REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

COMPARISON BETWEEN URCI AND PASER FUNCTIONAL CLASSIFICATIONS IN AN UNPAVED ROAD SECTION WITH COMPLEMENTARY GEOTECHNICAL TESTS

COMPARATIVO DAS CLASSIFICAÇÕES FUNCIONAIS URCI E PASER EM SEÇÃO NÃO PAVIMENTADA COM ENSAIOS GEOTÉCNICOS DE APOIO

COMPARACIÓN ENTRE LAS CLASIFICACIONES FUNCIONALES URCI Y PASER EN UMA SECCIÓN NO PAVIMENTADA CON ENSAYOS GEOTÉCNICOS COMPLEMENTARIOS

Matheus do Prado WOLF
Mestre em Engenharia Civil, Universidade Tecnológica Federal do Paraná - Guarapuava, Brasil
E-mail: matheuswolf@utfpr.edu.br

Abstract

Unpaved roads constitute the majority of the Brazilian road network and remain widely present in rural and between cities connections, and in peripheral neighborhoods and expanding urban areas. Despite their importance for mobility, the management boards still relies largely on visual surface evaluations. This study compared two traditional functional assessment methodologies, the Unsurfaced Road Condition Index (URCI) and the Pavement Surface Evaluation and Rating (PASER) for gravel roads, complemented by geotechnical characterization including grain-size distribution, Atterberg limits, soil classification according to the USCS and AASHTO systems, and pocket penetrometer testing. The investigation was conducted on a 250 m² unpaved road section near Jordão River located in Guarapuava, Paraná State, Brazil. The two methodologies indicated different functional conditions for the same section, reflecting their distinct evaluation philosophies. After consolidating the deduct values by distress type and severity, as required by the URCI procedure, the section reached a URCI of approximately 50, corresponding to a fair condition, whereas PASER was rated as condition 2, corresponding to a very poor condition. Geotechnical characterization revealed exploratory differences between the two sampling locations, particularly regarding the Plasticity Index, AASHTO classification, and pocket penetrometer resistance, consistent with the greater deterioration observed near the end of the evaluated section, although the limited number of sampling points and the uncontrolled moisture conditions preclude establishing a causal relationship. The results demonstrate that integrating functional assessments with geotechnical characterization provides a more comprehensive preliminary diagnosis of unpaved roads, supporting the identification of further investigations required for technically based maintenance planning.

Keywords: unpaved roads; URCI; PASER; geotechnical characterization; pocket penetrometer.

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Resumo

As vias não pavimentadas representam a maior parte da malha viária brasileira, amplamente presentes tanto em ligações rurais e intermunicipais quanto em bairros mais periféricos e expansões das cidades. Apesar de sua importância para a mobilidade, as gestões utilizam, em grande parte, de avaliações visuais da superfície. Este estudo comparou duas metodologias tradicionais para avaliação funcional, o *Unsurfaced Road Condition Index* (URCI) e o *Pavement Surface Evaluation and Rating* (PASER) versão para vias não pavimentadas, complementando a análise com ensaios geotécnicos de granulometria, limites de Atterberg, classificação dos solos pelos sistemas USCS e AASHTO e ensaio com penetrômetro de bolso. O estudo foi realizado em uma seção de 250 m² não pavimentada localizada próxima ao Rio Jordão em Guarapuava, Paraná. As duas metodologias indicaram condições funcionais distintas para a mesma seção, refletindo suas diferentes filosofias de avaliação. Após a consolidação dos valores dedutíveis por tipo de defeito e severidade, exigida pelo procedimento do URCI, a seção obteve índice URCI de aproximadamente 50, correspondente à classe Regular, enquanto o PASER apresentou condição igual a 2, correspondente a muito ruim. A caracterização geotécnica evidenciou diferenças exploratórias entre os dois pontos amostrados, principalmente quanto ao Índice de Plasticidade, classificação AASHTO e resistência medida pelo penetrômetro de bolso, resultados consistentes com a maior deterioração observada na porção final da seção, embora o número reduzido de pontos amostrados e a ausência de controle de umidade impeçam estabelecer relação causal. Os resultados demonstram que a integração entre avaliações funcionais e caracterização geotécnica proporciona um diagnóstico preliminar mais abrangente das vias não pavimentadas, auxiliando na identificação de investigações complementares necessárias para o planejamento técnico da manutenção.

Palavras-chave: vias não pavimentadas; URCI; PASER; caracterização geotécnica; penetrômetro de bolso.

Resumen

Las vías no pavimentadas constituyen la mayor parte de la red vial brasileña y continúan siendo ampliamente utilizadas tanto en conexiones rurales y intermunicipales y en barrios más periféricos y zonas de expansión urbana. A pesar de su importancia para la movilidad, las gestiónes aún depende principalmente de evaluaciones visuales de la superficie. Este estudio comparó dos tradicionales metodologías utilizadas para la evaluación funcional, el Unsurfaced Road Condition Index (URCI) y el Pavement Surface Evaluation and Rating (PASER) versión non pavimentadas, complementando el análisis con ensayos geotécnicos de granulometría, límites de Atterberg, clasificación de suelos según los sistemas USCS y AASHTO, y penetrómetro de bolsillo. La investigación se realizó en un tramo de 250 m² de una vía no pavimentada cerca del río Jordão en Guarapuava, estado de Paraná, Brasil.

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Ambas metodologías indicaron condiciones funcionales distintas para el mismo tramo, reflejando sus diferentes filosofías de evaluación. Tras consolidar los valores deducibles por tipo de defecto y severidad, como exige el procedimiento del URCI, el tramo obtuvo un valor de 50, correspondiente a la clase Regular, mientras que el PASER presentó una clasificación correspondiente a la condición 2, muy deficiente. La caracterización geotécnica evidenció diferencias exploratorias entre los dos puntos de muestreo, especialmente en el Índice de Plasticidad, la clasificación AASHTO y la resistencia medida con el penetrómetro de bolsillo, resultados consistentes con el mayor deterioro observado en la parte final del tramo evaluado, aunque el número reducido de puntos y la ausencia de control de humedad impiden establecer una relación causal. Los resultados demuestran que la integración entre la evaluación funcional y la caracterización geotécnica proporciona un diagnóstico preliminar más completo de las vías no pavimentadas, contribuyendo a identificar las investigaciones complementarias necesarias para la planificación técnica del mantenimiento.
Palabras clave: vías no pavimentadas; URCI; PASER; caracterización geotécnica; penetrómetro de bolsillo.

1. INTRODUCTION

Unpaved (gravel or earth-surfaced) roads are critical connectors in rural and developing regions worldwide (World Bank, 2026). These roads provide connection of the farms and villages to schools, healthcare facilities, and local markets, while also supporting the transportation of agricultural products, forestry resources, and raw materials (ERA, 2016; FHWA, 2015). Despite their strategic importance, these roads generally receive fewer financial resources and less systematic maintenance than paved ones, resulting in accelerated deterioration and reduced serviceability over time (Chamorro & Tighe, 2011).

Brazil presents a scenario not different from the worldwide however higher than most countries: according to the latest reports from the Confederação Nacional do Transporte (CNT), approximately 80% of the Brazilian road network consists of unpaved roads. Most of Brazil's unpaved roads are under municipal administration connecting rural communities, supporting agribusiness logistics, and ensuring access to public services. Nevertheless, the limited technical and financial capacity of many municipalities often results in reactive maintenance practices, where interventions are performed only after severe deterioration has already occurred, increasing maintenance costs and reducing road safety and user comfort (CNT, 2024).

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Unlike paved pavements, where stone, block, asphalt or concrete layers protect the structural materials from direct environmental exposure, unpaved roads consist predominantly of natural soils and granular materials that remain directly exposed to traffic loads and climatic conditions (Keller & Sherar, 2003). Consequently, their performance is strongly influenced by rainfalls, as reported by Jones (2017): repeated wetting and drying cycles modify soil consistency and strength, while precipitation accelerates defects and the loss of fine particles, often leading to worse roadway surface.

The sensitivity of unpaved roads to environmental conditions turns continuous monitoring an essential task (Silva *et. al.*, 2019). Historical condition records enable infrastructure managers not only to identify maintenance priorities but also to monitor deterioration trends, optimize maintenance budgets, and develop predictive models capable of estimating future conditions under different traffic and environmental scenarios (Austroads, 2020). For unpaved roads, however, this monitoring becomes considerably challenging for many reasons: besides being highly variable and strongly dependent on seasonal weather conditions, unpaved roads have received limited attention in the literature, and municipalities typically have a limited specialized workforce to address the wide variety of demands faced by cities.

To support monitoring and management activities, functional evaluations have been developed to quantify the condition of unpaved roads from the perspective of surface performance and ride quality. These methodologies provide standardized procedures for classifying roadway condition, facilitating communication and supporting maintenance planning at both project and network levels (DNIT, 2006). Among the well-established methods are the Unsurfaced Road Condition Index (URCI), originally developed by the U.S. Army Corps of Engineers, and the Pavement Surface Evaluation and Rating (PASER) system, developed by the University of Wisconsin Transportation Information Center. Although both methods classify the functional condition of road surfaces they have different philosophies. URCI employs a rational procedure founded on defect identification, severity, measurement and

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

quantification of individual distresses, whereas PASER relies on the overall visual perception of the evaluator to assign a condition rating (Eaton & Beaucham, 1992; TIC, 2002).

Although functional assessment methods provide valuable information regarding the current serviceability of unpaved roads, they primarily describe the surface condition and do not directly explain the mechanisms responsible for deterioration as stated by Nervis and Nuñez (2019). Roads exhibiting similar functional ratings may present distinct structural or geotechnical characteristics, requiring different maintenance strategies. Therefore, relying exclusively on surface condition indices may limit the understanding of the factors controlling pavement performance, particularly under varying environmental and traffic conditions.

Grain-size distribution controls particle interlocking, permeability, and the proportion of coarse and fine fractions, whereas the Atterberg limits provide important information regarding soil plasticity, consistency, and moisture susceptibility. Likewise, soil classification systems such as the AASHTO and Unified Soil Classification System (USCS) allow engineers to infer the expected engineering performance of soils based on their gradation and plasticity characteristics. Complementary field tests, such as the pocket penetrometer, provide a rapid estimation of soil strength and consistency, supporting the interpretation of laboratory results and field observations (Das & Sobhan, 2018; Massad, 2016; Mousavi *et al.*, 2021).

Integrating functional condition surveys with basic geotechnical characterization may therefore contribute to a more comprehensive diagnosis of unpaved road performance as expressed by Keller & Sherar (2003). While functional indices identify the location and severity of surface deterioration, geotechnical parameters help explain the material behavior responsible for the observed distresses, including rutting, erosion, corrugation, and pothole development. Such an integrated approach can improve maintenance planning by supporting the selection of interventions that address not only the symptoms of deterioration but also their underlying causes.

