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STRENGTHENING OF FLEXIBLE PAVEMENT THROUGH BENKELMAN BEAM DEFLECTION (BBD) TECHNIQUE

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ABSTRACT

A distressed pavement requires maintenance. Maintenance measures constitute fresh investment on the existing roads. The maintenance expenditure can be reduced through proper planning, design, construction and quality control. If the causes of possible distresses are removed, or judiciously taken care of during design stage, the expenditure due to maintenance measures on in-service roads reduces. This paper analyzes the method of flexible pavement strengthening by BBD technique. The entire methodology and parameters involved in this technique are taken care of and lastly the design aspects of pavement strengthening are also put forth. This work is an attempt to study the BBD technique fully and then deduce the useful conclusions from the study and apply in field for strengthening of in-service pavements

KEYWORDS: Benkelman beam, Corrections, Deflection, Flexible pavements, Inservice Pavements

1. INTRODUCTION

Strengthening of Pavement is Defined as the Process of Providing the Required Overlays on the Existing Pavements So that it Performs More Efficiently Over A Given Design Period of Time Under Given Dynamic and Static Loads, Once the Pavement is Evaluated. There are Various Methods by which the Overlay Required Can be Calculated. These Methods Actually Calculate the Deflections in the Pavements. Some of these Methods are; Benkelman Beam Deflection (Bbd) Method, Lacroix Deflectograph, Dynaflect, Falling Weight Deflectometer (Fwd).Now If Roads are Properly Strengthened the Maintenance Expenditure (In Millions and Billions of Dollars) Can be Reduced to a Considerable Extent

1.1 Pavement Evaluation

Since there is the need for maintenance of pavement thus a pavement is first to be evaluated well. Pavement evaluation is a technique of assessing the condition of a pavement, both structurally and from the point of view of surface characteristics. Pavement evaluation is a handy tool in the hands of a highway engineer and serves a variety of purposes, such as To research on the performance of pavement of different specifications over a period of time or to assess maintenance needs such as patch repairs, renewals and resealing or to assess the need for structural overlays on distressed pavements. Now, this evaluation of pavement is done under two main categories:

- Functional Evaluation
- Structural Evaluation

Various types and forms of pavement distresses ply on a pavement. And all of these stresses or few of them in combination may act on a pavement. Thus individual assessment and quantification of the distresses may not therefore be very use- -ful. Rather there is a need to access the functional condition of the pavement as a whole. The structural evaluation of pavement can be broadly classified into two major categories, namely, DESTRUCTIVE EVALUATION and NON-DESTRUCTIVE (NDT) EVALUATION.

In Non-destructive evaluation the structural strength of the pavement is evaluated without causing any damage to the pavement or disruption of traffic. A number of Non-destructive devices have been developed for the structural evaluation of pavement. The Non-destructive equipment is used to determine the; (i) In -situ moduli of pavement layers, (ii) Load transfer efficiency at joints in the concrete pavements, and (iii) Location and extent of void in a pavement structure.

1.2Pavement Maintenance Measures

Pavement maintenance can be done by certain methods under two main categories namely Pavement maintenance measures other than overlay & Pavement maintenance with overlay.

The pavement maintenance measures other than overlay are the minor maintenance or repair works which are performed on the pavement. These works do not enhance the structural strength of the pavement, but can improve the functional standards and check the rate of deterioration. The two most important among them are surface repairs anddrainage maintenance

On the other hand overlay is the extra thickness provided on the pavement surface which strengthens the pavement structurally, and thereby enhances its longevity. The overlay design comprises the determination of thickness and the type of material to be laid over the existing pavement surface so as to extend its longevity by a given period. Earlier (prior to 1960), the overlay design used to be based on judgment and experience [7]. There are various overlay design methodologies in vogue now and among which at least three basic approaches may be identified as follows:

- Effective thickness approach
- Deflection approach
- Mechanistic approach.

