DEVELOPMENT OF A LOW COST ROAD ROUGHNESS MEASURING DEVICE

A Thesis submitted in partial fulfillment of the requirements
for the award of the Degree of

Master of Technology
in
Transportation Engineering

by

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NATIONAL INSTITUTE OF TECHNOLOGY
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CERTIFICATE

This is to certify that the thesis entitled "**DEVELOPMENT OF A LOW COST ROAD ROUGHNESS MEASURING DEVICE**" submitted by **Mr. JYOTI BIRAJ DAS** (Roll No. 212CE3054) in partial fulfillment of the requirements for the award of Master of Technology Degree in Civil Engineering with specialization in Transportation Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

Place: Rourkela, India

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ACKNOWLEDGEMENT

First and foremost I offer my sincere gratitude and respect to my project supervisor, **Prof. Mahabir Panda,** Department of Civil Engineering, for his invaluable guidance and suggestions to me during my study and project work. I consider myself extremely fortunate to have had the opportunity of associating myself with him for one year. This thesis was made possible by his patience and persistence.

I express my sincere thanks to **Prof. Ujjal Chattaraj** and **Prof. Prasant Ku. Bhuyan** of Civil Engineering Department, NIT Rourkela for providing valuable co-operation and advice all along my M.Tech study. I also express my thanks to all my friends of Transportation Engineering Specialization who helped me to learn many things about my project.

Also I would like to extend my gratefulness to the Head of Department, **Prof. N. Roy**, and to all the Professors and staff members of Civil Engineering Department for helping and providing me the necessary facilities for my research work.

Last but not the least, I express my love to my parents, family and the one above all of us, the omnipresent God, for answering my prayers and giving me strength and patience always.

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ABSTRACT

One of the most important measures of road condition is roughness of road surface. Mainly there are two different types of instruments used for the measurement of road roughness in this report. First one is the Merlin. It is a machine which evaluates roughness using low cost instrumentation, utilized either for immediate estimation or for adjusting reaction sort instruments. Secondly is the Auto-Level which is an automated leveling optical instrument. During construction site surveys for gathering, transferring or setting horizontal levels and grade applications, is normally used. The estimation of rough distance between instrument and grade staff is done by the stadia reticle present in auto level. In this study a low cost device has been indigenously fabricated/ developed to measure the roughness of a road's surface. Finally, experiments on ten road stretches have been conducted using three methods including the developed device. It has been observed that the overall roughness parameters in terms of (IRI) in all the methods are almost same.

Key words: Roughness, Merlin, Auto- level, IRI

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List of Abbreviations

MERLIN	Machine for Evaluating Roughness using Low cost Instrumentation
IRI	International Roughness Index
RTRRMS	Response Type Road Roughness Meters
PSR	Present Serviceability Index
UI	Unevenness Index
LCD	Liquid Crystal Display
LED	Light Emitting Diode
NAASRA	National Association of Australia State Road Authorities
CRRI	Central Road Research Institute

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Roughness is characterized as the longitudinal unevenness of road surface. It is a great factor which measures road condition vehicle operating cost and ride quality. Now a day there is an importance of study on the effect on vehicle operating cost. Number of experiments and studies have shown that roughness has greater influence on vehicle productivity, running speed, maintenance and tire damage and hence vehicle productivity.

Roughness is a figured measure of the longitudinal smoothness for the segment of Road being overviewed. It is used as an indicator to determine how the road has deteriorated with regard to ride comfort. Roughness can be determined by different ways in units such as, IRI, NAASRA, ride number etc. All of these systems of measurement consider the amount of vertical displacement that is felt by a passenger in the car driving over the section of road. Generally the higher the number the rougher the road and the less comfortable the ride is to road users.

So it is seen roughness measurement is an important activity for pavement management that's why various roughness measuring machines and different scales for roughness have been developed. As per the requirement for developing countries, there is a need of simple de eloping machine which can measure roughness over a constrained span of road system specifically or for aligning different roughness measuring machines.

1.2 OBJECTIVES

The overall objectives of the project are as follows:

1. Assess the capabilities of currently available low cost products such as merlin and auto level.
2. Develop concepts and specifications for a new low cost device.
3. Design and construct the new product.
4. Validate the measurement capabilities of the new product and compare with the existing two methods.

