PERFORMANCE STUDY OF FLEXIBLE PAVEMENTS: A SAMPLE STUDY

Ritesh.P

Department of Civil Engineering

National Institute of Technology Rourkela

PERFORMANCE STUDY OF FLEXIBLE PAVEMENTS: A SAMPLE STUDY

Thesis submitted in partial fulfillment of

the requirements of the degree of

Masters of Technology

in

Department of Civil Engineering

by

Ritesh.P

(Roll Number: 711CE3104)

based on research carried out under

the supervision of

Prof. Mahabir Panda

May, 2016

Department of Civil Engineering

National Institute of Technology Rourkela

DepartmentofCivilEngineering
NationalInstituteofTechnologyRourkela

May 31, 2016

Certificate of Examination

Roll Number: *711CE3104*

Name: *Ritesh.P*

Title of Dissertation: *PERFORMANCE STUDY OF FLEXIBLE PAVEMENTS:A SAMPLE STUDY*

We the below signed, after checking the dissertation mentioned above and the official record book (s) of the student, hereby state our approval of the dissertation submitted in partial fulfilment of the requirements of the degree of Doctor of Philosophy in Department of Civil Engineeringat National Institute of Technology Rourkela. We are satisfied with the volume, quality, correctness, and originality of the work.

Prof. Mahabir Panda
Principal Supervisor

DepartmentofCivilEngineering
NationalInstituteofTechnologyRourkela

Prof. Mahabir Panda
Professor

May 31, 2016

Supervisor's Certificate

This is to certify that the work presented in the dissertation entitled *PERFORMANCE STUDY OF FLEXIBLE PAVEMENTS: A SAMPLE STUDY*submitted by *Ritesh.P*, Roll Number 711CE3104, is a record of original research carried out by him under my supervision and guidance in partial fulfilment of the requirements of the degree of *Masters of Technology* in *Department of Civil Engineering*. Neither this thesis nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

Prof. Mahabir Panda

Dedication

This Thesis is dedicated to my beloved parents

Ritesh.P

Declaration of Originality

I, *Ritesh.P*, Roll Number *711CE3104*hereby declare that this dissertation entitled*PERFORMANCE STUDY OF FLEXIBLE PAVEMENTS: A SAMPLE STUDY* presents my original work carried out as a postgraduate student of NIT Rourkela and, to the best of my knowledge, contains no material previously published or written by another person, nor any material presented by me for the award of any degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the sections "Reference" or "Bibliography". I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

MAY 31, 2016

Ritesh.P NIT

Rourkela

Acknowledgments

First of all, I would like to express my sincere gratitude and respect to my project supervisor Prof. Mahabir Panda, Professor, department of civil engineering for his encouragement, valuable suggestions and support for successful completion of my project work. This thesis would not have been possible without his thorough guidance thorough out my study.

I am grateful to Prof. P.K Bhuyan, department of civil engineering and Prof.UjjalChattaraj, department of civil engineering for providing suggestions and advices throughout my course work. I am also thankful to Prof. S.K. Sahoo, HOD of civil engineering for providing necessary facilities required for my project work.

I am also thankful to all of my friends, my well-wishers who helped me to explore myself and extendedtheirsupport during my course work. I am also grateful to my mentors (Ph. D scholars) for their suggestions and immense support all along my thesis work.

I am also thankful to my mother and father who have encouraged mefrom time to time in all aspects of my life.

May 31, 2016 *Ritesh.P*

NIT Rourkela Roll Number: 711CE3104

Abstract

Pavements are major assets of highway infrastructure. In India, mostly the flexible pavements deteriorate faster than expected design life. Hence, there is a great need for pavement performance study. In this thesis, an attempt is made to study performance on pavements on sample basis. Performance indicators considered are International Roughness Index, Structural Number, traffic in terms of Equivalent single axle loads, Pavement Condition Index, and Characteristic deflection from Benkelman Beam test. In total, four sections are chosen to study the pavement performances. At first, merlin equations are calibrated and validated with respect to auto-level for calculating IRI, and then structural number is obtained with respect to layer coefficients and corresponding thicknesses of pavement layers. Rebound deflection is calculated from Benkelman. Traffic is calculated for three days and based on this; ESAL is obtained at all sections. Visual observations with simple measurements have been done to study pavement surface conditions to assess Pavement Condition Indices of corresponding sections at a particular point of time. Finally simple modelling has been done to relate functional performance with structural performance of sample pavement sections considered.

Keywords: Performance, International Roughness Index, Structural Number, Pavement Condition Indices. Characteristic deflection

Contents

Chapter 1: Introduction

1. 1 GENERAL

Road infrastructure is one of the transport infrastructures that play a prominent role in improving any area accessibility and movement of population as it provides door to door service. The road network in India accounts world's second largest which is widely spread across 30 states of the country. The road network has increased to 4.82 million km (considering all type of roads) from 2 million km that was in 1990s. It is observed that annually billions of rupees are lost to economy due to constraints of road quality and its capacity. Developing countries like India is now facing a challenge of preserving and enhancing transportation system infrastructure, so there is a need of planning and maintenance strategies.

In India mostly there are two types of pavement (i) Flexible pavement and (ii) Rigid pavement. This study limits only to flexible pavements. As, the funding available for pavement periodic maintenance and its management system is limited, there is great need for optimum and efficient maintenance and management of road network. Normally, flexible pavements are designed for 15-20 years but because of increase in traffic intensity, repetition of load, durability of various pavement conditions, unpredictable environmental factors, improper construction practices, lack of good quality materials, high tyre pressure, drainage, increase in axle loads, etc., flexible or bituminous pavements are showing early signs of distresses. This reduces performance of pavements. Hence there is a need to study the performance of flexible pavements.

The ability of road to serve traffic demands and change in environment parameters over its design life is called Performance and premature changes in performance indicators like distresses, roughness, etc. is called deterioration.

As Pavements deteriorates faster than its design life, there is a need for developing performance models so as to predict future condition of pavement. This predicted deterioration models play a major role both in project and network level. The overall facilities can be planned for estimating budget and materials with the help of these models. Transportation policies and proper scheduling of traffic, proper economic use of materials can be developed if there is accurate deterioration model. By performance parameters, we can interlink a dependency on infrastructure facility and traffic users like for example, we can impose a limitation on axle loads which is one of the sole causes of damage to pavement. These models help the pavement when it should get overlay so that the pavement can be free from further damage.

Pavement performance indicators considered in this study are International Roughness Index, Benkelman beam deflection, traffic, different distress studies, Structural number of pavement. Hence, both structural and functional evaluation of pavements is considered in this study.

` Roughness is the main parameter considered for functional evaluation of pavements. It is termed as unevenness of road surface along longitudinal direction or along direction of traffic. It covers road quality and vehicle operating cost. Its value gives an indication how much the road has deteriorated with respect to ride comfort. It is measured in terms of IRI which has SI unit of m/km. The higher the value the more discomfort, the road causes to passengers. In our study, roughness is calculated by merlin and has been validated with respect to readings taken from auto-level. Here, merlin equations for IRI based on auto-level are developed for both D>42 and D<42. Calibration equations are not provided for D less than 42. Here, in this study, the sections which are chosen to study the pavement performance, exhibited values of D <42. Attempt was made to obtain equation for lesser values of D, like choosing such sections at NIT Rourkela where roads have lesser D and thereafter at these sections, to find IRI, auto-level is used. Finally, calibrating both these values an equation is developed for D<42.

The main parameter that takes into account for structural strength of pavements is deflection of pavement which is determined by Benkelman beam in this study. The pavement which experiences continuously moving traffic will undergo some deformation at each wheel load application. When load is removed, it exhibits elastic recovery called rebound deflection. Repeated deflection may cause excessive flexural stresses induced which may result in permanent plastic deformation thereafter making pavement prone to fatigue or alligator cracking. Based on this characteristic deflection value, thickness of overlays can be determined provided there is traffic data. The primary purpose of calculating the deflection of an existing pavement is to obtain stress-strain properties of a pavement structure. That means the deflection should have an upper limit so that pavement can perform well. This deflection value is so important because many pavement design methods are based on serviceability-deflection criteria. In this study, modelling is done on prediction of pavement characteristic deflection considering as a function of IRI, traffic, and structural number. Benkelman beam deflection is calculated using IRC 81-1977.

