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Analysis of pathological manifestations of a stretch of Avenida Perimetral in Belém, Pará, Brazil – A case study

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***Abstract*—** *Paving and drainage of roads are important infrastructure works in a city, which deserve special attention in terms of design, execution and conservation, so that they do not generate more problems than solutions. This work sought to bring real and updated data on the conditions of use of Perimetral Avenue, in Belém-PA, Brazil, regarding the conditions of the pavement and the rainwater drainage system. For this purpose, data collection was carried out in loco, in a section of the road, with cataloging and analysis. The results showed that in a section of the road, despite having several pathologies, such as: holes, cracks, obstruction of storm drains, flooding, etc.; is functional and in regular condition.*

I. INTRODUCTION

Of all civil engineering works, the urbanization of roads, with drainage and paving, which, together with water supply and sanitary sewage, are part of the essential works of urban infrastructure in a city stand out as being of great public interest.

Brazil has the largest movement of goods and passengers in the road modal. On the contrary, only a small portion of Brazilian highways was properly urbanized, with paving and drainage. This is a huge demand, for a small and poorly distributed road network, in a country whose fleet of vehicles only grows every year.

The mismatch between the increase in the fleet of vehicles in circulation and the expansion of the paved road network forces a greater demand on the infrastructure. Result: the intensification of the wear process and the emergence of defects (pathologies), and hence the need for more frequent interventions and maintenance, CNT (2021).

According to the Secretary for the Development of Public Works of the State of Pará - SEDOP, in a technical note presented, Perimetral Avenue, in Belém do Pará, is of fundamental importance as a direct link between the neighborhoods of Guamá, Terra Firme and Marco, directly benefiting a population of more than 300,000 people, as an alternative exit corridor from the center of the capital to the interior of the state through Avenida João Paulo II and Almirante Barroso Avenue (AGÊNCIA PARÁ, 2013).

Despite its importance, there are still few published data on road traffic and drainage conditions. This research sought to analyze pathological manifestations in the paving and drainage of Perimeter Av., identifying, cataloguing, classifying the problems found and suggesting possible ways for recovery and/or maintenance on the road.

II. THEORETICAL FRAMEWORK

2.1 Urbanization of roads

Road urbanization works, such as drainage and paving, when incorporated into the water supply and sanitary sewage, are part of the essential works of urban infrastructure in a city. They are civil engineering works of great social, economic and political importance. High cost, they are often poorly planned, executed and lack regular maintenance.

Tavares, et al., (2014), understand that the roads are the arteries of a city, and through them people circulate daily on foot and in their vehicles, in the coming and going of busy urban life. The urbanization of these roads implies the waterproofing of the ground cover, with paving and paving, aiming, logically, to improve the quality of life of the population.

The roads are also the recipients of part of the rainwater precipitated in the urban area, which flows over the surface of the land. Also according to Tavares et al., (2014), a rainwater collection system occupies a prominent place among urban public works of a sanitary nature, because it constitutes a fundamental component for the planning and sanitation of human groups.

2.2 Paving.

Paving is the technique of superimposing one or more layers of materials, in order to increase durability and facilitate the flow of vehicles and people on a road.

The pavement is composed of finite layers of varying thickness, depending on their function. The dimensioning of the thickness of each layer depends on factors such as traffic studies, geotechnical studies and materials to be used (SOLANKI and ZAMAN, 2017).

The ancient Egyptians and later the Romans were the first to perfect the construction of roads and a paving method, whose surface layer was made of stones - fig. 1 (BALBO, 2007).

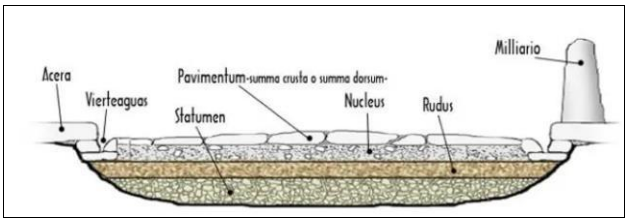

Fig. 1 - Floor of Via Appia, in Rome

Source: Balbo (2007).

In order to provide safety to road traffic, the pavement must withstand the effects of the weather, allow smooth movement, not cause excessive tire wear or high noise levels, resist the flow of vehicles, allow water to flow on its surface, directing it to a for an efficient drainage system, and have good skid resistance (CNT, 2021).

