GOVERNMENT OF PAKISTAN
MINISTRY OF COMMUNICATIONS
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CALIBRATING ROAD ROUGHNESS MEASUREMENTS

NTRC No.205

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Contents

EXECUTIVE SUMMARY

The evenness of road surface is a major variable in the economic evaluation of highway improvement because of its influence on vehicle operating costs, which comprise the majority of total transportation costs, and it is a primary determinant of the timing and cost of pavement rehabilitation. Reliable measurement of road roughness is therefore an important activity in road network management.

A wide variety of equipment are used for the measurement of roughness, which can be grouped in to three major classes namely (a) TRL Abay Beam or the Modified Dipstick Profiler, which measure the undulations of road surface at regular intervals; (b) High Speed Laser Guided Profilometer, which is a dynamic profile measuring device and (c) the Bump Integrator (BI), which measure the cumulative vehicle movement of a wheel or axle with respect to the chassis of the vehicle as it travels along the road.

For reasons of cost and convenience, Bump Integrator is commonly used in Pakistan. Since many sources of error affect the output of a B.I unit, therefore there is need for regular and controlled calibration of the instrument.

NTRC has undertaken to calibrate and standardize road roughness measurements made by vehicle mounted Bump Integrators with respect to the Abay Beam and MERLIN.

For this purpose ten road sections of approximately 500 meters in length were selected in the vicinity of Islamabad, five of which were asphaltic concrete surfaced, while the other five surface treated. As a result of detailed data analysis, appropriate regression equations have been worked out for the calibration of vehicle mounted Bump Integrator. The main findings of the exercise are :

- The Abay Beam is more accurate than MERLIN for calibration purposes.

- MERLIN is much faster than Abay Beam and also much simple and cheaper.
- For consistent performance from the Bump Integrator, it is necessary to have a "dedicated vehicle" as any change in the vehicle or even of its characteristics would require re-calibration.
- Although there are limitations in the use of vehicle mounted Bump Integrator but for reasons of cost and convenience, it is adequate for roughness surveys in the country.

ACKNOWLEDGMENTS

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1. INTRODUCTION

The functional condition of any pavement can be assessed on the basis of three distinct measurements, namely road roughness, surface distress, and skid resistance. Evenness (Roughness) and Skid resistance are aspects which directly affect the interaction between vehicles and the pavement surface while surface distress include cracking, disintegration, deformation, pavement edge condition etc.

Evenness includes characteristics of both the longitudinal and transverse profiles of the pavement surface. Usually this has been quantified by the longitudinal profile in the wheel tracks. For this concept, a wide variety of terms are currently used in the world, including roughness, smoothness, evenness, serviceability rating, ride condition index etc. and various device specific scales are adopted to measure it. In this study, the term used for the concept is "Roughness" and the standard measure adopted is the Bump Integrator Index (BI in mm/km).

According to ASTM (E867-87), the road roughness is defined as "The Deviations of a Pavement Surface from a True Planar Surface with Characteristics Dimensions that affect Vehicle Dynamics, Riding Quality, Dynamic Pavement Loads, and Pavement Drainage" [1].

Roughness measuring instruments can be grouped into three different classes. The first class covers the instruments which measure the undulations at regular intervals such as TRL, ABAY beam or the modified DIPSTICK profiler. The second class is the dynamic profile measuring device, such as the TRL High-Speed Profillometer. Finally, there are the Response Type Road Roughness Measuring Systems (RTRRMS). These measure the cumulative vertical movements of a wheel or axle with respect to the chassis of a vehicle as it travels along the road [2].

Roughness affects vehicle operating costs and riding comfort. It is the basic parameter which has been adopted in computing vehicle operating costs to quantify the economic benefits emerging from improving road conditions and is definitely a key parameter used as a criteria for rehabilitation and reconstruction of road projects [3].

2. BACKGROUND OF THE STUDY

Although many different types of road roughness measuring system exist, they all can be classed into two main groups. The first group consist of the system that measures or base their measurement system on the profile of roads and they can be termed Profilometric System for example the TRL, Abay Profile Beam (Abaynayka 1984)or modified Diptick Profiler (Face Company). The second group of system relay on measuring the movement of suspension system in response basically to the unevenness of the road surface it is travelling on. These measure the cumulative vertical movements of a axle with respect to the chassis of a vehicle as it travels along the road. This group could be called Response Type Road Roughness Measuring Systems (RTRRM's). In the case of a standard device such as the towed fifth wheel Bump Integrator (BI, Jordan and Young 1980), the response is used directly as a roughness index. In other non-standard devices, such as the vehicle-mounted Bump Integrator, the response is converted to a standard roughness measure by calibration. The towed fifth wheel BI is expensive and needs careful operation. The vehicle-mounted Bump Integrator commonly referred to as Roadmeters, however, is much cheaper and can perform as long as it is correctly used and is calibrated regularly. It the most widely used device for collecting roughness data.

At present in the country, mostly people use the vehicle mounted roughness meter for the measurement of roughness. Also the National Highway Authority (NHA), uses the vehicle mounted BI units for the routine conditional surveys of the national road network in the country.

TRL vehicle mounted roughness meter is a response-type road roughness measuring system (RTRRM's) which measure the motion between the vehicle body and reference axle and yield a displacement per unit distance measure that relates to roughness. It consists of essentially three components: a vehicle, a transducer that detects relative movements of the suspensions, and a display that is connected electrically to the transducer. As every vehicle has different suspension characteristics (springs, shock absorbers, rubber bushes etc.) and the roughness meter reading given by one vehicle will not be same as another. Roadmeter data are therefore of little value unless the device has been calibrated to a standard reference. The Bump Integrator (BI) reference has been adopted for this study [4].

Keeping in mind, the importance of the roughness surveys, it is necessary to calibrate a particular vehicle installed with a roughness meter, periodically. For this purpose it is necessary to select number of short road sections, termed as "control road sections", which cover the range of roughness exhibited by National/Provincial Highway of the country under the supervision of qualified Highway Engineers.

The most successful method of calibrating vehicle mounted roughness meter to date has been the calibration through correlation. The calibration is performed by running the RTRRMS over a number of "Control road sections" that have been assigned known "Reference" roughness values. Correlating the known "Reference" roughness values with the RTRM's measurements of sections termed as "Vehicle Response" provides calibration equation for conversion of raw RTRRM's data.