The most important parameter considering pavement performance is pavement distress. There are different types of distresses like cracking (longitudinal, transverse, fatigue, edge, reflective, block), deformation (corrugation, rutting, depression, shoving, bumps), deterioration (delamination, potholes, patching, ravelling, stripping), mat problem (segregation and bleeding) and problems in seal coats. Based on the amount of severity present at each distress, ASTM D 6433 considers different graphs for different distresses to calculate deduct values for obtaining Pavement Condition Index. This ranges from 0 to 100 where 0 represents weakest pavement and 100 as strongest pavement. These amounts of severities are calculated by field survey. PCI is calculated using ASTM D 6433. In this study, four sections are chosen to calculate pavement condition index. Effort is made to check how this value is changing over time. Due to lack of time, in total at a section two readings are taken by giving a gap of six months.

Structural number indicates strength of the pavement layers and of the total structure of pavement. This is derived by adding each layer coefficient multiplied by layer thickness. In order to determine layer coefficients, CBR of different courses of pavement are calculated so that they can be interpolated by AASHTO method. Drainage coefficients depends on quality of drainage facility and per cent of time in the year the pavement would normally be exposed to moisture levels that causes saturation (depends on average rainfall and prevailing drainage conditions at site) Tables are given to calculate the coefficients. Modified structural number is calculated using CBR value of subgrade. Structural number helps to determine no of equivalent single axle loads the pavement can take. Here, in this study modelling is done to correlate modified structural number as a function of pavement characteristic deflection obtained by non-destructive method i. e Benkelman-beam method.

Traffic varies from season to season, year to year which in turn finds difficulty in predicting. Because of in reliability of traffic prediction, the pavement performance goes down. In this study, traffic is calculated for 3 days at the time of field observations that took place. It is assumed a growth percentage of 7.5% for all mixed traffic. This traffic is used to calculate Equivalent single Axle loads. Finally, this value is used in modelling of some pavement sections.

In-situ tests like sand replacement method, Benkelman beam test are conducted. Pavement temperature is calculated using glycerol and thermometer. Samples of different layers are taken from trial pits so as to calculate pavement layer thicknesses and make tests in the laboratory. Different tests include modified proctor test, California Bearing Ratio test, liquid limit, plastic limit, grading, etc.

1. 2NEED FOR THE STUDY

The roads of the country are showing early signs of distress after each monsoon. This is leading to heavy loss on maintenance and also resulting in poor riding quality, prone to accident, and speed reduction. The factors causing deterioration of roads are so complex to understand and they vary from one place to another. Hence, there is a need to study the different pavement performance indicators like roughness, traffic, deflection, etc. mechanism on a regular basis, say for six months. In this study, readings are taken only two times at a section.

1. 3 OBJECTIVES OF THE STUDY

The main objectives of this study are the following:

i. To collect data on the performance of roads including the road inventory data.
ii. To conduct traffic volume study and study axle load pattern.
iii. To conduct functional and structural evaluation of the pavement sections in respect of sustainability of the concerned pavements.
iv. Evaluation of structural number of pavements.
v. To establish relationships of pavement deterioration with traffic growth with due consideration of independent variables/parameters.

1. 4 SCOPE OF THE STUDY

The scope of works covers the following:

i. Selection of pavement sections under different traffic, different pavement thickness and pavement crust conditions including up gradation ones.
ii. Collection of road inventory data of selected pavement sections.
iii. Collecting performance data in respect of identified parameters.
iv. Analysis of collected data and development of models to predict the performance of road pavements to establish sustainability.

First chapter gives introduction to the current topic i.e. Performance study of flexible pavements.

Second Chapter gives the previous work done on the empirical studies and literature review on pavement performance parameters.

Third chapter comprises of several experiments conducted in several locations. Experiments are done to study the properties of pavement performance indicators.

Fourth chapter gives the results obtained from laboratory studies. These results include modelling done on different pavement performance parameters.

Fifth Chapter gives the summary and conclusions of the work done.

Chapter 2: Literature review

2. 1 GENERAL

Pavement performance is change in its state with respect to as it was at the time of construction. It gives an idea whether the pavement is able to carry traffic and satisfy according to environmental conditions during its design life. The road network is getting overstressed as a result of gradual increase in traffic. This results in performance failure. If it fails to carry the design loads, then it is structural type and it is a functional type if it doesn't provide a smooth riding surface. This uneven surface not only cause discomfort to traffic but also increases operating cost of vehicles. (Thube et al. 2008)

2. 2 DETERIORATION MECHANISM OF FLEXIBLE PAVEMENTS

The repeated effects of vehicular loads, different characteristics of traffic and its composition with its loading, traffic volume, change in environmental and surrounding conditions, some maintenance related activities with time changes both structural and functional capacity of pavement. So, the main cause of pavement failure is combination of environment with unpredicted value of traffic with unreliability of loading. Accumulation of cracking or distresses is called deterioration and it is termed as failure when it can't serve any further traffic. Deterioration patterns show the same trend irrespective of place. The factors that cause failure to the pavements include cracking like alligator, longitudinal, transverse, block; rutting along wheel paths and roughness along longitudinal profile. These are also termed as distresses of flexible pavements. The amount of distress gives a value or an indication to the overall pavement condition. Different distress modes occur independently and so the models which we have to plan should be based on whether it is of load type or non-load type. (Gedafa D S, 2007)

Many factors that cause pavement deterioration are interlinked to each other. So, the factors responsible for this deterioration can be shown as follows:

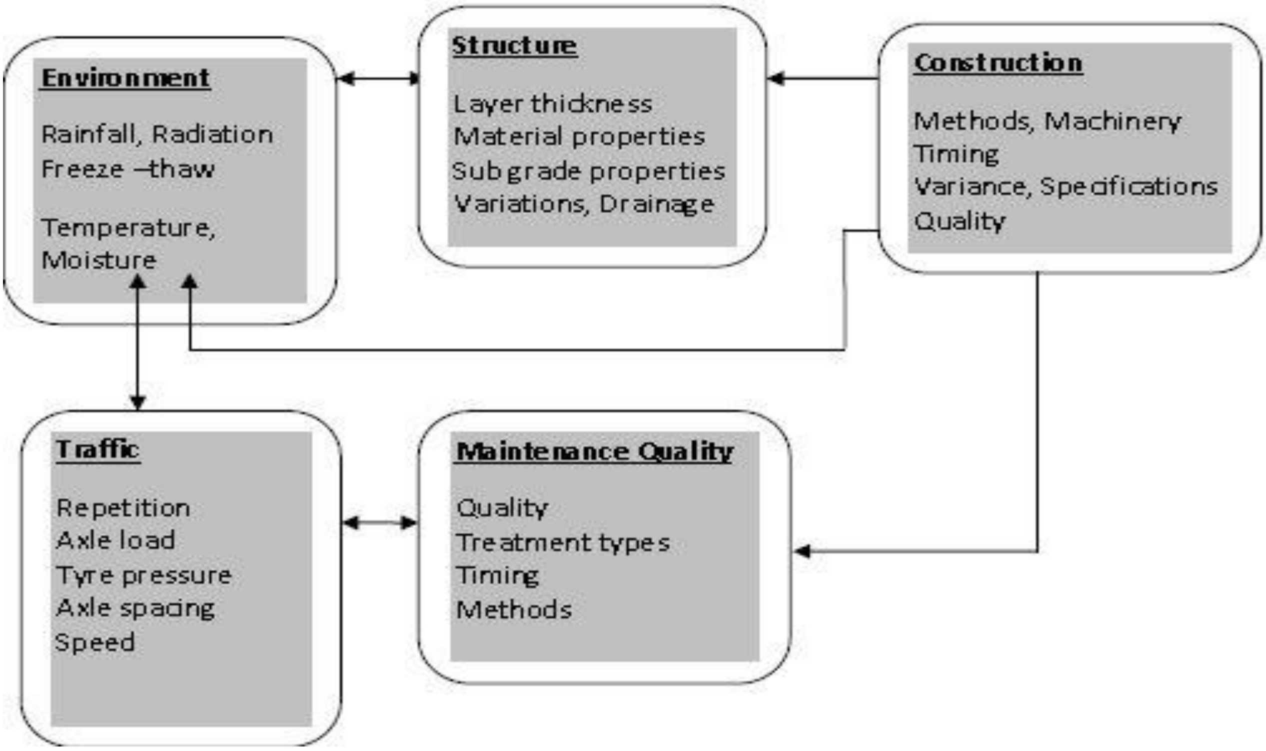

Figure 1: Factors influencing Pavement Performance (Gedafa D S, 2007)

