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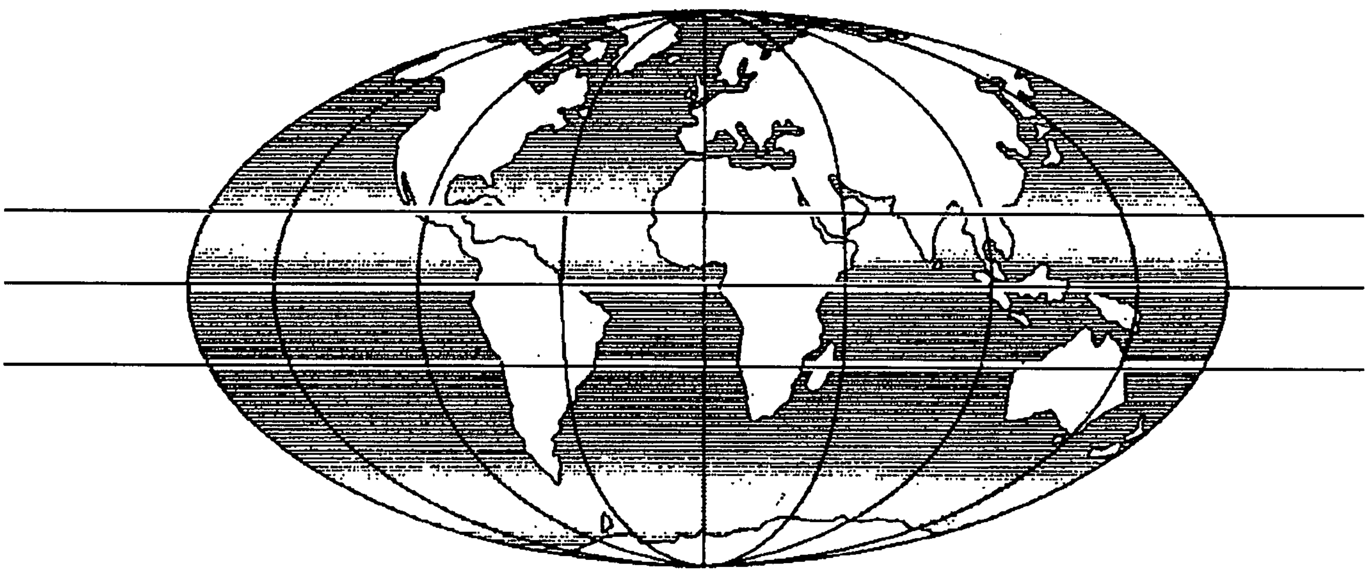

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ROUGHNESS CALIBRATION STUDIES USING DIFFERENT MEASURING SYSTEMS

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PREFACE

Road roughness is considered to be the most important parameter affecting vehicle operating costs which account for a large proportion of total transport costs. Since maintenance management systems aim to minimise total transport costs, the measurement of roughness is of prime importance in optimising the use of available funds for maintaining a road network.

In Indonesia one of the main tasks of the Ministry of Public Works has been devising and setting-up an appropriate system of maintenance management. An important part of this system is the need to measure road roughness and correct these values to the reference standard, the International Road Roughness Index (IRI).

The reported research describes calibration studies using four measuring systems, namely the DIPSTICK (which enables calculation of IRI), the TRRL towed-fifth wheel Bump-integrator, the MERLIN (a Machine for Evaluating Roughness using Low-cost INstrumentation) and the NAASRA meter. The systems tested span the range from low to high technology (and cost) and their operating speeds are from slow to fast.

Correlation between the reference standard and the various systems are reported and conclusions drawn on the suitability of each for use in gathering information for input to planning or research studies. Details of the development and listings of computer programmes used to analyse roughness data are given.

The results of the research should contribute to the advancement of road technology and the more efficient use of human and financial resources in areas of both high and relatively low economic development.

Bandung, January 1991
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ROUGHNESS CALIBRATION STUDIES USING DIFFERENT MEASURING SYSTEMS

ABSTRACT

Road roughness is considered to be the most important parameter affecting vehicle operating costs which account for a large proportion of total transport costs. Since modern maintenance systems aim to minimise total transport costs, the measurement of roughness is of prime importance in optimising the use of available funds for maintaining a road network.

Traditionally the assessment of road roughness has been based on the riding quality measured by an instrumented car or other suspension-type response instruments. Such devices are, however, neither time-stable in themselves nor consistent between similar vehicles. It is therefore necessary for their output to be calibrated against a standard roughness scale, such as the profile-based International Roughness Index (IRI) devised by the World Bank.

This report describes calibration studies involving a number of response type and profile-based roughness measuring systems including the Dipstick profilometer, the MERLIN, the NAASRA roughometer and the TRRL towed fifth wheel Bump-integrator. Correlations between each system tested are given and the suitability of the various systems for research or planning purposes is discussed.

The report also contains the user manuals and descriptions of the computer programmes devised to process the data together with programme listings.

1. INTRODUCTION

In the past decade, Engineers and Planners in Indonesia have been particularly challenged by the task of devising and setting-up an appropriate system of maintenance management which can be applied throughout Indonesia. An important part of this has been the measurement of road roughness.

Road roughness is one of the most important inputs to maintenance management since the level of roughness has a large effect on the cost of transportation. Its measurement is of prime importance in optimising the use of available funds for maintaining a road network and, thereby, minimising total transport costs (ABAYNAYAKA et al 1977 and PATERSON 1987).

The measurement of road roughness has traditionally been based on the riding quality assessed by an instrumented car or other suspension type response instruments.

The measured riding quality, or roughness, is primarily controlled by the road condition. Features such as potholes, rutting, corrugations, surface texture, patches and general unevenness contribute to its absolute level.

As is commonly known, the condition of a road is not static but changes with time and traffic and the execution of road maintenance or betterment operations. Hence regular surveys need to be undertaken to monitor changes in roughness.

In research or planning studies it is essential that suitable devices are available to enable absolute levels of roughness to be determined accurately. The output of a device needs to be stable with time to enable changes in roughness to be identified or else a calibration procedure needs to be employed so that the values can be corrected to a reference standard. The International Roughness Index (IRI) has generally been accepted world-wide as the standard to which measured values are converted (SAYERS et al 1985a).

In general the instruments used for measuring roughness can be divided into two groups as follows:

(i) Systems which measure or sample the road profile from a static base. These are represented by rod and level techniques, the DIPSTICK, MERLIN and the TRRL Roughness Calibration Beam.

(ii) Systems that measure the road profile over a moving datum. This group includes all dynamic profilometric systems including the TRRL towed fifth wheel Bump-integrator and the NAASRA roughness meter.

A number of the above systems have been examined by the Institute of Road Engineering (IRE) to obtain correlations between the output of each and to define their suitability for use in both planning surveys (ie. as input to maintenance management) and research. The requirements for the latter two activities are different, mainly in terms of the accuracy and repeatability of output. In addition, the level of sophistication and cost of the devices vary greatly and at this stage in Indonesia's development it is particularly important to use reliable and affordable data collection techniques.

This report describes the studies undertaken to derive correlations and examine the accuracy of the following roughness measuring systems:

(a) the DIPSTICK (which enables calculation of IRI),
(b) the TRRL towed-fifth wheel Bump-integrator,
(c) the MERLIN (Machine for Evaluating Roughness using Low-cost INstrumentation),
(d) the NAASRA roughness meter.

A further objective of the research was to develop computer- based analysis programmes and accompanying user manuals. These are described in appendices at the end of this report.

2. DESIGN OF THE STUDY

2.1 Overview

Two types of roughness measuring systems are presently available, namely; profilometer systems and response type systems.

Instruments in the first group measure the road profile at pre-determined intervals or points located along a wheelpath. Their speed of measurement is generally slow, being of the order of two to three hours per wheeltrack kilometre.

The second group comprise instruments which are mounted within a suspension system, either in a vehicle or on a trailer, and these can measure the road profile faster, usually at speeds between 30 and 80 kilometres per hour. However, the disadvantage of this group is that the measuring systems are dependent on the performance of the suspension system on which they are mounted and this can change with time and is also a function of load, tyre pressure, tyre roundness, etc..

It is necessary for results to be obtained using instruments from the first group, but to assess the condition of a national road system at regular intervals for maintenance purposes this is not practicable. The preferred method of operation is to measure long lengths of road using systems in group 2 and to calibrate their output with systems in group 1.

In Indonesia at the present time the NAASRA roughness meter is used for routine surveys and is calibrated to the IRI standard using a DIPSTICK (EDWARD FACE CO., undated). Normally about six short calibration sections are chosen, each 300 metres long.

In the joint IRE-TRRL research programme on road deterioration the TRRL towed fifth wheel Bump-integrator is used for measuring roughness and is also calibrated at regular intervals using a DIPSTICK profilometer.

The MERLIN is a simple, low-cost device developed by TRRL (1990) to measure roughness and has not previously been used in Indonesia. It has the potential to be used as a calibration and roughness measuring instrument.

2.2 Selection of measuring systems

At present three internationally recognised roughness measuring devices are available in Indonesia. They are the NAASRA car-mounted roughness meter (SCALA and POTTER 1977), the towed fifth wheel Bump-integrator (BI) trailer (JORDAN and YOUNG 1980) and the DIPSTICK (EDWARD FACE CO., undated). In addition, the MERLIN apparatus (TRRL 1990) is also available. This equipment spans the range from high to low technology and their operating speeds is from slow to fast. During the calibration studies all four systems were used.

