Development of Statistical Deterioration Model for Low Volume Roads in Indian Scenario

B. G. Vijay and Raghavendra S. Sanganaikar

Abstract Pavement serviceability is the concept representing the level of service that pavement structure offers to the road users. International Roughness Index (IRI) and Present Serviceability index (PSI) are the parameters which are used to represent the performance of pavement. Road roughness is considered to be the most important parameter affecting vehicle operating costs which account for a large proportion of total transport costs. Roughness is concerned with vehicle vibration, operating speed and wear & tear of the wheels. It affects the road user cost to a significant extent. Therefore, roughness of the pavement plays the decisive role in exercising the option of implementing the optimum maintenance and rehabilitation strategies of the road network at appropriate time. Four study stretches, which include conventional and treated, each of 400 m long were selected. The pavement distresses are collected, processed and analysed for developing a deterioration model. Pavement distress viz cracking, rutting, ravelling, potholes, patching were measured. Rating (both visual and ride rating) studies were also carried. An attempt is made to develop International Roughness Index equation for the selected study stretches. A model is developed to correlate International Roughness Index (IRI) with different types of pavement distresses.

Keywords Pavement distress · Multiple linear regression model · IRI · PSI

1 Introduction

Efficient road transportation plays a vital role in the economy of any nation. Road transport in India, occupies a dominant position in the overall transportation system of the country due to its advantages like easy availability, flexibility of operation, door to door service and reliability. India owns the second largest network of roads in the world, next to USA. Out of the total road network of India, village and other

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roads (Low Traffic Volume Roads) consist of 80% share. Low traffic volume roads are mainly rural roads in India carrying daily traffic less than 450 Commercial Vehicles per Day (CVPD) The thickness of sub-base layer is around 200 mm and the total thickness of each layer of base course varies from 100 to 120 mm. Surface course is usually 20 mm thick premix carpet layer. Low volume roads serve as one of the key infrastructure work, placed for integrated rural development, which has become a matter of growing urgency for considerations of social justice, national integration and economic uplift of the rural areas. The importance of preserving road network in good condition is widely recognized and therefore, performance evaluation of the existing roads is an absolute necessity. Performance of flexible pavements has long been recognized as an important parameter in their design and maintenance. In order to measure and prepare model for pavement performance, it is necessary to clearly define the pavement performance. Deterioration of pavement can be attributed to various factors like age, traffic, environment, material properties, pavement thickness, strength of pavement as well as subgrade properties which affect the mechanical characteristics of a pavement. These factors affect the performance of the pavement in a complex manner. To understand the mechanism and to forecast the future condition of pavement, these deterioration models are necessary. Pavement deterioration model is a mathematical relationship between the pavement condition and the factors listed above. The pavement deterioration model predicts the future condition of the pavement, which is helpful in development of Maintenance Management Model or Maintenance Priority Index (MPI). This index is a rating used to prioritize the maintenance schedule of pavement based on the severity of distresses and its condition.

2 Literature Review

Hernán de Solminihac et al. [1] studied on relating serviceability results obtained by a 9-member evaluation panel, representing the general public as closely as possible, to parameters (particularly of roughness) measured with instruments on road sections of asphalt concrete, Portland cement concrete, and asphalt overlay, respectively. Results show that prediction of serviceability is quite accurate based on roughness evaluation, while also revealing that, by comparison to studies in more developed countries, Chileans are seemingly more tolerant, in that they assign a somewhat higher rating to ride quality. Jorge et al. [2] have developed an incremental Nonlinear Model for predicting Serviceability. The objective of this research was the development of sound flexible pavement performance models to be used primarily for the management of the road infrastructure because accurate prediction of pavement performance is important for effective management of the infrastructure. The model highlights some of the advantages of relaxing the linear restriction that is usually placed on the specification form of pavement performance models. Bektas et al. [3] developed a pavement condition rating system that provides a consistent, unified approach in rating pavements in Iowa is being proposed. The proposed 100-scale system is based on five individual indices such as cracking, ride, rutting, faulting, and friction. The researchers compared PCI-2 results to PCI results and found that, in general, PCI-2 which is established by combining individual indices with weight factors offers fairly good correlation to PCI condition results, particularly, for the pavement types where PCI utilizes distress and roughness data. The poorly related ones are due to the fact that some of the current PCI is heavily characterized by pavement age with various other data, such as material property and traffic and is characterized less than PCI-2 by the pavement distress and roughness data. Bin Ab. Latif et al. [4] worked on developing relationship between International Roughness Index (IRI) and Present Serviceability Index (PSI). IRI was measured by using the walking profilometer. PSI data was collected manually. Both IRI and PSI were measured along the 100 m section of road. This study only focused on the asphaltic pavement. The objectives of this study were to determine the IRI, PSI and relationship between IRI and PSI. The statistical analysis which is R^2 value was used to evaluate the relationship between IRI and PSI. From this study, it was found that IRI value increased when PSI value decreased. While the PSI rating shows the tested road for this study is still in good condition.