2. 3 PERFORMANCE EVALUATION OF PAVEMENTS

It is necessary to find out how pavements and its materials response under repeated axle loads of traffic in order to have more durable pavements in future. It has been observed that deterioration of pavements is minimal during initial stage after construction like 2-3 years and this progress at a larger rate during its late years. For performance evaluation the first task is to identify different factors that cause damage. The main factors that many researchers adopted are pavement strength (structural number), traffic loading, environmental conditions, and subgrade support. Mainly evaluation is carried out using three criteria (i) Roughness of pavements (ii) Pavement distress or surface condition of pavements (iii) Pavement deflection, here in our study deflection is carried out by Benkelman beam test. Many researchers termed different terms to describe pavement condition. (Thube et al.2005)

i. Present Serviceability Index: It is an index where it ranges from 0 to 5, 0 being the weak pavement and 5 being the strongest. Its value is given by set of panel members where they consider all the parameters. It can also be calculated using slope variance and amount of cracking and patching done in pavements.

ii. Present Serviceability: This is a term that is used to describe whether pavement is able to cope with present traffic and environment.

iii. Performance Index: It gives the summary of PSI that changes over a period of time and so it is represented as area under PSI versus time curve.

iv. Pavement Condition Index: It ranges from 0 to 100. 100 being rhe best and 0 worst. It is calculated using ASTM D 6433. This value is found from deduction curves which in turn depend on amount of severity of distresses present.(AASHO, 1993)

2. 4 Pavement performance models Scenario

Yoder (1966) stated that pavement deflection which occurs due to many factors; is one of the main cause which effects pavement performance. He stated permissible deflection varies with stiffness of pavement and with difference in pavement materials. He has also calculated pavement stresses and strains under controlled loading conditions by assuming viscoelastic behaviour of pavements.

Collop and Cebon(1995) reported a whole-life performance model (WLPPM). Thismodel is capable of making deterministic pavement damage predictions resulting fromrealistic traffic and environmental loading. Realistic predictions of pavement degradationwith traffic has been obtained by taking into account most of the primary factors ofvehicle/pavement interaction. Simulation by WLPPM shows that short- wave lengthsurface – roughness components can be smoothed out, and traffic loading increases theamplitude of long wave length components.

Sebaaly et al. (1996) developed a pavement performance model for bituminous concrete overlays at Nevada. The aim is to predict pavement behaviour under combined influence of environment and traffic. The performance index taken here is Present Serviceability Index for long term pavement performance.

Fujiezhouet al. (2002) developed, calibrated, and validated pavement performance prediction models for the Texas mechanistic-empirical flexible pavement design system. This report proposed many models for crack initiation and propagation for different distresses. VESYS rutting model was recommended for predicting flexible pavement layer rutting where its validation of field data is done by repeated load test. McGhee (2002) developed and implemented Pavement Condition Index for Virginia department of transportation. ItIncluded indices to describe load and non-load related distresses and pavement longitudinal and cross-slope information including rutting and ride quality. Pavement types to be included in index development were flexible (asphalt), rigid (concrete), and composite (a combination of asphalt and concrete).

Chai (2000) conducted preliminary optimization of HDM-4 at North South Expressway in Malaysia for studying parameters that effect pavement performance. He found that the factors which effect the deterioration are roughness, age and environmental data. He has not chosen material properties of pavement.

Bose et al. (2005) conducted studies on distresses that occur prematurely and also failure of bituminous pavements. After five case studies which he has taken, it is reported that cause is due to improper sub surface drainage and aggregate getting stripped. Later Mariaa et al. (2005) in the same year studied the effect of bond that effect performance of flexible pavements. It was concludes that life of the pavement gets reduced by 80% if there is a poor bond between base and binder course. Aggarwal et al. (2005) has given an overall picture of the problems of road networks in developing countries, which are rapid traffic growth, inadequate funding for maintenance and upkeep, lack of skilled man power, attitude towards maintenance etc. Thube et al.(2005) critically reviewed the maintenance management strategy for low volume roads in India and stressed the need for development of pavement distress data base, deteriorationmodels, optimal investment and maintenance strategy and highlighted the need for a suitable national level policy regarding paving of unpaved low volume roads in India. Reddy et al. (2005) developed flexible pavement preservation framework for an integrated asset management. In this study methodology integrates pavement condition data management, pavement performance and its standards to generate pavement preservation program. Riding Comfort Index (RCI) has been established to determine the preservation needs. Various maintenance management tools were derived as part of this study

Masad et al. (2006) reported a study to compare effect of wheel loads to deflection of pavements that occur at surface. He has done by finite element method considering isotropic and later it was found that tensile stresses which got induced at lower regions of bituminous layer are higher than those predicted. So the pavement can’t be treated as isotropic while doing analysis. Salama et al. (2006) studied relative damaging effect of different type or configuration of truck traffic. Studies on different distresses are done like both crack initiations and propagations. It was shown that multiple axles create more damage compared to single and tandem axles. Bayomy et al. (2006) analysed long-term pavement performance for the Idaho general pavement sections and specific pavement sections. The research investigated into the use of the data to develop models that enable the prediction of the seasonal variation effects on the pavement materials (soils and asphalt mixes). Models were developed based on analysis of national data for the subgrade and asphalt concrete moduli.

Mathew et al. (2008) developed deterioration models for ravelling initiation and progression, pothole progression, roughness progression and edge failure using neural network and regression techniques. The ANN models were compared and found to be more suitable to the rural roads as compared with the conventional empirical statistical models.

Gedafa et al. (2010) presented a methodology for the estimation of flexible pavementsremaining service life by using the surface deflection data. Models were developed usingnonlinear regression procedure in the Statistical Analysis Software and Solver inMicrosoft Excel. This study reported a sigmoidal relationship between remaining servicelife and central deflection. Kumar et al. (2010) developed deterioration prediction models for deflection androughness of 17 road sections in Uttarakhand, using Artificial Neural Network (ANN) and linear regression. Pavement Serviceability Rating (PSR) and Riding Comfort Index (RCI) were worked out based on visual inspections of the test sections.

Sreedevi et al.(2011) conducted Field performance indicators for NRMB in a tropical setting. Pavement performance indicators for road sections constructed using Natural Rubber Modified Bitumen and Ordinary bitumen operating under identical conditions has been derived from periodic field data collection and analysis. Study on decision support system for performance based maintenance management of highway pavements was done by Muralikrishna and Veeraragavan (2011). Deterioration models were developed for deflection progression and roughness progression. One set of data was used for the validation process, done by chi-square test. Markussvensson et al. (2011) has modelled pavement performance prediction, based on rutting and cracking data. The aim of this project is to develop prediction models for flexible pavement structures for initiation and propagation of fatigue cracks in the bound layers, and rutting for the whole structure. A statistical approach has been used for the modelling where both cracking and rutting are related to traffic data, climate conditions, the subgrade characteristics as well as the pavement structure.

Subagio et al. (2013) has conducted a case study on structural and functional performance in Indonesia. The research evaluates the Structural and Functional performance of National Road (PANTURA) located in the North Java's Corridor. Two methods were used in this evaluation, BinaMarga's (CASE STUDY section of Jalan Kaliurang, MALANG)method and the AASHTO-93 method. The BinaMarga's (Pavement condition value ranges from 0 to 7)method focused on the evaluation of the Functional Performance, while the AASHTO-93 method was used to analyse the Structural Condition. Some parameters considered are: IRI, PSI while in the Structural analysis the SN (Structural Number) was used.

Harold (2014) considered structural factors of flexible pavements for initial evaluation of the sps-1 experiment. This project relates structural property of pavement with materials used in pavement construction. Different tests were conducted on subgrade, unbound granular base, asphalt treated base, asphaltsurface, etc. so as to account for the correct reason for deterioration of pavement. It also discusses different methodologies to analyse field data.

2.5 CRITICAL REVIEW OF LITERATURE AND MOTIVATION FOR RESEARCH

The factors that are mostly responsible for deterioration of pavements are vehicular loading, traffic, drainage, environmental factors, adhesive property of bitumen, etc. Different studies have used different indices to calculate pavement conditions like RCI, PSI, PCI, PSR, etc. For pavements to perform satisfactorily, it is necessarily important to satisfy functional and structural conditions. Functional analysis includes IRI whereas structural analysis includes rebound deflection.