In this study for each of the control road section, the reference roughness is calculated with the help of TRL, Abay Profile Beam and the TRL designed Machine for Evaluating Roughness using Low-Cost INstrumentation(MERLIN). The TRL, Abay Profile Beam is a 4m long, beam carrying a profile measuring carriage and microprocessor which records profile elevations relative to the beam datum. It generates a Root Mean Square Deviation (RMSD) statistic with the help of profile data and then the inbuilt microprocessor generates the "

Reference " roughness in mm/km (BI scale) value. A complete set of TRL, Abay Beam is available in NTRC as shown in Plate.1. Similarly the MERLIN is a device, which can be used either for direct measurement or for calibrating other instruments such as the vehicle mounted Bump Integrator. Merlin is shown in Plate.2.

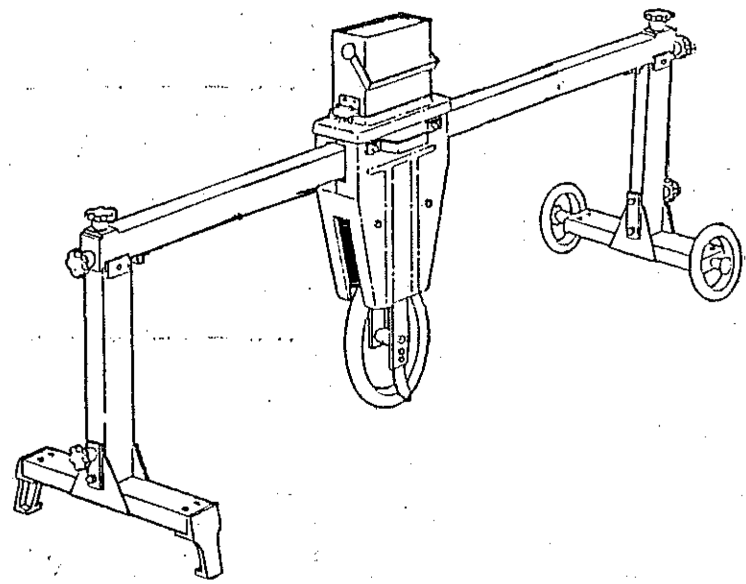


Plate.1 The TRL Abay Profile Beam

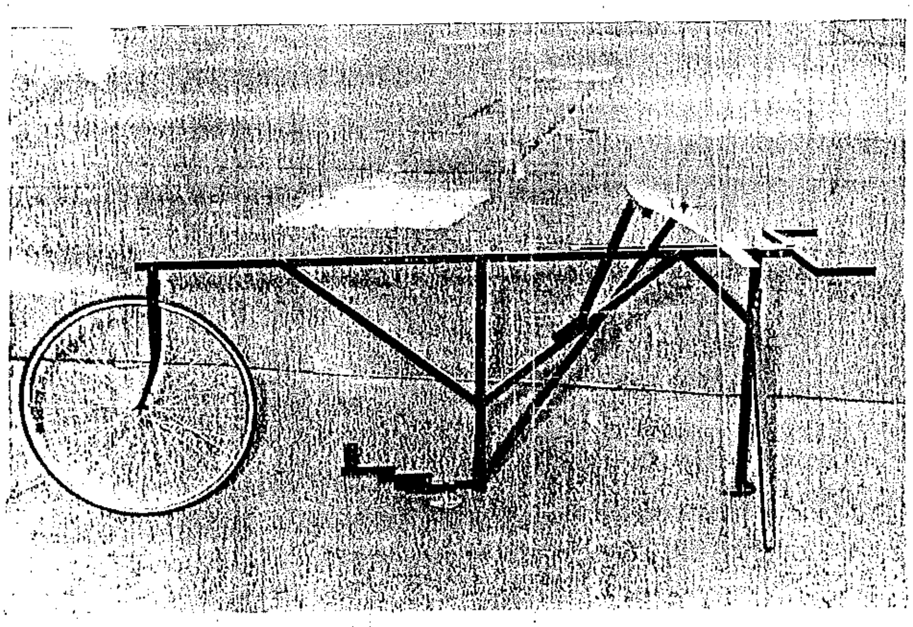


Plate.2 TRL designed MERLIN

3. OBJECTIVE

The objective of the project is to arrange for the calibration and standardising road roughness measurements made with the vehicle mounted roughness meters installed in NHA and NTRC vehicles with the help of ABAY beam and as well as the MERLIN. To produce regression equations which shall be used in future, for all sort of roughness surveys performed with these vehicle mounted roughness meters.

4. PLANNING & EXECUTION OF A CALIBRATION PROJECT

The conduct of a successful calibration project requires well planned procedures for field operation and a high level of accuracy of measurement and data analysis. For a calibration to be valid the calibration sites must be representative of the roads being expected to be surveyed in future. Methodology adopted for this project, cover the following steps:

- **Abay Beam Installation and its Calibration**
- **The Selection of Calibration Sites**
- **Maintenance and Operation of RTRRM's (Vehicle mounted B.I Units)**
- **Application of MERLIN**
- **Execution of the Calibration project**
- **Data Analysis**
- **Results and Discussion**

4.1 ABAY BEAM INSTALLATION & CALIBRATION

The TRL Abay beam uses a highly precise LVDT for measuring the profile and employs standard electronic methods of calibration. The ABAY calibration beam is a product of appropriate technology. It utilises manual methods for propelling the beam along the wheelpaths for profile measurement but thereafter uses modern processor technology for measuring the profile, and performing the data manipulation and computations. It is therefore necessary that the operators of the beam should have enough capability and practice to install the beam and used it properly before going in to an actual calibration project. For this project two laboratory technicians from NTRC were trained to install and operate the beam as per manufacturer's recommendations.

4.2 SELECTION OF CALIBRATION SITES

The sites selected covered the full range of road roughness under expected in the roughness survey carried by National Highway Authority and be distributed uniformly among the different roughness levels. A calibration is technicaly valid only over the range of roughness covered by the calibration sites. Extrapolation of the results should be avoided whenever possible. While selecting the control road sections following aspects have account for:

4.2.1 **UNIFORMITY**: The sites selected were uniformly rough over their full length. They were also be reasonably uniformed across the two wheelpaths.

4.2.2 **APPROACH**: RTRRMS respond to the road after they have passed over it, therefore those sites were avoid that have a distinctly different roughness characteristics in the 25-50 meters approach to the site.

4.2.3 **GEOMETRY**: The sites selected were preferably be on level tangent sections of road. As to avoid the even slight curvature, although, gentle grades which were uniform within the section were acceptable.

4.2.4 **IDENTIFICATION OF WHEELPATHS**: The wheelpaths were identified to by marking the road surface with paint, to ensure that the same lines along the roads are traversed by the wheels of the RTRRMS as are measured through profiles by the ABAY beam. The start and end points and the lateral locations of the wheelpaths of the section were identified with paint or other suitable markers.

