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Correlation between functional and structural properties of flexible pavement

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Abstract. The functional properties and structural properties are very important in order to evaluate and determine the pavements performance. In pavement condition assessment, monitoring and measurement on the functional and structural properties of the pavement are really needed in order to determine the remaining life of the pavement before any rehabilitation work can be done. This study had further looked on the correlations between these functional and structural properties on a flexible pavement. The study had collected 1198 numbers of functional properties data namely International Roughness Index (IRI), rut depth and texture depth. While for structural properties, 120 numbers of elastic modulus and 12 numbers of California Bearing Ratio (CBR) data has been measured. The functional properties were measured by using Multi Laser Profiler (MLP), while the structural properties were collected by using Falling Weight Deflectometer (FWD) and Dynamic Cone Penetrometer (DCP). The data collection was done along 60 km of asphalt pavement road. Regression analysis shows that the coefficient of determination, R2 obtained for all parameter is near to 0. These results generally conclude that there are no correlations between the functional properties and structural properties on a flexible pavement.

1. Introduction

Pavement evaluation is carried out to determine the existing condition of pavements in terms of its functional and structural adequacy. The data obtained from pavement condition assessment were used to decide the type of maintenance operations required, prioritization of maintenance works and for establishing a pavement maintenance management system. Evaluation of pavement surface condition can be studied with reference to the riding quality in terms of surface roughness, undulations cracking, potholes and other surface distresses which relate to the functional properties [1, 2]. Deterioration on functional properties will lead to this functional failure, which describes pavement structures incapable of carrying out their functions at the intended serviceability; causing discomfort to passengers or high stresses to vehicles given their excessive roughness [3-5].

Pavement structural evaluation is concerned with the structural capacity of the pavement as measured by deflection, load bearing, layer thickness, and material properties [6]. The main structural function of pavement is to support the wheel loads applied to the carriageway, distribute them to the underlying subgrade and to provide a uniform skid-resistant running surface with adequate service life [7]. The structural properties of pavement include density, thickness, stiffness and deflection.

The conditions of flexible pavement are important to ensure the roads are always in a safe and comfortable to be used. Comfort and road safety is also influenced by the nature of the functional properties and structural properties of the road. Other than that, material properties play a vital role to determine the structural and functional performance of pavement layers during its service life.

A finding from Rada et al. [8] shows that there is no correlation between riding quality and structural properties of the road. Rada et al. [8] concludes that a good riding quality does not represent a good structural support. Clearly, pavement structural and functional performances are not dependent on each other, even though they are not related in a one-to-one manner that can provide a Pavement Management System (PMS) shortcut. However, this does not mean that structural parameters are not important for consideration in roughness prediction models, that roughness could not be one factor in the rate of structural deterioration, or that many common factors do not affect both roughness and structural capacity [8].

According to Trivedi and Kumar [9], the strength parameters of subgrade and granular layer are correlated with the permanent deformations characteristics. The characteristics of subgrade, granular and base layer material properties have a significant impact on the performance of the flexible pavement. In this study, the correlation of CBR and modulus of elasticity are moderated with the rutting. The characteristic of deflection, California bearing ratio (CBR) were correlated individually with the rutting measurement and sensitivity analysis has been performed. The result shows that characteristic deflection and modulus of elasticity of subgrade, and granular layer individually consist good relation with rutting value. However, no correlation was found between CBR and rutting value for both subgrade and subbase layer. Findings from Kim and Park in 2002 [10] also concludes that the rutting prediction procedure using multi-load level deflections can estimate an excessive level of rutting quite well and, thus, improve the quality of prediction for rutting potential in flexible pavements.

As additional, the correlation between functional parameter itself was also explored by Suleiman et al. [11]. Findings from Suleiman et al. shows weak correlation between texture depth and roughness index of the road surfaces but the general trend shows a weak positive correlation where a higher texture depth will leads to a higher roughness index [11].