Currently, pavements are classified as rigid, flexible and semi-rigid; the second being used in 95% of paved roads in Brazil. Depending on the type of pavement, the number and types of layers change, as well as the distribution of loads.

Absorbing all the stresses of the applied load, the rigid pavement is known for its constitution in Portland cement concrete slabs. These plates are laid out on the ground, serving as a coating and base, and may or may not be reinforced with steel bars.

Due to the construction method, the rigid pavement has a better distribution of efforts per area, high cost (since it is made of concrete) and, less need for maintenance (SILVA, 2008).

Balbo (2017) defines as flexible, the pavement that includes a bituminous coating, whose materials used are asphalt, forming the coating layer, a granular material that makes up the base and another granular material (which may be the soil itself), which forms the subbase.

In flexible pavements, as there is less cohesion between the layers, they deform, generating a depression located at considerable depth on the surface (PINTO, 2003).

The difference in load application on the two types of pavements can be observed by observing fig. 2.

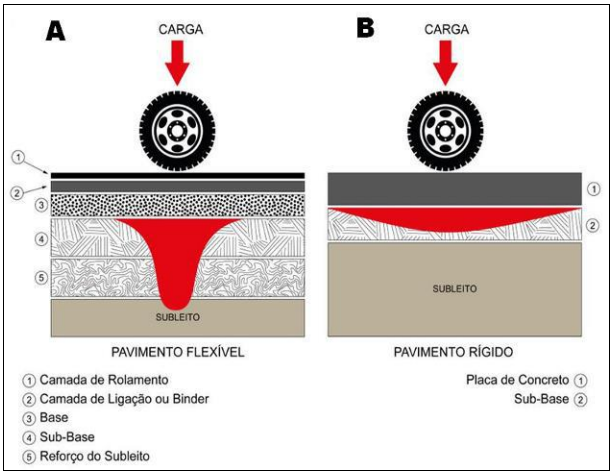

Fig. 2 - Load distribution: Flexible pavement (A); Rigid floor (B).

Source: Silva (2008), adapted by the author.

Due to construction factors, loads and weather, paving does not last forever, deteriorating over time.

Bianch, Brito and Castro (2008) state that flexible pavement has a maximum lifespan of 10 years, requires more maintenance, has a more slippery surface when wet and has a lower light reflection index.

As it is a non-perennial structure, the pavement must be evaluated as to its usefulness to the user. For Bernnuci (2010), the functional evaluation of a pavement is related to the appreciation of the pavement surface and how this state influences the rolling comfort.

2.3 Urban drainage

Urban drainage also composes the infrastructure network of a city, being considered one of its urban

equipment. Within the context of environmental sanitation, the drainage system is primarily responsible for the collection, management and disposal of rainwater in bodies of water suitable for its reception.

In Brazil, Law 11,445 (2007) establishes guidelines for basic sanitation throughout the country. This Law defines that basic sanitation is composed of the following items:

- Water supply;
- Sewage treatment;
- Solid waste management;
- Urban drainage and rainwater management.

Of the four components, the public service of drainage and management of urban rainwater stands out, which comprises the set of activities, infrastructures and operational facilities for transport, detention or retention for the attenuation of flood flows, treatment and final disposal of water. of rains drained in urban areas (ADASA, 2022).

Philippi Jr. et al. (2017) consider that the basic drainage system of a city must be structured respecting all legal and technical aspects, in addition to the economic, social, environmental and institutional dimensions and a minimum physical composition with paving of streets, gutters, curbs, mouths of wolves, drainage galleries and ditches - fig. 3. In addition to these instruments, the characteristics of hydrographic basins play an essential role in the drainage process.

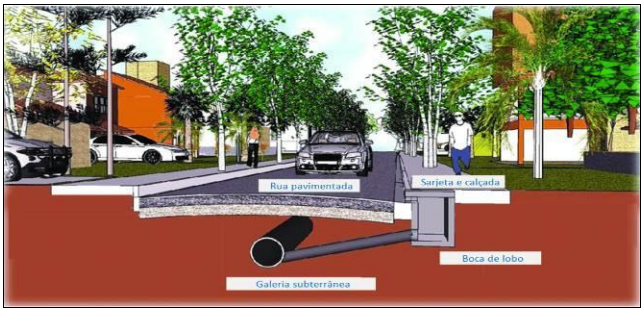

Fig. 3 – Elements of urban microdrainage.