In relation to the World Bank's definition of roughness measurement systems (SAYERS et al 1985a), the available systems can be classified as follows :

Class 1 -	precision profiles	:	DIPSTICK profilometer
Class 2 -	other profilometric methods	:	MERLIN
Class 3 -	IRI estimates from correlation equations	:	NAASRA roughness-meter and TRRL towed Bump-integrator trailer.

During earlier World Bank studies (SAYERS et al 1985b) carried out as part of the International Road Roughness Experiment the MERLIN was not available but, since it is profile-based, it has been grouped in Class 2.

2.3 Selection of calibration sections

Nineteen (19) roughness calibration sections have been established in the Bandung area.

The principle aim in selecting sections was to cover both the variety of surface types and to span the range of roughnesses encountered on paved roads in Indonesia. The selection process was relatively straight forward since many of the sites had previously been tested and, hence, initial estimates of the roughness on these sections were available. The data on which these were based are contained in Table 1. The selection also took into account practical constraints, such as traffic conditions, sight distances and geometry.

Details of the sections and the testing done on each are contained in Table 2. In each case the effort was not uniform since the aim was also to develop a more extensive data-base on the surface characteristics of the sections, rather than only to calibrate the instruments. In cases where the BI, the MERLIN or the DIPSTICK were used then measurements were taken in each wheelpath.

The coverage of surface type with respect to roughness is given in Table 3.

As shown in the table, the spread of roughness with respect to surface type is not uniform, reflecting the surface conditions in the vicinity of Bandung, the high initial roughness of penetration macadam surfaces and the relatively low roughnesses of roads overlaid with plant-mixes.

3. STAGES OF THE STUDY

3.1 General

Test sections were marked out along 300 metre lengths of road with the outer wheeltrack (OWT) located at a distance of approximately 0.70-1.00m from the pavement edge. The exact distance depended on the width of the road and traffic patterns. The inner wheel track (IWT) was located at a distance of 1.30m from the OWT. The purpose of the marking was to enable tests to be repeated along the same path. Permanent reference posts were inserted at each end of a calibration section so that the sections could be re-located in the future.

3.2 Data collection

The data collection was carried out in November and December 1989.

Between 3 and 5 Bump-integrator measurements were taken in both the OWT and the IWT of each road calibration section, at a speed of approximately 32 km/hour.

Measurements with the NAASRA roughness meter were also repeated, between 3 and 5 times also at a test speed of 32 km/hour.

When using the vehicle mounted response-type systems, care had to be taken near cross roads or junctions. Traffic was temporarily halted during testing to give priority to the test vehicle.

The DIPSTICK measurements were taken only once. Approximately one hour was taken to complete each wheelpath (length = 300 m).

The MERLIN measurements were taken three times in each wheel track with each measurement taking about half an hour.

4. DESCRIPTION OF MEASUREMENT METHODS

4.1 Bump Integrator

The Bump-integrator (BI), or BPR Roughmeter, was originally developed by the United States Bureau of Public Roads. TRRL have since made a number of modifications to improve its performance and simplify maintenance (JORDAN and YOUNG 1980). The instrument used in this study was to the current TRRL design.

The Bump-integrator consists of a single-wheeled trailer comprising a rectangular chassis within which a pneumatic tyred wheel is mounted, the load, tyre size and pressure are standardised. The BI is towed by a station-wagon or similar vehicle (see Plate 1).

During operation, the vertical movement of the wheel-axle assembly relative to the chassis is measured by an integrator unit mounted on one side of the chassis. This is made possible by connecting the axle to the integrator unit by a cord tied to the cylindrical drum on the integrator unit. Tension in the cord is maintained by a clock-type return spring fitted to the integrator unit. The integrator works by accumulating the down-ward movements of the axle which are transmitted through a clutch-system to give a uni-directional movement of a cam which then triggers the "making" and "breaking" of an electrical contact. The pulses of electric current which this creates activates the counter. On the present system one count is equal to an accumulated downward movement of 1-inch (or 25.4 mm).

The distance the BI travels along the road is measured automatically by recording the number of revolutions of the wheel.

Recording is made possible by having two sets of Bump- integrator and wheel-revolution counters together with an on/off switch and a changeover switch mounted on an instrument board located within the towing vehicle.

Determination of the Bump-integrator Irregularity Index (BIr) requires the number of counts of the bump integrator counter, the time (in secs) and the number of wheel revolutions to be recorded. The BIr value is then calculated as shown below.

Example,

Time	=	31 sec.
Wheel revolutions	=	137.
Integrator counter	=	17.

The distance the bump integrator has travelled is calculated by multiplying the number of wheel revolutions by the wheel circumference :-

$$\text{The distance} = 137 \times 2.18 = 298.66 \text{ m}$$

$$\text{The speed} = \frac{\text{distance}}{\text{time}}$$

$$\text{Speed} = \frac{298.66}{31} \text{ m/sec.}$$

$$= 9.63 \text{ m/sec}$$

$$= \frac{9.63 \times 60 \times 60}{1000} = 34.67 \text{ Km/h}$$

The irregularity index is calculated as follows:

$$\frac{\text{Integrator counter value} \times 25.4 \times \text{number of wheel revolutions in one km.}}{\text{Recorded number of wheel revolutions}}$$

$$\text{BIr} = \frac{17 \times 25.4 \times 1000}{137 \times 2.18}$$

$$\text{BIr} = 1{,}446 \text{ mm/Km}$$

Measurements are corrected for speed variations to a standard index (BI_{32}) corresponding to a speed of 32 km/h. Studies by Jordan and Young (1980) led to the following expressions for this purpose :

(i) For uneven surfaces and operating speeds of 20 to 65 km/h and for even surface and operating speeds of 20 to 32 km/h :

$$BI_{32} = (V/32)^{0.5}(BIr - 474) + 474 \text{ mm/km.}$$

(ii) For even surfaces and operating speeds of 32 to 65 km/h.

$$BI_{32} = (V/32)(BIr - 474) + 474 \text{ mm/km.}$$

Where V is the measurement speed in km/h.

Applying expression (i) above to the example the standard index is :

$$BI_{32} = 1{,}527 \text{ mm/km.}$$

A computer programme which was developed to calculate the corrected irregularity index, BI_{32}, is contained in Appendix A.

4.2 The NAASRA roughness meter

The NAASRA roughness meter was developed by the National Association of Australia State Road Authorities (SCALA and POTTER 1977).

The meter is mounted above the middle of the rear axle of a saloon car. Guidelines for its operation include the specification of a suitable vehicle, tyre pressures and ballast (load).

The basic principle of the meter is that it sums the movement (in one direction) of the rear axle with respect to the vehicle body. This results from the movements of a flexible cable which is connected from the meter to the centre of the rear axle. The cable is joined to a chain which passes over a toothed sprocket held on a shaft fitted with clutches so that the shaft will only rotate in one direction. Movements in the shaft are transmitted by a flexible drive to a counter mounted in the front of the car.

The essential features of the NAASRA roughness meter are shown in Fig. 1.

The output is in the form of the number of counts over a given distance and the roughness is expressed in counts/km.

In Indonesia the normal speed of measurement is 32 km/hour.

4.3 The DIPSTICK

The Dipstick Floor Profiler is manufactured by The Edward W. Face Company Inc. of Norfolk, Virginia, USA and was originally developed for checking the evenness of floors.

The DIPSTICK, illustrated in Plate 2, measures the surface profile along a line by indicating level differences between its two supporting feet which are one foot, or 304.8 mm, apart. Consecutive measurements are obtained by walking (frog-marching) the instrument along a line for the length of a test section and recording the level difference at each placement.

Level differences measured by the DIPSTICK are usually in increments of 0.001 inch (0.0254 mm). The standard analysis involves inputting the data into the IRILEVEL or VERICAL computer programme and determining the International Roughness Index (in m/km). The analysis programme is based on the system of profile analysis derived by the World Bank (SAYERS et al 1985).

The VERICAL analysis programme available in Indonesia was developed by Bina Karya and Lea (1987). For this research, the original World Bank programme was rewritten in Turbo- PASCAL. The equivalent IRE version to VERICAL is named IRILEVEL which requires the data to be input in level differences. A second programme, named IRIELEV, was also written and accepts data input as elevations. The programme listings and details of their development are contained in Appendix B.

4.4 MERLIN

MERLIN is an accronym for a Machine for Evaluating Roughness using Low cost INstrumentation. The machine was developed by the Transport and Road Research Laboratory (TRRL 1990). Construction drawings for MERLIN are available on application to TRRL or IRE.

The MERLIN is a simple, low cost and easy to use instrument for measuring road roughness. The device, illustrated in Figure 2, consists of a metal frame 1.8 metres long with a wheel at the front and a metal foot at the rear. Midway between the two wheels is a probe which is attached to a weighted arm to hold it onto the road surface.

At the other end of the arm a pointer moves over a prepared chart consisting of a series of columns, each 5mm wide.

The device measures the vertical height difference between the road surface under the probe and the centre point of an imaginary line joining the two points in contact with the road surface. A movement of 1 mm of the probe moves the pointer 1 cm.

