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Pavement Roughness Prediction Systems: A Bump Integrator Approach

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Abstract**—**Pavement surface unevenness plays a pivotal role on roughness index of road which affects on riding comfort ability. Comfort ability refers to the degree of protection offered to vehicle occupants from uneven elements in the road surface. So, it is preferable to have a lower roughness index value for a better riding quality of road users. Roughness is generally defined as an expression of irregularities in the pavement surface which can be measured using different equipments like MERLIN, Bump integrator, Profilometer etc. Among them Bump Integrator is quite simple and less time consuming in case of long road sections. A case study is conducted on low volume roads in West District in Tripura to determine roughness index (RI) using Bump Integrator at the standard speed of 32 km/h. But it becomes too tough to maintain the requisite standard speed throughout the road section. The speed of Bump Integrator (BI) has to lower or higher in some distinctive situations. So, it becomes necessary to convert these roughness index values of other speeds to the standard speed of 32 km/h. This paper highlights on that roughness index conversional model. Using SPSS (Statistical Package of Social Sciences) software a generalized equation is derived among the RI value at standard speed of 32 km/h and RI value at other speed conditions.

Keywords**—**Bump Integrator, Pavement Distresses, Roughness Index, SPSS.

I. Introduction

PAVEMENT indices are the key measures for better understanding of the present condition, serviceability and performance of the pavement. Roughness is widely regarded as the most important measure of pavement indices which affects safety, comfort, travel speed, vehicle operating costs etc. Therefore, it has been considered as one of the key factors to make a decision for further road works. Recent literature regarding optimization of pavement maintenance strategies also addresses roughness as an important indicator that affects lifecycle costs of a road stretch.

But evaluation of roughness of pavement surface is very difficult as it also depends on the working principal or strategy of measuring instruments in addition to the actual road surface conditions. Different instruments have been developed by different agencies and standardized at different manner for the collection of pavement roughness data. Among various instruments, Towed Fifth Wheel Bump Integrator is the most popular equipment being used by several organizations in developing countries because it is affordable, simple and quite easy to operate. It also needs less frequent maintenance and calibration technique. But this instrument is standardized to a particular speed value of 32km/h. That means for accurate roughness result the surveyor have to drive this instrument at a speed of 32km/h. If the speed changes from 32km/h, the instrument will show different values of roughness and this value will not match with the actual profile of the road surface. That's why it is mandatory to maintain the constant speed of 32km/h throughout the road. But sometimes it is not possible to retain this constant speed in field due to traffic variance, sharp horizontal curve, steep gradient, narrow path etc. Somewhere it needs to increase or decrease the vehicle speed while driving a long travel distance. Therefore, it becomes very essential to negotiate this drawback of Bump Integrator instrument so that it may possible to evaluate the RI value even it is operated in any speed other than its standard speed of 32km/h. Some correlations between BI values of surface roughness at standard speed and BI values of surface roughness at various speeds have been presented in this paper.

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II. Some Highlights on Existing Works

A group of researcher worked on road roughness and its measurement. Most of them preferred response-type road roughness measuring systems which estimate pavement roughness from correlation equations. Using several case studies, they have shown how the bias created by speed fluctuations affects the road roughness. Most of the calibration systems recommend to maintain a constant survey speed or to keep the speed within a certain range. But carrying out a survey with this speed constraint may not always be possible due to the existence of traffic control devices and heavy traffic flow. Therefore, these systems may produce a significant bias in roughness measurement because of survey speed fluctuations. A simplified regression relationship for IRI with bump integrator reading and survey speed as explanatory variables is developed using ROMDAS bump integrator [1]-[6].

Few researchers worked on the distress of road pavement. They presented the timely identification of undesirable distress in pavements at network level using pavement management system summarizing the implementation of a condition prediction or methodology using different techniques to forecast cracking, raveling, rutting and roughness for Low Volume Roads (LVR) in India [7]-[10].

Presently Artificial Neural Networks (ANN) is broadly using by researcher to analyzed the Long Term Pavement Performance (LTPP) database to predict the international roughness index (IRI) in rigid flexible and rigid pavements.

Different pavement roughness parameters such as initial IRI value, age, faulting, traffic data, and transverse cracking data for different severity levels (low, medium, and high) were used as input data set for development of ANN model in most of the studies [11]-[15].

III. Bump Integrator

It is an automatic Road Unevenness Recorder, an indigenous device developed by CRRI (Central Road Research Institute). It comprises of a standard pneumatic wheel mounted within a rectangular frame with single leaf spring on either side. Spring dashpots mounted on the leaf spring provide damping for the suspension. An integrating unit is there which is mounted on one side of the frame and integrates the unevenness in cm. For the measurement it is towed by a jeep at a constant speed of 32km/h under standard tyre pressure of 2.1kg/cm^2 along the designated wheel path. Bumps in cm and corresponding road length in terms of wheel revolution pulses are displayed / recorded on a panel board. The wheel runs on the pavement surface and the vertical reciprocating motion of the axle is converted into unidirectional rotary motion by an integration unit. The accumulation of this unidirectional motion is recorded by operating electronic sensors incorporated in the circuit, once for every 10mm of accumulated unevenness.