3 Objectives of the Study

- Collection and processing of pavement deterioration data for analysing.
- Analysis and development of suitable pavement deterioration model.
- Evaluation of effect of various pavement distresses on IRI.

4 Data Collection

Data collection is done for analysis from all the considered road stretches. The structural evaluation and functional evaluation data is collected and is processed for further studies. The data includes values for 3 cycles.

4.1 Test Stretches for Field Study

For the study, totally 4 road stretches each of length 400 m with different treatment given. The following criteria were used for the selection of the test stretches.

- The test stretches were straight without horizontal curves and steep gradient.
- The test stretches have fairly uniform riding quality and surface condition throughout the length of stretch.

Table 1 Selected test stretches for the present study

Stretch	Name of test stretches	Type of construction
Section 1	Ganjalaghatta road	Conventional
Section 2	Ganjalaghatta road	Conventional
Section 3	Rayashettyhalli road	Coir treated
Section 4	Rayashettyhalli road	Coir treated

- Cross drainage works, over bridge are to be avoided within the selected test stretches.

  The test stretches selected in the present study are shown in Table 1.

4.2 Structural Condition Evaluation

Tables 2, 3, 4, 5, 6 and 7 give the details of Structural condition evaluation for the stretches mentioned above.

Table 2 Structural condition evaluation of Ganjalaghatta road for cycle-I

Sl. No.	Stretch	Rutting measured in the middle of the section (mm)		Cracking of bituminous layer severity and area (%)	Pot holes (number)	Ravelling area (%)	Patching (% of area of subsection)
		LWP	RWP				
1	Section 1	18	25	1	0	0	0
2	Section 2	20	13	1	1	0	0
3	Section 3	31	16	1	0	1	0
4	Section 4	23	13	3	0	1	0

Table 3 Structural condition evaluation of Ganjalaghatta road for cycle-II

Sl. No.	Stretch	Rutting measured in the middle of the section (mm)		Cracking of bituminous layer severity and area (%)	Pot holes (number)	Ravelling area (%)	Patching (% of area of subsection)
		LWP	RWP				
1	Section 1	24	34	10	0	10	0
2	Section 2	39	30	13	5	27	9
3	Section 3	38	28	18	0	13	0
4	Section 4	40	25	16	0	22	0

Table 4 Structural condition evaluation of Ganjalaghatta road for cycle-III

Sl. No.	Stretch	Rutting measured in the middle of the section (mm)		Cracking of bituminous layer severity and area (%)	Pot holes (number)	Ravelling area (%)	Patching (% of area of subsection)
		LWP	RWP				
1	Section 1	64	62	30	2	43	20
2	Section 2	77	39	30	11	46	19
3	Section 3	86	42	46	10	39	0
4	Section 4	55	38	35	0	39	0

