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INVESTIGATION ON A METHOD TO ASSESS ROAD CONDITION BASED ON VIBRATION MEASUREMENTS

Gayan U.K.A, Subashi De Silva G H M J and Sudhira De Silva

University of Ruhuna, Galle, Sri Lanka
E-mail: ukagayan@gmail.com, subashi@cee.ruh.ac.lk and sudhira@cee.ruh.ac.lk

Abstract: Transportation has become a critical measure of development in most of the developing countries. Building and maintaining transport infrastructure is essential for economic and social development of a country. The high costs of repair and maintenance of the existing road networks required to manage the road repair and maintenance and regular planning for this process. Due to daily usage of newly constructed roads, the quality condition of roads, decreases with the time. As a result, discrete faults such as bumps, depressions or potholes are appearing on the road surface. These unevenness and undulations of road surface along longitudinal profile of the road causes vertical oscillations in moving automobiles and its effects on the passenger as Whole Body Vibration. Uneven pavement or road surfaces cause discomfort and fatigue to the passenger directly. The objectives of the current study is to investigate the condition of the road surface both using vibration measurements and visual inspections and to determine possible methods to assess the existing road condition based on the vibration measurements. Different types of roads were selected based on the condition of the roads. For the measurements of the vibration induced while transportation Seat Pad Accelerometer was used to measure the frequency weighted acceleration in m/s2 and vibration levels in three directions; X, Y and Z on the seat. International Roughness Index (IRI) was determined and used as a quantitative measure to indicate the quality of the selected roads. Vibration dose values (VDV) of the compartment recorded signals were evaluated. The correlation found between RMS value and IRI value implies that the road condition can be evaluated and categorized based on the whole body vibration measurements.

Keywords: International rough index; Pavement serviceability; Road condition; Road roughness; Vibration dose value; Whole body vibration

1. Introduction

Transportation plays a major role in development, being an international scale of measuring development of a country. Hence people expect better system of transportation. Moreover, roads are key part of the people in their lives. Hence the monitoring of road surface conditions plays a key role in ensuring safety and comfort to the various road users: from pedestrians to drivers. Relating pavement surface condition with vibration intensity transferred to the vehicle gives an opportunity to evaluate the pavement condition, and to systematically and rationally plan road maintenance and reconstructions [1].

Road roughness is one of the most important road condition measure and primary an indicator of the utility of roads [2]. Road pavements are constructed to provide a firm and even surface for carriage way. The main purpose of pavement or roads is to provide a satisfactory smooth surface upon which traffic can be operated smoothly or easily.

However, due to daily usage of newly constructed roads, the quality condition of roads decreases with the time. As a result, discrete faults such as bumps, depressions or potholes are appearing on the road surface. Those unevenness and undulations of road surface along longitudinal profile of the road causes vertical oscillations in moving automobiles. Therefore, uneven pavement or road surfaces cause discomfort and fatigue to the passenger or fast moving vehicles. Due to vertical oscillations of the vehicles, it is necessary to keep a stationary driving force to control and maintain a constant velocity. So that extra amount of fuel has to be combust. Other than that the life time of the automobiles becomes shorter when they are on the way of uneven pavements or roads.

Exposure to vibration induced by unevenness and undulations of road surface results in complex distribution of oscillatory forces within the body [3]. It may have effects on human activities significantly: Inability of senses to achieve and processing information, amount of excitement, motivation or fatigue and intentional actions. Hence continuous monitoring of road surface conditions and renovating at appropriate time are necessary to ensuring safety and comfort of road users.

1.1 Objectives

Objectives of this research are

- to investigate the condition of the road surface using visual inspections.
- to determine possible correlation between the existing road condition and the whole body vibration measurements.

2. Methodology

In order to estimate the road surface condition whole body vibration at passenger-seat interface and visual inspections of road texture were obtained. In addition, experimental measurements of Present Serviceability Index (PSI), and International Roughness Index (IRI) determinations based on experimental measurements were performed. Vibration on the seat was measured simultaneously as objective measurements.

2.1 Selection of site

As a suitable road segment for measuring the vibrations induced while transportation in vehicle, three different road categories were selected in nearby area (Table 1)

Table 1: List of selected roads

Road Identity	Number of sub segments	Name of Road	Road Grade
R1	1	Karapitiya - Joolgaha	B
R2	2	Wakwalle - Galle	
R3	1	Wakwalle-Ganegoda	C
R4	1	Labuduwa - Godakanda	
R5	1	Ganegoda - Thotagoda	D
R6	3	Poddala - keembiya	

During the selection of road segment for vibration measurement, straight portion of road segment was selected to minimize the higher variation of vehicle speed. In each category of road, the selected road segment was divided in to sub-sections with about 500m in length.