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

This approach is particularly relevant in municipalities with extensive rural road networks, where maintenance resources are often limited and engineering decisions must be prioritized. The municipality of Guarapuava, located in the central-southern region of Paraná State, Brazil, is the largest municipality in the state by territorial area and possesses an extensive network of unpaved rural roads that are fundamental for agricultural production, forestry activities, and rural mobility. The region is characterized by frequent rainfall and significant seasonal moisture variations, environmental conditions that directly influence the performance of unpaved road materials and accelerate surface deterioration.

Despite the widespread use of functional condition indices and the well-established role of geotechnical characterization in pavement engineering, relatively few studies have investigated both URCI and PASER with geotechnical parameters simultaneously. Consequently, there remains a need to better understand the relationship between functional condition and geotechnical characteristics composing the roadway, particularly under the environmental conditions found in south Brazil.

Therefore, the main objective of this study is to compare the functional classifications obtained using the Unsurfaced Road Condition Index (URCI) and the Pavement Surface Evaluation and Rating (PASER) methodologies on an unpaved road section located in the municipality of Guarapuava, Paraná, Brazil, and to examine, in an exploratory manner, whether the geotechnical characterization of two contrasting points adds information to the surface diagnosis. Specifically, the study aims to: (i) compare the results and evaluation philosophies of the two functional assessment methods on a single, intentionally selected deteriorated section; (ii) perform grain-size distribution, Atterberg limits, and pocket penetrometer tests on two samples collected at the beginning and end of the evaluated section; and (iii) explore, without establishing causal relationships, whether the geotechnical properties of these two points are compatible with the surface distresses observed at their respective locations.

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

2. LITERATURE REVIEW

This chapter reviews the main concepts and methodologies related to the present study. It discusses the functional evaluation methods URCI and PASER, the geotechnical procedures used for soil characterization, including grain-size distribution, soil classification systems, Atterberg limits, and pocket penetrometer testing, as well as the relationship between functional assessment and geotechnical characterization.

2.1 Unsurfaced Road Condition Index (URCI)

The Unsurfaced Road Condition Index (URCI) was developed by the U.S. Army Corps of Engineers (USACE) to provide a standardized methodology for evaluating the surface condition of unpaved roads within military installations. Its development was based on the successful application of the Pavement Condition Index (PCI) to paved roads, adapting the methodology to account for the deterioration mechanisms commonly observed in gravel and earth roads (Eaton & Beaucham, 1992).

The URCI methodology evaluates the road surface by identifying and quantifying the most common distresses found on unpaved roads. Each distress is classified according to its severity level (Low, Medium or High) and its density in a sample unit. The evaluated defects of the method are: improper cross section, inadequate roadside drainage, corrugations, dust, loose aggregate, potholes and rutting (Eaton & Beaucham, 1992). Depending on the distress type, the affected length, area, or a subjective evaluation is adopted to determine its impact, which is subsequently converted into a Deduct Value (DV).

Each of the seven distress types considered by the URCI methodology – improper cross section, inadequate roadside drainage, corrugations, dust, loose aggregate, potholes, and rutting – is classified into low, medium, or high severity according to measurable criteria (e.g., ponding depth and cross-slope for improper cross section and drainage; corrugation and rut depth; pothole diameter and depth), defined in detail by Eaton and Beaucham (1992) and summarized graphically in Figure 1. With the exception of dust, which is rated subjectively and assigned fixed

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

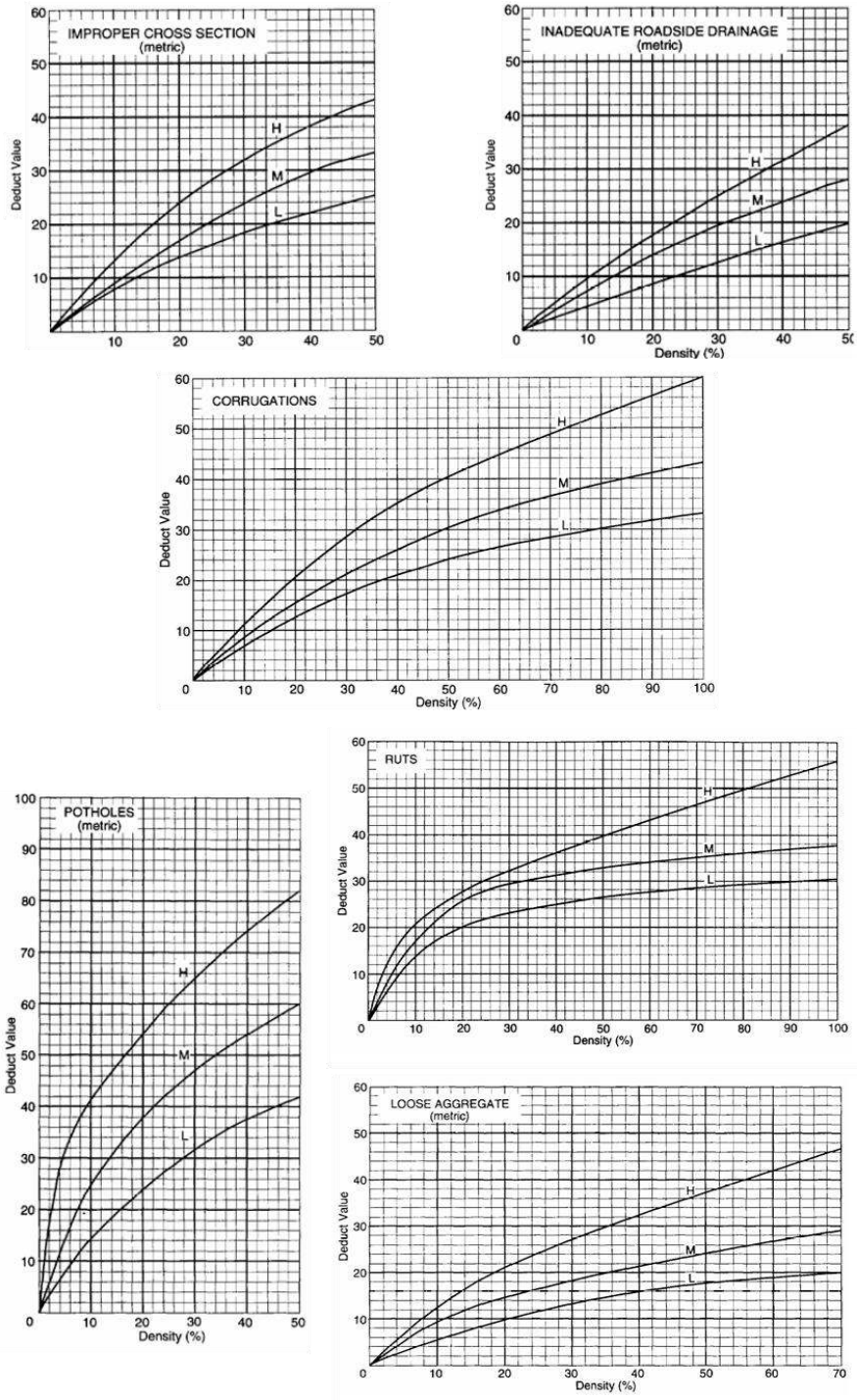
deduct values of 2, 4, and 15 points for low, medium, and high severity respectively, each distress is quantified by its affected length, area, or count within the sample unit and converted into a deduct value through the corresponding curve. As only improper cross section, inadequate roadside drainage, potholes, and rutting were observed in the evaluated section (Section 4.1), the full severity criteria for corrugations, dust, and loose aggregate are not reproduced here and can be consulted directly in Eaton and Beaucham (1992).

Each distress counted (except dust as described above) the calculated density and corresponding severity level are converted into an individual Deduct Value (DV) using empirical curves developed during the calibration of the URCI methodology. These curves represent the relative influence of each distress on the overall functional condition of the road surface. An example of these deduct value curves is presented in Figure 1.

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Figure 1 – Deduct Value curves for the different distress types considered in the URCI methodology



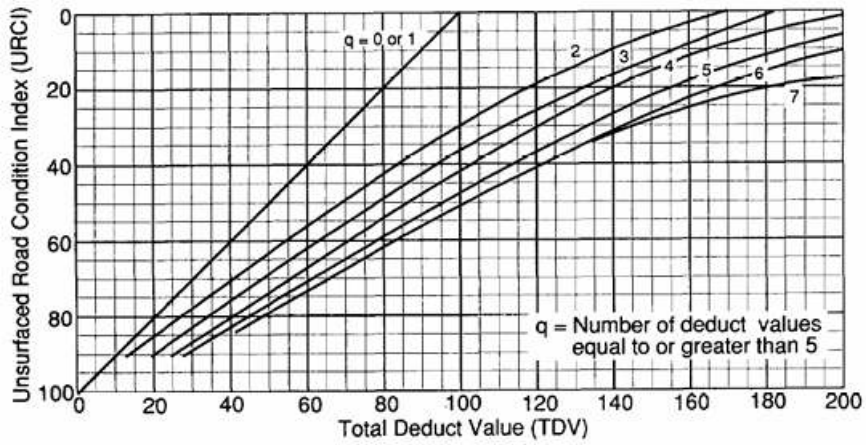
Font: USACE-TM 5-626 (1995)

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

After determining the Deduct Value (DV) for each identified distress, all deduct values are summed to obtain the Total Deduct Value (TDV). Subsequently, the parameter q is determined as the number of type of distress with deduct values greater than five. The pair of values (TDV and q) is then used to enter the URCI value chart as illustrated in Figure 2 (Eaton & Beaucham, 1992).

Figure 2 – URCI values through correlation of TDV and q



Font: USACE-TM 5-626 (1995)

According to Eaton and Beaucham (1992), the methodology provides correction curves only for q values ranging from 1 to 7. Therefore, when more than seven significant distresses are identified within a sample unit (q > 7), the q = 7 curve should be adopted. This recommendation is based on the fact that the original methodology was calibrated only for sample units containing lesse than seven significant distresses, and no experimental calibration is available for higher values of q. The applicability of this procedure was maintained during the field evaluation of the URCI methodology conducted by Soria and Fontenele (2003). Once the URCI value has been determined, the corresponding functional condition of the unpaved road is established according to the classification ranges proposed in the original methodology. The URCI functional condition classes are presented in Table 1.