Table 5 Structural condition evaluation of Rayashettyhalli road for cycle-I

Sl. No.	Stretch	Rutting measured in the middle of the section (mm)		Cracking of bituminous layer severity and area (%)	Pot holes (number)	Ravelling area (%)	Patching (% of area of subsection)
		LWP	RWP				
1	Section 1	14	15	1	0	1	0
2	Section 2	13	5	0	0	3.5	0
3	Section 3	18	0	2	0	0	0

Table 6 Structural condition evaluation of Rayashettyhalli road for cycle-II

Sl. No.	Stretch	Rutting measured in the middle of the section (mm)		Cracking of bituminous layer severity and area (%)	Pot holes (number)	Ravelling area (%)	Patching (% of area of subsection)
		LWP	RWP				
1	Section 1	0	42	0	0	0	0
2	Section 2	0	47	0	3	0	0
3	Section 3	20	49	58	0	0	0

Table 7 Structural condition evaluation of Rayashettyhalli road for cycle-III

Sl. No.	Stretch	Rutting measured in the middle of the section (mm)		Cracking of Bituminous layer Severity and area (%)	Pot Holes (number)	Ravelling Area (%)	Patching (% of area of subsection)
		LWP	RWP				
1	Section 1	9.9	17.0	0.0	1.4	73.1	0.0
2	Section 2	23.0	32.0	0.0	3.0	65.0	0.0
3	Section 3	63.2	82.1	6.0	2.2	99.1	30.0

4.3 Benkelman Beam Rebound Deflection Studies

Performance of flexible pavements is closely related to the elastic deflection of pavement under the wheel loads. The deformation or elastic deflection under a given load depends upon subgrade soil type, its moisture content and compaction, the thickness and quality of the pavement courses, drainage conditions, pavement surface temperature etc.

The deflection survey essentially consists of two operations:

(i) Condition survey for collecting the basic information of the road structure and based on this, the demarcation of the road into sections of more or less equal performance; and
(ii) Actual deflection measurements.

Deflection measurements are conducted as per IRC 081-1997 [5].

4.4 Functional Condition Evaluation

4.4.1 Pavement Condition Rating

A rating scale with 0 to 5 points, as adopted on CGRA studies was selected in this study. The raters were given adequate training regarding assessment of the riding quality and deciding the rating value in a 5 point rating scale.

Two types of ratings were conducted namely, Visual Rating and Riding Rating.

Visual Rating Technique

The members of the rating panel were trained to walk along the left and right wheel paths on the selected stretches and condition of the pavements was assessed based on the visual judgment of surface characteristics (Table 8).

Ride Rating Technique

For the rating by riding technique the raters were taken in test vehicle driven along the stretches at a speed of 30 kmph and are trained to assess the PSR value according to comfort condition (Table 9).

The Functional Condition Evaluation details are as given in Tables 10 and 11.

Table 8 Description of visual rating scale

Sl. No.	Description based on visual rating	Numerical scale
1	Perfectly even surface Without undulation, Cracking Patching	4–5
2	Slightly uneven Surface with some undulation, no pot holes and slight cracking	3–4
3	Moderately uneven surface, Visible patching and medium cracking	2–3
4	Uneven surface with improper patched, potholes medium to heavy cracking	1–2
5	Uneven surface with different type undulation, badly patched potholes, heavy cracking	0–1

Table 9 Description of ride rating scale

Sl. No.	Description based on ride rating	Numerical scale
1	Without discomfort perfect smoothness	4–5
2	Little distortion, fairly smooth riding	3–4
3	Medium distortion fair to uneven riding	2–3
4	Heavy distortion uncomfortable riding	1–2
5	Intolerable, very discomfort in riding	0–1

Table 10 Functional condition evaluation for Ganjalaghatta road

Ganjalaghatta						
Stretch	PSR values					
	Cycle I		Cycle II		Cycle III	
	VR	RR	VR	RR	VR	RR
Section 1	4.6	4.6	4.0	4.2	3.5	3.9
Section 2	4.3	4.7	3.9	4.1	3.5	3.8
Section 3	4.6	4.8	4.0	4.0	3.6	3.6
Section 4	4.7	4.8	4.1	4.2	3.4	3.6

