Correlation between Deflection and Unevenness Index for Evaluation of Flexible Pavements

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Received: 16.07.2014 *Accepted: 15.12.2014*

Abstract:

Evaluating existing flexible pavement condition is a pre-requisite to choose improvement technique that has to be adopted to enhance its quality. To evaluate existing pavements, non-destructive testing methods are desirable. Benkelman Beam and 5th Wheel Bump Integrator are used to conduct non-destructive tests like deflection and roughness surveys on the existing pavement of 4 lane divided carriageway of Nandigama – Ibrahimpatnam section of NH-9 in the state of Andhra Pradesh (India). In this paper, an attempt has been made to develop and validate linear and logarithmic models between deflection and unevenness index for pavement under study and the correlation between these two parameters. The section selected for model validation is Naidupet – Sullurpet section of NH-5 in the state of Andhra Pradesh. It is found that validated unevenness index (UI) values from the model are 90% similar with the UI values obtained from roughness survey at second location. Conducting deflection and roughness surveys cost around ₹. 2,00,000 per Km and is time consuming. The objective of the study is to develop a relation between deflection and unevenness index, such that, if one parameter is known, the second parameter can be calculated and hence, the survey time and cost can be minimized.

Keywords: Flexible pavement, Benkelman Beam, 5th wheel bump integrator, unevenness index, correlation, roughness survey

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1. Introduction

Road transport is the dominant mode of transport in India, because of advantages like flexibility, door-to-door service and easy accessibility to rural habitations [Thabassum, 2013]. Road network in India has expanded from 0.4 million km in 1951 to about 3.32 million kilometers presently, a sevenfold increase, but traffic has increased 120 times. This leads to the deterioration of surface of the pavements and a need to rehabilitate them before further damage could occur [Jundhare et al. 2012]. Pavement is the actual travel surface especially made durable and serviceable to withstand the traffic load commuting upon it. Today a lot is known about how to build roads, but not so much is known on how to keep roads in a good condition, and very little is known about how to determine the structural condition of a road in some not too complicated and slow manner [Andren, 2006]. Pavement evaluation should be done to know the nature, severity and extent of the road deterioration. The key determinants for the performance of any road are analyzed through unevenness index and structural deflection [Kumar et al. 2010]. Non-destructive testing is a collective term for evaluations conducted on an existing pavement structure. Non-destructive testing methods can assess either functional or structural condition. In the present study, the four lane divided carriageway of National Highway (NH) No: 9 from Km. 240.000 to Km. 270.000 (Nandigama – Ibrahimpatnam section) is selected as location: 1 to conduct deflection and roughness surveys to evaluate its structural and functional condition and to establish a model between these two. The location: 2 selected to validate the model is from Km. 55.000 to Km. 70.000 (Naidupet – Sullurpet section of 4 lane divided carriageway) of NH-5 in the State of Andhra Pradesh (India). Study locations: 1 and 2 are shown in Figures 1 and 2.

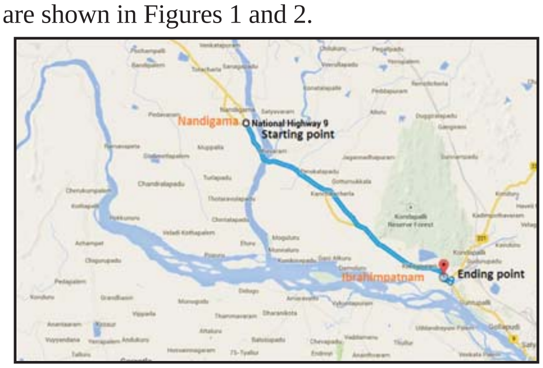

Figure 1. Location - 1

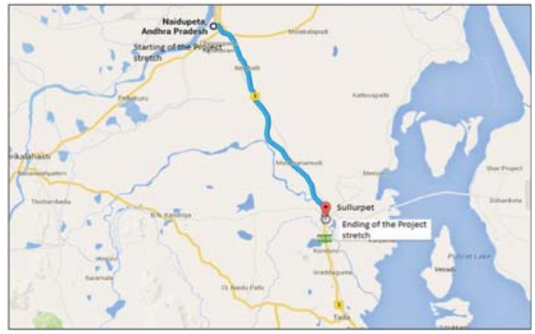

Figure 2. Location - 2

2. Non-Destructive Evaluation of Pavement Functional Properties

Functional properties of pavements include skid resistance and unevenness. Skid resistance is a function of micro and macro texture of the pavement surface. Pavement unevenness is generally defined as an expression of irregularities in the pavement surface that adversely affect the ride quality of a vehicle (and thus the user). Unevenness is an important pavement characteristic because it affects not only ride quality but also vehicle delay costs, fuel consumption and maintenance costs. The roughness measurement of stretches under consideration has been done by using 5^{th} wheel bump integrator.

