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Prediction of the surface rutting of unpaved road – Case study from B&T Quang Binh windfarm project

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Abstract: Unpaved roads, lacking a permanent surface course, are susceptible to surface deformation known as rutting. However, rutting estimation is often overlooked in the design process. The objective of this study is to investigate existing correlations from literature and present the results of a case study conducted at the B&T Quang Binh windfarm project in Vietnam. The findings demonstrate that some 2-parameters empirical correlations from literature can predict rutting depth effectively, with a coefficient of determination (R^2) exceeding 0.90. The value of 2 parameters of each correlation can be obtained by regression analysis from the results of trafficking tests. Therefore, the use of these correlations shows promising prospects for rutting prediction in unpaved roads.

Keywords: unpaved road; surface rutting; cyclic loading; permanent deformation; strain accumulation.

1. Introduction

Unpaved roads are characterized by their construction method, which involves placing an unbound aggregate layer directly on the existing ground or subgrade. Unlike paved roads, these roads lack a permanent surface course such as asphalt or concrete, with the vehicle wheels relying directly on the aggregate layer for support. However, a major drawback of unpaved roads is the occurrence of surface deformation in the form of rutting. Surface rutting can significantly impact the smooth passage of vehicles and pose safety risks.

Despite the importance of rutting in unpaved roads, its estimation is often overlooked in the design process. Therefore, this paper aims to address this knowledge gap by investigating and summarizing existing correlations found in literature regarding rutting depth prediction. Instead of proposing a new method, the paper focuses on presenting the findings of a real project conducted in Vietnam, which serves as a case study. Based on the results of this study, observations are made about the existing correlations in the literature. The ultimate goal is to contribute to the enhancement of design practices for unpaved road systems.

2. Literature review

In the existing literature, there is a lack of direct research specifically focused on the topic of rutting depth in unpaved roads. Most studies in the literature primarily concentrate on predicting settlement, which refers to the permanent or accumulated deformation or strain of the soil, whether it is cohesionless or cohesive, under repeated or cyclic loading conditions. To explore the parameter of rutting depth, two main approaches are commonly utilized: the implicit method and the explicit method.

The implicit method, based on elastoplastic theory, involves simulating each cyclic loading process, where the permanent strain is derived from calculated stress-strain loops. However, this method requires significant computation time, rendering it impractical for engineering applications involving large cycle numbers.

On the other hand, the explicit method often relies on empirical fitting formulas derived from real tests, typically cyclic triaxial tests, to establish correlations between accumulative strain and various influencing factors such as initial stress state, soil density, cyclic stress amplitude, and number of cycles. Explicit models are more specific and practical for engineering applications. Compared to implicit models, explicit models offer greater convenience and accuracy when dealing with a high number of cycles, as the accumulation of systematic errors aligns with the physical accumulation process.

Given that the explicit method is deemed more suitable for engineering applications, this paper solely focuses on utilizing the explicit method for predicting rutting depth in unpaved roads. Considering that unpaved roads in Vietnam typically employ drained materials as aggregates, the research specifically concentrates on correlations applicable to drained materials. Additionally, to ensure practicality and ease of implementation, the paper avoids overly complex correlations with numerous parameters that would pose challenges for regression analysis. Instead, correlations featuring only two regression parameters are selected as they strike a balance between accuracy and simplicity.

Barksdale [1], based on cyclic triaxial tests with 10^5 load cycles, found that the accumulation of permanent axial strain was proportional to the logarithm of the number of load cycles for a given stress state. The prediction model can be expressed as follows:

$$\epsilon_p = a + b.\log N \quad (1)$$

where a and b are regression parameters.

Similarly, Lentz [2], through drained cyclic triaxial tests on highway subgrade sand, observed the same relationship between permanent axial strain and the number of cycles.

