

Developing Correlation Between Structural Parameter and Functional Parameter for Pavement Evaluation

Ayesha Ahmad^{1,*}, Prof. Dr. Zia ur Rehman², Prof. Dr. Ammad Hassan Khan³

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Abstract

Pavement functional and structural parameters are important for pavement evaluation. This research aims at developing a prediction model to predict the deflection of flexible pavements using International Roughness Index (IRI) values to optimize maintenance activities without conducting deflection testing. For this purpose, Multan-Lodhran south bound section, a part of N-5 is selected as study area. It starts from km 929+000 and ends at km 867+000, having a length of 62 km, dual carriageway having two lanes each side. The data used for this study had been collected from the database of Road Asset Management Division (RAMD), National Highway Authority, Islamabad, Pakistan on basis of data availability and reliability. Collected data includes International Roughness Index (IRI) values measured by profilometer and deflection data measured by Falling Weight Deflectometer (FWD). Existing pavement structure data was collected from NHA Regional office. Linear and Logarithmic Regression analysis methodology using SPSS Statistical Analysis Software was used to develop correlation between pavement functional and structural parameters for flexible pavement. Also, Microsoft Excel was used for data analysis and validation purpose. The developed regression model showed significant relationship between deflection and IRI. Additionally, AASHTO Back calculation method was also used for determining the effective structure number (SN_{eff}) using deflection results from FWD to determine correlation of IRI with another structural parameter. Considering this, a significant correlation was found between SN_{eff} and IRI. However, it was found that other parameters i.e., subgrade resilient modulus (M_r) and pavement elastic modulus (E_p) did not show any significant relation. The result showed that if pavement IRI values are known, deflection and SN_{eff} can be predicted providing feasibility for transportation agencies that do not have the capabilities as deflection tests are costly and require sophistication for its data handling.

Keywords: Flexible Pavement, International Roughness Index (IRI), Deflection, Falling Weight Deflectometer (FWD), Profilometer; Correlatio

* Corresponding author. E-mail: aishaahmad98@outlook.com

¹ Department of Transportation Engineering and Management, Faculty of Civil Engineering, University of Engineering and Technology, Lahore, Pakistan

² Department of Transportation Engineering and Management, Faculty of Civil Engineering, University of Engineering and Technology, Lahore, Pakistan

³ Department of Transportation Engineering and Management, Faculty of Civil Engineering, University of Engineering and Technology, Lahore, Pakistan

1. Introduction

Road maintenance is a routine work performed to keep a pavement under normal condition. Continued construction and enhancement of roads is required due to increasing demand of traffic in urban and rural areas. Sufficient maintenance keeps road network in good condition and operate smoothly without any major deterioration preventing economic losses. Insufficient road maintenance curtails the life of the roads that affects vehicle operating cost and road safety. This also increases the risk of damage to road infrastructure. Continuous maintenance is required to bring optimization in road infrastructure. Identification of proper maintenance tools and planning maintenance tasks, are significant factors. Maintenance should be timely, preventing rather than curing significant road deterioration.

Road infrastructure development is crucial to country's economy and socio-economic development. As growth of these sectors depend on road networks that provide well-timed accessibility and disposal of goods and services. Hence, continuous maintenance, rehabilitation, up-gradation and preservation of Pakistan's highway assets are critical to national economic growth. To maintain this prestige, roadways require pavements in good overall physical condition with both structural soundness and increased serviceability. It is the need of time to bring optimization in these activities to get more benefit from it. Roads in Pakistan experiences lack of proper and timely maintenance resulting in decreased design life. Hence, a research study to find time effective and cost-effective pavement evaluation method needs to be conducted.

2. Literature Review

This section features importance of conducting functional and structural performance test of a pavement to evaluate pavement overall performance.