4.2.5 **NUMBER OF TEST SECTIONS AND SECTION LENGTH** : An effective calibration requires a sufficient amount of data. The number of test sites required depends on the range of roughness to be covered and the levels of roughness within this range to be examined. They also depend on the length of the test sites, as long sites provide greater calibration accuracy but take longer time to measure. Practical constraints on staff and time would make it impossible to design a valid calibration project to meet all the ideal requirements. A minimum of 5 sites for a partiular surface type were selected for calibrating RTRRMS with recommended length of 432 meters and minimum approach distance of 25 meters.

4.2.6 **SURFACE TYPES**: In order to bring more reliability on the calibration, it has been decided to cover two types of surfaces that is the Asphaltic Concrete and Surfaced dressed roads for the regression analysis.

4.3 SELECTION, MAINTENANCE AND OPERATION OF RTRRMS

An RTRRMS consists of three components, a vehicle, a transducer that measures the movement of the vehicle suspension and a display count. The measurement obtained is a complex combination of the response of the vehicle to the road surface and a host of other variables. For the purpose of successful calibration of any particular RTRRMS system using the Abay Beam and the MERLIN specific additional requirements need to be observed as discussed below:

4.3.1. **OPERATING SPEED**: Measurements obtained from RTRRMS are speed dependent and thus calibration of these systems need to be undertaken at the recommended speed for the calibration procedure in use. The ABAY beam calibration procedure has been designed for an RTRRMS operating speed of 32 km/h (20 mile/h) based on a profile sampling interval of 100 mm and a baselength of 1.8 meters. Therefore all RTRRMS measurements made for calibration purpose were obtained at an operating speed of 20 mile/h for maximum calibration accuracy.

4.3.2 **TRAINING OF DRIVERS AND OPERATORS OF RTRRMS**: Drivers should be conditioned to accept that they are part of the experimental team and not just vehicle drivers. The importance of their role in collecting accurate data must be stressed as they control the passage of the vehicle on desired wheel paths and are required to propel the vehicle smoothly on the test section without creating spurious input signals to the instrument through acceleration, deceleration and braking. They should also be trained to enter and exit test sections correctly by being at the right speed in the correct gear well before entry into the section, through the section and a short while after exiting the section, vehicle response is affected by all these manoeuvres.

4.3.3 **VEHICLE LOADING** : The weight of the vehicle effects the roughness measure, care must be taken to always maintain the same vehicle loading during measurements. Some load variation is inevitable due to consumption of fuel. Otherwise the RTRRMS should be restricted only to the driver an observer without extra cargo or other occupants.

4.3.4 **TYRE PRESSURE**: Roughness measurements increase with tyre pressure. They should be checked when cold and maintained at a regular pressure - usually recommended by the vehicle manufacturer.

4.3.5 **TYRE IMBALANCE AND OUT-OF-ROUNDNESS**: These generate oscillation of the axle over and above that caused by the unevenness of the road surface, thus increasing the roughness counts the effect being greater on smooth roads. They should be statically balanced and regularly inspected for tyre/wheel damage an replaced if necessary. If replaced, new calibrations will be required on that RTRRMS.

4.3.6 **MECHANICAL LINKAGES, SPRINGS AND SHOCK ABSORBERS**: These combine as the most important components affecting RTRRMS response. They should be inspected regularly and carefully serviced. Change or adjustments in any of these components would require a recalibration. The mechanical properties of the above components plus the vehicle tyres contribute to the overall damping characteristics of the vehicles suspension. Unfortunately damping changes significantly with the operating temperature of the components resulting in changes in the measured roughness. Therefore RTRRMS should be adequately 'warmed-up' prior to measuring road roughness. The above components tend to stabilise themselves after 15 to 30 minutes of operation depending on the roughness of the road. It is therefore essential to run the RTRRMS for these periods before commencing roughness measurements.

4.4 THE MERLIN

MERLIN stands for " a Machine for Evaluating Roughness using Low-cost Instrumentation " . In Pakistan this device previously has been used by NTRC, NHA and other consultants for the calibration of response type instruments such as the vehicle mounted bump integrator.

4.4.1 **METHOD OF USE**: To measure the roughness of a section of road, 200 observations are made at regular intervals, say once every wheel revolution. At each place where an observation is to be made the position of the pointer on the chart is recorded with a cross in the appropriate column. In moving from one observation place to the next, the handles of the MERLIN are raised so that only the wheel remains in contact with the road. A typical completed chart is shown at Annexe A.

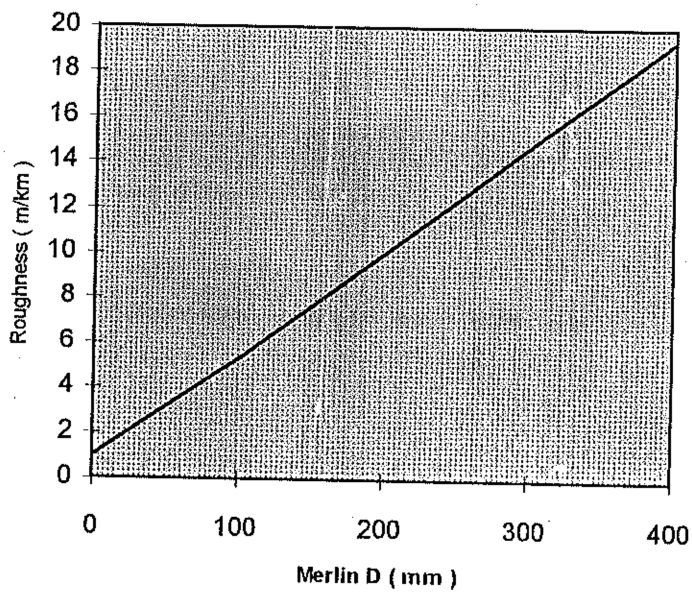
The chart is then removed from the MERLIN and the position mid-way between the tenth and the eleventh cross, counting in from one end of the distribution, is marked interpolating if necessary. The procedure is repeated for the other end of the distribution and the spacing between the two marks ,D, is measured in millimetres.

Road roughness can then be found from calibration relationships similar to those shown in the accompanying graphs. Two alternative standard roughness scales are used, the International Roughness Index and the towed fifth wheel Bump Integrator. The graphs were derived from computer simulation of the MERLIN's operation on road profiles surveyed in the 1982 International Road Roughness Experiment in Brasilia.

When estimating roughness for a vehicle, the normal procedure is to assume that the combined roughness for the two wheel tracks can be equated to the mean of the individual tracks, although this does give rise to a small error. Hence, in practice, a minimum of two sets of MERLIN observations are required. The roughness of individual wheel tracks can differ considerably.

