Government of Nepal

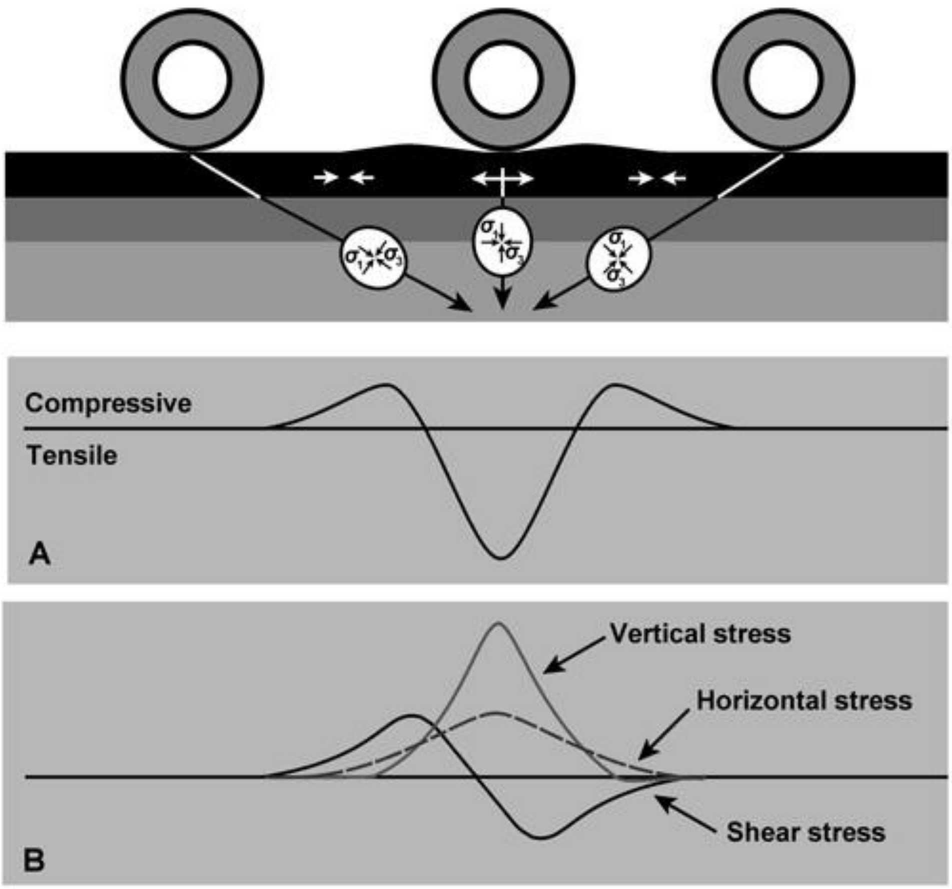
Ministry of Physical Infrastructure and Transport

Department of Roads

Chakupat, Lalitpur

Guidelines for the Design of Flexible Pavements-2014

(Second Edition 2021)



April, 2021

FOREWORD

Flexible pavements are preferred over rigid concrete roads because of their certain advantages, such as they can be strengthened and improved in stages with the growth of traffic. Flexible pavements are less expensive in regards to their initial cost and maintenance.

The guideline has been prepared based on IRC: 37-2018, Guidelines for the Design of Flexible Pavements, IRC SP 72:2015 and Road Note 3: A Guide to Surface Dressing in Tropical and Subtropical countries.

The guideline covers the design of flexible pavements for National Highways as well as other types of roads such as urban highways with traffic volume more than 2 million standard axles (msa). It also covers the design of Surface Dressing, and separate design for the road with traffic volume less than 2 million standard axles (msa).

The effort of Dr. Padma Bahadur Shahi, for preparation of the guideline; is highly appreciated. The suggestions and experience shared by peer review team, engineers and experts has been incorporated.

I hope the guideline will guide the Department of Roads to follow rational and economic design of road pavements.

Thank You

……………………………

Er. Arjun Jung Thapa
Director General
Department of Roads
April 2021

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Acknowledgement

This 'Guidelines for the Design of Flexible Pavement-2014, Second Revision 2021 is prepared as per the contract agreement between Quality, Research and Development Center (QRDC) and an individual consultant Dr. Padma Bahadur Shahi. The Guidelines has been revised on the basis of the existing Design Guidelines and relevant practices used in India and neighboring countries.

I express my sincere thanks and gratitude to DoR DG Mr. Arjun Jung Thapa, former DoR DG Mr. Keshav Kumar Sharma, former DDG Mr. Shiva Hari Sapkota, former Director, QRDC Mr. Ghanashyam Gautam, Superintending Engineers Mr. Rajendra raj Sharma and QRDC team. The successful Completion of work was possible only with their technical support.

At the same time, I should like to take this opportunity of expressing my sincere thanks to Six Members of Drafting and Review Committee, Er. Prabhat Kumar Jha(SE), Er. Laxmi Dutt Bhatt(SDE), Er. Prem Prakash Khatari, (SDE), Er. Jibendra Mishra(SDE), Er. Shankar Khanal and Er. Shiv Raj Adhakari, for their immense effort in developing this guideline.

I believe that the Guideline will be helpful to all Practicing engineers in Pavement design, Construction and Maintenance.

……………………

Dr. Bijaya Jaishi

Director

Quality, Research and Development Center

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ABBREVIATIONS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
BC	Bituminous Concrete
BM	Bituminous Macadam
CBR	California Bearing Ratio
DBM	Dense Bituminous Macadam
DoR	Department of Roads
E	Elastic Modulus
EF	Equivalent Factor
esa	Equivalent Standard Axles
FHWA	Federal Highway Administration
GB	Granular Base
GSB	Granular Sub Base
IRC	Indian Road Congress
MPa	Mega Pascal
msa	Million Standard Axles
ORN	Overseas Road Notes
PC	Premix Carpet
SDBC	Semi-Dense Bituminous Concrete
SSRBW	Standard Specification for Road and Bridge Works
TRB	Transportation Research Board
TRL	Transportation Research Laboratory
VDF	Vehicle Damage Factor
WBM	Water Bound Macadam
ORN	Overseas Road Note
AASHTO	American Association of State Highway and Transport Officials
TRB	Transport Research Board
SAMI	Stress Absorbing Membrane Interlayer
CTB	Cement Treated Base
CTSB	Cement Treated Sub-base
FHWA	Federal Highway Administration
msa	Million Standard Axles
CFD	Cumulative Fatigue Damage
WMM	Wet Mix Macadam
WBM	Water Bound Macadam
cpvd	Commercial Vehicles Per Day
VDF	Vehicle Damage Factor
AADT	Average Annual Daily Traffic

ADT	Average Daily Traffic
SSRBW	Standard Specifications for Roads and Bridge Works
GBS	Granular Sub-base
CTSB	Cement Treated Sub-base
UCS	Unconfined Compressive Strength
SMA	Stone Matrix Asphalt
GGRB	Gap Graded Rubberized Bitumen
PMC	Premix Carpet
SD	Surface Dressing
BM	Bituminous Macadam
BC	Bituminous Concrete
ITS	Indirect Tensile Strength
BSD	Bituminous Surface Dressing

CONTENTS

1. INTRODUCTION

'Highway Pavement' is most important element for entire highway construction. The overall performance of the road transport sector relies on the well functioning of the pavement in terms of its structural strength as well as surface condition. Besides these, vehicle operating cost and entire highway economics and life cycle are interrelated to the pavement design practice. The design procedure of flexible pavement consists of a number of variables, such as wheel loads, traffic intensity, climate, terrain and sub-grade soil conditions etc. Depending upon specific regional or nationwide characteristics, most of the countries are practicing some empirical and experience based methods for the design of flexible pavement.

DoR has formulated the 'Guidelines for the Design of Flexible Pavement' in 2014. Basic principles in the first design guidelines were taken from the ORN-31, IRC-37-2001, and AASHTO which were relevant in the context of Nepal. The 1st Edition has been withdrawn for pavement design purpose. The changes in the vehicular technology, loading pattern, and intensity of freight traffic, the Guidelines requires in the revision of the method of design and fundamental issues. Furthermore, IRC Guidelines have already been revised in 2018. Therefore, DoR has taken initiation for the revision of this document with the considerations of recent research outcomes, trend in the construction as well as vehicular technology.

This manual is prepared with the view to have an unified approach for working out the design of flexible pavement in Nepal. The objective of this manual is to guide or assist the highway engineer with sufficient information in pavement design so that one could propose a suitable pavement structure for any specific cases of sub-grade soil, traffic scenario and materials available on the site. Furthermore, these guidelines include the design of surface dressing and design of flexible pavements for low volume roads. Worked out examples with the step wise procedure of design have been included in the guidelines.

2. SCOPE AND APPLICABILITY

Guidelines in this booklet are preferred for the design of flexible pavements for National Highways as well as other types of roads such as urban highways with the traffic volume more than 2 million standard axles (msa). Pavement type selection process is presented in section 3.1 that guides for the selection of pavement types such as Surface Dressing or Asphalt concrete with or without DBM or CTB etc. . The design of Surface Dressing is presented in Annex D while Annex E is applicable for the roads with the traffic volume less than 2 million standard axles (msa).

After reviewing the recent development in the construction technology, choice of construction materials as well as growth of traffic intensity, following considerations have been newly incorporated in this Guideline:

- The basis for the construction of bituminous pavement is the "Standard Specifications for Road and Bridge Works, 2073 published by the Department of Roads"
- The concept of Effective California Bearing Ratio (CBR) has been introduced,
- New types of pavement compositions have been recommended such as Cement treated Sub-base/base layers, crack relief layers, Stress Absorbing Membrane Interlayer (SAMI)
- The recent axle load pattern and trend have been considered for new values of Vehicle Damage Factors (VDF),
- Mechanistic-empirical performance models have been taken for the rutting in sub-grade and bottom-up cracking in bituminous layers for two different levels (80% and 90%) of reliability,
- Concepts for reliability for pavement performance equations as 80 % reliability for roads having traffic volume less than 20 msa and 90 % reliability for road having traffic volume more than 20 msa.

The Guidelines may require revision from time to time in the light of future experience and development in the field. The principal users of this manual are the Highway Engineers from government or their agents (i.e. Consultants).

The previous version of Flexible Pavement Design Guidelines 2014 has been taken as the basis for updating and the various other recent design documents have been referred for upgrading the Design Guidelines. The design procedures incorporated in this document are based on the *IRC 37-2018 guidelines*, *American Association of State Highway and Transportation Officials (AASHTO, 1993) Guide for Design of Pavement Structures*, *Transportation Research Board (TRB), Federal Highway Administration (FHWA)* publications, Pavement Structural Design of the Austroads *Guide to Pavement Technology* (Austroads, 2009), *Road Note 31* (TRL, UK, 1993) and *Road Note 3* (TRL, UK, 2000).

3. DESIGN APPROACH AND CRITERIA

The previous design of flexible road pavement is generally thought to be a specialist activity that can only be undertaken by consultants experienced in this type of design. Design approach of empirical methods and failure criteria of pavement surface as well as structure have been taken into considerations in the previous guidelines. In these guidelines the design principle and criteria are described in the below sub-topics.

3.1 Pavement type selection

Pavement type selection is the important and foremost step of pavement design procedure to identify the most beneficial type of pavement structure for a given set of traffic, soils, climate, and other factors. There are options for carrying the pavement type selection process from very simplified as specifying a certain type of pavement on the basis of traffic level, or it may be as complicated as assigning weighting factors to several characteristics and evaluating the outcome through a scoring system.

Pavement type selection process is determined by considering the primary as well as secondary factors.

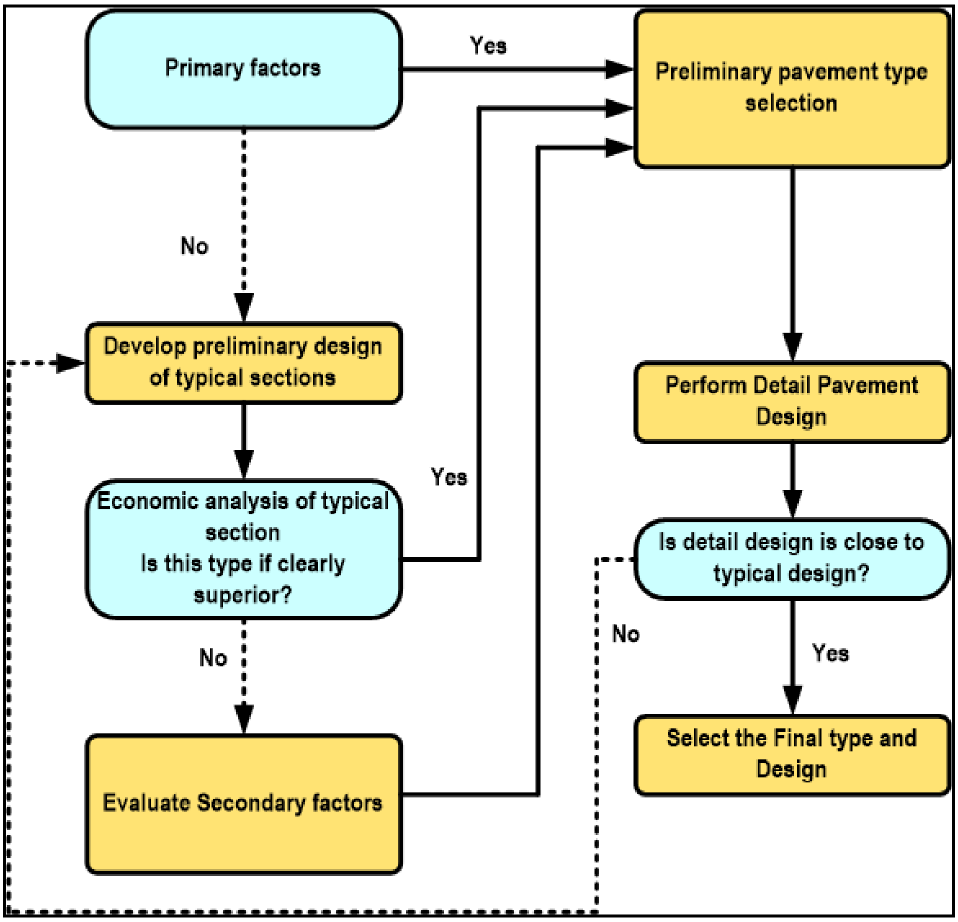


Figure 1: Pavement type selection process

3.1.1 Primary factors

- Traffic: the total volume of traffic affects the geometric requirements of the highway; the percentage of commercial traffic and frequency of heavy load applications generally have the major effect on the structural design of the pavement.

- Soil characteristics: The load-carrying capacity of a native soil, which forms the subgrade for the pavement structure, is of paramount importance in pavement performance. Even in given limited areas the inherent qualities of such native soils are far from uniform, and they are further subjected to variations by the influence of weather.
- Weather: it affects subgrade as well as the pavement wearing course. The amount of rainfall, snow and ice, and frost penetration will seasonally influence the bearing capacity of subgrade materials.
- Construction considerations: Stage construction of the pavement structure may dictate the type of pavement selected. Other considerations such as speed of construction, accommodating traffic during construction, ease of replacement, anticipated future widening, seasons of the year when construction must be accomplished, and perhaps others may have a strong influence on paving type selections in specific cases.
- Recycling: the opportunity to recycle material from an existing pavement structure or other sources may dictate the use of one pavement type. Future recycling opportunities may also be considered.
- Cost of construction: Where there are no overriding factors and several alternate pavement types would serve satisfactorily, cost comparison can be used to assist in determining pavement type.

3.1.2 Secondary Factors

- Performance of the similar pavement in the area: It is important that the experience and judgment of the highway engineer is based on the performance of pavements in the immediate area of his jurisdiction. Past performance is a valuable guide, provided there is good correlation between conditions and service requirements between the reference pavements and the designs under study.
- Adjacent existing pavement: if there is no radical change in conditions, the choice of paving type on highway may be influenced by adjacent existing sections which have given adequate service. The resultant continuity of pavement type will also simplify maintenance operations.
- Conservation of material and energy: Pavement type selection may be determined by the pavement type which contains less of a scarce critical material or the type whose material production, transportation, and placement requires less energy consumption.
- Availability of local materials: The availability and adaptability of local material may influence the selection of pavement type. Also, the availability of commercially produced mixes and the equipment capabilities of area contractors may influence the selection of pavement type, particularly on small projects.
- Traffic safety: The characteristics of wearing course surface, the need for delineation through pavement and shoulder contrast, reflectivity under highway lighting, and the maintenance of a nonskid surface as affected by the available materials may each influence the paving type selection in specific locations.
- Carrying out the experiments: In some instances, the performance of material or design concepts must be determined by field testing under actual construction, environmental, or traffic conditions. Where the material or concept is adaptable to only one paving type, the incorporation of such experimental features may dictate pavement type selection.
- Promotions of competition: It is desirable that monopoly situations be avoided, and that improvement in products and methods be encouraged through continued and healthy competition among industries involved in the production of paving materials.
- Preferences of local industries: As per the priority and preference for the promotion of local industries it can be noted for the selection of pavement type.

3.2 Pavement a multi-layered system

The theory for the analysis of pavements is 'linear elastic layered theory' in which the pavement is modeled as a multi-layer system. The bottom most layer sub-grade is considered as the semi-infinite and all the upper layers are assumed to be infinite in the horizontal extent and finite in thickness. Elastic modulus, Poisson's ratio and thickness of each layer are design inputs required for calculation of stresses, strains and deflections produced by a load applied at the surface of the pavement. ***IITPAVE software*** or ***DoR developed Excel based software*** can be applied for the analysis of the pavement layers.

The sub-grade rutting due to the vertical compressive strain at the top of the sub-grade is taken as the critical mechanistic parameter in this guideline. The horizontal tensile strain at the bottom of the bituminous layer is taken as the contributing mechanistic parameter which has to be limited to control the bottom-up cracking in those layers. The Cement Treated Base (CTB) is checked against the fatigue cracking, tensile strain and tensile stress at the bottom of this layer.

Heavy wheel loads and relatively higher pavement surface temperature may cause the unacceptable extent of the rut depth. The cause of rutting of the bituminous layer is taken as the plastic deformation of these layers due to repeated application of wheel loads. Excessive age hardening of the upper layer may result in brittle cracking. These types of distresses are overcome by making suitable choice of binder and considering its volumetric performance models used in different layers.

Suitable recommendations for the pavement analysis are proposed as:

a. Bottom (Base) layer with Bituminous mixes that are resistant to Fatigue cracking and Moisture damage for the

b. Intermediate (Binder) Layer with Bituminous mixes (if provided) that are resistant to Rut and Moisture damage,

c. Surface course that is resistant to Rut, Moisture damage, Fatigue cracking and Age

d. Drainage layer for removal of excess moisture from the interior of the pavement.

3.3 Performance criteria

Sub-grade Rutting criteria, Fatigue criteria of bituminous layers and Fatigue performance of the CTB have been taken into consideration for design analysis of the pavement layers.

3.3.1 Sub-grade Rutting criteria

An average rut depth of 20 mm or more, measured along the wheel paths, is considered in these guidelines as critical or failure rutting condition [1]. The equivalent number of standard axle load (80 kN) repetitions that can be served by the pavement, before the critical average rut depth of 20 mm or more occurs, is given by Equation 1 and Equation 2 respectively for 80 % and 90 % reliability levels [1].

a) For the reliability of 80 % (design traffic of less than 20 msa):

$$N_R = 4.1656 * 10^{-8} \left[\frac{1}{\varepsilon_v} \right]^{4.5337}$$ *Equation 1*

b) For the reliability of 90 % (design traffic of 20 msa or more):

$$N_R = 1.4100 * 10^{-8} \left[\frac{1}{\varepsilon_v} \right]^{4.5337}$$ *Equation 2*

Where,

N_R: sub-grade rutting life (cumulative equivalent number of 80 kN standard axle loads that can be served by the pavement before the critical rut depth of 20 mm or more occurs.

ε_v: vertical compressive strain at the top of the sub-grade calculated using linear elastic layered theory by applying standard axle load at the surface of the selected pavement system.

The computation of stresses, strains and defections in the pavement is done for the given values of pavement thicknesses and elastic properties (elastic modulus and Poisson's ratio) of different layers. IITPAVE software or Software developed by DoR is taken as the analysis tool for these calculations. All the analysis is done for the traffic loading of 80 kN (single axle with dual wheel). The shape of the contact area of the tyre is assumed in the analysis to be circular. The uniform vertical contact stress shall be considered as 0.56 MPa. However, the contact pressure for fatigue damage analysis of cement treated bases (CTB) is taken as 0.80 MPa. The layer interface condition was assumed to be fully bound for all the layers of the pavement. The materials are assumed to be isotropic.

3.3.2 Fatigue cracking criteria for bituminous layers

The appearance of fatigue cracking on the pavement surface, whose total area in the section of the road under consideration is 20 % or more than the paved surface area of the section, is considered to be the critical or failure condition [1]. The equivalent number of standard axle (80 kN) load repetitions that can be served by the pavement, before the critical condition of the cracked surface area of 20 % or more occurs, is given by Equation 3 and Equation 4 respectively for 80 % and 90 % reliability levels [1].

a) For the reliability of 80 %:

$$N_f = 1.6064 * C * 10^{-4} \left[\frac{1}{\varepsilon_t} \right]^{3.89} \left[\frac{1}{M_{Rm}} \right]^{0.854}$$

Equation 3

b) For the reliability of 90 %:-

$$N_f = 0.5161 * C * 10^{-4} \left[\frac{1}{\varepsilon_t} \right]^{3.89} \left[\frac{1}{M_{Rm}} \right]^{0.854}$$

Equation 4

Where,

$$C = 10^M \; and \; M = 4.84 \left[\frac{V_{be}}{V_a + V_{be}} - 0.69 \right]$$

V_a = per cent volume of air void in the mix used in the bottom bituminous layer,

V_{be} = per cent volume of effective bitumen in the mix used in the bottom bituminous layer,

N_f = fatigue life of bituminous layer (cumulative equivalent number of 80 kN standard axle loads that can be served by the pavement before the critical cracked area of 20 % or more of paved surface area occurs)

ε_t = maximum horizontal tensile strain at the bottom of the bottom bituminous layer (DBM) calculated using linear elastic layered theory by applying standard axle load at the surface of the selected pavement system.

M_{RM} = resilient modulus (MPa) of the bituminous mix used in the bottom bituminous layer, selected as per the recommendations made in these guidelines

The factor '***C***' is an adjustment factor used to account for the effect of variation in the mix volumetric parameters (effective binder volume and air void content) on the fatigue life of bituminous mixes and was incorporated in the fatigue models to integrate the mix design considerations in the fatigue performance model.

3.3.3 Fatigue performance models for Cement Treated Base

The fatigue performance check for the CTB layer should be carried out using Equation 5 [1]. The model is useful when the cumulative standard axle load repetitions are estimated by using vehicle damage factors.

$$N = RF\left[\frac{\left(\frac{113000}{E^{0.804}}+191\right)}{\varepsilon_t}\right]^{12}$$ *Equation 5*

Where,

RF = Reliability factor for cementitious materials for failure against fatigue (for Expressways, National Highways, Sate Highways and Urban Roads = 1 and for other categories of roads if the design traffic is more than 10 msa = 2 for all other cases

N = No of standard axle load repetitions which the CTB can sustain

E = Elastic modulus of CTB material (MPa)

ε_t = Tensile strain at the bottom of the CTB layer

The cumulative fatigue damage of the CTB layer is caused by the application of axle loads of different categories and different magnitudes applied over the design life period. The fatigue life N_{fi} of the CTB material when subjected to a specific number of applications (n_i) of axle load of class ***'i'*** during the design period, is given by Equation 6 [1].

$$\log_{10} N_{fi} = \frac{0.972-(\frac{\sigma_t}{M_{Rup}})}{0.0825}$$ *Equation 6*

Where,

N_{fi} = Fatigue life of CTB material which is the maximum repetition of axle load class 'i' the CTB material can sustain,

σ_t = tensile stress at the bottom of CTB layer for the given axle load class

M_{Rup} = 28-day flexural strength of the cementitious base

$\frac{\sigma_t}{M_{Rup}}$ = Stress ratio

For the purpose of analysis, each tandem axle repetition may be considered as two repetitions of a single axle carrying 50 % of the tandem axle weight as axles separated by a distance of 1.30 m or more do not have a significant overlapping of stresses. Similarly, one application of a tridem axle may be considered as three single axles, each weighing one third the weight of the tridem axle. For example, if a tridem axle carries a load of 45 tonnes, it may be taken to be equivalent to three passes of a 15 tonne single axle.

For analyzing the pavement for cumulative fatigue damage of the CTB layer, contact stress shall be taken as 0.80 MPa instead of 0.56 MPa

The cumulative fatigue damage (CFD) caused by different repetitions of axle loads of different categories and different magnitudes expected to be applied on the pavement during its design period is estimated by using Equation 7 [1].

$$CFD = \sum\left[\frac{n_i}{N_{fi}}\right]$$ *Equation 7*

Where,

n_i = expected (during the design life period) repetitions of axle load of class ***'i'***

N_{fi} = fatigue life or maximum number of load repetitions the CTB layer would sustain if only axle load of class ***'i'*** were to be applied

If the estimated CFD is less than 1.0, the design is considered to be acceptable. If the value of CFD is more than 1.0, the pavement section has to be revised.

3.4 Design Approach and Criteria

These Guidelines recommend 90% reliability performance equations for sub-grade rutting and fatigue cracking of bottom bituminous layer for all important roads such as Expressways, National Highways, State Highways and Urban Roads. For other categories of roads, 90 % reliability is recommended for design traffic volume of 20 msa or more and 80 per cent reliability for design traffic volume of less than 20 msa.

3.5 Analysis of Flexible Pavements

Pavement has been considered as the linear elastic layered system for the calculation of stresses, strains and deflections. IITPAVE software or Software developed by DoR is recommended for the analysis of linear elastic layered pavement systems. The vertical compressive strain on top of sub-grade and the horizontal tensile strain at the bottom of the bituminous layer are considered to be the critical mechanistic parameters which need to be controlled for ensuring satisfactory performance of flexible pavements in terms of sub-grade rutting and bottom-up cracking of bituminous layers. Similarly, the horizontal tensile stress and horizontal tensile strain at the bottom of the CTB layer are considered to be critical for the performance of the CTB base.

The different flexible pavement compositions and the locations of the different critical mechanistic parameters to be calculated are shown in Figure 2, Figure 3 and Figure 4. The critical locations are indicated as dots. Standard conditions for the pavement analysis using IITPAVE software or Software developed by DoR are shown in the table below.

