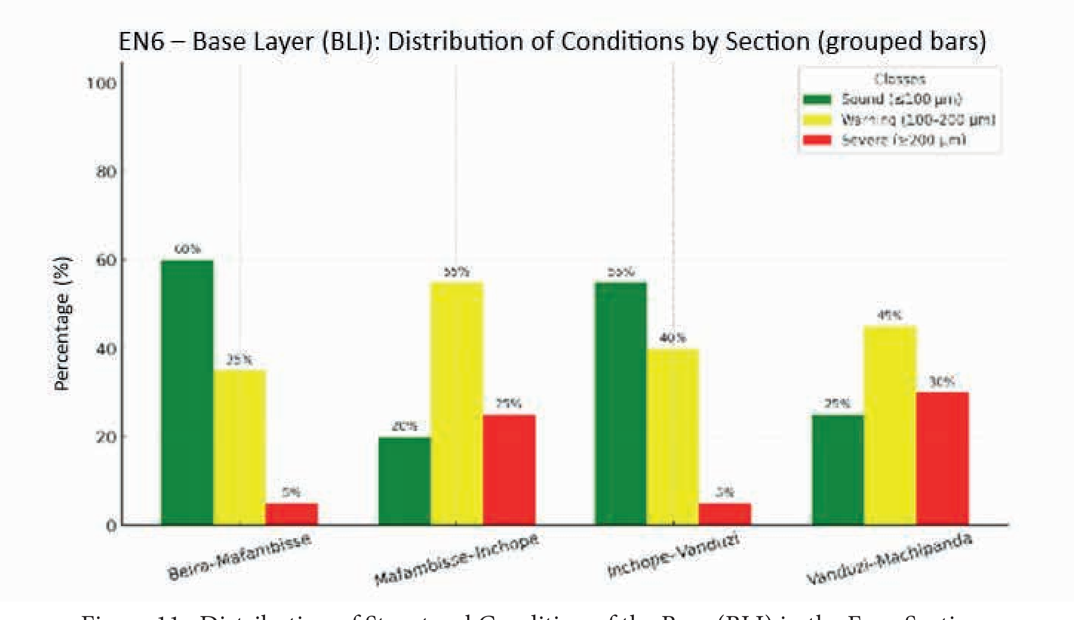

Figure 11 : Distribution of Structural Condition of the Base (BLI) in the Four Sections

ting observed in critical sections suggest a structural origin of wear that is not limited to the subgrade (Huang, 2004; Bernucci et al., 2007). Additionally, localized peaks in MLI are recorded in transition zones (embankment-cut, culverts, low elevations) and in sections with poor drainage, underscoring the role of water in degradation (FHWA, 2016).

Analyzing section by section, it is clear that the Beira Mafambisse section is overwhelmingly in critical "Severe" condition, i.e., 88% of the section is in poor condition, 2% in excellent condition, and 10% in alert condition. This result is consistent with the high and highly variable basins, thus showing that the sub-base has generalized insufficient rigidity, probably due to saturation and contamination by fines. This condition is totally contrary to the state of the Inchope Vanduzi section, where only 1% of the section is in critical condition, 45% in alert condition, and 51% in optimal condition. The basins confirm heterogeneity (frequent peaks > 150–200 µm), suggesting degraded lateritic materials and poor drainage. In the Vanduzi–Machipanda section, the data are critically high, similar to the Beira–Mafambisse section, confirmed by high and dispersed basins. The combination of heavy international traffic and poor drainage explains the loss of stiffness.

Evaluation of the base layer index

The base layer distributes traffic loads from the road surface to the lower layers, reducing the stresses that reach the subgrade. According to Huang (2004), the base must have high rigidity and stability to prevent permanent deformation and ensure pavement durability. In addition to withstanding repetitive loads, the base must provide adequate support to the wearing course and contribute to internal drainage, mitigating water infiltration and the consequent structural weakening Bernucci et al. (2007). Therefore, the integrity of the base is decisive for the service life of the pavement, since failures in this layer, such as loss of support, cracking, or pumping of fines, directly reflect on the degradation of the upper layers (Horak, 2008; AASHTO, 2012). In the context of EN6 (Beira–Machipanda), the BLI (Base Layer Index) of the deflection basins of this layer showed a predominance of sections with acceptable structural conservation behavior.

On the Beira–Mafambisse section, most of the length (60.8%) shows low deflection values, indicating that the base layer maintains good structural rigidity and performs its support function satisfactorily, while a significant fraction is at a reasonable alert level (38.5%), showing sections with incipient fragility that require monitoring and preventive maintenance, and practically nonexistent, indicating that there are no extensive areas with serious base failures in the section, i.e., only (0.8%)8 in poor condition. In the Mafambisse–Inchope section, however, the picture is different, with 50% of measurements at warning level and 20% at severe level, revealing a progressive loss of support capacity. This deterioration may be associated with the high frequency of heavy traffic (international transport trucks) and the aging of granular materials. According to Maina et al. (2017), the interaction between traffic and moisture is the main factor in structural degradation in untreated bases. On the other hand, from Inchope to Vanduzi, there is a trend toward partial re-

DOI https://doi.org/10.22533/at.ed.3175825011015

covery of stiffness, with 50% of points in excellent condition (Sound), 40% in a state of alert (Warning), and only 10% in critical condition (Severe). This condition suggests local variation in the type of material used or recent maintenance in certain segments. Statistical analysis of the BLI shows a coefficient of variation of less than 30%, characterizing relatively homogeneous structural behavior, with few critical points concentrated in areas with poor drainage. However, for the Vanduzi–Machipanda section, the situation is more critical, with only 26% in good condition (Sound), 41% in warning condition (Warning), and 33% in critical condition (Severe). The high percentage of severe points reflects the combination of heavy traffic, steep slopes, and frequent torrential rains. The pumping effect of fines and the collapse of layers under cycles of saturation and drying explain the poor performance. According to Thenoux, Zanelli & Bell (2015), bases with high plasticity and insufficient drainage degrade rapidly when subjected to variations

Conclusion

The integrated analysis of EN6 shows that the structural performance of the pavement is directly affected by extreme weather conditions and the growth of heavy international traffic. However, the results show that the base layer (BLI) performs satisfactorily in Beira–Mafambisse and Inchope–Vanduzi, but with signs of degradation in Mafambisse–Inchope and Vanduzi–Machipanda, and the subbase (MLI) and subgrade (LLI) are the critical points of the structure, with high deflections and high variability (CV > 30%), indicating loss of stiffness and water saturation. However, the anomalies observed are strongly related to areas of poor drainage and geotechnical variation in local materials. From an engineering point of view, it is concluded that the structural resilience of EN6 depends on improved drainage, selective stabilization of foundations, and periodic maintenance based on FWD measurements.

The implementation of an integrated structural condition management and monitoring system, combining FWD–IRI–PCI parameters, is recommended to support preventive decisions in the context of climate change.

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