IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Relationship between rutting, roughness and resilient modulus of flexible expressway pavement

To cite this article: Z A M Noor *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **220** 012019

View the article online for updates and enhancements.

This content was downloaded from IP address 103.61.37.179 on 11/10/2019 at 20:18

Relationship between rutting, roughness and resilient modulus of flexible expressway pavement

Z A M Noor[1], M R Hainin[2], M K Idham[2], M N M Warid[2] and S N Naqibah[2]

[1] Politeknik Merlimau, 77300 Merlimau, Melaka
[2] School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia 81310 Johor Bahru, Johor

Abstract. The study was conducted to investigate the relationship between rutting, roughness and resilient modulus of flexible expressway pavement. The evaluation was conducted at Shah Alam Expressway from km 17.90 to km 52.20. The expressway consisted of three lanes for each bound (slow, middle and fast lanes). The scanner vehicle was used to evaluate the roughness and rutting of the entire test section and the roughness value was given in the International Roughness Index (IRI). While, the resilient modulus values for bituminous layer (E1), road base (E2) and subgrade (E3) were determined by Falling Weight Deflectometer (FWD). IRI and rutting values show that the expressway was in a good to satisfactory condition. In term of resilient modulus, most of the E1 and E2 layers were in the sound to satisfactory condition except 20.1% and 32.1% of the slow lane section was in poor condition, respectively. Resilient modulus of E3 for the entire section was in the sound to satisfactory condition. As a conclusion, the fast lane shows a better condition compares to the middle and slow lanes. In addition, poor correlation was found between rutting, roughness and resilient modulus respectively.

1. Introduction

Pavement can be classified into flexible and rigid pavements. About 95% of the whole world's highways are flexible pavement [1]. A flexible pavement typically consists of layers of different materials that increase with strength as you move towards the surface (weakest layer on the bottom, strongest layer at the surface). A flexible pavement relies on a layered system to distribute traffic loads over the subgrade. The load carrying capacity of a flexible pavement is brought about by the load-distributing characteristics of each layer in the layered system. The layers of a flexible pavement structure typically consist of hot mix asphalt (HMA) at the surface, with a stabilized base, base course gravel, and/or sub-base course gravel. Flexible pavement is designed to bend and rebound with the subgrade. The design concept is to lace sufficient layers of base and intermediate courses of the pavement so as to control the strains in the subgrade so that no permanent deflections result.

The Mechanistic-empirical design of flexible pavement is based on limiting the distress in the pavement structure. Pavement distress is caused by the different types of loadings mainly structural and environmental loadings. Environmental loadings are addressed in the selection of the asphalt binder. The structural loading distresses are mainly fatigue cracking and permanent deformation (rutting). Although these two distresses are caused by the structural loading (vehicular loading on the pavement structure), they are also affected by the environmental conditions.

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

The primary means of evaluating a flexible pavement structure is pavement surface deflection. Although other measurements can be made that reflect a pavement's structural condition, surface deflection is an important pavement evaluation method. Back calculation methods based on the surface deflection can be used to determine the characteristics of pavement structural layers. Surface deflection measurements are rapid, inexpensive and non-destructive and are used frequently as an indicator of pavement structural capability and performance potential. The use of non-destructive testing has become an integral part of the structural evaluation and rehabilitation process of pavements. Various types of equipment are used by state highway agencies to apply patterns of loading and record deflection along the pavement. When pavements experience some form of distress, variations in pavement deflections and shape of the deflection basin along a project will occur because of differences in the condition of pavement layers [2].

When a pavement fails before its intended design life, it may require excessive repair and rehabilitation costs. Adequate knowledge on the structural condition and resilient modulus of pavement is very important to avoid wrong and costly decisions when selecting the type of rehabilitation on a pavement. Therefore there is a need to study the relationship between rutting, roughness and resilient modulus of flexible expressway pavement.

2. Methodology

The evaluation was conducted at Shah Alam Expressway from km 17.90 to km 52.20 particularly from Pandamaran to Sri Petaling Interchange. The temperatures and the deflection values were measured by Falling Weight Deflectometer (FWD). The information attained was used to determine the resilient modulus (M_R) using back calculation method. The high speed network survey vehicle (NSV) was used to collect the road condition data such as surface roughness and rut depths at prevailing traffic speed.

2.1 Falling Weight Deflectometer (FWD)

The Falling Weight Deflectometer (FWD) was used in this research for measuring the pavement surface deflection which is a non-destructive testing device. It is a testing device used to evaluate the physical properties of pavement. FWD data is primarily used to estimate pavement structural capacity for 1) overlay design and 2) to determine if a pavement is being overloaded. Use includes (but is not limited to) highways, local roads, airport pavements, and railway tracks. The machine is usually contained within a trailer that can be either towed to a location by another vehicle or, when used on railway tracks, placed on a hand trolley and pushed to the location.