1.3 THESIS ORGANISATION

The thesis consists of five chapters as described below:

1. Chapter 1 describes general idea about road roughness.
2. Chapter 2 deals with literature review
3. Chapter 3 explains the development of new device.
4. Chapter 4 deals with analysis of results and discussions.
5. Chapter 5 explains the conclusion and future scope.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

International roughness index (IRI) is the accepted standard for measuring road surface's roughness in worldwide. The IRI was obtained by the experiment led in Brazil. This experimental result helps in comparing directly data from different instruments and different countries that helps in enabling historical trend to be estimated with confidence. Without a common method for calculation, results from research could not be compared without the use of conversion factors from one unit to the next.

As stated by Sayers (1995):

1. From a solitary longitudinal profile might be processed. The specimen interim ought to be no bigger than 300 mm for exact figuring. The obliged determination is reliant on the roughness level and for smooth streets better determination is required.

2. It's assumed that between sampled elevation point a constant slope persists.

3. By using the method of moving average the profile of base length 250mm.

4. After this by using quarter car simulation this smoothed profile is filtered, with Car at a simulated speed of80km/hr (49.7 m/hr).

5. For finding out IRI direct amassing of mimicked suspension movement is partitioned by the profile length. Thus, IRI is measured with units in/mi or m/km.

2.2 ROUGHNESS MEASURING INSTRUMENT

Rod and level survey: This survey is an accurate measurement of pavement profile for large projects. This type of survey is inappropriate and uneconomical.

Dipstick profiler: This instrument can measure the road profile accurately. It records 10-15 readings per minutes. Analysis through software provides accuracy to ± 0.127 mm for a longitudinal profile. Measurements by dipstick are most commonly used for measuring a road profile.

Profilographs: Profilographs is mounted at the centre of frame for the free vertical movement. From the motion of sensing wheels the recorded deviation for reference plane is recorded on graph paper. Very slight surface deviation or the undulation up to 6m of length can be easily detected by profilographs. However, because of slow speed profilographs are not practical for road network condition.

Response type road roughness meters (RTRRMs): This type of instrument helps for indirect measure of longitudinal road profile. The RTRRM readings are affected of tyre pressure, load, vehicle suspension system, speed of vehicle, etc. Due to this type of sensitivity the readings or the measurements re to be aligned when there is change in the above factors significantly. The CRRI's fifth wheel bump integrator falls in this category which is most commonly used in India. The advantage of these RTRRMs is that the roughness can be easily measured at speedup to 80 km/hr. Since no to RTRRMs are exactly alike, the measurements are to be converted in (unevenness index) to a standard common international scale is necessary. The IRI was created by World Bank to give a base on for comparing roughness values from different instruments. The IRI summarizes the longitudinal surface profile in the wheel path which is collected by different roughness measuring device and then the computation is done from surface elevation data. IRI is represented in units of m/km.

Profiling devices: By using either contact or non-contact sensor system these type of devices very accurately can evaluate the longitudinal profile of a pavement. For the measurement or mapping of road profile the non-contact systems use laser/ultrasonic devices. These profile-meters used to calibrate RTRRMs are normally expensive.

Indian Practice

In India the roughness is measured using fifth wheel bump integrator (developed by CRRI) and is reported as Unevenness Index (UI) in mm/km. For arriving at IRI from UI values the bump integrator needs to be calibrated for specific set of parameters using dipstick profiler. A typical relationship between IRI (m/km) and UI (mm/km) is given as

$$IRI = UI / 720$$

2.3 ROUGHNESS VALUES RANGE

The below given figure shows IRI value range for different pavements to corresponding speeds.