During operation the MERLIN is brought to rest at intervals equal to one circumference of the wheel and at each consecutive location the position of the pointer is recorded on the chart.

The results of a series of MERLIN measurements are represented by a histogram. A typical result is shown in Figure 3. From this, a MERLIN Dispersion Value (DISP) is derived by omitting ten per cent of the readings, divided equally between the two tails of the distribution,and the dispersion recorded as the width in mm of the remaining distribution.

During this research the analysis of the data was facilitated using the specially developed analysis programmes described in Appendix C.

Research by TRRL based on computer simulations has shown that the MERLIN can be correlated directly with standard roughness scales such as the International Roughness Index and the towed fifth wheel Bump-integrator (CUNDILL 1990).

5. RESULTS AND ANALYSIS

5.1 Results

A summary of the results of the measurements taken during the surveys is shown in Table 4.

The range of the values measured by each system is shown in Table 5. For each system, lower values correspond with a smoother road, ie. good riding quality, and higher values with poor riding quality.

5.2 Correlations between measuring systems

To establish the correlations between the various measuring systems a line of best "fit" was determined for each pair of systems using simple linear regression techniques. Statistical coefficients and a plot of residuals were also obtained.

The following three correlations were examined:

(i) Towed bump integrator (BI32) versus IRI.
(ii) NAASRA roughness meter (N) versus IRI.
(iii) MERLIN (DISP) versus IRI.

The regression models included a linear model and a multiplicate model, as follows :

Linear model	$Y = a + bX$ and
Multiplicative model	$Y = aX^b$

In each case the IRI was the dependent variable (Y) and the corresponding roughness system the independent variable (X).

The results of the analysis are given in Table 6. In each case the multiplicative model gave a slightly better fit. The resulting regressions for the three multiplicative models are plotted in Figs. 4, 5 and 6 and given below.

$$IRI\ (m/km) = 0.0027\ BI32^{0.944}$$
$$IRI\ (m/km) = 0.324\ N^{0.606}$$
$$IRI\ (m/km) = 0.153\ DISP^{0.796}$$

In all cases the data sets included both the outer and inner wheelpath data. In the case of the NAASRA-IRI correlation the IRI value used was the arithmetic mean of each pair of wheeltracks.

Because of the limited range of roughness values within each surface type, separate relationships were not developed.

5.3 Comparison with previous studies

5.3.1 Bump Integrator and IRI

The particular Bump Integrator unit used in this research has not previously been calibrated against IRI. In previous studies by TRRL the performance of each Bump-integrator has been assumed to be similar provided the calibration guidelines are followed (JORDAN and YOUNG 1980). In the International Road Roughness Experiment (IRRE) in Brazil a standard BI was calibrated against the IRI standard. The following expression resulted from these studies :

$IRI = 0.0032\ BI^{0.89}$ (Cox and Rolt 1986)

The relationship derived from the present study was :

$$IRI = 0.0027\ BI^{0.944} \quad \text{(This study)}$$

where IRI is expressed in m/km, and BI is expressed in mm/km.

The output of the two expressions is compared in Figure 7 in which a linear regression has been fitted to the plotted data. From the figure it is clear that the model developed in this present study overestimates the IRI by about 30%. The indication from this is that the performance of the present BI is behaving in a non-standard manner which emphasises the need for calibration studies.

The results of the earlier study and a more recent calibration survey are compared in Figure 8. A maximum difference between the two relationships of between 12 and 3 per cent (from low to high roughness) is noticeable.

5.3.2 NAASRA and IRI

The relationships between NAASRA and IRI derived during this study and also in May 1988 and August 1989 are compared in Fig. 9. The basic data for the early studies is included in Table 1. As indicated in the figure a maximum difference of about 10 percent exists between the May 1988, the August 1989 and the November 1989 calibrations. This difference is surprisingly small and is at the lower end of the expected change between successive calibrations for a single vehicle, which typically ranges from less than 10 per cent to as much as 35 per cent (PATERSON 1983).

6. DISCUSSION AND CONCLUSIONS

Statistically significant correlations have been obtained between the International Roughness Index (IRI) derived from DIPSTICK measurements and the three other measuring systems tested, namely the TRRL towed fifth wheel Bump-integrator trailer, the NAASRA car-mounted roughness meter and the MERLIN.

Of the three non-standard systems only the output of the MERLIN is based on the analysis of points along a road profile and, for a given surface type with a correspondingly similar range of spectral signatures, a unique relationship will exist with the IRI. Further work should be done to derive individual correlations for each surface type across a wider range of roughness. Following this the MERLIN, could effectively replace or supplement the DIPSTICK in circumstances where the sole purpose of the exercise is to calibrate a response type instrument.

Advantages of the MERLIN are its low-cost, approximately 250 US dollars, and its suitability for manufacture in local workshops. It is also easy-to-use and its output, as a calibration device, is about 600 metres per hour. This compares with the relatively sophisticated DIPSTICK, which costs approximately 7000 US dollars, has an output of about 300 metres per hour and requires supporting computer software.

Although valid correlations were obtained between IRI and the Bump-integrator and NAASRA meter it is widely accepted that these systems are not time-stable and the output between different vehicles or trailers of the same kind can vary significantly. This is principally because of initial differences and changes with time of suspension characteristics. Paterson (1983) indicated that even for vehicles which are dedicated to measuring roughness and which are maintained and used in accordance with strict procedures the difference between successive calibrations for a single vehicle typically ranged from less than 10 per cent to as much as 35 per cent. Differences between vehicles of the same type would be expected to be even greater. However, in this particular study the IRE NAASRA meter appears to have changed by only a small amount, approximately 10 per cent over two years. On average the change in the BI between successive calibrations was slightly less, between 12 and 3 per cent, although this was over a shorter period and only involved two calibrations.

Although the time-stability of the NAASRA meter was better than expected the results do not preclude the need for both regular calibration and the use of control sites when extended route surveys are undertaken. This is because favourable results from a small number of calibrations cannot guarantee that the same degree of control and measurement consistency is achieved at the operational level. In this context, control sites are sites which are distributed throughout a network and whose profile characteristics have been recently measured and can, therefore, provide a check on whether significant changes in the calibration have occurred during the course of a network survey. The adoption of such a procedure also provides a measure of additional quality control which is independent of the operators.

In the present IRE-TRRL road deterioration research programme approximately one-in-four of the monitoring sections are measured using the DIPSTICK and BI.

Although the BI, calibrated against the DIPSTICK, provides valid measurements the large differences between the IRI-BI relationships derived at the International Road Roughness Experiment and the results of this study are of concern and are being investigated.

In summing-up, response type instruments are most useful for undertaking network surveys at fairly high speeds. However, calibration to a reference standard is necessary and, as the results of this study indicate, this can be achieved with a

DIPSTICK or a MERLIN. The choice can be based purely on cost and level of expertise available.

For research purposes the DIPSTICK provides the precise profiles required although the financial cost of data collection and use of human resources is high. A combination of using the DIPSTICK and BI provides a compromise solution particularly where control sites are used, and precise profiles measured.

A procedure involving calibration and control sites has been implemented in IRE-TRRL research studies both on monitoring sections and at a network level. The continuation of this study will enable calibration and operating procedures to be established which will allow small changes in roughness to be accurately and consistently identified.

7. ACKNOWLEDGEMENTS

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Table 1

ORIGINAL ROUGHNESS CALIBRATION SITES INCLUDED IN REVIEW STAGE

NO.	ROAD LINK	MAY 1988 (1) N(Ct/km)	MAY 1988 (1) IRI(m/km)	MARCH-JULY 1989 (1) N(Ct/km)	MARCH-JULY 1989 (1) IRI(m/km) (7)	AUGUST 1989 (1) N(Ct/km)	AUGUST 1989 (1) IRI(m/km)	ORIGINAL SURFACE TYPE (3)	REMARKS
1	JL. LODAYA	287	8.60 (4)	-	-	-	-	PM	
2	JL. GUDANG UTARA	160	5.86 (6)	162	6.52	-	-	PM	
3	JL. TONGKENG	164	5.90 (4)	152	6.24	141	5.9 (5)	PM	
4	JL. CITARUM	213	7.29 (6)	-	-	-	-	PM	
5	JL. DIPONEGORO I	157	5.77 (6)	-	-	-	-	PM	OVERLAID BY HRS
6	JL. DIPONEGORO II	-	-	124	5.46	-	-	PM	OVERLAID BY HRS
7	JL. S U C I	27	2.27 (6)	-	-	-	-	AC	
8	JL. TAMAN SARI	120	4.78 (6)	111	5.09	114	5.8 (5)	PM	
9	JL. RAYA TIMUR	80	3.70 (6)	-	-	64	3.9 (5)	HRS	
10	JL. SOEKARNO-HATTA I	37	2.54 (6)	-	-	-	-	AC	OVERLAID BY HRS
11	JL. SOEKARNO-HATTA II	-	-	31	2.85	-	-	AC	OVERLAID BY HRS
12	JL. SAPAN I	927	26.57 (6)	-	-	-	-	PM	RECONSTRUCTED WITH PM
13	JL. SAPAN II (DESA BOJONG EMAS)	300	9.64 (6)	309	10.64	-	-	PM	RESEALED WITH CRUSHER WASTE
14	JL. SAPAN III	-	-	-	-	264	8.6 (5)	PM	
15	JL. RANCAEKEK I	240	8.02 (6)	-	-	-	-	PM	OVERLAID BY HRS
16	JL. RANCAEKEK II	367	11.70 (4)	-	-	-	-	PM	OVERLAID BY HRS
17	JL. BDG-MAJALAYA II	186	7.30 (4)	-	-	-	-	PM	
18	JL. BDG-MAJALAYA I	197	6.86 (6)	193	7.39	-	-	PM	
19	JL. K O P O	14	1.75 (4)	-	-	10	1.8 (5)	HRS	
20	JL. SUPRATMAN	-	-	22	2.60	-	-	HRS	
21	JL. GUDANG SELATAN	-	-	150	6.19	-	-	PM	
22	JL. PATRA KOMALA	-	-	228	8.37	251	9.5 (5)	PM	