Chapter 3: Empirical Observations: Data Collection

In this chapter, a detailed explanation of several experiments that are conducted both on field and laboratory are given. In this study, a total of 4 sections are chosen in such a way that they differ each from intensity of traffic, pavement material composition, different terrain, etc. Models are developed based on these sections details and are shown in chapter 4.

3.1 Field Data Collection and Laboratory Investigations

Data collection has ranged from visual observations to the use of 8.16KN axle load truck to measure surface deflection, unevenness by merlin, field density by sand replacement method, distress studies, traffic flow with axle load surveys, and laboratory tests like compaction, CBR, Gradation, etc.

The data include:

i. Inventory of study sections.
ii. Pavement shoulder condition.
iii. Pavement distress studies or surface deflection.
iv. Unevenness of pavement using MERLIN.
v. Characteristic deflection using Benkelman beam as per IRC 81, 1997.
vi. Traffic studies for 3 days.
vii. Pavement layer composition from in-situ trial pits and sample is obtained for further study of its properties.
viii. In-situ density of sub-base and base course by sand replacement method.
ix. Laboratory investigation on subgrade, sub-base, base properties which mainly include CBR.

3. 1. 1 Inventory details of Study Sections

i. Four sections were chosen from sites close to Rourkela. Length of each section is chosen as 500m.
   Details of sections are not presented here for publication purposes.

Figure 2: Trial pit and Sand replacement method in progress.

ii. **Rainfall data**: Average rainfall data in these sections from previous year studies have rainfall less than 1300mm. This information will be helpful both for surface drainage characteristics and also for finding characteristic deflection.

iii. **Temperature**: Field temperature is calculated using glycerol and thermometer.

iv. Shoulder condition is checked whether it is good or not.

Details of traffic data are not presented here for publication purposes.

3. 2 Roughness Survey

Roughness gives an idea about functional performance of pavement. Roughness is expressed in terms of convenient index that gives comfort to traffic user while accessing roads of any given profile while travelling. Both surface distresses and profile have influence on ride comfort. There are many indices to measure roughness like Bump Integrator value, MERLIN index, Unevenness Index, International Roughness Index. The standard index followed across world for determining roughness is IRI. This IRI can be calibrated for different instruments. (IRC, SP 16)

3. 2. 1 Roughness Measuring Instrument

There are different experimental setups to use roughness. They include Rod and level Survey, Dipstick Profiler, Profilo-graphs, Response type road roughness meters, MERLIN, fifth wheel Bump indicator (Indian practice), Profiling devices, etc. (Internet Source)

Here, in this study roughness is measured by both merlin and auto-level (rod and level survey).

3. 2. 2 THE MERLIN

It is an instrument that is developed to measure longitudinal road profile. The readings are taken graphically. With less estimation in error, merlin roughness index can be converted into IRI. It is widely used because of its simplicity, easy to work and handle. It is not suitable for calculating roughness at long stretches as it is slow and manually done.

The device is called MERLIN-Machine for Evaluating Roughness using Low-cost instrumentation. (TRL Report 229, 1996)

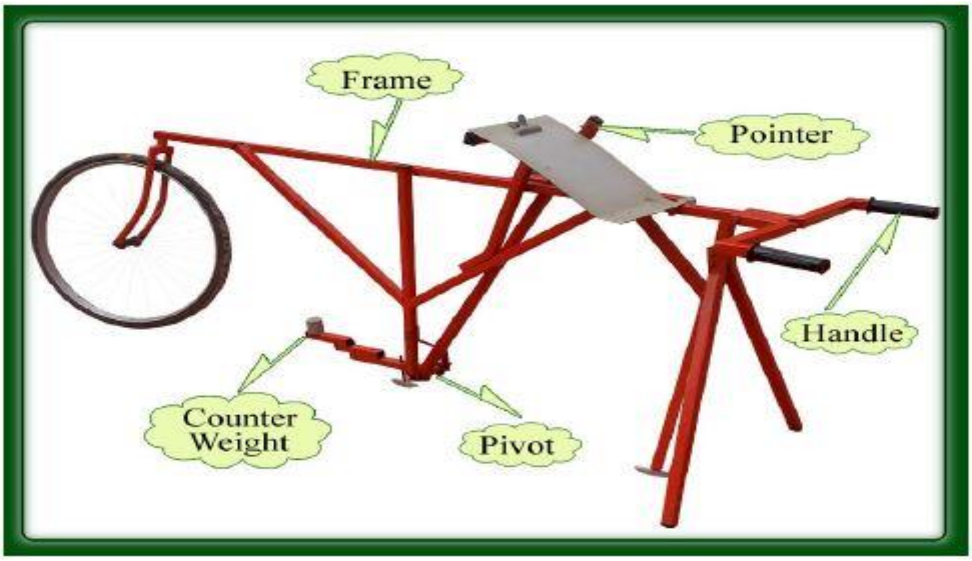

Figure 3: The MERLIN (Kumar et al. 2008)

Merlin consists of front and rear legs where it can rest on pavement surface along with probe at half the midway. The device is 1.8m separated. With reference to imaginary line between front and rear foot, the position of probe which can be above or below the line and this gives mid-chord deviation. The probe goes up or down relative to the imaginary line joining front and rear foot. The probe moves because of counter weight located at same side and at the end of probe there is a hinge where it connects with moving arm. A moving arm has a pointer that is attached to chart. For each position, we have to mark a cross in chart provides where the arm points. The pointer movement depends on mid chord deviation exhibited by probe.(TRL Report 229, 1996)

Figure 4: MERLIN Readings at site

3. 2. 3 Method of use

Initially, before starting the experiment all the front feet, rear feet and probe is levelled to same level. The level of probe is adjusted using turnscrew. Place Merlin chart at plank available at top and mark the mid position of chart. Now the pointer of moving arm should point the midpoint of chart. As, the circumference of front wheel is 2.25m so readings are taken at every multiple intervals of 2. 25m. In total, 200 readings are to be taken so as to cover 450m. At each point, the position of pointer with a cross in a suitable section is carried out by administrator. For further system of estimations, the merlin's handle is rolled forward and heading towards and rehashed. To have a note on number of cross done till yet, there is a tally box provided at extreme left corner. The chart is removed after 200 observations. The distribution of marks or cross on chart gives roughness on road. Depending on movement of pints, the graph is scattered. We now consider 90% of the points in the chart that means eliminating 5% points on both top and bottom side

3. 2. 4 CALIBRATION EQUATIONS

The IRI scale and the Merlin scale are related by the following equation for all type of pavement surface:

IRI (in m/km) =0. 593+0. 0471D, 42 > D > 312 (2. 4> IRI > 15. 9)

D=roughness in Merlin scale measured in mm(TRL Report 229, 1996)

3.3 AUTO-LEVEL (ROD AND LEVEL SURVEY)

Roughness measured by this method is very accurate. This method is generally preferred when survey stretch is small. Auto-level is an automatic operated optical instrument that helps in establishing or checking any point in horizontal planes. It is used as it involves only two people, one to focus the auto-level and other to hold the staff. These levels set up quickly as so it become easy to operate. (FHWA, 2008)

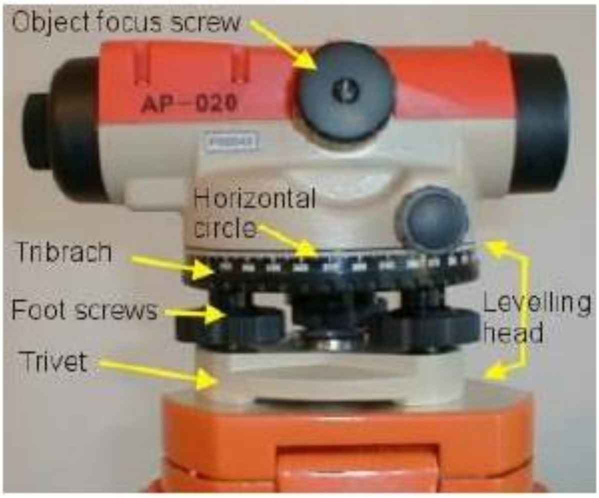

Figure 5: Auto- level.(Punmia, 2012)

3.3.1 General Description

It consists of tripod, auto level and staff to take readings. After setting up the instrument, the height of any station is found after knowing the height of collimation or instrument height by measuring the plane with the help of staff. Height of instrument is obtained by choosing a reference point called bench mark. The levelling head consists of 3 parts (i) A tribach or top plate that carries spirit level, (ii) Foot screws, (iii) Trivet or foot plate that is attached with tripod head. (Punmia, 2012)

The steps followed before starting the experiment are as given below:

i. Attaching the instrument or auto-level to tripod.
ii. Adjusting the levelling head with the help of foot screws.