Table 1: Standard conditions for the pavement analysis using IITPAVE software or Software developed by DoR

Analysis Conditions	
Material response model	Linear elastic model
Layer interface condition	Fully bonded (all layers)
No. of Wheels	Dual wheel
Wheel loads	20 kN on each single wheel (two wheels)
Contact stress for critical parameter analysis	0.56 MPa for tensile strain in bituminous layer and vertical compressive strain on sub-grade; 0.80 MPa for CTB
Critical mechanistic parameters	
Bituminous layer	Tensile strain at the bottom
Cement treated base	Tensile stress and tensile strain at the bottom
Sub-grade	Compressive strain at the top

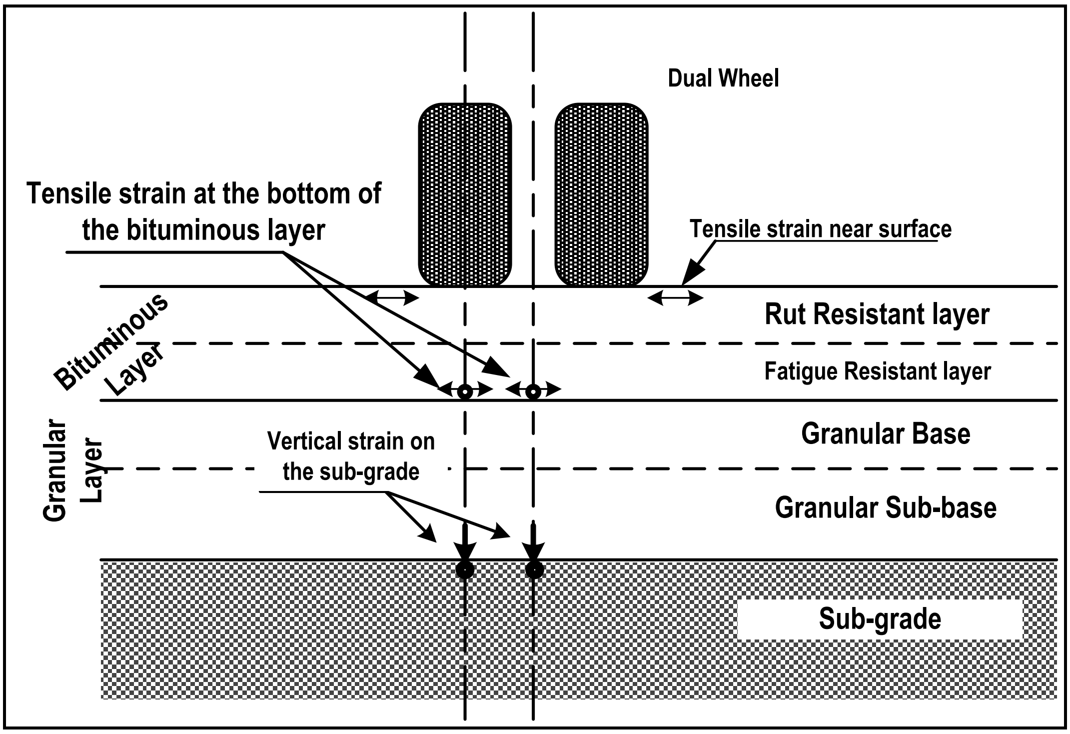


Figure 2: Pavement Section with Bituminous layer(s), Granular Base and GSB and locations of critical strain[1]

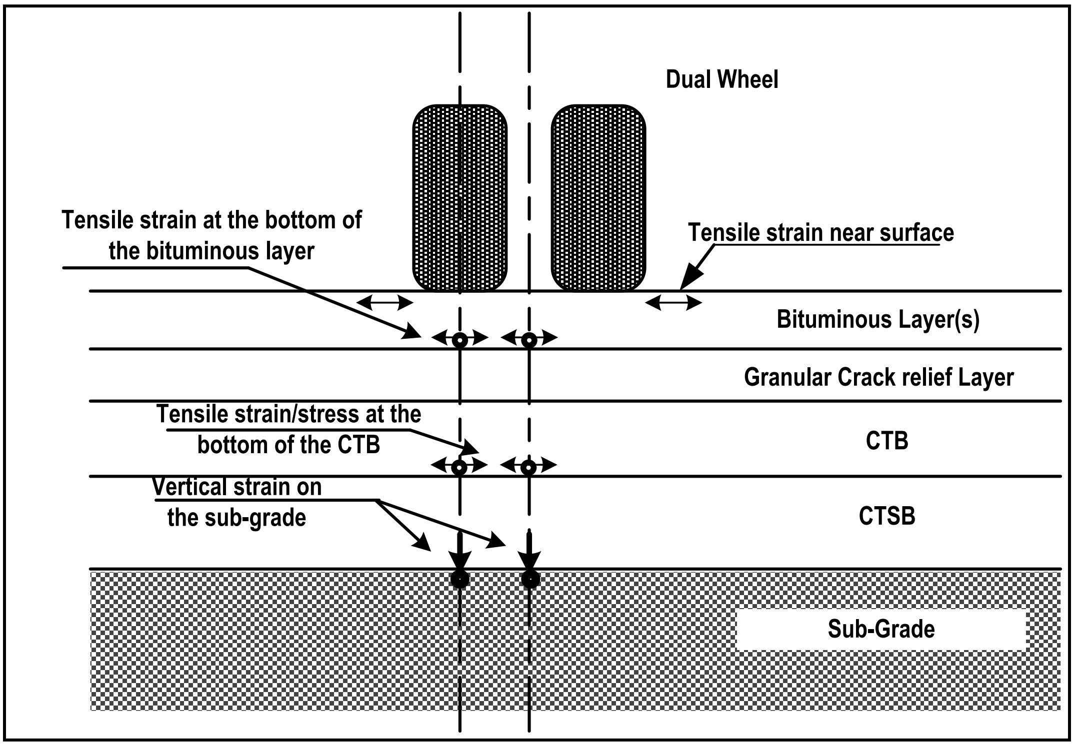


Figure 3: Pavement Section with Bituminous layer(s), Granular crack relief layer, CTB and CTSB and locations of critical strain/ stress[1]

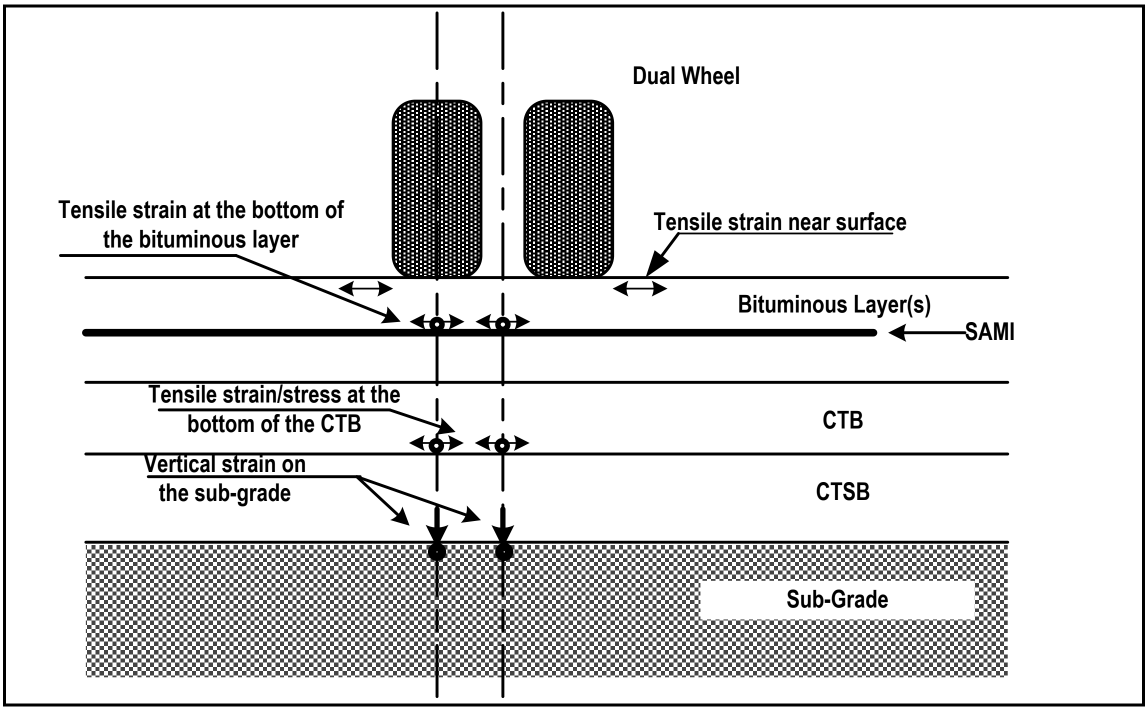


Figure 4: Pavement Section with Bituminous layer(s), SAMI, CTB and CTSB and locations of critical strain/stresss[1]

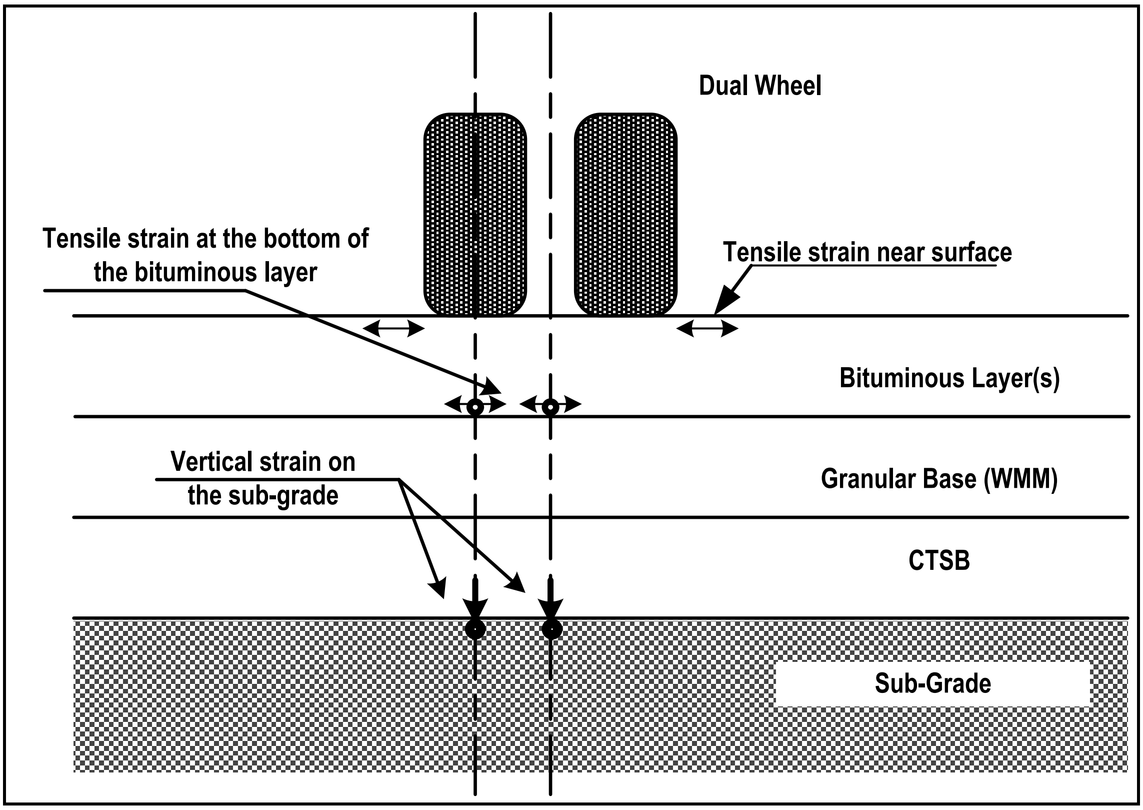


Figure 5: Pavement Section with Bituminous layer(s), Granular Base (WMM) and CTSB and locations of critical strain [1]

4. TRAFFIC

4.1 General

Road pavement failure is mainly due to the traffic movement from both the magnitude of the individual wheel loads and the number of times these loads are applied. The total number of vehicles as well as wheel loads (axle load) should be considered for pavement design. The load imposed by passenger cars does not contribute significantly to the structural damage of the pavement. Therefore, cars and similar sized vehicles can be ignored for the structural design of pavement. Only the total number and the axle loading of the commercial vehicles (heavy vehicles) that will use the road during its design life need to be considered. The structural damage of the pavement layers i.e., fatigue cracking in bound layers and rutting in the sub-grade is caused by the applied traffic loads. The relative structural damage due to the different types of axle-loads is considered by using Vehicle Damage factor (VDF) in the estimation of the design traffic.

The design traffic is estimated in terms of equivalent number of cumulative standard axles (80 kN single axle with dual wheels). For estimating the factors required to convert the commercial traffic volumes into equivalent repetitions of the standard axle, it is necessary to determine the axle load spectrum relevant for the stretch of road under consideration. Axle load spectrum data are especially required for the design of pavements with layers treated/ stabilized using cementitious materials such as cement, lime, fly ash, etc., for estimating the cumulative fatigue damage caused by different axe load groups to the treated base. The following inputs are required for estimating the design traffic (in terms of cumulative standard axle load repetitions) for the selected road for a given design period.

a. Initial Traffic (two-way) volume on the road after construction in terms of the number of commercial vehicles (having the laden weight of 3 tonnes or more) per day (cvpd)
b. Average Traffic growth rate(s) during the design life period
c. Design life in number of years
d. Spectrum of axle loads
e. Lateral distribution factors of commercial traffic over the carriageway

4.2 Traffic growth rate

The calculation of cumulative traffic expected to use the pavement over the design period, shall be based on the estimated traffic growth rate of the commercial vehicles over design period. The estimation of growth rates shall be determined based on the following:

a) Past trends of traffic growth, and

b) Demand elasticity of traffic with respect to macroeconomic parameters such as the Gross Domestic Product (GDP) and State Domestic Product (SDP) and the demand expected due to specific developments and land use changes likely to take place during the design life period. *[Example: If national income is defined as GDP then traffic growth can be calculated as (E x G/100) x 100%, G is the annual real growth rate of GDP, E is the income elasticity of transport demand, which is ratio of % change in transport in transport indicators and % change in economic indicators, is calculated from historical data of annual GDP and vehicle registration number with its type.]*

Traffic growth rates shall be established for each category of commercial vehicles. In the absence of data for estimation of the annual growth rate of commercial vehicles a minimum annual growth rate of ***5 percent*** *shall be used for commercial vehicles for estimating the design traffic. The growth rate for the design of pavement layer could vary depending on the land-use type, status of development plans and projects, existing rate of motorization (registered vehicles per 100,000 populations etc). In fact, growth rate varies for each year of the design life. Generally, growth rate for initial years (after construction or upgrading) is higher than the values for near to the end of the design life.*

4.3 Design period

The time span of functioning of road pavement without major rehabilitation can be considered as the design period. It is recommended that the structural design of the pavement for National Highways a design period of 20 years. However, for expressways pavement shall be designed for the period of 30 years. The commercial traffic, converted into the equivalent repetitions of standard axles and adjusted for directional, lateral distribution over the carriageway width is the design traffic. The design period for the case of low volume roads may be taken as 10 years.

4.4 Vehicle Damage Factor

Vehicle Damage Factor (VDF) is a multiplier to convert the given number of commercial vehicles having different axle configurations and different axle weights into an equivalent number of standard axle load (80 kN single axle with dual wheels) repetitions. In the case of pavements with CTB layer, in addition to the fatigue performance check carried out by using VDF, CFD analysis should also be carried out using axle load spectrum data.

The conversion of one repetition of a particular type of axle carrying a specific axle load into equivalent repetitions of 80 kN single axle with single wheel, single axle with single dual wheel, tandem axle with dual wheel, tridem axle with dual wheel on either sides are given in the equations below:

a) Single axle with single wheel on either side:

$$VDF = \left[\frac{axle\,load\;in\;kN}{65}\right]^4 \qquad \textit{Equation 8}$$

b) Single axle with dual wheel on either side:

$$VDF = \left[\frac{axle\,load\;in\;kN}{80}\right]^4 \qquad \textit{Equation 9}$$

c) Tandem axle with dual wheel on either side:

$$VDF = \left[\frac{axle\,load\;in\;kN}{148}\right]^4 \qquad \textit{Equation 10}$$

d) Tridem axle with dual wheel on either side:

$$VDF = \left[\frac{axle\,load\;in\;kN}{224}\right]^4 \qquad \textit{Equation 11}$$

Above equations can be used for the multi-axle vehicles of different axle configurations. The VDF should be derived by carrying out the axle load survey on the existing roads for a minimum period of 24 hours in each direction. The minimum sample size of commercial vehicles (cv) to be considered for the axle load survey is given in Table 2. On some sections of roads, there may be a significant difference between the axle loads of commercial vehicles plying in the two directions of traffic. In such situations, the VDF should be evaluated separately for each direction.

The axle load spectrum is developed by class interval of the axle load survey data of 10 kN, 20 kN and 30 kN for single, tandem and tridem axles respectively.

Table 2: Minimum sample size of the axle load survey [1]

Commercial traffic volume (cvpd)	Min.% of Commercial Traffic to be surveyed
< 3000	20 per cent
3000 to 6000	15 per cent (subject to a minimum of 600 cv)
> 6000	10 per cent (subject to a minimum of 900 cv)

The axle load survey is not necessary for small projects due to the similar types of commercial vehicles plying on the existing roads. Therefore, after the analysis of recently conducted axle load survey VDF values can be used for the purpose of converting volume of commercial traffic into the number of standard axles for each category of vehicle types as shown in Table 3.

Table 3: Indicate values of VDF

Vehicle type	VDF	Remarks
Heavy truck (three axle or more)	6.50	
Heavy two axle	4.75	hilly terrain 3.5
Mini truck/tractor	1.0	
Large bus	0.50	
Bus	0.35	

4.5 Lateral Distribution of commercial traffic over the carriageway

Total traffic AADT (both way) is distributed over the whole carriageway for design of pavement. During the calculation of design traffic volume (total equivalent standard axle), realistic study should be done for the directional distribution of total traffic. In the absence of adequate and conclusive data for particular project, it is recommended that following distribution may be assumed for design.

a) **Single lane roads:** traffic tends to be more channelized on single lane roads than two-lane roads and to allow for this concentration of wheel load repetitions, the design should be based on total number of commercial vehicles in both direction.
b) Intermediate lane roads of width 5.5 m: Design traffic based on the 75 percent of the two-way commercial traffic.
c) **Two-lane two-way roads:** the design should be based on 50 percent of the total number of commercial vehicles in both directions.
d) **Four-lane single carriageway roads:** the design should be based on 40 percent of the total number of commercial vehicles in both directions.
e) **Dual carriageway roads:** The design of dual two lane carriageway roads should be based on 75 percent of the number of commercial vehicles in each direction. For dual three-lane carriageway and dual four lane carriageway, the distribution factor will be 60 percent and 45 percent respectively.

The traffic in each direction may be assumed to be half of the sum in both directions when the latter only is known. Where significant difference between the two streams can occur, condition in the more heavily trafficked lane should be considered for design.

Where the distribution of traffic between the carriageway lanes and axle loads spectrum for the carriageway lanes are available, the design should be based on the traffic in the most heavily trafficked lane and the same design will normally be applied for the whole carriageway width.

4.6 Traffic Estimation

4.6.1 Base year traffic flow

For the determination of the total traffic over the design life of the road, the first step is to estimate base year traffic flows. The estimate should be the Average Daily Traffic (ADT) currently using the route, classified into the vehicle categories of cars, light goods vehicles, trucks (heavy goods vehicles) and buses. The ADT is defined as the average number of traffic summed for ***both*** directions. Further ADT is multiplied by the seasonal factors to convert it into Average Annual Daily Traffic (AADT). Base year traffic flow can be expressed by using a single number i.e. Passenger Car Unit. It is recommended that traffic count for the purpose of pavement design is conducted for twenty four hours and for seven days.

4.6.2 Traffic forecasting

The extent of future traffic depends on the many factors such as economic, land-use and demographic factors. Therefore, traffic forecasting is an uncertain process. In a developing economy the problem becomes more difficult because such economies are often very sensitive to the world prices of just one or two commodities. In order to forecast traffic growth it is necessary to separate traffic into the following three categories:

a) Normal traffic: Traffic which would pass along the existing road or track even if no new pavement were provided. The common method of forecasting normal traffic is to extrapolate time series data on traffic levels assuming its growth will either remain constant in absolute terms i.e. a fixed number of vehicles per year (a linear extrapolation) or in relative terms i.e. a fixed percentage increase.

b) Diverted traffic: Traffic that changes from another route (or mode of transport) to the project road because of the improved pavement, but still flows between the same origin and destination. Where parallel routes exist, traffic will usually flow on the quickest route although this may not necessarily be the shortest. Thus, improving an existing road surface may divert traffic from a parallel and shorter route to the improved one because of savings in travel time owing to the higher speeds on the improved road surface. Origin and destination surveys should be carried out to provide data on the traffic diversions likely to arise. Diverted traffic is normally assumed to grow at the same rate as traffic on the road from which it is diverted.
c) Generated traffic: Additional traffic which occurs in response to the provision or improvement of the road. Generated traffic arises either because a journey becomes more attractive by virtue of a cost or time reduction or because of the *increased* development that is brought about by the road investment.

Generated traffic is difficult to forecast accurately and can be easily overestimated. It is only likely to be significant in those cases where the road investment brings about large reductions in transport costs. For example, in the case of a small improvement within an already developed highway system, generated traffic will be small and can normally be ignored. However, in the case of a new road allowing access to a undeveloped area, there could be large reductions in transport costs as a result of changing mode from, for example, animal-based transport to motor vehicle transport. In such a case, generated traffic could be the main component of future traffic flow.

4.7 Computation of design traffic

The design traffic is considered in terms of cumulative number of standard axles to be carried during the design life of the pavement. This can be computed as:

$$N = \frac{365*[(1+r)^n - 1]}{r} * A * D * F$$

Equation 12

Where,

N = the cumulative number of standard axles to be catered for in the design in terms of msa

A = Initial traffic in the year of completion of construction in terms of number of commercial vehicles per day

D = Lane distribution factor

F = Vehicle damage factor

n = Design life in year

r = annual growth rate of commercial vehicle (in the absence of detail traffic study r can be taken as 5% i.e 0.05)

The traffic in the year of completion is estimated using the following formula: $A = P(1+r)^x$

Where, ***P*** is the number of commercial vehicles as per the last traffic count; ***x*** is the number of years between the last traffic count and the year of completion of construction.

5. PAVEMENT SUB-GRADE

5.1 General

Flexible pavement mainly consists of functional layers above the sub-grade. These are Sub-base, Base and bituminous layers. Sub-base and base layer may be constructed as granular, cement treated or combination of granular and cement treated materials. When CTB is used, a crack relief layer is to be provided either as an aggregate interlayer or as a stress absorbing membrane interlayer (SAMI). Bituminous layers can be made with the two layers as binder and base bituminous layers.

The top 500 mm of the prepared foundation layer immediately below the pavement is considered as Sub-grade. The level difference between bottom of the sub-grade and the water table flood level generally should not be less than 1.0 m. In water logged areas, where the sub-grade is within the zone of capillary saturation, suitable method of capillary cut-off shall be provided.

The sub-grade in cut and fill should be well compacted to utilize its full strength and to economize on the overall thickness of the pavement required. Heavy compaction is recommended for the construction of expressways, National highways and other roads including urban roads. The Standard Specification for Road and Bridge Works, 2073 (SSRBW) describes the provision of Capping layer (Clause 1004), mechanical stabilization (Clause 1005) and Lime stabilization (Clause 1006) for the preparation of sub-grade in different soil conditions. The general requirements for the construction detail of sub-grade should be referred to the Section 1000 of Standard Specifications for Road and Bridge Works, 2073.

The type of soil used in the different stretches of the sub-grade varies along the length of the road. The CBR value of each type should be the average of at least three specimens prepared using that soil. 90th percentile sub-grade CBR should be adopted for the design of high volume roads such as expressways and National Highways. The design can be based on the 80th percentile CBR value for the roads with the design traffic volume of less than 20 msa.

5.2 Resilient Modulus of the Sub-grade

Resilient modulus is the measure of its elastic behaviour determined from recoverable deformation in the laboratory tests. The resilient modulus of soils can be determined in the laboratory by conducting the repeated tri-axial test as per the procedure detailed in AASHTO T307-99. However, the resilient modulus of sub-grade soil (MRS) can be estimated from its CBR value by using the following equations.

$$M_{RS} = 10.0 * CBR \qquad \textbf{(for CBR} \le 5\%) \qquad \textit{Equation 13}$$

$$M_{RS} = 17.6 * (CBR)^{0.64} \qquad \textbf{(for CBR} > 5\%) \qquad \textit{Equation 14}$$

Where,

MRS = Resilient modulus of sub-grade soil (in MPa).

CBR = California bearing ratio of sub-grade soil (in %)

Poisson's ratio value of sub-grade soil may be taken as 0.35.

5.3 Effective Modulus/ CBR for Design

Sometimes, there may be a significant difference between the CBR values of the soils used in the sub-grade and in the embankment layer below the sub-grade. Alternatively, the 500 mm thick sub-grade may be laid in two layers, each layer material having different CBR value. In such cases, the design should be based on the effective modulus/ CBR value of a single layer sub-grade which is equivalent to the combination of the sub-grade layer(s) and embankment layer. The effective modulus/CBR value may be determined as per the following procedure.

a) Determine the maximum surface deflection (***σ***) due to a single wheel load of 40,000 N and a contact pressure of 0.56 MPa for two or three layer elastic system comprising of a single (two sub-layers) of the 500 mm thick sub-grade over the semi-infinite embankment layer The elastic modulus of sub-grade and embankment soils/ layers may be estimated by using the Equation 13 and Equation 14. This calculation can be performed by using the IITPAVE software or Software developed by DoR.

b) Effective Resilient Modulus (***M_{RS}***) of an equivalent layer can be calculated by using Equation 15.

$$M_{RS} = \frac{2(1-\mu^2)pa}{\sigma}$$ *Equation 15*

Where,

p = contact pressure, 0.56 MPa

a = radius of circular contact area, which can be calculated by using the load applied (40,000 N) and the contact pressure 'p' (0.56 MPa); 150.8 mm

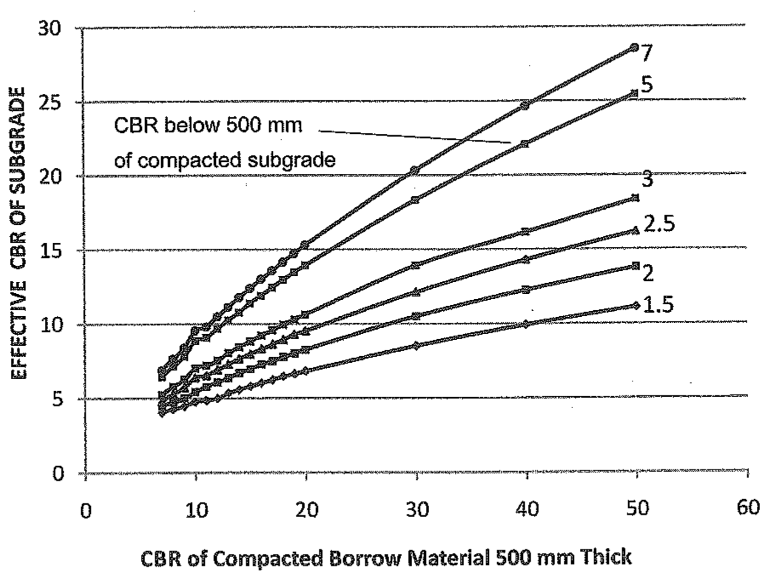
ϑ = Poisson's Ratio

The detail procedure with worked-out example for determining the effective Resilient Modulus (M_{RS}) is shown in ***ANNEX C***.

In case the borrow material is placed over a rocky foundation, the effective CBR may be larger than the CBR of the borrow material. However, only the CBR of the borrow material shall be adopted for the pavement design. Additionally, proper safeguards should be taken against the development of pore water pressure between the rocky foundation and the borrow material.

If the embankment consists of multiple layers of materials having different CBR values, multi- layer analysis can be carried out using IITPAVE software or Software developed by DoR and the effective resilient modulus can be estimated using the concept discussed above.

For the purpose of design, the resilient modulus (MRS), thus estimated, shall be limited to a maximum value of 100 MPa.
The effective sub-grade CBR should be more than 5 % for roads estimated to carry more than 450 commercial vehicles per day (cvpd) (two-way) in the year of construction.



If CBR is less than 5%, Capping Layer Material (CBR>15%) shall be used as subgrade, and effective CBR shall be calculated from above graph. Example: If Ground CBR is 2%, and we propose Capping Layer of 20% CBR, the effective CBR for pavement design is 8.5%. (Source IRC 37: 2012)

6. SUB-BASE

6.1 Granular Sub-base layer

Sub-base layer are mainly provided for supporting the compacted granular base (WMM/ WBM) layer, protecting the sub-grade from overstressing and serving as drainage and filter layers. Material requirements and construction procedure of Granular Sub-base shall be conformed as Standard Specification for Road and Bridge Works, 2073 (Clause 12001). Cement treated Sub-base shall be constructed as mentioned in Clause 1202.

The grading requirement is given in Table 12.1 of the Standard Specifications and physical requirement in Table 12.2. Gradings III and IV shall preferably be used in lower sub-base. Gradings V and VI shall be used as sub-base cum drainage layer. The minimum thickness of the granular sub-base shall be as:

a) The minimum thickness of drainage as well as filter layer (two layers) shall not be less than 200 mm (100 mm minimum thickness of each layer).

b) The minimum thickness of a single filter-cum-drainage layer shall be 150 mm for functional requirements.

c) The minimum thickness of any compacted granular layer should preferably be at least 2.5 times the nominal maximum size of aggregate subject to a minimum of 100 mm.

d) The two-layer system (sub-grade and GBS) should be analyzed by placing a standard load over it (dual wheel set of 20,000 N each creating the contact pressure of 0.56 MPa) and computing (Using IITPAVE software or Software developed by DoR) the maximum sub-grade vertical compressive strain. The GBS thickness should be verified until the computed strain, given by Equation 1 and Equation 2.

The testing of the adequacy of the Granular Sub-base thickness is given in the ***ANNEX C***.

6.2 Resilient Modulus of Granular Sub-base (GSB) layer

The Resilient Modulus value of the granular layer is dependent on the resilient modulus value of the foundation or supporting layer on which it rests and the thickness of the Granular Sub-base layer. The Resilient Modulus of granular layer can be calculated by using Equation 16.

$$M_{RGRAN} = 0.2(h)^{0.45} * M_{RSUPPORT}$$ *Equation 16*

Where,

h = Thickness of the granular layer

M_{RGRAN} = Resilient Modulus of the granular layer (MPa)

$M_{RSUPPORT}$ = Effective Resilient Modulus of the supporting layer (MPa)

6.3 Cement Treated Sub-base (CTSB) Layer

The construction of Cement Treated Sub-base payer is mentioned in SSRBW, 2073. The material used for cement treatment shall be soil including sand and gravel, laterite, kankar, brick aggregate, crushed rock or slag or any combination of these. For use in a sub-base course, the material shall be of grading shown in Table 12.3. It shall have a uniformity coefficient not less than 5, capable of producing a well closed surface finish. For using as base course, the material shall be sufficiently well graded to ensure a well-closed surface finish and have a grading within the range given in Table 12.3. If the material passing 425 micron sieve is plastic, it shall have a liquid limit not greater than 45 percent and plasticity index not greater than 20 percent.

Recommended minimum thickness for CTSB layer is 200 mm.

6.4 Mechanical properties of CTSB

The elastic modulus (E) of the CTSB material may be estimated from the Unconfined Compressive Strength (UCS) of the material. The cement Treated Sub-base (CTSB) should have a 7-day UCS of 1.5 to 3.0 MPa. Third point loading test flexural modulus E_{CGSB} of 28-day cured CTSB material can be estimated by using the following equation.

$$E_{CTSB} = 1000 * UCS$$ *Equation 17*

Where,

UCS = 28-day unconfined compressive strength (MPa) of the cementitious granular material. It should be ensured that the average laboratory strength value should be more than 1.5 times the required (design) field strength.

E_{CTSB} = Elastic modulus (MPa) of 28-day cured CTSB material

The typical Cement Treated Granular Sub-base materials, the E_{CTSB} can vary from 2000 to 6000 MPa. Poisson's ratio value of CTSB layer may be taken as 0.25.

7. BASE COURSE

7.1 Unbound Base layer

Unbound granular bases are various types such as Water Bound Macadam base (Clause 1203), Crusher Run Macadam base (clause 1204), Telford Base (Clause 1206), Dry Bound base (1207) and Wet Mix macadam (1208) base. These bases are prepared as per the Standard Specifications for Road and Bridge Works. Similarly the base materials must satisfy the grading and physical requirements for respective types as mentioned in the Standard Specifications. The recommended minimum thickness of granular base is 150 mm.

The thickness of the unbound granular layer shall not be less than 150 mm except for the crack relief layer placed over cement treated base for which the thickness shall be 100 mm.

When both sub-base and the base layers are made up of unbound granular layers, the composite resilient modulus of the granular base can be estimated using Equation 16 taking M_{RGRAN} as the modulus of the combined (GSB and Granular base) granular layer in MPa, ***'h'*** as the combined thickness (mm) of the granular sub-base and base and $M_{RSUPPORT}$ as the effective modulus (MPa) of the sub-grade.

For the granular base placed on CTSB layer, the resilient modulus may be taken as 300 MPa and 350 MPa for natural gravel and crushed rock respectively. Poisson's ratio of granular bases and sub-bases may be taken as 0.35.

7.2 Cementitious base layer

The material used for cement treatment shall be soil including sand and gravel, laterite, kankar, brick aggregate, crushed rock or slag or any combination of these. The materials for the base layer shall be sufficiently well graded to ensure a well-closed surface finish and have a grading within the range given in Table 12.3. If the material passing 425 micron sieve is plastic, it shall have a liquid limit not greater than 45 per cent and plasticity index not greater than 20 percent determined in accordance with IS:2720 (Part 5). The physical requirements for the material to be treated with cement for use in a base course shall be same as for Grading I Granular Sub-base, Clause 1201.