1.3 BBD Technique of Pavement Strengthening

The Benkelman beam measures the deflections under standard wheel load conditions. The beam is a handy instrument which is most widely used for measuring deflection of pavements [1, 5]. The instrument is shown in diagram. It consists of a lever 3.66 m long pivoted 2.44 m from the end carrying the contact point which rests on the surface of the pavement. The deflection of the pavement surface produced by the test load is transmitted to the other end of the beam where it is measured by a dial gauge or recorder. The movement at the dial gauge end of the beam is one-half of that at the contact point end. The load on the dual wheel can be in the range of 2.7 to 4.1 Tones.

1.4 Background of BBD Technique

A.C. Benkelman devised the simple deflection beam in 1953 for measurement of pavement surface deflection on the WASHO Test Road [3]. It is widely used all over the world for evaluation of the requirements of strengthening of flexible pavements. Deflection beam has been in use in India for more than two decades by different organizations. To lay down a uniform procedure for the design of flexible overlays using the Benkelman beam deflection technique “Tentative Guidelines of Flexible Road Pavements Using Benkelman Beam Deflection Technique” IRC: 81-1981. The BBD technique is a popular test all over the world for estimating the required overlay thickness. The popularity is possibly because of its simplicity and low cost. The permissible maximum allowable Benkelman beam deflection for satisfactory performance of a road stretch depends upon the traffic, material of construction, and the environmental factors. This forms the basis of the BBD study .Benkelman deflection more than the allowable deflection suggests that the pavement may require an overlay.In India, the earlier guidelines [4] on strengthening by overlay using BBD method have been revised, and the present guidelines [3] have evolved from a broader perspective of experience gained through research and practice [2] in India and other countries.

2. METHODOLOGY OF BBM TECHNIQUE

The BBD technique involves field survey (which further involves the determination of deflection and traffic survey) and the correction for influencing factors (such as temperature and moisture content). The methodology of BBD technique is classified into 2 major steps. The first one is the overall survey and the other is the traffic data collection. The overall survey involves classifying pavement as good, fair or poor depending upon the rut depth measurements, deflection measurements using Benkelman beam and lastly calculation & application of correction factors. Then comes traffic data collection.The cumulative number of standard axles to be catered for in the design is determined which further requires the data for design life (in years); initial traffic (in terms of number of commercial vehicles per day); annual growth rate of commercial vehicles and vehicle damage factor (in terms of number of standard axles per commercial vehicles). The various deflections obtained from the Benkelman beam are to be reduced to a characteristic deflection (in mm). The design of overlay is then obtained from the design curves relating the characteristic pavement deflection to the cumulative number of standard axles to be carried over the design life.

2.1 Background of BBD Technique

A conceptual working of a Benkelman beam is depicted in figure 2. A’B’ represents the position of a Benkelman beam when the probe A’ is placed between the dual wheel of a loaded truck. The point A’ touches the maximum deflected point of the deflected bowl. When the truck moves forward by a given distance (from P/ to P), the deflection bowl also moves forward, and the probe point A’ comes back to a point position A. This deflection is called the rebound deflection, and is used for the estimation of overlay thickness. There may be some residual deflection at the present position of the truck wheel (at P) and therefore, the truck is further moved forward to measure the residual deflection .If the deflection bowl has a large spread, the pivot (O) may itself fall within the deflection bowl, giving erroneous results. This error, to some extent is taken care by incorporating corrections in the observed reading. In Benkelman beam the length of AO is double that of OB; the dial gauge being placed at B, and the rebound deflection of the pavement is twice the reading obtained.