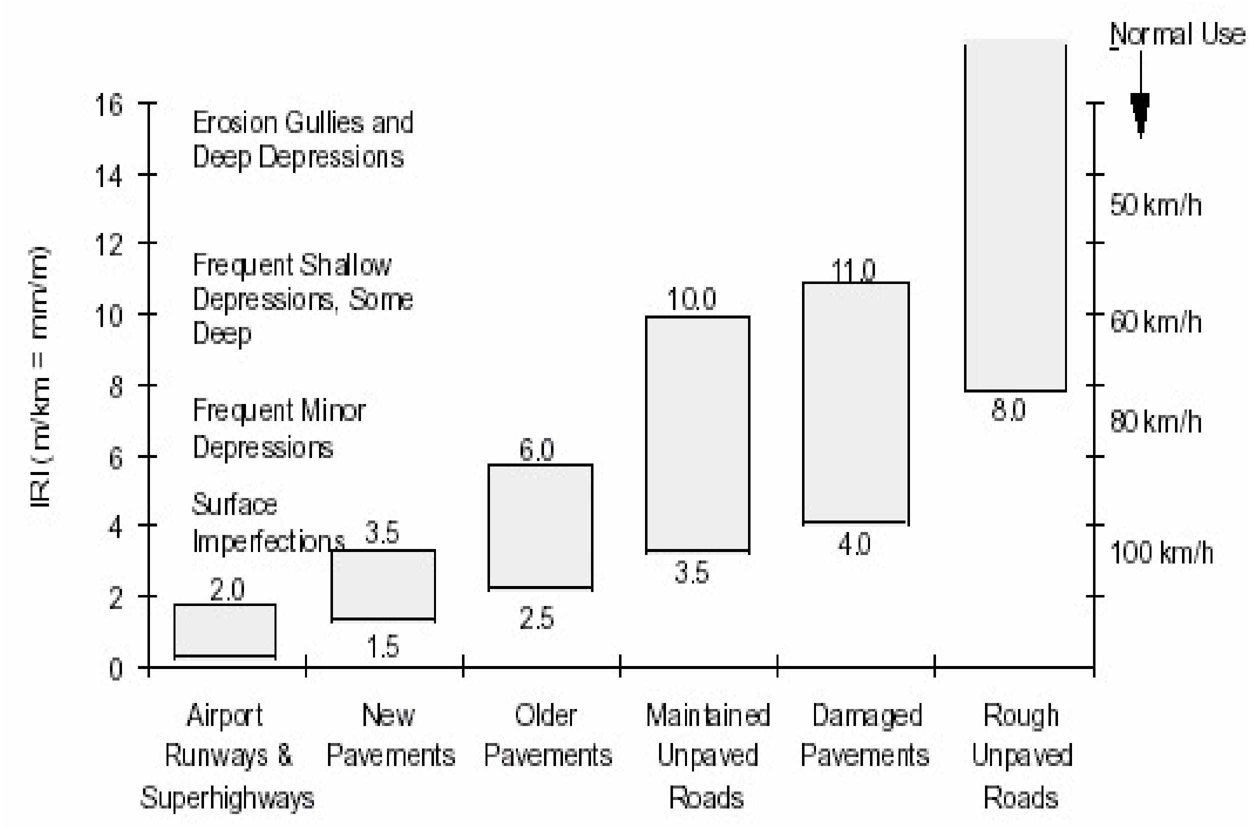

Figure 2.1Range of Roughness Values

(www.pavementinteractive.org/wp-content/uploads/2007/08/Iri1.jpg)

2.4.1 THE MERLIN

INTRODUCTION

It is another instrument developed to measure road profile. It is a physically worked instrument to measures surface unevenness at regular interims. The roughness readings are effortlessly taken through graphical system for the examination of recorded information. The road roughness can be measured over standard roughness scale with less complex estimation and methods. Its specific attractions for utilization in pavement are that it is simple to make, easy to work and keep up.

The device is called MERLIN-Machine for Evaluating Roughness utilizing Low-cost Instrumentation. In the universal way roughness analyze this instrument was outlined on the premise of a workstation recreation of its operation on longitudinal way profile.

Figure 2.2 The Merlin (www.aimil.com/product-MERLIN_(AIM_570)-267.aspx)

2.4.2 PRINCIPLE OF OPERATION

Merlin is a device with a probe and two feet which rests on the surface with course of wheel track whose roughness by this device is to be measured. This device is at 1.8 meters separated and the probe lies at the mid-path between two feet. At the contact of road surface and the two feet this instrument measures the vertical relocation between the way surface and the focal point. The measured vertical relocation is called as the mid-harmony deviation.

The relocation relies on upon the progressive interims to be undertaken way surface, if the readings are taken at progressive interims along a longitudinal profile of way, then the rougher the street surface the more amazing will be the variability of the vertical displacement. There is an outline is mounted on the device on which the estimations are recorded by arranging the relocations as a histogram on a Chart. It is not difficult to record specifically their overlay and this has been observed that to connect well with the way roughness is measured, spread of mid–chord deviation method is much important. Case in point, different investigates have proposed two roughness records MO and OI which are depicted by Sayers et al (1986a),

The Merlin device works on one base length measuring mid harmony deviations and there is no requirement for bar and level throughout measurements mid harmony deviations variability is dictated by variability and for determination of roughness next to no estimation is include.

2.4.3 GENERAL DESCRIPTION

The accompanying figure demonstrates the Merlin instrument. For simple operation, there is a wheel as the front leg and back leg is made up of inflexible metal pole. Shorter settling leg is available at one side of back leg that aides in keeping the device from falling over throughout taking perusing. There are two handles anticipating behind the primary back leg that gives the device resemble a long and thin wheel barrow.