Ziaria, Jafar, Ayoubinejad, & Hartmann, (2015) mentions that most important issue in pavement management system is pavement condition prediction. Fakhri & Dezfoulian, (2019) wrote that pavement condition evaluation is predictable using structural or non-structural methods (i.e., functional methods). This provides pavement maintenance and rehabilitation decision. The most important parameter in case of pavement maintenance performance is pavement strength evaluation. The second major contributor in pavement performance evaluation is Road Roughness (Alharbi & Smadi, 2017). Functional condition is related to user safety and comfort. On the other hand, the structural condition is not considered in maintenance decisions as its not related to user's perspective. However, engineering perspective considers both the users' safety and the pavement structural condition equally (Rahman & Tarefer, 2014). Kavussi, Ghorbani, Nejad, & Ziksari, (2017) mentioned that pavement condition assessment can be attained using Falling Weight Deflectometer (FWD) that structurally evaluates the pavement. Further, pavement structural performance is evaluated through structural number (SN) and deflection measurements (Huang, 2019). Abdelaziz, Abd El-Hakim, El-Badawy, & Afify, (2018) mentioned IRI evaluates the pavement functionally considering riding quality and users comfort level.

A good ride quality is not the assurance of structural adequacy as roughness might indicate structural issue in the pavement. Absence of any of the two information can lead to inaccurate maintenance planning. The amalgamation of both Roughness Surface Profilometer (RSP) and FWD lead to holistic pavement assessment. Roughness causes vehicle's suspension response while it travels on the road. Pavement surface is completely smooth when IRI equals zero, however IRI value greater than 8m/km indicates uneven surface that require low vehicle speeds. Performing roughness surveys

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using profilometer is comparatively economical. However, deflection data collection by Falling Weight Deflectometer (FWD) is slow, costly, and disruptive to traffic due to the stop-and-go procedure (Sollazzo, Fwa, & Bosurgi, 2017).

Researchers had developed correlation between pavement structural parameter and functional parameter. Thabassum, (2015) showed a strong positive correlation of deflection with unevenness index (roughness) and concluded that if deflection values are known for any existing pavement, unevenness index can be calculated. Sollazzo, Fwa, & Bosurgi, (2017) demonstrated good correlation between IRI (functional parameter) and SN_{eff} (structural parameter). Alharbi & Smadi, (2017) modelled a relationship between structural capacity and functional condition and found a significant relation between rut data (functional parameter) and pavement structure number (structural parameter). Momin & Hamim, (2021) showed that IRI and age are positively correlated with pavement deflection, however, IRI has a better ability to predict deflection (structural parameter) as compared to age. While many studies had been conducted on developing correlation between functional and structural parameter around the world, it remains unpractical in Pakistan as no research on it has been conducted since today. To best of our knowledge, deflection is recognized by pavement researchers as a vital parameter to evaluate pavement structural strength. In comparison with measuring deflection, IRI is easier and less costly to measure on the field. Hence, a model correlating IRI and deflection can be useful. Consequently, this study develops a correlation between pavement structural and functional parameter by using easily collectible IRI values (functional) to predict pavement deflection (structural), facilitating transportation agencies to take adequate rehabilitation and maintenance measures at regular intervals.

3. Research Objective

The main objective of this research is to develop correlation between pavement roughness and structural deflection.

4. Research Methodology

Linear and logarithmic regression analysis methodology using SPSS Statistical Analysis Software were used to develop correlation between pavement roughness and structural deflection for flexible pavement. Besides, Microsoft Excel was used for data analysis and validation purpose.

4.1. Data Collection

To study the relationship between functional and structural parameter, IRI values measured through profilometer and deflection data measured through dynatest falling weight deflectometer were obtained from the database of Road Asset Management Division (RAMD), National Highway Authority, Islamabad, Pakistan. The study area; Multan-Lodhran south bound section is a dual carriageway having two lanes each side is a part of N-5 starts from km 929+000 and ends at km 867+000, having a length of 62 km. The Figure 1 (a) shows location of study section. The testing was carried out in month of July-August 2022.