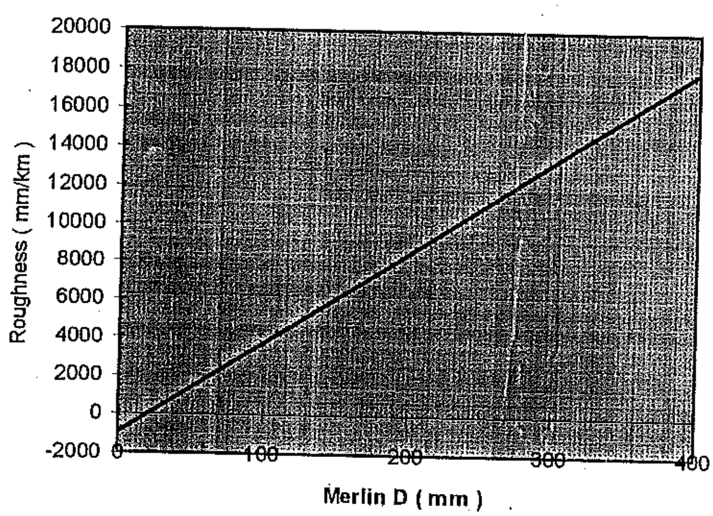
Bearing in mind the above limitations, it is normally better to calibrate an RTRRMS device at larger number of sites than make many repeat measurements at the same site. Moreover, particularly if working on the BI scale, these sites should have similar surfaces to those on which the RTRRMS is to be used.

International Roughness Index



$$IRI = 0.593 + 0.0471\ D$$

Bump Integrator (32 km/h)



$$BI = -983 + 47.5\ D$$

4.5 EXECUTION OF THE CALIBRATION PROJECT

The sequential steps for executing the calibration of vehicle mounted B.I units using the ABAY calibration beam and the MERLIN are listed below. They should be read and implemented according to the instructions and recommendations given earlier. The project officer must ensure that all recommendations and requirements given in section 4.1 - 4.4 are met or satisfied that is with regard to the planning of a calibration project.

4.5.1 CALIBRATION THROUGH CORRELATION USING ABAY BEAM: The ABAY beam performs four main tasks:

i. It measures the profile of the road at 100 mm intervals in units of millimetres with a resolution of better than 0.20 mm.

ii. It calculates the Root Mean Square of Deviation (RMSD) statistic for the road section from the above profiles. The RMSD is derived by determining the profile deviation from a simple linear regression line (analogous to the ideal road surface profile) for a given baselength and then calculating the root mean square of these deviations. For a given baselength **L**, with n profile points, the regression line y = a+bx is calculated and the deviation d determined. The RMSD for the baselength **L** is then computed as:

$$RMSD_{\mathbf{L}} = \sqrt{\Sigma d_i^{2} / n}$$

the weighted mean RMSD for the entire test section of road containing N baselengths of length **L** is given by :

$$RMSD = \sqrt{\Sigma RMSD_{\mathbf{L}}^{2} / N}$$

The ABAY beam is programmed to calculate RMSD for a baselength of 1.8 metres using 100 mm profile intervals. This combination of baselength and profile interval was determined through optimising the correlation between RMSD and RTRRMS measures obtained at a speed of 32 km/h.

iii. It develops a calibration equation for the RTRRMS. This is performed by re-scaling the RMSD values for each test section of road to a reference roughness value. The Reference roughness is determined through the following equation.

$$\mathbf{R.R.(\ mm/km\ ) = 2045\ RMSD + 68\ RMSD^2}$$

Which was developed on the basis of output of the towed 5th wheel bump integrator (which was an earlier TRRL standard for roughness measurements). The above equation is the TRRL standard index of road roughness expressed in mm/km. A guide to rroughness levels by this standard s given in Table.4.5.1.

Table-4.5.1 Levels of Road Roughness in mm/km for diffferent road surface types.

Description	Pavement Surface	Types
	Paved	Unpaved
Good	1000 - 2000	2000 - 4000
Average	2000 - 4000	4000 - 6000
Poor	4000 - 5500	6000 - 10000
Very poor	>5500 pot-holed	>10000

The reference roughness for the entire calibration section of road is calculated from the average RMSD value for the left and right wheelpaths of the section. The calibration equation is calculated by the beam processor after the operator has input the data requested by the processor via the processor key pad. The data requested is the left and right wheelpath RMSD values, the number of placements of the beam in each wheelpath and the corresponding RTRRMS values for each section.

iv. Having computed the calibration equation for a particular RTRRMS the processor will calculate calibrated roughness values for "raw" RTRRMS measurements input by the operator.

4.5.2 **CALIBRATION THROUGH CORRELATION USING MERLIN**: The recommended procedure to determine the roughness of a stretch of road is to take 200 measurements at regular intervals, say once every wheel revolution. When the 200 observations have been made, the chart is removed from the MERLIN. The positions mid-way between the tenth and the eleventh crosses, counting in from each end of the distribution, are marked on the chart below the columns. It may be necessary to interpolate between column boundaries. The spacing between the two marks, D, is the measured in millimetres and this is the roughness on the MERLIN scale. Road roughness, in terms of the International Roughness Index (IRI) or as measured by a towed fifth wheel bump integrator (BI), can then be determined using one of the equations given in section 4.4.1.

After being computing the reference roughness of the particular road section with the help of MERLIN and Abay beam, the vehicle with mounted B.I unit has been passed over the control road section at a constant speed of 20 mile/hr, and the counts measured by the meter will be noted for the particular length of the road section. At least five values for each road section have to be measured. The average value of RTRRMS measurements must be quoted for a unit distance of 1 kilometer.

4.5.3 **DATA COMPUTATION**: Completion of the field work have produced three sets of results containing information on each calibrated road section. They are the Abay Beam profile results for the left wheelpath and the right wheelpath and the average value of RMSD for the section. The second data set will consist of " D" for the right and left wheelpaths as measured by the MERLIN for each road section. Similarly the third data set will comprise of the average value of RTRRMS measurements for the road section. These are referred to as Vehicle Roughness.

All these data sets need careful examination and the analysis. As the data received is in raw form therefore it is carefuly examined and reduced to the needed form in subsequent tables shown in next chapter.

5. DATA ANALYSIS

In order to calibrate the vehicle mounted BI units with respect to the Abay beam and the Merlin, ten road sections in the vicinity of Islamabad have been selected as per requirements. Out of ten road sections five were selected with Asphaltic concrete surface, while the other five with Surface treated surfacing in order to develop separate correlation equations for each type of surface.

5.1 DATA FROM ABAY BEAM

Reference roughness data on the BI scale of all the control road sections have been computed on the basis of left and right tracks profile data recorded with the Abay beam. These are listed in table-5.1 together with the location of control road sections and their codes. As can be seen there are five road sections with Asphaltic concrete surfacing, while other five sections are surface dressed roads.