IV. Work Methodology

A no. of dataset is required to test the BI value at different speeds. In this regard total 15 PMGSY road stretches of 225m are selected at Melagarh subdivision at west district of Tripura, India. Roads are such way selected that other parameters which affects roughness value and riding comfort ability such as soil characteristics, materials properties, traffic condition, etc. are same for all stretches and the stretches should be consists of noticeable surface undulations. During case study, it is noticed that the speed change during BI test usually differs in between 20km/h to 50km/h in low volume roads in Tripura due to traffic variance, sharp horizontal curve, steep gradient, narrow path etc. So, it is decided to conduct BI tests with speeds varying from 20km/h to 50km/h with an increment of 5km/h and for correspondence the standard speed value of 32km/h is also considered. For bump integrator reading, first the total stretch is marked properly. Then at starting point i.e. at 0 distance, the BI reading is adjusted to "0" cm. The instrument is driven over the stretch with a speed of 20km/h and after crossing the end point marking; BI reading is taken and noted. The result of bump integrator is generated in terms of count per km, which is the accumulation of the number of pulses in the total stretch. Same test is repeated considering the speeds as mentioned above. During analysis, BI values of 10 stretches (among 15 stretches) are used for developing the models and rests 5 are used for validating the equations. Using SPSS software linear Regression analysis is done for developing correlation models. Table I shows the result of BI tests at 20, 25, 30, 32, 35, 40, 45 and 50km/hr speed. Some individual equations are developed with the BI value of standard speed of 32 km/h against the BI values of above mentioned speeds. But it is required to generalize the equations to expand the measuring area and for universal use of bump integrator instrument. So, using multiple linear regression analysis by SPSS, a generalized model is developed. For validation of the models, percentage error is calculated which may be regarded as reliable.

V. Result and Discussion

It is observed that for every stretch, BI value at 20km/hr speed is highest conversely BI value at 50km/hr is lowest. With the increase of speed, BI value is consequently decreasing. This phenomenon can be focused to the fact that when the Bump Integrator wheel travels at higher speed it tends to miss out micro and small distresses on the pavement surfaces, showing lesser BI values. On the contrary, when it travels at lower speeds, it follows the actual profile of the road surface and the wheel covers both micros as well as large-scale irregularities and hence indicates higher BI values. Graphs are plotted between the observed values taking speeds as abscissa and corresponding BI values of roughness as coordinates. From the graphs (Fig. 1) it is observed that for all operating speeds, BI values forms almost distinct straight lines with a descending order slope. Table II shows the equations at corresponding speeds with satisfactory R^2 values. The generalized equation derived by multiple linear regression analysis is established between the observed BI values at standard speed as the dependent variable and the observed BI values at a particular speed of operation as the independent variable and that particular speed as another independent variable (1).

$$(\mathrm{BI})_{32} = 0.956(\mathrm{BI})_{\mathrm{V}} + 0.842\mathrm{V} - 25.544 \ (R^2 = 0.958) \quad (1)$$

where,

$(\mathrm{BI})_{32}$ = BI value at standard operating speed of 32 km/hr.

$(\mathrm{BI})_{\mathrm{V}}$ = BI value at Operating speed V.

For validation of these equations, BI values at 32km/hr are calculated using the individual equations as well as the generalized equation for the rest 5 stretches. The percentage of error is calculated for both cases following (2).

V = Operating speed in km/hr.

$$\%\ \text{deviation} = \frac{((\text{Observed } (\mathrm{BI})_{32}) - (\text{Calculated } (\mathrm{BI})_{32}))\ \text{x}\ 100}{\text{Observed } (\mathrm{BI})_{32}} \quad (2)$$

It may be observed from Table III that there was not much variation between the BI values with those of the predicted values using individual and generalized equations. The Mean percentage error of the values with the developed individual and generalized equations were -2.219 and -2.439 respectively. Thus the equations were found to be satisfactory for predicting BI values when the data could not be collected at standard operating speed of 32km/hr. Also it was observed that the individual equations were more accurate than the generalized equation.

TABLE I
OBSERVED BI VALUES AT DIFFERENT SPEEDS

No of Stretches	BI Values at Different Running Speed "V" km/hr							BI Values at 32km/hr
	V=20	V=25	V=30	V=35	V=40	V=45	V=50	
Stretch 1	125	112	109	100	97	96	91	108
Stretch 2	110	104	101	98	97	89	76	99
Stretch 3	74	63	62	60	57	55	46	61
Stretch 4	138	122	112	109	104	104	98	112
Stretch 5	77	61	59	58	56	49	44	60
Stretch 6	65	59	54	49	45	38	36	50
Stretch 7	91	88	82	78	74	69	63	81
Stretch 8	62	58	52	48	45	40	37	50
Stretch 9	107	103	99	93	88	82	79	97
Stretch 10	77	74	68	63	57	55	48	66