The FWD is capable of applying dynamic loads to the pavement surface, similar in magnitude and duration to that of a single heavy moving wheel load. It can measure the exact force and deflection when a weight drops to the ground from an optional height, and sends a non-destructive shock-wave through the bearing soil. The test was carried out at 100 m interval along the slow lane main line and 500 m intervals for middle lane and fast lane. The contact pressure applied was 707 kPa on a 300 mm radius loading plate simulating 10 tonnes lorry with standard tandem axle. Pavement temperature was taken at a minimum 40 mm depths below the riding surface. All surveys were carried out in proper traffic management installations.

The generated data, combined with layers thickness, can be used to obtain the 'in situ' resilient modulus (M_R) of the pavement structure. The computer programme used in association with this device is ELMOD5 which is an acronym for Evaluation of Layer Moduli and Overlay Design (Version 5). It can be used to perform back calculation, calculate stresses and strains, and determine the overlay requirements. Parameters such as the pavement material and information about the loadings imposed on the pavement, including traffic data, can be imported manually.

2.1.1 Deflection. Pavement surface deflection is measured by the vertical deformation of the pavement caused by the application of a static or dynamic load. The more advanced measurement devices record this vertical in multiple locations, which provides a more complete characterization of pavement deflection.

2.1.2 Resilient Modulus (M_R). The resilient modulus (M_R) is the ratio of deviation stress applied to the recoverable strain observed or simply a recoverable strain under repeated load [3-5]. Figure 1 illustrates how MR is measured under repeated load. It is the single most important unbound material property input in most current pavement design procedures. Beginning in 1986, the AASTHO Design Guides have recommended use of M_R for characterizing subgrade support for flexible and rigid pavements and for determining structural layer coefficients for flexible pavements. It is also the primary material property input for unbound materials in the NCHRP 1-37A Design Guide for both flexible and rigid pavements. It is an essential input to mechanistic pavement response models used to compute stresses, strains, and deformations induced in the pavement structure by the applied traffic loads.

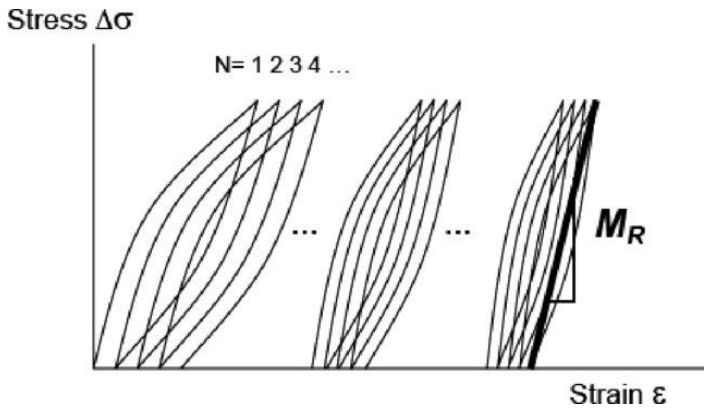


Figure 1. Resilient modulus under cyclic loading. [6]

2.2 High Speed Network Survey Vehicle (NSV)
The High Speed Network Survey Vehicle (NSV) was used to collect the road condition data at prevailing traffic speeds. The data recorded by the NSV includes surface roughness (IRI – International Roughness Index) in m/km, rutting depth in mm, texture depths (SMTD – Sensor Measure Texture Depth), visual road surface conditions for example, cracks, bleeding etc., visual road-site assets and road geometry and mapping (including grade, cross-slope and position). All measurements were carried out in a single operation for each trafficked lane. However, only rutting and roughness values were analysed in this study.

2.2.1 Rutting. Rutting is indicated by the permanent deformation along the wheel path. Rutting can occur in any of the pavement layers or the subgrade, usually caused by the consolidation or the lateral movement of the materials due to traffic loads. Rutting in the HMA layer is controlled by the creep compliance of the mix [7-9]. Rutting occurring in the subgrade is caused by the vertical compressive strain at the top of the subgrade layer. To control rutting occurring in the subgrade, the vertical compressive strain at the top of the subgrade is limited to a certain value. It is noticed that fatigue cracking and rutting depend on the level of strain; tensile strain at the bottom of the HMA layer for fatigue cracking, and compressive strain at the top of the subgrade layer for rutting. Therefore, to be able to predict the fatigue as well as the rutting lives of the pavement structure, the aforementioned strains must be determined. Load induced stresses and strains in pavements are determined using the elastic layered theory. This requires the determination of the moduli of the different layers in the pavement structure. Moduli are usually determined in the field by performing the FWD test. However, near surface moduli (modulus of the wearing surface) are difficult to obtain using FWD results. Moreover, for the design of the pavement, layers moduli must be determined prior to the pavement is construction. For evaluation, rut depth indications are shown in Table 1.

