Pavement Surface Unevenness Evaluation

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***Abstract*: The Research offers with the degree and assessment of the unevenness and texture of street pavements, it turned into resolved a way to determine asphalt floor circumstance, for example, unpleasantness and a knock with rushing up predicted on a automobile hub. In the primary place, we gauged growing pace on a automobile pivot at some dimensions of automobile pace to determine the relationship among the quickening and the velocity, from which the circumstance for institutionalizing the quickening with the velocity turned into set up. Next, for the assessment of asphalt surface unevenness in an undertaking level, the connection was made between the standard deviation and IRI at each 20 m long segment. The asphalt surface unevenness could be sensibly assessed by the connection. Likewise, a measure of a knock could be assessed quantitatively from the pinnacle estimation of quickening and the speed. Moreover, in a system level, the strategy was created to assess the asphalt surface unevenness of various kinds of street in a similar list.**

***Keywords*: Skid Resistance, Benkelman Beam, Bump Integrator.**

Introduction

The increasing traffic intensity, high tire pressure, increasing axle loads etc are causing early signs of distress to bituminous pavements throughout the world. The deterioration of the paved roads in tropical and subtropical countries differ from those in the more temperate regions of the world. This can be due to the harsh climatic conditions and sometimes due to the lack of good pavement materials and construction practices.

Pavement performance can be defined as the ability of the road to meet the demands of traffic and environment during its design life. The reduction in the performance level of the pavement with time is termed as deterioration. Flexible pavements deteriorate due to many factors, predominantly traffic, climate, material, construction quality and time. These multiple parameters make the process very complex. The condition of the road at any time can be predicted approximately using performance models.

For managing the transport infrastructure system, prediction and modelling of their performance are the main inputs as well as major challenges. The predicted deterioration play major roles at both network level and project level. The overall facilities can be planned for justifying the budget and resources with help of deterioration models. The planning and scheduling of the maintenance work for individual project is dependent on the time at which the section becomes deficient in service. This can be predicted through accurate deterioration models. Development of appropriate transportation policy and evaluation of the economic impacts also depend on the performance and interplay between the infrastructure facility and its user (traffic). One such example is the imposition of axle load limits, which is responsible for the damage of the pavement at exponential rates.

Lack of necessary maintenance results in deterioration of the pavement, which in turn cause damage to the vehicles and higher fuel consumption, thereby increasing the vehicle operating (VOC) and user costs. To ensure an acceptable level of service, comfort and safety on these roads, road maintenance activities are very essential. Also, for increasing the life of the pavement, timely and appropriate maintenance is very essential. In this context, by understanding the performance of the pavement accurately has great significance. Performance prediction of flexible pavements is an essential activity in the design of flexible pavement overlays, can be used to develop appropriate strategies, and improved design methodologies. Also a developing country like India is now facing the challenge of preserving and enhancing its transportation system infrastructure within limited budget allocation. So, prioritization of roads is required for planning optimum Maintenance and Rehabilitation (M&R) strategies.

Efficient management of the road infrastructure can be achieved by predicting their performance accurately. Since the deterioration and performance of the pavements depend on multiple factors like traffic, climate, environment, construction quality, age, etc., the process is very complex. Many researchers all over the world have developed performance prediction models applicable for particular set of conditions. But these models require more generalisation to have accurate and comprehensive predictive ability.

Scope and limitation of study

To fulfil the above objectives, the scope of the study was set to two parts. In the first part, study of the strength parameters of urban roads with respect to different subgrade soil properties were attempted using one time data collected from 44 road stretches divided into 68 homogeneous sections distributed in five Municipal Corporations in Uttar Pradesh. The field data include structural and functional condition of the pavement, inventory, traffic and drainage characteristics. In the second part of the study, performance evaluation of 8 road stretches representing NH, SH and MDR located in different geographical settings was attempted using time series data collected from the field to develop deterioration models.

OBJECTIVES OF THE STUDY

The broad aim of the study is to evaluate the performance of in-service roads in terms of reliability, surface condition, structural failure and safety with respect to the strength of the pavement layers and subgrade soil properties and develop relationships and models for prediction. Towards achieving this aim, the objectives of this research work have been formulated as given below:

i. Evaluate the structural and functional condition of the study stretches.
ii. Study the condition of pavements under different soil conditions in Uttar Pradesh.

iii. Develop correlation between the strength of the pavement with subgrade soil properties and pavement condition.
iv. Study the periodic performance of the study roads.
v. Review the models available for predicting the pavement condition.
vi. Develop models to predict the performance of flexible pavements and compare the same with models developed using other techniques.
vii. Calibrate HDM-4 to Uttar Pradesh conditions.
viii. Compare the different overlay strategies and select the most feasible option.
ix. Develop models to predict the Riding Comfort and Skid Resistance of the pavement to support timely intervention.

Theory of Pavement

The Pavement effecting is mostly defined by evaluation in the following categories:

- Skid Resistance
- Deflection
- Roughness
- Surface Distress

SKID RESISTANCE

The basic function of a pavement is to extend smooth and safe surface for the as the resistance offered by the surface of the pavement against skidding of vehicle.

DEFLECTION

The amount of pavement deflection under a wheel load is the measure of the structural stability of the pavement system. For weaker sections, higher value of deflection is shown. From the data obtained through field investigations conducted with Benkelman Beam. Pavement deforms elastically under the wheel load application. It regains to the original state when the load is released. This deflection is called elastic deflection or rebound deflection. In pavement evaluation, deflection measured is rebound deflection. The amount of deflection measured under a wheel load is a measure of structural stability of the pavement system. Higher deflection values indicate weaker pavement structure, which may require higher overlay thickness or early strengthening.