Notes :
1. Dates of calibration survey or measurements.
2. N(Ct/km) = NAASRA counts/km
   IRI (m/km) = Equivalent IRI value from DIPSTICK data.
3. Original surface type :
   PM - Penetration macadam
   AC - Asphaltic concrete
   HRS - Hot rolled sheet
4. DIPSTICK survey performed on both wheelpaths.
5. DIPSTICK survey performed pn a single wheelpath.
6. IRI value estimated from correlation equation derived in May-July 1988 on sites identified by Note (4).
7. IRI value estimated from correlation equation derived in August 1989 on sites identified by Note (5).

Table 2

DETAILS OF ROUGHNESS CALIBRATION SECTIONS

NO.	ROAD LINK	TYPE OF OBSERVATION				TYPE OF SURFACE PAVEMENT	PCS2
		B1	N	MERLIN	DIPSTICK		
1	JL. TONGKENG	*	*	*	*	PMA	*
2	JL. PATRAKOMALA	*	*	*	*	PMA	*
3	JL. GUDANG UTARA	*	*	*	*	PMA	*
4	JL. RAYA TIMUR	*	*	-	*	HRS	*
5	JL. TAMAN SARI	*	*	*	*	PMA	*
6	JL. SAPAN II	*	*	*	*	PMA/SAND SEAL	*
7	JL. SAPAN III	*	*	-	*	PMA/SAND SEAL	*
8	JL. SAPAN I	*	*	-	*	PMA/SAND SEAL	*
9	JL. KOPO-RANCABALI I	*	*	*	*	HRS	*
10	JL. KOPO-RANCABALI II	*	*	-	*	HRS	*
11	JL. SOEKARNO-HATTA	*	*	-	-	HRS/AC	*
12	JL. RANCAEKEK I	*	*	-	-	HRS	*
13	JL. RANCAEKEK II	*	*	-	-	HRS	*
14	JL. CITARUM	*	*	-	-	PMA	*
15	JL. DIPONEGORO	*	*	-	-	HRS	*
16	JL. SUPRATMAN	*	*	*	*	HRS	*
17	JL. SURAPATI-CICAHEUM	*	*	-	-	AC	*
18	BANDUNG-MAJALAYA I	-	*	*	-	PMA	*
19	BANDUNG-MAJALAYA II	-	*	-	-	PMA	*

Note : * = Observations
- = No observations

Table 3

COVERAGE OF SURFACE TYPE AND ROUGHNESS

SURFACE TYPE	ROUGHNESS (m/km)						NUMBER OF SECTIONS
	0 - 1.99	2 - 3.99	4 - 5.99	6 - 7.99	8 - 9.99	>10	
Hot Rolled Sheet	1	6	-	-	-	-	7
Asphaltic Concrete	1	1	-	-	-	-	2
Penetration Macadam	-	-	1	5	2	1	9

Table 4

ROUGHNESS DATA SUMMARY

Site	Name	Bump Integrator			Naasra			Merlin		
		Position	BI32	IRI	Naasra	IRIAM	IRIVM	Position	Disp.	IRI
1	Tongkeng	OWT	4060	6.15	134	5.95	5.95	OWT	111.9	6.15
		IWT	3760	5.74				IWT	99.4	5.74
2	Patrakomala	OWT	4990	10.71	252	10.30	10.31	OWT	184.2	10.71
		IWT	5380	9.90				IWT	154.4	9.90
3	Gd. Utara	OWT	4070	7.20	149	6.99	6.99	OWT	116.9	7.20
		IWT	4010	6.78				IWT	125.8	6.78
4	Taman Sari	OWT	3620	5.86	113	5.37	5.39	OWT	122.5	5.87
		IWT	3190	4.87				IWT	89.8	4.87
5	Supratman	OWT	1470	3.43	30	2.82	2.88	OWT	41.0	3.43
		IWT	1200	2.22				IWT	30.2	2.22
6	Kopo-R Bali 1	OWT	1130	2.08	25	1.98	1.98	OWT	23.4	2.08
		IWT	1240	1.89				IWT	27.0	1.88
7	Kopo-R Bali 2	OWT	1440	2.80	24	2.51	2.53			
		IWT	1260	2.22						
8	Raya Timur	OWT	2530	3.90	78	3.94	3.94			
		IWT	2350	3.99						
9	Sapan 1	OWT	4740	8.86	192	8.78	8.78			
		IWT	4890	8.70						
10	Sapan 2	OWT	5980	9.35	283	9.54	9.55			
		IWT	6110	9.74						
11	Sapan 3	OWT	5720	8.80	269	9.07	9.07			
		IWT	5810	9.33						

Note :

BI32 = BI roughness index at 32 km/h in mm/km
Disp = MERLIN dispersion value in mm
OWT = Outer wheel track
IWT = Inner wheel track
Naasra = NAASRA meter counts/km
IRI = International Roughness Index in m/km
IRIAM = Arithmetic mean of IRI in m/km
IRIVM = Variance mean of IRI in m/km

Table 5

RANGE OF MEASUREMENT VALUES OBTAINED USING EACH MEASURING SYSTEM

Measurement System	Units	Position	Lowest Value	Highest Value
Bump Integrator (BI32)	mm/km	OWT	1130	5980
		IWT	1200	6100
NAASRA roughness meter	counts/km	OWT/IWT	21	283
DIPSTICK (IRI)	m/km	OWT	2.08	10.70
		IWT	1.88	9.90
MERLIN	mm	OWT	23.4	184.2
		IWT	27.0	154.4

Table 6

RESULTS OF REGRESSION ANALYSIS

MODEL	DEPENDENT VARIABLE (Y) (1)	INDEPENDENT VARIABLE (X) (2)	INTERCEPT (a)			SLOPE (b)			SE OF ESTIMATE	CORRELATION COEFFICIENT (r)
			VALUE	STANDARD ERROR (SE)	t-VALUE	VALUE	STANDARD ERROR (SE)	t-VALUE		
Y = a + bX	IRI	BI32	0.2190	0.366	0.59	0.00164	9.21E-05	17.8	0.742	0.970
Y = aX^b	IRI	BI32	0.0027	0.334	-17.69	0.94400	0.04150	22.7	0.115	0.981
Y = a + bX	IRI	N	1.8540	0.382	4.84	0.03030	0.00226	13.5	0.701	0.975
Y = aX^b	IRI	N	0.3240	0.167	-6.72	0.60600	0.03560	17.0	0.107	0.985
Y = a + bX	IRI	DISP	0.5640	0.392	1.43	0.05330	0.00367	14.5	0.646	0.977
Y = aX^b	IRI	DISP	0.1530	0.215	-8.74	0.79600	0.04890	16.2	0.118	0.981

Notes : 1. IRI = International Roughness Index (units of m/km)
2. BI32 = Corrected TRRL Bump-integrator value at 32 kph. (units of mm/km)
N = NAASRA roughness in counts per km.
DISP = MERLIN dispersion value in units of mm.