Table 1. Rut depth indication. [10, 11]

Category	Indication
Good	Rut < 5mm
Fair	10mm < Rut < 5mm
Poor	20mm < Rut < 10mm
Bad	> 20mm

2.2.2 Roughness. Surface roughness, often shortened to roughness, is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface [12, 13].

Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces (see tribology). Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. On the other hand, roughness may promote adhesion. For evaluation, roughness (IRI) indications are shown in Table 2.

Table 2. IRI indication. [10, 11]

Category	Indication (m/km)
Good	IRI < 2.0
Fair	2.0 < IRI < 3.0
Poor	3.0 <IRI < 3.8
Bad	IRI > 3.8

3. Results and Discussion

Table 3 shows the summary of the Falling Weight Deflectometer (FWD) data. Overall result for slow lane shows E1 layer (Bituminous Layer) and E2 layer (Road base Layer) was in the sound to satisfactory category with 79.8% for E1 and 68.0% for E2. Thus, the remaining section was in poor condition and needs possible preventive treatment as soon as possible. Overall the E3 layer (Subgrade) was found to be in sound to satisfactory condition.

For the middle lane, the result shows 95.5% and 89.4% of the E1 and E2 layers respectively were in the sound to satisfactory condition. About 4.5% for E1 and 10.6% of E2 need preventive maintenance due to poor in the condition. On the other hand, the E3 layer was still in sound to satisfactory condition.

For the fast lane, the result shows E1 and E2 layers were in the sound to satisfactory condition with 98.5% and 98.5% respectively. Only 1.5% of E1 and E2 need preventive maintenance. Overall E3 layer was still in sound to satisfactory condition.

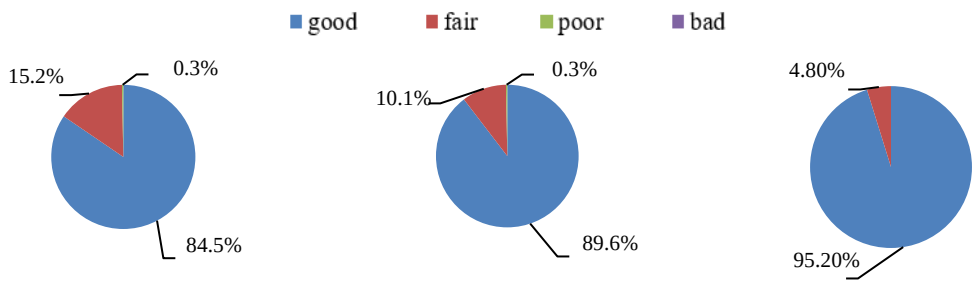
Table 3. Summary of FWD data for expressway flexible pavement.

Layer of Structure	Condition	Kuala Lumpur Bound		
		Slow lane	Middle Lane	Fast Lane
E1 Bituminous Layer	Sound	61.9%	89.4%	97.0%
	Satisfactory	17.9%	6.1%	1.5%
	Poor	20.1%	4.5%	1.5%
E2 Road base Layer	Sound	49.3%	67.4%	83.5%
	Satisfactory	18.7%	22.0%	15.0%
	Poor	32.1%	10.6%	1.5%
E3 Subgrade Layer	Sound	86.6%	88.6%	91.7%
	Satisfactory	13.4%	11.4%	8.3%
	Poor	0.0%	0.0%	0.0%

3.1 Rutting and Roughness

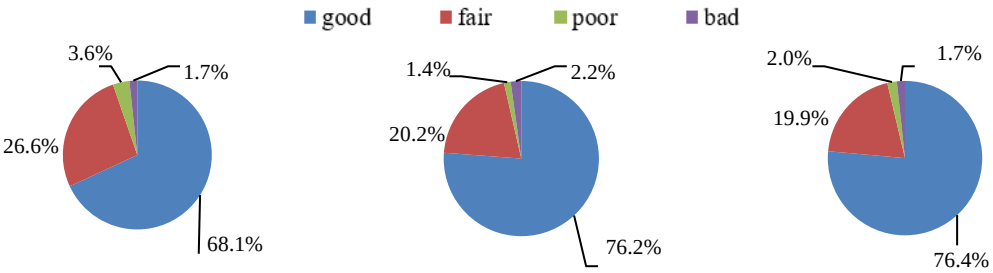
From the survey result, the rutting and roughness for expressway flexible pavement can be concluded in Figure 2 and Figure 3 respectively. Rutting for slow, middle and fast lanes are as showed in Figure 2(a) to (c) respectively. 84.5% of the slow lane was in a good condition, 15.2% fair condition and only 0.3% are in a poor condition. None of the road section falls under bad rutting condition. For the middle lane, 89.6% are in good category, 10.1% is in fair, 0.3% is in and 0% is in bad condition. For the fast lane 95.2% are good, 4.8% is fair and 0% for poor and bad category. From these results, it was found that fast-lane rutting rate is less than the middle and slow lanes.