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Table 1 – Functional Classes of URCI Methodology

URCI score	Class
0 – 10	Failed
10 – 25	Very Poor
25 – 40	Poor
40 – 55	Fair
55 – 70	Good
70 – 85	Very Good
85 – 100	Excellent

Font: Eaton & Beaucham (1992)

Table 1 presents ranges of fifteen points for each class, except for failed.

2.2 Pavement Surface Evaluation and Rating (PASER)

The Pavement Surface Evaluation and Rating (PASER) system was developed by the Transportation Information Center (TIC) of the University of Wisconsin–Madison as a simplified methodology for evaluating roads surface condition through visual inspection. Although originally proposed for paved pavements, specific manuals were later developed for gravel roads, making the methodology applicable to unpaved road networks (TIC, 2002).

Unlike the Unsurfaced Road Condition Index (URCI), which requires the measurement of individual distresses and their conversion into deduct values, PASER is based on the overall visual assessment of the roadway performed by a trained evaluator. The assigned rating reflects the general functional condition of the road surface through evaluator considering the severity and extent of visible distresses. Consequently, PASER can be applied rapidly over extensive road networks, making it particularly attractive for municipalities with limited financial and technical resources (TIC, 2002).

The PASER Gravel methodology evaluates five principal aspects of unpaved road performance: cross-sectional shape, roadside drainage, gravel surface condition, surface deformation, and surface performance irregularities. The first two

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

categories assess the roadway geometry and its ability to efficiently drain water from the travelled surface. The gravel surface evaluation considers the presence, thickness, and adequacy of the aggregate layer for the expected traffic demand. Surface deformation includes defects such as corrugations, rutting, potholes, and depressions, whereas surface performance irregularities comprise dust generation, loose aggregate, and other visible signs of surface degradation (TIC, 2002).

Throughout the PASER Gravel Manual, representative photographs are provided for each condition level, illustrating typical road sections with severe, moderate, slight, or negligible deterioration. The rating system of PASER classifies road sections into five condition levels ranging from Excellent (5) to Failed (1). Each rating combines descriptions of visible distresses with the expected operational condition of the roadway and the corresponding maintenance strategy. Figures 3-7 ilustrate PASER examples (black and white pictures from the manual) along examples took by Wolf (2026), his work applied an accelerometer to verify unpaved surface conditions and compared the surface images captured during the measurements with analogous examples from the PASER manual.

Figure 3 – Unpaved Roads Surfaces examples of level 5 in PASER Gravel ranking



Font: Adapted from TIC (2002) and Wolf (2026)

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Figure 4 – Unpaved Roads Surface examples of level 4 in PASER Gravel ranking



Font: Adapted from TIC (2002) and Wolf (2026)

Figure 5 – Unpaved Roads Surfaces examples of level 3 in PASER Gravel ranking



Font: Adapted from TIC (2002) and Wolf (2026)

Figure 6 – Unpaved Roads Surfaces examples of level 2 in PASER Gravel

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

ranking



Font: Adapted from TIC (2002) and Wolf (2026)

Figure 7 – Unpaved Roads Surfaces examples of level 1 in PASER Gravel ranking



Font: Adapted from TIC (2002) and Wolf (2026)

These visual examples are accompanied by descriptions of the observed defects and recommended maintenance actions, allowing evaluators to compare field conditions directly with the reference images. According to the manual, the evaluated

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

characteristics directly influence ride quality, traffic safety, and overall user comfort, thereby supporting maintenance decision-making (TIC, 2002).

The manual denotes roads as 5 when considered Excellent, 4 to Good, 3 for Regular, 2 as Bad and 1 for Failed. Table 2 describes the conditions observed in each class.

Table 2 – Descriptions of PASER Gravel manual for each road condition

PASER Rating	Visible Distresses	General Condition and Recommended Treatment
5 – Excellent	No visible defects. Minor dust during dry periods. Excellent riding quality.	Newly constructed or recently reconstructed road. Adequate gravel layer and excellent drainage. Little or no maintenance required.
4 – Good	Moderate dust during dry periods. Slight loose aggregate. Minor corrugations may be present.	Recently graded road with good crown, adequate drainage, and sufficient gravel thickness. Routine grading and occasional dust control may be required.
3 – Fair	Moderate corrugations, isolated potholes, shallow rutting, moderate dust generation, and localized gravel loss. Drainage is generally adequate, although some deficiencies may occur.	The road exhibits normal traffic-related deterioration. Routine maintenance, grading, localized drainage improvements, culvert maintenance, and additional gravel may be necessary.
2 – Poor	Limited or absent crown. Moderate to severe corrugations, potholes, rutting, depressions, significant gravel loss, and deficient roadside drainage.	Vehicle speeds are considerably reduced. Additional gravel, regrading, drainage rehabilitation, and culvert maintenance are required to restore acceptable operating conditions.
1 – Failed	No effective cross slope. Extensive ponding water. Severe corrugations, deep rutting, numerous potholes, severe depressions, extensive gravel loss, and non-functional drainage system.	Very poor trafficability with possible road closure. Complete reconstruction of the roadway and drainage system is generally required.

Font: Adapted from TIC (2002)

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Although PASER is simple and operationally efficient as shown in Table 2, some of its evaluation criteria are not directly associated with the functional performance perceived by road users. Parameters such as roadside drainage efficiency, ditch condition, and cross-sectional geometry may influence the assigned rating even when the travelling surface itself provides acceptable ride quality. Consequently, a road section may receive a relatively low PASER score despite presenting satisfactory operational performance from the users' perspective. The PASER Gravel Manual itself acknowledges this characteristic by stating that "individual road sections will not have all of the types of distress listed for any particular rating; they may have only one or two types" (TIC, 2002).

Another important characteristic of PASER is its inherent subjectivity. Because the final rating depends primarily on the evaluator's visual interpretation and engineering judgment, differences in training, experience, and perception may lead to variability between inspectors evaluating the same road section. This evaluator dependency has been recognized as one of the principal limitations of visual pavement assessment systems and may reduce the repeatability of condition surveys when standardized training procedures are not adopted (Montgomery *et al.*, 2019). Nevertheless, due to its rapid application and low implementation cost, PASER remains a valuable tool for network-level management of unpaved roads, particularly when the objective is to prioritize maintenance interventions over extensive rural road systems.

2.3 Grain Size Distribution

Grain-size distribution is one of the most fundamental properties for the geotechnical characterization of soils and granular materials used in unpaved roads. The relative proportions of gravel, sand, silt, and clay directly influence the mechanical behavior of the road surface, affecting strength, permeability, compaction, moisture susceptibility, and resistance to traffic loads. Consequently, particle-size distribution plays a decisive role in the functional performance and durability of unpaved roads (Das & Sobhan, 2018; Holtz, Kovacs & Sheahan, 2011).

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

A well-graded material generally provides better particle interlocking, higher density after compaction, and improved load distribution, resulting in greater resistance to rutting and surface deformation. Conversely, poorly graded materials or soils containing excessive amounts of fine particles may become highly susceptible to moisture variations, leading to reduced bearing capacity, dust generation during dry periods, and severe surface deterioration under wet conditions (Skorseth & Selim, 2000; Austroads, 2020).

Grain-size analysis is performed by mechanical sieving for coarse particles and hydrometer sedimentation for fine fractions, following standardized laboratory procedures. The resulting particle-size distribution curve enables the determination of characteristic diameters, such as D10, D30, and D60, from which the coefficients of uniformity (Cu) and curvature (Cc) are calculated. These parameters provide important information regarding the gradation of the soil and further are used for soil classification (ASTM, 2009; ASTM, 2021).

Besides supporting soil classification systems, grain-size distribution provides an initial indication of the expected engineering behavior of road materials and constitutes one of the principal inputs for selecting suitable materials for the construction and maintenance of unpaved roads.

2.4 Atterberg Limits

The Atterberg limits constitute one of the most important laboratory procedures for the characterization of fine-grained soils. Originally proposed by Atterberg and later standardized and improved by Casagrande, these limits define the consistency states of cohesive soils as a function of their moisture content, providing valuable information regarding their engineering behavior (Massad, 2016; ABNT, 2025ab).

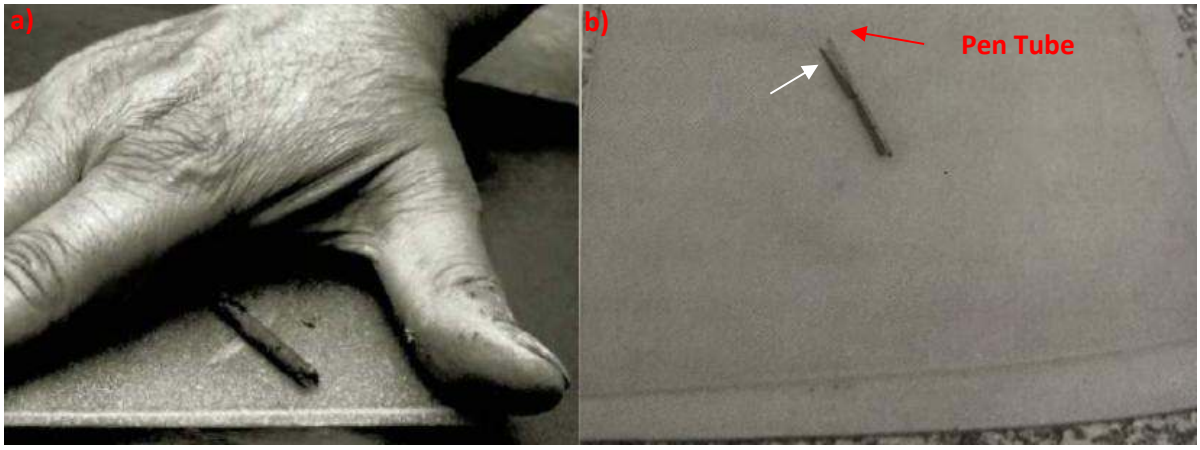
The Plastic Limit (PL) represents the transition between the semi-solid and plastic states. It is determined by manually rolling soil threads on a smooth surface until they reach a diameter of approximately 3.2 mm at which point the material begins to crumble. The corresponding moisture content is defined as the Plastic Limit. For

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

pratical comparation, a plastic pen tube is used to see if the cylinder rolled is of the size required. A typical Plastic Limit specimen is presented in Figure 8 (ABNT,2025b).