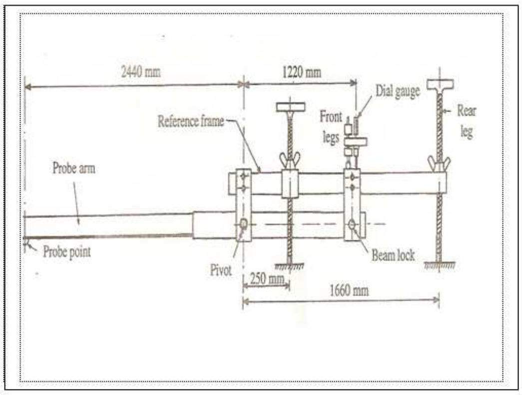

Figure 1: Diagram of Benkelman Beam

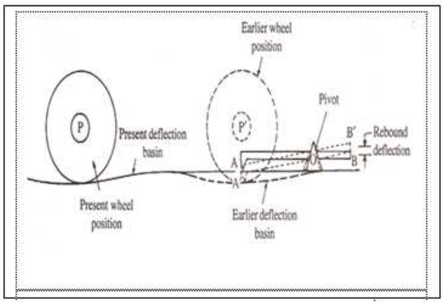

Figure 2: Conceptual Working of Benkelman Beam

2.2 Taking the Dial Gauge Reading

The procedure of measuring the rebound deflection is as follows

- Select 10 points along the outer wheel path (i.e., 60 cm from the pavement edge) for each lane.
- Bring the rear dual wheel assembly of the truck over the marked point and insert the probe of the beam between the dual wheels so that the probe is placed exactly over the point where the deflection is to be measured.
- A standard loading of 8170 kg is used for the test, the tyre pressure being 5.6 kg/cm2
- The dial gauge reading s noted initially (D0) in the position described under b above.
- The truck is driven forward at a slow speed and dial gauge readings (D1 and D2) are taken when the truck stops at 2.7 m and 9 m from the measuring point, and when the rate of recovery is equal to 0.025 mm per minute or less. The Pavement temperature is recorded.

If D1-D2 $\leq$ 0.025 mm, the actual rebound deflection 2(D0-D2). If, however D1-D2 > 0.025 mm, correction is needed for the vertical movement of the front legs; the true deflection is obtained by the formula: XT = XA + 2.91 Y

Where XT = true pavement deflection, XA = apparent pavement deflection & Y = vertical movement of the front legs i.e., twice the difference between the final and intermediate dial readings.

2. 3 Deflection Measurement

In each road section of uniform performance minimum of ten points should be marked at equal distance in each lane of traffic for making the deflection observations in the outer wheel path. The interval between the points should not be more than 50 m. On roads having more than one lane, the points marked on adjacent lanes should be staggered. In the transverse direction, the measurement points should be 60 cm from the pavement edge if the lane width is less than 3.5 m and 90 cm when the lane width is more than 3.5 m. for divided four lane highway, the measurement points should be 1.5 m from the pavement edge. Variability of deflections in a given section should be considered for detecting spots where extra deflection measurements have to be made. For this purpose, highest and lowest values in a group of ten should be compared with mean value. If the highest or lowest values differ from the mean by more than one-third of mean then extra deflection measurements should be made at 25 m on either side of point where high or low values are observed.

For measuring pavement deflection the C.G.R.A. procedure which is based on testing under static load may be adopted. In this method, a standard truck having a rear axle weighing 8170 kg fitted with dual tyre inflated to a pressure of 5.60 kg/cm2 is used for loading the pavement. During actual tests, the total load and the tyre pressure are maintained within a tolerance of +/ - 1 percent and +/- 5 percent respectively.

Before starting the deflection measurements, the Benkelman Beam should be calibrated to ensure that the dial gauge and beam are working correctly, accordingly the beam is placed and leveled on a hard level ground. A number of metallic blocks of different thickness (measured accurately with a precision micrometer) with perfectly plane faces and placed under the probe and the dial gauge reading recorded each time. If the beam is in order, the dial gauge on beam should read one-half the thickness of the metallic block on which the probe was placed. Otherwise, the dial gauge should be checked and replaced if necessary. If the dial gauge is functioning correctly, the beam pivot should be checked for free and smooth operation, secondly the striking plate beneath the dial gauge spindle should be checked to ensure that it is tightly secured and has not become grooved by the dial gauge stylus.

Deflections measured by the Benkelman Beam are influenced by the pavement temperature and seasonal variation in climate. For design purposes, therefore, all deflection values should be related to a common standard temperature otherwise necessary corrections are to be applied. Similarly for climatic factors pavement deflections should pertain to the period when the sub grade is at its weakest condition (monsoons in India).It is, therefore, desirable to conduct deflection measurements during this period. Where the same is not feasible, a correction factor should be applied, discussed further.