Table 11 Functional condition evaluation for Rayashettyhalli road

Rayashettyhalli						
Stretch	PSR Values					
	Cycle I		Cycle II		Cycle III	
	VR	RR	VR	RR	VR	RR
Section 1	4.5	4.3	4.0	4.0	3.5	3.7
Section 2	4.6	4.6	3.8	4.0	3.4	3.6
Section 3	4.6	4.5	3.8	3.6	3.5	3.4

5 Analysis of Data

5.1 *Variation of Individual Distresses for Different Cycles*

The variation of individual distresses for all the four sections of Ganjalaghatta Road stretch is tabulated as under (Table 12; Fig. 1, Table 13; Fig. 2, Table 14; Fig. 3, Table 15; Fig. 4, Table 16; Fig. 5).

Table 12 Variation of rutting for different cycles

Cycle	Sub-section No.	Section number	Rutting measured in the middle of the section (mm)	
1	1	Section 1	18	25
2	1		24	34
3	1		64	62
1	2	Section 2	20	13
2	2		39	30
3	2		77	39
1	3	Section 3	31	16
2	3		38	28
3	3		86	42
1	4	Section 4	23	13
2	4		40	25
3	4		55	38

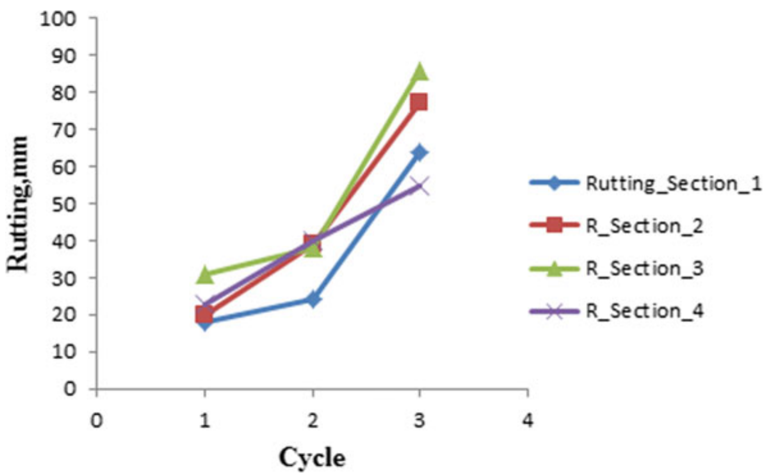

Fig. 1 Variation of rutting for different cycles

Table 13 Variation of cracking for different cycles

Cycle	Sub-section No.	Chainage of sub-section (50 m length)	Cracking of bituminous layer severity and area (%)
1	1	Section 1	18
2	1		24
3	1		64
1	2	Section 2	0
2	2		13
3	2		30
1	3	Section 3	1
2	3		18
3	3		46
1	4	Section 4	3
2	4		16
3	4		35

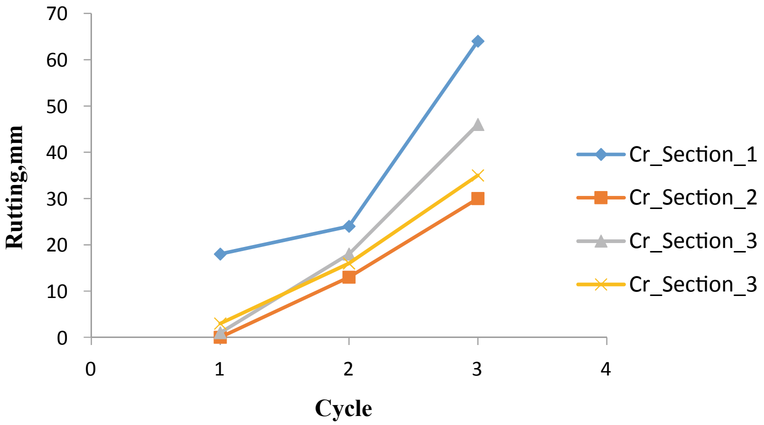

Fig. 2 Variation of Cracking for different cycles

5.2 Effect of Various Distresses on IRI for Ganjalaghatta Road Section

See Table 17; Figs. 6, 7, 8 and 9.