Apart from that, based on Lin et al. [12], the results of the analysis prove that IRI can be used either to evaluate the quality of pavement projects or to fully respond to the characteristics of the pavement deterioration process, which can be used as the basis for road maintenance evaluation.

Functional and structural properties of a flexible pavement remain as the main criteria that need to be assessed continuously. One could argue that riding quality as functional properties is not an indicator of structural properties adequacy. However, if the pavement is not properly designed, distresses will likely develop quickly, which could result an increase in roughness. Perhaps this increase in roughness could be related to structural properties adequacy. Therefore, correlations between functional and structural properties of a pavement need to be further explored. This study will further look into various probabilities of the correlations exist between the functional and structural properties of a flexible pavement.

2. Methodology

The data collection was performed along 60 km of road which involved three different sites testing located at Jalan Muar – Yong Peng (FT24), Jalan Parit Yusuf (FT085) and Jalan Pintasan Muar (FT224) as seen in Figure 1. The types of material on the road involved are asphaltic concrete for surface layer and granular base for road base. This research had focused only on data collection relates to IRI, rut depth, texture depth, elastic modulus and California Bearing Ratio (CBR). The study was involved data collection by non-destructive test by using the Multi Laser Profiler (MLP), Falling Weight Deflectometer (FWD) and Dynamic Cone Penetrometer (DCP). Pavement evaluation is carried out to determine the existing condition of pavements in terms of its functional and structural adequacy. The data obtained from pavement condition assessment.

Figure 1. Site location.

Table 1: Pavement Functional Properties Classification [13].

Functional Properties	Values
International Roughness Index (m/km)	
Good	<2
Fair	2 - 3
Poor	3 – 3.8
Bad	> 3.8
Rut Depth (mm)	
Good	< 5
Fair	5 -10
Poor	10 -20
Bad	> 20
Texture Depth (mm)	
Good	< 0.5
Fair	0.3 – 0.5
Poor	> 0.5

For functional properties, the data was collected at every 100m interval on by using Multi-laser Profiler, that produced 1198 numbers of data for IRI, rutting and texture depth. While for structural properties, there were two non-destructive tests has been conducted. Elastic modulus properties were collected at every 1000m interval by using Falling Weight Deflectometer that produced 120 numbers of data and CBR data was collected at every 5000 m interval by using dynamic cone penetrometer which produced 12 numbers of data in total. All tests were conducted at both direction of road.

The measured data on functional properties were then classified according to Malaysian Highway Authority (MHA) [13] specification, which is shown in Table 1. While data collected for structural properties such as elastic modulus and CBR were classified based on JKR 1994 [14] and JKR 2013 [15] respectively. This can be seen as in Table 2.

Table 2. Pavement Structural Properties Classification.

Structural Category	Types of Layer		
	E1 (Bituminous)	**E2 (Granular Base)**	**E3 (Subgrade)**
Elastic Modulus (Mpa) [14]			
Poor	< 1500	< 200	< 50
Satisfactory	1500 - 2500	200 - 300	50 - 100
Sound	> 2500	> 300	> 100
California Bearing Ratio (%) [15]			
Above Min Limit	NA	> 80	> 5
Below Min Limit	NA	< 80	< 5

3. Results

3.1 Pavement functional and structural condition

Figure 2 shows the percentage for International Roughness Index. It can be seen, in terms of roughness, 31 % of the roads are in good conditions. Only 20% of the roads are in bad while the rest are in fair and poor conditions. Figure 3 shows the rut depth value for 60 km of road. It shows that 85% of the roads are in good condition with maximum rut depth value of less than 5 mm. For texture depth, Figure 4 clearly shows that 69% of the roads are having texture depth greater than 0.5mm. Generally it can be seen that the functional properties are in good condition.

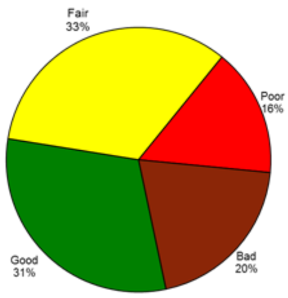


Figure 2. IRI.