Table-5.1 **REFERENCE ROUGHNESS OF CONTROL SECTIONS BY ABAY BEAM**

S.no	Road Section	Surface Type	Section Code	Reference Roughness BI (mm/km)
1	Sector H-8 Opp.NTRC	Asphaltic Conc.	12346	1224
2	Sector F-7 / 2	Asphaltic Conc.	12348	2163
3	Islamabad Highway	Asphaltic Conc.	12360	2476
4	Lithrar Road	Asphaltic Conc.	12370	6052
5	Sector F-6	Asphaltic Conc.	12380	2794
6	Q.University Road	Surface Dress	12390	1561
7	Sector H-9 Int.School	Surface Dress	23900	3918
8	Sector F-11	Surface Dress	85610	3863
9	Sector I-10	Surface Dress	35220	3666
10	Sector H-8 / 4	Surface Dress	16589	5200

5.2 DATA FROM MERLIN

Reference roughness data on the BI scale of all the control road sections have been computed on the basis of right and left tracks "D" values as recorded with the help of Merlin. These are listed in table-5.2 together with the location of control road sections . As can be seen there are five road sections with asphaltic concrete, while other five sections are surface dressed roads.

Table-5.2 **REFERENCE ROUGHNESS OF CONTROL SECTIONS THROUGH MERLIN**

S.no	Road Section	Surface Type	Average "D" mm	Refrence Roughness BI (mm/km)
1	SectorH-8 Opp.NTRC	Asphaltic Conc.	50	1891
2	Sector F-7 / 2	Asphaltic Conc.	76	2575
3	Islamabad Highway	Asphaltic Conc.	96	3102
4	Lithrar Road	Asphaltic Conc.	188	6151
5	Sector F-6	Asphaltic Conc.	86	2839
6	Q.University Road	Surface Dress	51	1830
7	Sector H-9 Int.School	Surface Dress	112	3861
8	Sector F-11	Surface Dress	115	3960
9	Sector I-10	Surface Dress	107	3694
10	Sector H-8 / 4	Surface Dress	172	5858

5.3 DATA FROM B.I UNITS

The average value of RTRRMS measurements referred to as Vehicle Roughness (VR) of all the control road sections have been computed with the help of data obtained with the B.I units mounted on NTRC vehicle number IDC-8495 and NHA vehicle number IDG-5475. Five values for each road section have been measured, while the average value of RTRRMS measurements has been quoted for a unit distance of 1 kilometer. These are listed in table-5.3

together with the location of control road sections . As can be seen there are five road sections with asphaltic concrete surfacing, while other five sections are surface dressed roads.

Table-5.3 **ROUGHNESS OF CONTROL SECTIONS BY B.I UNITS**

S.no	**Road Section**	**Surface Type**	**Av.Vehicle Response (VR)IDC-8495 (mm/km)**	**Av.Vehicle Response (VR)IDG-5475 (mm/km)**
1	Sector H-8 Opp.NTRC	Asphaltic Conc.	168	124
2	Sector F-7 / 2	Asphaltic Conc.	264	157
3	Islamabad Highway	Asphaltic Conc.	363	273
4	Lithrar Road	Asphaltic Conc.	1035	664
5	Sector F-6 /2	Asphaltic Conc.	451	262
6	Q.University Road	Surface Dress	139	164
7	Sector H-9 Int.School	Surface Dress	400	479
8	Sector F-11	Surface Dress	398	502
9	Sector I-10	Surface Dress	389	502
10	Sector H-8 / 4	Surface Dress	579	567

6. RESULTS AND CONCLUSIONS

In order to produce calibration equations for the vehicles IDG-5473 belongs to National Highway Authority (NHA) and the vehicle IDC-8495 of National Transport Research Center (NTRC), regression analysis were carried out for each surface type separately on the data obtained from the Abay beam and the Merlin with respect to B.I.. Also the calibration equations for the all road sections combine are derived for these vehicle mounted B.I units.

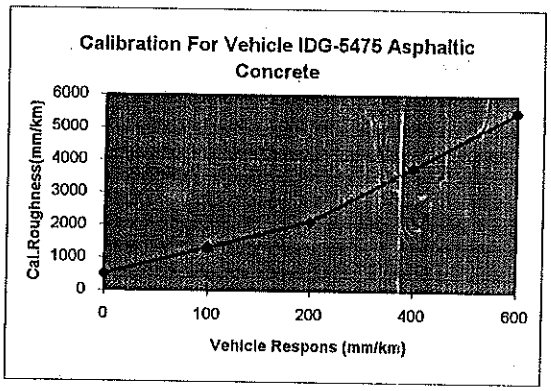
6.1 CALIBRATION EQUATIONS FOR IDG-5475 (NHA)

6.1.1 ABAY BEAM DATA ASPHALTIC CONCRETE SURFACE

Road Section	Veh.Response		Ref.Roughness		Calibrated Roughness
No.	X	X^2	Y	X(fit)	Y(fit)
1	124	15376	1224	0	515
2	157	24649	2163	100	1318
3	273	74529	2476	200	2131
4	664	440896	6052	400	3790
5	262	68644	2794	600	5491

Regression Output:

Constant		515.2191
Std Err of Y Est		399.029
R Squared		0.976358
No. of Observations		5
Degrees of Freedom		2
X Coefficient(s)	7.974274	0.00053
Std Err of Coef.	5.859123	0.007074



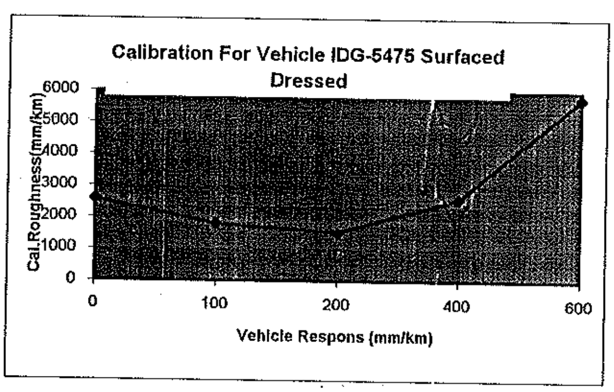
CR = 515.219 + 7.974 * VR + 0.00053 VR^2

6.1.2 ABAY BEAM DATA SURFACE DRESSED

Road Section	Veh.Response		Ref.Roughness		Calibrated Roughness
No.	X	X^2	Y	X(fit)	Y(fit)
6	164	26896	1561	0	2579
7	479	229441	3918	100	1792
8	502	252004	3863	200	1533
9	502	252004	3666	400	2602
10	567	321489	5200	600	5785

Regression Output:

Constant		2578.953
Std Err of Y Est		317.0739
R Squared		0.970789
No. of Observations		5
Degrees of Freedom		2
X Coefficient(s)	-10.5126	0.026426
Std Err of Coef.	9.220826	0.013181



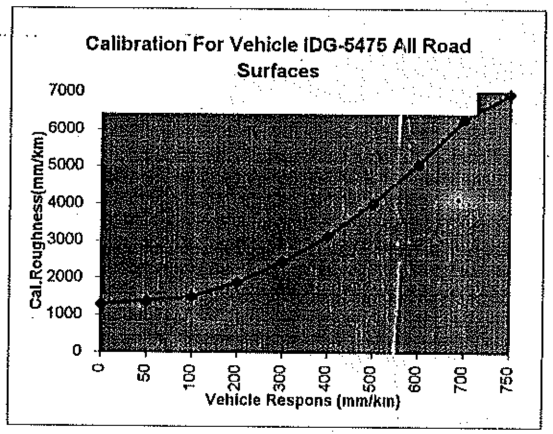
CR = 2578.953 - 10.512 * VR +0.026426 * VR^2

6.1.3 ABAY BEAM DATA FOR ALL ROAD SURFACES

Road Section No.	Veh.Response X	X^2	Ref.Roughness Y	X(fit)	Calibrated Roughness Y(fit)
1	124	15376	1224	0	1289
2	157	24649	2163	50	1376
3	273	74529	2476	100	1505
4	664	440896	6052	200	1886
5	262	68644	2794	300	2433
6	164	26896	1561	400	3146
7	479	229441	3918	500	4023
8	502	252004	3863	600	5066
9	502	252004	3666	700	6275
10	567	321489	5200	750	6941

Regression Output:

Constant		1288.509
Std Err of Y Est		402.4389
R Squared		0.947459
No. of Observations		10
Degrees of Freedom		7
X Coefficient(s)	1.335799	0.008268
Std Err of Coef.	4.034162	0.005294



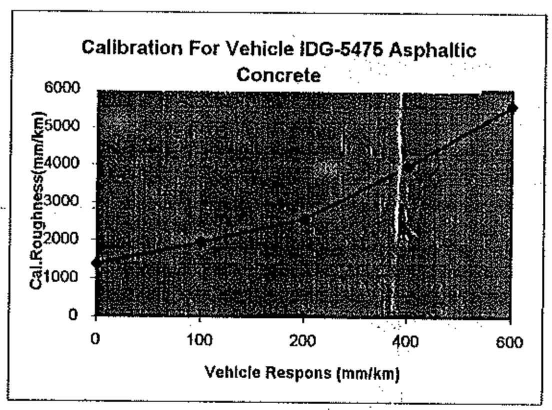
CR = 1288.509 + 1.3358 * VR + 0.008268 VR^2

6.1.4 MERLIN DATA ASPHALTIC CONCRETE SURFACE

Road Section No.	Veh.Response X	X^2	Ref.Roughness Y	X(fit)	Calibrated Roughness Y(fit)
1	124	15376	1891	0	1381
2	157	24649	2575	100	1946
3	273	74529	3102	200	2566
4	664	440896	6151	400	3967
5	262	68644	2839	600	5584

Regression Output:

Constant		1380.677
Std Err of Y Est		265.3407
R Squared		0.98707
No. of Observations		5
Degrees of Freedom		2
X Coefficient(s)	5.384205	0.002702
Std Err of Coef.	3.896118	0.004704



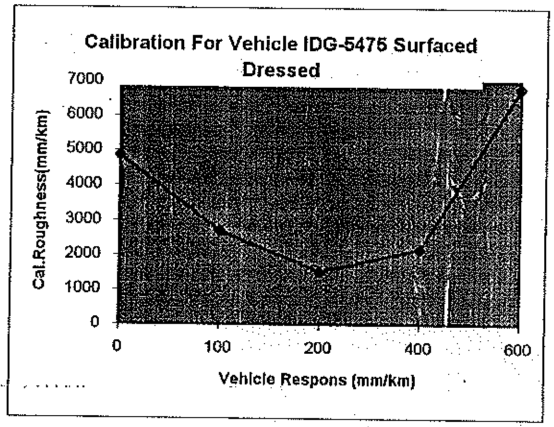
CR = 1380.677 + 5.384 * VR + 0.0027 VR^2

6.1.5 MERLIN DATA SURFACE DRESSED

Road Section No.	Veh.Response X	X^2	Ref.Roughness Y	X(fit)	Calibrated Roughness Y(fit)
6	164	26896	1830	0	4866
7	479	229441	3861	100	2699
8	502	252004	3960	200	1528
9	502	252004	3694	400	2174
10	567	321489	5858	600	6804

Regression Output:

Constant		4865.613
Std Err of Y Est		349.4567
R Squared		0.970027
No. of Observations		5
Degrees of Freedom		2
X Coefficient(s)	-26.6458	0.049794
Std Err of Coef.	10.16255	0.014527



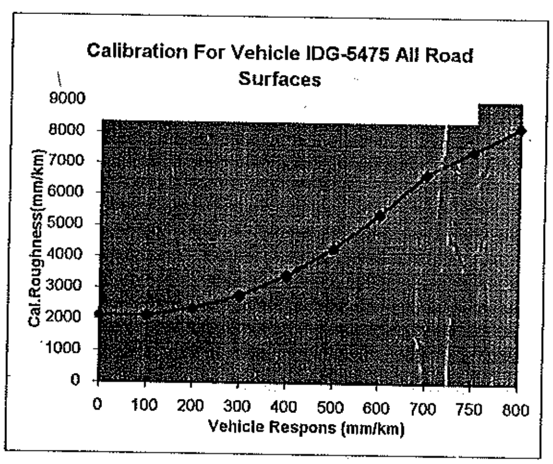
CR = 4865.613 - 26.646 * VR + 0.0498 * VR^2

6.1.6 MERLIN DATA FOR ALL ROAD SURFACES

Road Section No.	Veh.Response X	X^2	Ref.Roughness Y	X(fit)	Calibrated Roughness Y(fit)
1	124	15376	1891	0	2116
2	157	24649	2575	100	2120
3	273	74529	3102	200	2340
4	664	440896	6151	300	2776
5	262	68644	2839	400	3429
6	164	26896	1830	500	4299
7	479	229441	3861	600	5385
8	502	252004	3960	700	6687
9	502	252004	3694	750	7420
10	567	321489	5858	800	8207

Regression Output:

Constant		2116.448
Std Err of Y Est		527.6759
R Squared		0.901253
No. of Observations		10
Degrees of Freedom		7
X Coefficient(s)	-1.04805	0.010826
Std Err of Coef.	5.289573	0.006942