Source: Philippi Jr. et al. (2017), adapted by the author

It can be seen that the function of the drainage system is essential in the urban context, since a malfunction of this system is responsible for severe flooding, with large flooded areas, causing damage and exposing the population to various risks.

The rainwater drainage project therefore requires the correct dimensioning, construction and maintenance of the networks and components of its system, ensuring constant availability and efficiency.

2.4 Pathological manifestations

Pathological manifestations, popularly known in academia as pathologies, are defects that affect both the pavement and the drainage system of the roads, due to various causes. For Grandiski (2011), the causes that give rise to pathological manifestations are:

Exogenous - originating outside the work and caused by factors produced by third parties, or by nature;

Endogenous - originating from factors inherent to the building itself

Natural - which can be predictable or unpredictable, avoidable or unavoidable failures, as the case may be.

2.4.1 Pathological manifestations on the pavement

When pathologies are manifested in the flexible pavement, they can be classified as: defects, degradations or surface deformations. We can also classify these imperfections as functional or structural (ALVES, FERNANDES and BERTEQUINI, 2018).

According to the National Department of Infrastructure and Transport - DNIT (2003), surface defects are damage or deterioration in the surface of asphalt pavements that can be identified with the naked eye and classified according to standardized terminology.

The main pathological forms of pavements are: fissures and cracks; sinkings; deformations; ripples; exudation and wear. These pathologies will be discussed in Title 5, according to the terminologies and classifications found in the Brazilian standard as well as in other literature.

2.4.2 Pathological manifestations in the drainage system

Urban drainage is a service that is only useful when it rains. However, the provision and maintenance of the service need to be continuous, as the drainage infrastructure, when unavailable, is the cause of several inconveniences.

When drainage networks are obstructed in the process of carrying water or are undersized in design, they can cause flooding, inundation, landslides and even damage to rivers and lakes (COSTA and MAIA, 2021).

For Tucci (2016), floods due to urbanization are those that occur in urban drainage due to heavy rains and the effect of soil sealing or obstruction to flow.

Flooding usually falls under this type of flood, except for other conditions that do not have intense rain as one of the causes.

The main pathologies found in draining devices are: wear; degradation; silting; waste accumulation;

obstructions and clogging. These pathologies overload the microdrainage network.

III. METHODOLOGY

In order to carry out this study, the theme of urbanization and pathological manifestations in the paving and drainage of roads was initially defined, as well as its importance in solving the problems faced in the vast majority of Brazilian cities.

A qualitative, descriptive and deductive approach was used, based on bibliographic research (specialized magazines, articles and news portals related to the topic).

The nature of the study is exploratory, with the delimitation of the study area to a stretch of Perimetral Avenue, in the city of Belém do Pará, in which field research was carried out to collect, catalog and later analyze data with presentation of the results.

3.1 Study area

The city of Belém was founded on January 12, 1616. It is currently the capital of the State of Pará, located at the mouth of the Amazon River, bathed by the Guamá River and the Guajará Bay. Such location provides it with great waterway and tourist potential. It has a tropical climate with high levels of temperature and humidity. Insolation and rainfall are abundant throughout the year in Belém.

About 120 km away from the Atlantic Ocean, the city has two major ports in operation: Belém and Miramar. According to IBGE data (2010), Belém has approximately 1,059,406 km² of land area, and a population of approximately 1,393,399 inhabitants.

Fig. 4 - Belém-PA and insular region

Source: Google Maps (2022), adapted by the author.

Together with the municipality of Barcarena, it is part of the second largest industrial park in the Amazon. With the implementation of the Tocantins Waterway and the arrival of the North-South Railway, the city awaits a new cycle of development. However, it has only one the road access road for entry and exit: the federal highway BR316 (PMB, 2022). - Fig. 4.

4.2 Perimetral Avenue

Avenida Perimetral was designed in the 1940s, being paved only in the mid-1960s. It currently crosses the neighborhoods of Guamá, Terra Firme and Marco. Its geographic coordinates are: latitude -1.4673035 and longitude -48.4485268 - fig. 5.

Fig. 5 - Av. Perimeter in Belém-PA (highlighted in red)

Source: CARDOSO and MIRANDA (2018), adapted by the author.