Figure 8 – Plastic Limit (PL) guiding images: a) Determination by rolling soil in malleable consistency; b) Comparision with pen tube of nearly 3 mm of external diameter



Font: Adapted from Das & Sobhan (2018) and Massad (2016)

It is notable that in the plastic limit test the soil must be ruptured to then measure moisture level by setting a portion in laboratory oven. The test to measure the moisture which the soil has to behave like a liquid is the Liquid Limit (LL) usually with the Casagrande cup apparatus. The Liquid Limit (LL) corresponds to the water content at which the soil changes from the plastic to the liquid state. In the Casagrande cup test, a standard groove is opened in a soil paste, and the number of blows required to close it over 12.7 mm is registered. The Liquid Limit corresponds to the moisture content associated with 25 blows, according to NBR 6459 (ABNT, 2025a). The apparatus used for determining the Liquid Limit is illustrated in Figure 9 with images of the start and end of the test.

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Figure 9 – Guiding images of Casagrande cup: a) Equipment formed by cup, handler and base; b) breach between testing soil; c) closed region which determines end of the test



Font: Adapted from Pinto (2016) and Das & Sobhan (2018)

Like the plastic limit, Liquid Limit depends on the measure of moisture of a portion of soil. It is recomended at least three samples of a same soil to plot a curve of logarithmic blows vs. moisture to define which moisture is related to the 25 blows. The difference between the Liquid Limit and the Plastic Limit defines the Plasticity Index (PI), which represents the range of moisture contents over which the soil remains plastic (Pinto, 2016, Massad, 2016, Das & Sobhan, 2018).

These parameters are directly associated with several engineering properties, including compressibility, shrinkage, swelling potential, workability, and shear strength. In unpaved roads, soils exhibiting high plasticity generally become softer and more deformable under wet conditions while being susceptible to shrinkage and cracking during prolonged drying periods. Consequently, the Atterberg limits provide valuable information regarding the expected seasonal performance of road materials and their susceptibility to climatic variations (Das & Sobhan, 2018; ABNT, 2025ab).

2.5 Soil Classification Systems

The results obtained from grain-size distribution and Atterberg limits constitute the basis for the most widely used engineering soil classification systems. Among them, the Unified Soil Classification System (USCS) and the American

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Association of State Highway and Transportation Officials (AASHTO) classification system are the most commonly employed in geotechnical and transportation engineering.

The USCS, standardized by ASTM D2487 (ASTM, 2009), classifies soils according to particle-size distribution and plasticity characteristics. Coarse-grained soils are classified based on the proportions of gravel and sand and their gradation, whereas fine-grained soils are classified using the Atterberg limits and the Casagrande plasticity chart. This system provides a general indication of engineering properties such as permeability, compressibility, and expected mechanical behavior (ASTM, 2009; Das & Sobhan, 2018). A summary of the USCS classification adopted in this study is presented in Figure 10.

Figure 10 – Soil Definitions by USCS Classification

Criteria for assigning group symbols				Group symbol
Coarse-grained soils More than 50% retained on No. 200 sieve	**Gravels** More than 50% of coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines[a]	$C_u \geq 4$ and $1 \leq C_c \leq 3$[c] $C_u < 4$ and/or $C_c < 1$ or $C_c > 3$[c]	GW GP
		Gravels with Fines More than 12% fines[a,d]	$PI < 4$ or plots below "A" line (Figure 5.3) $PI > 7$ and plots on or above "A" line (Figure 5.3)	GM GC
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5% fines[b]	$C_u \geq 6$ and $1 \leq C_c \leq 3$[c] $C_u < 6$ and/or $C_c < 1$ or $C_c > 3$[c]	SW SP
		Sands with Fines More than 12% fines[b,d]	$PI < 4$ or plots below "A" line (Figure 5.3) $PI > 7$ and plots on or above "A" line (Figure 5.3)	SM SC
Fine-grained soils 50% or more passes No. 200 sieve	**Silts and clays** Liquid limit less than 50	Inorganic	$PI > 7$ and plots on or above "A" line (Figure 5.3)[e] $PI < 4$ or plots below "A" line (Figure 5.3)[e]	CL ML
		Organic	$\frac{\text{Liquid limit—oven dried}}{\text{Liquid limit—not dried}} < 0.75$; see Figure 5.3; OL zone	OL
	Silts and clays Liquid limit 50 or more	Inorganic	PI plots on or above "A" line (Figure 5.3) PI plots below "A" line (Figure 5.3)	CH MH
		Organic	$\frac{\text{Liquid limit—oven dried}}{\text{Liquid limit—not dried}} < 0.75$; see Figure 5.3; OH zone	OH
Highly organic soils	Primarily organic matter, dark in color, and organic odor			Pt

[a]Gravels with 5 to 12% fine require dual symbols: GW-GM, GW-GC, GP-GM, GP-GC.

[b]Sands with 5 to 12% fines require dual symbols: SW-SM, SW-SC, SP-SM, SP-SC.

[c]$C_u = \frac{D_{60}}{D_{10}}$; $C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$

[d]If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 5.3, use dual symbol GC-GM or SC-SM.

[e]If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 5.3, use dual symbol CL-ML.

Font: Das & Sobhan (2018)

The AASHTO soil classification system was specifically developed for highway engineering applications. Similar to the USCS, it combines grain-size distribution with the Atterberg limits but additionally incorporates the Group Index

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

(GI), an empirical parameter used to estimate the expected quality of subgrade materials. Granular materials classified as Groups A-1, A-2, and A-3 generally exhibit satisfactory engineering performance, whereas Groups A-6 and A-7 correspond to clayey soils with greater plasticity and higher susceptibility to moisture-induced strength loss according to AASHTO M145 (1991). The classification groups adopted by the AASHTO system are summarized in Figure 11.

Figure 11 – Classification Charts for AASHTO classification

General classification	Granular materials (35% or less of total sample passing No. 200)						
	A-1			A-2			
Group classification	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7
Sieve analysis (percentage passing)							
No. 10	50 max.						
No. 40	30 max.	50 max.	51 min.				
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.
Characteristics of fraction passing No. 40							
Liquid limit				40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.
Usual types of significant constituent materials	Stone, fragments, gravel and sand		Fine sand	Silty or clayey gravel, and sand			
General subgrade rating	Excellent to good						

General classification	Silt-clay materials (more than 35% of total sample passing No. 200)			
Group classification	A-4	A-5	A-6	A-7 A-7-5[a] A-7-6[b]
Sieve analysis (percentage passing)				
No. 10				
No. 40				
No. 200	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40				
Liquid limit	40 max.	41 min.	40 max.	41 min.
Plasticity index	10 max.	10 max.	11 min.	11 min.
Usual types of significant constituent materials	Silty soils		Clayey soils	
General subgrade rating	Fair to poor			

[a]For A-7-5, $PI \leq LL - 30$
[b]For A-7-6, $PI > LL - 30$

Font: Das & Sobhan (2018)

Although both systems are based on relatively simple laboratory procedures, they provide important preliminary information regarding the suitability of natural soils

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

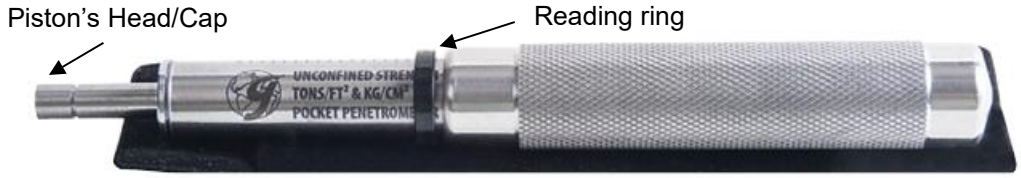
and granular materials for transportation infrastructure. However, they should be interpreted as predictive tools rather than direct indicators of pavement performance, since traffic loading, drainage conditions, compaction quality, and environmental factors also influence the field behavior of unpaved roads.

2.6 Pocket Penetrometer

The pocket penetrometer is a portable field device designed to provide a rapid estimate of the unconfined compressive strength of cohesive soils. According to ASTM D8605 (2026), the test provides an approximate field estimate of soil strength and should not be considered a substitute for standardized laboratory strength tests.

The test is performed by pressing the cylindrical tip of the instrument perpendicularly against a freshly exposed soil surface until the engraved calibration mark becomes flush with the soil surface. The maximum penetration resistance is then directly converted into an approximate value of unconfined compressive strength, commonly expressed in kg/cm² or kPa, depending on the equipment calibration. A typical pocket penetrometer used for field investigations is shown in Figure 12.

Figure 12 – Example of Pocket Penetrometer



Font: Adapted from Gilson Company Inc. (2019)

Although the test does not replace standardized laboratory procedures, the pocket penetrometer provides a rapid estimate of soil strength and enables comparisons among different sampling locations. Because soil resistance is strongly affected by moisture content, the measured values should always be interpreted together with grain-size distribution, Atterberg limits, and field moisture conditions rather than as isolated indicators of material quality (ASTM, 2026).

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

For unpaved roads, pocket penetrometer testing constitutes a practical complementary tool capable of assisting in the identification of weaker zones and supporting the interpretation of functional deterioration observed during visual pavement inspections. Table 3 presents how to interpretate the reading obtained by the pocket penetrometer according with the material consistency.

Table 3 – Correlation between Pocket Penetrometer Readings and soil consistency

Reading (kg/cm²)	Consistency
<0.25	Very soft
0.25-0.50	Soft
0.51-1.00	Medium
1.01-2.00	Stiff
2.01-4.00	Very stiff
>4.00	Hard

Font: ASTM D8605 (2026)

2.7 Functional Assessment integrated Geotechnics

Functional evaluation methodologies, such as the Unsurfaced Road Condition Index (URCI) and the Pavement Surface Evaluation and Rating (PASER) system, provide valuable information regarding the operational condition of unpaved roads by quantifying or classifying visible surface deterioration. However, these methodologies primarily describe the current functional condition and do not directly explain the mechanisms responsible for the observed distresses.

The development of defects such as rutting, corrugations, potholes, loose aggregate, dust generation, and drainage deficiencies is strongly influenced by the engineering properties of the road material. Particle-size distribution governs aggregate interlocking and permeability, while plasticity controls the soil response to moisture variations. Likewise, soil strength directly affects its resistance to traffic-induced deformation. Consequently, road sections presenting similar functional classifications may require entirely different maintenance strategies depending on their geotechnical characteristics (Skorseth & Selim, 2000; Austroads, 2020).

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Integrating functional condition surveys with basic geotechnical characterization therefore provides a more comprehensive understanding of pavement performance. Functional indices identify where deterioration occurs and quantify its severity, whereas geotechnical investigations help explain why deterioration develops. This complementary approach enables maintenance interventions to address not only the visible manifestations of pavement distress but also their underlying causes, contributing to more efficient, technically supported, and economically sustainable management of unpaved road networks.