Even though deflection is not a measure of pavement deterioration, it influences the rate of pavement deterioration. Performance and life of the flexible pavements are closely related to rebound deflection under the wheel loads. Hence, it is important to predict the deflection value. The magnitude of deflection or the elastic rebound of a flexible pavement due to a wheel load depends on the structural stability of the pavement system and also on the magnitude of the load. The rate of change of deflection depends on the initial deflection, strength of the pavement, vehicle loading etc**.**

Roughness

Pavement Roughness is generally defined as an expression of is irregularities in the pavement surface that skeptically effect the ride quality of a vehicle.

The serviceability of a pavement is largely a function of its unevenness, which is represented as IRI values internationally. This is also represented in terms of mm per kilometre and measured using the Bump Integrator. The roughness values on the study stretches were measured from the field studies.

REVIEW OF LITERATURE

Performance of pavement can be generally defined as to the change in their condition or function with respect to age. It can also be indicative of the ability of a pavement to carry the intended traffic and satisfy the environment during the design life, both functionally and structurally. With the increased economic and development activities inIndia, the traffic has increased multi fold during the last 3 decades resulting in the overstressing of road network. The development of higher stresses leads to performance failure of the pavements. If the pavements fail to carry the design loads satisfactorily, then the failure is of structural type. It is of functional type, if the pavement does not provide a smooth riding surface. The uneven surface not only causes discomfort, but also increases the Vehicle Operating Cost (VOC), thus influencing the overall transportation cost. This chapter gives a broad outline of the importance of pavement performance evaluation, type of models, applications of performance models in other countries for their Pavement Management System and the research studies carried out so far.

Juang and Amirkhanian, (1992) documented the findings of a study carried out on the use of Pavement Management System (PMS) in the United States. A model using fuzzy logic for a PMS based on priority ranking was developed. The Unified Pavement Distress Index (UPDI) was also created, and it was used to measure the pavement's distress state. Guidelines for grading six distinct forms of distresses, weights for the various sorts of distresses, and fuzzy set representation, fuzzy mathematics and the definition of UPDI and its use in pavement database were given by this approach.

Collop and Cebon. (1995) reported a whole-life performance model (WLPPM). This model is capable of making deterministic pavement damage predictions resulting from realistic traffic and environmental loading. Realistic predictions of pavement degradation with traffic has been obtained by taking into account most of the primary factors of vehicle/pavement interaction Simulation by WLPPM shows that short- wave length surface - roughness components can be smoothed out, and traffic loading increases the amplitude of long wave length components.

The PMS of the Nevada Department of Transportation developed a total of 16 PPMs to cover the most frequent rehabilitation and maintenance actions used in all Nevada districts. The aims of these models are to predict the performance of flexible pavement sections under the combined influence of traffic and environment. These models use traffic, environment, materials and hot-mix asphalt data along with actual performance data, which is measured by the PSI. for predicting the long-term performance of pavement sections with application of rehabilitation and maintenance programs. In the Nevada PMS, a typical performance model for bituminous concrete overlays was formulated (Sehaaly et al 1996, 1999).

Roddy et al. (1999) collected extensive data on performance of in service flexible highway pements on NH & SH over a period of 10 years for development of indigenousdeterioration models. The deterioration prediction models were validated and used to predict the performance of different highway pavements during their design life. Computer programs were developed which can be used by the practicing engineers to select the best overlay strategy, among different combinations of overlay and thickness,. The program to evaluate the beat everlay strategy based on the developed deterioration models were applied to a project level management of NH section in Tamil Nadu.

Nagakumar al (2000) critically reviewed the various factors contribute to the use equations the prediction pavement temperature also examined. The deflection spreadability decreases with temperature and the thermal gradient asignificant bowl parametersThe relationship between number of repetitions of traffic wheel loads and strains both in the laboratory and in service pavements and certain aspects of predictionof pavement life were reviewed.

Reddy and Veeraragavan (2001) developed model for the network level management of flexible pavements. priority-ranking module developed which can provide a systematic procedure to prioritize road pavement sections for improvement and select suitable maintenance strategies depending upon the budget. This was based on priority index concept. Opinion survey and experience of experts were used to find out pavement distresses and weightages

Satyakumar and Kumar (2004) has conducted a study for certain major roads in Thiruvananthapuram to develop a methodology for priority ranking using composite criteria. The road stretches were selected on the basis of user response. Functional evaluations of the stretches were done to determine the crack area, percentage of potholes, present serviceability rating and unevenness index. Based on the result of the functional evaluation, expert opinion was again collected to rank the pavements for priority maintenance. The mean rating of the expert was found out and compared with user opinion. From the study it was concluded that user opinion varies but not to large extent with the expert opinion. Considering the vast number of roads in our country user opinion can be used for initial ranking and thus narrowed down to the one, which require immediate attention, and experts can concentrate on the selected roads in detail and develop better strategy.

Reddy et al (2004) highlighted in his paper that IRC guidelines for strengthening of road pavements using Benkelman Beam technique are based on limited experience in India gathered during the sixties and seventies and has little relevance to the present day traffic and axle load. Though overlay design methods using falling Weight Deflectometer and Deflectograph are accurate and scientific, they are costly and require skilled manpower/.