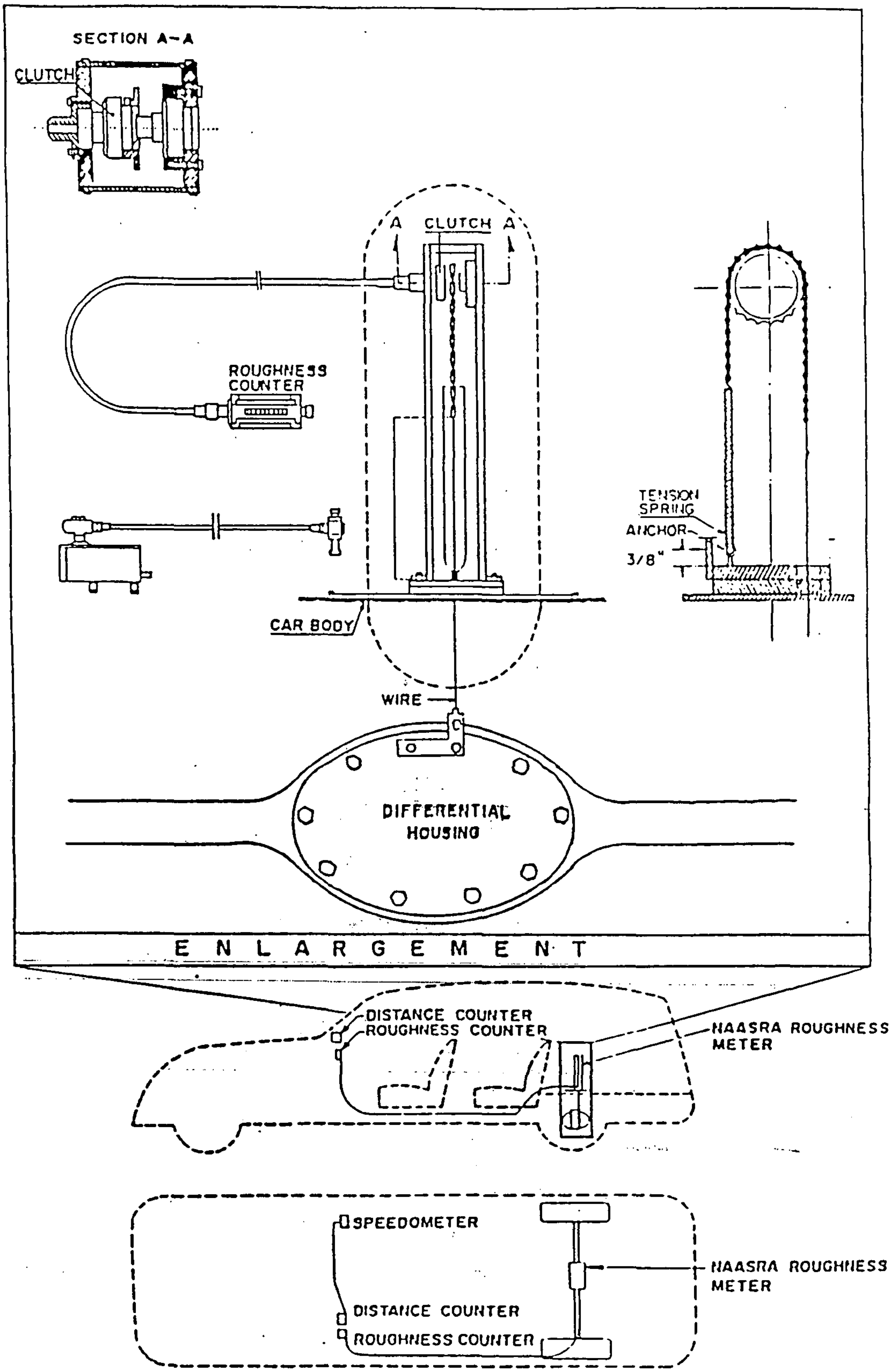


Figure 1 Diagram showing layout of the NAASRA Roughness Meter

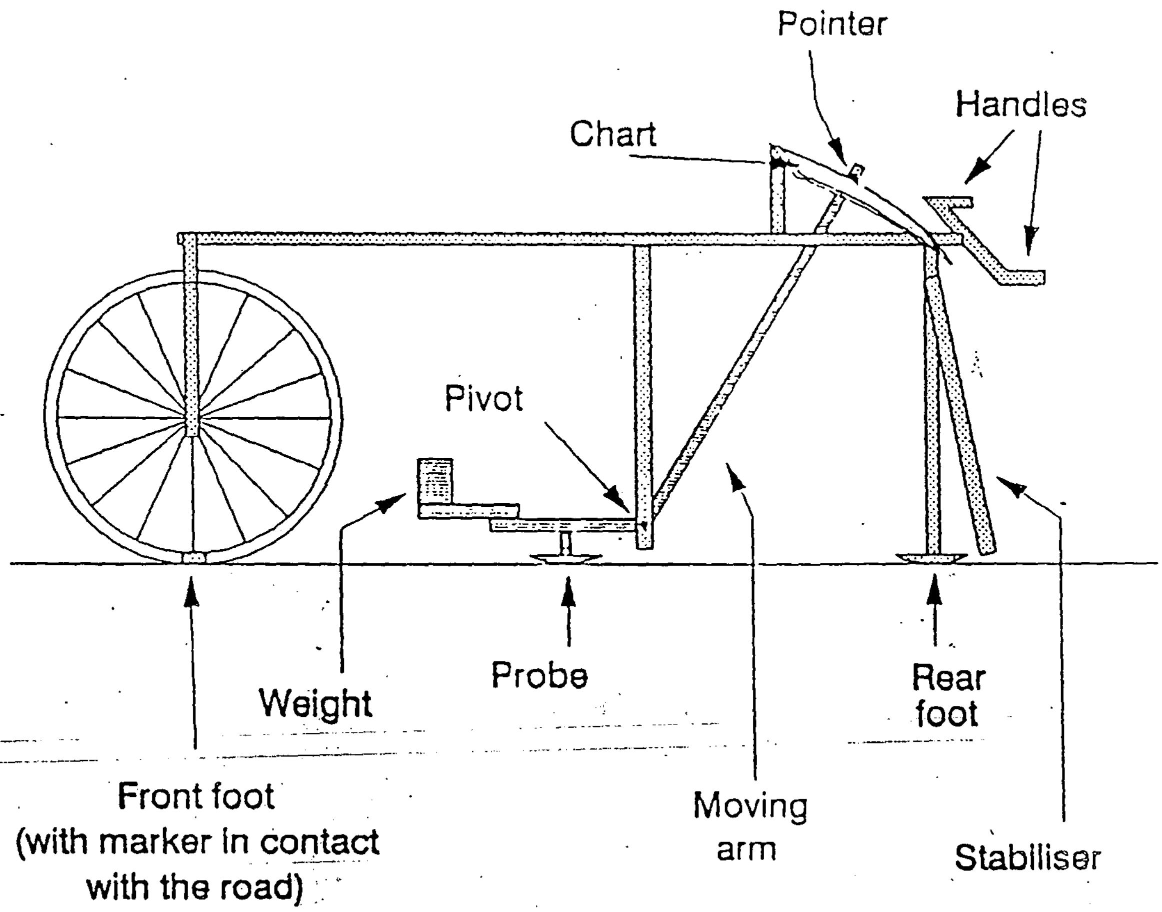


Figure 2 Sketch of MERLIN

TEST SECTION Kop-Ran-1

WHEEL PATH OWT

DATE 22/10/89

OPERATOR Djoko.