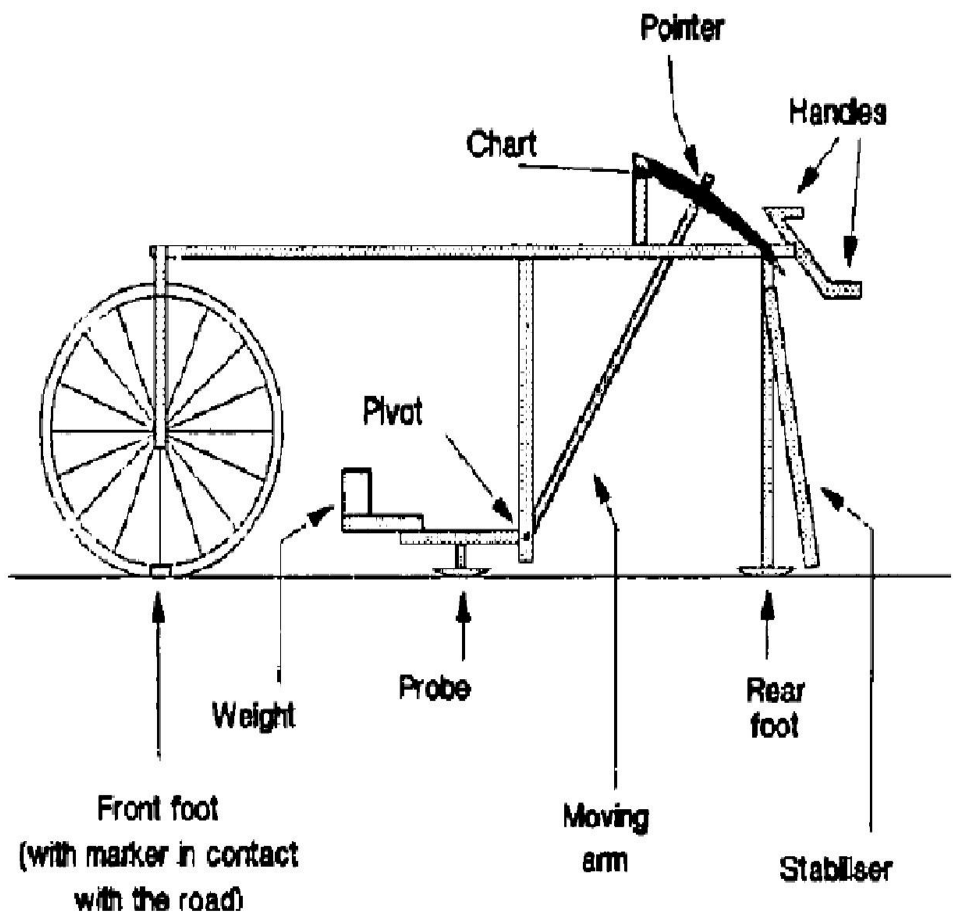

Figure 2.3 Description of Merlin (Figure from Merlin manual by AIMIL Ltd.)

A pointer is appended at the flip side of the arm, which proceeds onward the arranged information diagram. The arm is furnished with mechanical enhancement of tens that causes generation of development of the pointer of one centimeter when the probe moves by one millimeter. The diagram holds arrangement of segments, being 5 mm in width, and separated into boxes. On the off chance that the span of the wheel is non-uniform, then it will prompt a variety in the length of the front leg starting with one estimation then onto the next and bringing on incorrectness in the Merlin's results. An imprint is given on the edge of the wheel to keep away from this error and all the estimations are brought with the imprint at its closest vicinity with the street profile .Then the wheel is in its ordinary position.

2.4.4 METHOD OF USE

For determination of roughness of road surface profile, 200 estimations at consistent interims is to taken. The machine is situated with the wheels on its ordinary location and the back foot stabilizer probe in touch with the asphalt surface at each one measuring point. At that point the recording the position of the arm pointer on the graph with a cross in suitable section is carried out by the administrator. For keeping the record of aggregate number of readings, cross in the count box of chart is given.

For the further system of estimations the Merlin's handles are lifted up so that just the wheel stays in touch with the way surface and the machine is rolled in forward heading at the same methodology is rehashed. As long as the wheel is in the typical position the dividing between the measuring focuses does not make a difference. By taking the estimations at standard interims, will help in transforming both great normal specimens over the entire length of the area and decrease the danger of inclination because of the propensity of administrator to keep away from terrible areas of the street.