. Each pavement layer was characterized by a co-efficient of lateral stress, which is similar to the commonly used co-efficient of lateral earth pressure (k). Several instrumented test sections were established and studied to determine coefficients of lateral stresses for common paving materials. A closed form solution based on the central limit theorem of probability is presented which can be used for predicting stresses within pavement structures. It is also applicable to multilayered structures.

Bassam et al (2005) examined the effect of quality of subgrade and base and base thickness on the mechanical response of conventional flexible pavement foundation to dynamic traffic loading by using a three dimensional, implicit dynamic finite element method. ADINA. From this study, it was found that quality of subgrade and base and thickness of base have remarkable impact on rutting strains but in the case of fatigue strains, subgrade quality has a little impact.

Bose et al (2005) reported the studies conducted on premature distress and failure of bituminous pavements. Five case histories of failure of bituminous pavements due to moisture induced damage was reported as due to improper sub-surface drainage and stripping type of aggregate. Use of course graded and permeable granular sub base with fines less than 5% and addition of lime as filler in bituminous mixes reduce the premature failure due to moisture induced damage.

Materials and Method

This chapter was described on the methodology use to carryout this research work. It provide the information about the strategy analysis, programme analysis, Project analysis and approaches to data collection.

HIGHWAY DEVELOPMENT AND MANAGEMENT SOFTWARE

Highway Development and Management Software (HDM-4) is an effective tool, which can be used for the analysis of different alternatives for management of highways (**Morosiuk et al.**, 2002). This facilitates make comparison of cost estimates and economic evaluations of different construction and maintenance options. Different time- staging alternatives also can be evaluated, for a given road project on a specific alignmentor for groups of links on an entire network.

Applications: The applications of HDM-4 are Strategy Analysis, ProgrammeAnalysis and Project Analysis.

a) **Strategy Analysis:** Strategy analysis deals with entire networks or sub-networks managed by one road organisation. In this module, a chosen network can be analyzed as a whole to prepare medium or long term planning of investments. Different scenarios of road development can be analyzed.

Typical applications of strategy analysis are**:**

(a) Forecasting of funding requirements on medium and long term basis for predefined road maintenance standards and targets.

(b) Forecasting pavement performance under varying levels of funding on a longterm basis.

(c) Optimum allocation of funds according to defined budget heads such as routine maintenance, periodic maintenance and budgets.

(d) Optimum allocations of funds to sub-networks. This can be allocated byfunctional road class (main, feeder and urban roads etc.), administrative regionetc.

(e) Policy studies also can be done. This includes impact of changes to the axle load limit, energy balance analysis, provision of NMT facilities, sustainable road network size, pavement maintenance standards, evaluation of pavement design standards, etc.

b)

c) Programme analysis: The prioritization of a defined list of road projects into a one- year or multi-year work programme with defined budget allocations can be done in the programme analysis module. The major difference between strategy analysis and programme analysis is in the physical identification of road links and sections. Programme analysis deals with individual links and sections, which are unique physical units identifiable from the road network throughout the analysis. This can also be usedto prepare a multi-year rolling programme, within the resource constraints. Incremental NPV/cost ratio is used as the ranking index, which provides an efficient and robustindex for prioritization purposes. Also, it satisfies the objective of maximizing economic benefits for each additional unit of expenditure proposed.

d) Project analysis: One or more road projects or investment options are analyzed in Project Analysis. A road link or section with user-selected treatments, with associated costs and benefits, projected annually over the analysis period can be analyzed. For different investment options, economic indicators are determined. Project analysis allows the users to assess the physical, functional and economic feasibility of specified project alternatives by comparison against a base case (do nothing). The key parametersare structural performance of Pavement, prediction of Life cycle costs, deterioration, Maintenance effects & costs, Road user costs & benefits and Economic evaluation of project alternatives.

HDM-4 applies the concept of a road network matrix to predict the medium to longterm requirements of an entire road network or sub-network. This consists of a road network matrix with categories of the roads defined according to the key attributes that has influence on the performance of pavements and road user costs. The users candefine the road network matrix to represent the most important factors affecting transportation costs in the area. The road network matrix can be categorized accordingto Pavement types, Pavement condition, Traffic volume or loading and Environment or climatic zones.

HDM-4 Modules:

The three analysis tools (Strategy, Programme and Project) work on the data defined by one of the four data managers namely Road Network, Vehicle Fleet, Road Works and HDM Configuration.

The Road Network module contains the physical characteristics of road sections in a network or sub-network, which will be analysed. It provides the basic facilities for storingdata of one or more road sections. The users can define the networks and sub-networks, and road sections, and it is the fundamental unit of analysis. Sections, Links and Nodesare the data entities provided within the road network.

The Road Works module defines maintenance and improvement standards, along with their unit costs. This will be applied to different road sections to be analysed. Also, the standards defined in the Road Works Standards folder can be used in any of the three analysis tools namely Project analysis, Programme analysis or Strategy analysis**.**

Procedure for Project Analysis:

1. The road project to be analyzed is created by giving it a title. Specify the roadnetwork to be analyzed.

2. General information about the project is specified and the project is defined.Define the method of analysis and Road sections to be analyzed.

3. The maintenance and improvement standards proposed for each selected roadsection is provided. Then go to Set-up and run the analysis.