Roughness for slow, middle and fast lanes are as shown in Figure 3(a) to (c) respectively. 68.1% of the slow lane section is in a good condition, 26.6% (fair), 3.6% (poor) and 1.7% (bad) category. For middle lane, 76.2% is in good, 20.2% (fair), 1.4% (poor) and 2.2% (bad) category. For the fast lane, 76.5% is good, 19.9% (fair), 2.0% (poor) and 1.7% (bad) category. From these results, it was found that fast-lane roughness rate (IRI) is less than the middle lane and slow lane.



(a) (b) (c)

Figure 2. Rutting (a) Slow Lane(b) Middle Lane(c) Fast Lane.

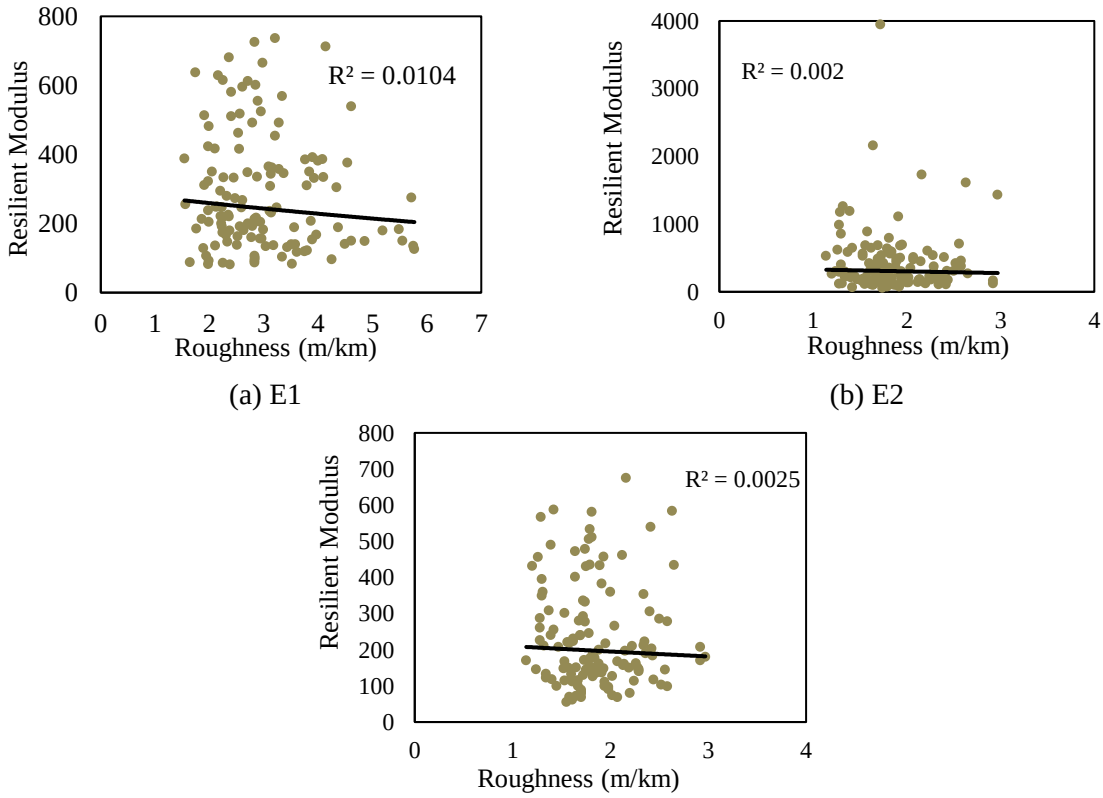


(a) (b) (c)

Figure 3. Roughness (a) Slow Lane(b) Middle Lane(c) Fast Lane.

