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Performance Evaluation of Rigid Pavements

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Abstract - Rural roads play an important role in the development of the country, as major part of the Indian population stays in rural areas. The construction of cement concrete rural roads has gained momentum due to the central government sponsored program called Pradhana Mantri Gram Sadak Yojana (PMGSY). In the present study, nine cement concrete test stretches constructed under PMGSY connecting many villages in Hangal Taluk, Haveri District at Karnataka state in India were selected, to develop the present serviceability index (PSI) equation for cement concrete roads. To carry out the studies, the test stretches were selected with varying pavement conditions from worst to good condition. The unevenness of the pavements was determined using MERLIN, and the unevenness values were expressed in terms of BI and are measured in millimeters per kilometer. The distress such as scaling (ravelling), spalling, faulting, cracking, rut depth etc were measured and recorded. The rating studies were also carried out by constituting two panels with five raters in each panel. The ratings of the two panels from the field observations were subjected to error elimination viz leniency error and central tendency error. The true ratings were obtained after application of corrections to the individual ratings. The distress data and the mean of the corrected ratings of both visual and ride ratings were used and regression analysis were carried out to develop PSI equations for these village roads based on both visual and ride ratings. The pavement distress data were substituted in the developed models to obtain the PSI values. Then the values were compared with the corrected PSR values obtained from rating studies. The pavement condition index (PCI) values were computed by the deduct value method.

Key Words: Present Serviceability Index (PSI), Pavement Condition Index (PCI), International Roughness Index (IRI), Present Serviceability Rating (PSR)

1. INTRODUCTION

Road transport is an important mode of transport having many desirable characteristics such as flexibility, door to door service and accessibility to remote areas. The development of distress in a road leading to failure can be considered as a continuation of the development of the irreversible strain in the road, after a period of initial compaction due to repeated loading of one or more elements of the road above critical values of stress and strain.

The service life of the pavement would be reached when any one of the structural or functional parameters reach a minimum acceptable level, at that point maintenance would be carried out and a new service life would begin.

Pavement condition consists of four main components; riding comfort, load carrying capacity, safety and aesthetics. Pavement condition data are collected to assist in making decision on highway maintenance, rehabilitation and reconstruction.

For successful maintenance of the pavements it is essential to know the present condition of the pavement to withstand the design traffic under prevailing climate and environmental conditions. When pavements are subjected to increased magnitude of wheel loads the pavement deterioration starts earlier than the anticipated design life. The PSI models and PCI help to analyze the present condition and to provide a proper maintenance to the pavements to increase the service life.

1.1 Location of the Roads selected for studies:

In the present study, nine different rural road stretches connecting many villages in Hangal Taluk, Haveri District at Karnataka State in India were selected. These nine stretches were further divided into 20 subsections for more precise studies.

The different technologies were adopted for the construction of these roads. These roads were constructed by under the initiation of Central Government programme 'Pradha Mantri Gram Sadak Yojana' (PMGSY).

The roads which are considered for this study comes under PMGSY and constructed as experimental stretches with varying the construction material and to evaluate their performance, durability and cost. The carriageway width of each road was found to be **3.75 m**.

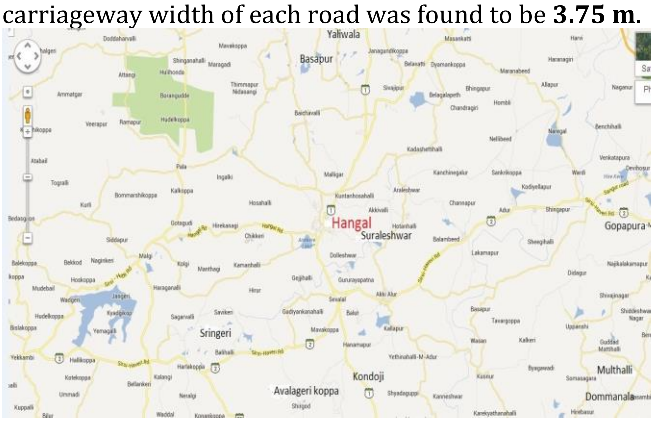

Fig 1: Map showing the project Location & project roads.