4. The reports are generated and if necessary, print the required outputs.

Alternative Maintenance Strategies: The most recent definition of preventive maintenance by AASHTO Standing Committee on Highway states that preventive maintenance is “A planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional conditions of the system without increasing structural capacity”. For adopting different Maintenance options, various Maintenanceand Rehabilitation Works Data is to be collected.

Serviceability Levels for Maintenance: [MORT&H, 2004] Serviceability levelsfor maintenance is a qualitative rating of the effectiveness of a highway in terms ofoperating conditions such as traffic volume, speed, comfort and safety. The maintenance program can be divided into three levels, level 1, 2 and 3 for maintenance purposes. Level 1is the desired level that provides for highest level of comfort, convenience and safety. Level2 is the level to which the road deteriorates from Level 1 after two-three years of use beforefresh maintenance is implemented. Level 3 represents the minimum level necessary to protect the investment and provide reasonable levels of safety.

Economic Analysis: The 'Committee for Maintenance Norms for Roads in India', (2001), has recommended the total costs for carrying out various types of maintenanceand rehabilitation (M&R) works on bituminous pavements situated in various price zones of the country. The economic indicators such as Net Present Value (NPV) and Internal Rate of Return (IRR) are also provided for comparison purposes.

Table : Serviceability Levels for Maintenance

Sl.No	Serviceability Indicator	Serviceability Levels		
		Level 1	Level 2	Level 3
1	Roughness by Bump Integrator(max. permissible) Equivalent IRI	2000mm/km 2.8m/km	3000mm/km 4.0m/km	4000mm/km 5.2 m/km
2	Potholes per km(max. number)	Nil	2-3	4-8
3	Cracking and patching area (max permissible)	5%	10%	10-15%
4	Rutting – 20 mm (maximum permissible)	1%	1.5%	2.5%
5	Skid number (minimum desirable)	50SN	40SN	35SN

Source: (MORT&H, Guidelines for maintenance of primary, secondary and urban roads, Indian Roads Congress, 2004).

Result and discussion

Results obtained from the field investigations and laboratory tests for the eight study roads identified for periodic pavement evaluation are discussed here. One time data on subsoil parameters, traffic and drainage characteristics were collected. The results were used as variables in development of models.

The second part of the study focuses on to develop pavement deterioration models applicable to Uttar Pradesh conditions using time series data. Eight road sections representing NH, SH and MDR with variation in traffic composition, soil properties, climate, drainage characteristics and land use were selected. Periodic data were collected fromthe field.

Selection of Road Stretches:

i. Urban roads

Based on a preliminary assessment with respect to the road conditions and traffic, 44roads from five corporations, which represent urban conditions, were selected for the study. These road stretches were further divided into 68 homogeneous sections.

ii. Study roads for periodic pavement performance evaluation

The road stretches for conducting the periodic evaluation were identified to represent variation in pavement composition, traffic composition, climatic conditions, terrain and soil characteristics. Eight roads with twelve homogeneous sections were selected asstudy stretches based on the above factors. Details of the study roads are discussed in Chapter 4.

Field Data Collection and Laboratory Investigations

Data collection ranged from simple 'windshield surveys' to the use of testing vehiclesthat measure deflection, unevenness, skid resistance and cracking on the surface and axle load surveys. The data include:

i. Inventory of the study sections

ii. Pavement drainage characteristics

iii. Pavement surface condition (cracks, raveling, potholes, rutting, edge break etc.).

iv. Unevenness using Bump Integrator (IRC SP 16, 2004).

v. Skid Resistance using portable skid-resistance Pendulum (BS 812-1967).

vi. Rebound deflection using Benkelman Beam (IRC 81, 1997).

vii. Traffic studies including axle load surveys using Portable Weigh Bridge (TRLOverseas Road Note 40).

viii. Pavement composition from trial pits and core cutter method.

ix. Texture depth using sand patch method (BS 598 part 105, 1990).

x. Field Density of the subgrade soil using sand replacement method (IS 2720 Part28, 1974).

xi. Laboratory investigation of the subgrade soil properties including CBR.

Development of Pavement Performance Models and Relationships:

The influencing parameters were identified from the literature. Non-linear regression models using SPSS were developed. Calibration of HDM-4 deterioration models to suit toIndian conditions was done. Fuzzy rule based models were also developed for deflection and compared with other models. The effect of subgrade soil type on the rebound deflection and Modified Structural Number relationship has been checked using appropriate plots. Performance models were developed for cracking, pothole, raveling, roughness and for safety considerations.

FIELD AND LABORATORY INVESTIGATIONS - INSTRUMENTATIONAND PROCEDURE

The instrumentation and procedure adopted for data collection is discussed in this section.

Inventory:

Detailed inventory of all study stretches were taken and the data were collected as per Indian Roads Congress format.