The chart is removed from the merlin after 200 observations. Mid path between the eleventh and the tenth checking from each one end of the diagram underneath the columns as given in the sample frequently it may be important to insert between segment limits. "D" is the dividing between the two imprints is measured in millimeters and it’s characterized as the roughness on the merlin scale.

2.4.5 PRACTICALDETAILS

The primary leg, the focal, the stabilizer, the moving arm and the handles are all made of steel tubing of square cross segment of 25 x 25 mm with 1.5 mm divider thickness for simple assembling methodology. The stabilizer handles are settled by jolts with the goal that they could be evacuated for simpler transportation yet the joints are welded where conceivable. Extra struts are utilized for reinforcing the joints between the principle pillar and legs. The wheel mounted in the pair of front forks might be any sort of bike wheel and with a tire having reasonably smooth tread design.

The back foot and the probe foot are 12 mm wide and adjusted in the path of the wheel track to a length of 100 mm for decreasing the affectability way surface micro-composition. This adjusting aide for keeping the purpose of contact of probe with way surface with the same vertical plane. To abstain from establishing on unpleasant streets the weight is stepped and the turn is created out of the bike wheel center and the arm between the turns.

The outline holder is ready from metal sheet and is bended in such a route, to the point that the graph is spoken to with the pointer over its run of development. An aide is altered to the side of the principle bar holding the arm near the pillar for ensuring the arm from unwanted sideways development. At the point when the machine is raised by its handle one end of this aide demonstrations as a stop.

The connection of the probe with moving arm is carried out by a strung pole passing through a prolonged gap that allows both parallel and vertical modification. The position of the probe which is vertical is situated to the point that the pointer is near the center of the outline when the histogram won't be focal or the probe dislodging is zero. At the point the machine is tilted side to side the pointer moves, if the above course of action is not legitimately done. After right modification of 15 readings the machine is hung to one side so that the stabilizer rests out and about has little impact on the position of the pointer. The enhancement of the arm ought to be checked by the assistance of a little alignments piece of 6 mm thickness before utilizing the machine.

The pointer ought to move by 60 mm after the insertion of piece under the probe. If the pointer is moved by 57 mm, then the estimation of D indicated on the graph is expanded by the component of 60/57.A look at is conveyed prior and then afterward each one set of estimations for guaranteeing that there has been no unwanted development of basic parts like back foot. This is done by furnishing a proportional payback to a correctly characterized position along the way and verifying that the pointer perusing is not changed. Throughout undertaking an unpleasant street, more than 10 readings are at breaking point of the histogram. The probe ought to be evacuated and connected to the given option settling focuses. The above clarified one makes the point twice from the turn and diminishes the mechanical intensification to 5. The scaling of graph is carried out by the prior depicted adjustment strategy. The failures are to be presented are little and could be disregarded for this situation although the dispersing between the probe and the two feet of the device is no more 0.9 meters.

2.4.6 CALIBRATION EQUATIONS

The IRI scale and the Merlin scale are related by the following equation

For all type of pavement surface:

IRI=0.593+0.0471D 42 > D > 312 (2.4> IRI > 15.9)