3. MATERIALS AND METHODS

The study was conducted on a unpaved road section of 50 m in length and 5 m in width (250 m² of surface área) located in the city of Guarapuava, Paraná State, Southern region of Brazil, inside a municipal park used for recreational purposes (picnic and barbecue area), and subjected to low-volume, predominantly light recreational traffic rather than heavy agricultural or commercial loading. No records of previous maintenance interventions on this section were available. The selected road segment is adjacent to the Jordão River; residual soils derived from basaltic rocks are a geological condition documented for the Guarapuava region and the Paraná Third Plateau more broadly (Ghidin *et al*., 2006), which is compatible with the material found along this segment, although not individually confirmed by geological site mapping. This location was intentionally selected because it represents a typical unpaved rural road subjected to frequent moisture variations due to its proximity to the river, allowing the applicability of the pocket penetrometer on cohesive soil. The field survey was carried out on 24 and 25 June 2026. According to Simepar records, a significant rainfall event of 80.4 mm was recorded in Guarapuava on 10 June 2026, approximately two weeks before the field survey, indicating antecedent conditions wetter than typically expected for the period, consistent with the water-filled potholes observed.

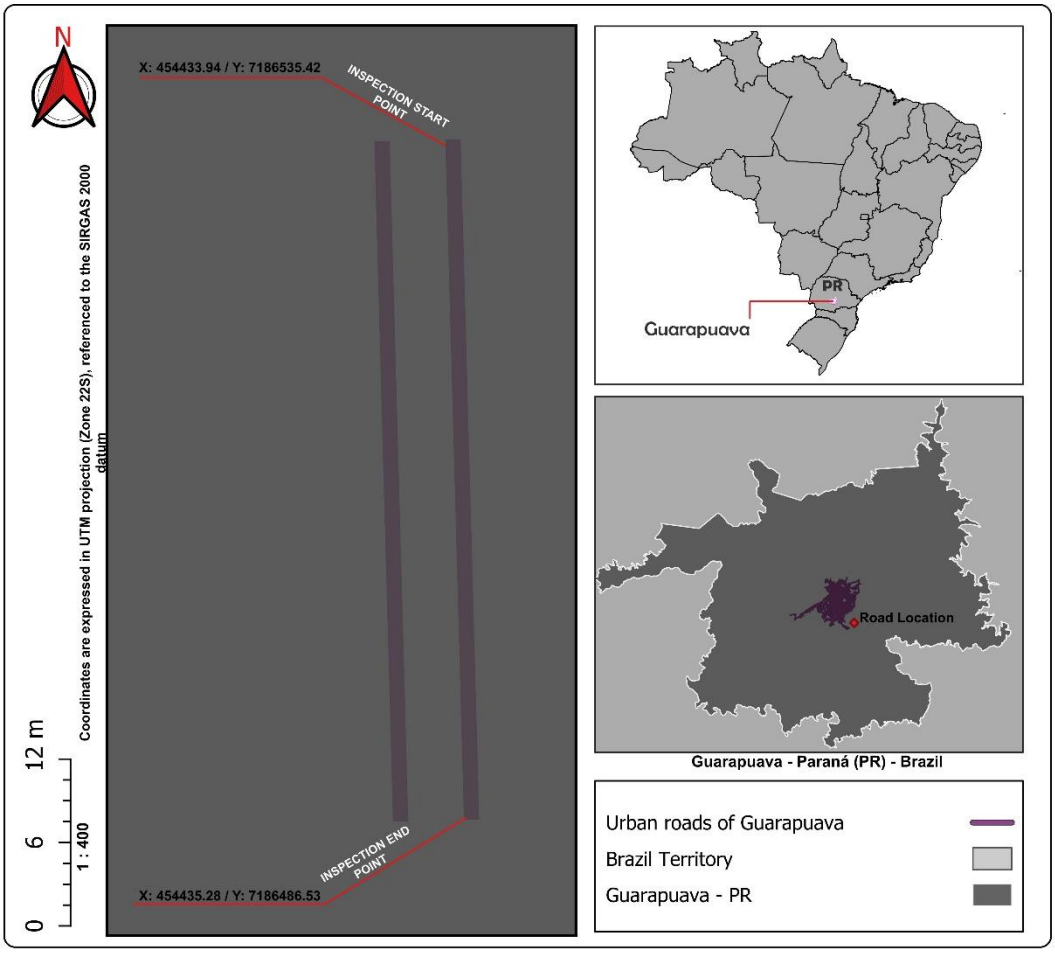
The evaluated section presented typical deterioration mechanisms of municipal unpaved roads, including rutting, potholes and drainage deficiencies,

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

making it suitable for comparing the URCI and PASER functional assessment methodologies while simultaneously investigating the engineering properties of the road material. The map indicating the section location within Brazil, Paraná, and Guarapuava is presented in Figure 13 while Figure 14 is the treated satellite image.

Figure 13 – Map indicating section position



Font: Author

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Figure 14 – Treated Satellite Image



Font: Adapted from Paraná Iterativo base

The field survey was performed to characterize the functional condition of the selected road section. During the survey, all surface distresses were identified, measured, and pictured for URCI methodology as the surface was recorded to evaluate by PASER. The equipment used in the field survey are shown in Figure 15.

Figure 15 – Field Survey Equipments



Font: Author

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

From Figure 15, the wheel ruler (a) was used to obtain linear extensions, tape measure (b) to obtain distress sizes, and bubble level to verify inclinations and diferences of height (c). The pocket penetrometer (d) used was an AMS 59032, applied at two points along the section: one at the beginning and one at the end, where soil samples were also collected.

Following the functional assessment, two representative sampling locations were selected: one at the beginning and the other at the end of the evaluated road section. Each point passed equally through the functional inspection before any excavation was carried out. Also, the in-situ soil was tested using a pocket penetrometer to obtain a rapid estimate of its consistency and unconfined compressive strength under natural field conditions. Immediately after the penetration test, the soil samples were collected from these locations using a pickaxe and shovel for subsequent laboratory characterization.

The collected material was transported to the Soil Mechanics Laboratory, where it was initially air-dried and subsequently oven-dried until reaching constant mass whenever required by the corresponding testing procedures. After drying, the material was gently disaggregated and prepared for laboratory characterization.

Grain-size distribution tests were performed in accordance with the applicable standards. It was used a total of 1000g in each granulometric test as shown in both Figure 16a and Figure 16b and the sieve set arranged in decreasing opening sizes, as illustrated in Figure 17. The size of opening of the sieves are accordlying with Table 4.

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Figure 16 – Weightint of soil for grainsize analysis: a) soil portion of the sample extracted in the begging point; b) soil portion of the sample extracted in the end point



Font: Author

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Figure 17 – Sieve set arranged in decreasing openings in the mechanical shaker



Font: Author

Table 4 – Sizes of Sieves used

Order (top from bottom)	Sieve #	Size of the opening (mm)
1	#3	6.7
2	#4	4.75
3	#6	3.35
4	#10	2
5	#20	0.85
6	#35	0.425
7	#65	0.212
8	#200	0.075
9	Pan	<0.075

Font: Author

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

The particle-size distribution curves were obtained from the retained mass on each sieve, allowing the determination of the characteristic diameters and subsequent soil classification. After grain-size analysis, the Atterberg limits were determined for each sampling point. The Plastic Limit (PL) was obtained from three independent determinations by manually rolling soil threads until reaching a diameter of approximately 3.2 mm, following the procedure described in ASTM D4318. The average value obtained from the three determinations was adopted as the Plastic Limit for each sample.

The Liquid Limit (LL) was determined using the Casagrande cup apparatus, also following NBR 6459. For each sample, three moisture contents were determined using different numbers of blows. These results were plotted on the flow curve, and the Liquid Limit was obtained by interpolation at 25 blows, as prescribed by the standard.

Based on the results of the grain-size distribution and Atterberg limits, the soils were classified according to both the Unified Soil Classification System (USCS) and the AASHTO classification system. The pocket penetrometer measurements were then analyzed with parameters defined by ASTM D8605.

4. RESULTS AND ANALYSIS

4.1 Functional evaluations results

URCI was the first methodology applied. All the distresses and their extetions were taken to evaluate by this system and are presented in Table 5. It should be noted that, for potholes with an average diameter greater than 3 ft, the manual recommends splitting them into sub-potholes which average diameter less than 3 foot of average diameter. Figure 18 presents examples of the distresses identified.

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Table 5 – List of Distresses obtained in URCI investigation

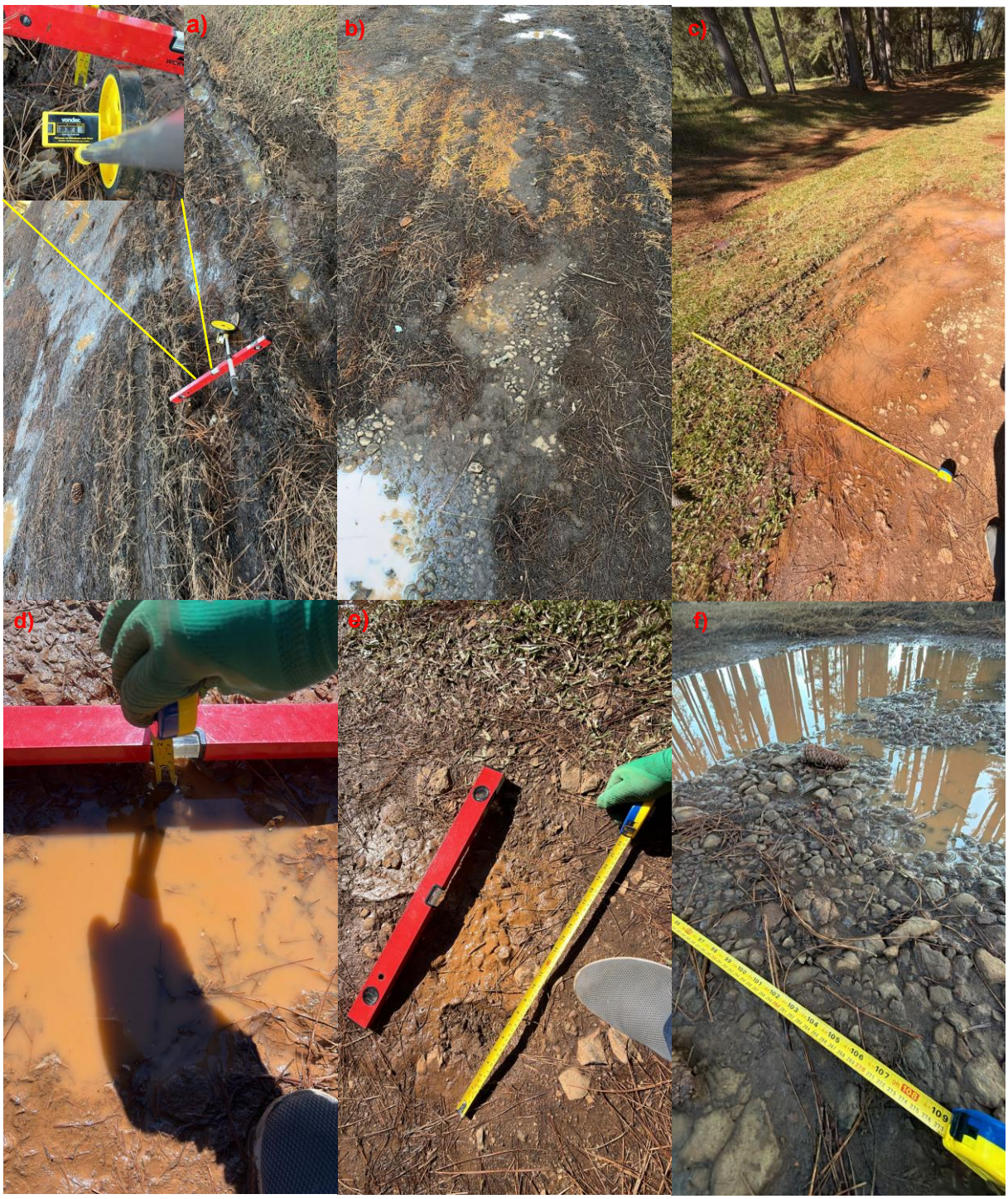
#	Type	Occurrences (n)	Area (m²)	Average Diameter (foot)	Density (%)	Severity	Deduct Value
1	Inadequate Drainage	1	9.219	-	3.69%	Medium	8.5
2	Improper Section	1	2.64	-	1.06%	Low	2.5
3.1	Rutting	6	41.3	-	16.52%	Medium	28
3.2	Rutting	1	1.1	-	0.44%	Low	0.4
4.1	Pothole	2	0.359	-	0.14%	Low	2
4.2	Pothole	31	15.847	-	6.34%	Medium	18
4.3	Pothole	12	6.875	-	2.75%	High	23
	Total:				**q = 4**	**TDV**	**82.4**