3.2 Effect of Resilient Modulus (M_R) on Roughness

Regression analysis conducted between the resilient modulus (E1), (E2) and (E3) and Roughness (IRI) for the slow lane as shown in Figure 4 (a), (b) and (c) resulted in poor correlations (R^2 = 0.0104, R^2 = 0.002 and R^2 = 0.0025). The resilient modulus (E1), (E2) and (E3) and Roughness for middle lane shown in Figure 5 (a), (b) and (c) resulted in poor correlations (R^2 =1E-09, R^2 = 0.008 and R^2 =0.006) for regression analysis. Figure 6 (a), (b) and (c) for the fast lane, shows that (R^2=0.035, R^2=0.042 and R^2=0.094) also resulted in poor correlation.



(a) E1 (b) E2

(c) E3

Figure 4. Resilient Modulus versus Roughness for slow lane.

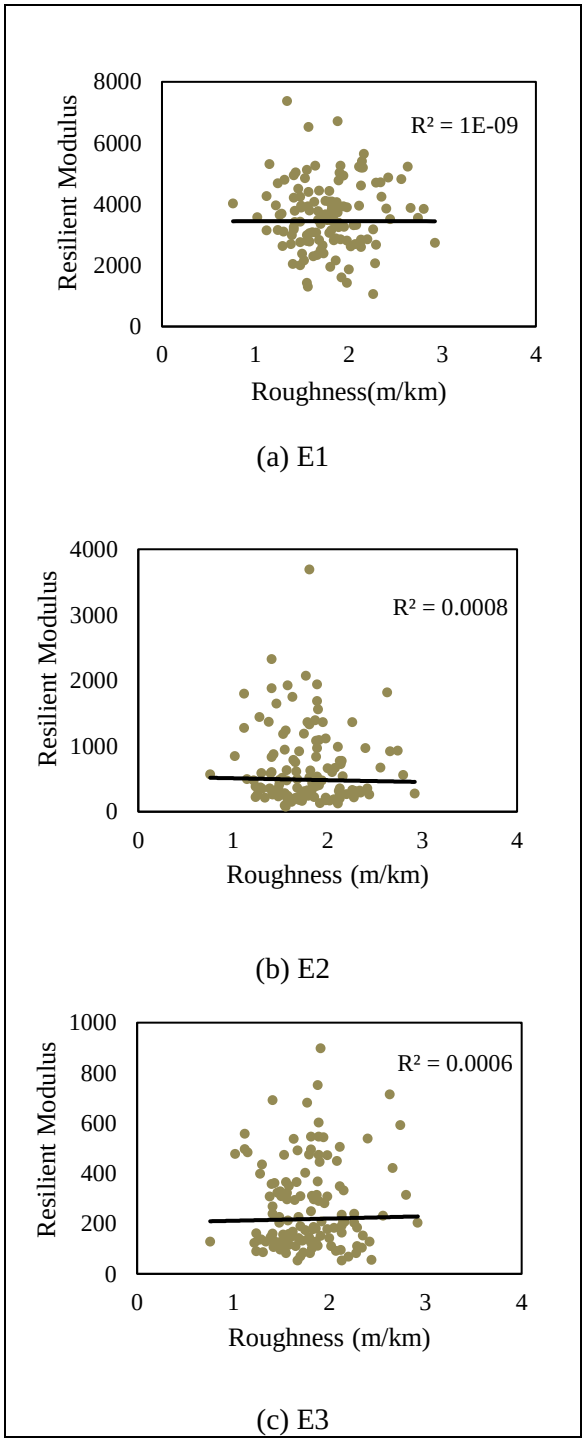


Figure 5. Resilient Modulus versus Roughness for middle lane.