2. 4 Procedure for Collecting Traffic Data

Traffic in terms of million standard axle shall be considered for the design of overlay. If sufficient data are available at the stretch with respect to the wheel load distribution of commercial vehicles or the vehicle damage factor and their transverse placement, the cumulative standard axles may be worked out based on actual data, otherwise design traffic may be calculated. For the purpose of design, only the number of commercial vehicles of laden weight of 2 tones or more and their axle loading will be considered. The traffic is considered in both directions in the case of two lane road and in the direction of heavier traffic in the case of multi lane divided highways. To obtain the realistic estimate of design traffic due to consideration should be given to the existing traffic, possible changes in road network and land use of the area served, the probable growth of traffic and design life. Estimate of the initial daily average traffic flow for any road should normally be based on 7-day 24-hours classified traffic counts. However, in exceptional cases where this information is not available 3-day count could be used.

Traffic Growth Rate An estimate of likely growth rate can be obtained as by studying the past trend in traffic growth or Elasticity of transport demand. If adequate data is not available, it is recommended that an average value of 7.5 per cent may be adopted for roads in rural routes.

Design Life It is recommended that the design life for strengthening of major roads should be at least 10 years. Less important roads may, however, be designed for a shorter period but not less than 5 years in any case.

Computation of Design Traffic The design traffic is considered in terms of the cumulative number of standard axles to be carried during the design life of the road. Its computation involves estimates of the initial volumes of commercial vehicles per day, lateral distribution of traffic, the growth rate, the design life in years and the vehicle damage factor (number of standard axle per commercial vehicle) to convert commercial vehicles to standard axles.

The following equation may be used to make the required calculation;

$$N = \frac{365xA\,[(1 + r) - 1]}{r} x\,F$$

Where, N = The cumulative number of standard axles to be catered for in the design, A = Initial traffic, in the year of completion of construction, in terms of a number of commercial vehicles per day duly modified to account for lane distribution, R = Annual growth rate of commercial vehicles , X = Design life in years, F =Vehicle damage factor (number of standard axles per commercial vehicles)

2. 4 Distribution of Commercial Traffic over the Carriageway

A realistic assessment of distribution of commercial traffic by direction and by lane is necessary as it directly affects the total equivalent standard axle load applications used in the design. It is recommended that for the time being the following distribution may be assumed for design until more reliable data on placement of commercial vehicles on the carriageway lanes are available.

- **Single-Lane Roads (3.75 m Width):** Traffic tends to be more channelized on single lane roads than on two lane roads to allow for this concentration of wheel load repetitions, the design should be based on the total number of commercial vehicles per day in both directions multiplied by two.
- **Two-Lane Single Carriageway Roads:** The design should be based on 75 per cent of the total number of commercial vehicles in both directions.
- **Four-Lane Single Carriageway Roads:** The design should be based on 40 per cent of the total number of commercial vehicles in both directions.
- **Dual Carriageway Roads:** The design of dual two lane carriageway roads should be based on 75 per cent of the number of commercial vehicles in each direction. The distribution factor shall be reduced to 20 per cent for each additional lane.

2. 4 Vehicle Damage Factor

The vehicle damage factor (VDF) is a multiplier for converting the number of commercial vehicles of different axle loads to the number of standard axle-load repetitions. The vehicle damage factor is arrived at from axle-load surveys on typical road sections so as to cover various influencing factors such as traffic mix, type of transportation, type of commodities carried, time of the year, terrain, road condition and degree of enforcement. The AASHO axle load equivalence factors may be used for converting the axle load spectrum to an equivalent number of standard axles. For designing a strengthening layer on an existing road pavement, the VDF should be arrived at carefully by using the relevant available data or carrying out specific axle load surveys depending upon importance of the project. Some surveys have been carried out in the country on National Highways; State Highways MDR's which reveal excessive overloading of commercial vehicles. The designer should take the exact value of VDF after conducting the axle load survey particularly in the case of major projects

2. 5 Correction to Deflection Measurements

2. 5. 1 Correction for Temperature Variation

The stiffness of bituminous layers changes with temperature of the binder and consequently the surface deflections of a given pavement will vary depending on the temperature of the constituent bituminous layers. For purposes of design, therefore, it is necessary that the measured deflections be corrected to a common standard temperature. For areas in the country having a tropical climate, the standard temperature is recommended to be 350C. Correction for temperature is not applicable in the case of roads with thin bituminous surfacing.