IRI= International Roughness Index in m/km

D=roughness in Merlin scale measured in mm

2.4.7 RELATIONSHIP BETWEEN IRI AND D

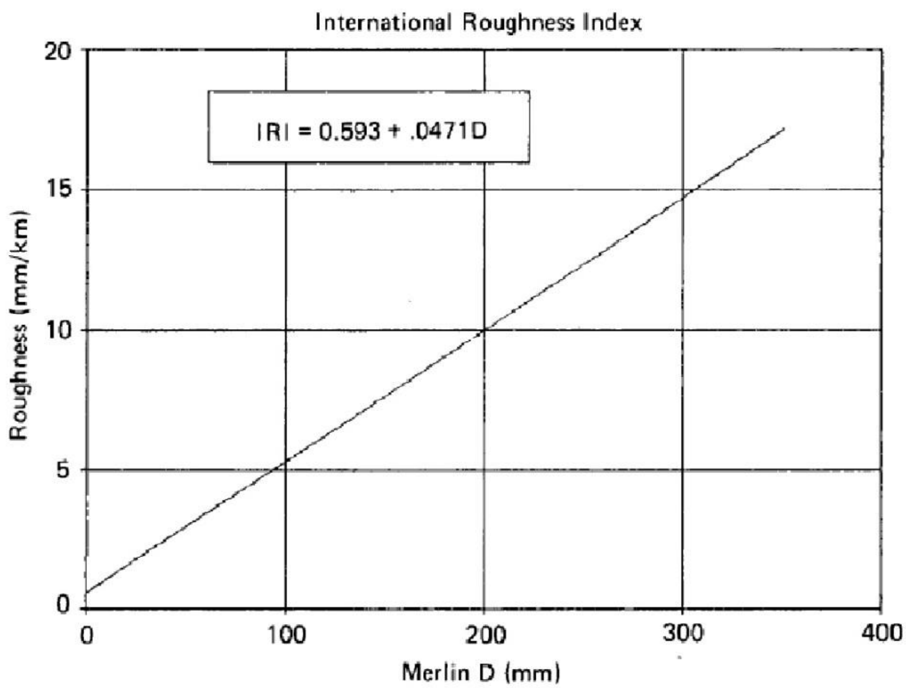

Figure 2.4 RELATIONSHIPS BETWEEN IRI AND D

(Figure from Merlin manual by AIMIL Ltd.)

2.5.1 AUTO LEVEL

INTRODUCTION

Auto level is an automatically operated optical instrument that helps in establishing or checking points on the horizontal planes. An automatic level, also known as builder's auto level or a dumpy level, is a laser marking; optical measuring device helps in estimating a horizontal plane. This can be done on a small scale such as residential home construction or on a much larger scale for surveying. Due to the wide range of jobs that can benefit from the use of an automatic level, the devices themselves are manufactured to different specifications. That is not to say they all don't perform the same basic function, they do. However, the function needed will determine the type of automatic level to be used.

Auto level is set upon a tripod, which is leveled as much as possible. When the auto level is set on the tripod, a swinging prism inside the level adjusts to compensate for imperfections in the tripod leveling. This is only good for small inaccuracies; larger variants will need to be dealt with before proceeding. These are used in the same manner as the dumpy level but are most often used on residential and smaller scale industrial building construction projects. These levels set up quickly and are easy to operate for most people. It is, however, still a two person job to use the level and an assistant will be needed to hold a tape measure or graduated measuring stick.

2.5.2 GENERAL DESCRIPTION

Principle of levelling

Height reference is provided by the Auto level which is an optical instrument. "Height of Collimation" is defined as this height reference which through the axis of the telescope at the horizontal plane. The height of other stations can be found after knowing the height of collimation or instrument height by measuring the plane with the help of a staff. The height of collimation can be obtained by taking the back sight to a staff placed on a bench mark and by adding the staff reading to the bench mark value.

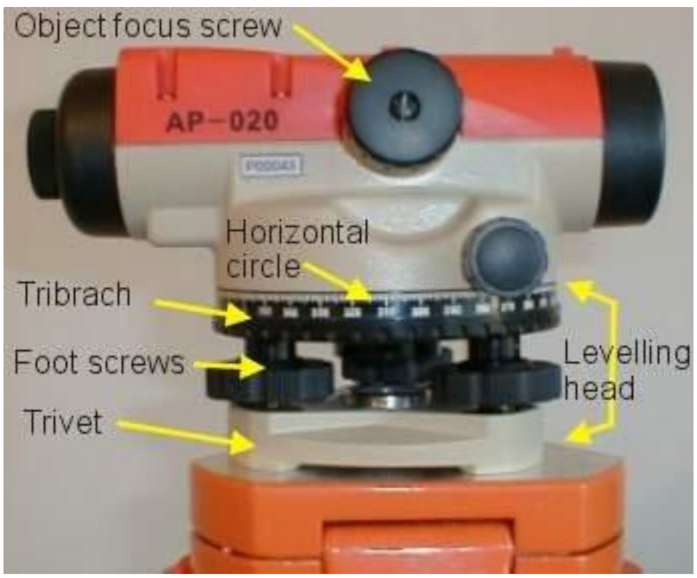

Figure 2.5Auto level (www.levelling.uhi.ac.uk/pics/pentaxR.jpg)

There are three parts in leveling head:

- A tribrach or top plate that carries the spirit level and the instrument
- Foot, screws and three leveling
- Trivet or a foot plate that is attached with tripod head

The staff or the other image can be brought in to focus by the help of object focusing screw. Auto level has a spherical level which is a bubble spirit level and it is the referenced to the axis of telescope and attached with the tribrach. The horizontal sight line (Collimation) can be achieved only if the bubble is within the circle for the instrument. Auto level's eye piece should match with observer's proximity; it should be adjusted and according to the observer to bring the cross hairs in to sharp focus. This device contains linear bubble level.