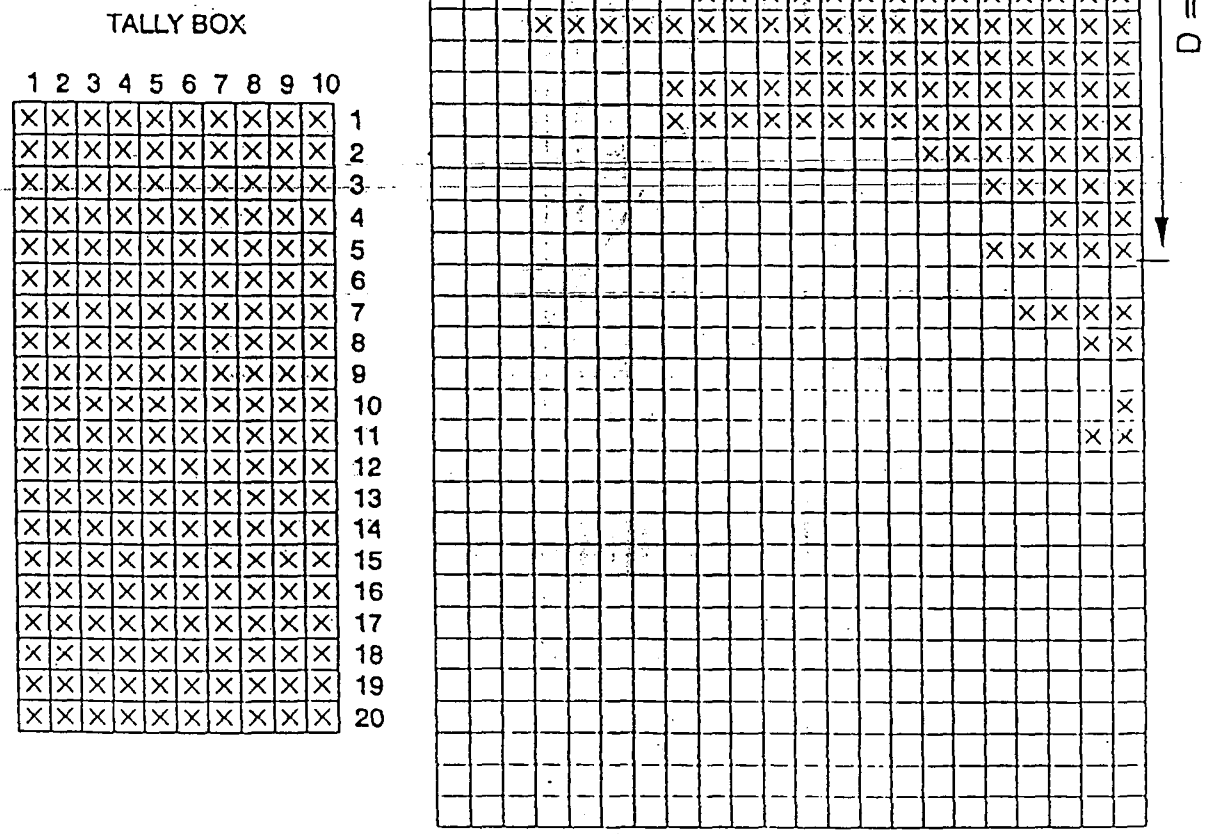


Figure 3 Specimen MERLIN result

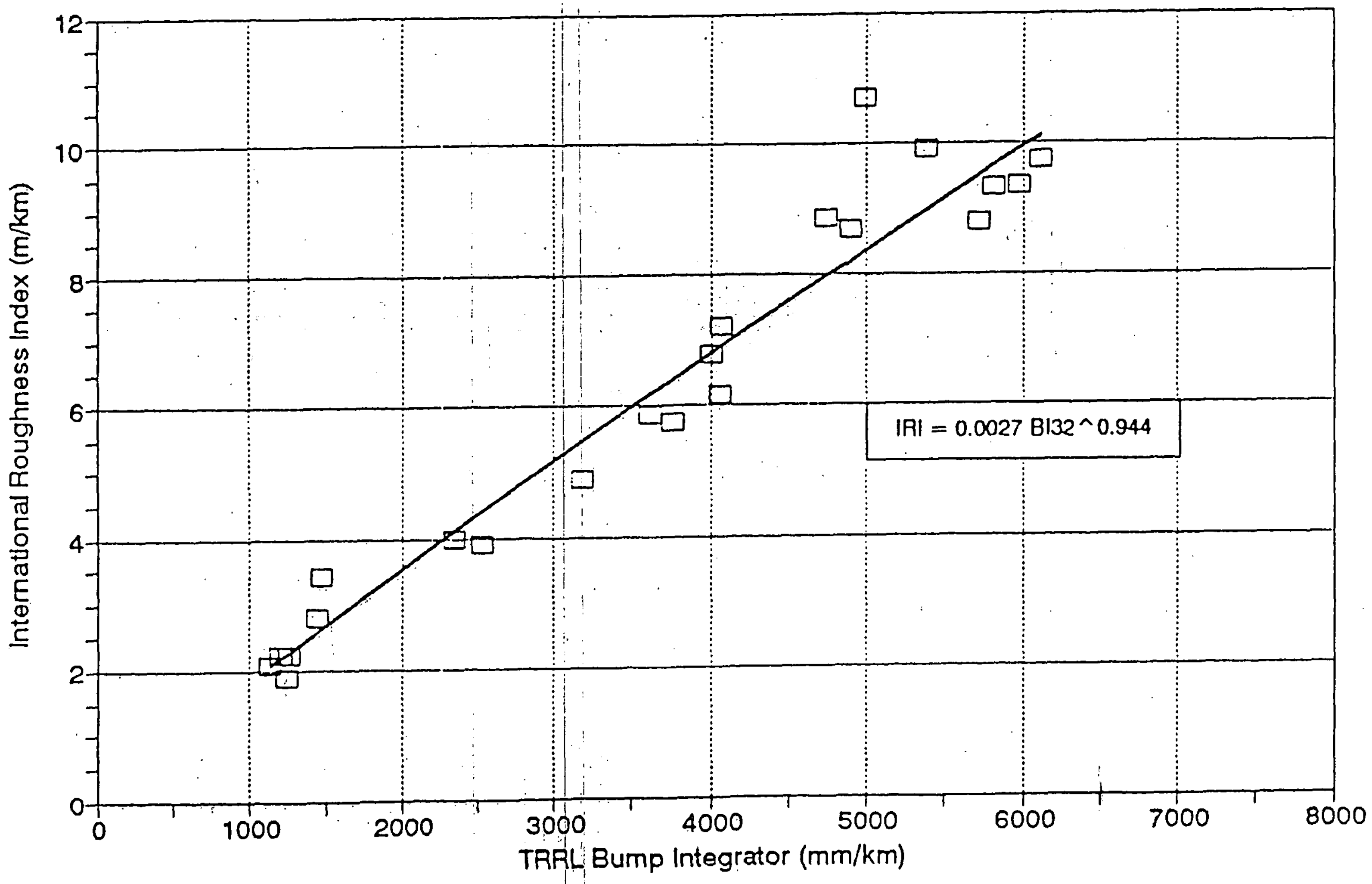


Figure 4 Relationship between IRI and BI

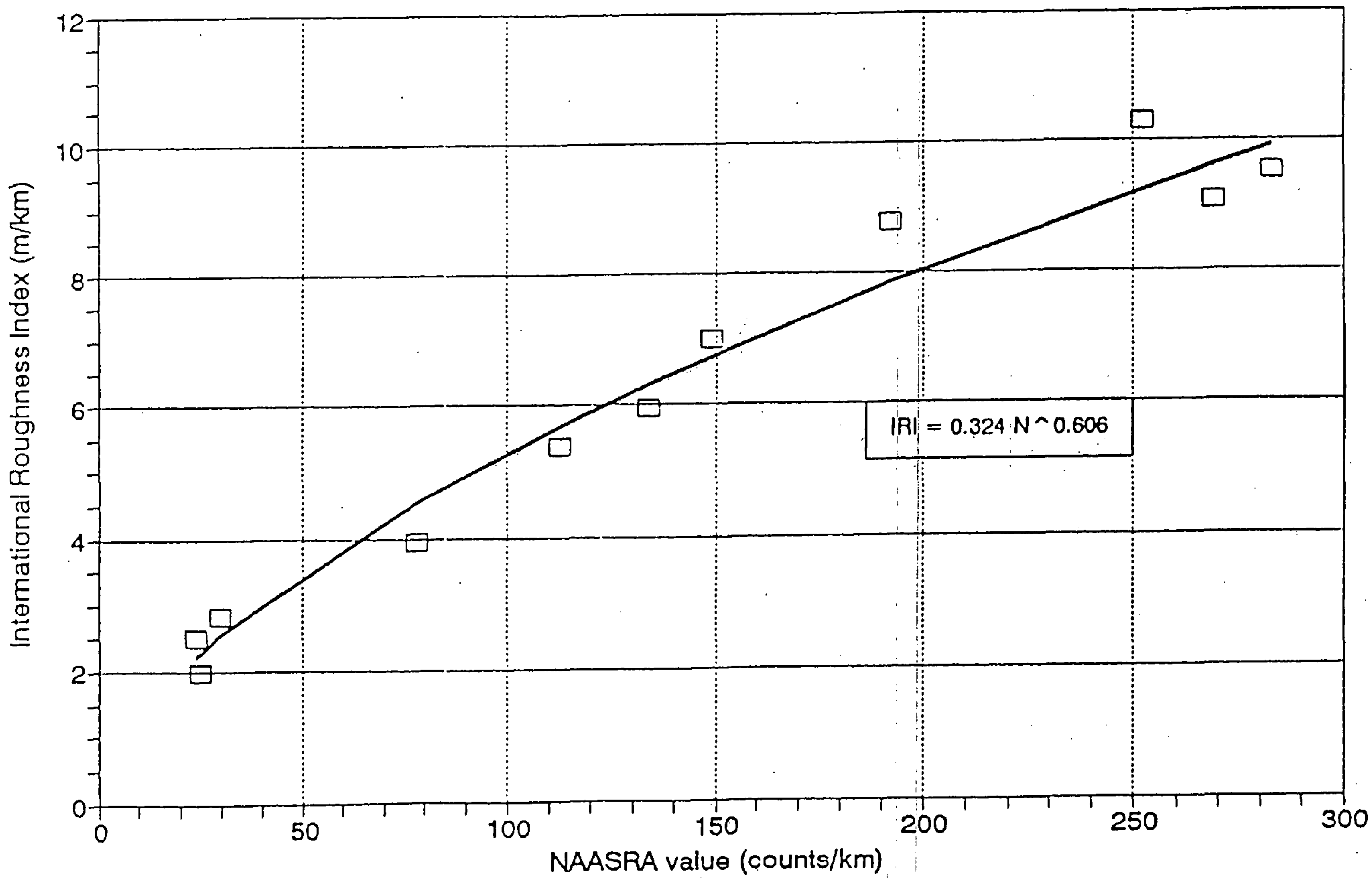


Figure 5 Relationship between IRI and NAASRA

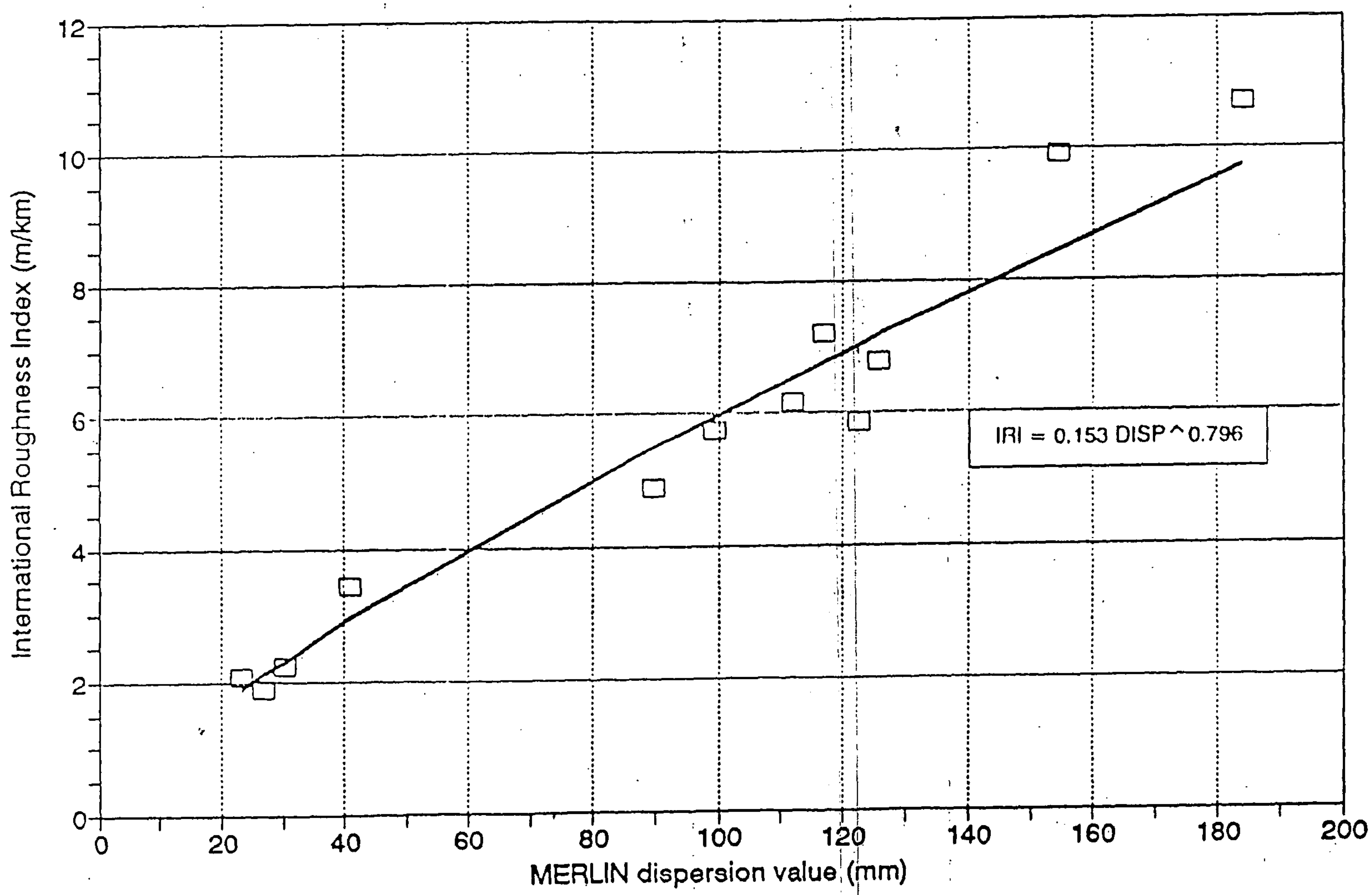