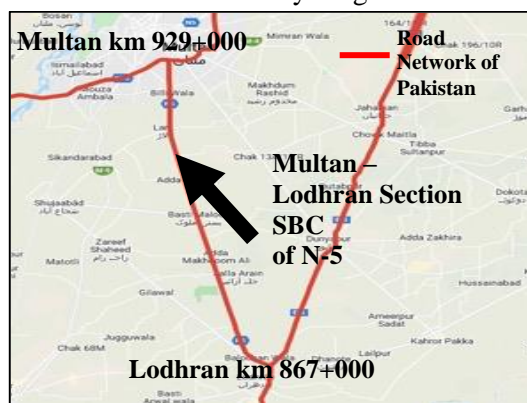


Figure 1 (a). Location of Multan-Lodhran N-5 Section (Source: Google Map)

As per the construction history provided by NHA Maintenance Unit Bahawalpur, construction of this section was completed in year 2001. After construction, there was no major rehabilitation or overlay laid as part of

preventative maintenance. However, routine maintenance treatments i.e. localized patchwork has been carried out. Details of existing pavement structure is presented in Table 1 (b).

Table 1 (b). Existing Pavement Structure

Construction year	1993 – 2001
Carriageway Type	Dual carriageway
No. of lanes on each side	2
Carriageway width (south bound)	24 ft.
Thickness of Asphalt concrete wearing course	2.4 in.
Asphalt concrete base course	5 in.
Thickness of Aggregate Base Course	8 in.
Thickness of Aggregate Sub Base	7 in.

5. Data Analysis and Discussion

5.1. Roughness Survey

Roughness survey was carried out in the outer lane of the road and values were taken at 200 m interval. IRI values are presented below in Figure 2.

5.2. FWD Survey and Analysis

Survey was carried out in the outer lane of the road and values were recorded at 200 m interval to match with IRI values. Additionally, based on FWD deflection data, SN_{eff} had also been calculated through AASHTO Back Calculation Method (AASHTO Guide, 1993) to study relation of IRI with other pavement structural parameters. Deflection values are shown in Figure 3.

5.3. Variables

Correlations were developed between functional and structural parameters for the variable (shown in Table 2) that showed strong Pearsman correlation coefficient with IRI. Significant variables i.e. deflection and SN_{eff} were considered for detailed analysis as discussed below. Whereas, M_r and E_p showed weak correlation with IRI. Table 2 shows descriptive statistics of variables used in the analysis.

5.4. Correlation between IRI and Deflection

IRI and deflection showed strong positive correlation. With $R^2 = 0.958$ as shown in Table 3, IRI accounts for 96% of variation in deflection. To further confirm these results analysis of variance (ANOVA) was done to find the correlation of variance of the two data sets as shown in Table 4. The standard error represents the average distance of the observed values from the trend line. As such, small values are preferred because they show that the precision of the data gathered in the research. ANOVA is the test of whether at R^2 value is significantly greater than 0 that we can see through p value < 0.05 (95% confidence interval (5% significance level)) in Table 4. Sig is less than 0.05 which shows that variable included in the model is significant and acceptable for model development. The overall regression model was significant.

$$F(1,281) = 6331.408, p < 0.001, R^2 = 0.96$$

Table 4 shows that F value is 6331.4 which is significant at $p < 0.001$. Therefore, we can conclude that regression model result in better prediction of deflection than if we used mean value of deflection.

Regression model predicts pavement deflection significantly well as shown in Table 5. The equation 1 obtained is as:

$$Deflection = 0.080(IRI) \quad (1)$$

Where IRI units are in inch/mile (in/mile) while deflection units are in mils. Equation 1 indicates that the possible minimum value of deflection of the pavement section is 0.08 mils but increases proportionately per in/mile of roughness.

For model validation, 2 km section data was analysed that showed that model and measured values have shown maximum 40% percentage increase and minimum 36% percentage decrease as shown in Figure 4.

Using excel, a plot is drawn between measured deflection and calculated deflection as shown in Figure 5. A 45-degree line has been drawn to clarify the distribution of plotted points on

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every side of the line. It has been noticed from Figure 5 that most of the points are close to 45-degree line and R^2 value is 0.7 thus model is considered valid.

Discussion

The results are in conjunction with (Momin & Hamim, 2021) and (Thabassum, 2015) study that showed a strong positive correlation of deflection with roughness. Thus, if IRI values are known for any existing pavement, deflection can be calculated through developed model.