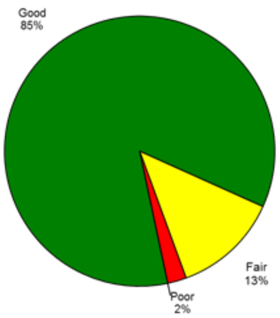


Figure 3. Rut depth.

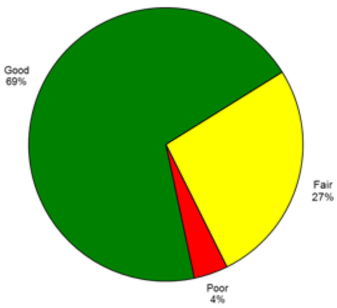
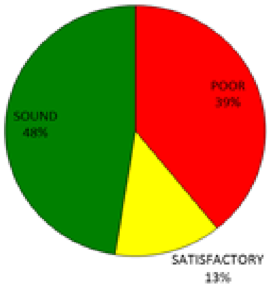


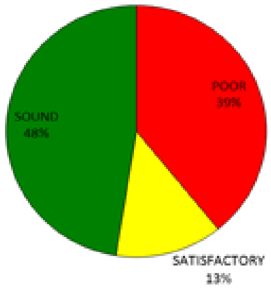
Figure 4. Texture depth.

Figure 5 show the results on the percentage of road having different condition types of elastic modulus. For elastic modulus, it can be seen that for all layers (bituminous surfacing, granular subbase and subgrade layer), nearly more than 50% of the road are having good conditions with elastic modulus comply with the requirement which has been stated in JKR 1994[14]. About 13% - 20% of the road experiencing elastic modulus within the satisfactory value and only 29% (bituminous layer) and 39% (granular subbase) from the total road are having poor value of elastic modulus.

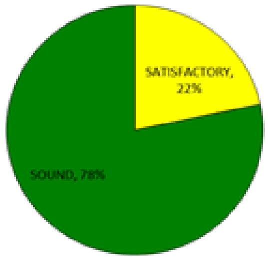
Figure 6 however shows the percentage of subgrade and granular subbase that having CBR which comply to the JKR 2013 [15] requirement. Based on JKR 2013 [15], the minimum value of CBR for subgrade layer and granular subbase layer is 5% and 80% respectively. As in Figure 6, it shows that 75% of the roads are having CBR below the minimum requirement, both for subgrade and granular subbase. Only 25% of the roads are having CBR subgrade and granular subbase that comply with the minimum requirement of the JKR (2013) [15].



(E1) Bituminous.

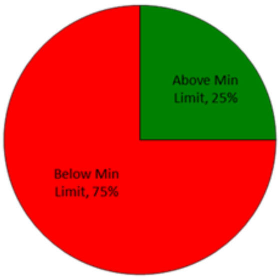


(E2) Granular.

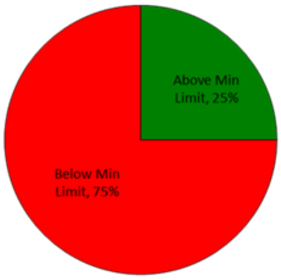


(ES) Subgrade.

Figure 5. Elastic Modulus at different layers.



(E2) Granular.



(ES) Subgrade.

Figure 6. California bearing ratio.

3.2 Correlation between elastic modulus (structural property) and IRI; rut depth; texture depth (functional properties)

Figure 7 shows the correlation between elastic modulus (for different structural layers) and IRI. The coefficient determination, R2, was found to be within the range 0.0007 – 0.3738, showing no correlations at all between IRI and elastic modulus. This result agrees with the findings by Rada et al. [8] where the study concludes that a good riding quality is not totally depending on the structural layers materials properties.