Pavement drainage characteristics:

The drainage characteristic of the pavement is controlled by the following factors and hence data on the same were collected from the field and secondary sources.

i. **Camber or cross slope:** The cross slope/ camber of the pavement surface was noted using a camber board (slope meter) in percent slope at 5 to 10 locations in each study stretch of 100 to 200m and the mean camber was recorded **.** Typical sections selected were at level road and with gradient, for rolling terrain and flat terrain. Under each category, at least one typical section was selected with

(a) **adequate camber** (b) **inadequate or deficient camber** and (c) **practically nil or zero slope**. The cross slope of shoulders (in percentage or as ratio) were noted at typical locations. The shoulder level in mm, i.e., shoulder drop or raised shoulder with respect to pavement edge was also recorded.

ii. **Presence of valley stretch:** Availability of cross drainages or culverts at valley locations were noted.

iii. **Soil moisture content:** Measurement of moisture content of soil and its variationswith depth (0.5, 1.0 and 1.5 m) during

2 or 3 typical seasons.

iv. **Water table data:** This was collected from local enquires**.**

v. **High Flood Level Data:** This was obtained from local enquiry.

vi. **Rainfall data:** Average rainfall data in the locality for the past 3 years of the study period was collected from secondary sources.

vii. **Land use data:** The collected data included land use of the adjoining road formation, type of cultivation with or without irrigation or built up along the road side. The relative level of the road land with respect to the road formation levelhad been collected from the field as primary data.

viii. **Cross slope:** Cross slope of the adjoining land were also recorded.

Longitudinal side drain: Availability of side drains on left and right side of the road with details including the depth with respect to road levelwere recorded.

Pavement Surface Condition:

(1)Cracking: 3 to 6 study stretches of 15 to 50m length with some cracks already developed on the surface were identified from the selected roads. Location of cracking, cracked area, wheel path (if visible) and distance of the cracked areawith respect to the pavement edge or centre were noted. The areas of classified cracks (fine, medium and wide cracks) were recorded in terms of the total area of pavement. The percentage of cracked area with fine cracks (width less than 1.0mm), medium crack (width 1.0 to 3. 0 mm), wide cracks (width more than 3.0 mm) and mixed cracks were noted.

(2)Crack length propagation studies on selected control stretches:

Control sections of dimensions 1m x 1 m were marked on the road and the crack length data were periodically measured. The selected area consisted of the following types

a. Area without any crack

b. Area with only fine cracks of width less than 1.0 mm

c. Area with medium cracks of width 1.0 mm to 3 mm

d. Area with wide cracks of width more than 3.0 mm

e. Area with all the above types of cracks

Methods and Pavement

- Visual rating
- Unevenness Index method
- Benkelman Beam Deflection method

Visual rating

It is simple method of inspecting the pavement surface for detecting and assessing the amount of various types of damages.

It occures in different forms :

- **Cracking**
- **Rutting**
- **Patholes**
- **Ravelling**
- **Undulations**
- **Alligator cracking**

Unevenness Index method

The sum value of pavement surface undulations per unit length of the road along with longitudinal profile are expressed in terms of Unevenness Index or roughness index. This type of pavement surface is measuring equipment such a 'bump integrator'

The roughness of pavement surface is commonly designated as unevenness index value and is expressed in surface roughness measured by a Bump Integrator. Roughness index is represented as the ratio of the cumulative vertical displacement to the distance travelledand is expressed in mm/km. A Towed Fifth wheel Bump Integrator was used in the present study, which consists of a trailer towed by a vehicle >

Fig : Fifth Wheel Bump Integrator

A standard pneumatic tire wheel inflated to a tire pressure of 2.1kg/sq.cm was mounted within the trailer chasis, with a single leaf spring on both sides of the wheel supporting chasis. The test was done at a speed of 32$\pm$1 km per hour. The readings of the revolution counter and integrating counters were noted and entered in the data sheet. One measurement in each lane was taken.

Fig: Roughness Survey in Progress

Calibration of the Bump Integrator was done using MERLIN – Machine for EvaluatingRoad Roughness using Low Cost Instrumentation.

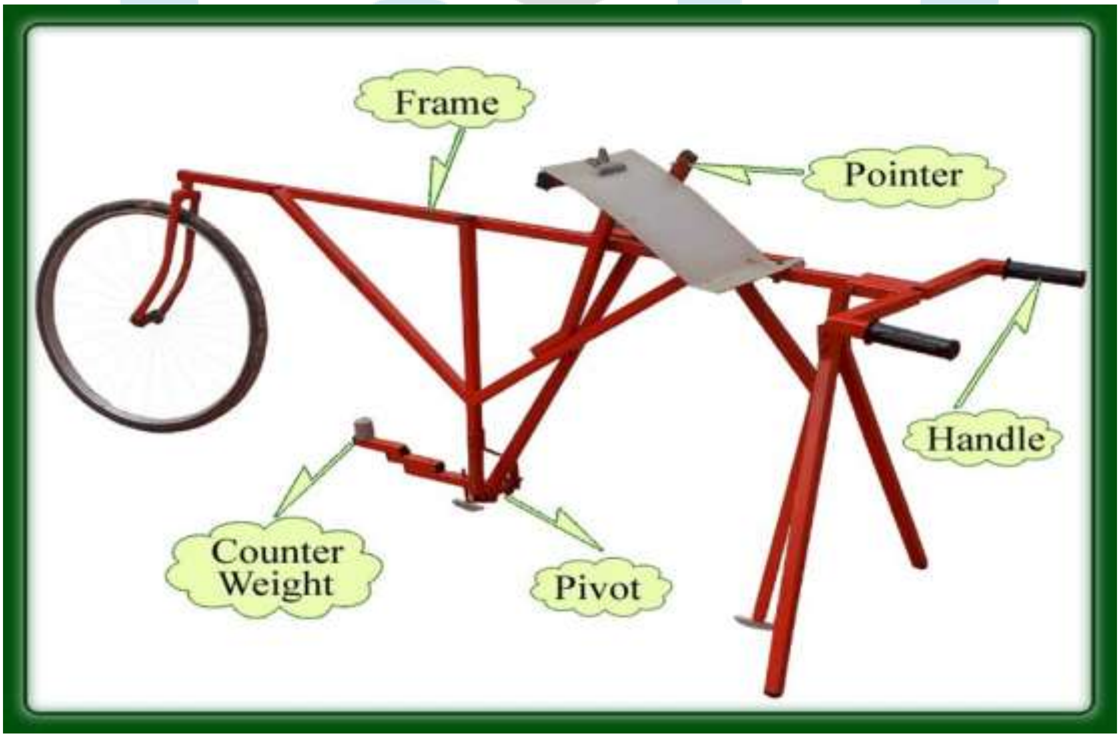

Fig : MERLIN

Recommended Standards for Roughness Values: The maximum permissible values of surface roughness measured with Bump Integrator for different surfaces as per IRC SP 16(2004) are given.