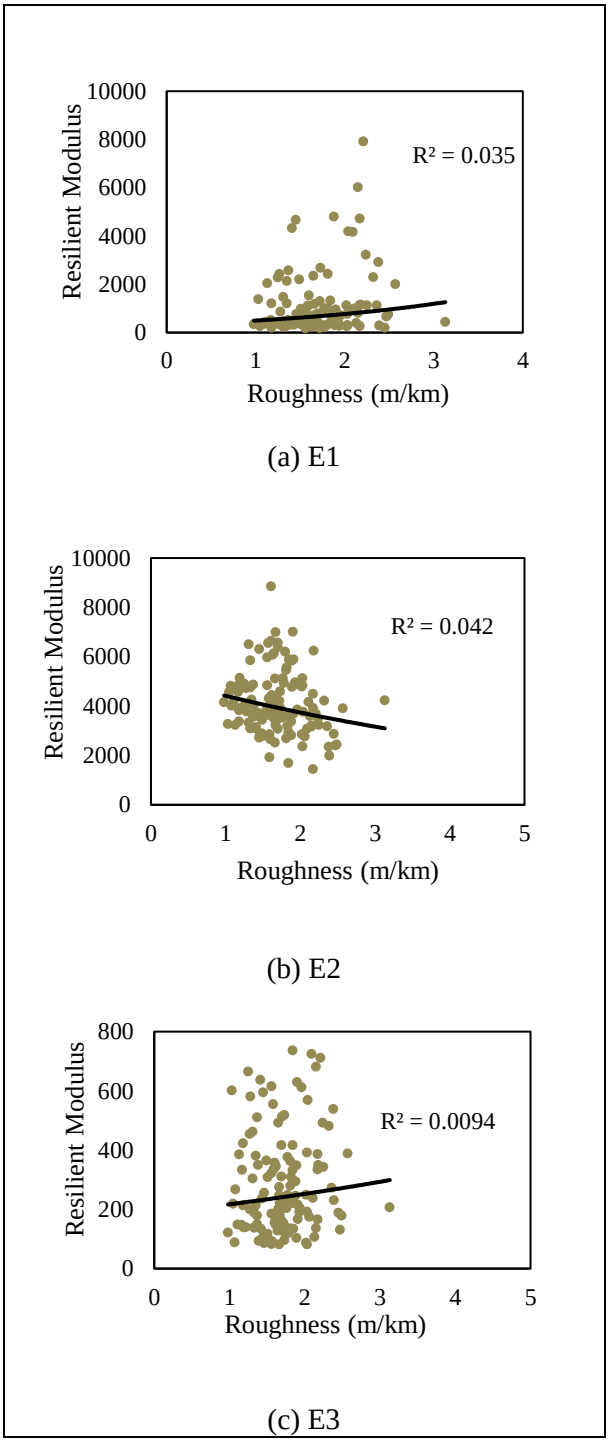


Figure 6. Resilient Modulus versus Roughness for fast lane.

3.3 Effect of Resilient Modulus (M_R) on Rutting

Regression analysis conducted on the resilient modulus (E1), (E2) and (E3) and Rutting for the slow lane as shown in Figure 7 (a), (b) and (c) resulted in poor correlations (R^2 = 0.013, R^2 = 0.1399 and R^2

= 0.00895). The resilient modulus (E1), (E2) and (E3) and rutting for middle lane shown in Figure 8 (a), (b) and (c) resulted in poor correlations (R^2 =0.0263, R^2 = 0.0668 and R^2 =0.0089) for regression analysis. Figure 9 (a), (b) and (c) for the fast lane, shows that (R^2=0.0003, R^2=0.0113 and R^2=0.0104) also resulted in poor correlation.

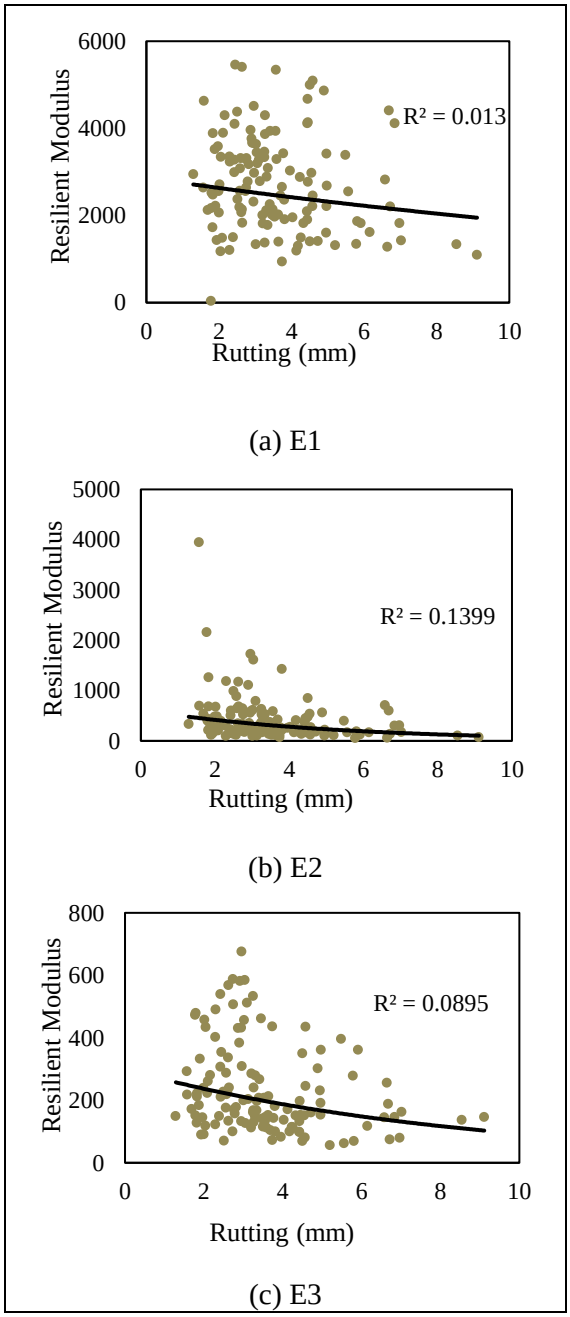


Figure 7. Resilient Modulus versus Roughness for slow lane.