CR = 2116.448 - 1.048 * VR + 0.01083 VR^2

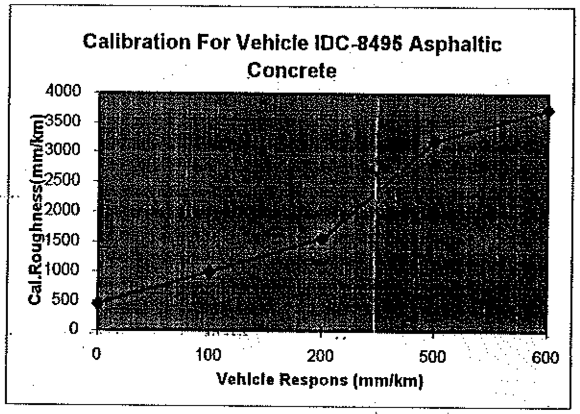
6.2 CALIBRATION EQUATIONS FOR IDC-8495 (NTRC)

6.2.1 ABAY BEAM DATA ASPHALTIC CONCRETE SURFACE

Road Section	Veh.Response		Ref.Roughness		Calibrated Roughness
No.	X	X^2	Y	X(fit)	Y(fit)
1	168	28259	1224	0	451
2	264	69637	2163	100	1005
3	363	132078	2476	200	1556
4	1035	1070650	6052	500	3192
5	451	203752	2794	600	3731

Regression Output:

Constant		451.4427
Std Err of Y Est		233.568
R Squared		0.9919
No. of Observations		5
Degrees of Freedom		2
X Coefficient(s)	5.55367	-0.00015
Std Err of Coef.	2.064706	0.001614



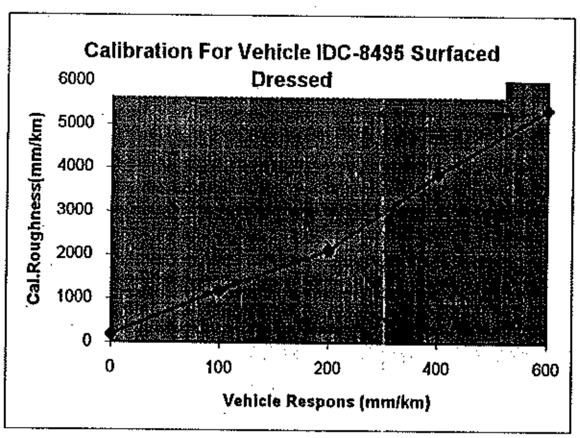
CR = 451.443 + 5.554 * VR - 0.00015 VR^2

6.2.2 ABAY BEAM DATA SURFACE DRESSED

Road Section	Veh.Response		Ref.Roughness		Calibrated Roughness
No.	X	X^2	Y	X(fit)	Y(fit)
6	139	19290	1561	0	191
7	400	160371	3918	100	1187
8	398	158522	3863	200	2128
9	389	151235	3666	400	3849
10	579	334898	5200	600	5353

Regression Output:

Constant		191.2204
Std Err of Y Est		82.99407
R Squared		0.997999
No. of Observations		5
Degrees of Freedom		2
X Coefficient(s)	10.22608	-0.0027
Std Err of Coef.	1.163399	0.001627



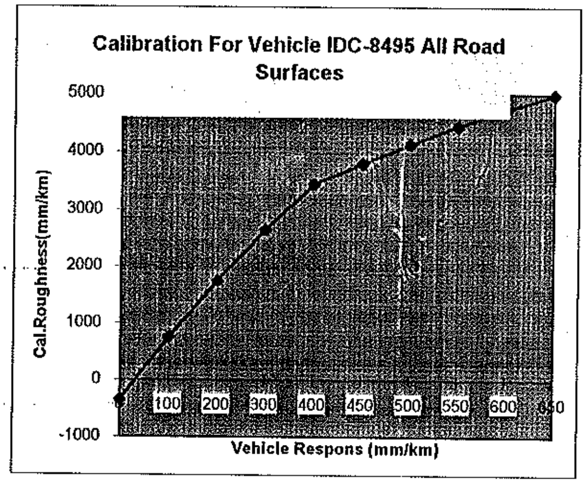
CR = 191.22 + 10.226 * VR - 0.0027 * VR^2

6.2.3 ABAY BEAM DATA FOR ALL ROAD SURFACES

Road Section No.	Veh.Response X	X^2	Ref.Roughness Y	X(fit)	Calibrated Roughness Y(fit)
1	168	28259	1224	0	-347
2	264	69637	2163	100	755
3	363	132078	2476	200	1755
4	1035	1070650	6052	300	2653
5	451	203752	2794	400	3448
6	139	19290	1561	450	3808
7	400	160371	3918	500	4142
8	398	158522	3863	550	4451
9	389	151235	3666	600	4734
10	579	334898	5200	650	4991

Regression Output:

Constant		-346.91
Std Err of Y Est		610.6495
R Squared		0.879028
No. of Observations		10
Degrees of Freedom		7
X Coefficient(s)	11.52867	-0.0051
Std Err of Coef.	3.166415	0.002599



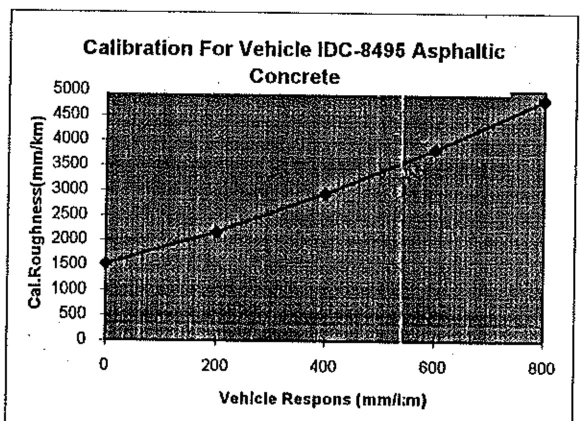
CR = -346.91+ 11.529 * VR - 0.0051 VR^2

6.2.4 MERLIN DATA ASPHALTIC CONCRETE SURFACE

Road Section No.	Veh.Response X	X^2	Ref.Roughness Y	X(fit)	Calibrated Roughness Y(fit)
1	168	28259	1891	0	1522
2	264	69637	2575	200	2175
3	363	132078	3102	400	2943
4	1035	1070650	6151	600	3824
5	451	203752	2839	800	4820

Regression Output:

Constant		1522.236
Std Err of Y Est		356.9543
R Squared		0.9766
No. of Observations		5
Degrees of Freedom		2
X Coefficient(s)	2.979544	0.001428
Std Err of Coef.	3.155422	0.002466