3.3.2 Method of use

(i) At start of the project, choose a datum/benchmark.

(ii) To get accurate results fix a scale of 1m to the staff so that readings can be taken in millimetres.

(iii) The length of the road section to be surveyed is measured.

(iv) The auto level is set up at location in such a way that benchmark is visible. Affix the auto-level and level it by adjusting it with levelling screws such that the bubble comes to middle called level circle.

(v) The elevation of bench mark on its horizontal plane is determined with the help of eyepiece. Further readings at a regular interval of 2. 25m distance should be determined.

(vi) Level difference is calculated from previous to present point.

(vii) Slope can be calculated for each interval by slope=level difference/interval distance.

(viii) Average slope is calculated by modulus of summation of all slopes divided by total no. of sections. (FHWA, 2008)

The IRI (International Roughness Index) is finally determined by IRI=avg. slope*1000

(ix) If auto-level readings are taken along any gradient roads, then slope is calculated as ((present reading –previous reading) - (difference in level as per gradient)) /interval length(Sayers 1996)

Figure 6: Auto-level readings at site.

Here in this study, Roughness is found from MERLIN for those four sections. Later it was found that some merlin roughness index value has a value less than 42. So, some sections where D<42, in NIT Rourkela are chosen. At those sections both merlin and auto-level tests are conducted. Now having D value and IRI value from auto-level, value of IRI for D<42 are calibrated.

3. 4 Benkelman beam Studies

A. C Benkelman devised this simple deflection beam for measuring deflection at pavement surface. This test is done by ‘IRC: 81-1997’ which has title ‘Guidelines for Strengthening of Flexible Road Pavements using Benkelman Beam Deflection Technique’. This study governs structural performance of pavements. Structural capacity is the amount of traffic or equivalent axle loads the pavement before it reaches its terminal serviceability value. It is widely used in India because of its simplicity, reliability and as it is a Non-Destructive test. But for more accurate results, destructive tests like falling weight deflectometer are used. (IRC, 1997)

Flexible pavements performance is more or less related to recovery or elastic deformation that occurs under wheel loads. More the recovery, more the performance. The elastic deflection depends upon many factors like pavement temperature at surface, quality and thickness of different pavement courses, subgrade soil and its type, amount of compactive effort used, drainage conditions, etc. (Yoder, 1966)

3. 4. 1 Benkelman Beam

Benkelman Beam consists of a beam that is slender in nature which is 3.66m long. It is pivoted at a distance of 2.44m from the tip or probe. So, the beam is divided into two parts in the ratio 2: 1. Dial gauge is attached at rear end to measure deflection under wheel load. The whole beam should be able to enclose in a casing (or locking device) so as to secure beam while it is shifted to new site. It consists of an adjusted supported leg at the pivot so as to rest in the ground. The beam is levelled by using turn screws and mercury level placed at rear part of the beam. To conduct this test a truck with suitable tyre pressure and tyre load, glycerol and thermometer, information regarding annual rainfall, etc. is required. (IRC, 1997)

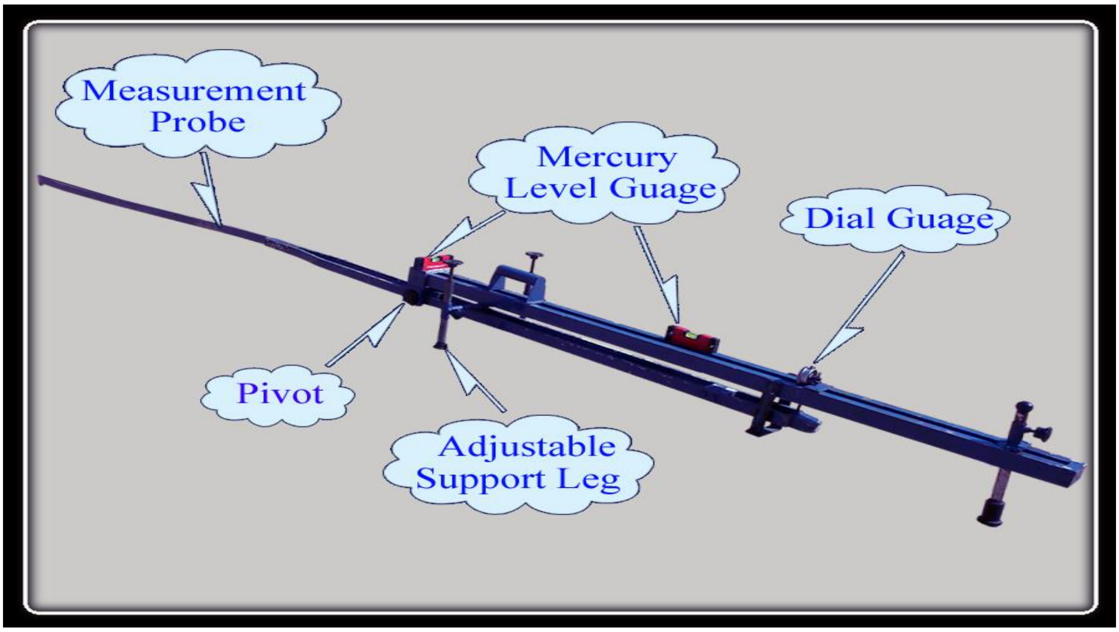

Figure 7: Benkelman Beam apparatus. (NPTEL, 2013)

3. 4. 2Method of use.

i. Before starting the experiment, standard truck must have a rear axle load of 8170kg and is equally distributed on two dual tyre wheels. The tyre is inflated to a pressure of 5. 60kg/cm2. A tolerance of +/-1% and +/-5% can be allowed for load and pressure.

ii. The Benkelman Beam is calibrated to check whether both beam and dial gauge are properly working or not.

iii. Initially, points are marked where readings are to be taken. In this study which covers 500m stretch, 20 points (both left and right wheel path) are chosen having Chainage 0, 50, 100, ………450, 475, 425, ………75, 25m respectively.

iv. The distance of measurement points in the transverse direction should be as follow:

Table1: Distance from pavement edge where Benkelman readings should be taken.

Lane width	Distance from edge of pavement
<3. 5m	0. 6m
>3. 5 m	0. 9m
For divided four lane highway	1. 5m

v. The truck is slowly made to move and made to stop at left wheel path initially and it is centrally placed at first point (Chainage: 0m) so as to measure deflection.

vi. The beams is levelled using mercury level and turn screws.

vii. The tip or probe is inserted between the gaps provided by dual wheels. The tip must touch the surface where deflection is to be measured.

viii. Reading is noted from dial gauge and this is termed as initial dial gauge reading denoted by Do.

ix. The truck is moved slowly to a further distance of 2. 7m from that point and made to stop. The reading which is termed as intermediate dial gauge reading (D_i) is noted through dial gauge.

x. The truck is further moved at a distance of 9m from the study point and final dial gauge reading (D_f) is noted.

xi. These three set of readings correspond to one deflection point or study point. Further, the truck is moved to another study point (Chainage: 50m) and readings are taken with the procedure discussed above.

xii. The temperature of the pavement is noted with the use of glycerol and thermometer.

Figure 8: BBD survey in progress and probe location

Rebound deflection (D) at any point is given by:

- If D_i-D_f<= 0. 025mm, D is given as 2 (D_o-D_f)
- D_i-D_f>=2. 5 divisions of dial gauge or 0. 025mm, then D is given as:

  D=2 (D_o-D_f) + (2*k* (D_i-D_f)) where value of K=2. 91

xiii. **Correction for pavement temperature**: Correction must be made if the pavement temperature differs from 35^0c. Correction is given by 0. 01 (35-T).

So, correction is positive if temperature is less than 35^0c and negative if temperature is greater than 35^0c.

xiv. **Correction for Seasonal variations**: Correction for seasonal variation depends on subgrade soil type, moisture content at field of subgrade, average rainfall in the area. The moisture correction factors were obtained from charts provided from IRC: 81-1997.