In 1990 it officially became known as Perimetral Avenue da Ciência, due to the existence of four campuses dedicated to scientific research along its little more than five kilometers: UFPa, UFRA, MPEG and EMBRAPA.

In November 2013, the Government of the State of Pará, with its own resources and a contribution from BNDES, started the duplication of Perimetral Avenue, covering five kilometers of paved road, going from the Bandeira Branca fair, on Almirante Barroso Avenue, to the Integration Terminal of UFPA, benefiting about 300 thousand people (REDE PARÁ, 2014).

This duplication work was the first work of real importance carried out on Perimetral Avenue, since its first paving. The construction was carried out by Montese Consortium, led by the companies Terraplena and Estacon Engenharia, including sidewalks for pedestrians, bike paths, signage (vertical, horizontal and traffic lights), bays

at bus stops, accessibility with protection for people with disabilities and landscaping design (GLOBO, 2013).

4.3 Field research

Fieldwork was carried out on a 600-meter stretch of Av. Perimeter, between gates 5 and 6 of UFPa, in both directions - fig. 6.

For data collection, we used: photographic camera, tape measure and notepad. The work was carried out on foot, on March 13, 2022, between 7:30 am and 8:30 am. Altogether, 64 high resolution photographs were produced and cataloged, some being chosen to compose the results of the work.

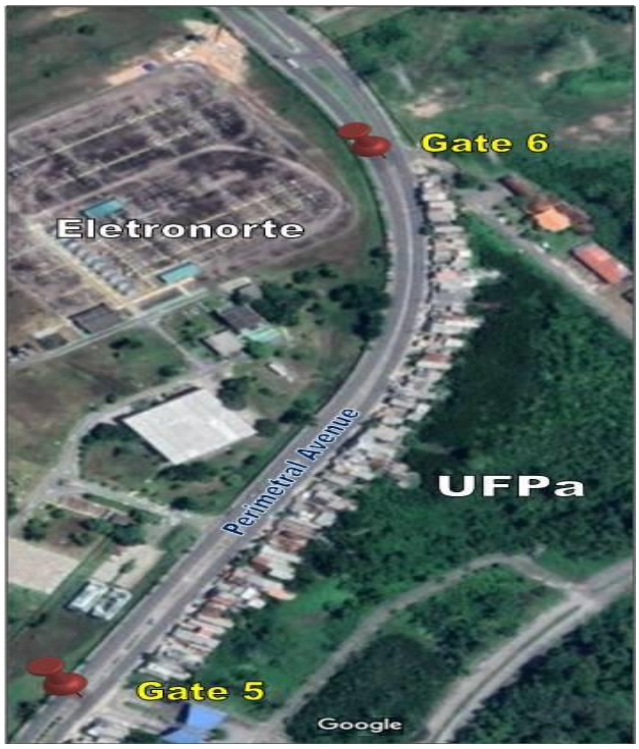

Fig. 6 - Perimetral Avenue, study section, between gates 5 and 6 of UFPa.

Source: Google Maps (2022), adapted by the author.

IV. RESULTS

5.1 Pathological manifestations diagnosed in the asphalt pavement.

Table 1 presents the pathologies found in the study section. In order to facilitate cataloging and analysis, the section was divided into six subsections with 100 meters in length each. All analyzed data have a photographic record.

Table 1 - Pathologies found in the pavement.

Sub-Section	Pathologies	Dimension	Location
01	Wear	10 m²	Stop/Return
02	Exudation	2 m²	transversal
03	superficial patch	80 m	Longitudinal
04	Exudation	4 m²	transversal
05	local plastic sinking	1 m	central bed
06	Wear	12 m²	Stop/Return
07	ligand degradation	7 m	transversal
08	pot or hole	0,7 m²	central bed
09	“Block” type crack	1 m²	Center Lane
10	local plastic sinking	1 m	central bed
11	long longitudinal crack	100 m	Longitudinal
12	superficial patch	60 m	Longitudinal

Source: Author (2022).

Note 1: Subsections 1 to 6 are from gate 5 to gate 6 of UFPa.

Note 2: Subsections 7 to 12 are in the direction of gate 6 to gate 5 of UFPa.

In subsections 1 and 6, areas affected by the effect of the progressive pulling of aggregates from the pavement were found. Characterized by surface roughness of the coating, due to tangential efforts of intense traffic in return and shoulder areas, this pathology is called wear, fig. 7A.