Table 14 Effect of number of pot holes on different cycles

Cycle	Sub-section No.	Chainage of sub-section (50 m length)	Pot holes (number)
1	1	Section 1	0
2	1		0
3	1		2
1	2	Section 2	1
2	2		5
3	2		11
1	3	Section 3	0
2	3		0
3	3		10
1	4	Section 4	0
2	4		0
3	4		0

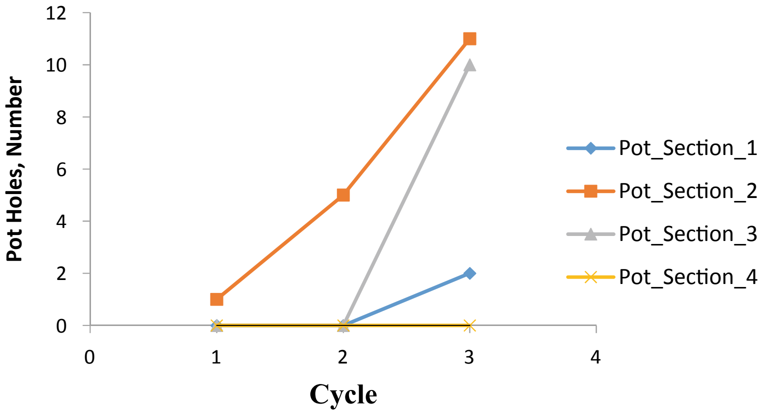

Fig. 3 Effect of number of pot holes on different cycles

5.3 Multiple Linear Regression Model for IRI

The model developed for IRI is Eq. (1) and their respective model summary and Anova given in Tables 18 and 19.

$$IRI = 4.095\sqrt{CRK} - 0.465RAV + 0.322PAT \quad (1)$$

CRK = Cracking
RAV = Ravelling
PAT = Patching
IRI = International Roughness Index.

Table 15 Effect of ravelling on different cycles

Cycle	Sub-section No.	Chainage of sub-section (50 m length)	Ravelling area (%)
1	1	Section 1	0
2	1		10
3	1		95
1	2	Section 2	0
2	2		27
3	2		90
1	3	Section 3	1
2	3		13
3	3		70
1	4	Section 4	1
2	4		22
3	4		39

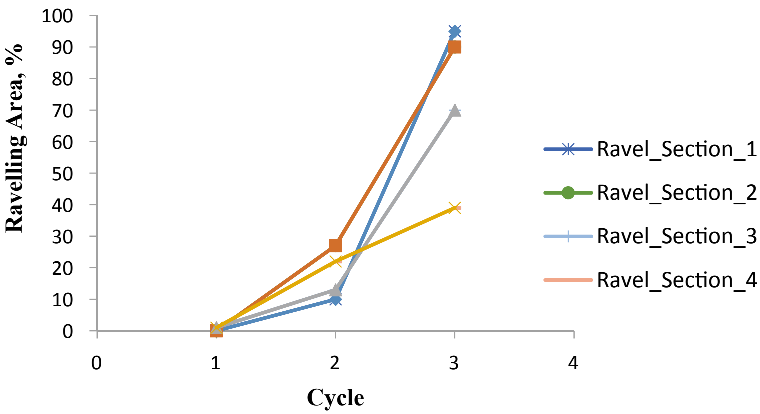

Fig. 4 Effect of ravelling on different cycles

6 Discussions and Conclusions

6.1 Discussions

(i) Quantification of Distresses

a. Rutting has varied linearly between cycles 1, 2, 3 and in case of Section 4, whereas Rutting, between cycles 1 and 2 has varied a little and variation is higher between cycle 2 and 3 for Sections 1,2 and 3.
b. Cracking has a linear variation for Sections 2, 3 and 4; variation of cracking is little between cycle 1 and 2 and higher between cycles 2 and 3.