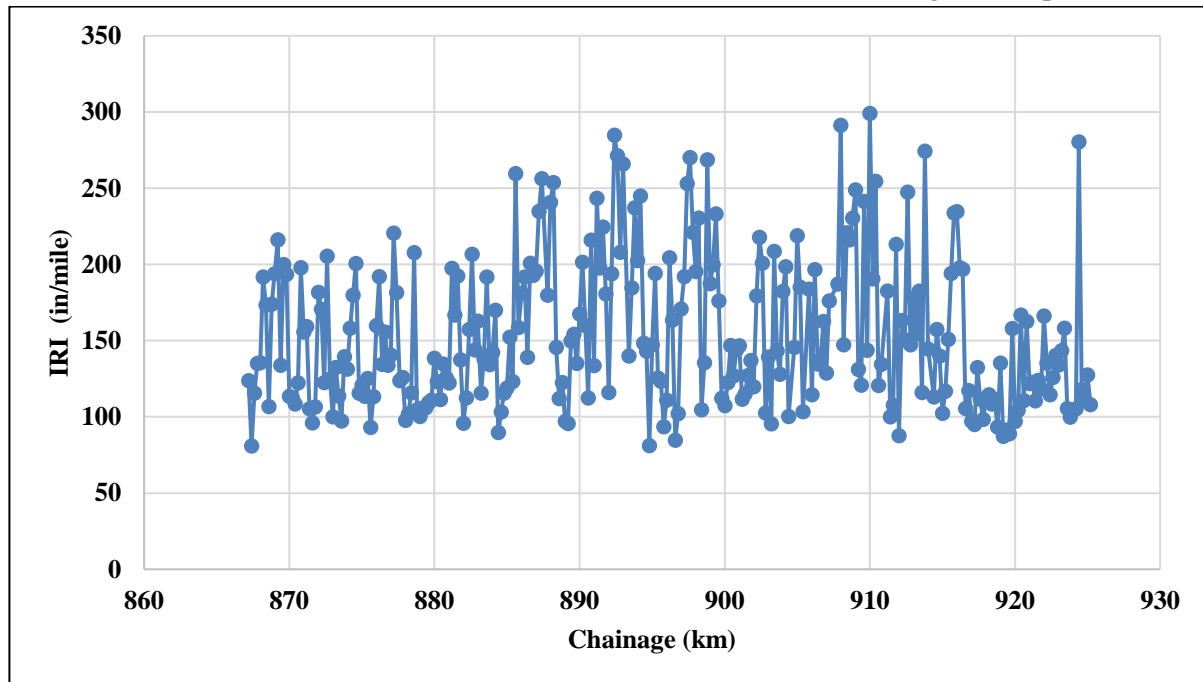


Figure 2. Roughness Values

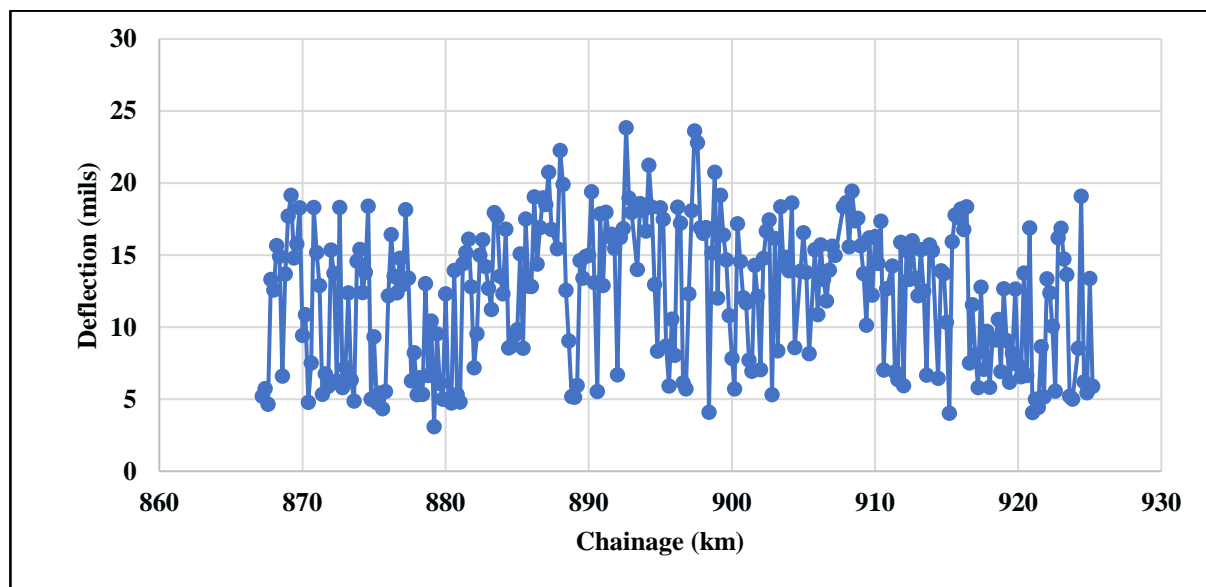


Figure 3. Deflection Values

Table 2. Descriptive Statistics (SPSS Software)

Variables	N	Minimum	Maximum	Mean	Std. Deviation	Pearson Correlation with IRI
IRI (in/mile)	282	80.97	299.12	153.69	48.48	1

Variables	N	Minimum	Maximum	Mean	Std. Deviation	Pearson Correlation with IRI
Deflection (mils)	282	3.1	23.8	12.33	4.82	0.82
M _r (psi)	282	11100.7	60916.7	27823.61	9924.09	-0.085
E _p (psi)	282	81451.89	2130304.7	428147.65	4.29x 10 ⁵	-0.57
SN _{eff}	282	4.37	12.97	6.94	2.14	-0.66

Table 3. IRI and Deflection Model Summary

R	R ²	Adjusted R ²	Std. Error of the Estimate
0.979	0.958	0.957	2.733

The independent variable is IRI (in/mile).

Table 4. IRI and Deflection ANOVA

ANOVA	Sum of Squares	df	Mean Square	F	Sig. (p)
Regression	47279.773	1	47279.773	6331.408	0
Residual	2098.367	281	7.467		
Total	49378.14	282			

The independent variable is IRI (in/mile).

Table 5. IRI and Deflection Coefficient Summary

Variable	Unstandardized Coefficients		Standardized Coefficients	t	Sig. (p)
	B	Std. Error	Beta		
IRI (in/mile)	0.08	0.001	0.979	79.57	0

Table 6. IRI and SNeff Model Summary

R	R ²	Adjusted R ²	Std. Error of the Estimate
0.705	0.497	0.495	1.523

The independent variable is IRI (in/mile).

Table 7. IRI and SNeff ANOVA Summary

ANOVA	Sum of Squares	df	Mean Square	F	Sig. (p)
Regression	642.36	1	642.36	276.869	0
Residual	649.623	280	2.32		
Total	1291.982	281			

The independent variable is IRI (in/mile).

Table 8. IRI and SNeff Model Coefficients

Variable	Unstandardized Coefficients		Standardized Coefficients	t	Sig. (p)
	B	Std. Error	Beta		
ln(IRI) (in/mile)	-5.013	0.301	-0.705	-16.639	0
(Constant)	31.944	1.506		21.216	0