3. Non-Destructive Evaluation of Pavement Structural Properties

The structural properties of pavement include density, thickness, stiffness and deflection. Evaluation of pavement deflection is an important study, because the magnitude and shape of deflection is a function of traffic (type and volume), structural condition, temperature and moisture affecting the pavement structure. The equipment to evaluate structural properties of pavement based on deflection criteria is Benkleman Beam.

4. Deflection of Pavement: Benkelman Beam

Pavement surface deflection measurements are primary means of evaluating a flexible pavement structure. A. C. Benkelman, an employee of the US Bureau of Public Roads, developed in 1953 the so called Benkelman beam or the deflection beam [Visser, 2000]. The Benkelman Beam, as shown in Figure 3, is a standard beam manufactured by STECO, New Delhi, India. Pavement deflections for locations 1 and 2 are measured by this beam, consists of a slender beam of 3.66m long pivoted at a distance of 2.44m from the tip. By suitably placing the probe between the dual wheels of a loaded truck, it is possible to measure the rebound and residual deflections of pavement structure. While the rebound deflection is due to pavement performance, the residual deflection is caused due to non-recoverable deflection of the pavement or because of the influence of the deflection bowl on the front legs of the beam.

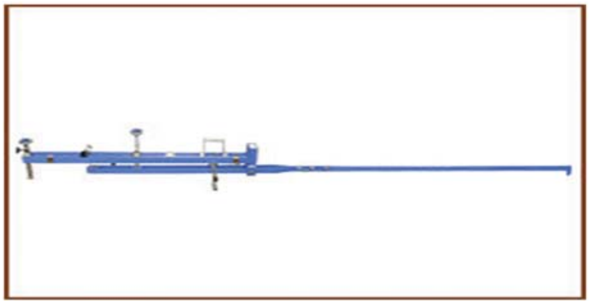

Figure 3. Benkleman Beam

Pavement deflection is measured using the procedure as described in IRC: 81 [IRC: 81, 1997]. The deflection survey is conducted on fast moving and slow moving lanes on both left and right hand side of the carriageway at an interval of 50 m in a staggered manner. A truck having rear axle weighing 8,170 kg fitted with dual tyre inflated to a pressure of 5.6 kg/cm^2 is used for loading the pavement. The deflection is measured along the wheel path viz 90 cm from the pavement edge. The dual wheels of the truck are centered above the selected point. The probe of the Benkelman Beam is inserted between the dual tyres and placed on the selected point. The truck is slowly driven a distance of 270 cm stopped and intermediate dial gauge reading is recorded and is further moved 900 cm away and final dial gauge reading is recorded. The pavement temperature and seasonal variation in climate influence the deflections and temperature has been recorded once every hour by inserting a thermometer in a hole (approximately 45 mm deep and 10 mm diameter) drilled in the pavement and filled with glycerol. At any deviation of the pavement temperature during measurements from the standard temperature of 35^{o}C, correction has been applied. Moisture correction factors were obtained from figures given in IRC: 81-1997. Plasticity Index (PI) and field moisture content of the sub-grade were established from test pit excavations. The mean and standard deviation for ten consecutive points in each Kilometer section has been computed after applying temperature and seasonal variation corrections. Finally, the average characteristic deflection for every kilometer for locations: 1 and 2 is determined as shown in Tables 1 & 2 and in Figures 4 & 5.

Table 1. Characteristic deflection (Location: 1)

S. No.	From Ch. (Km)	To Ch. (Km)	Char. Def. (Right carriageway in mm)	Char. Def. (Left carriageway in mm)	Char. Def. (Avg. in mm)	S. No.	From Ch. (Km)	To Ch. (Km)	Char. Def. (Right carriageway in mm)	Char. Def. (Left carriageway in mm)	Char. Def. (Avg. in mm)
1	240	241	0.750	0.796	0.773	16	255	256	0.603	1.603	1.103
2	241	242	0.606	0.606	0.606	17	256	257	0.703	0.703	0.703
3	242	243	0.610	0.610	0.610	18	257	258	0.477	1.077	0.777
4	243	244	0.638	1.238	0.938	19	258	259	0.557	0.957	0.757
5	244	245	0.882	1.488	1.185	20	259	260	0.564	0.948	0.756
6	245	246	0.825	1.025	0.925	21	260	261	0.510	0.910	0.710
7	246	247	0.588	1.188	0.888	22	261	262	0.575	1.175	0.875
8	247	248	0.568	0.568	0.568	23	262	263	0.539	1.111	0.825
9	248	249	0.635	1.435	1.035	24	263	264	0.560	0.960	0.760