Correction for temperature variation on deflection values measured at pavement temperature other than 350C should be 0.01 mm for each degree centigrade from the standard temperature of 350C. The correction will be positive for pavement temperature lower than 350C and negative for pavement temperature higher than 350C. In colder areas of altitude greater than 1000 m where the average day temperature is less than 200C for more than 4 months in a year, the standard temperature of 350C will not apply. In the absence of adequate data about deflection-performance relationship, it is recommended that the deflection measurements in such areas be made when the ambient temperature is greater than 200C and that no correction for temperature need be applied. In case where temperature correction is to be applied, the pavement temperature should be measured during the deflection survey. The measurement should be made at a depth of 40 mm deep and about 10 mm diameter should be drilled in the pavement and filled with glycerol and temperature can then be recorded after about 5 minutes.

2.5. 2 Correction for Seasonal Variation

Since the pavement deflection is dependent upon change in the climatic season of the year, it is always desirable to take deflection measurements during the season when the pavement is in its weakest condition. Since, in India, this period occurs soon after monsoon, deflection measurements should be confined to this period as far as possible. When deflections are measured during the dry months, they will require a correction factor which is defined as a ratio of the maximum deflection immediately after monsoon to that of the minimum deflection in the dry months.

Correction for seasonal variation shall depend on type of sub grade soil, its field moisture content (at the time of deflection survey) and average rainfall in the area. For this purpose, sub grade soils have been divided into three broad categories, namely sandy/gravelly, clayey with low plasticity (PI≤ 15) and clayey with high plasticity (PI > 15). Similarly rainfall has been divided in to two categories, namely low rainfall (annual rainfall ≤1300 mm) and high rainfall (annual rainfall > 1300 mm). Moisture correction factors (or seasonal correction factors) shall be obtained from given graphs (figure 3 to figure 8) for given field moisture content, type of sub grade soil and annual rainfall

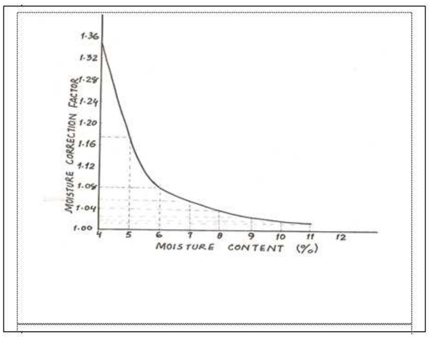

Figure 3: Moisture Correction Factor for Sand/Gravelly Soil Subgrade for Low Rainfall Areas (Annual Rainfall ≤ 1300mm)

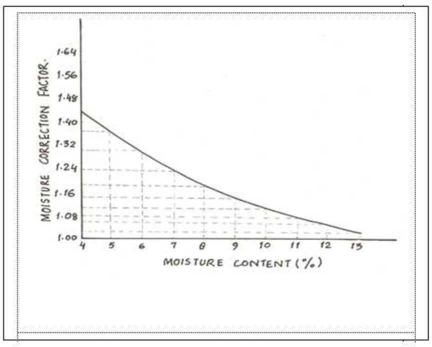

Figure 4: Moisture Correction Factor for Sandy/Gravelly Subgrade for High Rainfall Areas (Annual Rainfall > 1300mm)