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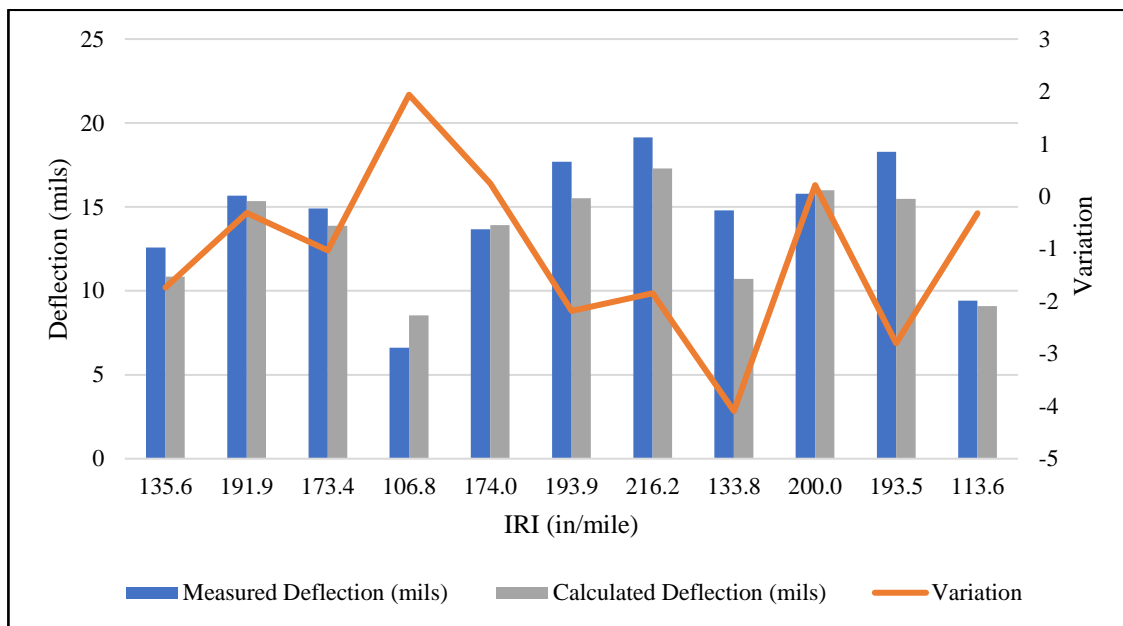


Figure 4. IRI and Deflection Model Validation

5.5. Correlation between IRI and SN_{eff}

IRI and SN_{eff} showed strong negative correlation. With $R^2 = 0.497$ as shown in Table 6, IRI accounts for 50% of variation in SN_{eff} . The standard error represents the average distance of the observed values from the trend line. As such, small values are preferred because they show that the precision of the data gathered in the research.

To further confirm these results, analysis of variance (ANOVA) was done to find the correlation of variance of the two data sets as shown in Table 7. ANOVA is the test of whether R^2 value is significantly greater than 0 that we can see through p value < 0.05 (95% confidence interval (5% significance level)) as shown in Table 7. Sig is less than 0.05 which shows that variable included in the model is significant and acceptable for model development. The overall regression model was significant

$F(1,280) = 276.87, p < 0.001, R^2 = 0.50$

Table 7 shows that F value is 276.87 which is significant at $p < 0.001$. Therefore, we can conclude that regression model result in better prediction of SN_{eff} than if we used mean value.

Hence, regression model predicts pavement SN_{eff} significantly well as shown in Table 8, The equation 2 obtained is as:

$$SN_{eff} = -5.013 \ln(IRI) + 31.9 \quad (2)$$

Where IRI units are in inch/mile (in/mile). Equation 2 indicates that 1 percent increase in IRI causes decreases in SN_{eff} by 0.050 percent. For model validation, 2 km section data was analysed that showed acceptable model and measured values difference as shown in Figure 6.

Using excel, a plot is drawn between measured SN_{eff} and caculated SN_{eff} as shown in Figure 7. A 45-degree line has been drawn to clarify the distribution of plotted points on every side of the line. It has been noticed from Figure 7 that most of the points are close to 45-degree line and R^2 value is 0.5 thus model is considered valid.

Discussion

The results are in conjunction with (Sollazzo, Fwa, & Bosurgi, 2017) that shows good correlation between IRI and SN_{eff} while considering factors such as pavement thickness, ESALS and climatic parameters.

