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Pavement Design Guidelines (Flexible Pavement)

Submitted by:

Prof. Dr. Padma Bahadur Shahi

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Contents

Acknowledgement....2
Abbreviation....3
1. Introduction....4
2. Scope & applicability....4
3. References....4
4. Design Approach and Criteria....4
5. Traffic....5
5.1 General....5
5.2 Design life....5
5.3 Traffic Estimation....6
5.3.1 Base year traffic flow....6
5.3.2 Traffic forecasting....6
5.4 Axle loading....6
5.4.1 Equivalence factor....7
5.4.2 Vehicle Damage Factor (VDF)....7
5.5 Distribution of commercial traffic over the carriageway....8
5.6 Computation of design traffic....8
6. Sub-grade....8
7. Pavement Thickness and Composition....9
7.1 Pavement Composition....9
7.1.1 Sub-base....9
7.1.2 Base course....9
7.1.3 Bituminous surfacing....9
7.2 Pavement Design Catalogue....10
8. Typical section of pavement layer....10
9. Worked out Example....10
10. Glossary of pavement Terms....13
11. References....15
Annex-I: Failure Criteria....16
Annex-II: Pavement Design Chart....19
Annex III: Pavement Design Catalogue....21
Annex IV: Standard Specifications for Bituminous Surfacing....38

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Sincerely

Prof. Dr. Padma Bahadur Shahi
Consultant
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Abbreviation

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

Guidelines for the Design of Flexible Pavements

1. Introduction

Pavement is most important component of highway section. The overall functioning of highway system greatly depends on the performance of its pavement. Furthermore, vehicle operating cost, and entire highway economics and life cycle are interrelated to the pavement design practice. The design procedure of flexible pavement involves the interplay of several variables, such as the wheel loads, traffic, climate, terrain and sub-grade soil conditions. Depending upon specific regional or nationwide characteristics, most of the countries are practicing some empirical and experience base methods for the design of flexible pavement.

This manual is written with the view to have a 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 on 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.

2. Scope & applicability

Guidelines in this booklet are preferred to for the design of flexible pavements for National Highways and Feeder Roads. Furthermore, this it could be followed for the design of Arterial and Sub-arterial roads of the urban road categories.

For the purpose of guidelines, flexible pavements are considered to include the pavements which have bituminous surfacing and granular base and sub-base courses conforming to Standard Specifications for Road and bridges Works published by the Department of Roads in 2001.

The manual 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).

3. References

The design procedures incorporated in this document are based on the IRC 37-2001 guidelines, American Association of State Highway and Transportation Officials (AASHTO) 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, 2008) and Road Note 31 (TRL, UK).

4. Design Approach and Criteria

The 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. Part of the reason for this may be that foreign consultants engaged on the design of road pavements in Nepal have tended to use design standards from their respective countries, or other international standards with which they are familiar. However, the design approaches and criteria for a country should be defined on the basis of local conditions i.e. climatic socio-economic and technological development and so on. In this way, intensive research activities should have conducted by the concerned authorities.

The flexible pavement has been modeled as a three layer structure and stresses and strains at critical locations have been computed using the linear elastic model. To give proper consideration to the aspects of performance, the following three types of pavement distress resulting from repeated (cyclic) application of traffic loads are considered:

- Vertical compressive strain at the top of the sub-grade which can cause sub-grade deformation resulting in permanent deformation at the pavement surface.
- Horizontal tensile strain or stress at the bottom of the bituminous layer which can cause fracture of the bituminous layer.
- Pavement deformation within the bituminous layer.

The permanent deformation within the bituminous layer can be controlled by meeting the mix design requirements as per the Standards Specifications for Road and Bridge Works (DoR, 2001). Thicknesses of granular and bituminous layers are selected by using the analytical design approach so that strains at the critical points are within the allowable limits. For calculating tensile strains at the bottom of the bituminous layer, the stiffness of dense bituminous macadam (DBM) layer with 60/70 bitumen has been used in the analysis. The relationships used for allowable vertical sub-grade strain and allowable tensile strain at the bottom of bituminous layer along with elastic moduli of different pavement materials and relationships for assessing the elastic moduli of sub-grade, granular and base layers are given in the **Annex I**. These theoretical are referred from the IRC 37-2001 guidelines.