However, Sweere [3], in their study on the long-term response of granular materials using cyclic triaxial tests, found that the previous equation did not fit the test results well. They proposed that the accumulation of permanent axial strain was proportional to the number of load cycles in a double logarithmic coordinate system for many cycles. The relationship between permanent axial strain and the number of cycles was given as follows:

$$\epsilon_p = a.N^b \quad (2)$$

where a and b are regression parameters.

Gotschol [4] obtained similar results based on a series of large-scale cyclic triaxial tests on ballast. Although these models have a simple form, they fail to account for the effect of cyclic stress level on accumulative deformation, limiting their applicability.

Paute et al. [5] suggested that permanent strain increases gradually towards an asymptotic value. They expressed the relationship between permanent axial strain and number of cycles as follows:

$$\epsilon_p = \frac{A\sqrt{N}}{\sqrt{N}+D} \quad (3)$$

In this study, the author aims to assess the applicability of the three selected correlations by applying them to the field results obtained from a real project in Vietnam. The focus is on evaluating how well these correlations perform in predicting the rutting depth in the specific context of the project. By comparing the performance of the correlations against the actual field measurements, the study seeks to determine their effectiveness and suitability for practical application in similar unpaved road scenarios. This comparative analysis will provide valuable insights into the predictive capabilities of the correlations and contribute to the understanding of rutting behavior in unpaved roads.

3. Case study of B&T Quang Binh windfarm project

The B&T Quang Binh windfarm project is situated in Quang Ninh and Le Thuy District, which are located in the central province of Quang Binh, Vietnam. This windfarm project has a total capacity of 252 MW, as depicted in **Figure 1**. As one of the largest windfarm projects in Vietnam that has successfully commenced commercial electricity generation, it comprises two clusters. The Quang Ninh district cluster consists of 26 turbines, while the BT2 wind farm cluster initially had 24 turbines in the first stage and an additional 10 turbines in the second stage.

Figure 1. B&T Quang Binh windfarm project location

As the EPC (Engineering, Procurement, Construction) contractor of BOP (Balance Of Plant) work of the project, Fecon Corporation was responsible for constructing a trial unpaved road and conducting a comprehensive series of tests to assess its performance and optimize its structure [6]. The access road structure was divided into three categories: windfarm pavement, trunk road pavement, and branch road pavement. The design of the road structure consisted of a 310mm thick aggregate sub-base of type 2 and a 150mm aggregate base of type 1, adhering to the current TCVN 8859:2011 Vietnamese standard [7]. Both the aggregate base and subbase layers were compacted to achieve a minimum compaction density of 98%. The subgrade was filled with a mixture of stone, compacted to a minimum density of 95%, and a layer of filling sand was added. **Figure 2** depicts the typical cross-section of the unpaved roads, providing a visual representation of the road's structure.

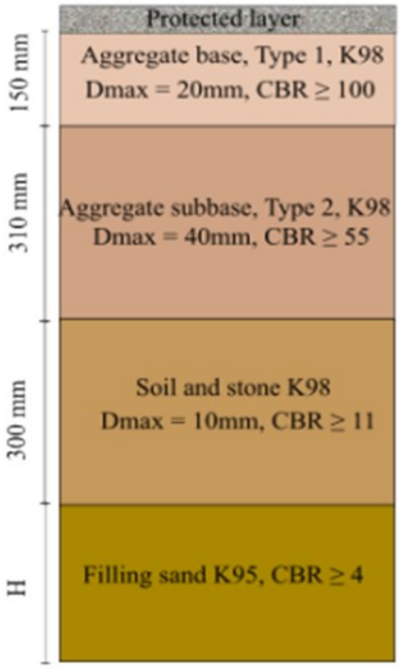

Figure 2. Structure of trial unpaved road

The construction process of the trial section involves several stages, including subgrade preparation, sub-base and base layer construction, and compaction. A depiction of the construction operations is provided in **Figure 3**, capturing the various stages of the construction process.