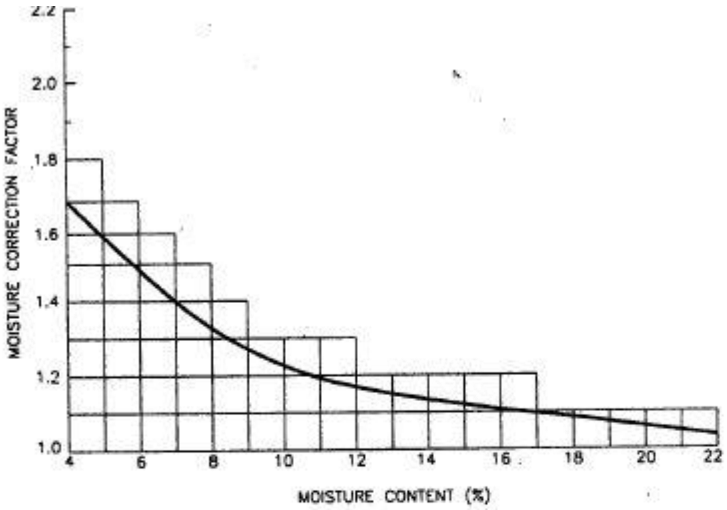

Figure 9: Moisture correction factors for annual rainfall<1300mm and PI<15 for Clayey soils (IRC, 1997)

xv. Limits of deflection values are shown in table below and are as per IRC code.

Table2: limits of Benkelman Beam deflection values (IRC, 1997)

Rebound Deflection(mm)	Strength of Pavement
0.5-1	Reasonably strong
1-2	Moderate
2-3	Weak
>3	Very Weak(permanent deformation)

xvi. Characteristic deflection is calculated as follows:

- Mean of rebound deflections at every study point is calculated
- Standard deviation of rebound deflection is calculated.

Finally, characteristic deflection is given as,

D'= (mean + D + temp correction+2*deviation) *seasonal correction factor.

3. 5 Structural Number

Structural number which was once called "Thickness Index" was developed by American Association of State Highway Officials (AASHO) road tests. It indicates strength of the pavement. It is calculated as per AASHTO guide for design of pavement structures. When strength of subgrade is also taken into account then it is termed as Modified Structural Number (MSN). MSN depends on CBR value of subgrade as AASHO has conducted tests on uniform subgrade soils. (AASHTO, 1993)

Pavement structural number gives an indication of layer thickness and layer materials and is given by, $SN=a_1D_1+a_2D_2m_2+a_3D_3m_3+\ldots$ (AASHTO, 1993)

Where,

$a_1, a_2, a_3..$ are layer coefficients of surface, base and sub-base course

$D_1, D_2, D_3..$ are respective thickness of pavement layers

$m_2, m_3, \ldots$ are drainage coefficient of drainage layers.

Determination of Layer Coefficients: This layer coefficient depends on how individual layer contributes towards performance of pavement. So, this value is different for different pavement materials used. AASHO has developed graphs to directly calculate layer coefficients values provided if we know any of the following (i) CBR (ii) Resilient Modulus (3) Reliability value of the pavement. There are different graphs for different conditions like for cement treated bases, bituminous treated bases, unbound bases, unbound sub-bases, etc. In this study the coefficient is found from CBR value (un-soaked) and all the sections are unbound bases and sub-bases. Below is a sample graph that is used to find layer coefficient. (AASHTO, 1993)

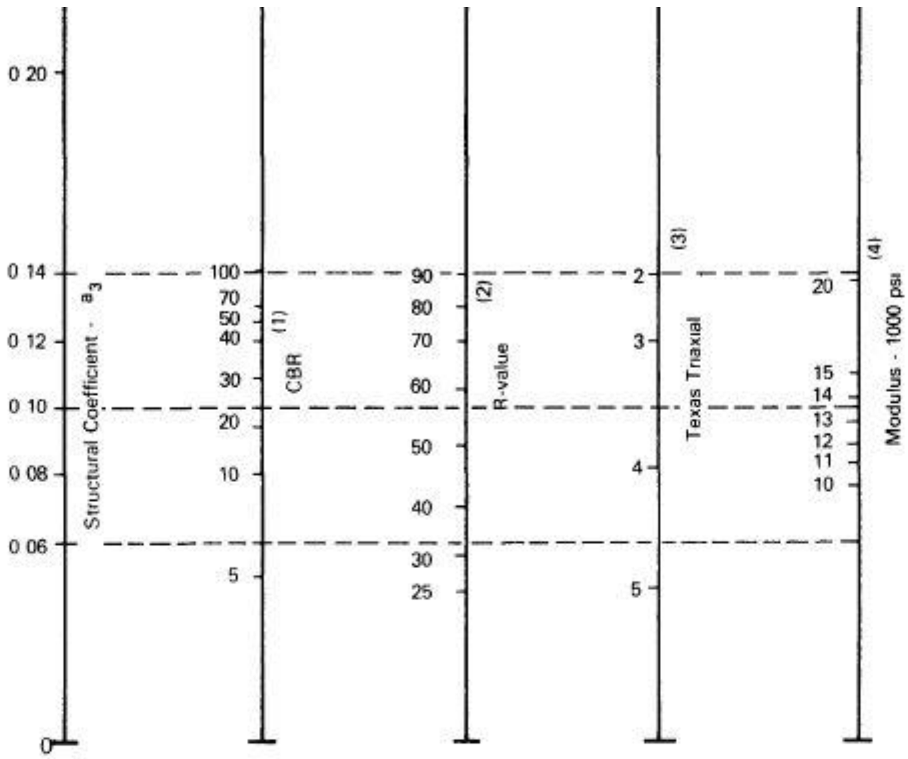

Figure 10: Variation of Granular Sub-base layer coefficient(AASHTO, 1993)

Determination of drainage coefficient:

This depends on quality of drainage facility and per-cent of time in a year the pavement will experience moisture saturation level**.** AASHTO guide has developed table to find this value and is presented below:

Table 3: Recommended drainage coefficients for base and sub-base courses (AASHTO, 1993)

	Percent of time pavement is approaching Saturation			
Drainage Quality	<1%	1-5%	5-25%	>25%
Excellent	1.4-1.35	1.35-1.3	1.2-1.2	1.2
Good	1.35-1.25	1.25-1.15	1.15-1	1
Fair	1.25-1.15	1.15-1.05	1-0.8	0.8
Poor	1.15-1.05	1.05-0.8	0.8-0.6	0.6
Very poor	1.05-0.95	0.95-0.75	0.75-0.4	0.4

In sections that we have taken under study, we assume drainage coefficients as 1 as it can be assumed 5-25% time the pavement has approached saturation and good drainage quality.

Determination of Modified Structural Number:

Structural number doesn't include strength of subgrade. In order to include subgrade strength of various subgrade soils, a contribution in terms of CBR value of subgrade is used and so modified structural number is given as: (AASHTO, 1993)

$$MSN=SN+3.51*\log_{10}(CBRs) -0.85*(\log_{10}CBRs)^2-1.43$$

Where, CBRs= California Bearing Ratio of the Subgrade.

3. 6 Pavement Surface Condition

Study of pavement surfaces helps in developing Pavement Condition Index. In this study, for evaluation of PCI, ASTM D 6433 method is followed. PCI is an indicator of present condition of pavement which is directly related to pavement surface operational condition. PCI ranges from 0 to 100, 100 representing very good condition and 0 representing worst condition. PCI value gives an idea to public work officials about current condition of pavement and rate of deterioration of road network. Deduct value method is used to find value of PCI.

Table4 : Maintenance intervention based on PCI(Handbook of Highway Engineers, 2001)

PCI	Rating	Type of Maintenance
80-100	Very Good	Preventive
60-80	Good	Resurfacing
40-60	Fair	Overlay
20-40	Poor	Strengthening
<20	Very Poor	Rehabilitation

3. 6. 1 Method of Use

i. The pavement section under study is divided into sample units of 25m length.
ii. Surface inventory is done on each sample unit. Inventory includes noting down severity levels (low, medium, high) of different distresses present.
iii. The density is computed after finding severity levels.
iv. As per ASTM D 6433, for each distress type and for each severity level deduction curves are present from where deduct value is obtained. Distress density is the amount of distress present divided by sample unit area taken for bituminous pavement. Deduct values have a range from 0 to 100.
v. The individual deduct values are added to get Total deduct value.
vi. Correction curves are used to determine the Corrected deduct value from total deduct value. The correction curves used vary by q (no. Of deduct value>5) values.
vii. After finding corrected deduct value, PCI is evaluated as PCI=100-CDV.
viii. Similarly PCI for all other sample units is calculated and final PCI is computed by taking average of all PCI values.