Table 2. Characteristic deflection (Location: 2)

S. No.	From Ch. (Km)	To Ch. (Km)	Char. Def. (Right carriageway in mm)	Char. Def. (Left carriageway in mm)	Char. Def. (Avg. in mm)
1	55.000	56.000	0.599	0.665	0.532
2	56.000	57.000	0.547	0.703	0.525
3	57.000	58.000	0.551	0.605	0.478
4	58.000	59.000	0.829	0.551	0.690
5	59.000	60.000	0.654	0.696	0.575

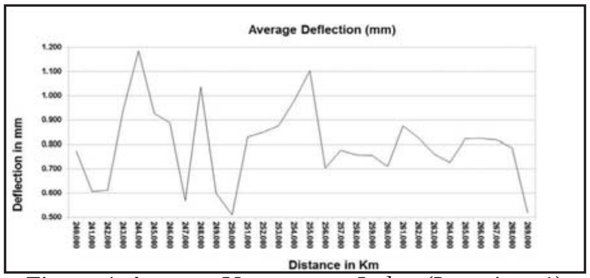

Figure 4. Average Unevenness Index (Location: 1)

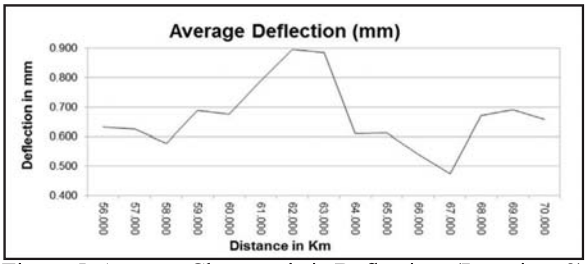

Figure 5. Average Characteristic Deflection (Location: 2)

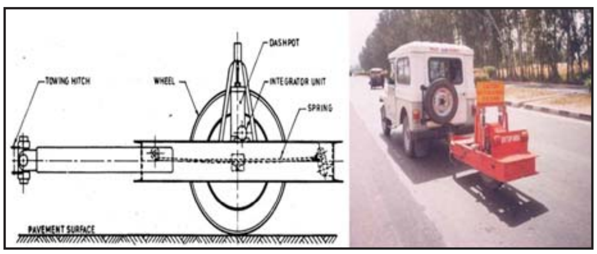

Figure 6. 5th wheel bump integrator

Table 5. Model relationship

S. No.	Model type	Equation	R^2 Value	F statistic	standard error for UI estimate
1	Linear	UI = 890.448 (def) +1367.234	0.756	87.55	82.256
2	Log-log	Ln (UI) = 0.337 (Ln def) + 7.719	0.768	93.17	0.038
3	Log-linear	UI = 695.85 (Ln def) + 2248.732	0.757	87.41	82.305

Table 4. Unevenness Index (UI) (Location: 2)

S. No.	Chainage, Km		Unevenness Index (mm/Km)		
	From	To	Left carriageway	Right carriageway	Average value
1	240	241	2090	2122	2106
2	241	242	2054	1888	1971
3	242	243	2063	1875	1969
4	243	244	2567	1884	2225
5	244	245	2158	1893	2025
6	245	246	2261	2315	2288
7	246	247	2297	2288	2293
8	247	248	2194	2491	2342
9	248	249	2009	1973	1991
10	249	250	1946	1996	1971
11	250	251	1866	1915	1890
12	251	252	1861	1861	1861
13	252	253	1969	1911	1940
14	253	254	1852	2000	1926
15	254	255	1969	1996	1982

Table 6. Model validation

S. No.	Chainage, Km		UI (Measured) (mm/Km)	UI (Model Validated) (mm/Km)
	From	To		
1	240	241	2106	1928
2	241	242	1971	1920
3	242	243	1969	1870
4	243	244	2225	1985
5	244	245	2025	1971
6	245	246	2288	2079
7	246	247	2293	2170
8	247	248	2342	2161
9	248	249	1991	1905
10	249	250	1971	1908
11	250	251	1890	1827
12	251	252	1861	1751
13	252	253	1940	1967
14	253	254	1926	1986
15	254	255	1982	1954