Figure 6 Relationship between IRI and MERLIN

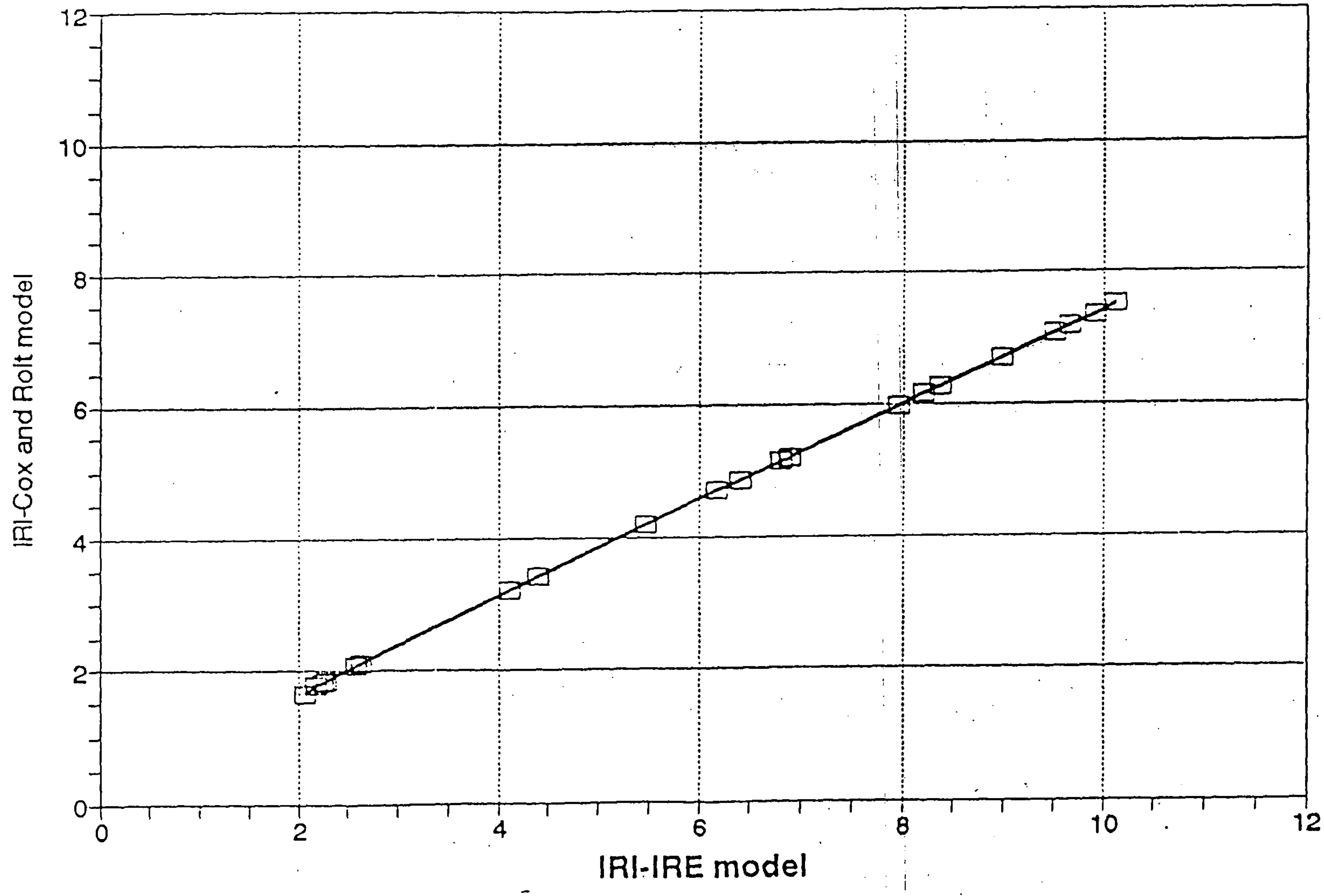


Figure 7 Relationship between IRI and BI models from two sources

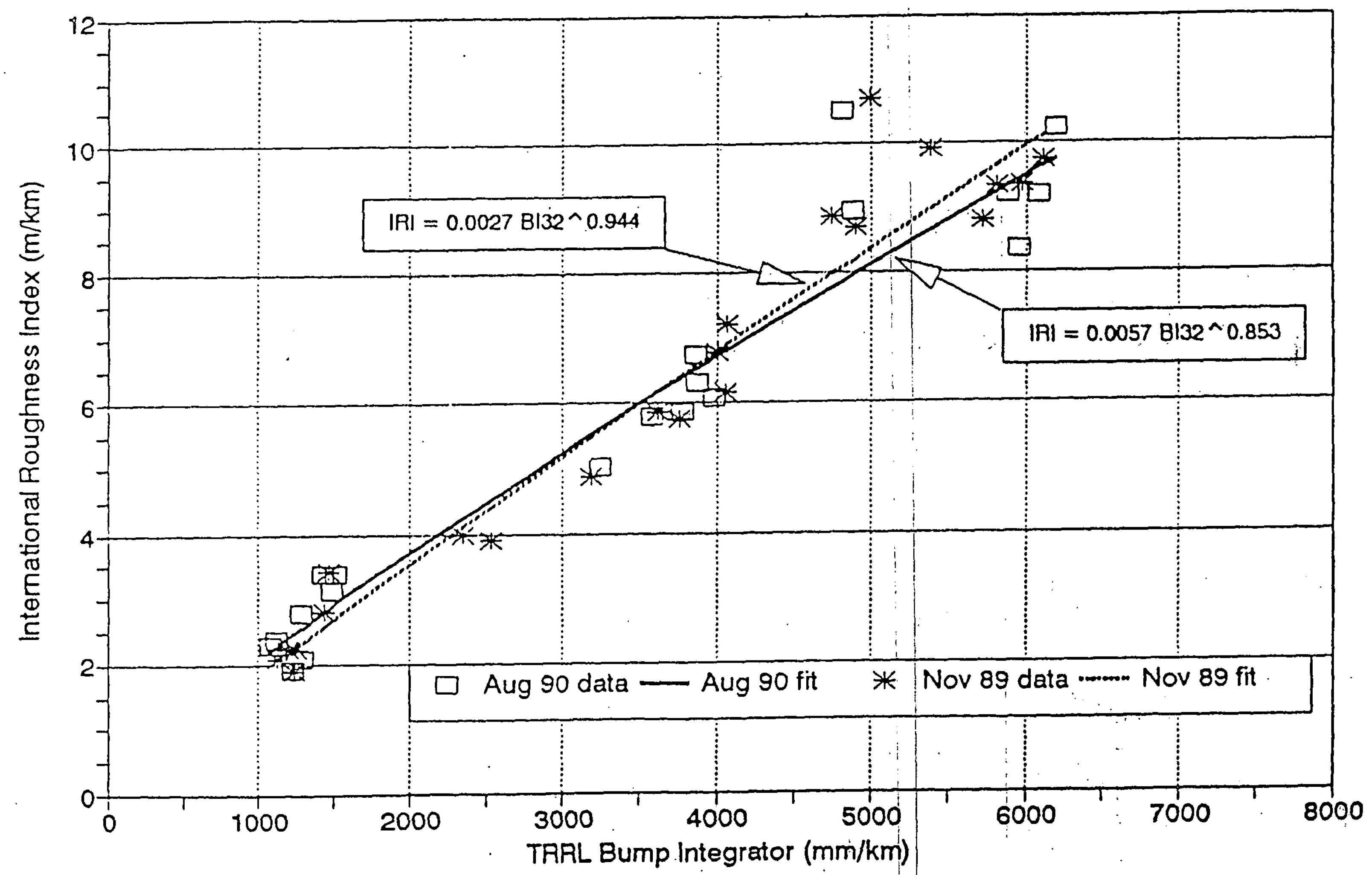


Figure 8 Relationship between IRI and BI

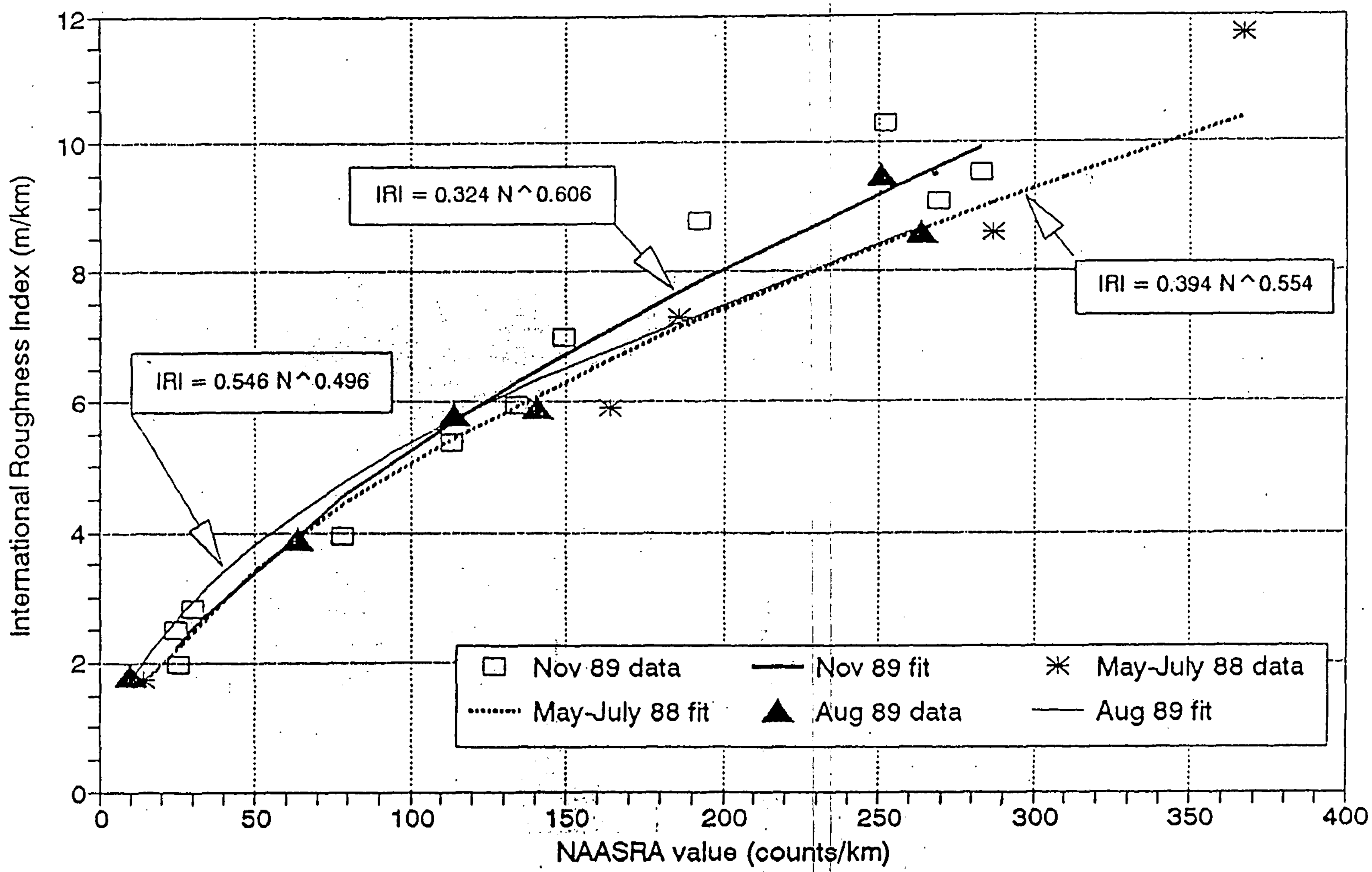