Severity values of different distresses are presented below:

Table 5: Severity values of each distress (ASTM, 2008)

Sl. No	Distress type	Unit of measurement		Severity	
			Low (exp)	Med (exp)	High (exp)
1	Alligator Cracking	Sq. metre	<6mm	6-19mm	>19mm
2	Longitudinal Cracking	Metres	<10mm	10-75mm	>75mm
3	Transverse cracking	Metres	<10mm	10-75mm	>75mm
4	Patch	millimetres	<6mm	6-12mm	>12mm
4	Rutting	Millimetre	6-13mm	13-25mm	>25mm
5	Block cracking	Sq. metre	<6mm	6-19mm	>19mm
6	Ravelling	Sq. metre	Loss of	<10%	>10%
7	Edge cracking	Metres	<6mm	6-19mm	>19mm
8	Depression	Millimetre	13-25mm	25-50mm	>50mm
9	Bleeding	Sq. metre	As per	D 6433	
10	Bumps and sags	Millimetre	13-25mm	25-50mm	>50
11	Lane shoulder drop off	Sq. metre	25-50 mm	50-100mm	>100mm

Some sample deduction curves are given below:

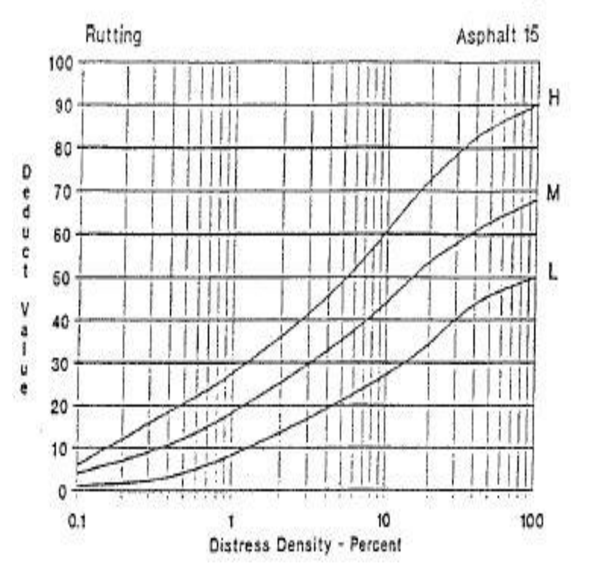

Figure 11: Deduction curve for rutting (ASTM, 2008)

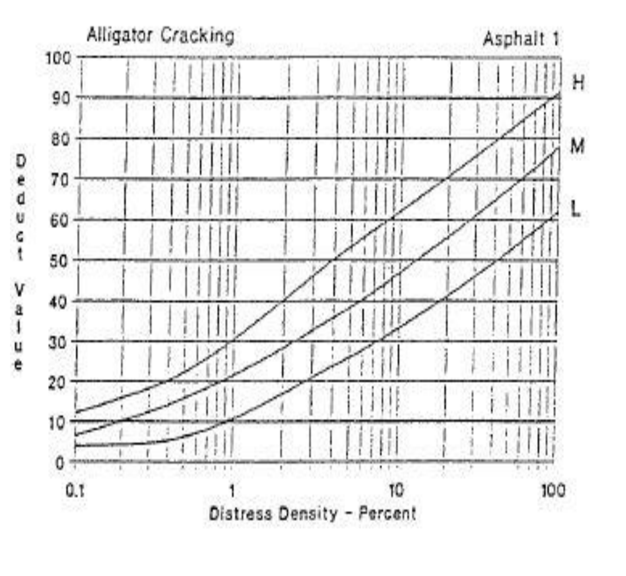

Figure 12 :Deduction curve for Alligator Cracking (ASTM, 2008)

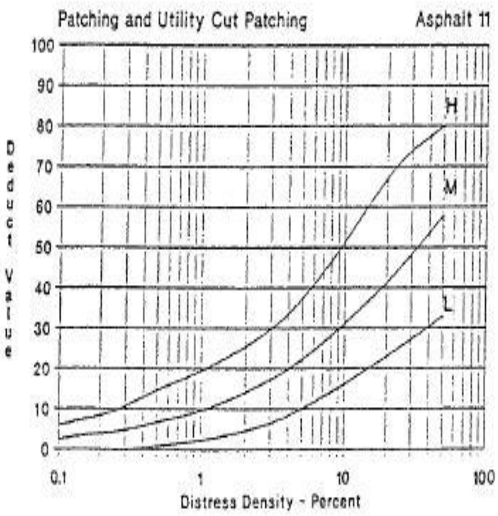

Figure 13: Deduction curve for patching (ASTM, 2008)

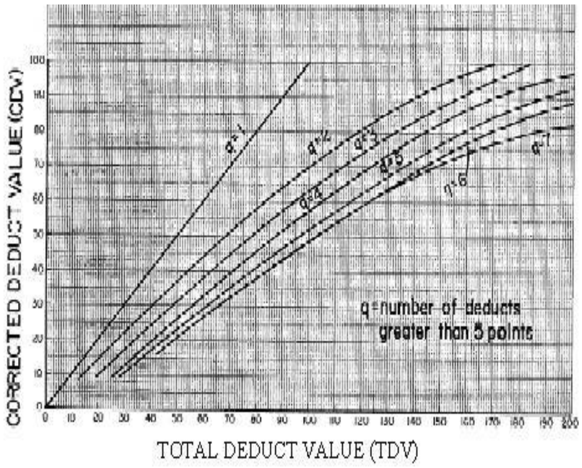

Figure 14: Corrected Deduct value curve.(ASTM, 2008)

3. 7 California Bearing Ratio

This test is performed as per IS 2720 (part 16) -1987. It is the ratio of force per cross sectional area of specimen that is required so as to penetrate a soil mass with standard circular plunger of diameter 50mm at the rate of 1.25mm/min to that required for the corresponding penetration of a standard material. Tests are conducted on both disturbed and remoulded soils. In this study, CBR (both soaked and unsoaked) is found for disturbed subgrade, sub-base and base. The steps involved for this test are given below: (IS 2720, 1987)

i. The material passing 19mm IS sieve should be used in remoulded specimen. Balancing the material for larger material is done by equal amount of material that passes 19mm IS Sieve and retained on 4.75mm IS Sieve.
ii. The soil is mixed with water (optimum moisture content) which is determined from Modified proctor test as per IS 2720 (part 8) -1983. Normally the sample mass weigh 4.5 kg for fine grained soils and 5.5kg for coarse grained soils.
iii. The empty mould is weighed and is filled with soil in 5 layers with 25 tamping for each layer.
iv. The mould is placed in water bath for four days in soaking tank (if test conducted for unsoaked samples, ignore this step).

v. The specimen is placed under the loading machine which has capacity of at least 5000kg and is equipped with movable head or base. A surcharge weight is placed on top of it. Before loading the specimen, it is ensured that the dial gauge tip should be in contact with the specimen. Readings are noted from proving ring. Different proving rings have different calibration equations.

vi. The load is applied and penetration values are noted.

vii. Finally, CBR is found for both 2. 5mm and 5mm penetrations. If $CBR_{2.5} < CBR_5$ then test is repeated.

viii. Normally CBR value is determined at 2. 5mm penetration. CBR is given by (Load required for sample to penetrate 2. 5mm) / (standard load required for same penetration) *100.

Calibration equation used here is shown below: (Proving Ring Specification)

Load (in KN) = (0. 1089*proving ring reading) +0. 3575 (for 100KN-12267)

Load (in KN) = (0. 0678*proving ring reading) +0. 0015 (for 50KN-02396)

Standard load for 2.5mm penetration is 1370kg and for 5mm penetration is 2055kg.