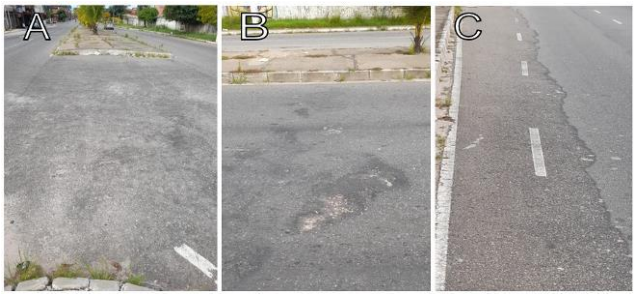

Fig.7 - (A) Wear; (B) Exudation; (C) Surface patch.

Source: Author (2022).

Areas affected by exudation, in the transverse direction of the road, were identified in subsections 2 and 4. This pathology is characterized by excess bituminous binder on

the surface of the pavement, caused by the migration of the binder through the coating. This pathological manifestation is very common after the "hole cover" operation - fig. 7B.

It was found in subsections 3 and 12 the existence of a long understanding of the surface patch. It is a correction, in an area located on the surface of the coating, by the application of a bituminous layer. Deep patching was not observed in the study section, that is, when the coating is replaced - fig. 7C.

In subsections 5 and 10, cases of local plastic sinking were identified. It is a pathology caused by the plastic creep of one or more layers of the pavement or subgrade, in this case, accompanied by lifting, as can be seen in Fig. 8A.

Fig. 8 - (A) Local plastic sinking; (B) Degradation of the ligand.

Source: Author (2022).

According to Portal G1 (2021), in December 2021, residents of the Terra Firme neighborhood, in protest, set fire to tires and pieces of wood, on Perimetral Avenue - fig. 8B. This fact exposed the asphalt pavement to the action of high temperatures, with degradation and disaggregation of the bituminous material (binder). This exogenous pathology was identified in subsection 7.

Pot or hole is the cavity that forms in the coating for various reasons and can reach the lower layers of the pavement, causing the disaggregation of these layers, as in this case, identified in subsection 8, where the exposure of the lower layer of the pavement can be seen, fig. 9A.

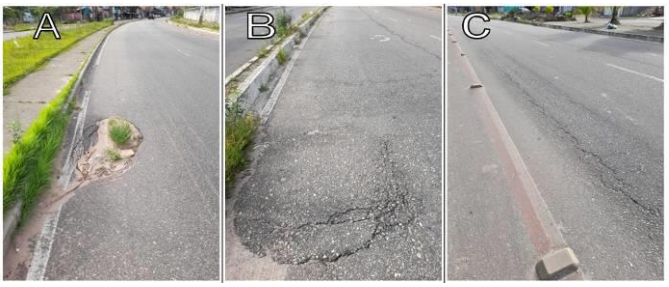

Fig. 9 - (A) Pot or hole; (B) Block-type crack; (C) Long longitudinal crack.

Source: Author (2022).

In subsection 9, the existence of block-type cracks was identified. It is a set of interconnected cracks, characterized by the configuration of blocks formed by well-defined sides, fig. 9B.

When the crack is isolated, presenting a direction predominantly parallel to the axis of the track, whose extension is greater than 100 cm, it is called a long longitudinal crack - fig. 9C. This pathology was identified in subsection 11. It is noteworthy that Perimetral Avenue has an intense flow of heavy vehicles, such as buses and trucks.

5.2 Pathological manifestations in the surface drainage system

The data referring to the pathologies identified in the surface drainage system were organized in table 2. As in the previous item, in order to facilitate cataloging and analysis, the study section was divided into six subsections with 100 meters in length each. All analyzed data have a photographic record. It can be seen from table 2 that in the same subsection several and repeated pathologies are identified.

Table 2 - Pathologies found in surface drainage.

