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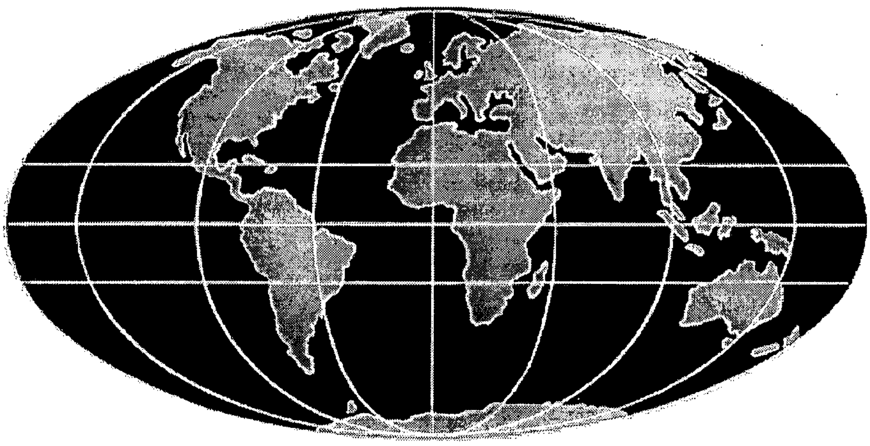
by: G Morosiuk, C R Jones and M Osman



Transport Research Laboratory
Crowthorne
Berkshire RG45 6AU
United Kingdom

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CALIBRATION AND STANDARDISATION OF ROAD ROUGHNESS MEASUREMENTS USING THE TRRL PROFILE BEAM

Dr G Morosiuk
Transport and Road Research Laboratory
United Kingdom

C R Jones
Transport and Road Research Laboratory
United Kingdom

Mahazan Osman
Public Works Department (JKR)
Malaysia

ABSTRACT

This paper describes the development of a new relationship between the towed fifth wheel bump integrator (BI) and the TRRL profile beam for use in the calibration of vehicle response instruments used to measure roughness on asphaltic concrete surfacings. A comparison has also been made with the original BI/profile beam relationship derived from data collected in the United Kingdom and Brazil by the Transport and Road Research Laboratory (TRRL). The results show that the BI/profile beam relationship developed during this study is the more appropriate one to use to calibrate and standardise vehicle response instruments on asphaltic concrete surfaced roads. This study was carried out under a joint cooperative research programme between the TRRL of the United Kingdom and the Jabatan Kerja Raya (JKR) of Malaysia.

1.0 INTRODUCTION

Vehicle operating costs are significantly affected by the quality of the road (Morosiuk and Abaynayaka 1982, Hide 1982). As vehicle operating costs account for a large proportion of the total transport cost over the life of the road (Parsley and Robinson 1982), it is important to measure road roughness accurately. In the past the standard instrument used by the TRRL and other road authorities in the UK has been the towed fifth wheel bump integrator (BI) (Keir 1974). Road authorities in other parts of the world use a wide variety of road roughness measuring devices, most being simple response type instruments which need regular calibration. In order to compare different devices, they need to be related to a standardised scale based on the absolute profile of the road itself (Gillespie et al 1980). The profile beam was designed by the Overseas Unit of TRRL to facilitate this calibration and standardisation procedure.

The profile beam measures the road profile and calculates a single numerical statistic (the root mean square of deviation - RMSD) from the road profile which has been shown to correlate extremely well with most response type instruments. Since roughness measured with the BI has been the UK standard, a relationship between RMSD and the BI has been programmed into the beam's micro-processor so that the profile statistic can be output directly in terms of the BI.

This relationship was developed from data collected on asphaltic concrete, surface dressed, gravel and earth roads thereby covering a range of roughness between 1000 mm/km and 15000 mm/km. The equation was not well established at its extremes and therefore it was desirable to collect more data to improve the overall accuracy.

The majority of the paved roads in Malaysia are surfaced with asphaltic concrete on which the roughness is likely to be in the range of 1000 to 4500 mm/km. This study was therefore designed to develop a relationship between roughness measured by the BI and the profile beam on these roads. The relationship was then compared with the original BI/profile beam relationship to establish the most appropriate one for use in calibrating and standardising roughness measurements made on asphaltic concrete surfacings.