Table 16 Effect of patching on different cycles

Cycle	Sub-section No.	Chainage of sub-section (50 m length)	Patching (% of area of subsection)
1	1	Section 1	0
2	1		0
3	1		20
1	2	Section 2	0
2	2		9
3	2		19
1	3	Section 3	0
2	3		0
3	3		0
1	4	Section 4	0
2	4		0
3	4		0

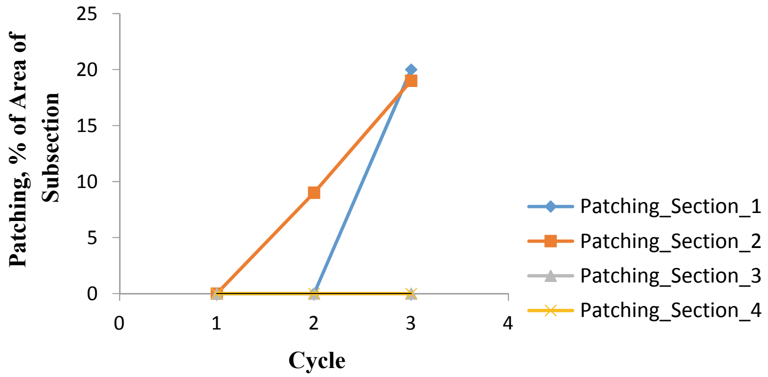

Fig. 5 Effect of patching on different cycles

c. Number of potholes has increased linearly for Section 2 and no distresses are found for all the cycles in case of Section 4. For Sections 1 and 3, potholes have appeared only after cycle 2.

d. In case of Section 4, variation in ravelling almost linear over 3 cycles, and for Sections 1, 2 and 3 variation is a little till cycle 2 and higher variation is observed between cycle 2 and 3.

e. For Section 1, no patching is observed till cycle 2 and patching is observed after cycle 2. There is a linear variation observed for Section 2. No patching is observed for Sections 3 and 4 for all cycles.

Table 17 Data compiled from three cycle reports of TDP

Cycle	Sub-section No.	Cracking of bituminous layer severity and area (%)	Pot holes (number)	Ravelling area (%)	Patching (% of area of subsection)	IRI
1	1	1	0	0	0	7.124
1	2	1	1	0	0	7.265
1	3	1	0	1	0	7.304
1	4	3	0	1	0	7.47
2	1	10	0	10	0	7.23
2	2	13	5	27	9	7.24
2	3	18	0	13	0	7.74
2	4	16	0	22	0	7.71
3	1	30	2	43	20	7.54
3	2	30	11	46	19	7.61
3	3	46	10	39	0	7.95
3	4	35	0	39	0	7.83

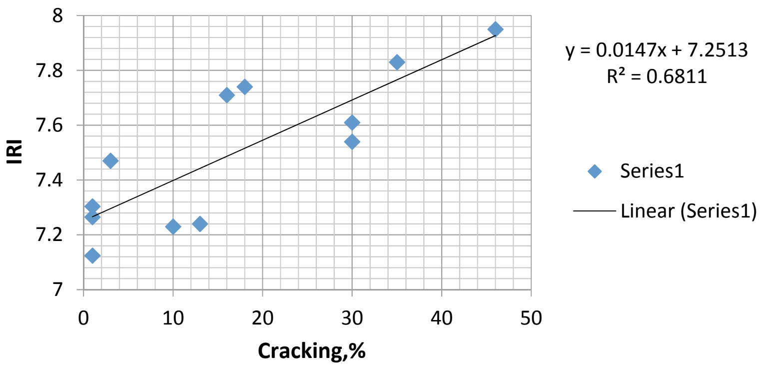

Fig. 6 Variation of IRI with respect to cracking

(ii) Effect of Distress on IRI

Model has been developed to assess the effect of Distresses on IRI. The model developed is as given below:

$$\text{IRI} = 4.095\sqrt{\text{CRK}} - 0.465\text{RAV} + 0.322\text{PAT}$$

With R^2 value of 0.907.