Figure 9 Relationship between IRI and NAASRA

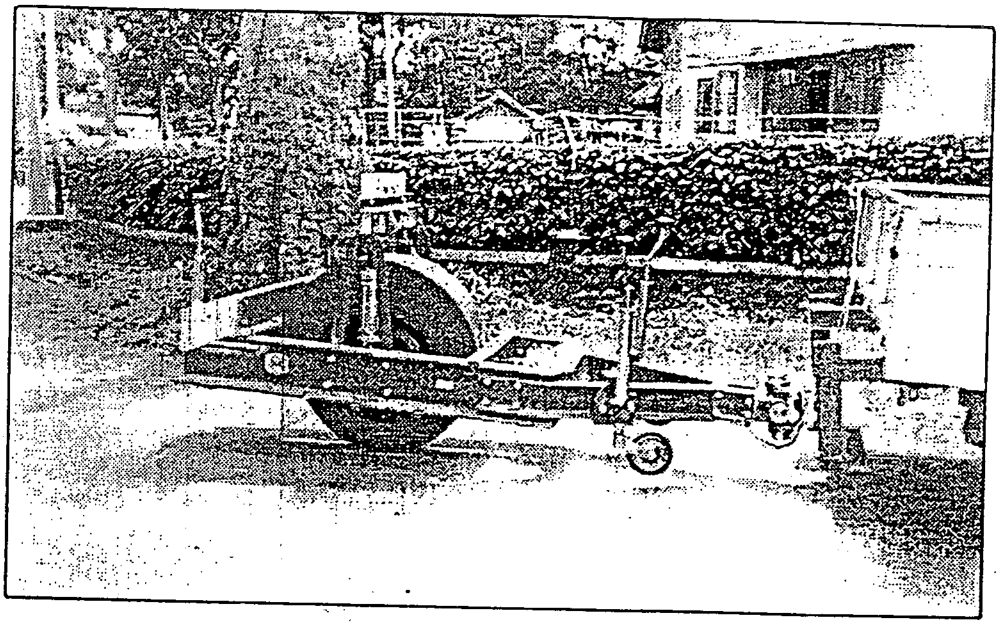
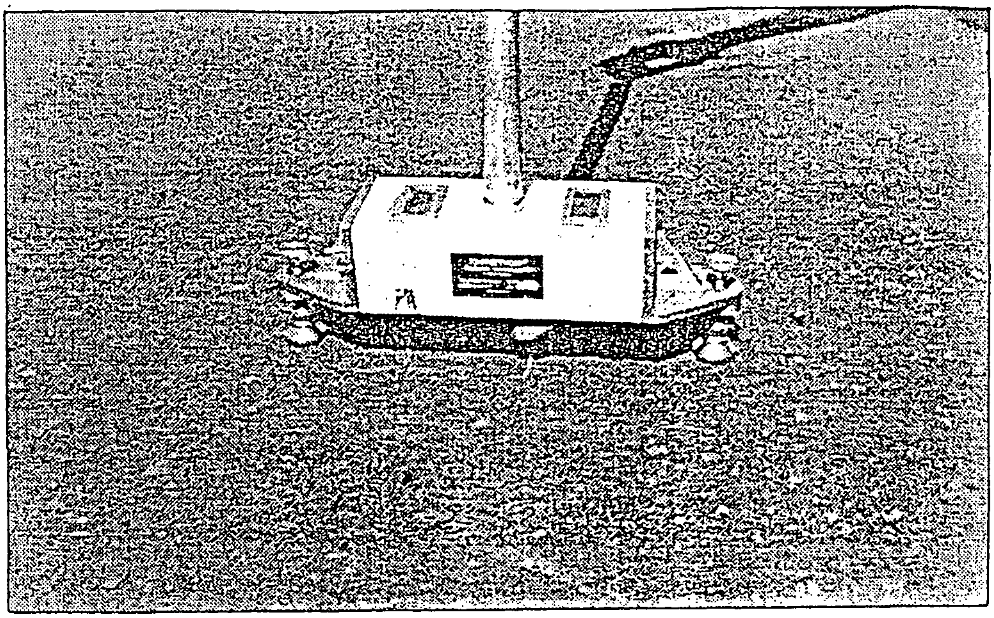


Plate 1 The TRRL towed fifth wheel Bump Integrator



(a) Close-up of DIPSTICK

(b) DIPSTICK in operation

Plate 2 The DIPSTICK Profilometer