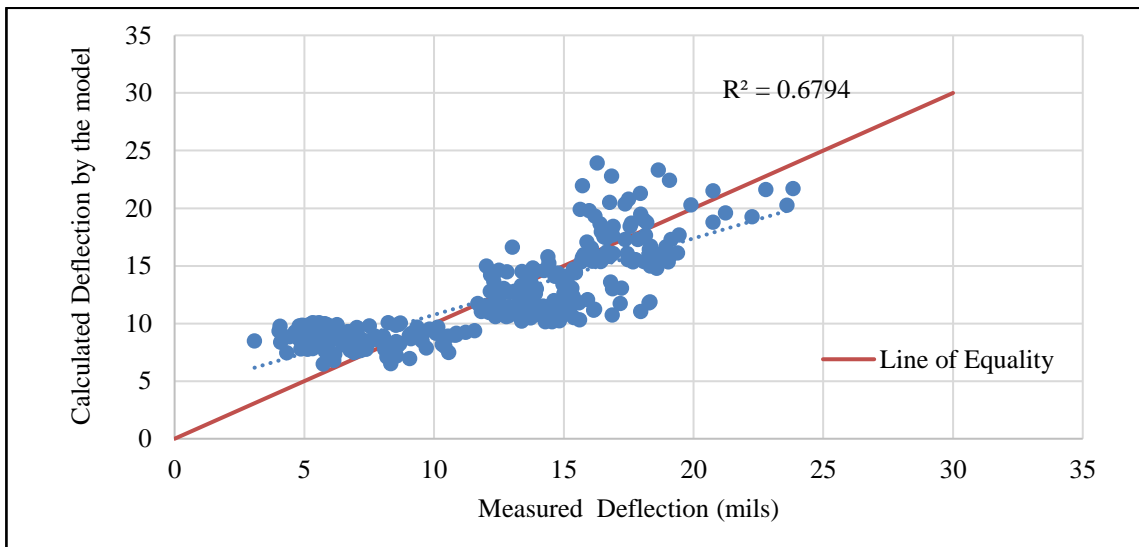


Figure 5. Comparison of Measured and Calculated Deflection through Line of Equality