Auto level has horizontal circle and one tangent screw which are replaced by markings at 90^0intervals, which leads for setting out of right angles. Focusing of telescope is done by the help of object focus screw which is on the right side of the device All instruments contains object focus screw and the eye piece of cross hair.

Attaching the instrument to the tripod:

The instrument can be centered by the tripod screw which is captive and rested on the movable bracket. To take tripod screw the device base plate or the trivet stage is threaded. To achieve a stable contact with the tripod head the three raised 'feet' are machined. At level tripod screw constitutes of a large head and is designed so that it can be tightened and easily undone by hand.

Adjusting the levelling head

The bubble tube should be so aligned that it will be parallel to two foot screws. The two foot screws should be rotated in opposite direction with facing the device, Either thumbs moving inwards or thumbs moving outwards in the direction of left thumb the bubble moves. The device is leveled on the axis only when the bubble is settled at the exact center. The bubble is aligned with respect to the third leveling screw by the rotation of the telescope by 90^0.When the bubble is at centre the auto level is said to be level, checking can be done through 90° of rotation. Re leveling of two foot screws and repeating the rotation can be done for necessary checking. The two sets of adjustments before leveling of the device and the bubble remaining in the centre of tube due to the rotation of the telescope may have to done.

Tripod's each leg can be easily adjustable with the length. By the help of lever clamp the legs are to be locked (left) or screw (right).it is important to check the locking of lever or the screw is tight or not after the legs is set to the correct length.

The device is to be set up again and all observations are to be taken again if the instrument height is changed due to the movement of legs during use. The tripod is to be set on the position and for sloping area two legs are to be on downhill side. By the change of length of each leg fine adjustments can be easily achievable. Always there should be surety to have the clamp or locking screw to be tight after the survey is finished. To keep the instrument at an exact point over the survey station the plumb rod is required.

2.5.3 METHOD OF USE

1. At the start of the project benchmark/datum is recorded since the primary measurement being recorded by the auto level is elevation.

2. The total length of the road section to be measured by tape to be surveyed.

3. The instrument is to be situated at the first station where the bench mark is visible, which establishes the elevation of the first point of the road section profile.

4. The auto level should be set up at the location on tripod with the help of plumb bob. Affix the auto level and level the tripod and auto level by adjusting first the tripod legs to get the bubble close to the 'level circle.' Fine leveling adjustments can be made using the leveling screws on the auto level.

5. The elevation at the horizontal line within the eyepiece should be determined. This will be foundation for future measurements. For future instrument elevation, set staff on the project datum (be sure your rod extends high enough so it is visible to the auto level).

6. At each 2.2 meter distance the staff should be placed for determination of elevation at the respective points.

7. The level difference is calculated from the previous point to the present point.

8. The slope for each interval is to be calculated by Slope=level difference/interval distance.

9. Avg. value of the slopes is to be calculated by Total summation of slopes/total no of sections.

10. The IRI (international roughness index) is determined which is the representation of road roughness, IRI=Avg. slope*1000

CHAPTER 3

DEVELOPMENT OF NEW DEVICE

(The details are being communicated for a technical paper for possible publication in a journal and hence are not covered in this chapter.)

CHAPTER 4

ANALYSIS OF RESULTS AND DISCUSSION

4.1 INTRODUCTION

This report gives the road roughness value in IRI scale by using three different kinds of instruments. The lists of instruments are as follows:

- Merlin
- Auto level
- New device

By the use of merlin and new device 10 roads inside NIT, Rourkela campus and 5 roads for auto level instrument inside NIT, Rourkela campus were conducted for the comparison between the instrument upon the basis of the roughness values in terms of IRI.

List of the roads used during experiments are listed below.

1. SAC to Hall Gate
2. Main Gate to Front Parking
3. Front Parking to Hall Gate
4. Temple Gate to Front Parking
5. Hall Gate to SAC
6. Library to SAC
7. Front parking to Temple Gate
8. Main Gate to Temple Gate
9. Temple Gate to SAC
10. LA Road

4.1.1 One of the readings from Merlin - Test no. 5 (Hall gate to SAC)

From chart

The value of D = 16 divisions [D= roughness on merlin scale]

= 16 * 5 mm [1 division = 5 mm]

= 80 mm [42<D<312]

Calculation of International Road Index (IRI)

IRI = 0.593 + 0.0471D = 0.593 + 0.0471*80

= 0.593 + 3.768 = 4.361 m/km [2.4<IRI<15.9]

Similarly readings were taken inside NIT, Rourkela campus for other 9 roads.