2.0 ROAD ROUGHNESS MEASURING SYSTEMS

Many systems have been devised and used for measuring road roughness. They can be categorised either as response type instruments or profiling devices.

2.1 Response Type Instruments

Most roughness measuring systems use instruments either mounted inside a vehicle or towed by a vehicle at a constant speed. Measurements made with this type of system are the result of the interaction of three basic components - the road, the vehicle and the instrument. They measure and record the cumulative displacement of an axle relative to the body of a vehicle or trailer caused by the unevenness of the road. The majority of these instruments are time, vehicle and speed dependent, and therefore suitable calibration procedures need to be employed to provide meaningful roughness data.

The BI is a single-wheeled trailer, manufactured to rigid specifications, which enables it to be used as a standard instrument for measuring road roughness. It consists essentially of a single axle and a rectangular chassis within which a pneumatic tyred wheel is mounted, the load and tyre size being standardised. An integrator unit is mounted on one side of the chassis and detects the total downward movement of the wheel axle relative to the chassis. When properly maintained, the measurements are stable over time and do not depend on the characteristics of the towing vehicle. Measurements are generally taken at a steady speed of 32 km/hr (20 mph).

BI's are not readily available in most countries but integrator units, similar to the one mounted on the BI, are commonly fitted inside a vehicle. In this case the integrator unit is fitted to the chassis of a vehicle directly over the rear axle to which it is connected.

Vehicle mounted instruments are dependent on speed and the suspension characteristics of the vehicle. The speed can be standardised, but the suspension characteristics differ between vehicles and may change for any particular vehicle over a period of time. Therefore it is necessary to calibrate these vehicles at regular intervals. The profile beam has been designed for the calibration of this type of instrument and to calculate the standard equivalent BI roughness.

2.2 Profiling Devices

These devices record the longitudinal profile of the road and then analyse this profile using standard mathematical procedures. There are several elaborate and expensive profilometers developed by a number of research bodies such as the TRRL high speed profilometer in the UK (Dickerson and Mace, 1976), the APL 125 in France (Lucas and Viano, 1979) and the GMR Profilometer in the USA (Walker et al, 1970).

3.0 THE TRRL PROFILE BEAM

The profiling instrument used for this project was the TRRL profile beam. This equipment consists of an aluminum beam, which is used as the datum, supported at each end by a tripod. The measuring unit, containing a linear transducer and a battery powered micro-processor, is suspended from the beam with its sensor wheel resting on the road surface. The wheel traverses the road along the beam's length and the transducer measures the distance from the beam to the wheel at 100mm intervals.

Earlier research work by TRRL in the UK and Brazil showed that sampling the road profile at 300mm intervals over a 1.8 metre baselength produced the most statistically significant correlations between profile numerics and response type instruments operated at 32 km/hr. The length of the profile beam therefore was fixed at 3.6 metres enabling two complete baselengths to be measured in one placement.

The beam's micro-processor calculates a single numerical statistic (the Root Mean Square of Deviation - RMSD) from the road profile. The RMSD is derived by determining the profile deviation at 300mm intervals from a simple linear regression line, analogous to the ideal road surface profile, for a 1.8 metre baselength and then calculating the root mean square of these deviations.

For a 1.8 metre baselength, with 7 profile points spaced at 300mm intervals, the regression line y = a + bx is calculated and the deviations d_i determined. The RMSD for a 1.8 metre baselength is then computed as:

$$RMSD_{1.8} = \sqrt{\frac{\sum d_i^2}{n}} \qquad [1]$$

The weighted mean RMSD for a section of road containing N baselengths of length 1.8 metres is given by:

$$RMSD = \sqrt{\frac{\sum RMSD_{1.8}^2}{N}} \qquad [2]$$

Measurements of the road profile are taken in both wheelpaths ie RMSD (left) and RMSD (right). The micro-processor then calculates the mean RMSD for a section of road using the formula:

$$\text{Mean RMSD} = \sqrt{\frac{(RMSD_L^2 * PL) + (RMSD_R^2 * PR)}{PL + PR}} \qquad [3]$$

where PL and PR are the number of placements in the left and right wheelpaths respectively; normally these are the same.