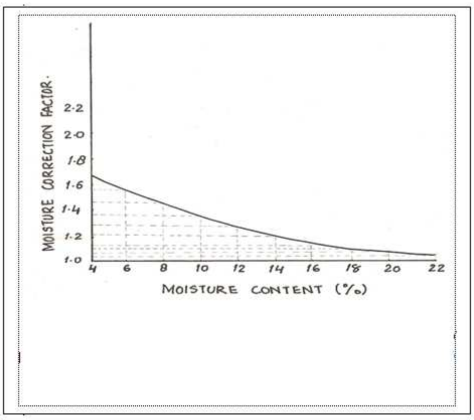

Figure 5: Moisture Correction Factor for Clayey Subgrade with Low Plasticity (PI< 15) For Low Rainfall Areas (Annual Rainfall ≤ 1300mm)

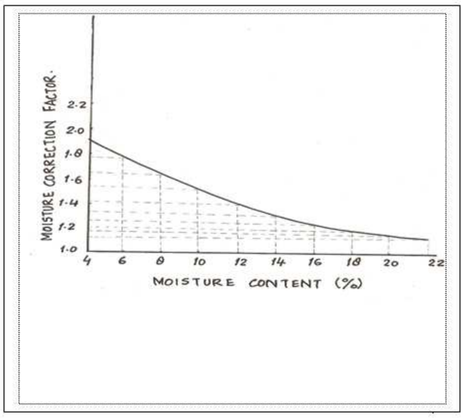

Figure 6: Moisture Correction Factor for Clayey Subgrade with Low Plasticity (PI< 15) for High Rainfall Areas (Annual Rainfall > 1300mm)

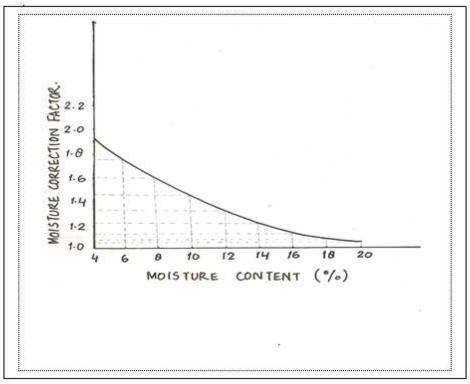

Figure 7: Moisture Correction Factor for Clayey Subgrade with High Plasticity (PI> 15) for Low Rainfall Areas (Annual Rainfall ≤1300mm)

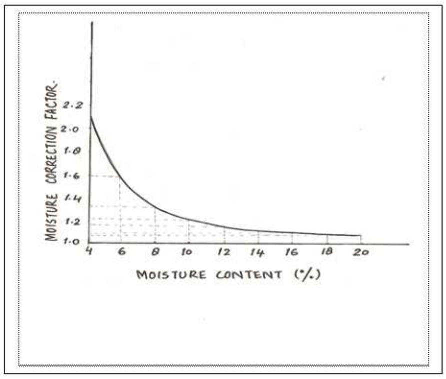

Figure 8: Moisture Correction Factor for Clayey Subgrade with Low Plasticity (PI< 15) for High Rainfall Areas (Annual Rainfall > 1300mm)

The soil sample for determination of sub grade type and its field moisture content shall be scooped from below the pavement. For this purpose a test pit at the shoulder (adjacent to pavement edge) shall be dug to a depth up to 15 cm below the sub grade level in every kilometer depending on the uniformity of sub grade soil, topography of the area and road profile. A soil sample of weight not less than 100 gm should be collected using auger from the sub grade underneath the deflection observation points i.e. 0.6 m and 0.9 m from the pavement edge for single and two lane pavements respectively at a depth of 50 mm to 100 mm below the sub grade level. The sub grade soil shall be tested as per IS-2720 for type of sub grade soil, plasticity index and field moisture content

3. DATA ANALYSIS AND OVERLAY DESIGN

Once the field work is being done, the entire field data is maintained in the form of tables and is then to be analyzed well and used to design an overlay

3. 1 Characteristic Deflection

Overlay design for a given section is based not on individual deflection values but on a statistical analysis of all the measurements in the section corrected for temperature and seasonal variations. This involves calculation of mean deflection, standard deviation and characteristic deflection. The characteristic deflection for design purposes shall be taken as given in following equations. The formulae to be used in the calculations are as follows:

$$\text{Mean deflection}, x = \frac{1}{n}\sum_{i=1}^{n} xi$$

Standard deviation, $б = \frac{\sqrt{(x-x)^2}}{n-1}$

Characteristic Deflection (Dc),

- Dc = X+ 2б ……… .(1)
  For Major arterial roads (Like NH and SH)
- Dc = X+ б ……… ..(2)
  For all other roads