Figure 3. Construction process of trial unpaved road (a) subgrade preparation; (b) Subbase & base preparation; (c) Base compaction

During the construction process, the density of the aggregate is carefully monitored using the sand cone method according to the current Vietnamese standard 22TCN 346:2006 [8]. This method involves measuring the volume of a hole created in the compacted aggregate and comparing it to the known volume of the hole (**Figure 4**). By calculating the density based on the volume and weight of the material, the density of the aggregate can be determined. This ensures that the aggregate meets the required specifications and provides a solid foundation for the road.

Figure 4. Checking density by sand cone method

Once the construction is finished, the structure of the road undergoes a plate load test according to the standard DIN 18134:2012-04 [9]. The plate load test involves placing a large, flat plate on the surface of the road and applying a known load. The resulting deflection of the plate is measured, allowing the determination of the deformation modulus of the road (**Figure 5**). This modulus provides valuable information about the road's load-bearing capacity and its ability to withstand the anticipated traffic loads.

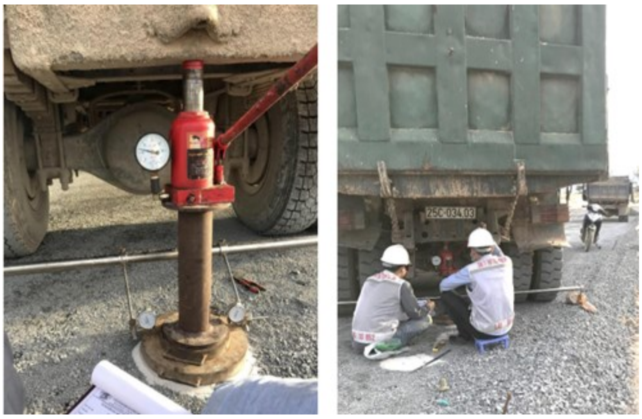

Figure 5. Plate load test

Subsequently, the road is subjected to a trafficking test, which involves the repeated loading and movement of fully loaded vehicles over different sections of the unpaved road. While trafficking tests are not commonly conducted in Vietnam, they are regarded as the most effective method for evaluating the performance of unpaved road sections. These tests are similar in approach to those conducted by the US Army Corps of Engineers [10] and the design guidelines provided by AASHTO 1993 [11]. By subjecting the road to realistic traffic loading, the trafficking test provides insights into the road's durability, deformation, and overall performance.

During the trafficking test, fully loaded dump trucks equipped with a single-axial dual wheel gear are utilized. These trucks are loaded and driven in both directions of the unpaved road. To minimize the side effects of the load, the tire position is carefully managed within the buffer zone outside the designated test area. The trucks typically travel at an approximate speed of 5 km/h while passing through the test area (**Figure 6**).

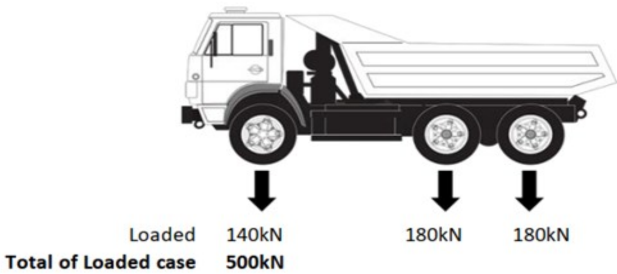

Figure 6. Trafficking test of the trial unpaved road

After a specified number of trucks pass over the road, measurements are taken to assess the surface rutting. Rutting depths are measured using a straight wooden bar, as illustrated in **Figure 7**. The frequency of measurement follows a specific pattern:

- Measurements are taken every 5 truck passes during the initial 30 passes.
- Subsequently, measurements are taken every 5 passes from 30 to 100 passes.
- Then, measurements are taken every 50 passes from 100 to 300 passes.
- Finally, measurements are taken every 100 passes from 300 to 1200 passes.

By adopting this measurement schedule, the progression of surface rutting can be effectively monitored and evaluated at various stages of truck trafficking. This data enables the assessment of the road's performance and the impact of truck loading on surface deformation.