2. FIELD STUDIES

2.1 Selection of the Test Stretches

The locations of the test stretches are given in Table 1

Table 1: Selected Test Stretches for Rating Studies

Name of the Road	Technology Adopted	Age of pavement in months
Gopapura (Ch 0.0 - 2.0km)	CC Pavement	27
Gopapura (Ch 2.0 - 4.5km)	CC Pavement	27
Dommanala (Ch 0.0 - 3.0km)	CC Pavement	27
Dommanala (Ch 3.0 - 6.3km)	CC Pavement	27
Shringeri (Ch 0.0 - 3.0km)	CC Pavement	24
Shringeri (Ch 3.0 – 5.9km)	CC Pavement	24
Multhalli (Ch 0.0 – 2.5km)	RCCP	31
Multhalli (Ch 2.5 – 5.0km)	RCCP	31
Multhalli (Ch 5.0 – 7.9km)	RCCP	31
Yaliwala (Ch 0.0 – 3.6km)	RCCP	25
Avalagerikoppa(Ch0- 2.5km)	RCCP	32
Avalagerikoppa(Ch2.5- 5km)	RCCP	32
Avalagerikoppa(Ch5- 7.0km)	RCCP	32
Kondoji (Ch 0.0 – 2.0km)	RCCP with Flyash	27
Kondoji (Ch 2.0 – 3.8km)	RCCP with Flyash	27
Suraleshwara(Ch 0 - 2.0km)	RCCP with Flyash	32
Suraleshwara(Ch 2 - 4.2km)	RCCP with Flyash	32
Basapur (Ch 0.0 – 2.5km)	RCCP with Flyash	27
Basapur (Ch 2.5 – 5.0km)	RCCP with Flyash	27
Basapur (Ch 5.0 – 7.9km)	RCCP with Flyash	27

2.2 Pavement Condition Measurement

- **Pavement Unevenness -** Pavement unevenness that affects the vehicle operating cost was measured using a MERLIN. The Merlin is a simple roughness measuring machine that has been designed for use in developing countries. "Merlin stands for – a Machine for Evaluating Roughness using Low-cost Instrumentation" (Cundill, 1991). Roughness in terms of the Merlin scale, D, is obtained by first plotting the recorded data onto a histogram. Five percent of the total number of recorded observations is counted in from each end of the distribution with the position marked. The value D, in millimetres, is then obtained by measuring the distance between the two marked points, representing a data spread of 90% for the collected data.

  Cundill (1991) a data spread of 90% produced the highest coefficient of determination (R2), when linear regression was undertaken using D values derived from different data percentages. Readers are referred to Cundill, (1991) for a more detailed description on how to obtain D, roughness in terms of the Merlin scale. With the value of D obtained, IRI by correlation can be calculated from Equation given below.

$$IRI = 0.593 + 0.047D$$

  Where IRI is the roughness in terms of the International Roughness Index, measured in metres per kilometre (m/km), and D is the roughness in terms of the Merlin scale, measured in mm.

- **Scaling -** The scaling surface is identified by the worn out or the loss of material on the top of the surface. The scaled surface is measured by converting the scaled surface into suitable geometric area for measurement using tape. The scaled surface is expressed in sq meters.

- **Faulting Measurement -** A three meter straight edge was used to determine the difference in height between the two slabs. The straight edge was placed on the longitudinal direction and faulting depth was measured with the aid of wedge scale.

- **Cracked Area -** Crack is defect in the pavement surface, which weakens the pavement structure. It allows water to percolate into the pavements which causes further damage. These cracks were measured in terms of its spread over area.