2.2 Whole Body Vibration measurements

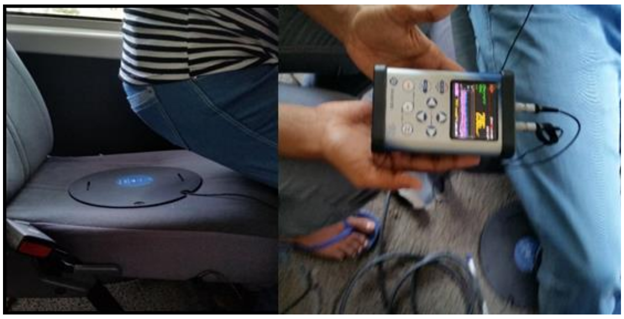

Figure 1: Whole body vibration measurements with Seat Pad Accelerometer

The induced vibration levels were measured by using a Seat Pad Accelerometer as shown in Figure 1. First the pad accelerometer was installed on the seat pan. Second tri-axial accelerometer was placed on the floor at the base of the seat. Each accelerometer was calibrated prior to the initiation of testing. The seat pad accelerometer which is capable of measuring three direction components of vibration was used for the measurement.

The seat pad accelerometer measures the frequency weighted acceleration in m/s^2 and vibration levels in three directions; fore and aft (X), lateral (Y) and vertical (Z). These vibrations were measured separately in constant speed with single vehicle type.

2.3 Visual inspection of road texture

Visual inspection of the same road segment was recorded using the video camera which was installed on the hand itself (Figure 2). Initially a selected road segment was divided into approximately equal intervals and slope variance and rutting depth were measured along the road segment and to the transverse direction of the road,

Figure 2: Camera mounted on vehicle

respectively, The total patched area and total crack lengths including longitudinal, transverse and diagonal cracks were measured all over the road segments of all category roads.

2.3.1 Slope variance

The profile based roughness statistic was obtained from the road profilometers. It was calculated from the statistical variance of surface slope defined for constant distance of 1 ft.

2.3.2 Rutting depth

Rutting is the longitudinal depression that occurs in the wheel path due to inadequate surface thickness, lack of compaction or stability in the surface or base coarse. The rutting depth was measured manually on the section of the road. A straight edge and tape were used to measure the rutting depth.

2.3.3 Patching Area Measurement

The patching area was also measured manually. The total patching area was considered for the selected section of road segment. The patching area was measured in square feet. In this study, the manhole cover was also considered as a patching. Mostly, the patching area was contributed by maintenance works and manhole covers.

2.3.4 Cracking Measurement

The length of the cracking was measured manually by using a tape. Normally various types of cracking including longitudinal, transverse and diagonal cracks were existed in the section of roads.

2.4 Present Serviceability Index (PSI) and International Roughness Index (IRI)

2.4.1 Present Serviceability Index (PSI)

Pavement serviceability refers to the ability of a pavement to provide the desired level of service to the user [4]. The present serviceability index is the subjective assessment of serviceability by a panel of raters and it's related to objective measurement of surface condition, PSI values for each road segments were calculated using Equation (1).

$$PSI = 5.03 - log(1 + SV) - 1.38(RD)^2 - 0.01(C + P)^{1/2} \quad (1)$$

Where

PSI = the present serviceability index which is a statistical estimate of the mean of the present serviceability ratings.

SV = Slope variance over section from CHLOE profilometer

RD = mean rutting depth (in.).

C = cracking (ft. / 1000 ft^2) (flexible),

P = patching (ft^2 / 1000 ft^2).

2.5.1 International Roughness Index (IRI)

IRI is obtained from the measurement of longitudinal road profiles with the measuring units of meter/kilometre (m/km) [5]. This parameter describes a vehicle's reaction to uneven spots in the pavement, which is most appropriate for the analysis of pavement evenness for driving comfort. International Road Roughness was determined as in Equation (2).

Relationship between PSI and IRI are given in equations (2 and 3) for different types of pavements

Asphalt pavement

$$PSI = 5 - 0.2397x^4 + 1.771x^3 - 1.4045x^2 - 1.5803x \quad (2)$$

Where

$$x = \log(1 + SV) \; and \; SV = 2.2704(IRI^2) \quad (3)$$

2.6 Calculation of PSI and IRI values

From the obtained PSI values IRI values were calculated by substituting to the equation 2.

2.7 Analysis

The coefficient of correlations for the Pearson method were calculated by using a SPSS software and significance of the correlation coefficients were considered.

For the analysis the Root Mean Squared (RMS) and the Vibration Dose Value (VDV) were correlated with International Roughness Index (IRI)

3. Results and Discussion

3.1 Visual inspections

For each selected road classes and in each road segment, slope variance, rutting depth cracking length and patched areas are shown in Table 2.