Table: Maximum permissible surface unevenness for road

Type of surfacing	Maximum permissible surface unevenness	
	Longitudinal profile(mm)	Transeverse profile(mm)
Surface dressing	10	8
Open graded Premix Carpet	8	6
Mix seal surfacing	8	6
Semi dense bituminous Concrete	6	4
Bituminous concrete	5	4
Cement concrete	5	4

(Source: IRC SP 16, 2004)

Benkelman Beam Deflection Method:

1. Structural capacity:

Structural capacity analysis is normally conducted at the project-level to determine the load-carrying capacity of the pavement and the capacity needed to accommodate the projected traffic. Structural capacity can be taken as the maximum load and number of repetitions a pavement can carry before reaching some defined condition. Non-destructivedeflection testing of the pavement is a simple and reliable method to evaluate the pavement; but destructive testing such as coring and component analysis techniques are used. Structural evaluation of pavement is required for the selection of appropriate treatments at the project-level.

2. Characteristic deflection:

Deflection measurements are tests used to evaluate the response of the pavement structureto a realistic load. The stress, strain and deformation condition in the pavement can be assessed by these tests. It is also possible to assess the deformation characteristics of the individual layers (Molenaar, 1983).

A number of road authorities use the representative maximum deflection for estimatingthe carrying capacity of road (Kennedy and Lister, 1978, Asphalt Institute, 1983). But the deflection criteria curves recommended in these design procedures (ie, the relationship between deflection and traffic carrying capacity) may not be applicable for the pavementsof tropical and sub tropical regions. (TRL Overseas Road Note 18).

. Deflection measurements are made at 20 points in a kilometer. The points are to be staggered at 50 meter interval on both directions. The loading is applied by a truck havingrear axle load of 8.17 tonnes and tire pressure of 5.6 kg/sq.cm. The measurements are done as per the CGRA procedure laid down in IRC 81-1997.

3. Procedure for Deflection measurement using Benkelman Beam:

- Based on the pavement condition survey, the road length to be surveyed wasdivided into homogeneous sections of lengths not less than 500 metre. The loading points on the pavement for deflection measurement were located alongthe wheel paths on a line 0.9 m from the pavement edge in the case of pavements of total width more than 3.5 m and the distance from the edge is reduced to 0.6 m on narrower pavements. The testing point shall be selected and marked in advance on the pavement. For highway pavements, the distances from the edge ofthe lane for the testing points shall be as given **.**

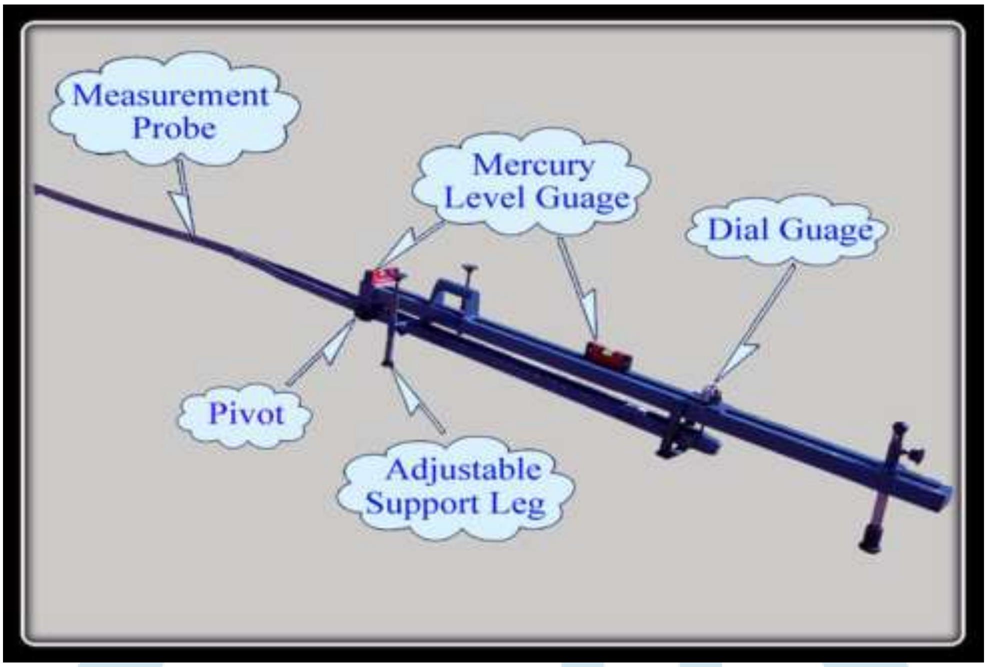

Fig: Benkelman Beam

Table : Distance from the Edge of the Lane for deflection measurement

Lane Width (Metres)	Distance from lane Edge (Metres)
2.8 or less	0.5
3.0	0.6
3.2	0.7
3.4	0.8
3.6 or more	0.9

- A minimum of 10 deflection observation points are taken on each of the selected stretch of pavement. The truck is driven slowly parallel to the edge and stopped suchthat the left side rear dual wheel is centrally placed over the first point for deflection measurement .