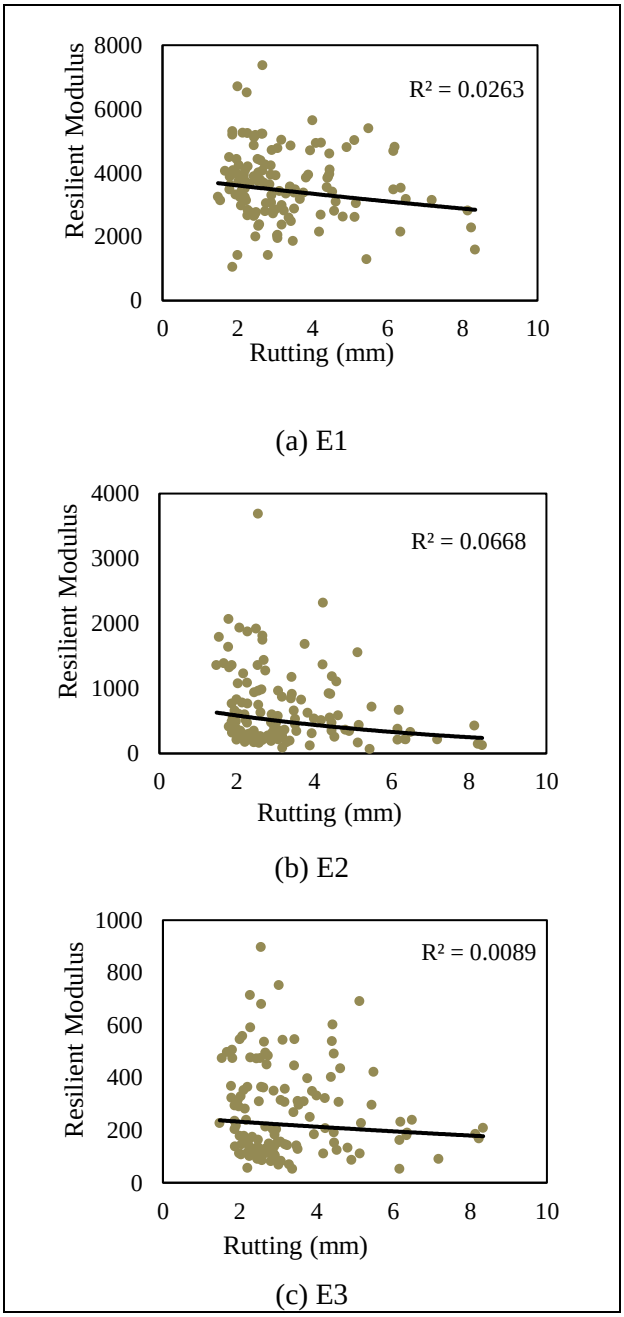


Figure 8. Resilient Modulus versus Roughness for middle lane.