Sub-Section	Pathologies	Dimension	Location
01	Accumulation of solid waste and vegetation, Obstruction of	100 m	Gutters, pavement, storm drains
02	Wolf mouths.	80 m	Gutters, pavement, storm drains
03	Accumulation of solid waste	100 m	Gutters, pavement, storm drains
04	Obstruction of wolf mouths	100 m	Gutters, pavement, storm

			drains
05	Structural damage	100 m	Gutters, pavement, storm drains
06	Accumulation of solid waste and vegetation, Obstruction of Wolf mouths.	100 m	Gutters, pavement, storm drains
07	Accumulation of solid waste and vegetation, Obstruction of	100 m	Gutters, pavement, storm drains
08	storm drains, structural damage.	100 m	Gutters, pavement, storm drains
09	Accumulation of solid waste and vegetation, Obstruction of	100 m	Gutters, pavement, storm drains
10	Wolf mouths.	50 m	Gutters, pavement, storm drains
11	Accumulation of solid waste and vegetation, Obstruction of	80 m	Gutters, pavement, storm drains
12	Wolf mouths.	100 m	Gutters, pavement, storm drains

Source: Author (2022).

Table 2 shows that the accumulation of solid waste and obstruction of storm drains was recorded in the 12 subsections. Such pathologies overload the drainage system, facilitating the accumulation of water and flooding, fig. 10.

Fig. 10 - Accumulation of solid waste in storm drains.

Source: Author (2022).

In subsections 2 and 4, almost all storm drains have a broken or missing concrete cover. In this case, the surrounding residents themselves provide some palliative form, such as a wooden cover. Also note the displacement of structural parts of the storm drains, fig. 11.

Fig. 11 – Wolf mouths with broken or missing lid

Source: Author (2022).

It was observed in subsection 9, the silting of the gutter, caused by the presence of vegetation and solid residues, such as sand. This pathology causes water retention, which often invades the track, providing a dangerous state for the rolling of vehicles that need to slow down, fig. 12.

Fig.12 – Gutter silting.

Source: Author (2022).

The pavement, in the study section, presents itself with vegetation and debris, impairing the mobility of pedestrians. Tactile floor boards for accessibility are practically useless. The central bed of the avenue, in subsection 10, shows degradation, with pronounced cracks and erosion, Fig. 13.

Fig. 13 - Degradation and presence of vegetation on the pavement.

Source: Author (2022).

5.3 Reviews

There are a variety of methods created to carry out evaluations of flexible pavements, widely used by municipal, state and federal agencies. The experimental procedure used in this work was based on DNIT-PRO 007/2003, which defines a weighting factor for each type of pathology, Table 3.

Table 3 - Pathologies and Weighting factor.

Pathologies	Weighting factor
Wear	0,3
Exudation	0,5
Superficial patch	0,6
Pot or hole	1,0
Local plastic sinking	0,9
Long longitudinal crack	0,2
“Block” type crack	0,2
Ligand degradation	0,2

Source: DNIT (2003b). adapted by the author.

The Individual Severity Index (IGI) is obtained from the product of the relative frequency by the respective weighting factor, according to Equations 5.1 and 5.2. The Global Severity Index (IGG), in turn, is obtained through the sum of the IGI's, according to Equation 5.3.

$$f_r = \frac{f_a \times 100}{n} \quad (5.1)$$

$$IGI = f_r \times f_p \quad (5.2)$$

$$IGG = \sum IGI \quad (5.3)$$

Where:

fr = Relative frequency of each event

fa = Absolute frequency of each event

fp = Weighting factor

n = Number of events

Table 3 presents the results of the calculations, according to which a dimensionless value of 51.68 was found for the IGG - General Severity Index. According to the DNIT-PRO 007/2003 procedure, the pavement degradation classification or concept scale is inversely proportional to the IGG, which is analyzed within ranges of values, or intervals.

Table 4 presents the concepts of degradation of the analyzed pavement, attributed according to the Global Severity Index. The concepts range from terrible to great, inversely proportional to IGG.

Table 4 - Concept of pavement degradation.

IGG Ranges	Pavement conditions
$0 < IGG \leq 20$	Excellent
$20 < IGG \leq 40$	Good
$40 < IGG \leq 80$	Regular
$80 < IGG \leq 160$	Bad
$IGG > 160$	Terrible

Source: DNIT (2003a).

In this way, as the 40 < IGG ≤ 80, it is concluded that the studied section has a "Regular" usefulness condition. It is noteworthy, however, that the evaluation criterion used in this work, besides being subjective, is experimental, as it simplifies the DNIT-PRO 007/2003 procedure.