The Reference Roughness (RR), which is the equivalent BI roughness estimated from the profile beam's numeric, is then calculated from the formula:

$$RR = 2045(RMSD) + 68(RMSD)^2 \qquad [4]$$

This equation, developed from research work in the UK and Brazil, covers a range of roughness between 1000 mm/km and 15,000 mm/km, as measured with the BI, on asphaltic concrete, surface dressed, gravel and earth roads.

Roughness measurements from a vehicle response device can be standardised by running the vehicle over the same lengths of road profiled with the TRRL beam. For each section of road the vehicle response reading (VR) is input to the micro-processor which then solves the second order polynomial:

$$y = A + Bx + Cx^2 \qquad [5]$$

where y = values of RR calculated from RMSD
x = values of VR

The y value is referred to as the 'Calibration Roughness' and is the estimated roughness in terms of the BI.

4.0 SITE MEASUREMENTS

In this study the BI and the profile beam were used on various asphaltic concrete surfaced roads to develop a new relationship between the two instruments for use in calibrating vehicle response devices. The vehicle used in this calibration exercise was a Toyota stationwagon fitted with an integrator unit which was run over the same lengths of road as the other two instruments.

4.1 Selection of Test Sites

A total of 21 test sites with asphaltic concrete surfacings were selected covering a range of roughness between 1200 mm/km and 3600 mm/km. The sites were flat and straight so that the speed of the vehicles could be easily and safely maintained at 32 km/hr. Each site was 500.4 metres in length (139 beam placements) and had a uniform roughness throughout its length.

4.2 Road Roughness Measurements

The profile of each section of road was measured using the profile beam in both wheelpaths to obtain the RMSD statistic for each wheelpath and thus a mean RMSD for a site.

The BI and the stationwagon were then run over each site at a steady speed of 32 km/hr. The BI, being a single-wheeled trailer, was run in each wheelpath separately whereas the stationwagon responds to the profile of both wheelpaths. The number of passes on each site was dependent on the consistency of the readings with the minimum number of passes being three. The roughness readings from both instruments recorded on the 21 sites, together with the RMSD values, are given in Table 1.

TABLE 1 ROUGHNESS MEASUREMENTS ON SITE

Site No	Toyota station-wagon	Bump Integrator (mm/km)			Profile Beam (RMSD)		
	(mm/km)	v/s	o/s	Mean	v/s	o/s	Mean
1	470	1705	1780	1743	0.459	0.484	0.472
2	510	1700	*	1700	0.495	0.463	0.479
3	540	1850	*	1850	0.589	0.603	0.596
4	1460	3225	3055	3140	1.365	1.285	1.326
5	905	2385	2550	2468	0.999	0.858	0.931
6	735	2285	2020	2153	0.988	0.807	0.902
7	905	2295	2380	2338	1.018	0.879	0.951
8	560	1535	1945	1740	0.587	0.683	0.637
9	1375	2985	3305	3145	1.260	1.319	1.290
10	1575	3020	3630	3325	1.237	1.531	1.392
11	1030	2750	2635	2698	1.250	1.047	1.153
12	1260	2850	2960	2905	1.204	1.177	1.191
13	670	2080	2055	2068	0.806	0.685	0.748
14	725	2300	1965	2133	1.098	0.717	0.927
15	940	2430	2370	2400	1.083	0.864	0.980
16	315	1330	1420	1375	0.383	0.407	0.395
17	305	1285	1340	1313	0.365	0.390	0.378
18	295	1200	1320	1260	0.340	0.361	0.350
19	315	1300	1310	1305	0.362	0.365	0.364
20	405	1690	1725	1708	0.478	0.540	0.510
21	320	1365	1300	1333	0.330	0.371	0.351

(Note: *BI not measured)

5.0 ANALYSIS OF DATA

5.1 Relationship Between the BI and Profile Beam

The relationship between the reference roughness (RR) and the RMSD statistic (equation [4]) incorporated in the profile beam's micro-processor was used to estimate the roughness of a site in terms of the BI.