Best on the performance of existing practices and using analytical approach, simple design charts and a catalogue of pavement design have been added for the use of engineers. The Pavement design Charts are given for sub-grade CBR value ranging from 2 percent to 10 percent and design traffic from 1 msa to 150 msa for an average annual pavement temperature of 35 ^{0}C. The layer thickness obtained from the analysis has been slightly modified to adapt the designs to stage construction. Using the following simple input parameters, appropriate design could be chosen for given traffic and sub-grade soil strength:

a) Design traffic in terms of cumulative number of standard axles; and
b) CBR values of Sub-grade

5. Traffic

5.1 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. In this context, heavy vehicles are defined as those having an unladen weight of 3000 kg or more. In some circumstances, particularly for low volume roads, construction traffic can be a significant component of overall traffic loading and the designs should take this into account. The total number of anticipated commercial vehicles during the design life is converted in to the cumulative equivalent standard axle of 8160 kg.

5.2 Design life

In the context pavement, design life does not mean that at the end of the period the pavement will be completely worn out and in need of reconstruction; it means that towards the end of the period the pavement will need to be strengthened so that it can continue to carry traffic satisfactorily for a further period. Condition surveys of bituminous pavements are used to determine not only the maintenance requirements but also the nature and rate of change of condition to help to identify if and when the pavement is likely to need strengthening.

The design life for the pavement is considered as cumulative number of standard axles that can be carried before strengthening of pavement is necessary. It is recommended that National highways should be designed for a life of 15 years. Expressways and urban roads may be designed longer life of 20 yrs. For other categories of roads, a design life of 10 to 15 years may be taken.

5.3 Traffic Estimation

5.3.1 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..

5.3.2 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 commonest method of forecasting normal traffic is to extrapolate time series data on traffic levels and assume that growth will either remain constant in absolute terms i.e. a fixed number of vehicles per year (a linear extrapolation), or constant 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 travels between the same origin and destination. Where parallel routes exist, traffic will usually travel on the quickest route although this may not necessarily be the shortest. Thus, surfacing an existing road may divert traffic from a parallel and shorter route because higher speeds are possible on the surfaced road. 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.

5.4 Axle loading

An accurate estimate of the current traffic loading is essential for an appropriate pavement design. Traffic volumes can be determined by traffic counts, but for current vehicle loads can be found by an axle load survey. It is not rational to design pavement layer on the basis of legal axle load limits because of the widespread problem of overloading. In addition to this, the proportion of vehicles with partially loaded in unknown. In these circumstances of axle loading, pavement design across the world is accepted to design on the basis of Standard Axle i.e. 8.16 tonnes (80 kN). In Nepal, the legal axle load limit is 10.2 tonnes.

5.4.1 Equivalence factor

The damage that vehicles do to a road pavement depends very strongly on the axle loads of the vehicles. For pavement design purposes the damaging power of axles is related to a 'standard' axle of 8.16 tonnes (80 kN) using equivalence factors which have been derived from empirical studies. In order to determine the cumulative axle load damage that a pavement will sustain during its design life, it is necessary to express the total number of heavy vehicles that will use the road over this period in terms of the cumulative number of equivalent standard axles (esa). Axle load surveys must be carried out to determine the axle load distribution of a sample of the heavy vehicles using the road. Data collected from these surveys are used to calculate the mean number of equivalent standard axles for a typical vehicle in each class. These values are then used in conjunction with traffic forecasts to determine the predicted cumulative equivalent standard axles that the road will carry over its design life. Equivalence factor is calculated by using the following relationships:

- Front steering wheel (single wheel) axle $EF = \left(\frac{Axle\, load, kgf}{5410\, kgf\, (53 kN)} \right)^4$
- Single axle dual wheel $EF = \left(\frac{Axle\, load, kgf}{8160\, kgf\, (80 kN)} \right)^4$
- Tandem axle dual wheel $EF = \left(\frac{Axle\, load, kgf}{14968\, kgf\, (146.8 kN)} \right)^4$