Table 2: Roughness and Pavement Distress Data of Selected Pavement Test Stretches

Stretch No	IRI m/km	Cracking in sq m	Scaling in sq m	Faulting in mm
1	3.62	0.15	12.56	2.2
2	3.52	2.54	82.24	4.1
3	8.22	1.87	10.16	7.5
4	6.53	1.8	156.33	14.2
5	7.61	6.9	8.26	3.5
6	6.81	5.8	29.81	6.2
7	8.75	2.2	137.65	11.2
8	8.26	2.4	188.84	10.8
9	8.04	2	166.82	18.2
10	7.61	2.12	97.87	12.8
11	6.89	1.3	127.63	8.6
12	6.34	0.72	116.65	9.2
13	6.15	1.3	118.21	14.8
14	6.69	1.67	106.42	7.4
15	6.37	0.6	142.48	6.8
16	6.60	6.5	138.71	14.2
17	6.24	1	143.45	10.8
18	6.55	3.68	145.17	24.2
19	6.85	6.4	87.09	12.6
20	6.77	4.7	69.76	18.9

2.3 Constituting of Rating Panel

To carry out the PSR studies, three panels were constituted viz highway, mixed and non highway panels, with five raters in each panel.

2.4 Visual Rating and Ride Rating

The members of the rating panel were trained to walk along the left and right wheel paths on the selected stretches and the condition of the pavement was assessed based on the visual judgment of surface characteristics. The rating scale adopted for the visual assessment of pavement is shown in Table 3. Based on the condition of the stretch the raters were allowed to rate the stretch on the scale of zero to five.

For the rating by riding technique the raters were taken in a test vehicle driven along the stretches and are trained to assess the PSR value according to comfort condition. The rating scale adopted for the riding assessment of pavement is shown in Table 4.

Table 3: Description of Visual Rating Scale

Sl. No	Description Based on Visual Condition of Pavement Surface	Numerical Scale
1	Perfectly even surface, without undulations, cracking, patching or scaling.	4-5
2	Slightly uneven surface with some undulations, Slight cracking.	3-4
3	Moderately uneven surface, medium cracking, slight faulting or scaling.	2-3
4	Uneven surface with improperly patched potholes, medium to heavy cracking and scaling	1-2
5	Uneven surface with different type of undulation, potholes, heavy cracking	0-1

Table 4: Description of Riding Rating Scale

Sl. No.	Description Based on Riding Condition of Pavement Surface	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 discomfortable riding	0-1

The following three panels were constituted for rating the ride and visual ratings:

- Highway panel- The panel consisting of 5 members having knowledge about highway technology.
- Non highway panel – The panel consisting of 5 members of non highway background.
- Mixed panel- The panel consisting of both the members of above two panels.

3. ANALYSIS OF DATA

3.1 Analysis of Present Serviceability Ratings

The compiled data were analyzed to estimate the mean and standard deviation of rating values. The rating values were thus determined for each pavement section both for ride and visual rating techniques. The same data were analyzed for the estimation and removal of errors present in the rating. The statistical analysis was carried out for the compiled data thus the values of mean and standard deviation of each pavement section and for each rater is calculated.

3.2 Estimation and Removal of Errors in the Individual Present Serviceability Ratings

The members rated the selected stretches both by visual and ride rating techniques as per the scale mentioned in the above tables.

But the ratings were modified due to the following errors:

- *Leniency error* - The leniency error was determined by computing mean of individual rater and mean of all single ratings and the leniency error is obtained by subtracting mean of the individual rater and mean of all single ratings.
- *Central tendency error* - The central tendency errors are determined by calculating the standard deviation of individual raters and standard deviation of all single ratings.

3.3 Determination of True Ratings

After the determination of errors in the visual and ride rating values for all the three panels the true present serviceability ratings were determined. The true ratings were obtained by adding corrected leniency error and central tendency error to the field ratings. The mean of the three panels and the overall mean value both for visual and ride rating are given in Table 5 and Table 6.

Table 5: Corrected Values of the Visual Ratings for Selected Pavement Test Stretches

Stretch No	Highway	Mixed	Non highway	Average
1	4.2	4.0	4.0	4.06
2	4.0	3.7	3.3	3.70
3	3.2	3.0	3.5	3.23
4	2.3	2.5	2.3	2.36
5	3.6	3.6	3.6	3.59
6	3.4	3.6	3.8	3.62
7	2.7	2.8	3.2	2.92
8	2.9	2.9	3.0	2.94
9	2.1	2.4	3.1	2.49
10	3.4	3.3	3.4	3.37
11	2.9	2.9	3.4	3.07
12	2.9	3.1	3.5	3.16
13	2.8	3.1	3.3	3.05
14	3.1	3.1	3.5	3.22
15	3.1	3.0	3.1	3.05
16	2.8	2.9	3.0	2.90
17	3.0	3.2	3.1	3.08
18	1.8	1.6	2.4	1.92
19	2.2	2.1	3.1	2.45
20	2.6	2.9	3.4	2.92