The slope variance varies in the range between 3-20. For D road category the ruttin g depth was found to be the highest value, implying poor road condition.

3.2 Present Serviceability index (PSI) and International Roughness Index (IRI)

Present serviceability index for the each road category is listed in Table 3.

Table 2: Table of visual inspections

Road Identity	Slope variance (mm)	Rutting Depth (mm)	Patched Area (m^2)	Crack length (m)
R1	3.7	5.4	1.4	0
R2S1	3.4	7.7	0.96	23
R2S2	3.6	7.9	0.48	17
R3	7.9	5.1	0	0
R4	10.7	12.5	0	27
R5	18.3	28.3	0	0
R6S1	12.7	27.6	3.4	74
R6S2	12.5	25.6	1.2	34
R6S3	12.5	23.5	1.1	34

Table 3: PSI and IRI values for each road segments

Road Identity	PSI	IRI(m/km)
R1	4.9	0.07
R2S1	4.8	0.07
R2S2	4.8	0.07
R3	4.9	0.07
R4	4.3	14.96
R5	3.3	15.32
R6S1	3.3	15.29
R6S2	3.6	15.21
R6S3	3.8	15.21

Higher PSI values obtained for B grade road category compared to other road categories, indicating the road condition is good. Present Serviceability Index represents the ride quality of a pavement based on a scale of 0 to 5, with 0 being the worst condition and 5 the best according to the AASHO Road Test studies [6]. In the IRI value consideration, IRI value was higher for D grade roads than that for B grade roads. Table 4 shows the threshold values for IRI.

Table 4: IRI Threshold values [7]

Road Quality	IRI Threshold (m/km)
Good	< 1.5
Acceptable	< 2.7
Bad	>2.7

3.3 Whole body vibration measurements

Figure 3: Whole body vibration response in 3 different axis.

It was found that the vibration to the direction of Z axis has become dominant portion of vibration relative to other two axes in whole body vibration as shown in Figure 3.

Table 5: Coefficient of correlation for whole body vibration measurements with IRI.

Whole body vibration measurement	Correlation Coefficient from Pearson Method
RMS-X	0.866**
RMS-Y	0.649
RMS-Z	0.614
VDV-X	0.611
VDV-Y	0.436
VDV-Z	0.588

** Correlation is significant at the 0.01 level

When considering the Pearson method as shown in Table 5, it is clear that X axis shows the dominant correlation between IRI and RMS, VDV.

3.4 Relationship between IRI value and different Road types

When the condition of the road segment became poor, indicated by IRI, significant vibration response was identified (Figures 4 and 5). This implies higher RMS and VDV values have been obtained for D grade road segments while lesser vibration response for B grade road segments.

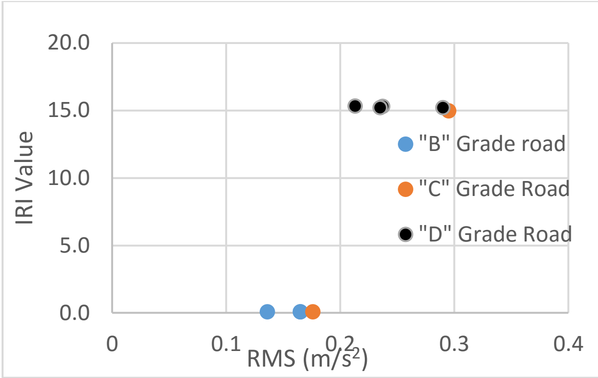

Figure 4: Variation of RMS values with IRI value in X axis

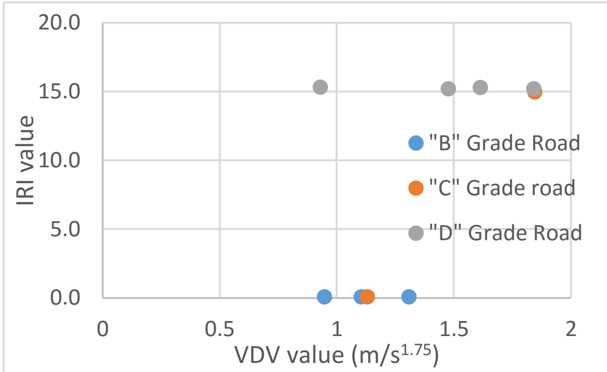

Figure 5: Variation of VDV values with IRI value in X axis

4. Conclusions

It was found that the measured whole body vibration in the vertical direction (Z axis) has become dominant portion of vibration relative to other two axes.

It can be concluded as IRI value is a fair parameter which can be used to identify the condition of the road and classification of roads, which are co-related with vibration measurements.

When the condition of the road became poor vibration response became significant and vice versa. Whole body vibration measurements can be used to categorized the road in to different classes and identify the road condition.

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