5.4.2 Vehicle Damage Factor (VDF)

Where sufficient information on axle load is not available and project size does not warrant conducting an axle load survey, the indicative values of Vehicle damage factor (VDF) may be used as given in the table below

The Vehicle Damage factor (VDF) is the multiplier to convert the number of commercial vehicles of different axle loads and axle configuration to the number of standard axle load repetitions. It is defined as equivalent number of standard axle per commercial vehicle. The VDF varies with the vehicle axle configuration, axle loading, and terrain type and from region to region. The VDF is arrived at axle load surveys on typical sections so as to cover various influencing factors, such as traffic mix, mode of transportation, commodities carried, time of the year, terrain, road conditions and degree of enforcement.

Table 1 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	

5.5 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 (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) **Two-lane single carriage roads/ Intermediate lane roads:** the design should be based on 75 percent of the total number of commercial vehicles in both directions.
c) **Four-lane single carriageway roads:** the design should be based on 40 percent of the total number of commercial vehicles in both directions.
d) **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.

5.6 Computation of design traffic

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

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

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 7% i.e 0.07)

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.

6. Sub-grade

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 express ways, National highways and feeder roads as well as urban roads. Current Standard Specification for Road and Bridge Works (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.

7. Pavement Thickness and Composition

Total pavement thickness is recommended to adopt from the Chart given in the **Annex II** of this document. Total thickness of the pavement (in mm) is interpolated based on the given values of the CBR of sub-grade and cumulative number of standard axles (msa). The composition of pavement layer and their thickness is found by using the 'Pavement Design Catalogue' given in the **Annex III**. Charts provided in the Annex II are based on the IRC 37-2001. Pavement Design Catalogue has been developed for particular CBR value and cumulative number of standard axles. The total thickness is reduced to granular sub-base, granular base and bituminous wearing course.

7.1 Pavement Composition

7.1.1 Sub-base

Sub-base construction material requirements and construction procedure shall be followed the standard Specification for Road and Bridge Works (Clause 12001). Gavel, Sands, Silty and Clayey sands could be used for the construction of sub-base course. The CBR values of the materials, after 4 days soaking, shall not be less than 30 % at 95 % heavy compaction (Clause 1201-3b). these requirements and the specified grain size distribution of the sub-base material should be strictly enforce in order to meet stability and drainage requirements of the granular sub-base layer.

From drainage consideration the granular sub-base should extended over the entire formation width. The minimum thickness of the sub-base layer shall be 150 mm. Where stage construction is adopted for pavements, the thickness of sub-base shall be provided for ultimate pavement section for the full design life. In the areas affected by frost, care should be taken to avoid using frost susceptible materials in the sub-base.

7.1.2 Base course

Unbound granular bases which comprise conventional Graded Crushed Stone and Water Bound Macadam (WBM) base shall be provided as per the Standard Specification (Clause 1202 and 1203). Materials used in the base must satisfy the grading and physical requirements in the Standard Specification. The recommended minimum thickness of granular base is 150 mm.

7.1.3 Bituminous surfacing

Bituminous surfacing shall consist of either a wearing course or a binder course with a wearing course depending upon the traffic to be carried. The most commonly wearing course used are surface dressing, open graded premix carpet, mix seal surfacing, semi dense bituminous macadam and dense bituminous macadam. For surfacing as well as binder courses the Standard Specification prescribes surface dressing, penetration macadam, asphalt concrete, sand asphalt and cold asphalt (Section 1300).

Specifications for Dense Bituminous Macadam (DBM) and Premix Carpet (PC) have been included herewith in **Annex IV**. These specifications have been developed on the basis of the IRC SPECIFICATIONS FOR ROAD AND BRIDGE WORKS (Ministry of Road Transport and Highways, India) and DoR publication SSRBW, Nepal.

The recommended pavement composition and thickness in terms of the cumulative standard axles to be carried during the design life are given in the design catalogue in the **Annex III**. The thickness of surface treatments such as Premix Carpet (PC) or Surface Dressing should not be counted towards the total thickness of the pavement as such surfacing will be purely for wearing and will not add to the structural capacity of the pavement.