Table 6: Corrected Values of the Ride Ratings for selected pavement test stretches

Stretch No	Highway	Mixed	Non highway	Average
1	4.2	4.1	4.0	4.13
2	3.8	3.4	3.9	3.71
3	3.7	3.9	3.3	3.61
4	2.4	3.0	2.4	2.60
5	3.4	3.6	3.6	3.55
6	3.3	3.7	3.5	3.51
7	2.6	2.9	3.0	2.82
8	2.6	3.2	3.2	2.98
9	1.9	2.9	3.1	2.64
10	3.2	3.2	3.5	3.30
11	3.3	3.4	3.5	3.41
12	3.5	3.3	3.8	3.54
13	3.0	3.4	3.2	3.19
14	3.2	3.4	3.2	3.27
15	2.7	3.0	3.4	3.02
16	2.9	3.0	3.1	2.99
17	2.8	2.9	2.7	2.85
18	1.5	1.7	2.5	1.88
19	2.2	2.4	3.2	2.61
20	2.8	2.8	3.5	2.99

3.4 Development of Model

The PSI model was developed along the lines of AASHO equation using the field measurements such as faulting, IRI, scaling and cracking and mean PSR values. The PSI equation was developed for both the visual and ride rating using analysis tool pak and regression analysis. The PSI models were developed for each of individual distress and finally a multiple linear regression analysis was carried out to develop models. The models are given below

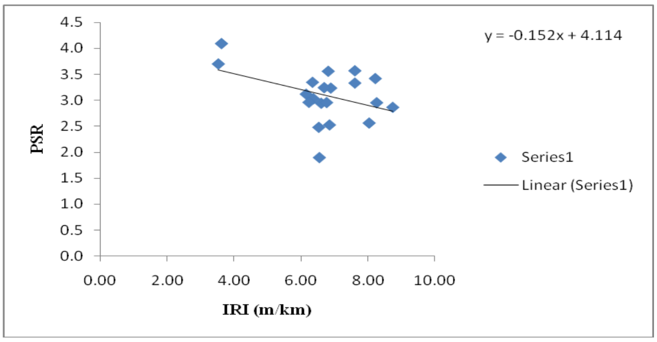

Chart-1: The linear graph representing PSR v/s IRI values.

PSI = 4.11 - 0.152 (IRI)

PSI model with roughness as a distress expressed in IRI

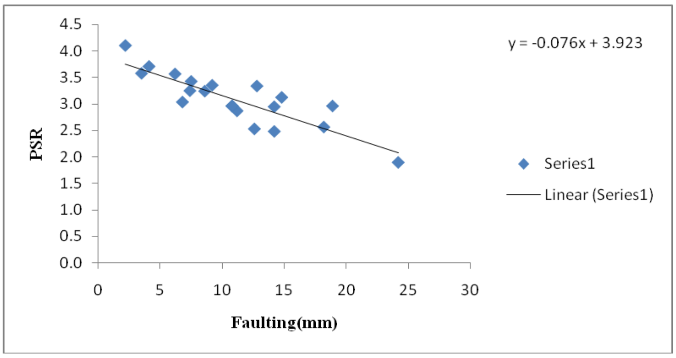

Chart-2: The linear graph representing PSR v/s Faulting values.

PSI = 3.92 – 0.076 (faulting)

PSI model with faulting as a distress expressed in mm (average) per 100 m^2 area.

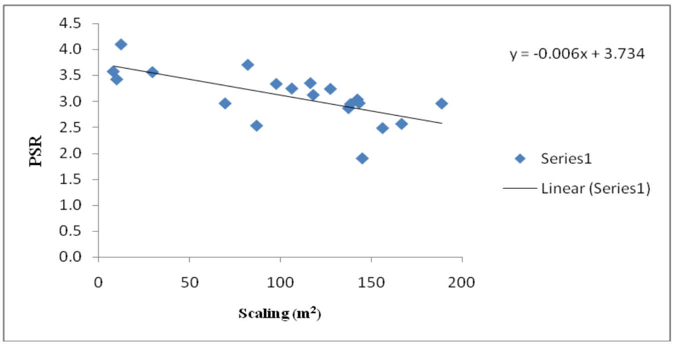

Chart-3: The linear graph representing PSR v/s Scaling values.