- The probe end of the Benkelman beam is placed between the gap of the dual wheel and is placed exactly over the deflection observation point .

- When the dial gauge reading is stationary the initial dial gauge reading D_o wasnoted.

- The truck was moved forward slowly through a distance of 2.7m from the point and stopped. The intermediate dial gauge reading D_i was noted when the rate of recoveryof the pavement was less than 0.025 mm per minute.

- The truck was then driven forward through a further distance of 9.0m and the final dial gauge reading D_f was recorded as before. The schematic plan of the survey segment is given.

- The three deflection dial readings D_o, D_i, and D_f form a set of readings at one deflection point under consideration. Similarly, the truck is moved to the nextdeflection point and the procedure is repeated.

Fig.: BBD Survey In Progress- Location of Probe

- The temperature of the pavement surface is recorded at intervals of one hour during the study. The moisturtervals subgrade soil is also to be determined at The rebound deflection value D at any point is given by one of the following two conditions

(i) If D_i - D_f□ 2.5 divisions of the dial gauge or 0.025mm, D = 2 (D_o - D_f) divisions of 0.01mm units = 0.02 (D_o - D_f) mm

(ii) If D_i- D_f> 2.5 divisions of the dial gauge or 0.025mm , this indicates that correction is needed for the vertical movement of the front legs. ThereforeD = 2 (D_o - D_f) + 2 K (D_i - D_f) divisions.

The value of K is to be determined for every make of the Benkelman Beam and is given bythe relation:

K = (3d – 2e)/f(3.5)

where,

d = distance between the bearing of the beam and the rear adjusting leg

e = distance between the dial gauge and rear adjusting legf = distance between the front and rear legs.
The value of K of Benkelman Beam generally available in India is found to be 2.91.Therefore, the deflection value in case (ii) with leg correction is given by:

D = 0.02 (D_o - D_f) + 0.0582 (D_i - D_f) mm(3.6)

Table : Limits of Benkelman Beam Deflection Values (IRC 81, 1997)

Rebound Deflection (mm)	Strength of pavement
0.5-1	Reasonably Strong
1-2	Moderate
2.3	Weak
>3	Very Weak (Permanent Deformation)