4.1.2 One of the readings from Auto level-Test no. 5 (Hall gate to SAC)

Table 4.1 One of the readings from Auto level-Test no. 5 (Hall gate to SAC)

Serial no.	Intervals in cm	Readings in cm	Difference	Slope
0	0	155.5	0	0
1	220	155.5	0	0
2	440	155	0.5	0.0025
3	660	154.2	0.8	0.004
4	880	153.6	0.6	0.003
5	1100	153.3	0.3	0.0015
6	1320	153.4	-0.1	-0.0005
7	1540	153.3	0.1	0.0005
8	1760	154	-0.7	-0.0035
9	1980	154	0	0
10	2200	154.8	-0.8	-0.004
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
191	42020	134.6	0.2	0.001
192	42240	134.5	0.1	0.0005
193	42460	134.1	0.4	0.002
194	42680	134	0.1	0.0005
195	42900	133.8	0.2	0.001
196	43120	133.6	0.2	0.001
197	43340	133.5	0.1	0.0005
198	43560	133.4	0.1	0.0005
199	43780	133.5	-0.1	-0.0005
200	44000	133.4	0.1	0.0005

Calculation

Total no. of readings = 200 Summation of slopes = 0.848

IRI = Avg. slope * 1000= (Summation of slopes/Total no. of readings)*1000

= (0.848/200)*1000 = 4.24 m/km

4.2 COMPARISION OF IRI VALUES

Table 4.2 COMPARISION OF IRI VALUES

Test no.	Section	IRI (m/km)		
		Merlin	Auto level	New device*
1	SAC to Hall Gate	4.361	4.167	
2	Main Gate to Front Parking	4.125	4.019	
3	Front Parking to Hall Gate	5.067	4.8	
4	Temple Gate to Front Parking	4.596	4.38	
5	Hall Gate to SAC	4.361	4.24	
6	Library to SAC	5.303	-	
7	Front parking to Temple Gate	4.596	-	
8	Main Gate to Temple Gate	3.89	-	
9	Temple Gate to SAC	5.538	-	
10	LA Road	6.009	-	

***** The results are being communicated for a technical paper for possible publication in a journal and hence are not covered in this table.

4.2.1 Merlin vs Auto level

Table 4.3 IRI reading Merlin vs Auto level

Test no.	Section	IRI (m/km)		Difference in reading	Error %	Avg. error %
		Merlin	Auto level			
1	SAC to Hall Gate	4.361	4.167	0.194	4.45	**3.95**
2	Main Gate to Front Parking	4.125	4.019	0.106	2.57	
3	Front Parking to Hall Gate	5.067	4.8	0.267	5.27	
4	Temple Gate to Front Parking	4.596	4.38	0.216	4.70	
5	Hall Gate to SAC	4.361	4.24	0.121	2.77	

4.3 DISCUSSION

All the experiments are carried on the roads inside NIT, Rourkela campus using Merlin, Auto level and new device. The three instruments gave the road's roughness values by different methods. Each method is considered for the respective instrument and the value of roughness was calculated. After the calculation of the roughness of the different section of road by three different instruments the value of roughness in terms of IRI was compared with the Merlin's roughness reading. After comparison with the merlin instrument the error % was calculated for auto level which is 3.95%. This error % calculated is very less and thus the instruments can be also used for the calculation of road's surface roughness. Merlin and auto level are the two instruments which are already available in the market. But new device is an indigenously fabricated/ developed device which can be used for the calculation of road's surface roughness.

The observations with the new device are not being covered here as the same are being communicated for a technical paper for possible publication in a journal.

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE

5.1 CONCLUSIONS

Merlin and auto levels are normally considered to be simple devices for measurement of road roughness. An attempt has been made in this study to design and develop a new device. Experiments have been carried out using this device and at the same time using other two types of equipments on the same road stretches. The results of the experiments on road roughness in terms of IRI using these three devices have been compared among the three methods considered. It is observed that auto level has an error% of 3.95% when compared with the IRI values obtained from merlin. All the three instruments have its unique importance in the calculation of the road roughness.

5.2 FUTURE SCOPE

It is proposed that the following works using this new device can be taken up in future.

1. A good number of experiments using these three experiments are to be conducted and the results to be statistically reviewed and compared.
2. The device is to be further modified to suit various roughness conditions.
3. The same stretches should be tested for roughness by using other roughness measuring methods such as bump integrator and RTRRM in order to establish the validity of this new setup.

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