PSI = 3.73 - 0.0062 (Scaling)

PSI model with scaling as a distress expressed in square meter per 100 sq m area.

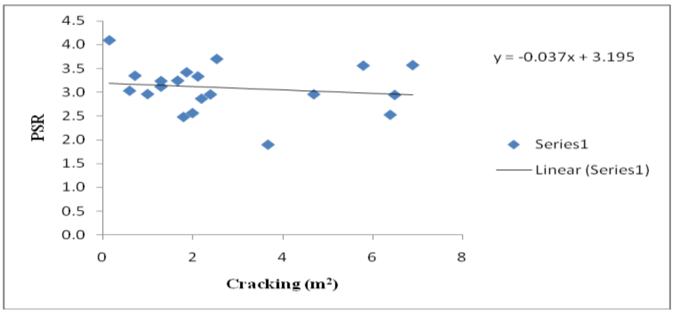

Chart-4: The linear graph representing PSR v/s cracking values.

PSI = 3.19 - 0.037 (cracking)

PSI model with cracking as a distress expressed in square meter per 100 sq m area.

3.4.1 Multiple Linear Regression Model for Visual Ratings

Model: Y_i (PSI) = $\beta_0+\beta_1$ (IRI)+β_2 (Faulting) +β_3 (Scaling) + β_4 R(Cracking) + ε_i

Assumptions

1) The response variable Y is linearly related to regressor variables IRI, cracking, faulting, scaling and
2) ε_i (error) i.e. errors are normal with mean zero independent common variance σ^2.

Model for Visual Rating of Pavements

PSI = 4.31 – 0.039 (IRI) – 0.055 (faulting) - 0.003 (scaling) – 0.025 (cracking)

PSI = Present serviceability Index for the range 0.00 to 5.00
IRI = International Roughness Index, m/km in the range 3.52 to 8.75 m/km
Faulting = faulting in mm in the range 2.2 to 24.2 mm (average) per 100 m² area.
Cracking = Cracking, in the range 0.15 to 6.9 square meter per 100 sq m area
Scaling = Scaling in the range of 8.26 to 188.84 square meter per 100 sq m area.

Table 7: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Observations
1	0.893	0.798	0.745	0.252	20

A Predictors: (Constant), IRI, Faulting, Cracking and Scaling
B Dependent Variable: PSR
R2 =0.798 tells us that 79.8% of variation in Y is explained by the regressor variables IRI, Cracking, Faulting and Scaling. (Note: anything more than 60% is good)

Table 8: Anova

Model		Sum of Squares	Df	Mean Square	F
1	Regression	3.783	4	0.945	14.88
	Residual	0.953	15	0.063	
	Total	4.730	19		

	Coefficients	Standard Error	t Stat	P-value
Intercept	4.313	0.305	14.12	4.53E-10
IRI	-0.039	0.048	-0.81	0.427
Cracking	-0.025	0.031	-0.79	0.439
Faulting	-0.055	0.013	-4.11	0.0009
Scaling	-0.003	0.001	-2.09	0.053

3.4.2 Multiple Linear Regression Model for Ride Ratings

Model: Y_i (PSI) = $\beta_0+\beta_1$ (IRI) $+\beta_2$ (Faulting) $+\beta_3$ (Scaling) + β_4 R (Cracking) + ε_i

Assumptions

1) The response variable Y is linearly related to regressor variables IRI, cracking, faulting, scaling and
2) ε_i (error) i.e. errors are normal with mean zero independent common variance σ^2.