Where X = individual deflection, mm

N = number of deflection measurements

Б = standard deviation, mm

Dc = characteristic deflection, mm

3.2 Design of Overlay

- The design curves relating characteristic pavement deflection to the cumulative number of standard axles to be carried over the design life is given in Figure 9
- The characteristic deflection (Dc) value to be used to be used for design purposes will be the same as given above.
- The thickness deduced from Figure 9 is the overlay thickness in terms of bituminous macadam construction. In case other components are to be laid for strengthening, the equivalent overlay thickness to be provided may be determined using appropriate equivalency factors as suggested below:

  1cm Bituminous macadam = 1.5 cm WBM/Wet Mix Macadam/BUSG

  1cm Bituminous macadam =0.7 cm of DBM/AC/SDC

- From structural considerations, the recommended minimum bituminous overlay thickness is 50 mm Bituminous macadam with an additional surfacing course of 50 mm DBM or 40 mm Bituminous concrete
- Where structural deficiency is not indicated from the deflection values, thin surfacing may be provided to improve the riding quality as required
- The type of material to be used in overlay construction will depend on several factors such as the importance of the road, the design traffic, the thickness and condition of existing bituminous surfacing, construction convenience and relative economics. For heavily trafficked roads, it will be desirable to provide bituminous overlays. The thickness of wearing course should be in conformity with IRC: 37.
- Before implementing the overlay, the existing surface shall be corrected and brought to proper profile by filling the cracks, pot holes, ruts and undulations. No part of the overlay design thickness shall be used for correcting surface irregularities

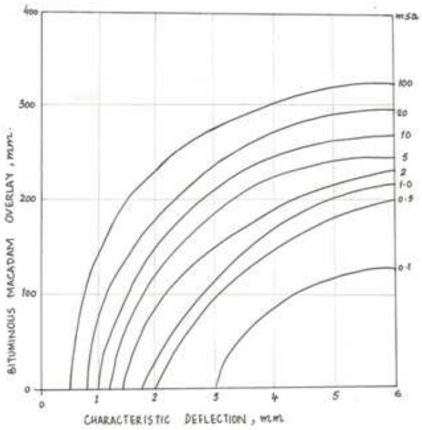

Figure 9: Overlay Thickness Design Curves

Table 1: Suggested Overlay Constructions

Thickness of Overlay Required in Terms of BM (Mm)	DBM/ SDBE (Mm)	DBM/SD BC (In Term of Equiva-lent BM) (Mm)	BM (Mm)	WBM	
				Calcu cu-lated (Mm)	Sug-gested (Mm)
100	40	57	50	-	Not Needed
150	40	57	50	43	75
200	40	57	50	93	100
250	40	57	50	143	150
300	40	57	50	193	200
350	40	57	50	243	250
400	40	57	50	293	300
Note: 1cm BM = 0.7cm DBM/SDBC/BC The recommended WBM thickness (as per IRC : 37) are 75 mm, 100 mm, 150 mm, 200 mm, 250 mm					

4. CONCLUSIONS

- It is advisable to implement the necessary maintenance measures at an early stage when the distresses have just started showing up. It is seen that proper pavement measures at an early onset of distresses, can obviate major maintenance expenditure in future. This is because, in general, the rate of deterioration increases with time.
- Out of all the deflection measuring methods the BBD technique is the most simple and reliable method.
- This method is used to measure the rebound deflection of pavement under static load.
- The correction of temperature is needed when bituminous layer is appreciably thick and temperature is standardized to 350C.
- In colder areas where the average day temperature is less than 200C for more than 4 months in a year, the standard temperature of 350C will not apply. It is recommended that the deflection measurements in such areas be made when the ambient temperature is greater than 200C and that no correction for temperature need be applied. Thus in case of Kashmir valley no correction for temperature variation is needed.

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