3. 8 Optimum Moisture Content

This test is done as per IS 2720 (part 8) -1983. Steps involved to carry this test are:

i. 5kg sample of air dried soil passing 19mm IS Sieve is taken and then it is mixed with some amount of water. The mould with a baseplate attached is weighed.

ii. In our study for GSB and WMM Modified Proctor, it is compacted in 5 layers with each of 55 blows. Compaction is done by 4. 5kg rammer with 31cm fall.

iii. After compaction total sample is weighed.

iv. This test is repeated till total sample weight decreases from previous value.

v. Some amount of soil mass is takenand is placed in oven for 24 hours to determine water content.

vi. A graph is plotted between dry density vs water content. Peak value of density gives maximum dry density and corresponding value for water is optimum moisture content.

Figure 15: Mould and Rammer(IS 2720, 1983)

3. 9 Liquid and Plastic limit test

The liquid and plastic limit test is determined as per IS 2720 (Part 5) -1985. Soil conducted for these tests must pass 425 micron sieve. Liquid limit test is conducted by Cassagandre apparatus and plastic limit test by rolling a thread of diameter 3mm. These values (plasticity index) are required to calculate seasonal correction factor which is used to calculate characteristic deflection by Benkelman-beam method.

Chapter 4: Analysis of Data, Results and Discussions

In this chapter, analysis of data is done. The results that are observed are international roughness index (by both merlin and auto-level) , traffic studies, Benkelman-beam deflection, structural number, California bearing ratio, optimum moisture content, liquid and plastic limit of subgrade. Later, modelling is done on these performance indicators.

4. 1 MERLIN

By the use of MERLIN, an attempt was made to determine IRI at four sections (1A, 2A, 3A, 4A) which were stated above. It is calculated for both left and wheel paths.

The MERLIN Roughness Index is as follows:

Details of test results are not presented here for publication purposes.

Clearly, most of the values are having MERLIN Roughness Index (D) < 42. Merlin calibration equations are valid only for D >42.

In order to find correlation between D and IRI by auto-level, some sections are chosen at NIT Rourkela. Some sections are found to have D>42 and some D<42.

Details of auto level and merlin data for IRI are not presented here for publication purposes.

4. 2 BENKELMAN BEAM RESULTS

By use of Benkelman-beam, characteristic deflection is obtained for all sections that arechosen.

For calculating characteristic deflection, plastic and liquid limit of soil is required.

Plastic and liquid limit of soil subgrade is as follows:

Details of test results are not presented here for publication purposes.

4. 3 Traffic Data Calculation

As present data of traffic is available (shown above), we can estimate number of equivalent standard axle loads the pavement has experienced till yet. Assumption is done on traffic growth rate. It is taken as 7. 5%. One of the readings how ESAL is estimated is given below. A per IRC 37, 2012 for the pavement which experiences commercial vehicles between (500-1500, vehicle damage factor is taken as 3.5 provided the section is plain.

Details of test results are not presented here for publication purposes.

4. 4 Structural Number

Layer coefficients of pavement courses are obtained by Soaked CBR values as per AASHTO that is discussed above. Surface and binder course are assumed to have layer coefficient of 0. 39.

Details of test results are not presented here for publication purposes.

4. 5 Pavement Condition Index

For calculating pavement condition Index, we should first calculate the amount and type of severity present in each type of distress. PCI values are shown below. The severities like low, medium and high should be calculated on percentage of pavement section.

Details of test results are not presented here for publication purposes.

4.6 Pavement Performance Modelling

Factors considered in pavement performance modelling are structural number, traffic in ESAL (in msa), IRI and characteristic deflection obtained from Benkelman-beam test. Linear and non-linear regression analysis is done on observed values. Here, in our study the reliability of regression model is measured by its goodness of fit, which is represented in terms of coefficient of correlation (R^2 value).

4.6.1 Relationship between IRI, Structural Number and ESAL.

Details of test results are not presented here for publication purposes.

4. 6. 3. Relationship between Deflection, IRI and ESAL.

Details of test results are not presented here for publication purposes.

Chapter 5: Summary and Conclusions

In this study, experiments are conducted in four sections close to Rourkela.to study the pavement performance of flexible pavements. It includes study of variation of International roughness Index, Benkelman beam deflection, Pavement distress study, etc. with time. The experimental setup for the selected sections is discussed in above chapter.

It is seen that MERLIN equations are calibrated and validated for D>42 and D<42. The results of the experiments on road roughness in terms of IRI using these two (auto level and merlin) have been compared and it is observed that auto level has small error when compared with values obtained by merlin. International Roughness Index values at all these sections are low even after 3-5 years of construction. This means pavement is functionally performing well.

Modelling is done on pavement performance indicators. IRI is modelled as a function of ESAL and structural number. Characteristic deflection is modelled as a function of SN and ESAL. Coefficient of correlation (R^2 value) is within permissible limits.

5.2 FUTURE SCOPE

i. A good number of experiments can be conducted to calculate IRI by both auto level and MERLIN and can be compared.
ii. Pavement Condition should be monitored every six months so as to understand factors effecting pavement performance.
iii. Crack initiation and propagation models can be developed after having pavement distress data which is taken every six months.
iv. A number of sections with different material properties should be considered for predicting Pavement performance.

REFERENCES:

[1] AASHTO (1993), 'AASHTO Guide for design of pavement structures', AmericanAssociation of State Highway & Transportation Officials, Washington, D C.

[2] Aggarwal S, Jain S S and Parida M (2002), 'A critical Appraisal of pavementmanagement system', Journal of the Indian Roads Congress, Volume 63-2, 327 –403.

[3] Cundill, M.A. (1996). “The Merlin Road Roughness Machine: User Guide”, ResearchReport 229, Transport Research Laboratory (TRL), Berkshire, United Kingdom.

[4] E. Spangler and W. Kelly, "GMR Road Profilometer - A Method for Measuring Road Profile." Highway Research Record 121, Highway Research Board, 1966.

[5] Bose S, Sridhar R, Kamaraj C, Sharma G and Kumar G (2005), ‘Investigation ofmoisture damage to bituminous pavement and effect on field performance – casestudies', Journal of Indian Road Congress, 66 (3), Paper No. 517, 438 – 449

[6] Gedafa D S (2007), 'Performance prediction and maintenance of flexible pavement', Proc. Mid-continent transportation research symposium, Ames, Iowa

[7] Gedafa D S, Hossain M and Miller R (2010), 'Estimation of remaining service life offlexible pavements from surface deflections', Journal of Transportation Engineering,@ ASCE, 342 - 352.

[8] Gupta A, Kumar P and Rastogi R (2011), 'Pavement deterioration and maintenancemodel for low volume roads', International Journal of Pavement Research andTechnology, Volume 4, 195-202.

[9] ASTM D 6433 (2007) ‘Standard Practice forRoads and Parking Lots Pavement Condition Index’.

[10] IRC 81 (1997), ‘Guidelines for strengthening of Flexible pavements using Benkelman Beam Deflection Technique’, Indian Roads Congress

[11] IS 2720 part 16 (1987), ‘Indian Standard methods of test for soil’, Laboratory determination of California Bearing Ratio.

[12] IS 2720 part 8 (1987), ‘Indian Standard methods of test for soil’, Determination of water content-dry density relation using heavy compaction.

[13] IRC 37 (2011), 'Guidelines for the design of Flexible pavements', Indian RoadsCongress’.

[14]Kumar P, Chandra S and Said M D S (2010), 'Performance Study of PMGSY Roads',Indian Highways, 47-57.

[15] MORT&H (2004), ‘Guidelines for maintenance management of primary, secondaryand urban roads’, Indian Roads Congress.

[16] B.C.Punmia (2012), ‘Principles of Surveying’.

[17] Nagakumar and Veeraragavan A (2000), ‘Effect of climatic and traffic factors onflexible pavement response, an overview,’ Journal of Indian Roads Congress, 112-141.

[18] Long Term Pavement Management, Informational Management SystemsDatabase, Federal Highway Administration

[19] Salt G and Stevens D (2004), 'Pavement Performance Prediction- Determination andCalibration of Structural Capacity (SNP)', Report.

[20] Turki I, Obedat S and Homoud A S (1996), Development of Models of PavementCharacteristics on Pavement Condition’, Journal of Indian Roads Congress, Volume57-1, 201-219.140. Udayakumar L, Robert

[21] Al-Omari and M.I. Darter. Effects of Pavement Deterioration Types on IRIand Rehabilitation. In Transportation Research Record 1505, TRB, NationalResearch Council, Washington, D.C., 1995, pp. 5'7-65