The CTB material shall have a minimum unconfined compressive strength (UCS) of 4.5 to 7 MPa in 7/28 days. While the conventional cement stabilized material should attain this strength in seven days, granular materials and soil-aggregate mixture stabilized with lime, pozzolanic stabilizers, lime-fly ash etc., should meet the above strength requirement in 28 days since the strength gain in such materials is a slow process. As considered in the case of sub-base, average laboratory strength values should be 1.5 times the required minimum (design) field strength.

For the functional requirement, the thickness of cement treated bases shall not be less than 100 mm. The procedure to be followed for the estimation of the thickness of the CTB layer required to cater to the construction traffic has been illustrated in ***Annex II.***

The elastic modulus of cementitious base depends upon the quality of materials. Elastic Modulus (ECTB) can be estimated by using Equation 17 from the 28 day unconfined compressive strength (UCS) of CTB material. Poisson's ratio value of CTB material may be taken as 0.25.

Strength of cementitious layers keeps on rising with time and an elastic modulus of 5000 MPa may be considered for analysis of pavements with CTB layers having 7/28 day unconfined compression strength values ranging between 4.5 to 7 MPa.

7.2.1 Flexural strength (modulus of rupture) of CTB material

The modulus of rupture (M_{RUP}) or flexural strength of the CTB material is required for carrying out fatigue damage analysis of the cement treated base. The values of modulus of rupture (MPa) for cementitious bases may be taken as 20 per cent of the 28-day UCS value (MPa), subject to the following limiting values:

- Cementitious stabilized aggregates: 1.40 MPa
- Lime-flyash-soil: 1.05 MPa
- Soil-cement: 0.70 MPa

7.2.2 Durability criteria

The minimum cementitious material in the bound base layer should be such that in a wetting and drying test (BIS: 4332 Part-IV, the loss of weight of the stabilized material does not exceed 14 per cent after 12 cycles of wetting and drying. In cold and snow bound regions durability should also be evaluated by freezing and thawing test and the loss of weight should be less than 14 per cent after 12 cycles as per BIS: 4332 Part-IV.

7.3 Crack Layers

In case of pavements with CTB, a crack relief layer, provided between the bituminous layer and the cementitious base, delays the reflection of crack from the CTB layer in to the bituminous layer. The crack relief layer may consist of dense graded crushed aggregates of 100 mm thickness conforming to specifications for wet mix macadam (WMM) or the Stress Absorbing Membrane Interlayer (SAMI) of elastomeric modified binder applied at the rate of 10 – 12 kg /10 m^2 covered with 0.1 m^3 of 11.2 mm aggregates. For the pavement analysis, the SAMI layer is not considered as a structural layer, i.e., it shall not be included in the pavement composition for pavement analysis.

The resilient modulus of a well-graded granular layer may be taken as 450 MPa for the analysis of pavement. Poisson's ratio of the granular crack relief layer may be taken as 0.35.

8. BITUMINOUS LAYERS

8.1 General

Bituminous surfacing shall consist of either a wearing course or a binder course with a wearing course depending upon the traffic to be carried. For high traffic volume roads with a design traffic of 50 msa or more, (a) Stone Matrix Asphalt (SMA), (b) Gap Graded mix with rubberized bitumen (GGRB) and (c) Bituminous Concrete (BC) with modified binders, are recommended for surfacing course for durable, aging resistant and crack resistant surface courses. For the Stone Matrix Asphalt (SMA) mix recommended for high traffic volume roads also, use of modified binders is preferred as it is expected that mixes with modified binders will result in longer service life and will be more resistant to aging. For roads with design traffic in the range of 20 to 50 msa, BC with VG40 bitumen can also be used for the surface course. For highly stressed areas or roads in high rainfall areas and junction locations, mastic asphalt mix can be used as an alternative surface course.

The Highways with less than 20 msa design traffic are recommended to build the wearing courses of Bituminous Concrete, Pre-Mix Carpet (PMC) and Surface Dressing (SD) with unmodified binders. The thin bituminous layers such as PC and SD shall not be considered as part of the bituminous layer for analysis of the pavement.

Dense Bituminous Macadam (DBM) mix with VG40 binder and confirming to Standard Specifications (Clause 1208), shall be the material used for base/ binder courses for roads with 20 msa or more design traffic. Dense Bituminous Macadam (DBM)/ Bituminous Macadam (BM) can be used as base/ binder courses for roads with design traffic less than 20 msa.

These guidelines recommend VG30/ VG40 bitumen for design traffic less than 20 msa and VG40 bitumen and modified bitumen for design traffic greater than 20 msa. For expressways and national highways, even if the design traffic is 20 msa or less, VG40 or modified bitumen shall be used for surface course and VG40 bitumen shall be used for the DBM.

In view of the overlap in the viscosity ranges specified in IS:73 for VG30 and VG40 bitumen, it is recommended that the VG40 bitumen used in the surface, binder and base bituminous courses shall have a minimum viscosity of 3600 Poise at 60^0 C temperature to safeguard against rutting. For snow bound locations, softer binders such as VG10 may be used to limit thermal transverse cracking (especially if the maximum pavement temperature is less than 30^0 C).

If the total thickness of the bituminous layers is less than 40 mm, VG30 bitumen may be used for the BC layers even if VG40 bitumen may be more appropriate from pavement temperature consideration. Thin pavements will deflect more under the traffic loads and stiffer VG40 mixes may not have adequate flexibility to undergo such large deflections [1]

The summary of bituminous mixes and binders recommended in the present guidelines is presented in Table 4

Table 4: Summary of Bituminous layer options recommended in these guidelines [1]

S/N	Traffic Level	Surface course		Base/Binder Course	
		Mix type	**Bitumen type**	**Mix type**	**Bitumen type**
1	>50 msa	SMA	Modified bitumen or VG40	DBM	VG40
		GGRB	Crumb rubber modified bitumen		
		BC	With modified bitumen		
2	20-50 msa	SMA	Modified bitumen or VG40	DBM	VG40
		GGRB	Crumb rubber modified bitumen		
		BC	With modified bitumen or VG40		
3	<20 msa	BC/DBC/PMC/MSS/ Surface Dressing	VG40 or VG30	DBM/ BM	VG40 or VG30

Special considerations can be provisioned as follow:

- Mastic Asphalt can also be used for roads in high rainfall areas and junction locations,
- BC/ DBC with VG30 is recommended if total bituminous layer requirement is less than 40 mm.
- VG10 bitumen may be used in the snow bound locations.

8.2 Resilient modulus of bituminous mixes

Resilient modulus of bituminous mixes depends upon the grade of binder, frequency/ load application time, air voids, shape of aggregate, aggregate gradation, maximum size of the aggregate, bitumen content, etc. Indicative maximum values of the resilient moduli of different bituminous mixes with different binders are given in Table 5.

Table 5: Indicative values of resilient modulus (MPa) of bituminous mixes [1]

Mix type	Average Annual Pavement Temperature				
	20	25	30	35	40
BC and DBM for VG10 bitumen	2300	2000	1450	1000	800
BC and DBM for VG30 bitumen	3500	3000	2500	2000	1250
BC and DBM for VG40 bitumen	6000	5000	4000	3000	2000
BC with Modified Bitumen (IRC: SP: 53)	5700	3800	2400	1600	1300
BM with VG10 bitumen	500 MPa at 35°C				
BM with VG30 bitumen	700 MPa at 35°C				

These guidelines recommend measurement of the resilient modulus at a temperature of 35°C as per ASTM: 4123 with an assumed Poisson's ratio value of 0.35. For the measurement of the resilient modulus of DBM, 150 mm diameter specimens should be used because of the larger size of aggregates used in the DBM mixes.

These guidelines, consider that all the bituminous layers in the pavement shall be as one layer in the analysis of the pavement and will be assigned the same elastic properties (elastic/resilient modulus and Poisson's ratio). It is recommended that the bituminous layer (combination of all the bituminous layers) shall be assigned the modulus value of the DBM mix (bottom DBM mix if two DBM layers are used) for analysis and design.

The design of pavement shall be carried out based on the actual values obtained with field designed DBM/ BM mix subject to the maximum values indicated in Table 5 for the selected mix (DBM/ BM mixes with selected unmodified binder) for an average annual pavement temperature of 35°C. If the resilient modulus value of the specimens prepared using the field bottom (base) bituminous mix is more than the corresponding maximum value indicated in Table 5 for 35°C, the value given in the table shall be used for the analysis and design.

Modified binders are not recommended for the DBM layers due to the concern about the recyclability of DBM layers with modified binders.

Note: for the purpose of design:-

a) Resilient modulus measured at 35°C temperature as per ASTM 4123 shall be adopted. For snowbound areas resilient modulus shall be measured at 20°C,

b) The same indicative maximum modulus values are recommended for BC (surface course) as well as DBM (binder/base course) with unmodified binders,

c) The resilient modulus values for surfacing courses with modified bitumen shall be taken to be same as the resilient modulus values indicated for DBM

The empirical relationships between resilient modulus and indirect tensile strength test of different bituminous mixes have been developed and are recommended for arriving at a reasonable estimation of the resilient modulus value.

- Resilient Modulus of 150 mm diameter DBM specimens at 35°C:

$$M_r = 11.088 * ITS - 3015.80 \qquad (R^2 = 0.68)$$ *Equation 18*

- Resilient Modulus of 102 mm diameter specimens with elastomeric polymer modified binder mixes at 35°C

$$M_r = 1.1991 * ITS + 1170 \qquad (R^2 = 0.89)$$ *Equation 19*

Where,

ITS = Indirect tensile Strength in kPa

M_r = resilient Modulus in MPa

- A Poisson's ratio value of 0.35 is recommended for the bituminous layer for analysis of the pavement.

The bitumen rich DBM bottom layer is recommended for longer life of bituminous pavements, to avoid moisture induced distresses and for better bottom-up fatigue resistance. The rich bottom mixes are typically designed to have more binder volume by selecting lower design air void content which yields more design binder content than normal. It is also a common practice to compact the rich bottom bituminous mixes to smaller in-place air voids. The increased compaction adopted for these mixes will result in mixes with good aggregate interlocking and will make the mixes stiffer. The increased compaction will also reduce the mix rutting that might be produced in the mix by secondary compaction under traffic load stresses.

The minimum thicknesses of different bituminous layers shall be as per relevant Standard Specifications and these guidelines. In the case of pavements with cement treated bases (CTB) for traffic exceeding 20 msa, the combined total thickness of surface course and base/ binder course shall not be less than 100 mm irrespective of the actual thickness requirement obtained from structural consideration.

9. LONG-LIFE PAVEMENTS

A long-life pavement is generally designed for the life of fifty years or longer. In other words, such pavement is termed as ***perpetual pavement***. It is recommended that pavements with design traffic of 300 msa or more shall be designed as long-life pavements. As per Asphalt Institute, MS-4, 7th edition [24], if the tensile strain caused by the traffic in the bituminous layer is less than 70 micro strain (considered to be the endurance limit of the material), the bituminous layer will never crack. Similarly, if the vertical sub-grade strain is less than 200 micro strain, there will be practically very little rutting in the sub-grade. The long-life pavement design involves selecting a suitable pavement layer combination which can keep the horizontal tensile strain and vertical compressive strain limited to the afore-mentioned limiting strain values corresponding to endurance condition. Different layers of the long life pavement have to be designed and constructed in such a way that only the surface course would need replacement from time to time. A design example is given in ***Annex-C.***

10. PAVEMENT DESIGN PROCEDURE

10.1 Design steps

10.1.1 Selecting a trial composition:

The pavement composition is selected as guided by the expected functional requirements of the layers in a high performing pavement, such as a strong sub-grade, a well-drained sub-base strong enough to withstand the construction traffic loads, a strong bituminous base that is resistant to crack, rutting and moisture damage and a bituminous surfacing that is resistant to rutting, top-down cracking and damages caused by exposure to environment.

10.1.2 Bituminous Mix design and the mix resilient modulus:

The ingredients for the mix have to be decided and the physical requirements/ properties of the sourced materials shall be checked for their conformity with the provisions of applicable Specifications and Guidelines. The right proportioning of the mix ingredients or the design mix should be achieved by trials and testing. Where the resilient modulus is required to be tested in accordance with the procedures recommended in these Guidelines, the samples of the design mix should be appropriately tested as specified. Where the resilient modulus is required to be derived indirectly by using empirical equations given in these Guidelines or are to be adopted as per a certain recommended value, the modulus should be selected/ determined accordingly and used for design subject to the compliance with the conditions specified in these Guidelines. In case the resilient modulus determined in this manner exceeds the limiting values specified in these Guidelines, the latter value has to be adopted. In case, it is less than the limiting value, the actual value should be adopted in the design.

10.1.3 Selecting layer thickness:

The selection of trial thicknesses of various layers constituting the pavement should be based on the designers' experience and subject to the minimum thicknesses recommended in these Guidelines and in other relevant specifications (when there is no specific recommendation in these guidelines) from functional and constructability considerations.

10.1.4 Structural Analysis of the selected pavement structure:

The analysis shall be done by running the IITPAVE software or Software developed by DoR using the layer thicknesses, the layer moduli, the layer Poisson's ratio values, the standard axle load of 80 kN distributed on four wheels (20 kN on each wheel), and a tyre pressure as 0.56 MPa as inputs. For carrying out fatigue damage analysis of cement treated bases, the axle load under consideration and a contact pressure of 0.80 MPa shall be considered. The program will give output values of stresses, strains and deflections at selected critical locations in the pavement from which the values of critical mechanistic parameters can be identified for design. Table 6 gives the details of different inputs to be considered for the analysis.

Table 6: Recommended material properties for structural layers [1]

Material Type	Elastic/Resilient modulus (MPa)	Poisson's Ratio
Bituminous layer with VG40 or Modified Bitumen	3000 or tested value (whichever is less)	0.35
Bituminous layer with VG30	2000 or tested value (whichever is less)	0.35
Cement treated base	5000	0.25
Cold recycled base	800	0.35
Granular interlayer	450	0.35
Cement treated sub-base	600	0.25
Unbound granular layers	Use Eq. 7.1	0.35
Unbound granular base over CTSB sub-base	300 for natural gravel 350 for crushed aggregates	0.35 0.35
Sub-grade	Use Eq. 6.1 or 6.2	0.35

10.1.5 Computing the allowable strains/ stresses:

The allowable strains in the bituminous layer and sub-grade for the selected design traffic are to be estimated using the fatigue and rutting performance (limiting strain) models given in these guidelines. The inputs to the models are the design period of pavement in terms of cumulative standard axles, the resilient modulus value of the bottom layer bituminous mix, and the volumetric proportions (air voids and effective binder) of the mix. For estimating the limiting tensile strain in the CTB layer, the elastic modulus of the CTB material is an input.

10.1.6 Doing the iterations:

A few iterations may be required by changing the layer thicknesses until the strains computed by IITPAVE software or Software developed by DoR are less than the allowable strains derived from performance models.

10.1.7 Check for cumulative fatigue damage:

Where cementitious bases are used in the pavement, the cumulative fatigue damage analysis is required to be done as done in the case of rigid pavement design to make sure that the cumulative proportion of damage caused by the expected axle load spectrum does not exceed unity.

10.1.8 Minimum Thickness

The minimum thicknesses, as specified in the guidelines, shall be provided to ensure intended functional requirement of the layer.

In the case of relatively low traffic volume roads, with design traffic not exceeding 50 msa, and in situations where investigations prior to design are not feasible on account of exigency, a thickness design catalogue is provided in these Guidelines to help the designers.

11. ALTERNATIVES FOR PAVEMENT CONFIGURATION

For all roads with more than 2 msa design traffic, the design shall be carried out using site specific inputs to satisfy the mechanistic-empirical performance models given in these guidelines which may require analysis of different trial pavement sections using IITPAVE software or Software developed by DoR. The design table for flexible pavement with Bituminous Surface Course with granular base and Sub-base (Figure 6) upto 250 msa are presented in below table 7 to 15.

Table 7: Effective CBR = 5%

Design Traffic, msa	GBS, mm	Base (WMM), mm	DBM, mm	AC, mm
5	200	250	0	40
10	250	250	0	40
20	250	250	0	60
30	300	300	75	40
40	300	300	90	40
50	300	300	110	40
70	300	300	150	40
80	300	300	150	50
90	300	300	150	60
100	300	300	150	60
110	300	300	150	65
120	300	300	150	75
130	300	300	150	80
140	300	300	150	85
150	300	300	150	90
160	300	300	150	95
170	300	300	150	95
180	300	300	150	100
190	300	300	150	105
200	300	300	150	110
250	300	300	150	120

Table 8: Effective CBR = 6%

Design Traffic, msa	GBS, mm	Base (WMM), mm	DBM, mm	AC, mm
5	200	200	0	40
10	250	250	0	40
20	250	200	0	60
30	300	250	60	40
40	300	300	60	40
50	300	300	75	40
70	300	300	100	40
80	300	300	100	50
90	300	300	100	60
100	300	300	110	60
110	300	300	115	60
120	300	300	125	65
130	300	300	130	65
140	300	300	135	65
150	300	300	140	65
160	300	300	150	65
170	300	300	150	65
180	300	300	150	70
190	300	300	150	75
200	300	300	150	80
250	300	300	150	95

Table 9: Effective CBR = 7%

Design Traffic, msa	GBS, mm	Base (WMM), mm	DBM, mm	AC, mm
5	200	150	0	40
10	250	200	0	40

20	200	200	0	60
30	250	250	60	40
40	300	250	60	40
50	300	300	60	40
70	300	300	70	40
80	300	300	75	40
90	300	300	75	50
100	300	300	75	50
110	300	300	90	50
120	300	300	90	60
130	300	300	95	60
140	300	300	100	65
150	300	300	105	65
160	300	300	110	65
170	300	300	115	65
180	300	300	120	65
190	300	300	120	70
200	300	300	120	75
250	300	300	135	75

Table 10: Effective CBR = 8%

Design Traffic, msa	GBS, mm	Base (WMM), mm	DBM, mm	AC, mm
5	200	150	0	40
10	250	150	0	40
20	200	200	0	60
30	300	200	50	40
40	300	200	50	40
50	300	250	60	40
70	300	250	65	40
80	300	300	70	40
90	300	250	75	40
100	300	250	75	50
110	300	300	75	50
120	300	300	80	50
130	300	300	80	50
140	300	300	85	50
150	300	300	85	50
160	300	300	90	50
170	300	300	90	50
180	300	300	95	50
190	300	300	100	50
200	300	300	105	50
250	300	300	115	60

Table 11: Effective CBR = 9%

Design Traffic, msa	GBS,mm	Base (WMM), mm	DBM, mm	AC, mm
5	150	150	0	40

10	200	150	0	40
20	200	150	0	60
30	250	200	50	40
40	250	200	50	40
50	250	200	60	40
70	300	200	65	40
80	300	250	70	40
90	300	250	70	40
100	300	250	75	40
110	300	300	75	40
120	300	300	80	40
130	300	300	85	40
140	300	300	85	40
150	300	300	90	40
160	300	300	90	40
170	300	300	95	40
180	300	300	95	40
190	300	300	100	40
200	300	300	100	40
250	300	300	100	50

Table 12: Effective CBR = 10%

Design Traffic, msa	GBS, mm	Base (WMM), mm	DBM, mm	AC, mm
5	150	150	0	40
10	150	150	0	40
20	150	150	0	60
30	250	150	50	40
40	250	200	50	40
50	300	200	50	40
70	300	200	60	40
80	300	300	60	40
90	300	200	70	40
100	300	200	75	40
110	300	250	75	40
120	300	300	75	40
130	300	300	80	40
140	300	300	80	40
150	300	300	85	40
160	300	300	85	40
170	300	300	90	40
180	300	300	90	40
190	300	300	95	40
200	300	300	95	40
250	300	300	95	50

Table 13: Effective CBR = 11%

Design Traffic, msa	GBS,mm	Base (WMM), mm	DBM, mm	AC, mm
5	150	150	0	40
10	150	150	0	40

20	150	150	0	60
30	200	150	50	40
40	250	150	50	40
50	250	250	50	40
70	250	200	60	40
80	300	200	60	40
90	300	300	60	40
100	300	300	65	40
110	300	300	65	40
120	300	300	70	40
130	300	300	75	40
140	300	300	75	40
150	300	300	80	40
160	300	300	80	40
170	300	300	85	40
180	300	300	85	40
190	300	300	90	40
200	300	300	90	40
250	300	300	90	50

Table 14: Effective CBR = 12%

Design Traffic, msa	GBS, mm	Base (WMM), mm	DBM, mm	AC, mm
5	150	150	0	40
10	150	150	0	40
20	150	150	0	60
30	200	150	50	40
40	250	150	50	40
50	250	150	50	40
70	250	150	60	40
80	250	200	60	40
90	300	250	60	40
100	300	300	60	40
110	300	300	65	40
120	300	300	65	40
130	300	300	70	40
140	300	300	70	40
150	300	300	75	40
160	300	300	80	40
170	300	300	80	40
180	300	300	85	40
190	300	300	85	40
200	300	300	90	40
250	300	300	90	50

Table 15: Effective CBR = 15%

Design Traffic, msa	GBS,mm	Base(WMM), mm	DBM, mm	AC, mm
5	150	150	0	40
10	150	150	0	40

20	150	150	0	60
30	150	150	50	40
40	150	150	50	40
50	150	150	50	40
70	250	150	50	40
80	250	150	60	40
90	250	150	60	40
100	250	200	60	40
110	300	200	60	40
120	300	250	60	40
130	300	275	60	40
140	300	275	60	40
150	300	300	65	40
160	300	300	70	40
170	300	300	70	40
180	300	300	70	40
190	300	300	75	40
200	300	300	75	40
250	300	300	75	50

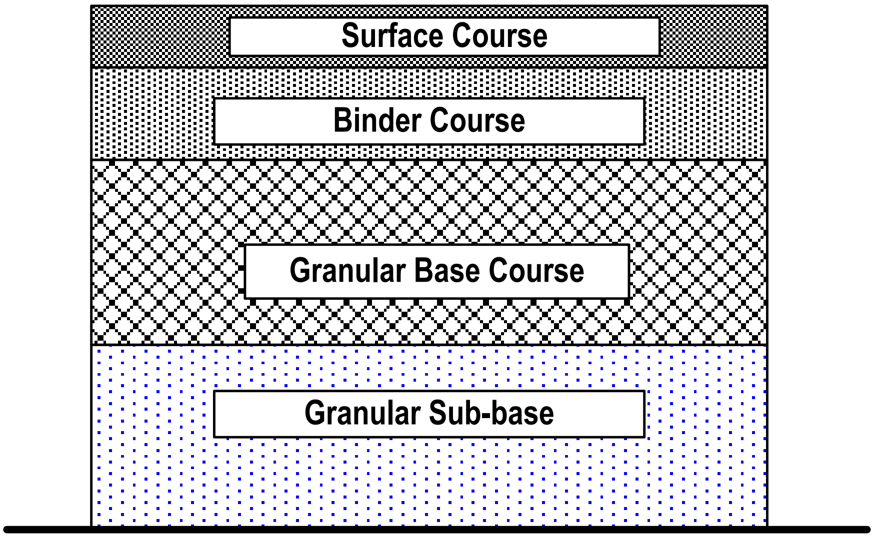


Figure 6: Bituminous Surface Course with granular base and Sub-base [1]

The other few optional pavement structural catalogues presented in these guidelines for design traffic levels up to 50 msa are intended for initial cost estimation and for guidance only (Source: IRC 37:2018). The individual layer thicknesses shown in the catalogues are only for illustration and the actual optimal requirement of layer thicknesses shall be evolved based on detailed analysis. Practical considerations and durability of the selected layers should always be kept in mind. The Design Catalogues have been given for the following four types of pavements sections:

- Bituminous surface course with CTSB, CTB and granular crack relief layer (Figure 7)
- Bituminous surface course with CTSB, CTB and SAMI (Figure 8)
- Bituminous surface course with GSB, CTB and granular crack relief layer (Figure 9)
- Bituminous surface course with CTSB and granular base course (Figure 10)

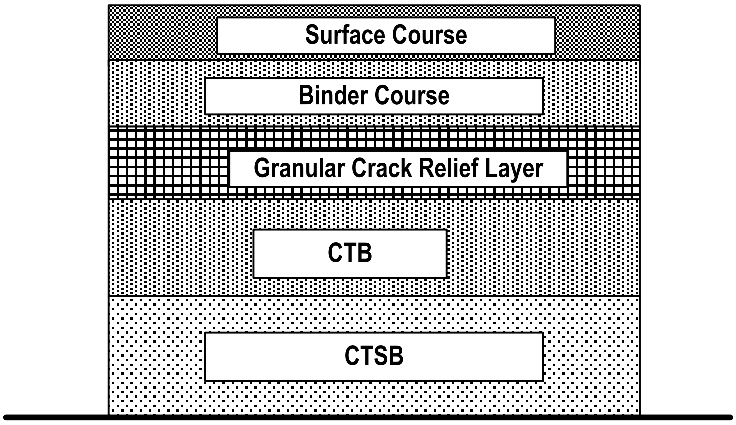


Figure 7: Bituminous Surface Course with CTSB, CTB and Granular Crack Relief Layer [1]

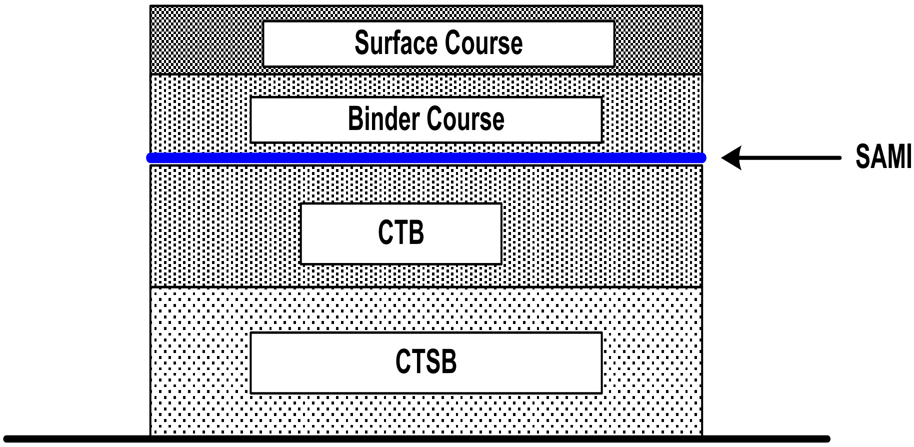


Figure 8: Bituminous Surface Course with CTSB, CTB and SAMI[1]

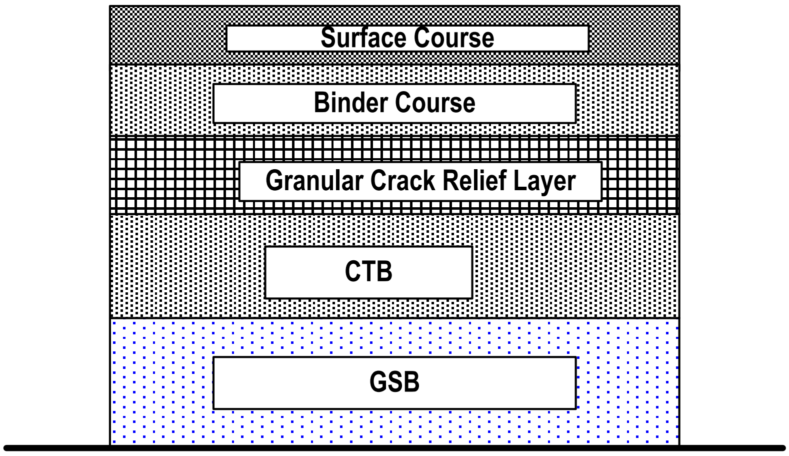


Figure 9: Bituminous Surface Course with GSB, CTB and Granular crack relief layer[1]

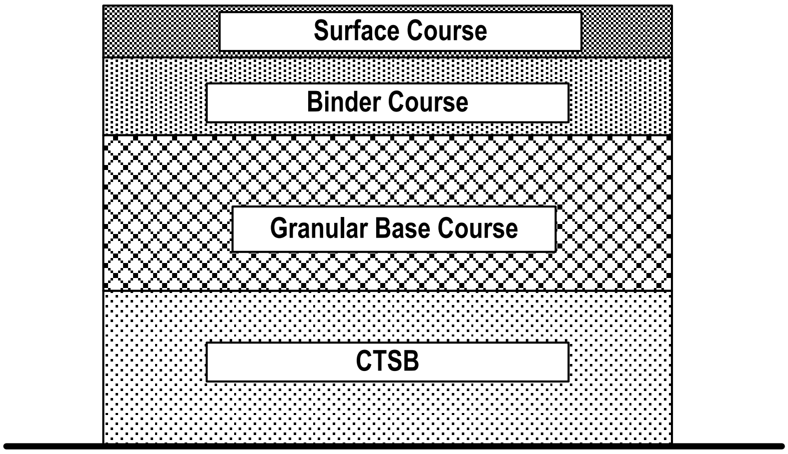


Figure 10: Bituminous Surface Course with CTSB and Granular Base Course [1]