The reference roughness values estimated from this relationship were then compared with the measured BI roughness values. Both the BI and the profile beam measure roughness in a single wheelpath therefore it was possible to compare 40 pairs of data. These data points are listed in Table 2 and plotted in Figure 1. The comparison shows that the observed BI roughness figures were generally substantially higher than the predicted roughness values from equation [4].

TABLE 2 COMPARISON BETWEEN OBSERVED AND PREDICTED BI ROUGHNESS VALUES

Site No.	BI ROUGHNESS (mm/km)			
	Vergeside		Offside	
	Observed	Predicted®	Observed	Predicted®
1	1705	953	1780	1006
2	1700	1029	*	961
3	1850	1228	*	1258
4	3225	2918	3055	2740
5	2385	2111	2550	1805
6	2285	2087	2020	1695
7	2295	2152	2380	1850
8	1535	1224	1945	1428
9	2985	2685	3305	2816
10	3020	2634	3630	3290
11	2750	2663	2635	2216
12	2850	2561	2960	2501
13	2080	1692	2055	1433
14	2300	2377	1965	1501
15	2430	2294	2370	1818
16	1330	793	1420	843
17	1285	755	1340	807
18	1200	703	1320	747
19	1300	749	1310	755
20	1690	993	1725	1124
21	1365	682	1300	768

® Using equation [4]
* BI not measured

The BI roughness reading on an asphaltic concrete road in good condition is known to be approximately 1200 mm/km (Gillespie 1980). The predicted roughness from equation [4] was below 1000 mm/km on eight sites and fell as low as 700 mm/km on a number of these sites. This suggests that equation [4] underestimates the roughness of relatively smooth asphaltic concrete surfacings.

Using the data from each wheelpath for all sites, a more appropriate relationship for estimating BI roughness values from RMSD numerics was derived. The new reference roughness relationship for asphaltic concrete surfacings (RR_{ac}) is given below and plotted in Figure 2.

$$RR_{ac} = 691 + 1811(RMSD) \qquad [6]$$

$$R^2 = 0.954$$

This new relationship is based on 40 points whereas the original relationship (equation [4]) was based on only 8 points at this end of the range of roughness (ie < 3600 mm/km).

5.2 Calibration of the Vehicle Mounted Integrator Unit

The mean RMSD values given in Table 1 were used to calibrate the stationwagon using the new reference roughness relationship (equation [6]). These reference roughness values and the corresponding vehicle response readings were then used to derive the calibration equation for the vehicle as shown in equation [7].

$$CR = 567 + 2.67(VR) - 0.00064(VR)^2 \quad [7]$$

$$R^2 = 0.976$$

where CR is the Calibrated Roughness in mm/km.
VR is the vehicle roughness reading in mm/km.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Vehicle response type systems are commonly used throughout the world as they offer a rapid and relatively inexpensive method of measuring the roughness of long lengths of road. A method of standardising these roughness measurements has been established using the TRRL profile beam. This study has developed a more appropriate relationship between the BI and road profile for roads with asphaltic concrete surfacings.

It is recommended that this relationship, shown in equation [6], should be used in place of the original relationship (equation [4]) when using the procedure outlined in Section 3.0 to standardise roughness measurements from vehicle response devices used on asphaltic concrete surfaced roads.