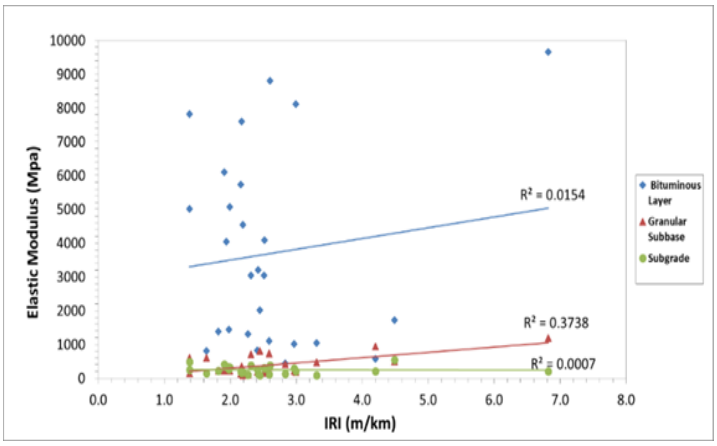


Figure 7. Correlation between Elastic Modulus and IRI.

Similar result has been found when looking at correlations between elastic modulus and rut depth as presented in Figure 8. Coefficient determination, R2, which is near to zero, indicates no correlation at all between these properties. This result slightly contradict from what been found by Trivedi and Kumar [9] where a moderate correlation between elastic modulus and rutting properties was reported.

A positive correlation is also found between elastic modulus of asphalt layer and texture depth. Higher elastic modulus for asphalt layer has leads to a higher texture depth. Higher stiffness asphalt mixture has led to a less embedment of aggregate which contributes to a higher texture depth. However, this coefficient determination was considered as very weak since R2 value is very near to zero as presented in Figure 9.

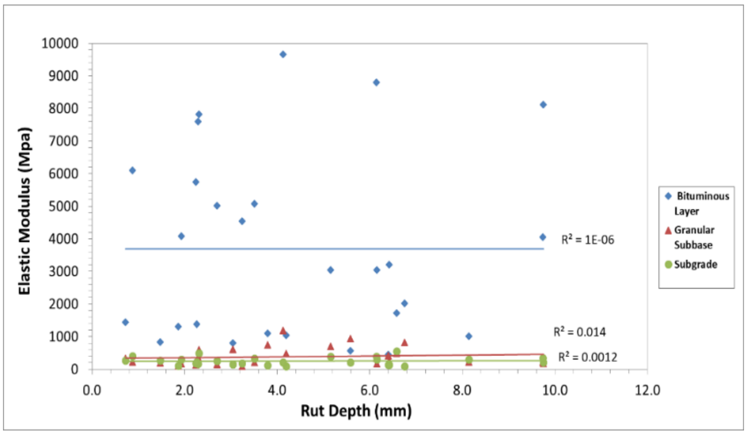


Figure 8. Correlation between Elastic Modulus and Rut Depth.

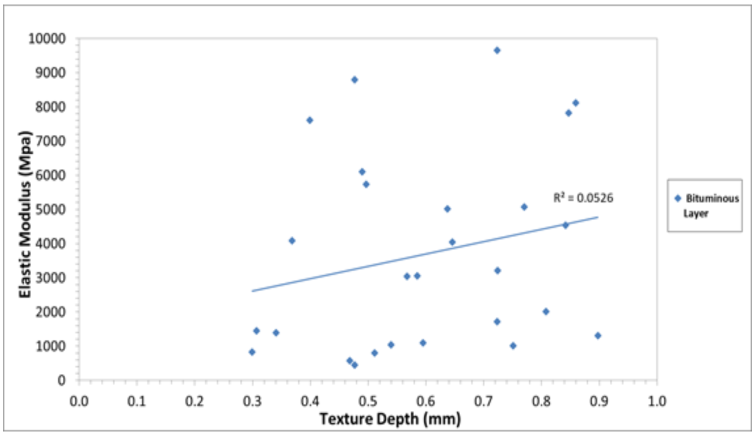


Figure 9. Correlation between Elastic Modulus and Texture Depth.