Model for Ride Rating of Pavements

PSI = 4.37 – 0.022 IRI – 0.051(faulting) - 0.003(Scaling) – 0.050(cracking)

PSI = Present serviceability Index for the range 0.00 to 5.00
IRI = International Roughness Index, m/km in the range 3.52 to 8.75 m/km
Faulting = faulting in mm in the range 2.2 to 24.6 mm (average) per 100 m² area.
Cracking = Cracking, in the range 0.15 to 6.9 square meter per 100 sq m area.
Scaling = Scaling in the range of 8.26 to 188.84 square meter per 100 sq m area.

Table 9: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Observations
1	0.901	0.812	0.762	0.245	20

A Predictors: (Constant), IRI, Faulting, Cracking and Scaling
B Dependent Variable: PSR
R^2 =0.90 tells us that 90% of variation in Y is explained by the regressor variables IRI, Cracking, Faulting and Scaling. (Note: anything more than 60% is good)

Table 10: Anova

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	3.898	4	0.974	16.23	2.52E-05
	Residual	0.900	15	0.060		
	Total	4.798	19			

	Coefficients	Standard Error	t Stat	P-value
Intercept	4.37	0.296	14.75	2.45E-10
IRI	-0.022	0.046	-0.485	0.634
Cracking	-0.050	0.030	-1.652	0.119
Faulting	-0.003	0.013	-3.881	0.001
Scaling	-0.051	0.001	-2.704	0.016

3.4.3 Determination of Pavement Condition Index (PCI)

The PCI was calculated according to **ASTM** Standards.
PCI =PCI $_{max}$ - ∑ Deduct
PCI – individual condition index based on measured condition.
PCI $_{max}$ = value for perfect condition with no measured defects =100
Deduct – deduct value assigned to distress type severity and extent.

Table 11: The PCI Values and Condition of Pavement for Selected Stretches.

Stretch No	Cracking	Faulting	Scaling	TDV	CDV	PCI	Condition
1	0.15	2.2	12.56	2	2	98	good
2	2.54	4.1	82.24	26	15	85	Satisfactory
3	1.87	7.5	10.16	16	9	91	Good
4	1.8	14.2	156.33	71	46	54	Poor
5	6.9	3.5	8.26	15	8	92	Good
6	5.8	6.2	29.81	24	16	84	Satisfactory
7	2.2	11.2	137.65	63	41	59	Fair
8	2.4	10.8	188.84	74	49	51	Poor
9	2	18.2	166.82	77	51	49	Poor
10	2.12	12.8	97.87	60	38	62	Fair
11	1.3	8.6	127.63	35	23	77	Satisfactory
12	0.72	9.2	116.65	56	37	63	Fair

13	1.3	14.8	118.21	62	41	59	Fair
14	1.67	7.4	106.42	52	33	67	Fair
15	0.6	6.8	142.48	58	36	64	Fair
16	6.5	14.2	138.71	44	27	73	Satisfactory
17	1	10.8	143.45	64	42	58	Fair
18	3.68	24.2	145.17	82	53	47	Poor
19	6.4	12.6	87.09	73	48	52	Poor
20	4.7	18.9	69.76	64	40	60	fair

4. CONCLUSIONS

The following conclusion has been drawn from the study:

- The pavement selected varies from worst to good condition covering the boundaries for the model. The PSI models developed for visual and ride rating shows IRI has a major influence on the PSI model and in ride rating model faulting has also a major influence compared to scaling and cracking.

For Visual rating studies,

PSI =4.31–0.039(IRI)–0.055(faulting)-0.003 (scaling) –0.025(cracking)

For Ride rating studies.

PSI=4.37–0.022 IRI–0.051(faulting) - 0.003(Scaling) –0.050(cracking)

- The IRI and age has a great influence on the PSI. PSI starts decreasing with increasing in age and IRI.
- Based on the remaining service life the lowest service life is 140 months and highest is 148 months. According to this the concrete rural roads provide better service upto 12 years based on roughness.

Using the Pavement Condition Index (PCI) values by deduct value method 3 stretches were found to be in good condition, 4 were satisfactory, 8 were in fair condition and remaining 5 in poor condition. The plain cement concrete roads have given better performance compared to the other roads constructed using different materials and different technologies. Hence the plain cement concrete pavements are in good condition and the other pavement conditions vary from satisfactory to poor condition.

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