Font: Author

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Figure 18 – Some defects measured in the field survey: a) Triple Rutting (11-13); b) Improper Section (16); c) Inadequate Drainage (1); d) Low Pothole (4); e) Medium Pothole (5); f) High Pothole (21)



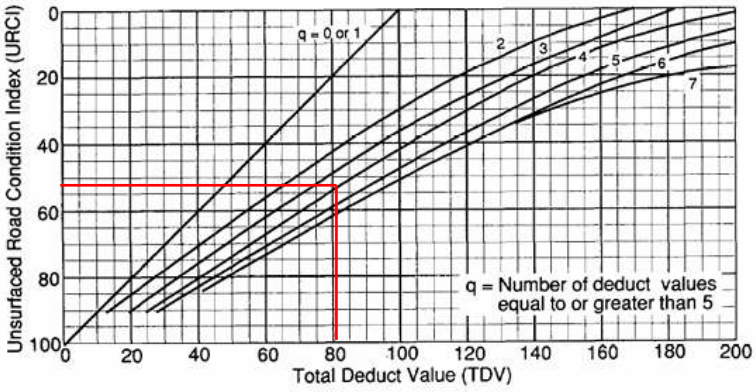
Font: Author

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Table 5 lists the field occurrences, which were then consolidated by distress type and severity level within the sample unit, as required by the URCI procedure: the areas of every occurrence sharing the same type and severity were summed, a single density was computed over the 250 m² sample unit, and a single deduct value was read from the corresponding curve in Figure 1. This consolidation reduced the 24 field-identified defects (measured as 54 individual entries once oversized occurrences were subdivided, following the manual's procedure) to seven actual type-severity combinations, yielding a Total Deduct Value of 82.4 and a q value of 4 corresponding to types of distress. Since q = 4 does not exceed 7, the corresponding curve in Figure 2 was used directly, without recourse to the q = 7 substitution rule. Projecting TDV = 82 on the q = 4 curve gives a URCI of 52, which classifies the road as fair. Figure 19 is the projection of the corrected TDV over the q = 4 curve.

Figure 19 – URCI score of the section evaluated



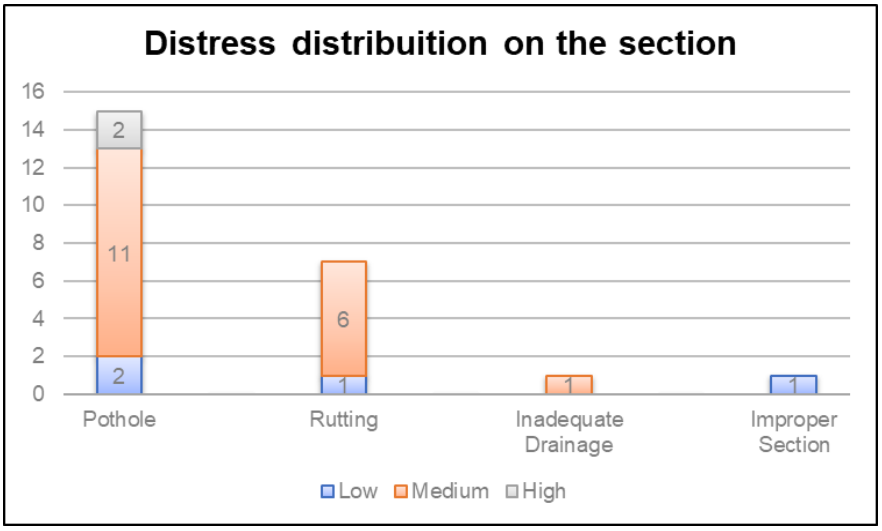
Font: Author

The concentration of distresses was analyzed also. From the total of 24, the most identified defect was potholes, then ruttings and in the bottom of the ranking improper section and inadequate drainage. Some graphs were drawn to illustrate these statistics: Figure 20 presents a bar graph of the distribution of the defects found in the section; Figure 21 shows the fractions of each type corresponds to the total count; and Figure 22 heads in potholes statitics focusing in the distribuition inside this type of defect.

REMUNOM
ISSN 2178-6925

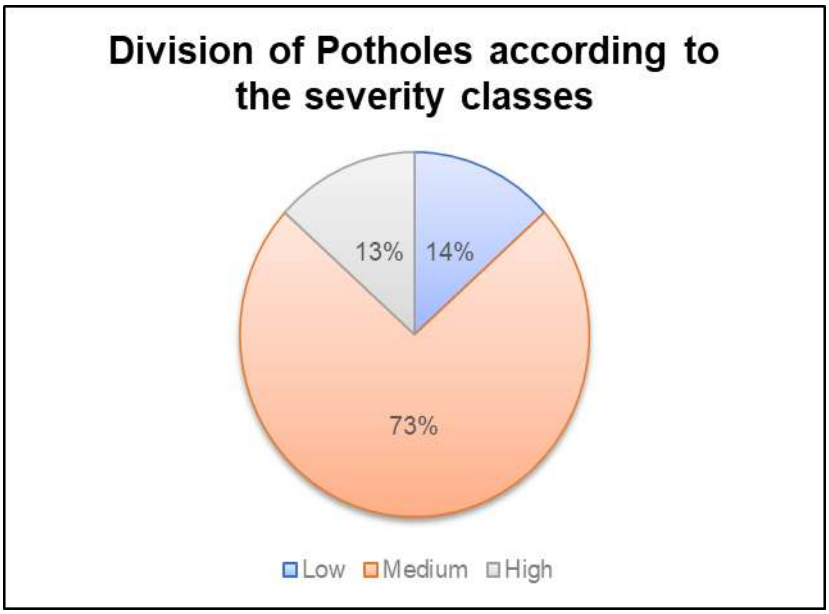
Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Figure 20 – Distribuition of defects found on the analysed section



Font: Author

Figure 21 – Percentagens of each type identified on the analysed section

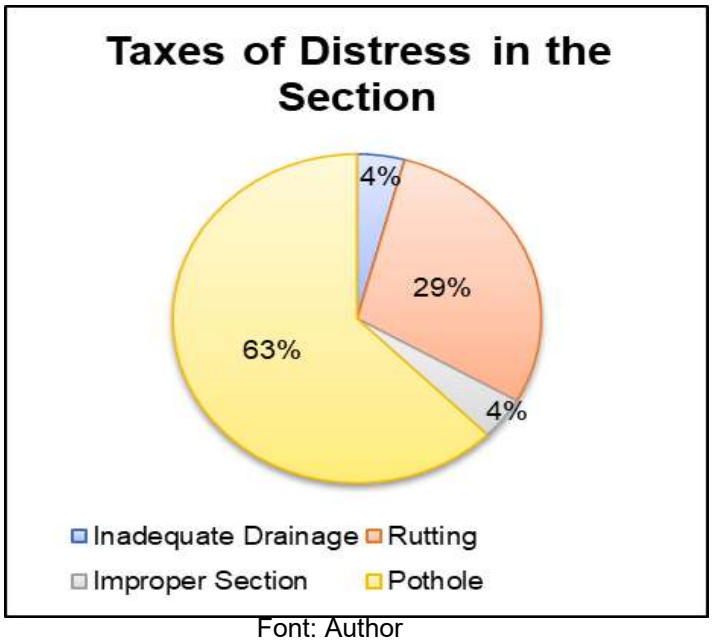


Font: Author

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Figure 22 – Potholes division in its severity classes



Font: Author

It is observed from Figure 20 to Figure 22 that potholes were the most frequent defect type, representing the majority of cases and the most common type of them were the medium severity ones. The points where penetrometer readings were taken and samples collected corresponded to two potholes: defect 5, medium pothole, and from defect 21, high pothole. It was a reasonable choice as the most common distress was potholes, specially the medium ones, indicating a performance usual to other points and the high one pothole a perfomance worst than the average of the section.

PASER gravel was analysed by the recordings made on the section. It was taken three average prints in the start-end orientation and three prints from end-start too. Respectively Figure 23 and Figure 24 present these prints. All six ratings were assigned by a single evaluator (the author), formally trained in pavement and unpaved road condition assessment. No second, independent evaluator was used, so inter-rater reliability could not be assessed; this is acknowledged as a limitation, although single-evaluator PASER surveys are common practice for network-level, resource-constrained municipal management, which is precisely the application scenario motivating this study.