3.3 Correlation between CBR (structural property) and IRI; rut depth (functional properties)

Figure 10 and Figure 11 show the correlations between CBR (granular roadbase and subgrade) towards IRI and rut depth respectively. With coefficient determination, R2, approaching near to zero, it is clearly shows that are no correlations observed between structural property (CBR) and functional properties (IRI and rut depth). The variations in CBR was not influenced either by IRI or rut depth. Rut depth that occurred might not cause by the structural failure which comes from the subgrade or subbase. This might be due to the non-structural rutting which originally comes from the failure of bituminous material at surfacing layer.

These results confirms with the findings by Trivedi and Kumar [9]. The study found that by having coefficient determination, R2 near to zero, it proves that the CBR were not related at all with rut depth for both subgrade and subbase layer.

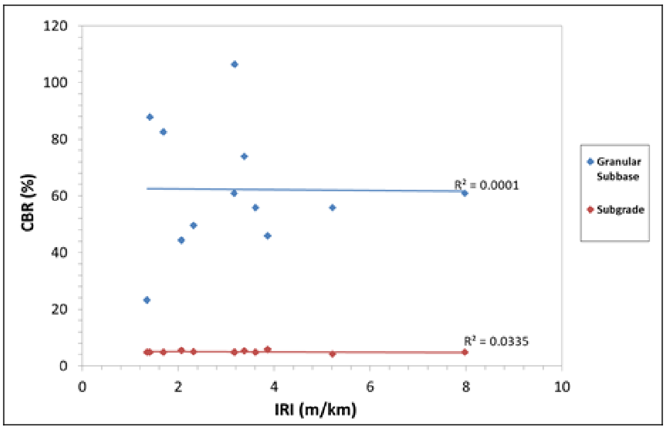


Figure 10. Correlation between CBR and IRI.

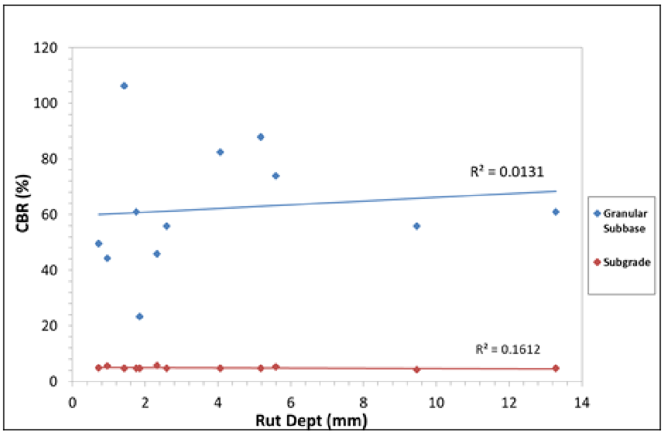


Figure 11. Correlation between CBR and Rut Depth.

4. Conclusion

The results obtained from this study indicate that there are no correlations (R2 near to zero) between functional and structural properties. These outcomes might be due to the lack of variations in data conditions severity. More than 60% of the roads are having functional data in good and fair conditions. With a very minimum numbers of poor and bad conditions data had led to a weak or no correlations between these properties. Apart from that, CBR data measured from DCP test was more to a spot measuring test which represents a small specific area of the road while the rest of the tests were considered as network survey where data collections were more precise at smaller scale and had been average at certain length depending on the setting of the equipment. Different data collection accuracy which represents the conditions of the pavement at existing locations might be another reason which contributes to these weak or no correlations results between structural and functional properties. Besides that, the functional and structural data collections were done separately at different time approximately 3 months apart. With 3 months different, there will be possibility that the conditions of the pavement had slightly changed and therefore, the structural data collected were not denote purely to the earlier functional conditions measured. This could be another reason that cause to this weak or poor correlations observed in this study.

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