Figure 7. Measure of rutting depth

The evolution of rutting depth during the test is depicted in **Figure 8**. Visually, the plot can be divided into two distinct stages. In the first stage, which spans approximately 100-200 initial passing, the rutting depth experiences rapid development, reaching a value of around 20mm. Following this, the second stage ensues, comprising approximately 1000 additional passing, during which the rutting depth develops at a slower rate, accumulating an additional 10mm of depth.

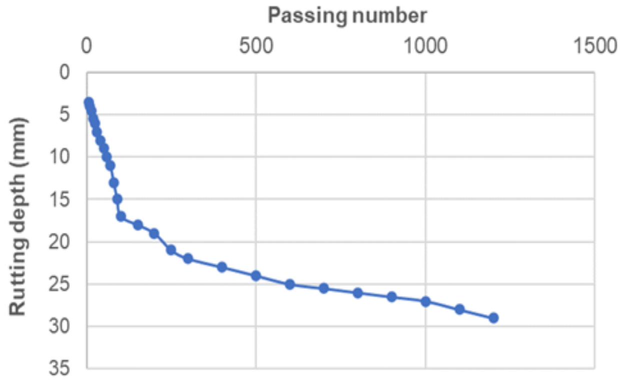

Figure 8. The rutting depth development during the trafficking test

To predict the evolution of rutting depth recorded in the field, three reported correlations (1), (2) and (3) are consecutively utilized. Each correlation involves two unknown parameters. The procedure for determining these parameters is as follows:

- Step 1: Apply the correlation to two specific passage numbers, denoted as N_1 and N_2, resulting in two equations.
- Step 2: Solve the system of two equations to obtain the values of the two parameters.
- Step 3: Repeat this procedure with different combinations of N_1 and N_2 to determine the value pair that provides the best fit with the measured values.
- The fitting degree of the predicted values with the measured values is evaluated using the classic coefficient of determination, R^2.

Notably, for all three correlations, the highest coefficient of determination is achieved when the values of the two parameters are calculated using the initial value (at 5 passes) and a value approximately halfway through the total number of passes (around 600 passes). **Table 1** displays the values of the two parameters that result in the best fit for each correlation, along with their corresponding coefficients of determination.

Figure 9 visually represents the curves generated by the three correlations, as well as the measured values, allowing for a direct comparison. This graphical representation enables an assessment of the accuracy and agreement between the predicted values from each correlation and the actual measured values of rutting depth.

Table 1. Three correlation with best fitting parameter value and corresponding coefficient of determination

	Parameters	R^2
Barksdale, 1972 $\epsilon_p = a + b.\log N$	a = -0.008 b = 0.010	0.900
Sweere, 1990 $\epsilon_p = a.N^b$	a = 0.004 b = 0.402	0.922
Paute et al. 1988 $\epsilon_p = \frac{A\sqrt{N}}{\sqrt{N}+D}$	A = 0.145 D = 39.477	0.966

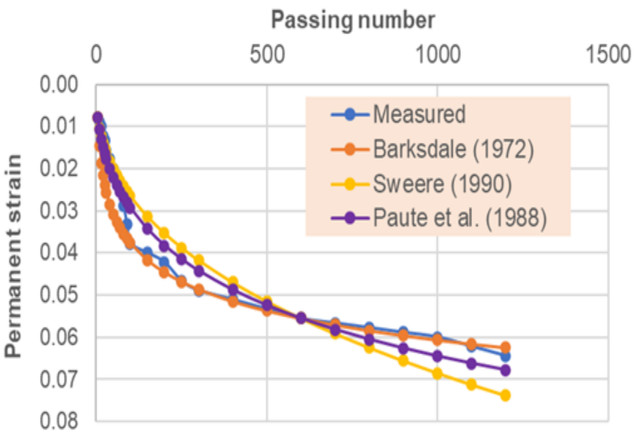

Figure 9. Comparing of the results predicted by three correlations and the measured value

It is observed that all three correlations demonstrate good fitting with the measured values, with coefficient of determination (R^2) exceeding 0.90. Among them, the Barksdale's correlation stands out as it provides the best overall fitting, particularly during the second stage of the test. Although it exhibits the lowest R^2 value, this can be attributed to higher deviations at certain local points during the first stage of the test. Despite this, the Barksdale correlation shows superior performance in predicting the rutting depth evolution in the unpaved road test.