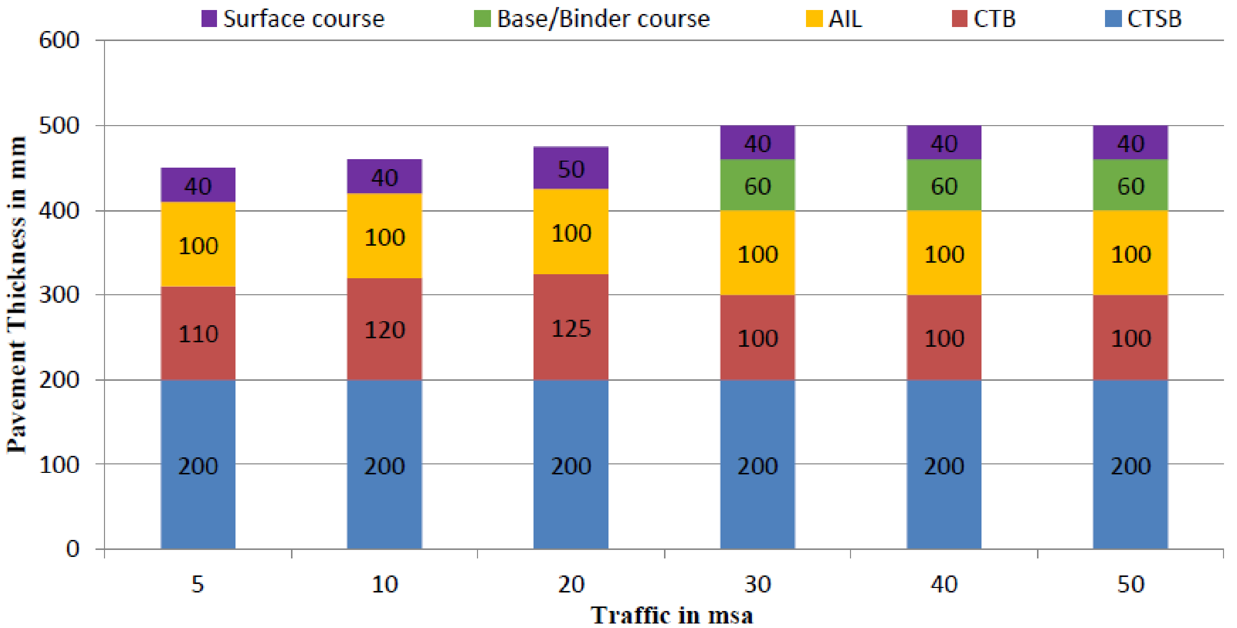


Figure 11: Catalogue for pavement with bituminous surface course with CTSB, CTB and granular crack relief layer - Effective CBR 5% [1]

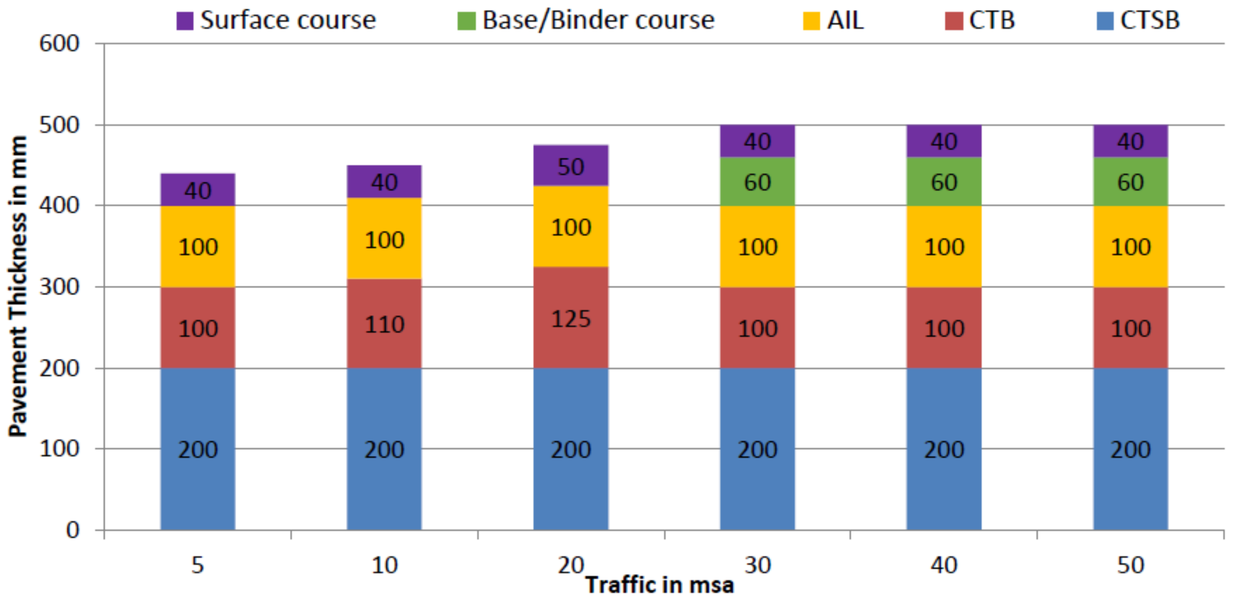


Figure 12: Catalogue for pavement with bituminous surface course with CTSB, CTB and granular crack relief layer - Effective CBR 6% [1]

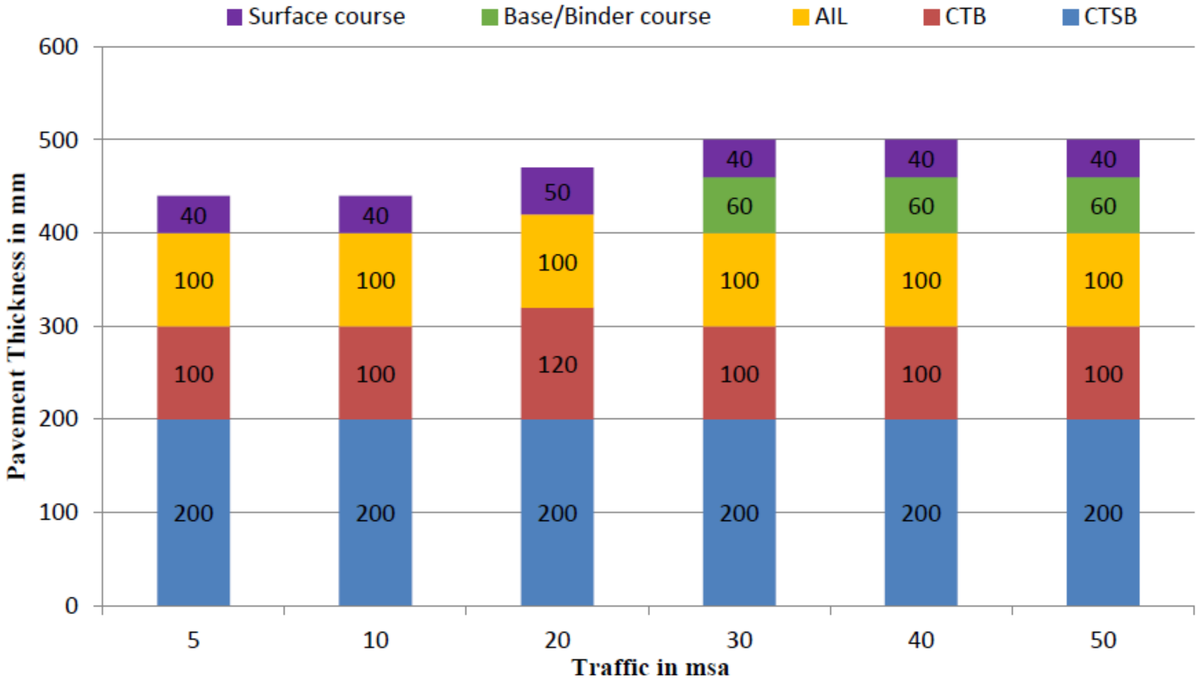


Figure 13: Catalogue for pavement with bituminous surface course with CTSB, CTB and granular crack relief layer - Effective CBR 7% [1]

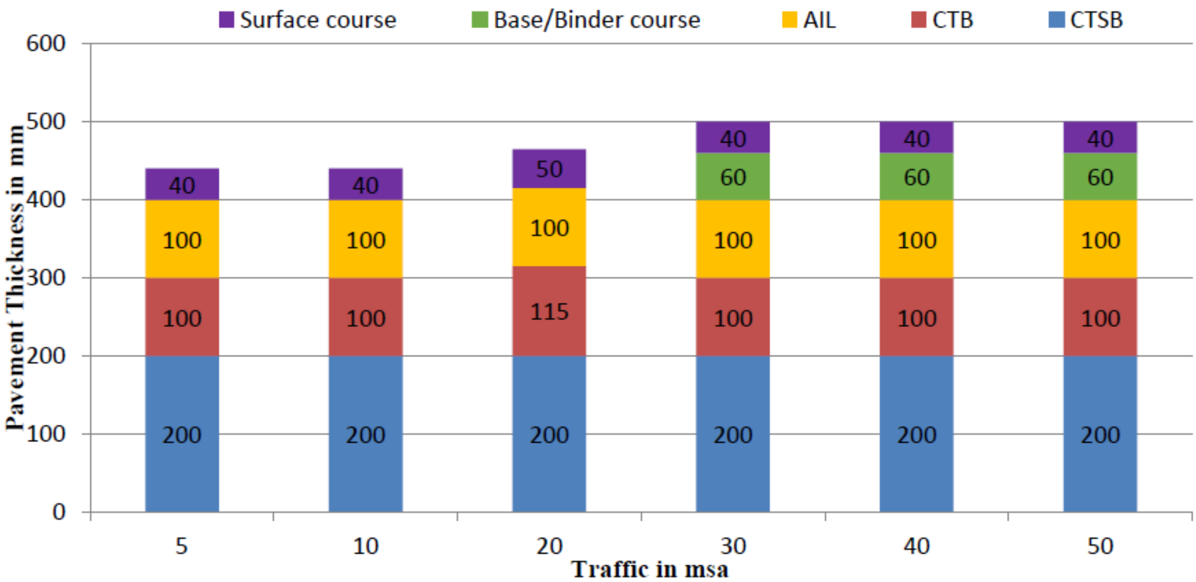


Figure 14: Catalogue for pavement with bituminous surface course with CTSB, CTB and granular crack relief layer - Effective CBR 8% [1]

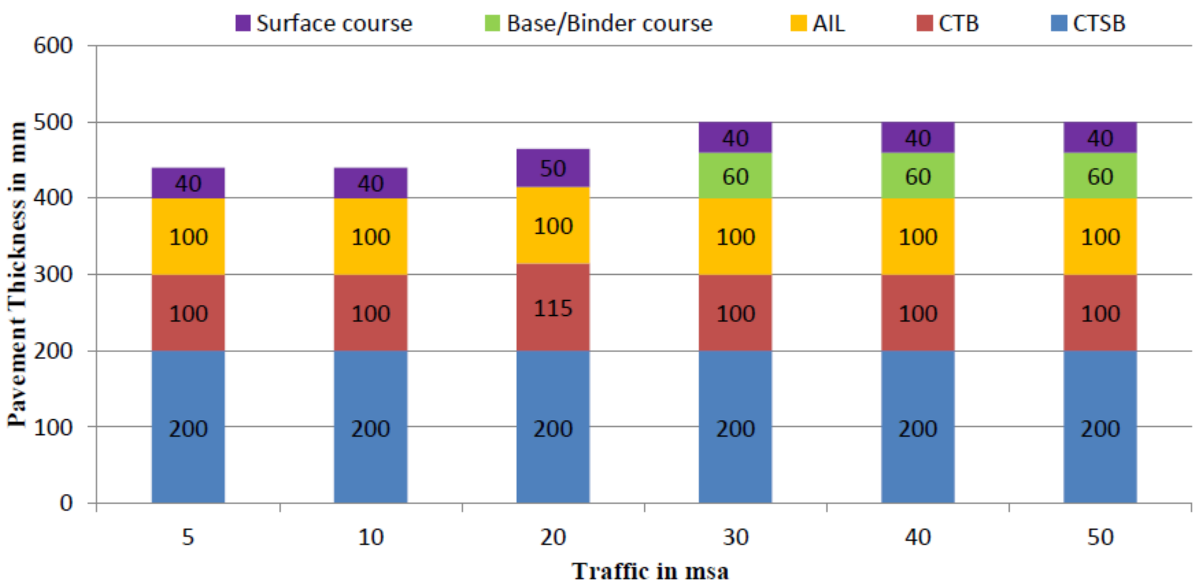


Figure 15: Catalogue for pavement with bituminous surface course with CTSB, CTB and granular crack relief layer - Effective CBR 9% [1]

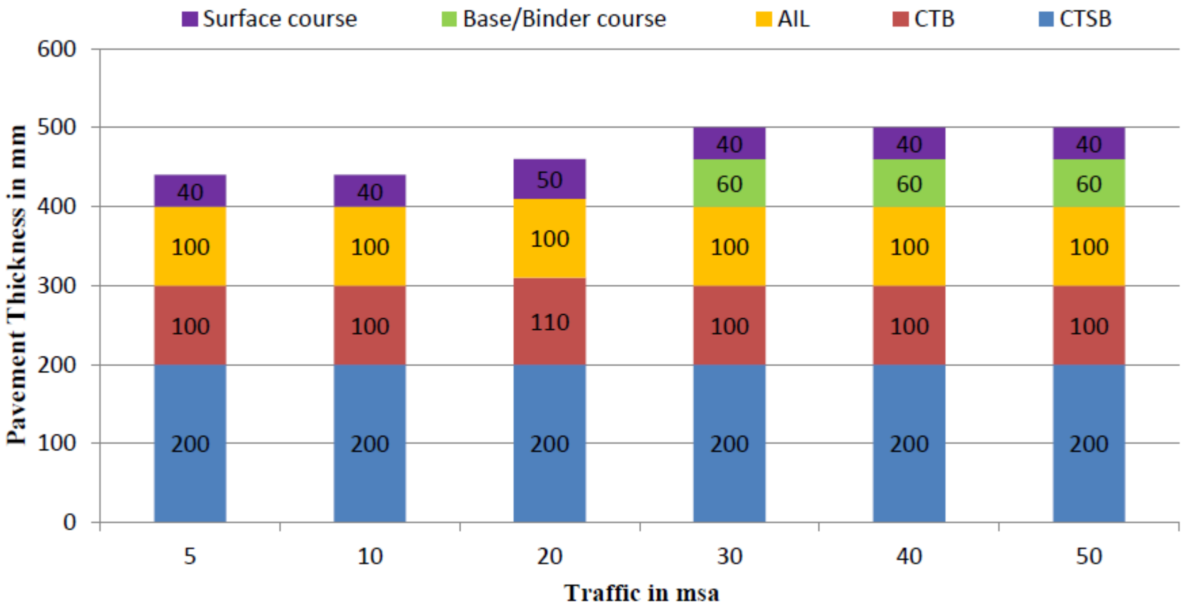


Figure 16: Catalogue for pavement with bituminous surface course with CTSB, CTB and granular crack relief layer - Effective CBR 10% [1]

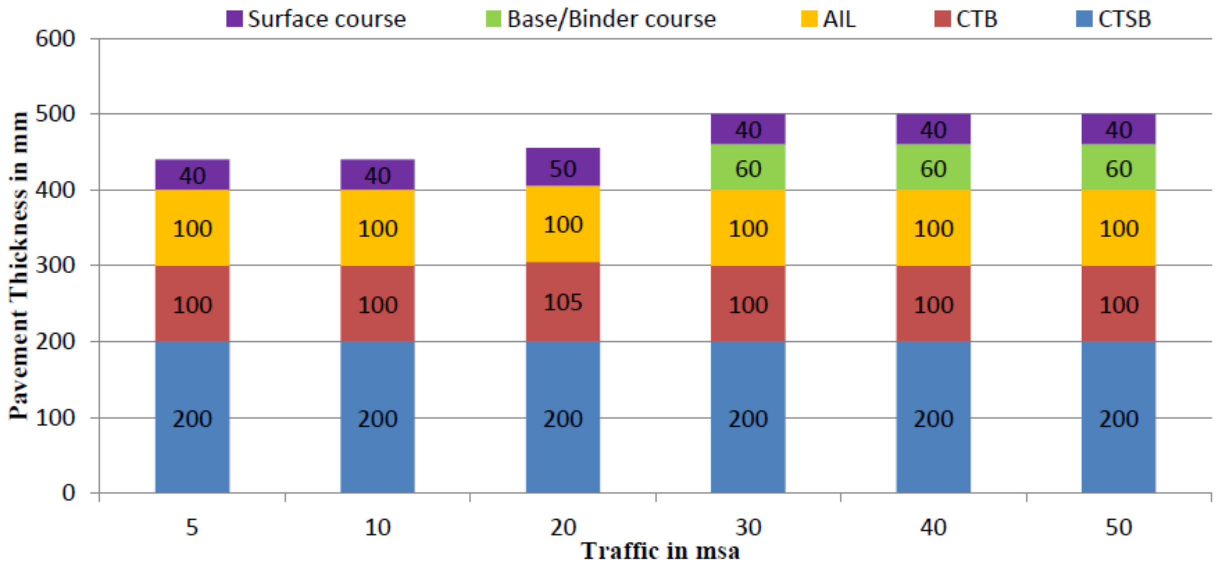


Figure 17: Catalogue for pavement with bituminous surface course with CTSB, CTB and granular crack relief layer - Effective CBR 12% [1]

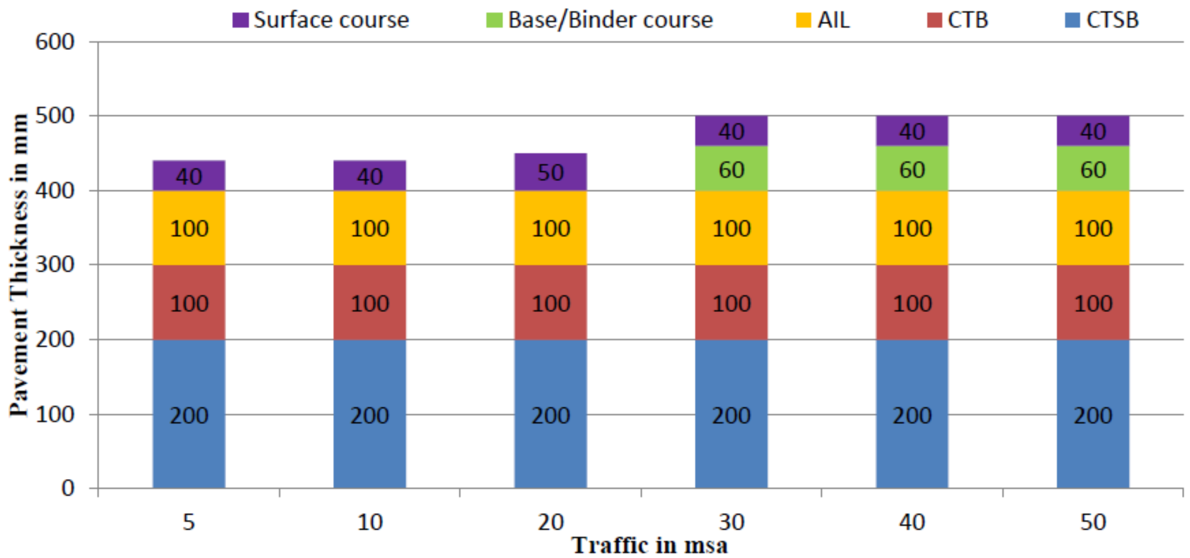


Figure 18: Catalogue for pavement with bituminous surface course with CTSB, CTB and granular crack relief layer - Effective CBR 15% [1]

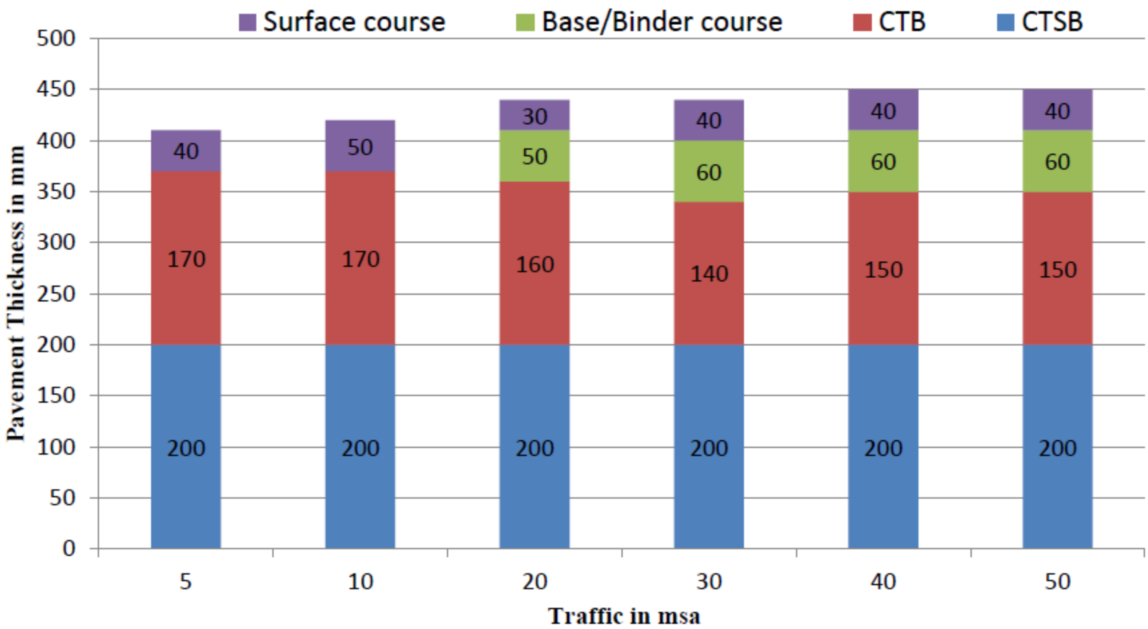


Figure 19: Catalogue for pavement with bituminous surface course with CTSB, CTB and SAMI - Effective CBR 5% [1]

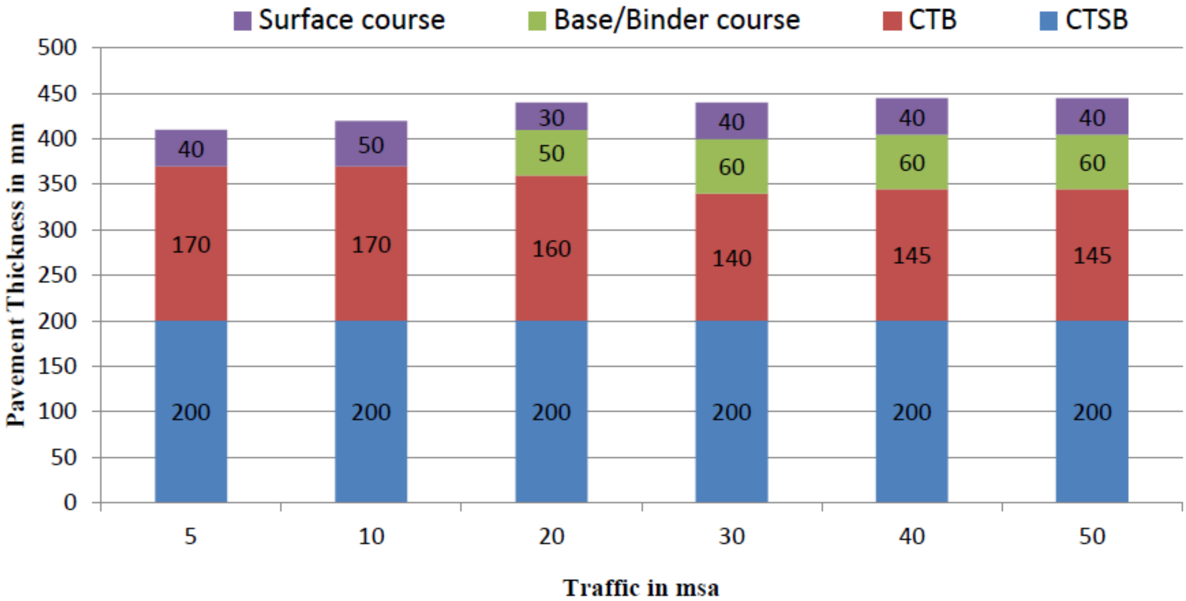


Figure 20: Catalogue for pavement with bituminous surface course with CTSB, CTB and SAMI - Effective CBR 6% [1]

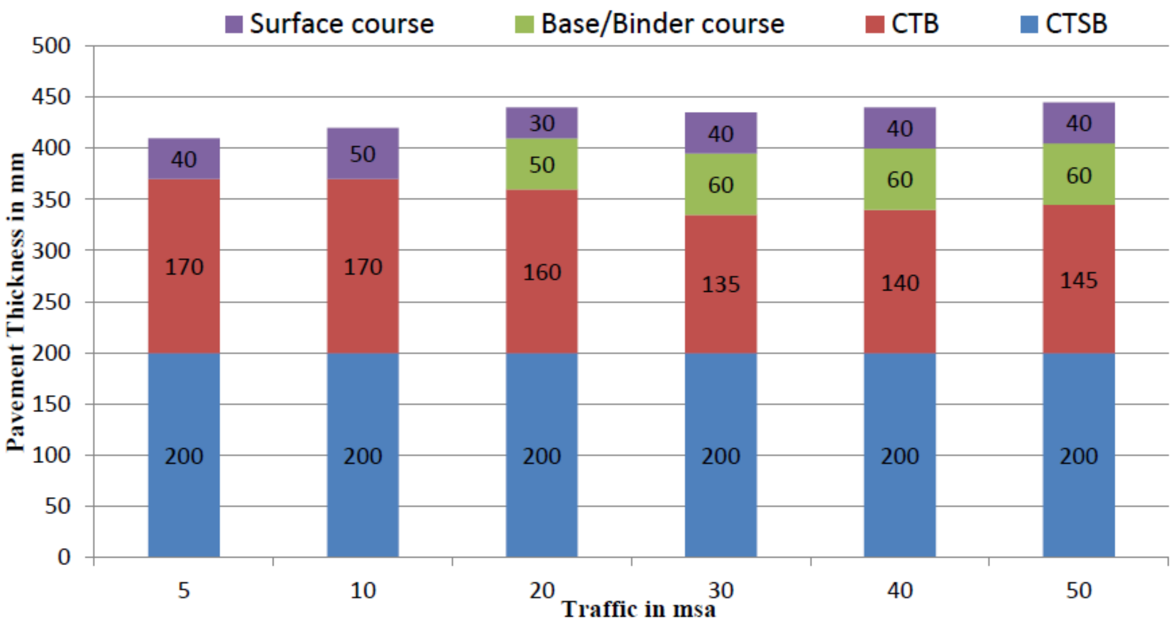


Figure 21: Catalogue for pavement with bituminous surface course with CTSB, CTB and SAMI - Effective CBR 7% [1]

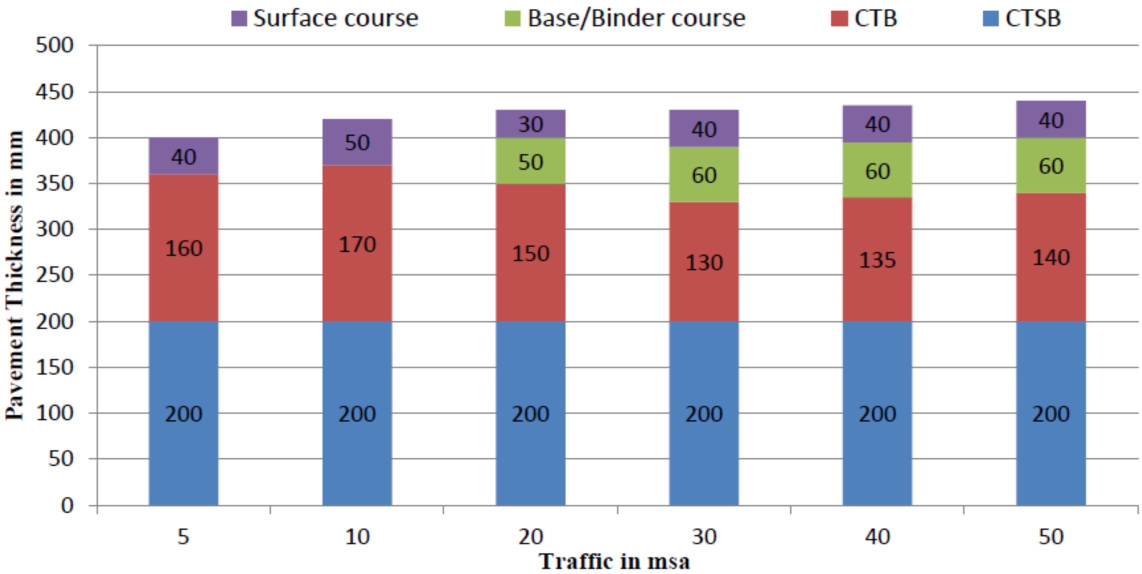


Figure 22: Catalogue for pavement with bituminous surface course with CTSB, CTB and SAMI - Effective CBR 8%[1]

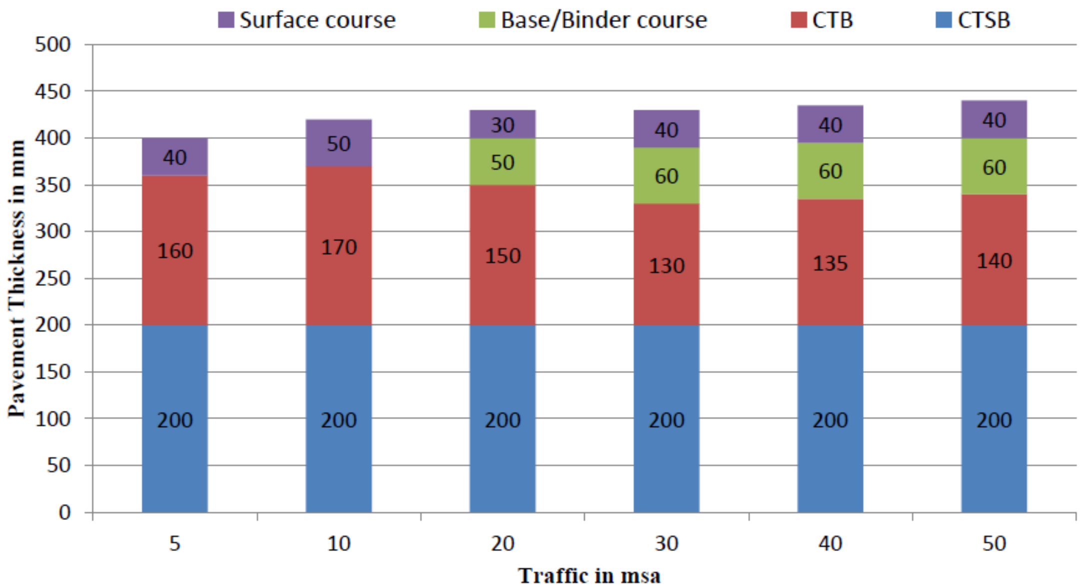


Figure 23: Catalogue for pavement with bituminous surface course with CTSB, CTB and SAMI - Effective CBR 9% [1]