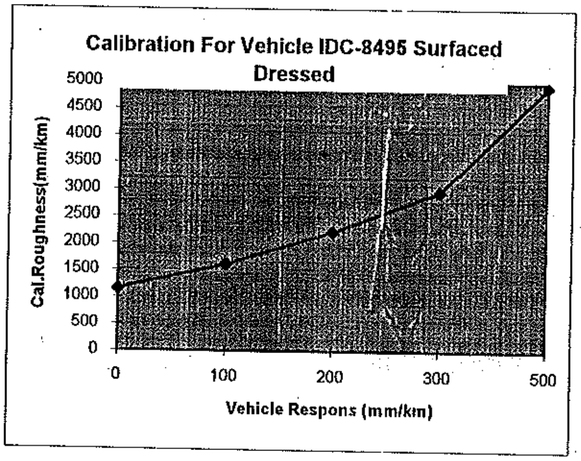
CR = 1522.24 + 2.979 * VR + 0.0014 VR^2

6.2.5 MERLIN DATA SURFACE DRESSED

Road Section No.	Veh.Response X	X^2	Ref.Roughness Y	X(fit)	Calibrated Roughness Y(fit)
6	139	19290	1830	0	1148
7	400	160371	3861	100	1610
8	398	158522	3960	200	2219
9	389	151235	3694	300	2975
10	579	334898	5858	500	4929

Regression Output:

Constant		1147.963
Std Err of Y Est		90.29785
R Squared		0.997999
No. of Observations		5
Degrees of Freedom		2
X Coefficient(s)	3.879627	0.007366
Std Err of Coef.	1.265783	0.00177



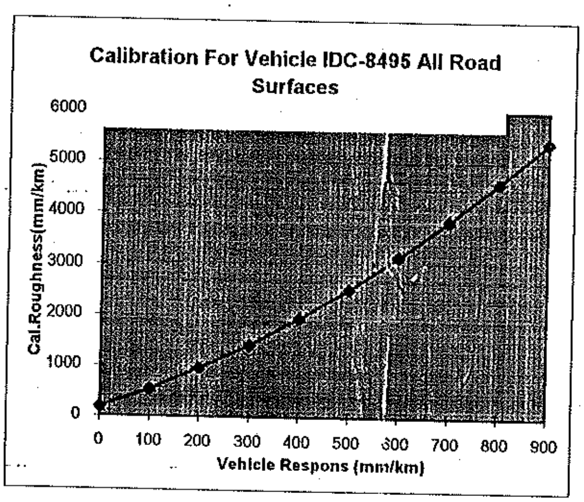
CR = 1147.963 + 3.880 * VR + 0.0074 * VR^2

6.2.6 MERLIN DATA FOR ALL ROAD SURFACES

Road Section No.	Veh.Response X	X^2	Ref.Roughness Y	X(fit)	Calibrated Roughness Y(fit)
1	168	28259	1891	0	183
2	264	69637	2575	100	543
3	363	132078	3102	200	958
4	1035	1070650	6151	300	1428
5	451	203752	2839	400	1953
6	139	19290	1830	500	2532
7	400	160371	3861	600	3166
8	398	158522	3960	700	3855
9	389	151235	3694	800	4599
10	579	334898	5858	900	5397

Regression Output:

Constant		182.6276
Std Err of Y Est		642.5915
R Squared		0.853561
No. of Observations		10
Degrees of Freedom		7
X Coefficient(s)	10.69093	-0.00465
Std Err of Coef.	3.332045	0.002735



CR = 182.628 + 10.691 * VR - 0.00465 VR^2

6.3 REGRESSION COEFFICIENTS

Upon closer examination of regression equations derived, it can be seen that there are consistent differences between the results for different road surface types. Table 6.3 lists the regression coefficients. The coefficient of determination (R^2) ranges from 0.901 to 0.987 for the vehicle no. IDG-5475(NHA), while for the vehicle no. IDC-8495 (NTRC) it ranges from 0.854 to 0.997.

Table-6.3 Results of the Regression Analysis ($CR = A_0 + A_1 * VR + A_2 * VR^2$)

CR = Calibrated Roughness VR = Vehicle Response

Veh. No	Machine	Surface Type	A_0	A_1	A_2	R^2	No.Of Sections
IDG-5475	Abay Beam	Asphaltic Concrete	515.219	7.974	0.0005	0.976	5
NHA		Surface Treated	2578.953	-10.513	0.0264	0.971	5
		All Surfaces	1288.509	1.336	0.0083	0.947	10
	Merlin	Asphaltic Concrete	1380.677	5.384	0.0027	0.987	5
		Surface Treated	4865.613	-26.646	0.0498	0.970	5
		All Surfaces	2116.448	-1.0481	0.0108	0.901	10
IDC-8495	Abay Beam	Asphaltic Concrete	451.554	5.554	-0.0015	0.990	5
NTRC		Surface Treated	191.220	0.226	-0.0027	0.997	5
		All Surfaces	-346.911	11.529	-0.0512	0.876	10
	Merlin	Asphaltic Concrete	1522.243	2.979	0.0014	0.975	5
		Surface Treated	1147.963	3.880	0.0074	0.997	5
		All Surfaces	182.628	10.691	-0.0046	0.854	10

6.4 CONCLUSIONS

The main findings of the exercise are as follows:-

- When regular roughness surveys are to established by vehicle mounted Bump Integrator, it is essential that rigorous calibration and operation control procedures be implemented as mentioned in this report.
- The roughness of control sections should be established from a profile-measuring system, such as a Abay beam.
- The Abay Beam is more accurate than MERLIN for calibration purposes.
- MERLIN is much faster than Abay Beam and also much simple and cheaper.
- For consistent performance from Bump Integrator, it is necessary to have a "dedicated vehicle" as any change in the vehicle or even of its characteristics would require re-calibration.
- Under well-established calibration procedures and controlled operating conditions, response-type roughness measuring systems (RTRRMS) are still susceptible to significant measurement errors.
- Although there are the limitations in the use of vehicle mounted Bump Integrator but for reasons of cost, and convenience it is adequate for roughness surveys in the country.

References

[1] Standard method for "Measuring of Road Roughness", ASTM Designation E867-87, Vol.04.03.

[2] William D.O & Thomson Scullion "Information Systems for Road Management", The World Bank Policy Planning and Research Staff Report INU-77, The World Bank Washington D.C, U.S.A, September 1990, pp.29-31.

[3] Chesher,A and Harrison,R " Vehicle Operating Costs: Evidense from Developing Countries" , 1987, John Hopkins University Press, Balitimore and London.

[4] Abaynayaka,SW " Calibrating and Standardising Road Roughness Measurements made with Response Type instruments", International Conference on Roads and Development, Paris, May 1984, pp13 - 18.