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Figure 23 – Surface condition in three images in the orientation start-end



Font: Author

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Figure 24 – Surfaces condition in three images in the orientation end-start



Font: Author

The URCI of 52 placed the section in the fair class, whereas PASER, with an average score compiling the six individual scores of 1.83, median and mode of 2 indicating a class 2 section, bad condition. Rather than validating one another, the two indices offer complementary readings of the same section: PASER captures the overall visual impression that motivated the initial, intentional selection of this visibly deteriorated segment, whereas the consolidated URCI shows that the measured distresses, once correctly aggregated by type and severity within the sample unit, do not accumulate to the extent of a bad or failed rating. This divergence illustrates, on

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

a single case, the distinct philosophies underlying each method: URCI's density-based quantitative procedure and PASER's holistic visual judgment need not converge, and neither result should be generalized beyond this single, intentionally deteriorated sample unit.

4.2 Geotechnical tests results

The grain test over the two samples (A - soil from defect 5, medium pothole near the start point and B – soil from defect 20, high pothole near end point) resulted in the fractions of Table 6. The Atterberg Limits confirmed that both soils were cohesive soils. The Plastic Limit results for both soils are presented in Table 7 and Liquid Limits graphs are presented in Figure 25.

Table 6 – Results of grain size over the two samples

Order (top to bottom)	Sieve #	Opening (mm)	Soil A – Retained (%)	Soil A – Cumulative Passing (%)	Soil B – Retained (%)	Soil B – Cumulative Passing (%)
1	#3	6.7	58.42	41.58	70.86	29.14
2	#4	4.75	8.13	33.45	7.25	21.89
3	#6	3.35	6.77	26.68	3.81	18.08
4	#10	2	9.01	17.67	0.97	17.11
5	#20	0.85	4.51	13.16	5.74	11.37
6	#35	0.425	3.30	9.86	1.73	9.64
7	#65	0.212	1.65	8.21	1.13	8.51
8	#200	0.075	2.29	5.92	2.30	6.21
9	Pan	<0.075	5.92	0.00	6.21	0.00

Font: Author

REMUNOM
ISSN 2178-6925

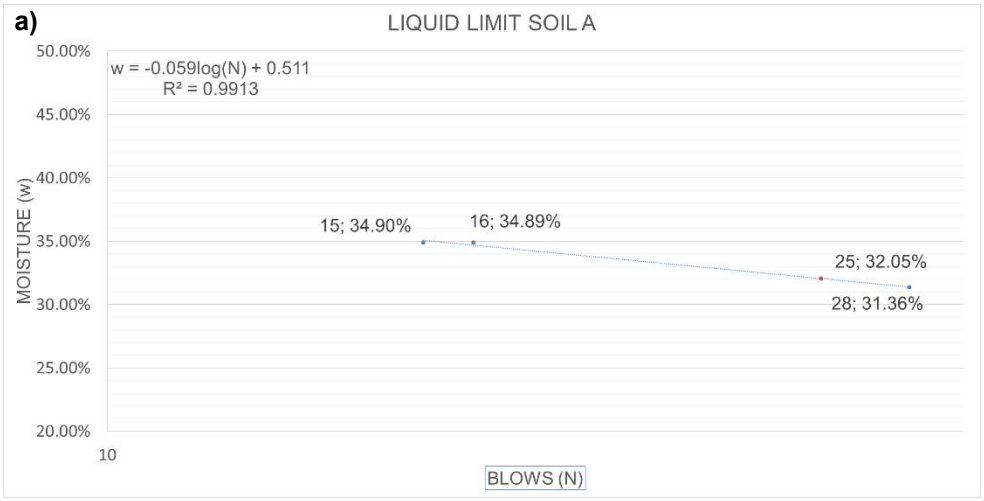
Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Table 7– Results of Plastic Limits of the two samples

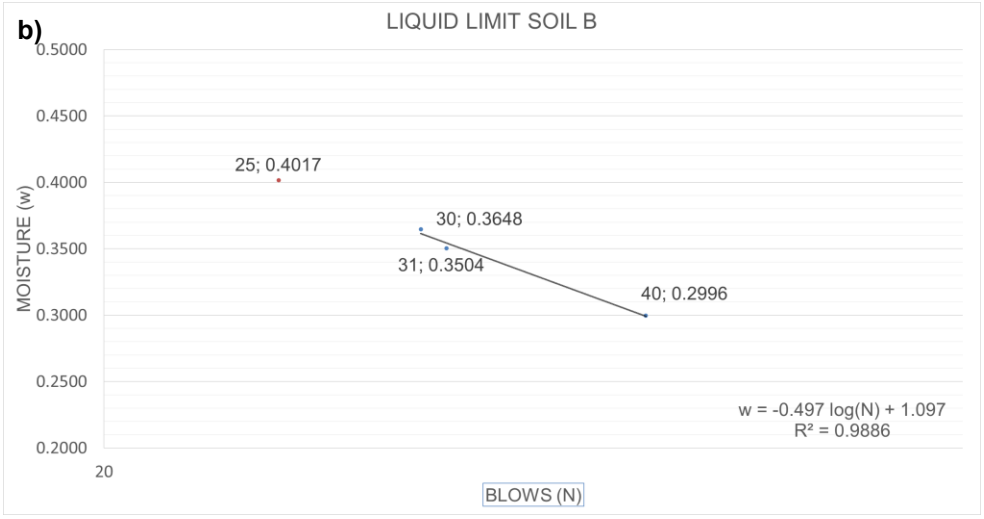
Subject	Moisture of Soil A (%)	Moisture of Soil B (%)
1	30.48%	34.39%
2	29.69%	29.28%
3	22.03%	26.71%
Average	27%	30%

Font: Author

Figure 25 – Liquid Limits from obtained from log curve of blows *vs.* moisture percentagem: a) Liquid Limit Soil near start point (A); b) Liquid Limit Soil near end point (B)



Font: Author



REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

It is particularly curious: the pothole from which Soil A was collected was not filled with water, whereas the pothole associated with Soil B was completely filled with water. Table 7 brings the results of classification systems of grain size with consistency limits and penetrometer results. These penetrometer results are showned before Table 8 in Figure 26 by pictures of the penetrometer.

Figure 26 – Results of Pocket Penetrometer before extration of soil samples: a) Soil A; b) Soil B.



Font: Author

Table 8 – Geotechnical results over the samples

Sample	AASHTO	USCS	LP	LL	PI	Group Index	Pocket Penetrometer (kgf/cm²)
A	A-1-a	GP-GM	27	32	5	0	3.75
B	A-2-4	GP-GM	30	40	10	0	2.85

Font: Author

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

The geotechnical characterization revealed that both sampling locations were classified as GP-GM according to the Unified Soil Classification System (USCS), indicating predominantly coarse-grained materials composed of poorly graded gravel containing silty fines. Despite this common classification, the AASHTO system distinguished the two samples, classifying Sample A as A-1-a (Group Index = 0) and Sample B as A-2-4 (Group Index = 0). This distinction suggests a greater influence of the fine fraction on the engineering behavior of Sample B, even though both materials belong to the same USCS classification. The dual USCS symbol (GP-GM) is confirmed for both samples by the position of their fines below the Plasticity Chart A-line, indicating silt-like (non-plastic to low-plasticity) fines rather than clay-like fines.

This difference becomes more evident when the Atterberg limits are analyzed. Sample A presented a Plasticity Index (PI) of 5 (Liquid Limit 32%, Plastic Limit 27%), indicating a material of low plasticity with limited sensitivity to moisture variations. In contrast, Sample B exhibited a PI of 10 (Liquid Limit 40%, Plastic Limit 30%), demonstrating a higher degree of plasticity and, consequently, a greater potential for strength reduction under increasing moisture conditions; it is worth noting that this PI falls exactly on the AASHTO A-2-4/A-2-6, so it should be interpreted with the corresponding caution. The higher Liquid Limit observed for Sample B (40%) further reinforces its greater susceptibility to water-induced changes in consistency. It is also noted that the Plastic Limit determinations for Sample A showed a relatively wide dispersion among the three individual readings (22.03% to 30.48%); as the test was performed as a single set of three determinations, without an independent repeat trial, this dispersion could not be checked against standard repeatability criteria and is reported here as a limitation of the present dataset rather than as a confirmed source of error.

The pocket penetrometer results followed the same tendency observed in the laboratory characterization. Sample A exhibited an average penetration resistance of 3.75 kgf/cm², whereas Sample B presented a lower value of 2.85 kgf/cm². Although both materials were classified as GP-GM by the USCS, their fine fraction exhibited

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

measurable plasticity (PI of 5 and 10, respectively) and, during field handling, the material displayed a cohesive, plastic behavior atypical of clean granular materials. This observed cohesive behavior in the field, rather than the grain-size classification alone, motivated the use of the pocket penetrometer as a practical, approximate field indicator.

The instrument nonetheless provides only an approximate, indicative estimate of field strength. Three readings were taken per point and the median one was used and showned before and averaged, following the same replication logic applied to the other index tests in this study, although the individual readings were not retained for a separate dispersion estimate. Moreover, the pothole from which Sample A was collected was dry, whereas the pothole associated with Sample B was completely filled with water at the time of inspection. Given this difference in field moisture condition, the lower resistance measured at Sample B cannot be attributed solely to its higher plasticity: it may reflect, at least in part, the higher moisture content of the material at the moment of the reading.

The functional assessment also exhibited a similar spatial tendency. As illustrated in Figures 23 and 24, the beginning of the evaluated road section was classified as PASER ratings 2 and 3 where Sample A was took, indicating poor to fair functional condition. Conversely, the end portion of the section, near Sample B, presented two locations classified as PASER 1, representing the most deteriorated areas identified during the inspection. These locations were characterized by extensive ponding water, pronounced surface deformation, potholes, and evidence of deficient drainage.

Although the PASER methodology is based on visual inspection, the observed deterioration pattern is broadly consistent with the geotechnical characterization. However, the two sampling points were not selected at random or on a regular grid: they were deliberately chosen by contrast, from a medium-severity and a high-severity pothole respectively, and were subject to different field moisture conditions at the time of testing (Item above). This design already selects points with different functional responses before the geotechnical comparison is made, and the reduced sample size (two points) precludes any statistical association. Therefore, the

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

lower field resistance and higher plasticity measured near the end of the section should be read as an exploratory, descriptive contrast between two specific points rather than evidence that plasticity causes deterioration; establishing such a relationship would require a spatially distributed sampling scheme with controlled or recorded moisture conditions.

It is noteworthy that the USCS alone was unable to clearly differentiate the engineering quality of the two sampling locations, as both materials received the same GP-GM classification. In contrast, the AASHTO classification, together with the Plasticity Index and pocket penetrometer results, provided a more detailed interpretation of the differences between the two materials. This observation highlights the importance of the use of more than one soil classification besides critically use and evaluate additional geotechnical parameters regarding performance of unpaved roads.