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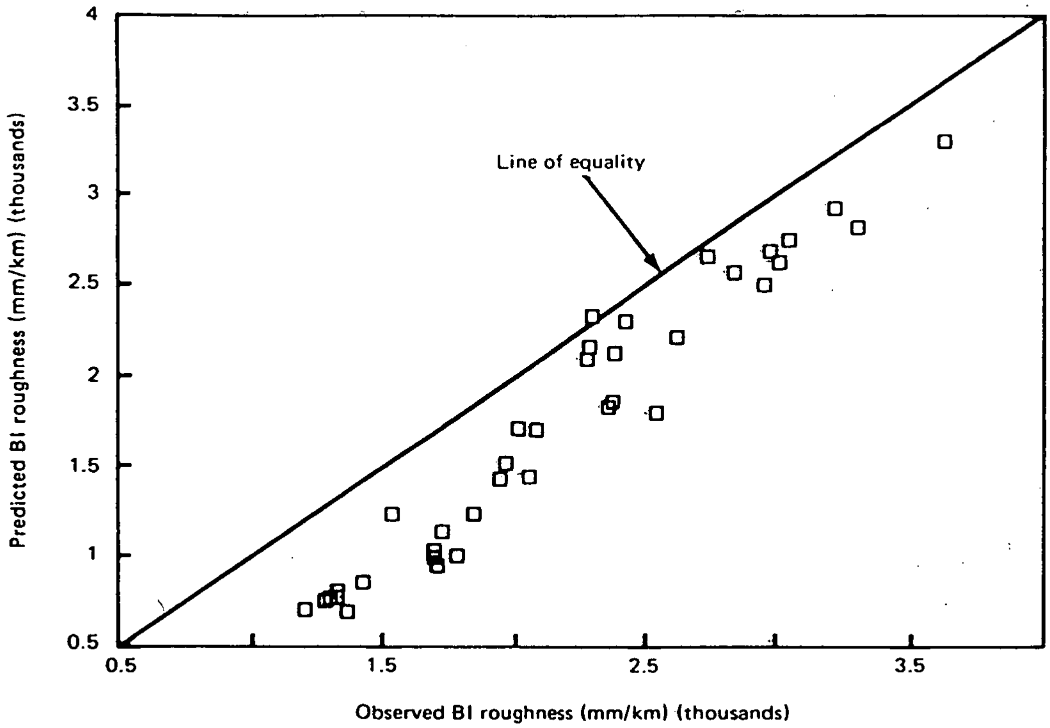

Fig.1 Comparison of observed and predicted BI roughness

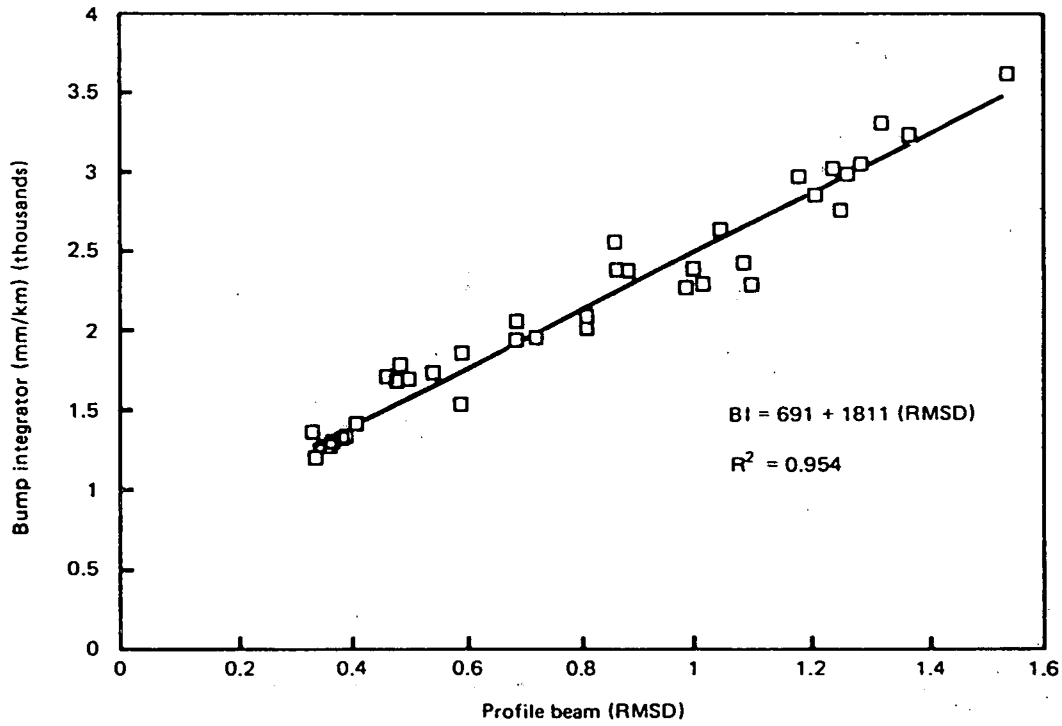

Fig.2 Relationship between BI and profile beam for asphaltic concrete roads in Malaysia