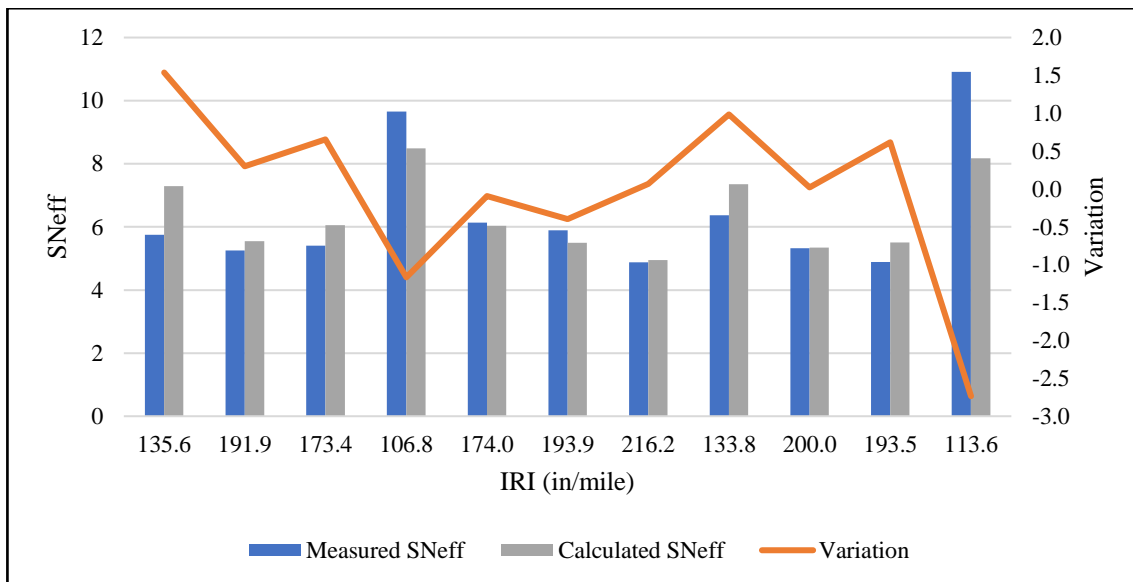


Figure 6. IRI and S_{Neff} Model Validation

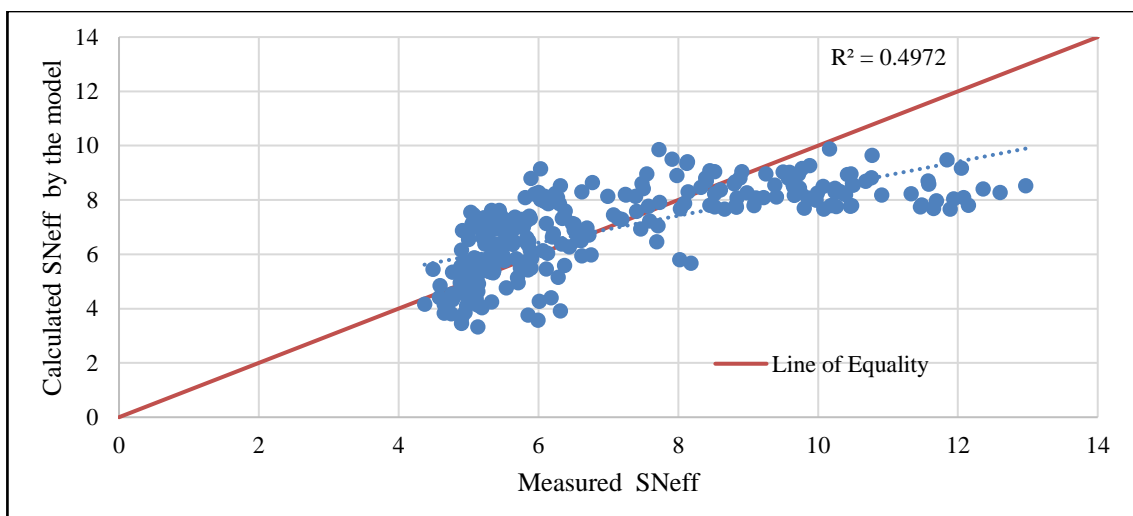


Figure 7. Comparison of Measured and Calculated S_{Neff} through Line of Equality

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6. Limitations

Based on the study carried out following are considered the limitation of this research:

1) Other developed model relating IRI and deflection are shown in Table 9. Since, linear-logarithmic and linear-exponential regression models showed greater difference between measured and calculated deflection. IRI accounted for 72% and 57% for variation in deflection as per R^2 value for logarithmic and exponential regression model. Therefore, Linear regression model was considered as most significant and validated between IRI and deflection. Also, it is the limitation of this study that no external factor is considered causing variation in deflection values.

Table 9. Developed Deflection-IRI Model

Developed Regression Model		R^2
Linear	$Deflection = 0.080(IRI)$	0.958
Linear-Logarithmic	$Deflection = 13.609 \ln(IRI) - 55.565$	0.7253
Linear-Exponential	$Deflection = 3.7021e^{0.0072(IRI)}$	0.5711

Note: Deflection in inch/mile and IRI in mils

2) Since, the measured and calculated SN_{eff} values are dispersed it is considered as limitation of the model. It was analysed that further research can be carried out to find out other variables such as traffic loading, climatic factors or pavement thickness that influence pavement effective structure number SN_{eff} to predict pavement IRI values.

3) The scope of the study was limited to 62 km of national highway N-5 south bound carriageway.

4) Developed models might not be applicable for rigid/composite pavements.

7. Conclusion and Recommendations

Based on the analysis of the collected data, following conclusions and recommendations are drawn.

7.1. Conclusions

Based on the analysis of the collected data, following conclusions are drawn:

- 1) Regression analysis demonstrates that a strong linear correlation exists between deflection and IRI. This concludes that for any flexible pavement if IRI values are known pavement deflection can be determined using the developed model.
- 2) Regression analysis also demonstrates that significant linear-log correlation exists between SN_{eff} and IRI. However, R^2 can be improved by considering other variables affecting pavement structural capacity.
- 3) M_r and E_p showed weak correlation with IRI. This concludes that subgrade resilient modulus (M_r) or pavement elastic modulus (E_p) alone are not sufficient to directly determine pavement roughness (IRI).

7.2. Recommendations

Based on the analysis of the collected data and considering limitations of the study following are the recommendations:

- 1) It is recommended that future research can be carried out to find out other variables such as traffic loading, climatic factors or pavement thickness that influence pavement IRI values to predict deflection and effective structure number SN_{eff} to improve R^2 values.
- 2) The study can be extended considering other road pavements in Pakistan for future research and utilization.

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