Table 3. Unevenness Index (UI) (Location: 1)

S. No.	Chainage, Km		Unevenness Index (mm/Km)			S. No.	Chainage, Km		Unevenness Index (mm/Km)		
	From	To	Left carriageway	Right carriageway	Average value		From	To	Left carriageway	Right carriageway	Average value
1	240	241	2089	2074	2081	16	255	256	2347	2347	2347
2	241	242	1982	1782	1882	17	256	257	2234	2234	2234
3	242	243	1964	1764	1864	18	257	258	2081	2081	2081
4	243	244	2333	2333	2333	19	258	259	2176	2176	2176
5	244	245	2342	2342	2342	20	259	260	2108	2108	2108
6	245	246	2288	2288	2288	21	260	261	1915	1915	1915
7	246	247	2036	2036	2036	22	261	262	2131	2131	2131
8	247	248	1857	1857	1857	23	262	263	2086	2086	2086
9	248	249	2387	2387	2387	24	263	264	2041	2041	2041
10	249	250	1906	1906	1906	25	264	265	2027	2067	2047
11	250	251	1942	1542	1742	26	265	266	2027	2027	2027
12	251	252	2032	2032	2032	27	266	267	2086	2086	2086
13	252	253	2054	2054	2054	28	267	268	2050	2050	2050
14	253	254	2041	2041	2041	29	268	269	2027	2027	2027
15	254	255	2261	2261	2261	30	269	270	1960	2347	1860

5. 5th Wheel Bump Integrator

Surface unevenness affects the vehicle speed, comfort, vehicle operating cost and hence it gives an indication to road users as well as the developer, which may likely impact on cost of construction. Surface unevenness of the road is determined by using the parameter Road Unevenness Index (UI). UI is measured using 5th wheel Bump Integrator as shown in Figure 5, which falls in the category of roughness instrument called Response – type developed by Road Roughness Measuring system (RTRRM) [Raju et al. 2012]. The machine basically relies on capturing the dynamic response of a mechanical system (e.g. a vehicle) moving along a wheel path to the road profile at a uniform speed of 32+/-0.5 Kmph besides maintaining the standard pneumatic tyre wheel inflated to the pressure of 5.6 Kg/ cm^2 [Raju and Raju, 2011]. The cumulative response (typically the sum of upward and downward movements of the axle with the chassis) is then related to the roughness characterizing the profile.

The equation for calculating the Unevenness index (UI) of the pavement is given in Eq - 1.

UI = (10*B*R)/ W -------------- (1)

UI: Unevenness Index, mm/km

B: Calibrated Bump Integrator readings from field, mm/km

R: No of revolutions of test wheel, rev

W: No of wheel revolutions from field, rev

Data recorded for each km of the road and analyzed as shown in Tables 3 & 4 and in Figures 6 & 7.

6. Concept of Correlation and Regression

The concept of ‘correlation’ is a statistical tool which studies the relationship between two variables and correlation analysis involves various methods and techniques used for studying and measuring the extent of relationship between two variables. Two variables are said to be in correlation, if the change in one of the variables results in a change in the other variable. Linear function is a function of x as the input variable and is drawn on a common (x, y) graph, usually expressed as: y = mx + c. Logarithmic function is defined as the inverse of the exponential function. It is written as y = Log Bx, which is equivalent to x = B y, for B > 0 and B<>1. In statistics, the coefficient of determination R^2 is the proportion of variability in a data set that is accounted for a statistical model. R^2 indicates the goodness of fit of a model. An R^2 of 1.0 indicates that the regression line perfectly fits the data.

An attempt has been made to develop linear, log-log and log-linear relationship using deflection values and unevenness index values obtained from surveys conducted at study location: 1. Correlation equations, statistical test results and R^2 values have been given in Table 5. The R^2 values for the three model types from the below table indicated that the deflection parameters are in correlation with unevenness index values.

7. Model Validation and Conclusion

It is found that Log-log relationship of two variables with high R^2 can be validated to calculate the UI values for the second location. Table 6 and Figures 7 and 8 presents the measured UI values from the survey and validated UI values from the model at the second location.

The study demonstrates clearly that the UI model depicts, the surveyed UI values at second location and hence it can be found that the model and measured values have approximately 90% similarity. Therefore, if deflection (mm) values are known for any existing pavement, unevenness values (mm/Km) can be calculated using this model resulting in cost minimization of roughness survey.

8. References

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