Correctly evaluating an existing rainwater drainage system, and in use on a highway, as is the case in this work, is not an easy task. A practical way to carry out this evaluation in the superficial elements (wolf mouths and gutters), is to apply the methodology of Medeiros et al. (2018), where the surface drainage index is obtained from four performance indicators: cleanliness, state of conservation, safety and cross section.

A score between 0 (bad) and 3 (good), based on visual inspection in loco, is assigned to each indicator. The final grade, for each of the elements, is given by the average between the scores obtained in the indicators, according to Equation 5.4.

$$d = \frac{L + Ec + S + St}{4} \quad (5.4)$$

Where:

L = Cleaning

Ec = State of conservation

S = Security

St = cross section

Also according to Medeiros et al. (2018), pavement conditions are evaluated based on five indicators: visual attractiveness, comfort, continuity, safety and security. Thus, for each indicator, a score between 0 (very bad) and 5 (excellent) is assigned, which are applied to the expression of the Quality Index of Sidewalks presented in Equation 5.5.

$$IQC = 0{,}21 \times S + 0{,}33 \times M + 0{,}17 \times Le + 0{,}2 \times Se + 0{,}1 \times Av \quad (5.5)$$

Where:

S = Security

M = Maintenance

Le = Effective Width

Se = Security

Av = Visual Attractiveness

To make the classification intervals of the surface drainage index (d) compatible with those of the sidewalk quality index (ICQ), an adjustment was made in the values, and classification categories, using Equation 5.6.

$$D = \frac{5d}{3} \quad (5.6)$$

Where:

d = surface drainage index (on the scale 0 to 3)

D = surface drainage index (on the scale 0 to 5)

From the calculation of the IQC, the sample is classified according to the level of service and the condition of conservation, as shown in Table 5.

Table 5 - Classification of surface drainage and pavement elements.

Range	Classification
0,0 - 1,0	Excellent
1,1 - 2,0	Good
2,1 - 3,0	Regular
3,1 - 4,0	Bad
4,1 - 5,0	Terrible

Source: Medeiros, et al.(2018).

Table 6 presents the calculated results for each surface drainage element evaluated, grouped into subsections.

Table 6 - Results of the evaluation of the surface drainage system and paving.

Evaluated Element	Sub-Section	L	Ec	S	St	d	D
Wolf mouths	1 to 6	2	1	1	2	1,5	2,5
	7 to 12	1	2	1	2	1,5	2,5
Gutters	1 to 6	1	2	2	2	1,75	2,91
	7 to 12	1	2	1	2	1,5	2,5
Totals						6,25	**2,6**

Source: Author (2022).

Thus, as 2.1 < D ≤ 3.0, surface drainage is in a "Regular" state of conservation.

Following the same procedure, Table 7 presents the calculated results for the pavement in the study section, taking into account the central bed.

Table 7 - Results of the evaluation of the surface drainage system and paving.

Evaluated Element	Sub-Section	S	M	Le	S	Av	IQC
Sidewalk	1 to 6	4	3	3	4	4	3,1
	7 to 12	3	3	2	3	3	2,86
	central	2	3	2	2	3	2,45
Totals							**2,8**

Source: Author (2022).

Thus, as 2.1 < IQC ≤ 3.0, the pavement is also in a "Regular" state of conservation.

V. CONCLUSION

The data obtained and cataloged in the field research clearly show the existence of several pathologies in the pavement and in the rainwater drainage in the study stretch, which represents 10% of the length of Perimetral Avenue.

Evaluating these pathologies through the experimental method proposed here, it is concluded that the avenue has a "Regular" state of conservation, both for the pavement and the surface drainage system, including the pavement.

Like most Brazilian infrastructure works, Perimetral Avenue lacks a more effective conservation and inspection plan. These two items are essential to prolong the useful life of the enterprise, saving resources for public coffers and taxpayers.

Due to public interest and strategic importance, Perimetral Avenue should have periodic maintenance services, involving modern repair techniques for paving, in addition to cleaning and preserving the drainage system, shoulders and pavement.

Inspection should be routine, firstly with investments in environmental education programs with community leaders and residents; for example: Lectures in schools; allocation of signs with educational messages; installation of garbage cans every 100 meters, etc.

As a last resort, fines remain. Penalizing users who are enemies of the public good and society may make them understand the need to preserve the environment in which they live and that corrective actions generate numerous mobility problems and financial costs.

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