When using the three correlations to estimate the rutting depth at a very large number of wheel passes, such as 100,000 passes, the predicted values by the correlation by Barksdale and Paute et al. show good agreement, with values of 48mm and 58mm, respectively. However, the correlation by Sweere yields an excessively large prediction of 187mm, approximately four times larger than the other two correlations.

Based on these results, it becomes evident that the Barksdale's correlation performs the best among the three correlations in predicting the rutting depth of the unpaved road. Therefore, it is recommended to preferentially utilize the Barksdale's correlation for accurate predictions of rutting depth in similar unpaved road scenarios.

4. Conclusion

In conclusion, several key findings can be drawn from this study:

For the B&T Quang Binh windfarm project, the evolution of rutting depth in the unpaved road during the first 1200 wheel passes can be accurately predicted using correlations with two regression parameters. These correlations exhibit a coefficient of determination (R^2) higher than 0.90, indicating a strong fit with the measured values.

The two parameters in each correlation can be determined through regression analysis using the results of the trafficking test. Notably, the best coefficient of determination is achieved when the parameter values are calculated using the initial value (at 5 passes) and a value approximately halfway through the total number of passes (around 600 passes).

When estimating the rutting depth at a very large number of wheel passes, such as 100,000 passes, the predictions by the Barksdale and Paute et al. correlations yield similar results, while the prediction by the Sweere correlation is significantly higher.

Among the three correlations examined, the Barksdale correlation consistently performs the best in terms of predicting the rutting depth of the unpaved road. Therefore, it is recommended as the preferred correlation for predicting rutting depth in similar unpaved road scenarios.

References

[1]. R.D. Barksdale. (1972). Laboratory evaluation of rutting in base course materials. *Proceedings of the Third International Conference on Structural Design of Asphalt Pavements, London*, pp 161-174.

[2]. R.W. Lentz. (1979). Permanent deformation of cohesionless subgrade material under cyclic loading. *Ph.D. Thesis, Michigan State University*.

[3]. G.T.H. Sweere. (1990). Unbound granular bases for roads. *Ph.D. Thesis, University of Delft.*

[4]. A. Gotschol. (2002). Veranderlich elastisches und plastisches Verhalten nichtbindiger Boden und Schotter unter zyklisch-dynamischer Beanspruchung. *Ph.D. Theis, University Kassel*.

[5]. J.L. Paute, P. Jouve, J. Martinez and E. Ragneau. (1988). Modèle de calcul pour le dimensionnement des chaussées souples. *Bulletin de Liaison des Laboratoires des Ponts et Chaussees*, 156, 21-36.

[6]. BT-BOP-CMWMS-1100-0001. Report on trial construction of access road by mechanically stabilised layers - triax geogrids.

[7]. Tiêu chuẩn Quốc gia Việt Nam. (2011). TCVN 8859:2011. Graded aggregate bases and subbases pavement - Specification for construction and acceptance.

[8]. Tiêu chuẩn ngành. (2006). 22TCN 346:2006. Testing procedure on definition of compaction of road foundation and embankment by sand cone method.

[9]. Testing and Improving Insitu Conditions. (2012). DIN18134:2012-04. Determining the deformation and strength characteristics of soil by the plate loading test.

[10]. G.M. Hammitt. (1970). Thickness Requirements for Unsurfaced Roads and Airfields. Bare Base Support. *Waterways Exp Sta Tech Repts, Army Ce*.

[11]. Transportation Officials. (1993). AASHTO Guide for Design of Pavement Structures, Vol. 1.