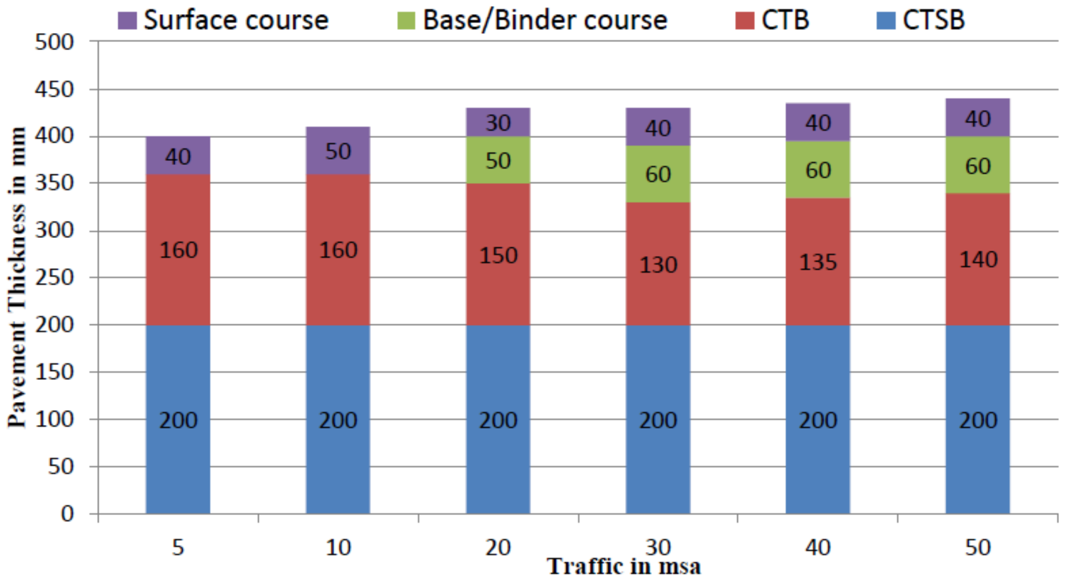


Figure 24 Catalogue for pavement with bituminous surface course with CTSB, CTB and SAMI- Effective CBR 10% [1]

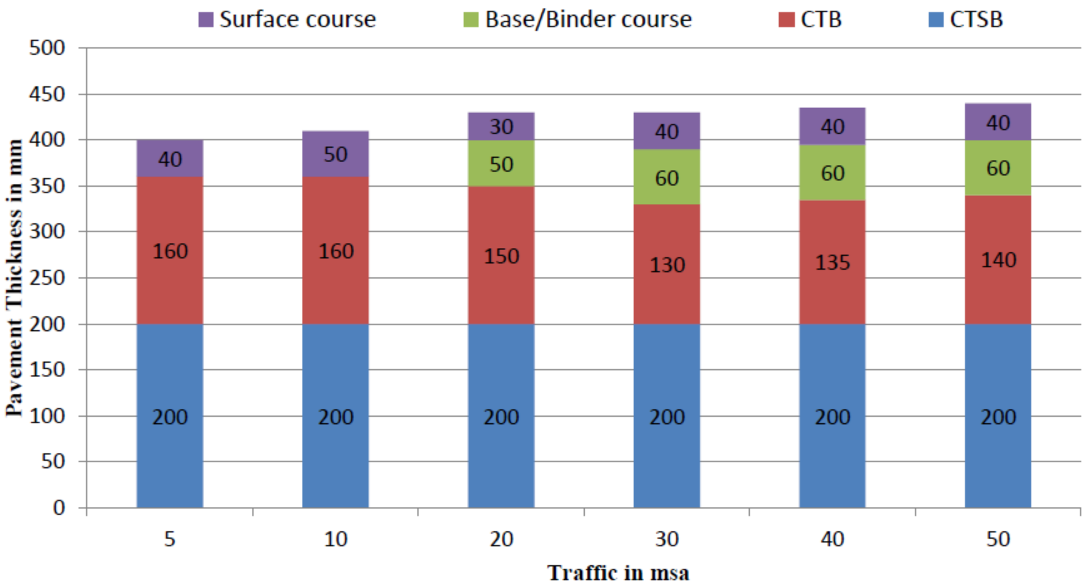


Figure 25: Catalogue for pavement with bituminous surface course with CTSB, CTB and SAMI - Effective CBR 12% [1]

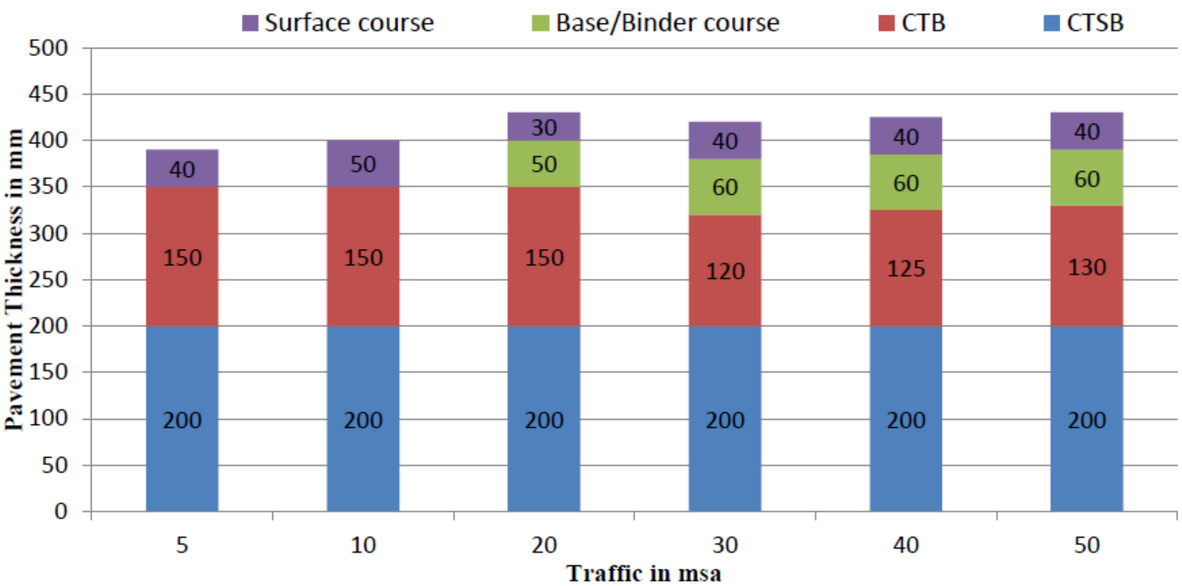


Figure 26: Catalogue for pavement with bituminous surface course with CTSB, CTB and SAMI - Effective CBR 15% [1]

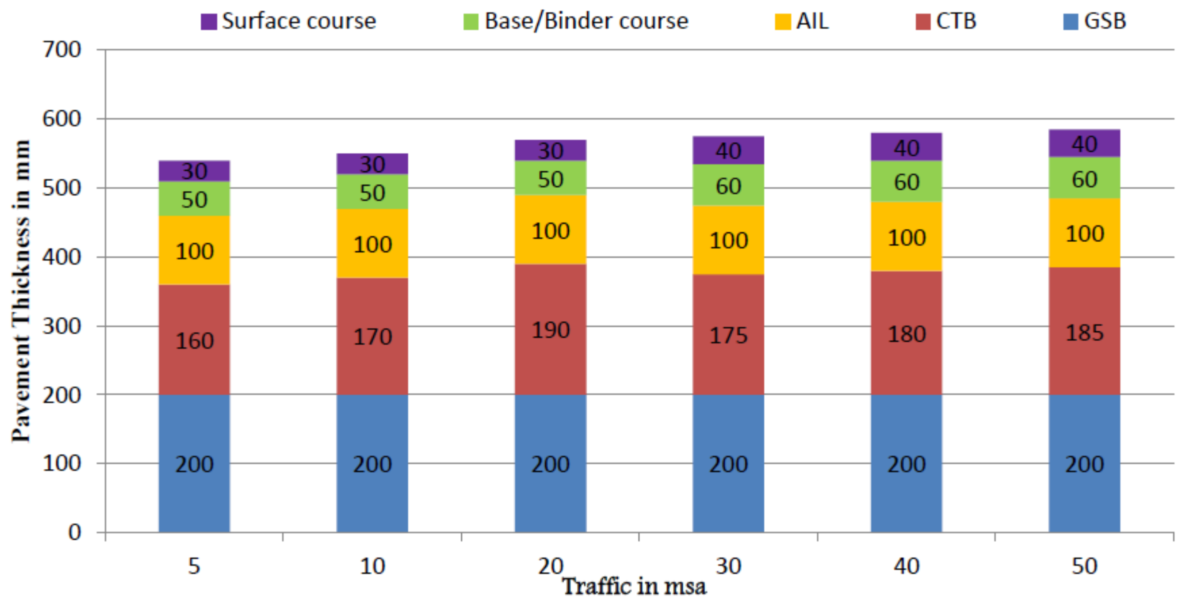


Figure 27: Catalogue for pavement with bituminous surface course with GSB, CTB and granular crack relief layer - Effective CBR 5% [1]

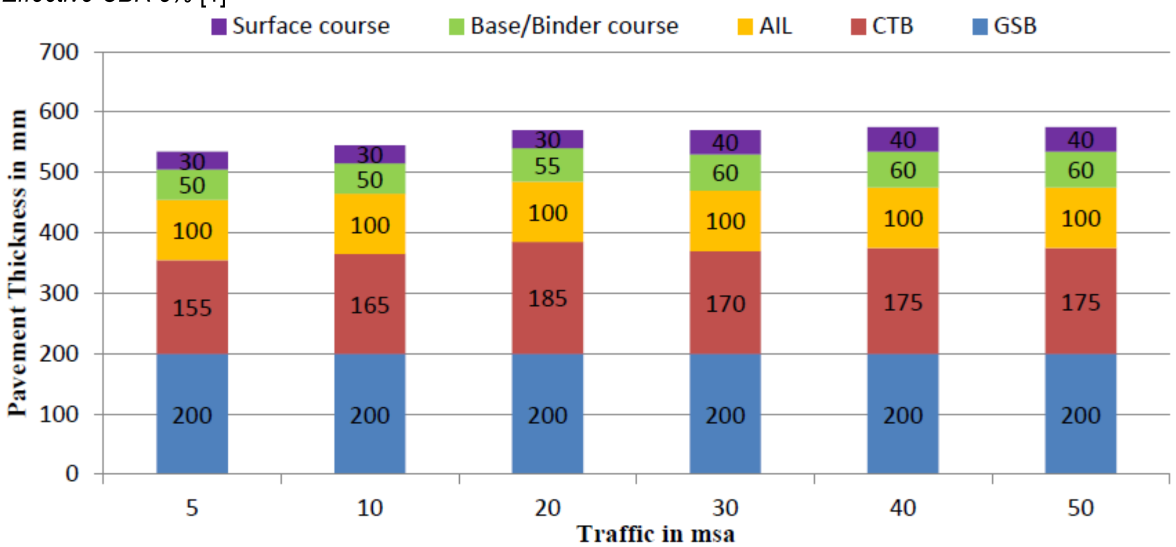


Figure 28: Catalogue for pavement with bituminous surface course with GSB, CTB and granular crack relief layer - Effective CBR 6% [1]

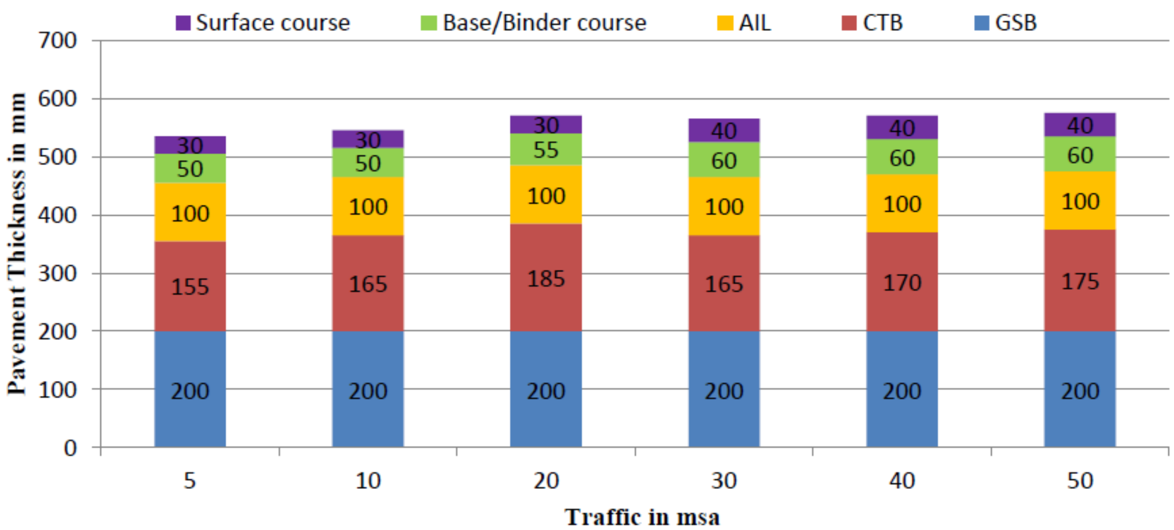


Figure 29: Catalogue for pavement with bituminous surface course with GSB, CTB and granular crack relief layer - Effective CBR 7% [1]

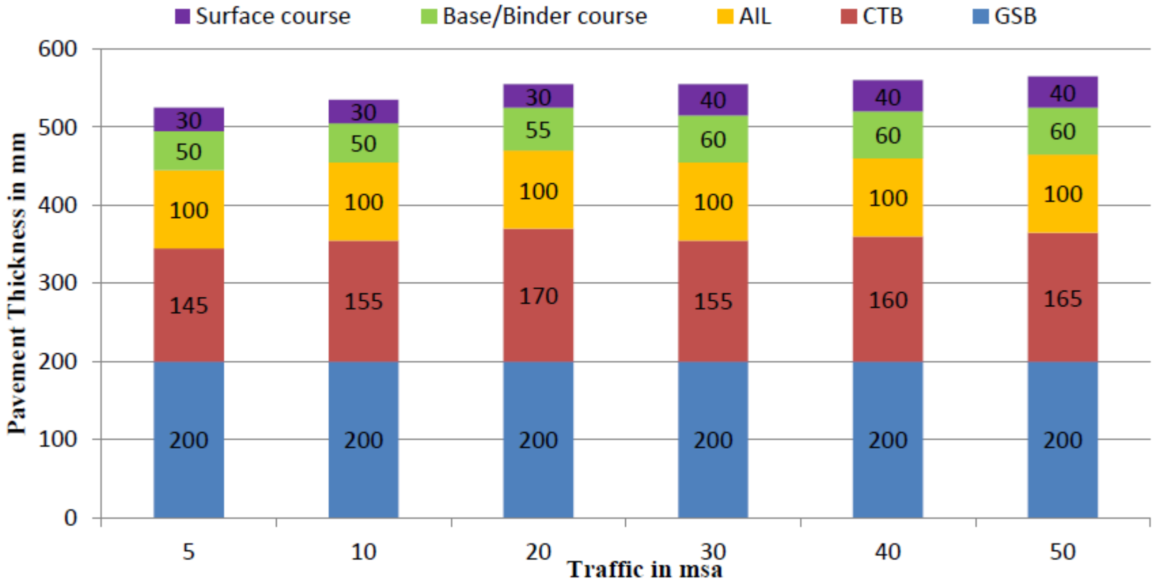


Figure 30: Catalogue for pavement with bituminous surface course with GSB, CTB and granular crack relief layer - Effective CBR 8%[1]

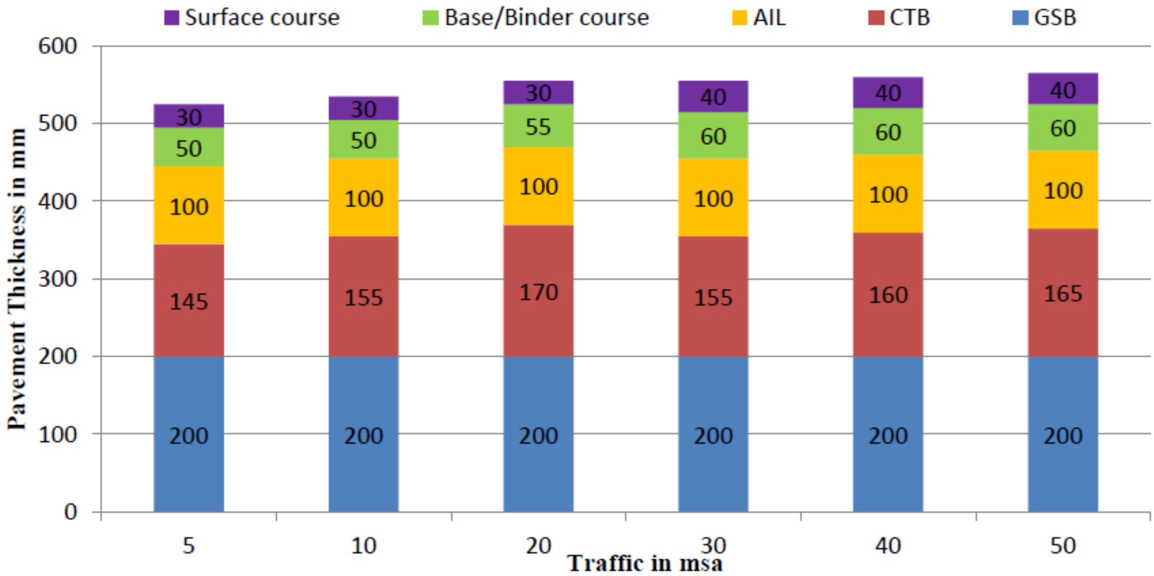


Figure 31: Catalogue for pavement with bituminous surface course with GSB, CTB and granular crack relief layer - Effective CBR 9%[1]

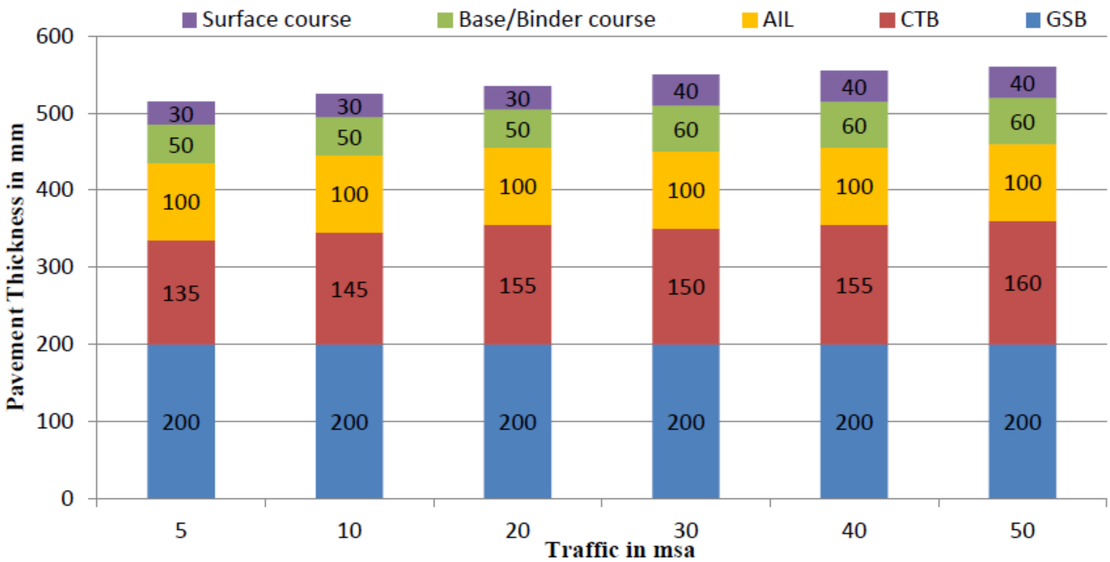


Figure 32: Catalogue for pavement with bituminous surface course with GSB, CTB and granular crack relief layer - Effective CBR 10% [1]

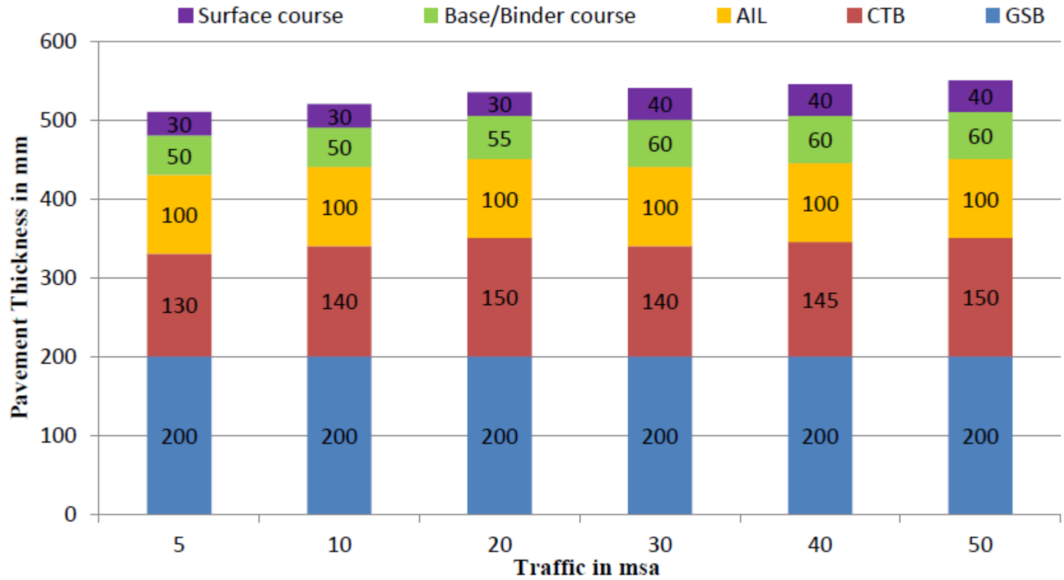


Figure 33: Catalogue for pavement with bituminous surface course with GSB, CTB and granular crack relief layer - Effective CBR 12% [1]

Figure 34: Catalogue for pavement with bituminous surface course with GSB, CTB and granular crack relief layer - Effective CBR 15% [1]

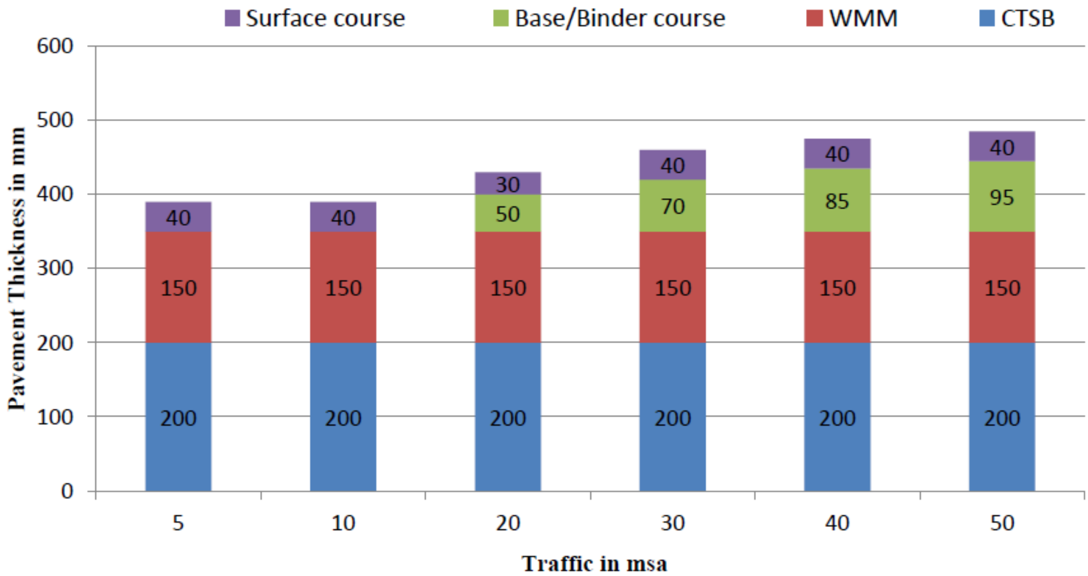


Figure 35: Catalogue for pavement with bituminous surface course with CTSB and granular base course - Effective CBR 5% [1]

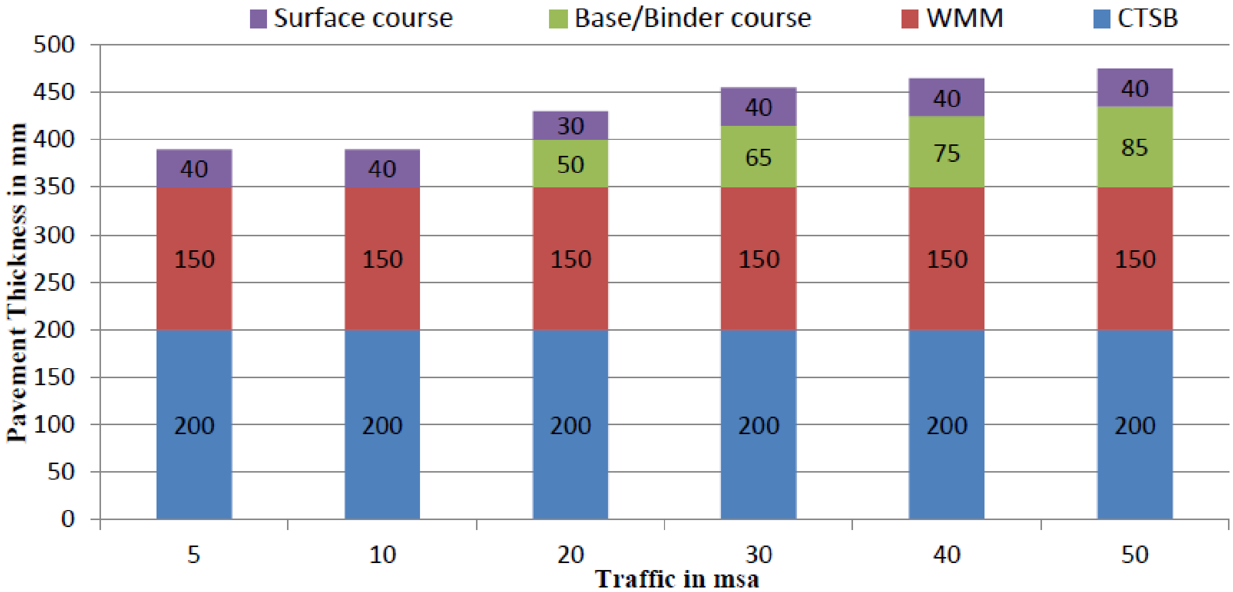


Figure 36: Catalogue for pavement with bituminous surface course with CTSB and granular base course - Effective CBR 6% [1]

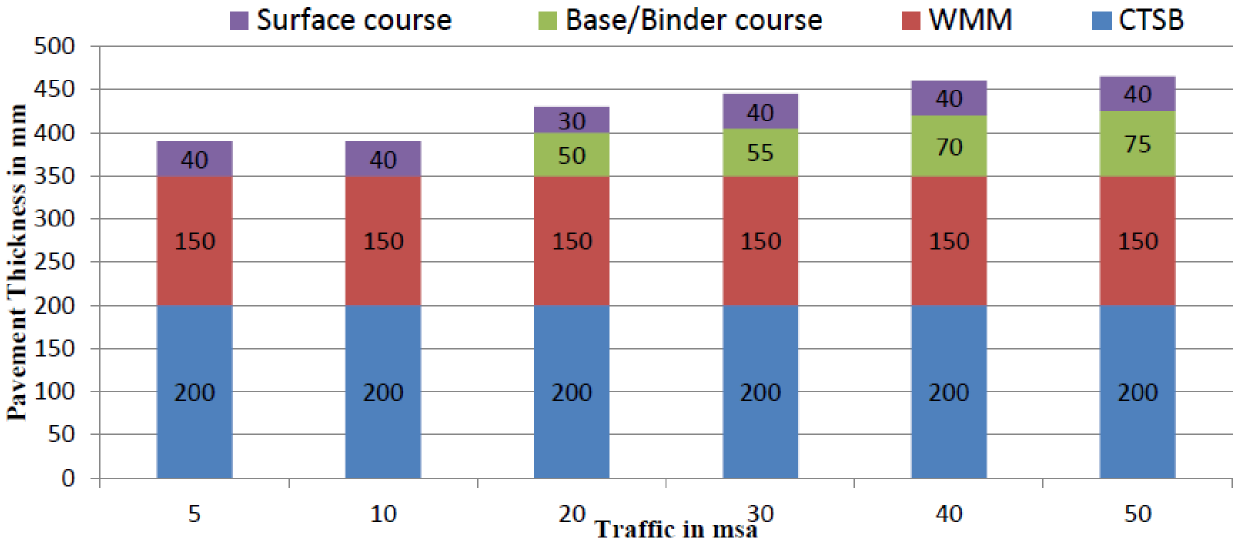


Figure 37: Catalogue for pavement with bituminous surface course with CTSB and granular base course - Effective CBR 7% [1]

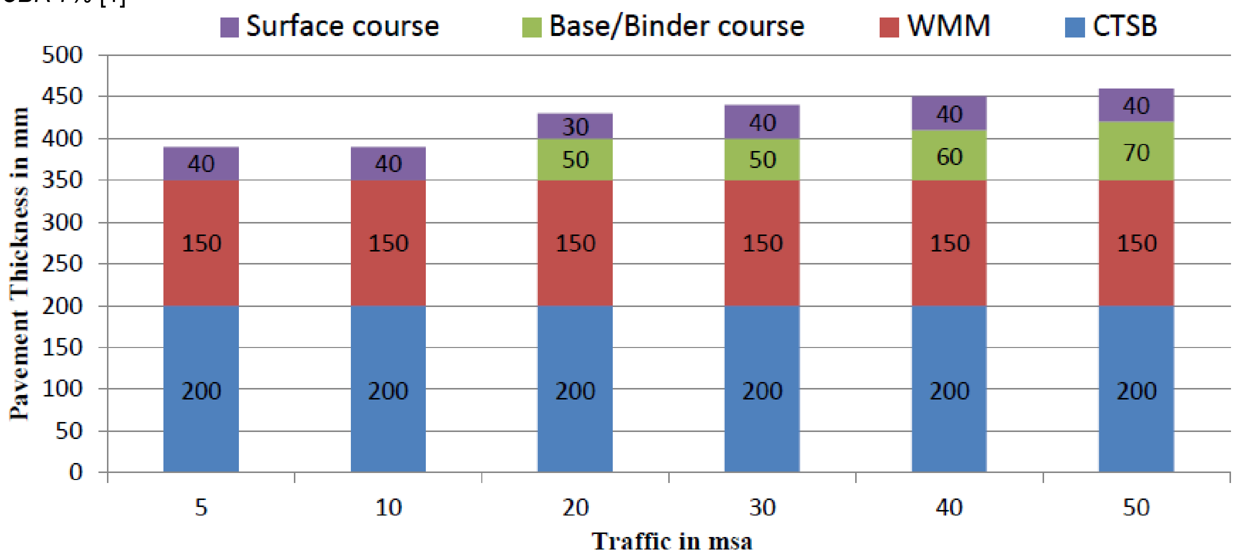


Figure 38: Catalogue for pavement with bituminous surface course with CTSB and granular base course - Effective CBR 8% [1]

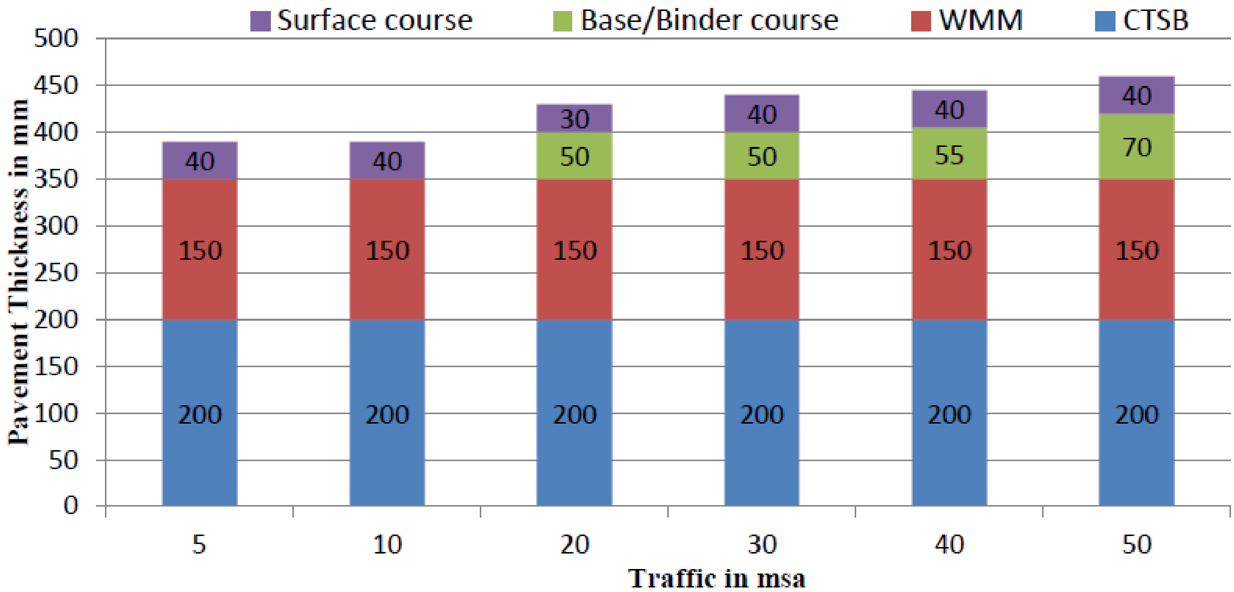


Figure 39: Catalogue for pavement with bituminous surface course with CTSB and granular base course - Effective CBR 9% [1]

12. QUALITY CONTROL TESTS DURING CONSTRUCTION

The recommendations mentioned in Clauses of Section 500 of Standard Specifications for Road and Bridge Works, 2073 regarding different tests along with their frequencies of tests to ensure quality in the construction shall be followed. In addition, the following tests are also required for addressing the Standard Specifications.