The results also demonstrate the complementary nature of functional and geotechnical evaluations. Functional manuals identify the type and severity of surface deterioration, whereas geotechnical tests provide information regarding the characteristics of the material that may influence the observed behavior. Consequently, integrating both approaches allows a more comprehensive diagnosis than either methodology applied independently.

Nevertheless, the results should be interpreted considering the limitations of the present study. Geotechnical characterization was performed at only two sampling locations representing the beginning and the end of the evaluated road section. Furthermore, although the URCI methodology was applied to the entire section, individual distresses were not georeferenced during the field survey, preventing the direct association between specific defects and localized soil properties. Therefore, the relationships discussed herein should be interpreted as indicative associations rather than definitive cause-and-effect relationships.

5. CONCLUSION

This study compared the functional assessment methodologies Unsurfaced Road Condition Index (URCI) and Gravel Roads Manual of Pavement Surface

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Evaluation and Rating (PASER). It was conducted on an unpaved road section of 250 m² (width of 5 for 50 meter extention) in Guarapuava-PR, southern Brazil, complemented by basic geotechnical characterization including grain-size distribution, Atterberg limits, soil classification, and pocket penetrometer testing.

The two functional methodologies indicated different conditions for the evaluated section, reflecting their distinct evaluation philosophies. After the deduct values were correctly consolidated by distress type and severity within the sample unit, the URCI classified the section with a value of 52, corresponding to the Fair class, while the PASER evaluation resulted in a section of level 2, indicating a very poor functional condition. Although URCI requires the measurement and quantification of individual distresses and PASER relies primarily on the evaluator's overall visual judgment, the two methods did not converge to the same maintenance priority for this section: PASER's holistic visual impression, which motivated the intentional selection of this segment as a deteriorated case, was more severe than the condition indicated by the consolidated, density-based URCI calculation. This divergence, observed on a single case, illustrates rather than resolves the difference between the two evaluation philosophies.

The complementary geotechnical investigation demonstrated that, despite both samples being classified as GP-GM according to the USCS, differences became evident through the AASHTO classification (A-1-a versus A-2-4), the Atterberg limits (PI of 5 versus 10), and the pocket penetrometer results. Sample B exhibited a higher Plasticity Index, lower in-situ penetration resistance at the time of testing, and a less favorable AASHTO classification, results that are compatible with, though not proof of, the greater functional deterioration observed in the corresponding portion of the road: the two sampling points differed both in pothole severity and in field moisture condition, so the geotechnical contrast should be read as an exploratory association between two selected points, not as a demonstrated cause of deterioration. These findings nevertheless reinforce that similar granulometric classifications may conceal important differences in engineering behavior when additional geotechnical parameters are not considered.

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

The results highlight the complementary nature of functional and geotechnical evaluations. While URCI and PASER successfully identify the severity and distribution of surface deterioration, laboratory and field geotechnical tests provide preliminary information regarding the material characteristics that may relate to the observed performance. Consequently, integrating both approaches supports a more comprehensive preliminary diagnosis of unpaved roads and helps identify which further investigations, such as compaction, CBR, field density, and drainage assessments, would be needed before defining specific maintenance or rehabilitation strategies.

The results highlight the complementary nature of functional and geotechnical evaluations. While URCI and PASER successfully identify the severity and distribution of surface deterioration, laboratory and field geotechnical tests provide valuable information regarding the material characteristics that may contribute to the observed performance. Consequently, integrating both approaches enables a more comprehensive diagnosis of unpaved roads and supports more technically based maintenance decisions.

One limitation of the present study is that geotechnical characterization was restricted to two representative sampling locations and individual URCI distresses were not georeferenced during the field survey. Therefore, the relationships discussed should be interpreted as indicative associations rather than definitive cause-and-effect relationships.

Future studies should integrate georeferenced functional surveys with localized geotechnical characterization at individual distress locations. Such an approach would allow direct correlations between specific deterioration mechanisms and soil properties, contributing to more robust deterioration models and improving maintenance planning for unpaved road networks.

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

REFERENCES

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO). **Standard Specification for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes** (M 145). Washington, DC, 1991. https://store.transportation.org/Item/PublicationDetail?ID=457

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 6459**: Solo — Determinação do limite de liquidez. Rio de Janeiro, 2025.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 7180**: Solo — Determinação do limite de plasticidade. Rio de Janeiro, 2025.

ASTM INTERNATIONAL. **ASTM D2487-21**: Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). West Conshohocken, PA, 2021. https://doi.org/10.1520/D2487-21

ASTM INTERNATIONAL. **ASTM D2488**: Standard Practice for Description and Identification of Soils (Visual-Manual Procedures). West Conshohocken, PA, 2009. https://store.astm.org/d2488-09.html

ASTM INTERNATIONAL. ASTM D6913/D6913M-17: **Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis**. West Conshohocken, PA, 2017. https://doi.org/10.1520/D6913_D6913M-17

AUSTROADS. **Guide to Pavement Technology – Part 6A**: Unsealed Pavements. Sydney, 2020. https://austroads.gov.au/publications/pavement/agpt06

CHAMORRO, A.; TIGHE, S. L. **Condition Performance Models for Network-Level Management of Unpaved Roads**. Transportation Research Record, Washington, DC, n. 2204, p. 1–9, 2011. https://doi.org/10.3141/2204-03

CONFEDERAÇÃO NACIONAL DO TRANSPORTE (CNT). **Pesquisa CNT de Rodovias 2024**. Brasília, 2024. https://cnt.org.br/documento/cbf59b9e-fd1a-41fc-b230-172c4dc42100

DAS, B. M.; SOBHAN, K. **Principles of Geotechnical Engineering**. 9. ed. Boston: Cengage Learning, 2018.

EATON, R. A.; BEAUCHAM, R. E. **Unsurfaced Road Condition Index (URCI)**: A Pavement Condition Rating Procedure for Unsurfaced Roads. Champaign: U.S.

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

Army Corps of Engineers, Construction Engineering Research Laboratory (USACERL), 1992. https://www.wbdg.org/FFC/ARMYCOE/COETM/tm_5_626.pdf

ETHIOPIAN ROADS AUTHORITY (ERA). **Design Manual for Low Volume Roads - Part A:** Introduction to Low Volume Road Design. Addis Ababa, 2016.

FEDERAL HIGHWAY ADMINISTRATION (FHWA). **Gravel roads**: construction & maintenance guide. Washington, DC: U.S. Department of Transportation, 2015. https://www.fhwa.dot.gov/construction/pubs/ots15002.pdf

GHIDIN, A. A. et al. Toposseqüências de Latossolos originados de rochas basálticas no Paraná: I – mineralogia da fração argila. Revista Brasileira de Ciência do Solo, v. 30, n. 2, p. 293-306, 2006. https://doi.org/10.1590/S0100-06832006000200011

HOLTZ, R. D.; KOVACS, W. D.; SHEAHAN, T. C. **An Introduction to Geotechnical Engineering**. 2. ed. Upper Saddle River: Pearson, 2011. https://rosap.ntl.bts.gov/view/dot/34136

JONES, D. **Guidelines for the Selection, Specification and Application of Chemical Dust Control and Stabilization Treatments on Unpaved Roads**. Davis: University of California Pavement Research Center, Research Report UCD-ITS-RR-17-59, 2017. https://www.escholarship.org/uc/item/0347c9zj.pdf

KELLER, G.; SHERAR, J. **Low-Volume Roads Engineering**: Best Management Practices Field Guide. Washington, DC: U.S. Agency for International Development (USAID), 2003.

MASSAD, F. **Mecânica dos Solos Experimental**. 2. ed. São Paulo: Oficina de Textos, 2016.

MONTGOMERY, S. R.; GKRITZA, K.; HADDOCK, J. E. **Factors Affecting the Accuracy and Variability of Pavement Surface Evaluations and Ratings**. Journal of Infrastructure Systems, Reston, v. 25, n. 2, 2019.

MOUSAVI, S. H.; et al. **Geotechnical properties and engineering behavior of unpaved road materials**: A review. Transportation Geotechnics, v. 29, 2021.

PARANÁ. Secretaria de Estado do Planejamento. **Paraná Interativo**. Curitiba, 2025. Base cartográfica digital do Estado do Paraná.

PINTO, C. S. **Curso Básico de Mecânica dos Solos**. 4. ed. São Paulo: Oficina de Textos, 2016.

REMUNOM
ISSN 2178-6925

Received: 13/08/2026 - **Accepted:** 20/09/2026
Vol: 13.20
DOI: 10.66104/pkee6f83
Pages: 1-48

SILVA, T. O.; PITANGA, H. N.; LOPES, E. C.; RIBEIRO, L. C. P. **Optimization Models for the Maintenance Management of Tropical Paved and Unpaved Roads**. Infrastructures, v. 9, n. 7, 2024. https://doi.org/10.3390/infrastructures 9070100

SKORSETH, K.; SELIM, A. **Gravel Roads**: Maintenance and Design Manual. Washington, DC: Federal Highway Administration, 2000. https://www.epa.gov/sites/default/files/2015-10/documents/2003_07_24_nps_ gravelroads_gravelroads.pdf

SISTEMA DE TECNOLOGIA E MONITORAMENTO AMBIENTAL DO PARANÁ (SIMEPAR). Notícias – boletim diário de chuvas, junho de 2026. Curitiba, 2026. https://www.simepar.br/simepar/timeline/noticias?page=9

SORIA, M. H. A.; FONTENELE, H. B. **Field Evaluation of Method for Rating Unsurfaced Road Conditions.** Transportation Research Record, Washington, DC, v. 1819, n. 1, p. 267–272, 2003. https://doi.org/10.3141/1819a-39

TRANSPORTATION INFORMATION CENTER (TIC). **PASER Manual**: Gravel Roads. Madison: University of Wisconsin–Madison, 2002. https://ltap.engr.wisc.edu /wp-content/uploads/2019/12/Gravel-PASER_02_rep15.pdf

UNITED STATES ARMY CORPS OF ENGINEERS (USACE). T**M 5-626: Unsurfaced Roads and Airfields**. Washington, DC: Department of the Army, 1995. https://www.wbdg.org/FFC/ARMYCOE/COETM/tm_5_626.pdf

WOLF, M. P. **Desenvolvimento do índice funcional de vias não pavimentadas RIA-UR baseado no uso de acelerômetro em reboque do tipo carretinha**. 2026. Dissertação (Mestrado em Engenharia Civil) – Universidade Tecnológica Federal do Paraná, Guarapuava, 2026. http://repositorio.utfpr.edu.br/jspui/handle/1/40496

WORLD BANK. **Design Principles for Resilient Low Volume Roads**: Engineering Best Practices Guide. Washington, DC: World Bank, 2026. https://doi.org/10.1596/44529