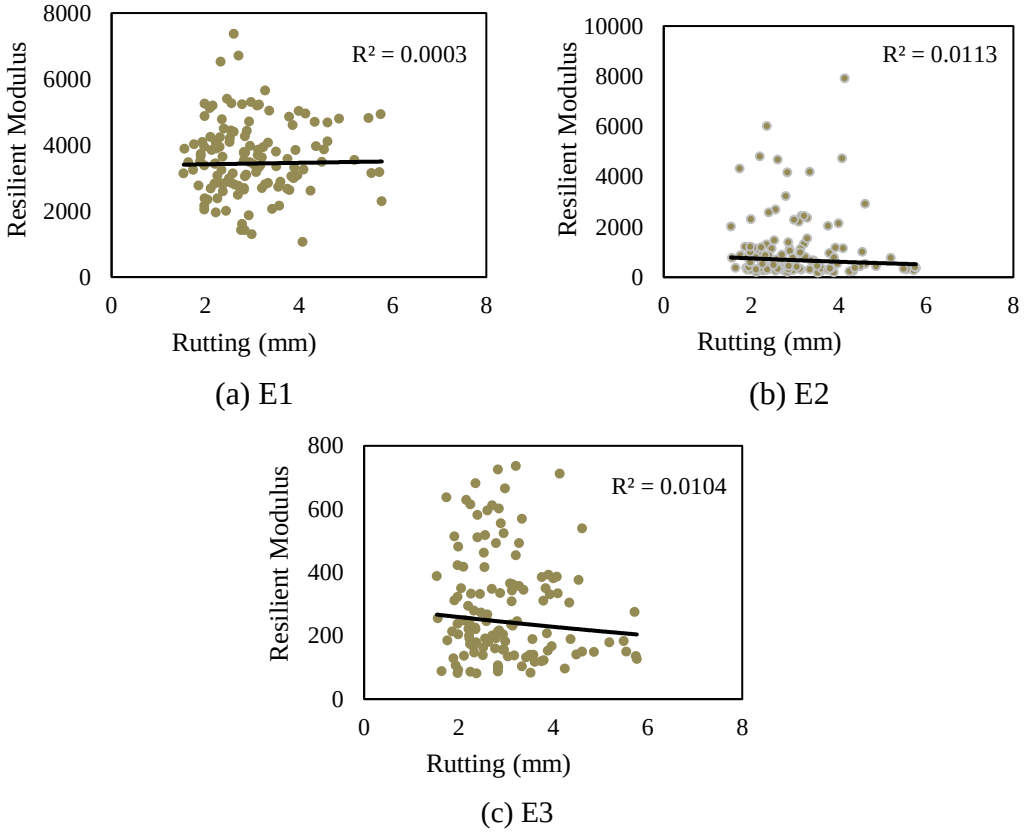


Figure 9. Resilient Modulus versus Roughness for fast lane.

4. Conclusions

Falling Weight Deflection (FWD) test result indicated that most of the bituminous layer (E1) was in the sound to satisfactory condition except 20.1% of the slow lane section was in poor condition. Meanwhile, 32.1% of road base layer (E2) for slow lane shows poor condition. On the other hand, overall subgrade layer (E3) still in sound to satisfactory condition.

The overall functional pavement condition in terms of rutting and roughness (IRI) values can be categorized as good to satisfactory condition. In addition, there is a poor correlation between rutting, roughness and the resilient modulus (M_R) of this expressway flexible pavement.

5. References

[1] Aziz M M A, Rahman M T, Hainin M R and Bakar W A W A 2015 *Const. and Build. Mat.* **84** 315319

[2] Sahar H 2007 *The Effects of Temperature on the Resilient Modulus of Flexible Road Pavements* (Malaysia: Universiti Teknologi Malaysia)

[3] Idham M K, Hainin M R, Yaacob H, Warid M N M and Abdullah M E 2013 *Adv. Mat. Research* **723** 291297

[4] Abdullah M E, Zamhari K A, Hainin M R, Oluwasola E A, Yusoff N I M and Hassan N A 2016 *J. of Cleaner Product.* **122** 326334

[5] Ahmad J, Yusoff N I M, Hainin M R, Rahman M Y A and Hossain M 2014 *Const. and Build. Mat.* **50** 567576

[6] Mukabi J N 2014. *Necessity for Review of Resilient Properties and Conventional Resilient Modulus Models of Characterizing Pavement Materials for MEPD*, Electronic Print, Academia. edu Website.

[7] Abdullah M E, Zamhari K A , Hainin M R, Oluwasola E A, Yusoff N I M and Hassan N A 2016 *J. of Cleaner Product* **122** 326334
[8] Suleiman A Y, Hainin M R and Yaacob H 2012 Determination of surface roughness index of various bituminous pavements. *International Journal of Research and Reviews in Applied Sciences*, **13**(1).
[9] Suleiman A Y, Hainin M R and Yaacob H 2012 The correlation between texture depth, pendulum test value and roughness index of various asphalt surfaces in Malaysia. *International Journal of Research and Reviews in Applied Sciences*, **13**(1).
[10] AASHTO Interim Guide for the Design of Pavement Structures 1986 (Washington: American Association of State Highway and Transportation Officials)
[11] AASHTO Guide for the Design of Pavement Structures 1993 (Washington: American Association of State Highway and Transportation Officials)
[12] Tranggono M and Seo Y 2009 Evaluation of elastic modulus properties of flexible pavement at Korea Expressway Corporation Test Road *Proc. of the 13th REAAA conf., Seoul, Korea*
[13] Huang Y H 1993 (New Jersey: Prentice Hall, Inc., Englewood Clifts)

Acknowledgments
The authors would like to thanks Universiti Teknologi Malaysia (UTM) for providing the research grant no. R.J130000.7322.4B331, Q.J130000.2622.14J09 and Q.J130000.2522.17H69.