Table 16: Additional Tests to be carried out during construction

SN	Item of Construction	Test	Frequency
1	Bituminous construction	Resilient modulus desired from indirect tensile strength test on specimens prepared using field mix*	Three specimens for each 400 tonnes of mix or minimum 2 tests per day.
2	Cement treated /stabilized base and sub-base	Unconfined compressive strength	Three specimens for each 400 tonnes of mix or minimum 2 tests per day.
3	Cement treated /stabilized base and sub-base	Binder/cement content	Three specimens for each 400 tonnes of mix or minimum 2 tests per day.
4	Cement treated /stabilized base and sub-base	Flexural strength / Indirect tensile strength test	Three specimens for each 400 tonnes of mix or minimum 2 tests per day.
5	Cement treated /stabilized base and sub-base	Soundness test (BIS 4332 Part IV)	One specimen for each source and whenever there is change in the quality of aggregate
6	Cement treated /stabilized base and sub-base	Density of compacted layer	One specimen of two tests per 500 sq m.
7	Emulsion/ Foam bitumen	Indirect tensile strength test	Three specimens for each 400 tonnes of mix or minimum 2 tests per day.
8	Emulsion/ Foam bitumen	Density of compacted layer	One specimen per 1000 sq m.

In case of M_R estimated from the indirect tensile strength is less than 90 % of the design value, the M_R should be rechecked in accordance with ASTM 4123.

13. REPEAL AND SAVING

1) Pavement Design Guidelines (Flexible Pavement) is hereby repealed.

2) Any acts done and actions taken under the Guidelines for the Design of Flexible Pavement-2014 (Second Edition-2021) shall be deemed to have been done and taken under this Guidelines.

REFERENCES

1 IRC:37-2018, Guidelines for the Design of Flexible Pavements, Indian Roads Congress, New Delhi

2 IRC:37-2012, Guidelines for the Design of Flexible Pavements, Indian Roads Congress, New Delhi

3 Standard Specifications for Road and Bridge Works, GoN, Department of Roads, 2073

4 Guidelines for the Design of Flexible Pavements, Department of Roads, 2014

5 A Guide to the Structural design of bituminous surfaced roads in tropical and sub-tropical countries. Overseas Road Note 31. Transport Research Laboratory (TRL), 1993

6 A guide to axle load Surveys and traffic counts for determining traffic loading on pavements. Overseas Road Note 40. Transport Research Laboratory (TRL), 2004

7 PAVEMENT DESIGN MANUAL, Supplement to ‘Part 2: Pavement Structural Design’, of the Austroads Guide to Pavement Technology. Queensland Department of Main Roads Pavements & Materials Branch, Australia, 2009

8 Pavement Design Guide for Local and Collector Roads, Roads Department, Road Planning Section, October 1998

9 AASHTO, Guide for the Design of pavement structures, 1993

10 GOVERNMENT OF INDIA, Central Public Works Department, CPWD Specifications Volume 2, 2009

11 Pavement Design Guide for Roads & Highways Department, Government of the People’s Republic of Bangladesh, Ministry of Communications, Roads and Railways Division2005

12 Flexible Pavement Design manual, Florida Department of Transportation Pavement Management Office 605 Suwanee Street, M.S. 32 TALLAHASSEE, FLORIDA, DOCUMENT NO. 625-010-002-g MARCH 2008

13 Guidelines for low volume sealed Roads, Southern African Development Community (SADC); SADC House, Private Bag 0095, Gaborone, BOTSWANA, 2003

14 Standard Specifications for Road and Bridge Works, UPGRADED SECTION 500, AND ITS RELATED, ASPECTS IN SECTIONS, 900 AND 3000, (Addendum to Third Revision), Ministry of Road Transport and, Highways, India, 2000

15 Design Manual for low volume sealed road Malawi, Ministry of Transport and Public Works, 2013

16 Guidelines for Traffic Prediction on Rural Highways, IRC 1996

17 MORTH, "Specifications for Road and Bridge Works, Ministry of Surface Transport (Roads Wing)," Indian Roads Congress, New Delhi, 2013

18 BIS:4332 (Part IV), "Methods of Test for stabilized soils: Wetting and drying, Freezing and Thawing Tests for compacted soil-cement mixtures," Bureau of Indian Standards , New Delhi, 1968, Reaffirmed in 2010.

19 IRC:SP:79, "Tentative Specifications for Stone Matrix Asphalt," Indian Roads Congress, New Delhi, 2008.

20 IRC:SP:107, "Guidelines for Gap Graded Wearing Course with Rubberised Bitumen (Bitumen-Rubber)," Indian Roads Congress, New Delhi, 2015.

21 IS:73, "Paving Bitumen-Specifications (Fourth Revision)," Bureau of Indian Standards, New Delhi, 2013.

22 ASTM D 4123, "Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous

Mixtures," ASTM International, 1982 (Reapproved 1995).

23 ASTM D 7369, "Standard Test Method for Determining the Resilient Modulus of Bituminous Mixtures by Indirect Tension Test," ASTM International, 2009.

24 MS-4, "The Asphalt Hand Book," Asphalt Institute, 2007.

25 A Guide to Surface Dressing in Tropical and Subtropical countries, Road Note 3, Second Edition 2000, Transport Research Laboratory (TRL), UK.

ANNEX A: THE PRINCIPLES AND APPROACH FOLLOWED IN THESE GUIDELINES

A.1. General

Highway pavements should be safe and serviceable. They should be capable of carrying the loads coming on it during their life period without unacceptable levels of failures. Unlike structures where the failure is usually followed by complete collapse, failure in pavements is not sudden but usually by gradual deterioration over time. At some stage in its life, when the deterioration renders it unserviceable to the users, the pavement is assumed as failed. Thus, safety criteria in pavement design are defined by serviceability thresholds (such as acceptable cracking and rutting), which, if breached, the design should be considered as unsafe and pavement unserviceable

A.2. Cracking in bituminous layers

Cracking in bituminous pavement can occur in three primary modes: (a) bottom up cracking, (b) top down cracking, and (c) low temperature cracking.

A.6.1. Bottom up Cracking

Cracks may initiate at the bottom of any bound layer due to fatigue phenomenon reducing the effective layer thickness causing the cracks to progress and move upwards with repeated application of traffic loads. When the whole layer cracks, the crack progresses into the upper layer and will eventually appear on the surface of the pavement as alligator cracks. Mixes should have adequate flexural tensile strength and should be sufficiently flexible at intermediate temperatures at which the traffic loads (except the very small proportion of traffic which is applied when the pavement has peak summer or peak winter temperatures) to resist fatigue cracking caused by repeated flexure under traffic loads. Stiffer mixes usually have larger flexural tensile strength compared to the softer ones. However, the higher stiffness is usually associated with more brittleness. The fatigue cracking in bituminous layers has been addressed in these guidelines using a performance model which gives limiting tensile strain value for a given design traffic level and for a selected mix.

The fatigue cracking susceptibility of the bituminous layer can be reduced by controlling the flexural tensile strains at the bottom of the bituminous layer. This can be done by (i) providing a strong support from the underlying layers which reduces the deflection in the bituminous layer (ii) using stiffer bituminous mix which reduces the tensile strain in the material and (iii) using a mix that is adequately elastic to recover from damage.

A strong sub-grade is essential for giving firm support to the upper pavement layers. The elastic modulus of the sub-grade (required as input for analysis using linear elastic layered theory) is recommended to be estimated from its CBR value using the empirical equations given in the guidelines. When there is significant difference in the mechanical properties of the material used in the prepared sub-grade compared to the material used in the embankment, it is proposed to estimate an equivalent sub-grade property (effective modulus) for use in design. These guidelines recommend the use of sub-grades with a minimum effective CBR of 5% for roads with more than 450 commercial vehicles per day.

A.6.2. Top Down Cracking

At the instance when the tyres come in contact with the road surface, they expand laterally and push the pavement surface at their edges. At the next instance when the tyre moves over, the laterally pushed surface should be elastic enough to pull itself back. If it is not elastic, the surface will crack at the wheel edges along the longitudinal direction and the crack will propagate downwards from the surface. Another reason for top down cracking is the age hardening of bitumen. With age and exposure to sun light and Ultra Violet rays, the volatiles in bitumen are lost and the binder becomes hard and brittle, which significantly increases the cracking susceptibility of the material.

The objective of design for controlling top down cracking should be to use mixes that can accommodate more bitumen to have thicker films which reduce the rate of aging, to minimize the effect of ageing by using ageing resistant modified binders in the surfacing course, to improve the visco-elastic properties of the binder by using binders that have better elastic recovery. These Guidelines recommend Stone Matrix Asphalt (SMA) and Gap Graded Rubberised Bitumen (GGRB) and Bituminous Concrete (BC) with modified binders, for high traffic (more than 50 msa) roads. In other cases, stiff grade binders or modified binders are considered suitable for surface course mixes.

A.3. Rutting in bituminous pavements

Rutting in pavement occurs in two ways: (a) Due to deformation in sub-grade and other unbound layers (granular sub-base and base and (b) due to rutting in bituminous layer. The guidelines provide limiting strain criteria for controlling rutting in sub-grade. Even though no separate criteria are included in the guidelines for rutting in the granular layers, controlling the vertical compressive strain on top of sub-grade indirectly results in the control of strains in the upper granular layers. Larger elastic strains in the sub-grade and unbound granular layers (which are calculated by linear elastic layered theory) are generally expected to produce larger plastic strains. Thicker bituminous layers and stronger sub-bases/bases (such as CTSB and CTB) reduce the sub-grade strains significantly.

Even if the sub-grade or unbound granular layers do not undergo rutting, the bituminous layers may do. This happens in various situations such as when the bituminous layers are not initially properly compacted and undergo large secondary compaction during their service life, the binder used is of a softer grade, has less elasticity, high pavement temperatures and high wheel load stresses. It is necessary to use sufficiently stiffer mixes with binders that will have less plastic deformation at high temperatures and high stresses, especially in the upper layers. At lower depths, the stresses as well as the temperatures will be less compared to the surface layers and thus the lower bituminous layers are less susceptible to rutting.

A.4. Structural analysis of pavement

These Guidelines continue to follow the Mechanistic-Empirical approach for pavement analysis as in its previous version. The stresses and strains in the pavement layers are analyzed by the IITPAVE software or Software developed by DoR, which requires inputs from users in terms of number of layers, their thicknesses and elastic moduli. Standard loading of 80 kN acting over four wheels (two dual wheel sets on each side of the axle) at 0.56 MPa uniform contact pressure is considered for the analysis. For evaluating the CTB bases, a contact pressure of 0.80 MPa shall be considered.

The trial pavement composition and layer thicknesses are selected and the stresses and strains at the critical locations are computed by running the IITPAVE software or Software developed by DoR. The permissible strains are obtained from the fatigue and rutting models, for a given design traffic volume (msa). If the computed strains are larger than those derived from the model (limiting strains), the trial composition and layer thicknesses are changed until the values come within the permissible limits.

A.5. Effect of climate and environment on pavement performance

The discussion so far has been on the response of the pavement to load repetitions and on the design of pavement to limit the cracking and rutting. Climate and environment are other factors, which can affect the performance of pavements.

Water entering the cracks from bottom (bottom up cracks), top (top down cracks) or sides (shoulders or medians) may strip the bitumen leading to loss of bond between aggregates and bitumen, and may reduce the strength of granular and sub-grade layers.

Binders age when exposed to environment and lose volatiles, harden, become brittle and then crack. Thus, it is necessary to use an appropriate grade of bitumen, with modifications if required, in the surfacing layer to make it resistant to the oxidation of bitumen.

At high temperatures, the binder and hence the mix becomes softer and is susceptible to rutting. At low temperatures, the mix is likely to become brittle and is susceptible to cracking. Hence, binders those are less temperature susceptible and have adequate properties at high as well low service temperatures are expected to yield better performance.

The appropriate grade of binder for a given project site should ideally be the one that is suitable for the range of variation in the pavement temperature. Even though there appears to be some gap in the existing standards with regard to the suitability of binders in extreme temperature conditions that are likely to prevail in the country, it is recommended that the grade suitable for temperatures nearest to the specified maximum could be adopted. Very broadly, the stiffest grade of available bitumen should be used where the pavement temperature is expected to rise above 60 ^{0}C and the softer grades under low temperature conditions.

A.6. Mix design

A.6.1. General

Bituminous binder courses and the surfacing courses have different requirements. The base is subjected to flexural tension and, therefore, needs to have sufficiently large stiffness (modulus) to reduce strains. Larger stiffness is usually achieved with dense aggregate grading as in DBM. Fatigue cracking starts at the bottom of the base. The mix also has to be sufficiently flexible to be more compliant with the deflections to which the layer will be subjected to traffic loads. The fatigue life of the layer/ mix can be increased by increasing the per cent of bitumen in the mix, but the dense grading of DBM does not allow enough void space to accommodate more bitumen without reducing the air voids. More bitumen and lesser air voids in the DBM would increase the fatigue life.

Top down cracking starts at the surfacing at the edges of the wheel because the inflation pressure of the tyres at the contact surface deforms it across the wheel path and the mix should be elastic enough to recover this deformation after the passage of the wheels. The binder in the surfacing layer should, therefore, have high elastic recovery. Surfacing is also exposed to atmosphere and thereby to ageing. Therefore, the surfacing material should be age resistant. The surfacing is also exposed to water damage by stripping or displacement of the bitumen film by water, and therefore, it should be resistant to water damage.

A.6.2. Some Considerations for design of bituminous mix for binder layer

A high resilient modulus of DBM (typical base/ binder course mix) should be targeted in the design, which in comparison to mixes having low or moderate resilient modulus values, will result in smaller tensile strain and less plastic strain under the same set of loading and hence will result in smaller DBM layer thicknesses. Thus, a higher resilient modulus mix will be more appropriate to resist both cracking (unless the mix becomes too brittle) and rutting.

A high resilient modulus mix can be achieved by a strong granular skeleton of aggregates represented by their grading. DBM grading-I having higher maximum nominal size of aggregates will have a stronger aggregate structure compared to DBM Grading-II of Standard Specifications. The choice between the two aggregate gradings, however, is also dependent upon the layer thickness, which should not be less than 2.5 times the maximum nominal size of the aggregate.

The lower layer DBM mix has to be rich in bitumen and low in air voids. The lower layer DBM, subject to the thickness and nominal size limitations, should be in Grading-I. The larger size fractions of aggregates and lower surface area would enable more void space to accommodate additional quantity of bitumen and thicker coating of aggregate particles by bitumen. The likelihood of rutting of the layer is minimal for two reasons, first because the lower layer is subjected to lower stresses as the intensity of the load decreases with depth, and secondly the maximum temperatures of the bottom bituminous layer will be significantly smaller compared to the maximum temperatures applicable for the surface layer. Also, the degree of secondary compaction in the bottom layer will be less due to the fact that the bottom layer will have more confining stresses than the upper layers.

A part of the quantity of bitumen used in the mix is lost in the aggregate pores where the aggregates have porosity even though it is within permissible limits. This will reduce the effective quantity of bitumen in the mix, which might make the mix deficient in bitumen. It is necessary that the binder quantity lost due to absorption by aggregates should be carefully estimated during the mix design process.

A.6.3. Some considerations for design of bituminous mixes for surfacing layer

Surfacing layer should have good elastic recovery property, which means that the binder should have less plastic deformation at higher temperatures. The surfacing layer should have adequate binder to make it durable. Selecting surface mixes in which more binder can be used has three main advantages; first, it will provide better bonding of aggregate and binder; second, on exposure to atmosphere it will resist the effects of oxidation and ageing, (with the resulting reduction in the top-down cracking susceptibility) and third, resistance to moisture damage.

For accommodating more binder, the aggregates should have more void space to accommodate the additional binder. This is somewhat difficult if the grading is a dense one as used in BC.

A.7. Tests and design documentation

Design has to be based on a number of tests conducted in accordance with the procedures indicated in the main document at the appropriate places. The tests on works and their frequencies are enumerated in Section 13 of these Guidelines. The designer has to plan all the required tests at different points of time such as when selecting material sources, at the time of delivery of materials, before using the material for preparation of specimens, at the time of testing of specimens; and at different places such as at the supplier's premises, in the laboratory, in the stock yards/ storage tanks, in the mixing plants, in the field, etc.

After material sources are selected, the designer needs to make sure that the supply from the source will be available for the entire project, otherwise the design has to be changed with change in material source. Conformity of all the material ingredients to the relevant specifications and the procedures to these Guidelines need to be ensured.

A design documentation comprising the complete design including the drawings, sketches, plans, assumptions made, if any, time and location referenced test results that the design is based on has to be prepared and made available to the Project Authority for monitoring the performance of the designed pavement over time.

A.8. Performance monitoring

These Guidelines strongly recommends the Project Authorities to monitor over time the performance of the designed pavement as laid in the field to validate the adopted design and to further refine the models and the procedures used in the design. This should be done by:-

a) Measuring a set of pavement performance parameters: surface irregularity, rutting, alligator cracking, top down cracking,

b) Observing other kinds of distresses: age hardening, raveling, potholes, bleeding, etc.

c) Investigating the distresses observed, if any; core samples of distressed portions,

d) Gathering the air and pavement temperature data.

ANNEX B: APPLICATION OF IITPAVE SOFTWARE

B.1. Introduction

IITPAVE software is based on the analysis of linear elastic layered theory for pavement analysis. IITPAVE is applied for computing the stresses, strains and defections caused at different locations in a pavement by a uniformly distributed single load applied over a circular contact area at the surface of pavement. The effect of additional loads (which should also be uniformly distributed loads over circular contact areas) was considered using superposition principle. The single vertical load applied at the surface is described in terms of:

- Contact pressure and radius of contact area,
- Wheel load and contact pressure,
- Wheel load and radius of contact area

Wheel load and contact pressure are the load inputs for using IITPAVE. The pavement inputs required are the elastic properties (elastic/resilient moduli and Poisson's ratio values of all the pavement layers) and the thicknesses of all the layers (excluding sub-grade). IITPAVE software, in its current version, can be used to analyze pavements with a maximum of ten layers including the sub-grade. Cylindrical coordinate system is followed in the program. Thus, the location of any element in the pavement is defined by (a) depth of the location of the element from the surface of the pavement and the radial distance of the element measured from the vertical axis of symmetry (along the centre of the circular contact area of one wheel load).

B.2. Using IITPAVE for the analysis of flexible pavement

Following steps may be performed for analyzing the pavement using IITPAVE Software.

a. Open the IRC_37_IITPAVE folder
b. Open the IITPAVE _EX_exe and the main page of the software can be seen. There are two options for ***Design of New Pavement System*** and edit existing file.
c. Inputs are:
   - Number of pavement layers including sub-grade (if all bituminous layers are taken as one bituminous layer and all the granular layers are taken as one layer, then the number of layers is 3 (bituminous layer, granular and sub-grade)
   - Resilient Modulus/ Elastic Modulus values of all layers in MPa
   - Poisson's Ration of all layers,
   - Thickness (in mm) of all the layers except sub-grade.
d. Single wheel load: For the purpose of calculation of critical strains such as vertical compressive strain on top of sub-grade, horizontal tensile strain at the bottom of bituminous layer and horizontal tensile strain at the bottom of cement treated layers, since the analysis is done for a standard axle of 80 kN, a single wheel load of 20000 (N) is given as input.

   In the case of CTB layer, cumulative fatigue damage analysis due to the tensile stress/ strain at the bottom of the CTB layer has to be calculated for different axle loads:
   - For example, if tensile stress due to a single axle load (with dual wheels) of 100 kN is to be calculated, a single wheel load of 25,000 (N) is given as input.
   - For estimating the effective sub-grade strength select a single wheel load of 40,000 (N)
e. Tyre (contact) pressure: For calculation of the vertical compressive strain on top of the sub-grade and the horizontal tensile strain at the bottom of bituminous layer, a contact pressure of 0.56 MPa is considered. For analyzing the tensile strain or tensile stress at the bottom of the CTB base for carrying out fatigue damage analysis of CTB, the contact pressure suggested is 0.80 MPa. The bituminous layer bottom-up fatigue cracking and sub-grade rutting performance models have been developed/ calibrated with the strains calculated with standard axle (80 kN) loading and a contact pressure of 0.56 MPa and hence, these inputs should not be changed.

f. The number of locations in the pavement at which stress/ strain/ deflection has to be computed. This input can be entered through a drop down menu

g. For the locations selected for analysis, the values of depth (mm) from pavement surface and the radial distance (mm) from centre of the wheel are to be given.

h. IITPAVE Software provides the option to carryout analysis for a single wheel load or for a dual wheel load set (two wheels at a centre to centre spacing of 310 mm) by selecting 1 or 2 respectively from the drop down menu next to “Wheel Set”. For design of pavements, select “Dual Wheel set” option.

i. Inputs can also be given through an input file. The name of the input file can be selected by clicking on ‘Edit Existing File’ option which appears on the IITPAVE Start Screen.

j. After all the inputs are entered, submit them by Clicking on “Submit”. To change the data submitted use “Reset” option

k. After successfully submitting the inputs use the “RUN” options which will appear next to “Reset” after the inputs are submitted.

l. Output screen: The output screen displays options for the mode of output to be viewed either through “Open file editor” or “view here”. Once either of the options is chosen the output page reports all the input data and gives the computed values of identified stresses, strains and deflections for the locations (represented by the depth (Z) of the location measured from pavement surface, and the radial distance (R) of the location measured from the centre of the circular contact area of the load) selected. The mechanistic parameters reported in the output page are: vertical stress (SigmaZ), tangential stress (SigmaT), radial stress (SigmaR), shear stress (TaoRZ), vertical deflection (DispZ), vertical strain (epz), horizontal tangential strain (epT), and horizontal radial strain (epR)

m. For locations on the interface of two layers, the analysis will be done twice: (a) assuming the elastic properties (elastic modulus and Poisson’s ratio) of the layer above the interface and then (b) with the elastic properties of the layer below. The second set of results, for the layer below the interface, are identified in the output by the suffix “L” appearing after the depth (Z) value.

n. For the results of pavement analysis presented in the screen shot of the output page, the critical mechanistic parameter, horizontal tensile strain (ε_t), will be the largest of the tangential and radial strains at the bottom of the bituminous layer (layer above the interface between bituminous layer and granular layer) computed at two radial distances of ‘0’ and ‘155’. Thus, horizontal tensile strain (ε_t) will be taken as 0.0001283 (0.1283*10-3) which is the maximum out of the four strain values (tangential and radial at ‘0’ and ‘155’ mm radial distances), i.e., 0.0001283, 0.0001249, 0.00008320 and 0.00006056 (shown in rectangular boxes). Note that the values have been taken from the upper line of the two sets of results reported for the interface between the bituminous layer and granular layer (at a depth of 140 mm). Similarly, for this pavement, vertical compressive strain (ε_v) will be taken from the results corresponding to the lower line (with “L”) of the two sets of results available for the interface between granular layer and subgrade. Thus, the vertical compressive strain (ε_v) value of 0.0002053 (0.2053*10-3) which is the larger of the two strain values obtained for the interface between the subgrade and the granular layer (at radial distances of ‘0’ and ‘155’ mm), i.e., 0.0002053 and 0.000193 (shown in rectangular boxes).

o. Positive stresses and strains are “tensile” whereas Negative stresses and strains are “Compressive”. Only the absolute values without the (+) or (-) sign will be used in the performance models.

ANNEX C: WORKED OUT EXAMPLES FOR PAVEMENT DESIGN

D.1. Estimation of Effective Sub-grade Modulus/CBR

Problem:

If the CBR of the soil used in the upper 500 mm of embankment is 8% and the CBR of the borrow soil used for preparing the 500 mm thick compacted sub-grade above embankment is 20%. What is the effective sub-grade Modulus/CBR for design of flexible pavement?

Solution:

Elastic modulus of the prepared (upper 500 mm) embankment soil: (from the Equation 14)

$$M_{RS} = 17.6 * (CBR)^{0.64} \qquad \textbf{(for CBR} > 5\%)$$

$$\boldsymbol{M_{RS}} = 17.6*(8)^{0.64} = 66.6 \text{ MPa}$$

Elastic modulus of the select borrow material:

$$\boldsymbol{M_{RS}} = 17.6*(20)^{0.64} = 119.7 \text{ MPa}$$

Consider a two-layer elastic system consisting of 500 mm of select borrow soil of modulus 119.7 MPa and the semi-infinite embankment soil of modulus 66.6 MPa as shown in Figure 11.

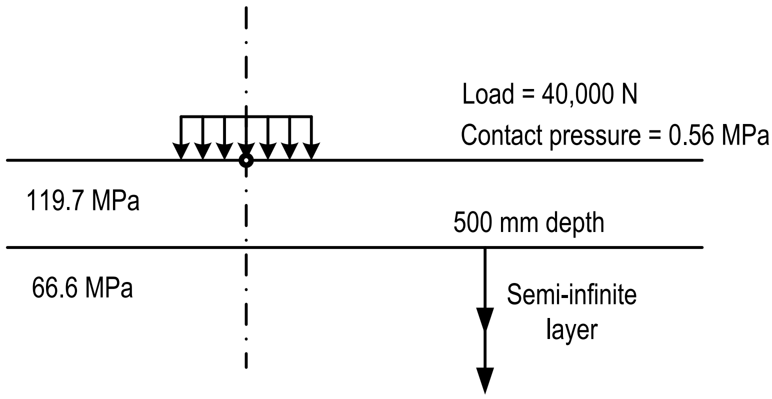


Figure 11: Two-layer pavement system with sub-grade and embankment

Consider the Poisson's ratio value of both the layers to be 0.35. Apply a single load of 40,000 N at a contact pressure of 0.56 MPa. Radius of circular contact area for this load and contact pressure = 150.8 mm. Calculate surface deflection at the centre of the load (Point A in Figure II.1) using IIPAVE (no of layers = 2; elastic moduli of 119.7 MPa and 66.6 MPa; Poisson's ratio of 0.35 for both the layers; thickness of 500 mm for upper layer; single wheel load of 40000 N, analysis points = 1; Depth = 0 mm; Radial distance = 0 mm. For this input data, surface deflection = 1.41 mm from IITPAVE.

The Modulus of resilient of an equivalent single layer to produce the deflection of 1.41 mm can be calculated by using the relationship below:

$$M_{RS} = \frac{2(1-\mu^2)pa}{\sigma}$$

$\boldsymbol{M_{RS}}$ is calculated as 105.81 MPa. However, the effective Resilient Modulus shall be limited to the 100 MPa. The corresponding effective CBR for this value of $\boldsymbol{M_{RS}}$ is taken as 15.1 %.