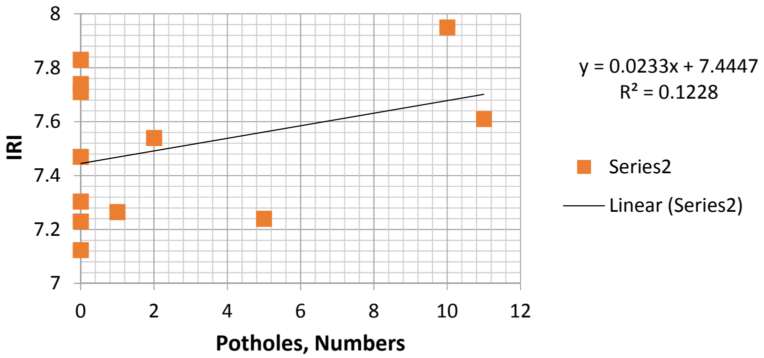

Fig. 7 Variation of IRI with respect to pot holes

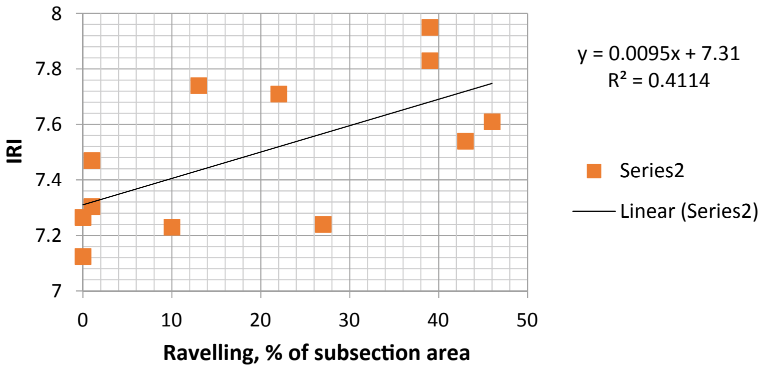

Fig. 8 Variation of IRI with respect to ravelling

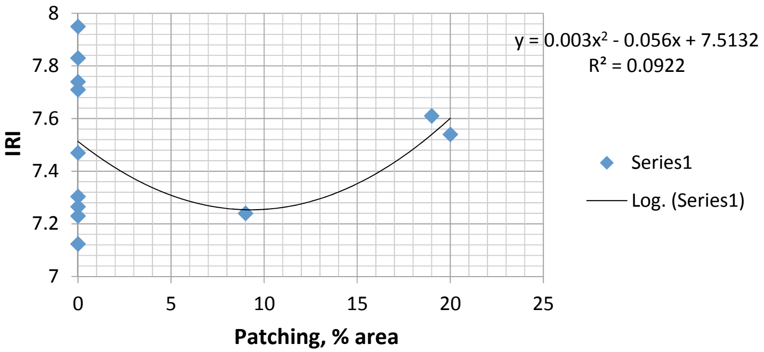

Fig. 9 Variation of IRI with respect to patching

Table 18 Model summary

Regression Statistics					
Model	Multiple R	R Square	Adjusted R Square	Standard error	Observations
10	0.952	0.907	0.776	2.63	12

Table 19 ANOVA

	Df	Sum of Square	Mean Square	F	Significance F
Regression	3	613.71	204.57	29.56	0.000112
Residual	9	62.29	6.92		
Total	12	676.00			

(iii) The observations were made, such as repairs and patching shall have high effect on IRI. The model is to be validated.

6.2 Conclusions

(i) Compared to the previous cycles of testing, the distress values have increased. This is due to lack of proper maintenance.
(ii) The data collected in previous 3 cycles show abnormality. The significance of the data variation is to be established. Hence further data collection shall be made.
(iii) The model shows high dependency on the cracking parameter whereas lowest dependency on patching.
(iv) The statistical approach used in the present study does not give satisfactory results in terms of statistical modulus.

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