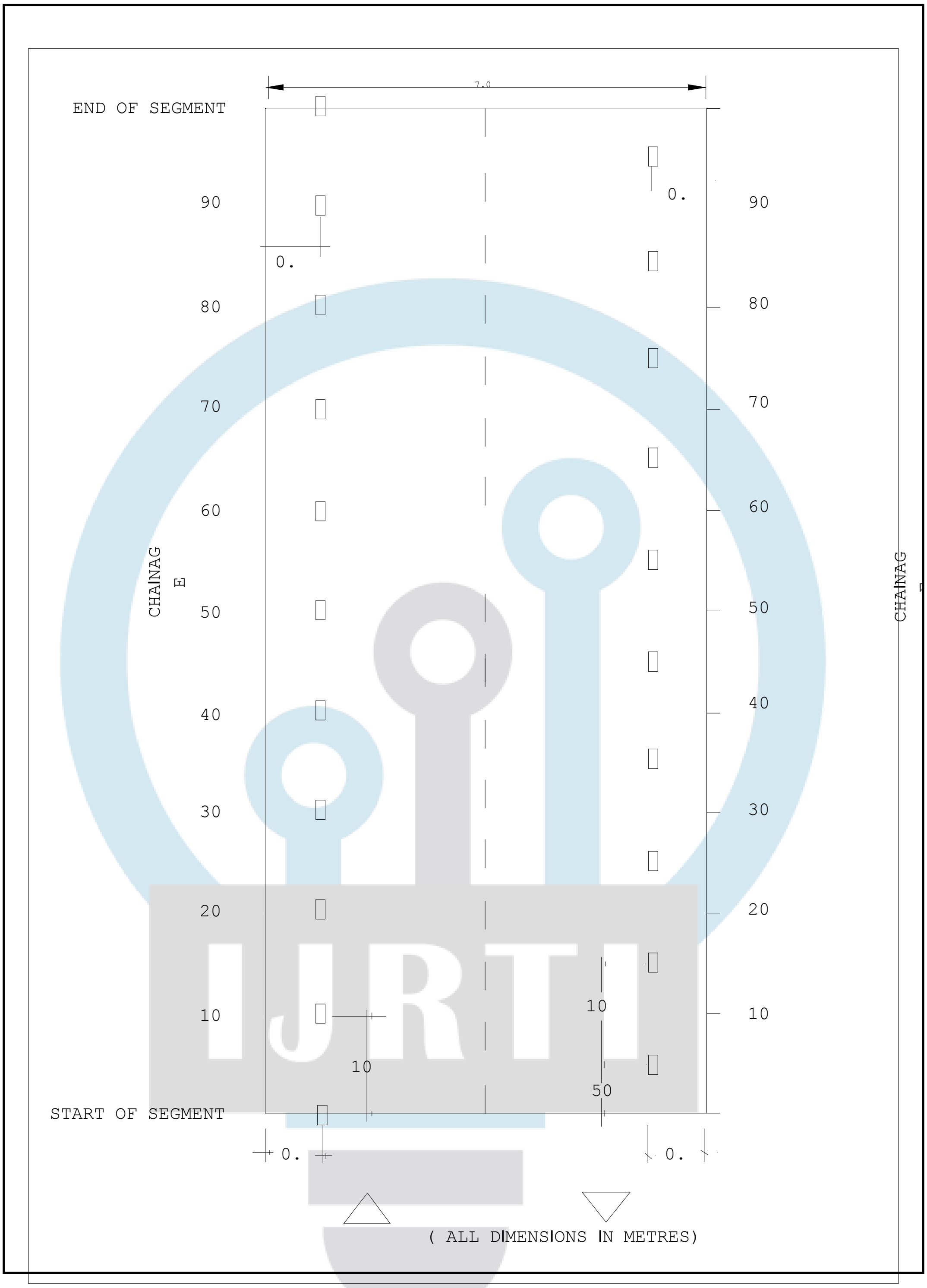

Fig : Location diagram of BBD Test

Fig : Cracks with patching

(3)Potholes: Study stretches of length about 200 to 500 m was selected considering identical conditions. The data of potholes on each study stretch were collected andrecorded periodically two or more times a year covering different seasons including the periods before and after monsoon season.

Open or unfilled potholes: The average depth, length and width of unfilled potholes were recorded in mm and classified into groups such as small, medium and large size. The numbers of potholes of each group for each study stretch were recorded to know the growth pattern.

Improperly filled potholes: Details of improperly filled potholes (size and number) were recorded with details such as unsuitable materials like soil, brick aggregates, large boulders, stones etc in adequate compaction, not cut to rectangular shape with vertical edges, not properly cleaned or loose materials not removed, a tack coat not properly applied and level difference of the finished surface with the adjoining surface.

Patched potholes: The features of the patched potholes such as slippery with excess binder, absence of seal coat, level of the patch, etc. were noted includingthe number and area.

Fig : Alligator cracks **Fig : Pothole and Alligator Cracks**

(4)Rutting: The data collected consists of location of the longitudinal rut withrespect to pavement edge or centre line or wheel path, mean depth and width ofthe longitudinal ruts in mm and location of the wheel path with respect to pavement edge, if visible.

(5)Undulations: Measurement of undulations or depressions were done using straight edge and wedge scale on stretches of length 30 to 50m, along three longitudinal lines, representing two wheel paths and centre line, and were groupedas per IRC/ MoRTH guidelines and number in each category was recorded. The Bump Integrator was used to measure the undulations as discussed in Section.
Shear failure denoted by large size depressions with heaving in adjoining portion were measured using a straight edge and vertical scale or steel tape. The mean length, width and depth of such depressions were noted.

(6)Raveling: Raveling is the loss of material from the surface of the pavement. The reason that can be attributed to raveling is mainly thin surfacing, such as surface dressing, seal coat and premix carpet. The affected area is expressed as percentage of the total pavement area.

SUMMARY & CONCLUSION

Based on the present study, the conclusions drawn are presented in three sections as givenbelow:

Relationship of Pavement Strength and Pavement Composition

- The strength of the pavement represented by the measured deflection at the surface on mature soil sub grades is influenced by the sub grade soil properties and layer composition on an in-service pavement in urban conditions.
- There is good correlation between deflection and Modified Structural Number for various classes of Pavement Condition Index for sub grade soil types SM and SC.
- In the case of pavement in good condition, ie, for the PCI range 60-80, linear relationship give better correlation.
- In the case of soil type SM, power function relationship showed better correlation.
- The parameters such as Field Dry Density, Field Moisture Content, Optimum Moisture Content, Maximum Dry Density, Atterberg Limits, CBR, Soil composition and the fraction of Silt & Clay of the subgrade soil have influence on the strength of the pavement.
- Field Dry Density and Plasticity Index of the sub grade soil influence the deflection, whereas Maximum Dry Density has got less impact when gravel and silt and clay fractions are considered as variables.

Pavement Performance Models:

- Rutting is found to be absent on the study road stretches. The reasons that can be attributed for this are the absence of lane segregation and lane discipline.
- The regression models developed for deflection and roughness progression gave promising results for predicted values when validated with the observed values.
- HDM-4 calibrated to the site conditions also can be effectively used for performance prediction.
- For predicting roughness, the models developed using SPSS and HDM-4 showed promising results and hence can be used depending upon the user's choice. For roughness, the HDM-4 predicted values were less in the initial years, but showed closer values later.
- Regarding deflection, the regression and fuzzy models showed lesser values than the observed values, but closer values were obtained in the case of Fuzzy models.
- For cracking and pothole progression, HDM-4 predicted values were closer to the actual values.
- The models developed for Riding Comfort Index and Unevenness growth showed good correlation and hence are useful for studying the functional behavior of in- service flexible pavements. The Unevenness growth model is useful toestimate the unevenness after an anticipated traffic loading/ age, from an initial unevenness and deflection. The increment in vehicle operation cost of various pavements can be evaluated using this model.
- The developed models are simple and are useful for estimating the structural and functional behavior of flexible

pavements with anticipated traffic loading. These models can be used to find the allowable traffic loading at different limiting values of deflection, crack area, RCI and UI. Thus, the phasing of maintenance/rehabilitation activities can be scientifically planned.

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