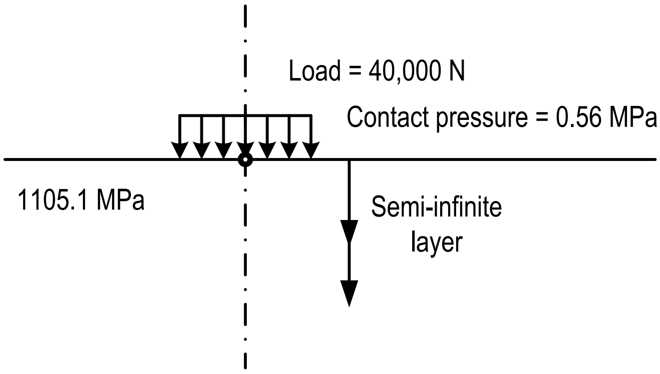


Figure C2: Equivalent (effective) sub-grade system

D.2. Design example for checking the adequacy of Granular Sub-base Thickness

The catalogues have been developed considering 80 % reliability sub-grade rutting and fatigue cracking performance models for design traffic up to 20 msa, and using 90% models for higher traffic levels.

Resilient moduli of 2000 MPa (VG30 binder mix for BC as well as DBM) and 3000 MPa (VG40 binder mix for BC as well as DBM) were considered for less than 20 msa and 20 to 50 msa categories respectively. It may be noted that, for expressways and national highways, even if the design traffic is 20 msa or less, VG40 bitumen shall be used for surface as well as DBM layers.

In the absence of axle load spectrum data, in the development of the design catalogues, the CTB layer was checked only for one fatigue criterion given by Equation 5. However, it is essential to check the CTB thickness with project specific axle load spectrum as mentioned in these guidelines.

The values of RF factor used in Equation 5 are taken as 2 for design traffic less than 10 msa and as 1 for design traffic of 10 msa or more.

D.3. Design of Bituminous pavement with granular base and sub-base

I. Problem:

Bituminous pavement is to be designed with the granular base and sub-base layers using the following input data:

a. Four lane divided highway
b. Initial traffic in the year of completion of construction = 5000 cvpd (two-way)
c. Annual traffic growth rate = 6.0 percent
d. Design life period = 20 years
e. Vehicle damage factor = 5.2 (for both direction)
f. Effective CBR of sub-grade = 7%
g. Marshall mix design carried out in the bituminous mix to be used in the bottom of the bituminous layer (DBM) for an air void content of 11.5%

II. Solution

a. Lateral Distribution factor = 0.75 (for each direction)
b. Initial directional traffic = 2500 CVPD (assuming 50 per cent in each direction)
c. Vehicle Damage Factor (VDF) = 5.2
d. Cumulative number of standard axles to be catered for in the design

$$N = \frac{2500\times365\times((1+0.06)^{20}-1)}{0.06} \times 0.75 \times 5.2 = 131 \text{ msa}$$

e. Effective CBR of sub-grade = 7 %

f. Effective resilient modulus of Sub-grade = $17.6x(7.0)^{0.64}$ = 62 MPa (less than 100 MPa, the upper limit)

g. Since the design traffic is more than 50 msa, provide a SMA/GGRB or BC with modified bitumen surface course and DBM binder/base layer with VG40 with viscosity more than 3600 Poise (at 600C)

h. Select a trial section with 190 mm total bituminous layer (provide 40 mm thick surface layer, 70 mm thick DBM-II, 80 mm thick bottom rich DBM-I); 250 mm thick granular base (WMM) and 230 mm thick granular sub-base (GSB). Total thickness of granular layer = 480 mm

i. Resilient modulus of the granular layer = 0.2 x (480)0.45x 62 = 200 MPa

j. Adopting 90 % reliability performance models for sub-grade rutting and bituminous layer cracking (design traffic > 20 msa)

k. Allowable vertical compressive strain on sub-grade for the design traffic of 131 msa and for 90 % reliability (using equation 3.2) = 0.000301 ($0.301 \text{ X } 10^{-03}$)

l. Allowable horizontal tensile strain at the bottom of bituminous layer for a design traffic of 131 msa, 90 % reliability, air void content of 3 % and effective binder volume of 11.5 %, and a resilient modulus of 3000 MPa for bottom rich bottom DBM layer (DBM-I) (using Equation 3.4) = 0.000150 ($0.150 \text{ X } 10^{-03}$)

m. Analyzing the pavement using IITPAVE with the following inputs (elastic moduli: 3000 MPa, 200 MPa, 62 MPa, Poisson's ratio values of 0.35 for all the three layers, layer thicknesses of 190 mm and 480 mm). Computed Horizontal tensile strain = 0.000146 < 0.000150. Hence OK

n. Computed vertical compressive strain = 0.000243 < allowable strain of 0.000301. Hence OK

D.4. Design example for Long Life Pavement

Long-life Pavement

(for traffic equal or greater than 300msa)

1.Bituminous Pavements with Granular Base and Sub Base

Effective CBR	7	%
Trial thickness of BT	310	mm
Thickness of GSB	200	mm
Thickness of Granular Base	250	mm
Allowable Subgrade Strain	200	με
Allowable Tensile Strain in the BT	80	με
Modulus of BT	3000	Mpa
Modulus of Subgrade	62	MPa
poisson Ratio	0.35	
Cumulative number of standard axles to be catered for in the design,(msa)	300	msa

IITPAVE Analysis

Elastic Modulus of top layer	3000	Mpa
Elastic Modulus of middle	200	Mpa
Elastic Modulus of bottom layer	62	Mpa
Poisson Ratio of top layer	0.35	
Poisson Ratio of middle layer	0.35	
Poisson Ratio of bottom layer	0.35	
Thickness of top Layer	310	mm
Thickness of Bottom Layer	450	mm
Single Wheel Load	20000	N
Tyer Pressure	0.56	MPa
Wheels	2	
Point Of Analysis	4	
Radial Distance	0	155
Depth	310	760
Computed Horizontal Tensile Strain	0.000080	Safe
Computed Vertical Compressive Strain	0.000152	Safe

2.Bituminous Pavements with Cement Treated Sub-Base, WMM as base Layer

Effective CBR	7	%
Trial thickness of BT	250	mm
Thickness of WMM	150	mm
Thickness of CTSB(min 200)	300	mm
Allowable Subgrade Strain	200	με
Allowable Tensile Strain in the BT	80	με
Modulus of BT	3000	Mpa
Modulus of Subgrade	62	MPa
poisson Ratio	0.35	
Cumulative number of standard axles to be catered for in the design,(msa)	300	msa

IITPAVE Analysis

Elastic Modulus of BT	3000	Mpa
Elastic Modulus of WMM	350	Mpa
Elastic Modulus of CTSB	600	Mpa
Elastic Modulus of Subgrade	62	
Poisson Ratio ofBT	0.35	
Poisson Ratio of WMM	0.35	
Poisson Ratio of CTSB	0.25	
Poisson Ratio of Subgrade	0.35	
Single Wheel Load	20000	N
Tyer Pressure	0.56	MPa
Wheels	2	
Point Of Analysis	4	
Radial Distance	0	155
Depth	250	700
Computed Horizontal Tensile Strain	0.0000791	Safe
Computed Vertical Compressive Strain	0.0001571	Safe

3.Use of high Modulus binder			
Effective CBR	7	%	
Thickness of high modulus mix	190	mm	
Thickness of WMM	150	mm	
Thickness of CTSB(min 200)	300	mm	
Elastic Modulus of BT	5500	Mpa	
Elastic Modulus of WMM(crushed aggrigrate)	350	MPa	(300 for natural)
Elastic Modulus of CTSB	600	MPa	
Modulus of Subgrade	62	MPa	
Allowable Subgrade Strain	200	με	
Allowable Tensile Strain in the BT	80	με	

IITPAVE Analysis

Elastic Modulus of BT	5500	Mpa
Elastic Modulus of WMM	350	Mpa
Elastic Modulus of CTSB	600	Mpa
Elastic Modulus of Subgrade	62	
Poisson Ratio ofBT	0.35	
Poisson Ratio of WMM	0.35	
Poisson Ratio of CTSB	0.25	
Poisson Ratio of Subgrade	0.35	
Single Wheel Load	20000	N
Tyer Pressure	0.56	MPa
Wheels	2	
Point Of Analysis	4	
Radial Distance	0	155
Depth	190	640
Computed Horizontal Tensile Strain	0.00007777	Safe
Computed Vertical Compressive Strain	0.0001721	Safe

Comparison with a Conventional design for 150 msa

Consider the same CBR	7	%				
Thickness						
WMM	250	mm				
GSB	250	mm				
BT	200	mm				
Cumulative number of standard axles to be catered for in the design,(msa)	150	msa				
Elastic Modulus						
Subgrade	62	MPa				
Granular Layer	204	MPa				
BT	3000	MPa	Vbe(in %)	Va(%)	M	MRm
Reliabitity perfomance model for subgrade Rutting and Bituminous layer cracking	90	%	11.5	3	0.4990207	3000
Computed Tensile Strain in Bituminous Layer	0.0001364	<	0.00014607	Safe		
Vertical subgrade strain	0.0002237	<	0.000292	Safe		

ANNEX D: DESIGN OF SURFACE DRESSING

D.1. Introduction

Surface dressing is a simple, highly effective and inexpensive road surface treatment if adequate care is taken in the planning and execution of the work. The process is used throughout for surfacing both medium and lightly-trafficked roads, and also as a maintenance treatment for roads of all kinds.

Surface dressing comprises a thin film of binder, generally bitumen or tar, which is sprayed onto the road surface and then covered with a layer of stone chippings. The thin film of binder acts as a waterproofing seal preventing the entry of surface water into the road structure. The stone chippings protect this film of binder from damage by vehicle tyres, and form a durable, skid-resistant and dust-free wearing surface. In some circumstances the process may be repeated to provide double or triple layers of chippings.

Surface dressing is a very effective maintenance technique which is capable of greatly extending the life of a structurally sound road pavement if the process is undertaken at the optimum time. Under certain circumstances surface dressing may also retard the rate of failure of a structurally inadequate road pavement by preventing the ingress of water and thus preserving the inherent strength of the pavement layers and the subgrade.

In addition to its maintenance role, surface dressing can provide an effective and economical running surface for newly constructed road pavements. Existing roads with bituminous surfacing, carrying in excess of 1000 vehicles/lane/day, have been successfully surfaced with multiple surface dressings. For sealing new road bases traffic flows of up to 500 vehicles/lane/day are more appropriate, although this can be higher if the road base is very stable or if a triple seal is used. A correctly designed and constructed surface dressing should last at least 5 years before resealing with another surface dressing becomes necessary. If traffic growth over a period of several years necessitates a more substantial surfacing or increased pavement thickness, a bituminous overlay can be laid over the original surface dressing when the need arises.

The success of a surface dressing depends primarily on the adhesion of the chippings to the road surface, hence both the chippings and the road surface must be clean and free from dust during the surface dressing process. Inappropriate specifications, poor materials, and bad workmanship, can also drastically reduce the service life of a surface dressing.

D.2. Types of surface dressing

Single surface dressing: When applied as a maintenance operation to an existing bituminous road surface a single surface dressing can fulfill the functions required of maintenance re-seal, namely waterproofing the road surface, arresting deterioration, and restoring skid resistance. A single surface dressing would not normally be used on a new road-base because of the risk that the film of bitumen will not give complete coverage. It is also particularly important to minimize the need for future maintenance and a double dressing should be considerably more durable than a single dressing.

Double surface dressing: Double surface dressings are robust and should be used when: a) A new road-base is surface dressed, b) Extra 'cover' is required on an existing bituminous road surface because of its condition (e.g. when the surface is slightly cracked or patched) and c) There is a requirement to maximize durability and minimize the frequency of maintenance and resealing operations.

The quality of a double surface dressing will be greatly enhanced if traffic is allowed to run on the first dressing for a minimum period of 2-3 weeks (and preferably longer) before the second dressing is applied. This allows the chippings of the first dressing to adopt a stable interlocking mosaic which provides a firm foundation for the second dressing. However, traffic and animals may cause contamination of the surface with mud or soil during this period and this must be thoroughly swept off before the second dressing is applied. Such cleaning is sometimes difficult to achieve and the early application of the second seal to prevent such contamination may give a better result.

Sand may sometimes be used as an alternative to chippings for the second dressing. Although it cannot contribute to the overall thickness of the surfacing, the combination of binder and sand provides a useful grouting medium for the chippings of the first seal and helps to hold them in place more firmly when they are poorly shaped. A slurry seal may also be used for the same purpose.

Triple surface dressings: A triple surface dressing may be used to advantage where a new road is expected to carry high traffic volumes from the outset. The application of a small chipping in the third seal will reduce noise generated by traffic and the additional binder will ensure a longer maintenance-free service life.

D.3. Chippings for surface dressings

The selection of chipping sizes is based on the volume of commercial vehicles having unladen weights of more than 1.5 tonnes and the hardness of the existing pavement. Ideally, chippings used for surface dressing should be single sized, cubical in shape, clean and free from dust, strong, durable, and not susceptible to polishing under the action of traffic. In practice the chippings available usually fall short of this ideal but it is recommended that chippings used for surface dressing should comply with the requirements:

Table SD1: Recommended nominal size of aggregate (chips) in mm (Table 13.14: SSRBW-2073)

Type of Surface	Traffic intensity in Terms of Number of vehicles per day in the lane under consideration		
	1000-2000	200-1000	20-200
Very Hard	10	6	6
Hard	13	10	6
Normal	13	10	6
Soft	19	13	13
Very Soft		19	13

To ensure size uniformity, 65% percentage of chips is required to fall within a range of ± 2.5 mm of the ALD,

D.4. Bitumen

It is essential that good bonding is achieved between the surface dressing and the existing road surface. This means that non-bituminous materials must be primed before surface dressing is carried out. The correct choice of bitumen for surface dressing work is critical. The bitumen must fulfill a number of important requirements. They must:

- be capable of being sprayed;
- 'wet' the surface of the road in a continuous film;
- not run off a cambered road or form pools of binder in local depressions;
- 'wet' and adhere to the chippings at road temperature;
- be strong enough to resist traffic forces and hold the chippings at the highest prevailing ambient temperatures;
- remain flexible at the lowest ambient temperature, neither cracking nor becoming brittle enough to allow traffic to 'pick-off' the chippings; and
- resist premature weathering and hardening.

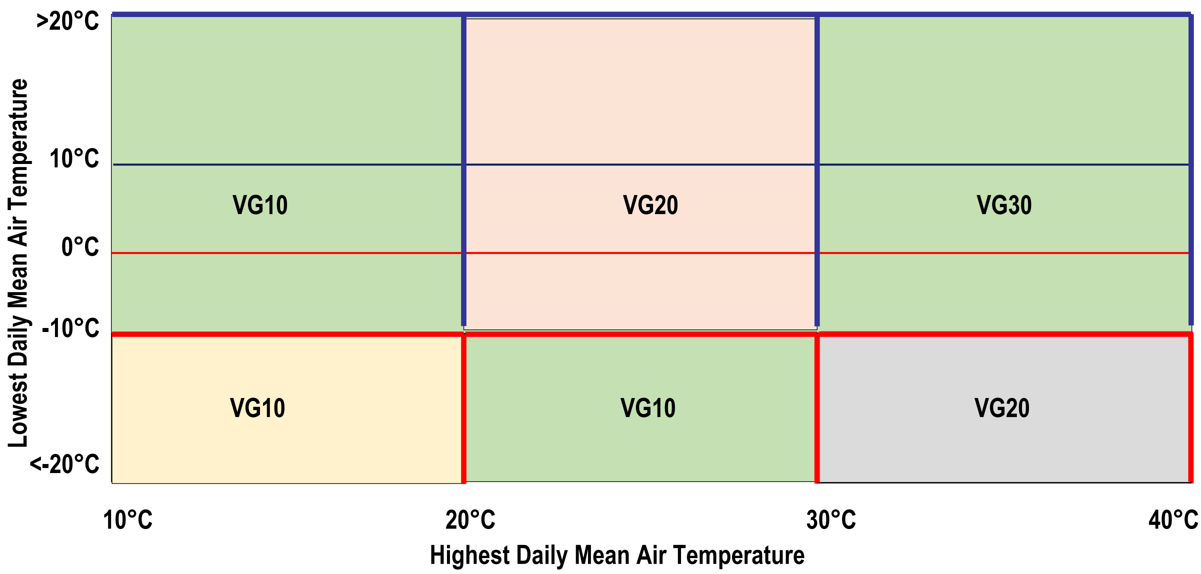


*Figure SD12: **Selection Criteria for Viscosity-Graded (VG) Paving Bitumen Based on Climatic Conditions***

The optimum choice of binder involves a careful compromise. For example, the binder must be sufficiently fluid at road temperature to 'wet' the chippings whilst being sufficiently viscous to retain the chippings against the dislodging effect of vehicle tyres when traffic is first allowed to run on the new dressing.

D.5. Adhesion agents

Proprietary additives, known as adhesion agents are available for adding to binders to help to minimize the damage to surface dressings that may occur in wet weather with some types of stone. When correctly used in the right proportions. These agents can enhance adhesion between the binder film and the chippings even though they may be wet.

D.6. Design

The key stages in the surface dressing design procedure are:

D.6.1 Existing site conditions

Selection of a suitable surface dressing system for a road and the nominal size of chippings to be used is based on the daily volume of commercial vehicles using each lane of the road and the hardness of the existing pavement surface.

With time, the action of traffic on a surface dressing gradually forces the chippings into the underlying surface, thus diminishing the surface texture. When the loss of surface texture reaches an unacceptable level a reseal will be required to restore skid resistance. The embedment process occurs more rapidly when the underlying road surface is softer, or when the volume of traffic, particularly of commercial vehicles, is high. Accordingly, larger chippings are required on soft surfaces or where traffic is heavy whilst small chippings are best for hard surfaces. For example, on a very soft surface carrying 1000 commercial vehicles per lane per day, 19mm chippings are appropriate, whilst on a very hard surface such as concrete, 6mm chippings would be the best choice.

Guidance on the selection of chipping size for single surface dressings, relating the nominal size of chipping to the hardness of the underlying road surface and the weight of traffic expressed in terms of the number of commercial vehicles carried per lane per day. These recommendations are shown in Table SD1.

Road surface hardness may be assessed as per the basis of judgement with the help of the definitions given in **Table SD2**

Table SD2: Categories of road surface hardness

Category of surface	*Penetration at 30^{0}C (mm)*	*Definition*
Very hard	0-2	Concrete or very lean bituminous structures with dry stony surfaces. There would be negligible penetration of chippings under the heaviest traffic.
Hard	2-5	Likely to be an asphalt surfacing which has aged for several years and is showing some cracking. Chippings will penetrate only slightly under heavy traffic.
Normal	5-8	Typically, an existing surface dressing which has aged but retains a dark and slightly bitumen-rich appearance. Chippings will penetrate moderately under medium and heavy traffic.
Soft	8-12	New asphalt surfacings or surface dressings which look bitumen-rich and have only slight surface texture. Surfaces into which chippings will penetrate considerably under medium and heavy traffic.
Very soft	>12	Surfaces, usually a surface dressing which is very rich in binder and has virtually no surface texture. Even large chippings will be submerged under heavy traffic.

The standard cone normally used with this penetrometer is replaced by a 4mm diameter probe rod with a hemispherical tip made of hardened steel. The probe is forced into the road surface under a load of 35 kgf (343N) applied for 10 seconds and the depth of penetration is measured by a spring loaded collar that slides up the probe rod. The distance the collar has moved is measured with a modified dial gauge. The temperature of the road surface is recorded and a graphical method is used to correct the probe measurements to an equivalent value at a standard temperature of 30⁰C.

The road surface temperature should be measured at the same time that the probe is used and the tests should not be made when the surface temperature exceeds 35⁰C. This will limit probe testing to the early morning. The probe readings are corrected to a standard temperature of 30⁰C using Figure SD2, and the mean of ten probe measurements is calculated and reported as the mean penetration at 30⁰C. Categories of road surface hardness and the corresponding ranges of surface penetration values are shown in **Table SD2.**

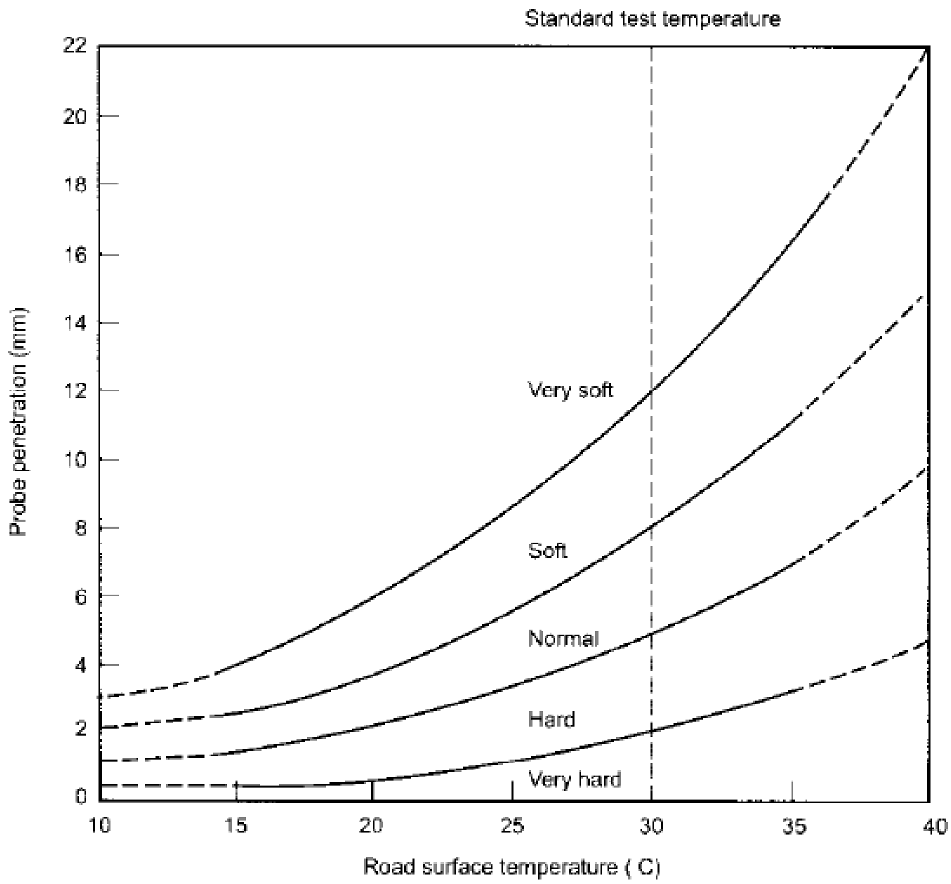


Figure SD2: Graphical method for correcting measurements of road surface hardness to the standard test temperature of 30⁰C

If larger sized chippings are used than is recommended in Table SD-1 then the necessary bitumen spray rate, required to hold the chippings in place, is likely to be underestimated by the design in the section.

This is likely to result in the 'whip-off' of chippings by traffic early in the life of the dressing and also to have a significant effect on the long term durability of low volume roads.

In selecting the nominal size of chippings for double surface dressings, the size of chipping for the first layer should be selected on the basis of the hardness of the existing surface and the traffic category as indicated in Table SD-1. The nominal size of chipping selected for the second layer should preferably have an ALD of not more than half that of the chippings used in the first layer. This will promote good interlock between the layers.

In the case of a hard existing surface, where very little embedment of the first layer of chippings is possible, such as a newly constructed cement stabilized road base or a dense crushed rock base, a 'pad coat' of 6mm chippings should be applied first followed by l0mm or 13 mm chippings in the second layer. The first layer of small chippings will adhere well to the hard surface and will provide a ‘key' for the larger stone of the second dressing.

D.6.2 Selecting the binder

The binder shall be either bitumen conforming to IS: 73 or rapid setting cationic bitumen emulsion (RS-2) conforming to IS: 8887. Grade of bitumen shall depend upon the climatic condition, for selection of grade of bitumen guidance may be taken from Figure SD1: Selection Criteria for Viscosity-Graded (VG) Paving Bitumen Based on Climatic Conditions.

D.6.3 Cutter for binder and timing of construction work

The purposes of cutter oil in surface dressing (Cunningham 2012) are as follows:

• To provide temporary viscosity reduction to allow a wide uniform spray jet without the need for excessive temperatures which cause increased cutter evaporation before reaching the road. Such evaporation at high temperature results in fuming

• To promote better initial aggregate adhesion

• To improve aggregate mosaic formation.

Ensure that an appropriate proportion of cutter oil is added to the binder for the existing pavement temperature. Cutter may be Cutter Oil (Kerosene) or Flux Oil (Diesel). For surface temperature 20°C to 50°C, the required binder viscosity before spray should lie between approximately 10^4 and 7×10^5 centistokes. Typically, 5 to 12% percent of cutter (kerosene) is used. The amount of cutter required for 'on-site' blending should be determined in the laboratory by making viscosity tests on a range of blends of bitumen and cutter.

Designing the surface dressing

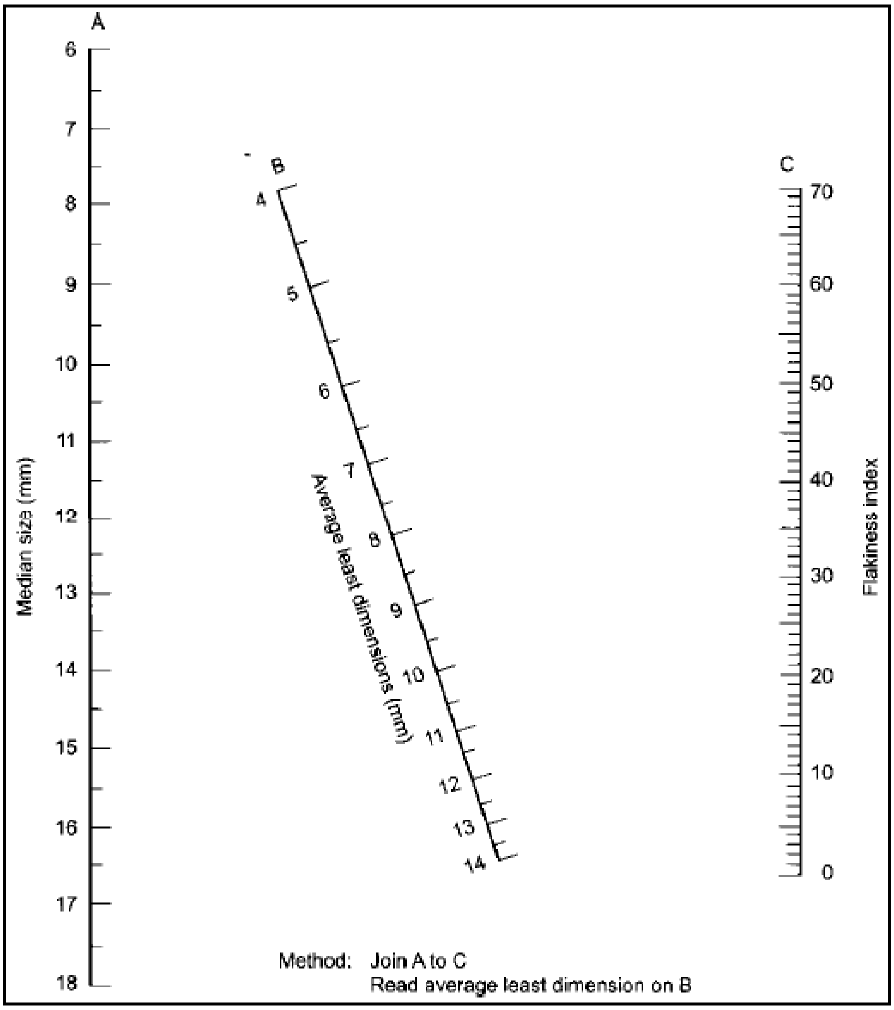


Figure SD3: Determination of average least dimension

D.6.4 Basis for the design method

Having selected the nominal size of chipping and the type of binder to be used, the next step in the design of a surface dressing is to determine the rate of spread of the binder. Differences in climate, uniformity of road surfaces, the quality of aggregates, traffic characteristics and construction practice, necessitate a more general approach to the determination of the rate of spread of the binder for application.

The method of surface dressing design put forward by Jackson (1963) is suitable for general application and trials undertaken by the TRL in Kenya (Hitch, 1981) indicate that with some minor modifications, it works well under a range of tropical and sub-tropical conditions.

The Jackson method of design incorporates concepts first put forward by Hanson (1934) which relate the voids in a layer of chippings to the amount of binder necessary to hold the chippings in place. Hanson calculated that in a loose single layer of chippings, such as is spread for a surface dressing, the voids are initially about 50 percent decreasing to about 30 per cent after rolling and subsequently to 20 per cent by the action of traffic. For best results, between 50 and 70 per cent of the voids in the compacted aggregate should be filled with binder.

Hence it is possible to calculate the amount of binder required to retain a layer of regular, cubical chippings of any size. However, in practice chippings are rarely the ideal cubical shape (especially when unsuitable crushing plant has been used) and this is why the ALD concept was originally introduced.

D.7. Determining the average least dimension of chippings

The Average least Dimension (ALD) of chippings is a function of both the average size of the chippings, as determined by normal square mesh sieves and the degree of flakiness. The ALD may be determined in two ways.

Method I: A grading analysis is performed on a representative sample of the chippings in accordance with British Standard 812:1985. The sieve size through which 50 percent of the chippings pass is determined (i.e. the 'median size'). The flakiness index is then also determined in accordance with British Standard 812:1985. The ALD of the chippings is then derived from the monograph shown in **Figure SD3**.

Method II: A representative sample of the chippings is carefully subdivided (in accordance with British Standard 812:1985) to give approximately 200 chippings. The least dimension of each chipping is measured manually and the mean value, or ALD, is calculated.

D.8. Determining the overall weighting factor

The ALD of the chippings is used with an overall weighting factor to determine the basic rate of spray of bitumen. The overall weighting factor F' is determined by adding together four factors that represent: the level of traffic, the condition of the existing road surface, the climate and the type of chippings that will be used. Factors appropriate to the site to be surface dressed are selected from Table SD3.