TABLE II
EQUATIONS TO CONVERT DIFFERENT BI VALUES TO STANDARD BI VALUES

Running Speed (km/hr)	Equation to find the BI value (cm/km) at 32km/hr ($(UI)_{32}$)	R^2
20	0.904x-5.310	0.969
25	0.975x-3.927	0.985
30	1.013x-2.464	0.997
35	1.047x-0.804	0.994
40	1.044x+3.181	0.987
45	1.003x+10.46	0.989
50	1.044x+13.87	0.987

TABLE III
CALCULATION OF % ERROR OF EXPECTED BI VALUES

No of Stretches	Observed BI at 32 km/h	Running Speed "V"	Observed BI at Running Speed "V"	Calculated BI at 32km/hr using Individual equations	% of error	Calculated BI at 32km/hr using generalized equation	% deviation
Stretch 1	53	20	65	53.685	-1.292453	53.436	-0.822641509
	53	25	59	54.781	-3.360377	51.91	2.056603774
	53	30	58	56.521	-6.643396	55.164	-4.083018868
	53	35	55	56.275	-6.179245	56.506	-6.61509434
	53	40	51	55.362	-4.456604	56.892	-7.343396226
	53	45	48	56.372	-6.362264	58.234	-9.875471698
	53	50	41	53.952	-1.796226	55.752	-5.19245283
Stretch 2	51	20	71	58.761	-15.21765	59.172	-16.02352941
	51	25	66	61.102	-19.80784	58.602	-14.90588235
	51	30	57	55.568	-8.956863	54.208	-6.290196078
	51	35	56	57.29	-12.33333	57.462	-12.67058824
	51	40	49	53.34	-4.588235	54.98	-7.803921569
	51	45	46	54.37	-6.607843	56.322	-10.43529412
	51	50	41	53.952	-5.788235	55.752	-9.317647059
Stretch 3	63	20	72	59.607	5.385714	60.128	4.558730159
	63	25	67	62.005	1.579365	59.558	5.463492063
	63	30	62	60.333	4.233333	58.988	6.368253968
	63	35	61	62.365	1.007937	62.242	1.203174603
	63	40	58	62.439	0.890476	63.584	-0.926984127
	63	45	56	64.38	-2.190476	65.882	-4.574603175
	63	50	58	71.836	-14.0254	72.004	-14.29206349
Stretch 4	86	20	107	89.217	-3.740698	93.588	-8.823255814
	86	25	103	94.513	-9.898837	93.974	-9.272093023
	86	30	99	95.594	-11.15581	94.36	-9.720930233
	86	35	89	90.785	-5.563953	89.01	-3.5
	86	40	88	92.769	-7.87093	92.264	-7.28372093
	86	45	81	89.405	-3.959302	89.782	-4.397674419
	86	50	74	88.668	-3.102326	87.3	-1.511627907
Stretch 5	51	20	55	45.225	11.32353	43.876	13.96862745
	51	25	50	46.654	8.521569	43.306	15.08627451
	51	30	48	46.991	7.860784	45.604	10.58039216
	51	35	42	43.08	15.52941	44.078	13.57254902
	51	40	41	45.252	11.27059	47.332	7.192156863
	51	45	36	44.36	13.01961	46.762	8.309803922
	51	50	35	47.64	6.588235	50.016	1.929411765
Mean Absolute Percentage Deviation					-2.21965		-2.439789062

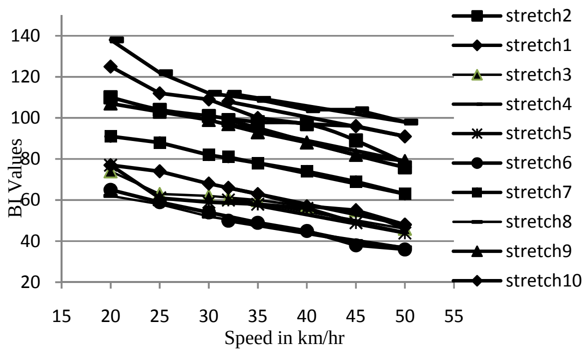

Fig. 1 BI values on different stretches at different speeds

VI. Conclusion

Generally Bump Integrator is used to determine road roughness measurements. But this instrument is not free from speed constraint and is not suitable for any survey speed or speed fluctuations. This limitation produces a significant bias in roughness measurement if the survey speed is not properly maintained at standard speed of 32km/h. In present study an attempt has been taken to develop an equation for the conversion of fifth wheel Bump Integrator values from different speed to a standard speed of 32 km/hr. In this regard some individual equations are derived to convert BI value at a speed of 20km/hr, 25km/hr, 30km/hr, 35km/hr, 40km/hr, 45km/hr & 50 km/hr. But it is required to establish a generalized equation so that we can convert BI values of any speed other than the speeds mentioned above. Using SPSS software the generalized equation is derived as:

$$(\mathrm{BI})_{32} = 0.956(\mathrm{BI})_{\mathrm{V}} + 0.842\mathrm{V} - 25.544 \ (R^2 = 0.958) \quad (3)$$

After validation with all the derived equations mean percentage error found by individual and generalized equations are -2.21965 and -2.439789 respectively, which are very negligible. It is observed that the BI values of roughness decreases significantly with the increase in operating speed of the Bump Integrator.

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