Table SD3: ***Weighting factors for surface dressing design***

Traffic	*Vehicles/lane/day*	Factros
Very light	0-50	+3
Light	50 - 250	+1
Medium	250- 500	0
Medium-heavy	500- 1500	-l
Heavy	1500 - 3000	-3
Very heavy	3000+	-5

Existing surface:

Untreated or primed base	+6
Very lean bituminous	+4
Lean bituminous	0

Average bituminous	-1
Very rich bituminous	-3

Climatic conditions

Wet and cold	+2
Tropical (wet and hot)	+1
Temperate	0
Semi-arid (hot and dry)	-l
Arid (very dry and very hot)	-2

Type of chippings

Round/dusty	+2
Cubical	0
Flaky (see Appendix A)	-2
Pre-coated	-2

The rating for the existing surface allows for the amount of binder which is required to fill the surface voids and which is therefore not available to contribute to the binder film that retains the chippings. If the existing surface of the road is rough, it should be rated as 'very lean bituminous' even if its overall colour is dark with bitumen. Similarly, when determining the rate of spread of binder for the second layer of a double surface dressing, the first layer should also be rated 'very lean bituminous'.

The Jackson method of determining the rate of spread of binder requires the estimation of traffic in terms of numbers of vehicles only. However, if the proportion of commercial vehicles in the traffic stream is high (say more than 20 per cent) the traffic factor selected should be for the next higher category of traffic than is indicated by the simple volume count.

D.9. Determining the basic bitumen spray rate

Using the ALD and 'F' values in Equation SD20 will give the required basic rate of spread of binder.

$$R = 0.625 + (F * 0.023) + [0.0375 + (F * 0.0011)]ALD$$ *Equation SD20*

Where, F = Overall weighting factor

ALD = the average least dimension of the chippings (mm)

R = Basic rate of spread of bitumen (kg/m2)

D.10. Spray rate adjustment factors

Research in Kenya (Hitch, 1981) and elsewhere, has indicated that best results will be obtained if the basic rate of spread of binder is adjusted to take account of traffic speed and road gradient as follows.

- For slow traffic or climbing grades with gradients steeper than 3 percent, the basic rate of spread of binder should be reduced by approximately 10 percent.
- For fast traffic or downgrades steeper than 3 percent the basic rate of spread of binder should be increased by approximately 10 percent.
- Emulsion binders: multiply the rate of spread by 90% bitumen content of the emulsion (per cent).

D.11. Adjusting rates of spray for maximum durability

The spray rate which will be arrived at after applying the adjustment factors (Flat terrain, moderate traffic speeds : No adjustment, High speed traffic, down hill grades >3% : 1.1 adjustment factor to basic design spray rate, & 0.9 adjustment factor to basic design spray rate for low speed traffic, uphill grade>3%) will provide very good surface texture and use an 'economic' quantity of binder. However, because of the difficulties experienced in many countries in carrying out effective maintenance, there is considerable merit in sacrificing some surface texture for increased durability of the seal.

Table 6 Typical bitumen spray rate adjustment factors

Binder grade	*Basic spray rate from Figure 7 or equation 1*	*Flat terrain, moderate traffic speeds*	*High speed traffic, down-hill grades >3%*	*Low speed traffic, up-hill grades >3%*
MC3000	R	R	R*1.1	R*0.9
300 pen	R	R*0.95	R*1.05	R*0.86
80/100 pen	R	R*0.9	R*0.99	R*0.81
Emulsion[1]	R	R*(90/%binder)	R*(99/%binder)	R*(81/%binder)

For roads on flat terrain and carrying moderate to high speed traffic it is possible to increase the spray rates obtained by applying the factors given above by approximately 8 percent. The heavier spray rate may result in the surface having a 'bitumen-rich' appearance in the wheel paths of roads carrying appreciable volumes of traffic. However, the additional binder should not result in bleeding and it can still be expected that more surface texture will be retained than is usual in an asphalt concrete wearing course.

D.11.1 Surface dressing design for low volume roads

If a low volume road, carrying less than about 100 vehicles per day, is surface dressed it is very important that the seal is designed to be as durable as possible to minimise the need for subsequent maintenance.

A double surface dressing should be used on new roadbases and the maximum durability of the seal can be obtained by using the heaviest application of bitumen which does not result in bleeding.

Where crushing facilities are put in place solely to produce chippings for a project, it will be important to maximise use of the crusher output. This will require the use of different combinations of chipping sizes and correspondingly different bitumen spray rates. The normally recommended sizes of chippings for different road hardness and low commercial traffic volumes are reproduced in Table SD.

Table SD4: ***Nominal size of chippings for different hardness of road surface***

No. of commercial Vehicles/lane/day[1]	*20-100*	*<20*
Category of road surface hardness	*Nominal chipping size (mm)*	
Very hard	*6*	*6*
Hard	*6*	*6*
Normal	*10*	*6*
Soft	*14*	*10*

Vehicles with an unladen weight greater than 1.5 tonnes

Ideally the ALD of the two aggregate sizes used in a double surface dressing should differ by at least a factor of two. If the ALD of the chippings in the second seal is more than half the ALD of the chippings in the first seal then the texture depth will be further increased and the capacity of the aggregate structure for bitumen will be increased.

D.11.2 Spread rate of chippings

An estimate of the rate of application of the chippings assuming that the chippings have a loose density of 1.35 Mg/m3, can be obtained from the following equation:

$$Chipping\ Application\ Rate(kg/m^2) = \mathbf{1.36 * ALD}$$ *Equation SD21*

Table SD5: ***Suggested maximum increases in bitumen spray rate for low volume roads***

ALD of chippings (mm)		3		6		>6
All traffic (vehicles/lane/day)	<20	20-100	<20	20-100	<20	20-100
Increase in bitumen spray rate (per cent)	15	10	20	15	30	20

An additional ten per cent is allowed for whip off. Storage and handling losses must also be allowed for when stockpiling chippings. The precise chipping application rate must be determined by observing on site whether any exposed binder remains after spreading the chippings, indicating too low a rate of application of chippings, or whether chippings are resting on top of each other, indicating too high an application rate. Best results are obtained when the chippings are tightly packed together, one layer thick. To achieve this, a slight excess of chippings must be applied. Some will be moved by the traffic and will tend to fill small areas where there are insufficient chippings. Too great an excess of chippings will increase the risk of whip-off and windscreen damage.

ANNEX E: DESIGN OF FLEXIBLE PAVEMENT FOR LOW VOLUME ROADS

E.1. Introduction

The annex has been developed with reference of IRC: SP 72:2015. Any road with design traffic up to 2 msa, has to be designed as per the annex. All such roads should be designed for a minimum sub-grade CBR of 5%.

E.2. Design considerations

E.2.1 Cumulative Equivalent Standard Axle Load Determination

Cumulative equivalent standard axle load is determined by considering the following:

- Only Trucks, Buses, Tractor-Tailors, with gross weight more than 3 tons have to be accounted
- For vehicles with single axle loads different from 80kN, and tandem axle loads different from 148 kN can be converted into standard axles using the Axle Equivalence Factor = $[W/W_s]^4$, where W is Axle load (in KN) for the vehicle in question and Ws is Standard Axle Load of 80KN or 128KN in case of tandem axles.

Vehicle Damaging Factor (VDF) is calculated by considering the following:

If axle load survey is available, VDF is calculated as per above mentioned method, if not then following assumption is taken for the design:

- Laden Heavy Commercial Vehicle (HCV) = 2.58
- Unladen/Partially Laden Heavy Commercial Vehicle (HCV) = 0.31 **(Suggested)**
- 10% Overloaded Heavy Commercial Vehicle (HCV) = 2.86 **(Suggested)**
- 20% Overloaded Heavy Commercial Vehicle (HCV) = 5.35
- Laden Medium Heavy Commercial Vehicle (MCV) =0.31
- Unladen/Partially Laden Medium Heavy Commercial Vehicle (MCV) =0.091 **(Suggested)**
- 10% Overloaded Medium Heavy Commercial Vehicle (MCV) = 0.34 **(Suggested)**
- 20% Overloaded Medium Heavy Commercial Vehicle (MCV) = 0.65

Lane Distribution Factor (L) is taken as following:

L= 1 for Single and Intermediate Lane roads, traffic is total traffic per day in both direction

L= 0.75 for Double Lane roads, traffic is total traffic per day in both direction

Cumulative ESAL = N = T_o x 4811 x L,

Where, T_o = ESAL per day = No. of Commercial Vehicle x VDF

Design Life = 10 yr and Growth rate = 6%

If HCV, MCV in traffic stream could not be ascertained, particularly for new roads, a reasonable estimate of design traffic in term of Cumulative ESAL as :

Table E1: ***Approximate Cumulative ESAL***

ADT*	CVPD	Cumulative ESAL (For 10yr Design Life)
100	25	19380
150	35	60969
200	50	96482
300	75	149952
400	100	192961
500	125	297225
1000	300	663120

* include both motorized and non motorized vehicle

E.2.2 Traffic Categorization

Traffic is classified as per the equivalent standard axle load calculated for the design. The category of traffic class is shown the table below:

Table E2: ***Traffic category***

Traffic Code	Cumulative ESAL (For 10yr Design Life)
T1	10000-30000
T2	>30000-60000
T3	>60000-100000
T4	>100000-200000
T5	>200000-300000
T6	>300000-600000
T7	>600000-1000000
T8	>1000000-1500000
T9	>1500000-2000000 (2 msa)

E.2.3 Sub-Grade

Sub-grade can be defined as a compacted layer, generally of natural occurring local soil, assumed 300mm in thickness just beneath the pavement crust, and is made up of in-situ material, select soil or stabilized soil that forms the foundation of the pavement. The sub-grade in embankment is compacted in two layers, usually to a higher standard than lower part of embankment. It should be well compacted to limit the scope of rutting in pavement due to additional densification during the service life of pavement. For poor sub-grade, sub-grade improvement technique should be adopted.

Sub-grade should be compacted to 100% of MDD achieved by the Standard Proctor Test (IS 2720-Part 7) and dry weight not less than 16.5 KN/m^3. If CBR <2%, Economic feasibility of replacing 300mm sub-grade with suitable soil is ascertained.

Method A: Based on Soil Classification

Table E3: ***Typical Soaked CBR***

Sub-grade Soil	IS Soil Classification	Typical Soaked CBR %
Highly Plastic Clay and Silts	CH, MH	* 2-3
Silt, Clay and Sandy Clay	ML, MI-CL, CI	4-5
Clayey Sands and Silt Sands	SC, SM	6-10

* For Expansive Clay, CBR = 2%

Method B: Conducting CBR Test in Laboratory (Most Reliable)

Method C: Quick Estimation

Plastic Soil

CBR = 75 / [1 + 0.728 x WPI]

Where, WPI = Weighted Plastic Index = $P_{0.075}$ x PI

$P_{0.075}$ = % passing 0.075mm Sieve in decimal

PI = Plasticity Index of Soil in %

Non-Plastic Soil

CBR = 28.091 x $(D_{60})^{0.3581}$

Where, D_{60} = Diameter in mm of Grain Size corresponding to 60 % finer

Method D: DCP Test

- Standard Steel Cone with an angle of 60 deg., 20mm diameter
- Standard 8Kg drop, fall height = 575mm
- Measurement up to 1.2 m depth at sub-grade level

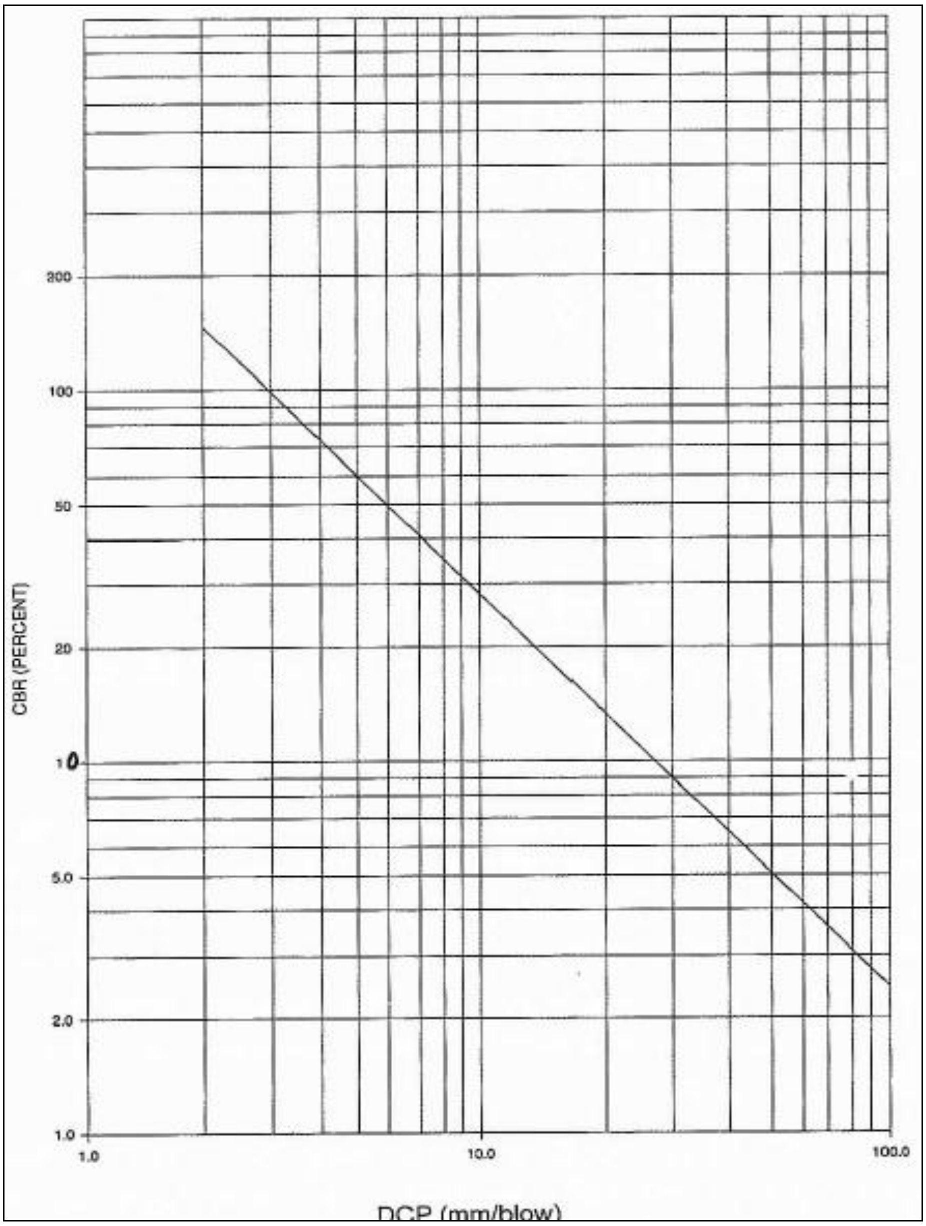


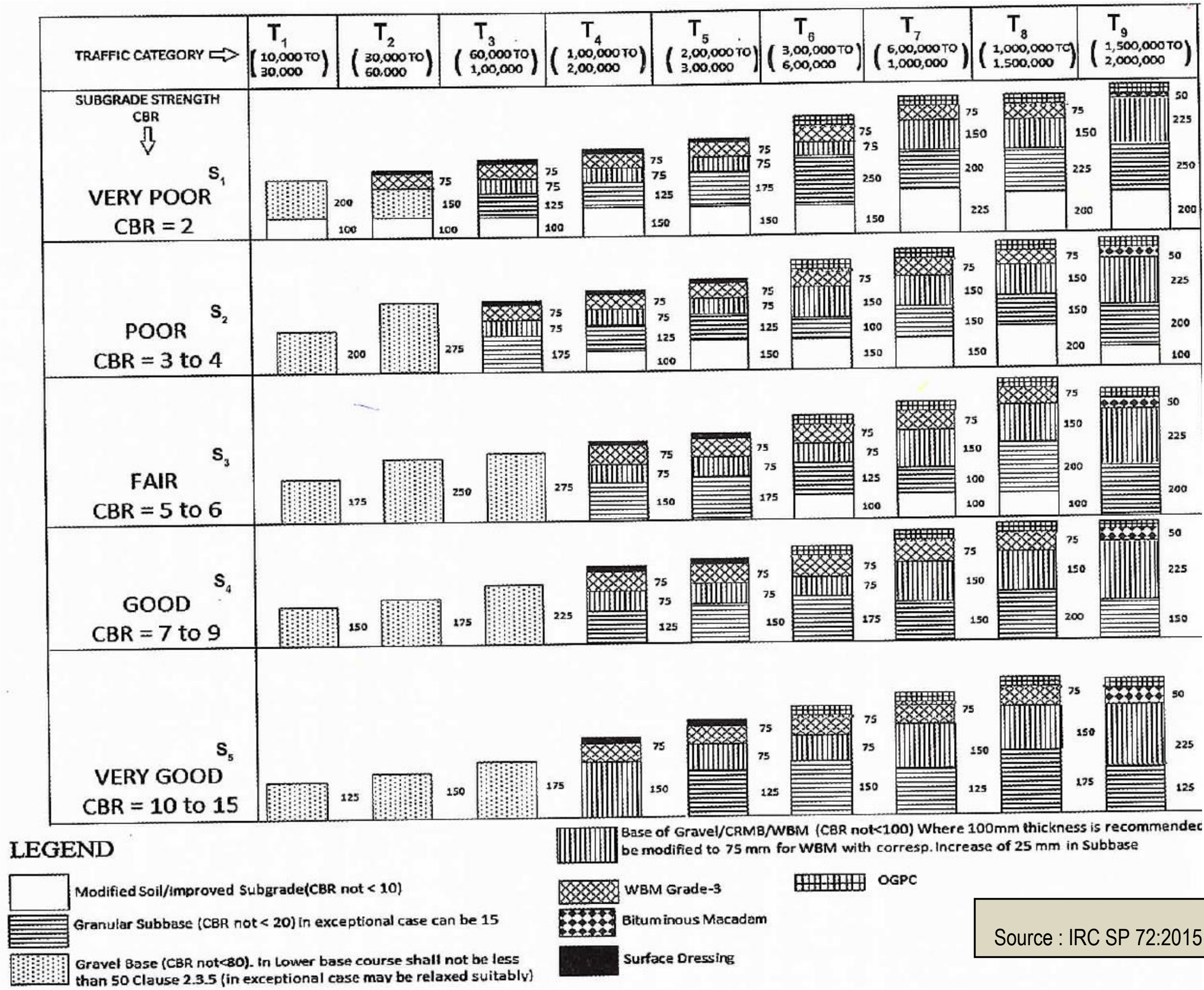
Figure E1: ***CBR estimation from DCP result***

E.2.4 Sub-Grade Strength Classes

Table E4: ***Sub-grade Class***

Quality	Range of CBR, %	Class of Sub-grade
Very Poor	2	S1
Poor	3-4	S2
Fair	5-6	S3
Good	7-9	S4
Very Good	10-15	S5

E.2.5 Design Chart



Source : IRC SP 72:2015

Variation in Legend Description:

Granular Subbase (CBR not <20%), Grade III/Table 12.1 of Yellow Book/DOR

Gravel Base (CBR not <80%), Table E-5

CRMB/WBM Grading -1/Table 12.6 of Yellow Book/DOR (CBR not <100)

WBM Grading-2, /Table 12.6 of Yellow Book/DOR

Table E5 : Gradation for Gravel Base

IS Sieve Size	% Passing
53	100
37.5	97-100
19	67-81
4.75	33-47
425 micron	10-19
75 micron	4-15
PI < 6 and LL < 25	

E.3. Pavement Design for Gravel Road

- For gravel roads, when the subgrade CBR is above 2%, the traffic level considered is upto 60,000 repetitions of 80KN ESAL. However, where the subgrade CBR is above 5%, a gravel road can take upto 1 msa applications during the design life.
- It is to be recognized that Gravel roads can serve low volume traffic adequately for many years, provided they are well-maintained, by regularly replenishing lost gravel and periodic regravelling. Regravelling by adding gravel, before surface starts deteriorating rapidly, using only agricultural tractors and manual labour. Regravelling may be justified periodically every 3-5 year, depending on traffic and climatic conditions.
- The gravel base thickness required for the five subgrade strength classes (S1,S2,S2,S4,& S5) and for Traffic categories of T1, T2 & T3, are as in E.2.5 Design Chart.
- A portion of the Gravel Base layer thickness to an equivalent thickness of sub-base with an intermediate CBR value between base and subgrade (**Table E6)** .The minimum base material thickness should be 100mm.

Table E6 : To convert portion of the Gravel Base to an equivalent thickness of Sub-base.

Design Base Thickness, mm	Base Thickness Provided, mm	Thickness of Sub-base, mm					
		CBR-15%	CBR-20%	CBR-25%	CBR-30%	CBR-40%	CBR-50%
150	100	100	100	100	100	75	75
175	100	150	150	150	150	125	125
200	100	200	200	175	175	150	150
225	100	250	250	225	225	200	200
250	100	300	275	250	250	225	225
275	100	350	325	300	300	275	275

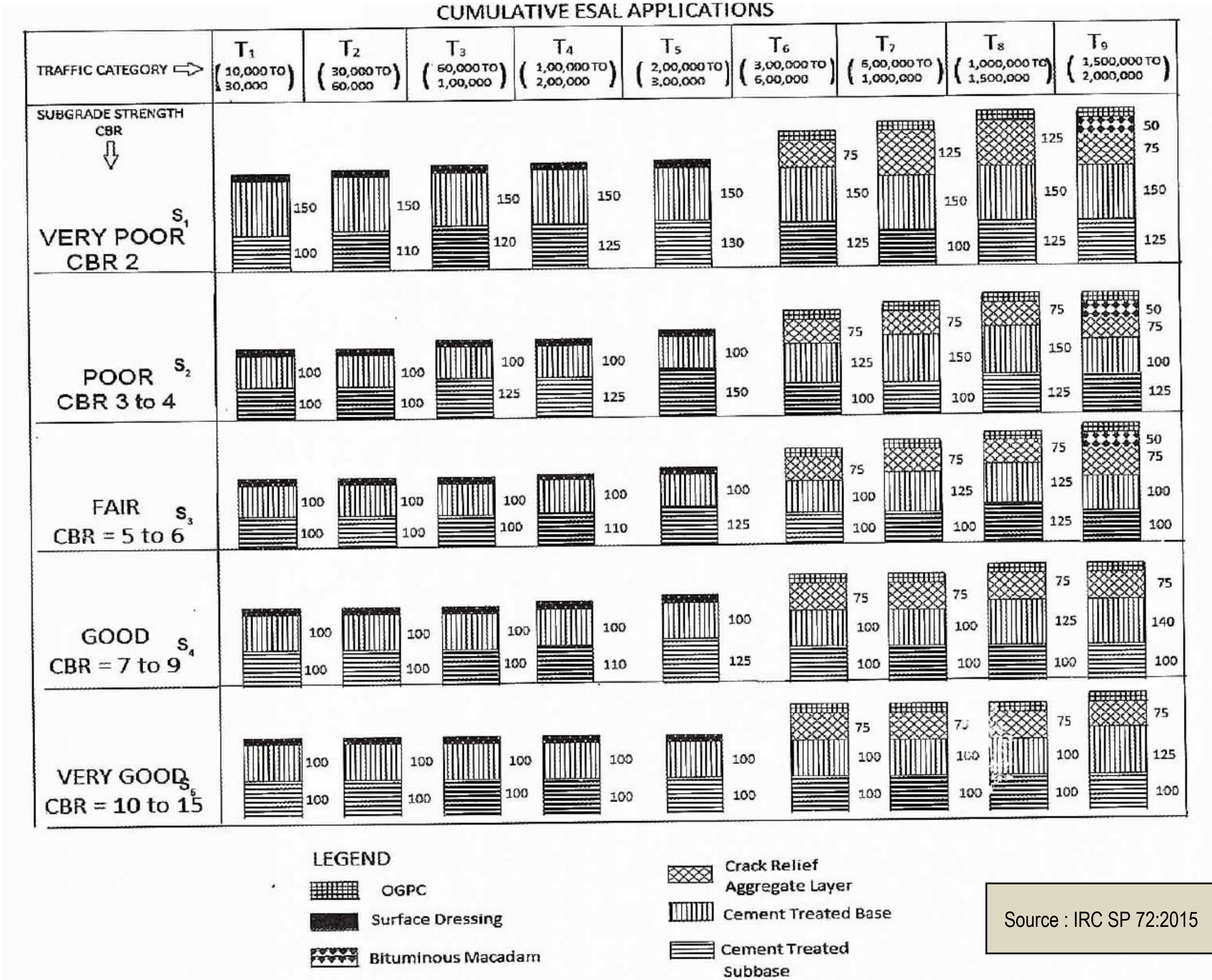
E.4. Surface Gravel

The gravel road shall be covered with surface gravel material conforming **Table E-7.** The thickness of the surface gravel will generally vary from 40-50mm depending to the designed gravel base thickness and quality of material. This thickness of the surface gravel is in addition to the gravel base thickness calculated from design as this is for protecting the gravel base and may require re-gravelling.

Table E7: Gradation for Surface Gravel

IS Sieve Size	% Passing
37.5	100
26.5	100
19	97-100
4.75	41-71
425 micron	12-28
75 micron	9-16
PI < 6 and LL < 25	

5. Pavement Design Catalogues with Cement Treated Bases and Sub-Base



Variation in Legend Description:

Cement Treated Bases and Sub-Base /Clause 1202 of Yellow Book/DOR

Source : IRC SP 72:2015

ANNEX F: GLOSSARY OF PAVEMENT TERMS

Asphalt Concrete	Bituminous concrete/ Asphalt Concrete is a dense graded premixed bituminous mix which is well compacted to form a high quality pavement surface. The AC consists of carefully proportioned mixture of coarse aggregates, fine aggregates, mineral filler and bitumen and the mix is designed by an appropriate method such as Marshall Stability method to full fill the requirements of stability, density, flexibility and voids.
Base course	main structural layer below wearing course
Binder course	An asphalt layer that is placed between an asphalt base layer and an asphalt surface layer. The binder layer is included for its better workability to reduce permeability and improve roughness levels.
Bituminous Macadam	BM or bituminous Bound Macadam is premixed type of construction consisting one or more courses of compacted crushed aggregates premixed with bituminous binder, laid immediately after mixing. BM is base course or binder course and should be covered by surfacing course before exposing to traffic.
Bituminous Surface Dressing	BSD is provided over an existing pavement to serve as thin wearing coat. It can be done in two layers. Function of surface dressing: to provide a dust free/mud free surface over a base course; to provide a waterproof layer to prevent infiltration of surface water; to protect the base course
Capping layer	Where shown on the Drawing or where in-situ material in the subgrade in cutting does not meet the requirements, in-situ materials shall be replaced with selected material from cuttings or borrow pits
Design period	The time span considered appropriate for the major structural elements of the road pavement to function without rehabilitation and/or reconstruction. Treatments, such as replacement of surfacing layers and stage construction treatments, that maintain the integrity of the other components of the pavement are included within the design period. The time span considered appropriate for the road pavement to function without major rehabilitation and/or reconstruction. It is defined in terms of cumulative number of standard axles that can be carried before strengthening of pavement is necessary
Diverted traffic	Traffic that changes from another route (or mode of transport) to the project road because of the improved pavement, but still travels between the same origin and destination
Flexible Pavement	Flexible pavements are so named because the total pavement structure deflects, or flexes, under loading. A flexible pavement structure is typically composed of several layers of material. Each layer receives the loads from the above layer, spreads them out, and then passes on these loads to the next layer below. Thus, the further down in the pavement structure a particular layer is, the less load (in terms of force per area) it must carry.
Formation level	The level of the top surface of the sub-grade upon which pavement structures is built up
Generated traffic	Additional traffic which occurs in response to the provision or improvement of the road
Normal traffic	Traffic which would pass along the existing road or track even if no new pavement were provided.
Penetration Macadam	Penetration Macadam or grouted Macadam is used as a base or binder course. The course aggregate are first spread and compacted well in dry state and after that hot bitumen of relatively high viscosity is sprayed in fairly large quantity at the top. The bitumen penetrates into the voids and binding stone aggregates together. After the penetration of bitumen, key aggregates are spread over the previous layer and it is compacted.

Premix Carpet	PC consists of course aggregates of 12.5 mm and 10 mm sizes premixed with bitumen or tar binder are compacted to a thickness of 20 mm to serve as a surface course of the pavement. Being open graded construction, the PC is to be covered by a suitable seal coat such as premixed sand-bitumen seal coal before opening to traffic.
Prime coat	Prime coat is applied over an existing porous or absorbent pavement surface (for example on WBM) with low viscosity. Main function of prime coat is to seal the pores and waterproof the underlying layer and to develop interface condition for bonding. Usually MC or SC cutback binders with suitable grade are used.
Rigid pavement	Rigid pavements are the pavement structure deflects very little under loading due to the high modulus of elasticity of their surface course. A rigid pavement structure is typically composed of a PCC surface course built on top of either (1) the subgrade or (2) an underlying base course. Because of its relative rigidity, the pavement structure distributes loads over a wide area with only one, or at most two, structural layers.
Seal Coat	Seal Coat is usually recommended as a top coat over certain bituminous pavements which are not impervious, such as open graded bituminous construction like premixed carpet and grouted Macadam. Seal coat is also provided over an existing bituminous pavement which is worn out. The seal coat is a very thin surface treatment or a single coat surface dressing which is usually applied over an existing black top surface. A premixed sand bitumen (hot mix) seal coat is also commonly used over the premixed carpet.
Stabilizer	The selected natural or crushed material, lime, cement and other similar materials to be mixed into the in-situ material of the subgrade is defined as the “stabilizer”.
sub-grade	Up to 300 mm below formation level is designated as “sub-grade”.
Sub-Base Course	The sub-base course is between the base course and the sub-grade. It functions primarily as structural support but it can also: to minimize the intrusion of fines from the sub-grade into the pavement structure; to improve drainage; to minimize frost action damage; to provide a working platform for construction
Tack coat	Tack coat is applied on relatively impervious layer for example existing bituminous or cement concrete pavement or a pervious layer like the WBM which has already been treated by prime coat.
Vehicle damage Factor (VDF)	It is a multiplier to convert the number of commercial vehicles of different axle loads and configuration to the number of standard axle load repetitions. It is equivalent number of standard axles per commercial vehicle. The VDF varies with vehicle axle configuration, axle loading, terrain, type of road and from region to region.
Water Bound Macadam	The water bound macadam (WBM) is the construction known after the name of John Mac Adam. Present understanding is made of crushed or broken aggregates. Crushed or broken aggregates are bound together by the action of rolling. Binding is achieved by stone dust used as filler in presence of water. The thickness of each compacted layer ranges from 10cm to 7.5 cm depending on the size and gradation of the aggregates used.