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The choice of appropriate type of bituminous surfacing will depend upon several factors, like design traffic over the service life, the type of base/binder course provided, whether the pavement is to be built up in stages, rainfall and other related factors. The recommended types and thickness of wearing courses for traffic from 10 msa to 150 msa are given in the design catalogue, which may be modified if the environmental conditions and experience so justify.

The grade of the bitumen will be selected keeping in view traffic, rainfall and other environmental conditions. The selection criteria for the grade of the bitumen to be used is given in the **Annex I**. Special consideration shall be given to the areas with high altitude with snow precipitation.

7.2 Pavement Design Catalogue

Based on the results of analysis of the pavement structure, practical requirements and specifications the recommended designs for the traffic range from 1 to 10 msa and for 10 to 150 msa are given in the Annex III (Pavement Design Catalogue). In some cases, the total pavement thickness are given in the recommended designs is slightly more than the thickness obtained from the design charts. This is in order to:

a) provide the minimum prescribed thickness of sub-base
b) Adapt the design to stage construction which necessitated some adjustment and increase in sub-base thickness.

8. Typical section of pavement layer

Typical section of the pavement layers is given in figure 1 as per the design approach in this design manual. Functions of each layer are described in the table below.

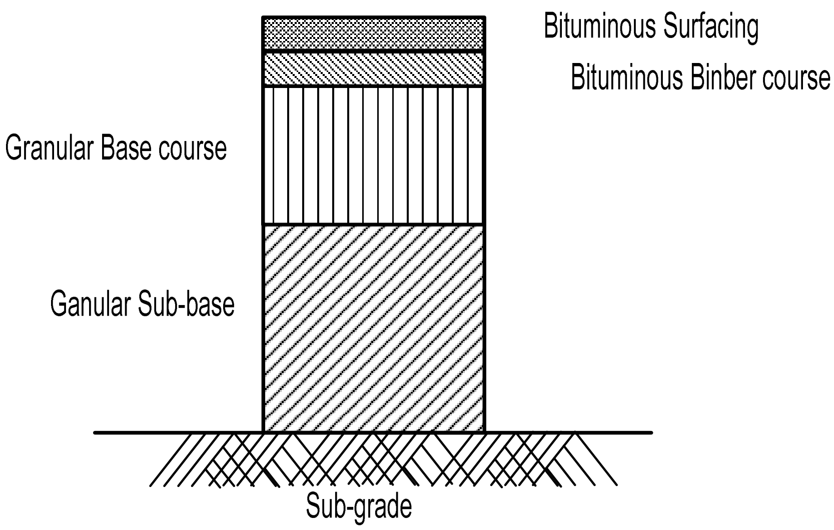

Figure 1 Typical pavement cross section

9. Worked out Example

Design the flexible pavement for construction of a new road with the following data:

- Two lane single carriage way is to designed in plain area
- Initial traffic in the year of completion of construction = 310 CVPD (sum of both directions) as mentioned below:
    - heavy truck three axle: 30
    - heavy truck two axle: 70
    - mini truck: 120
    - large bus: 60
    - bus: 30

- Traffic growth rate = 7.0 %
- Design life = 15 years
- Vehicle damage factor based on axle load survey
- vehicle
- Design CBR of sub-grade soil = 5%.

Solution:

a) Lane Distribution factor = 0.75

b) Cumulative number of standard axle for design life of 15 years

Vehicle type	**Numbers**	**VDF**	**Equivalent standard axle, per day**
heavy truck three axle	30	6.50	195
heavy truck two axle:	70	4.75	333
mini truck:	120	1.0	120
large bus	60	0.50	30
bus	30	0.35	11
			Total: 689 standard axles per day

Initial standard number of axles= A*F = 689 esa

Cumulative Number of standard axles for design period: $N = \frac{365*[(1+r)^n - 1]}{r} * A * D * F$

$$N = \frac{365*[(1+0.07)^{15} - 1]}{0.07} * 0.75 * 689$$

$$N = 4.73\ msa$$

c) Total thickness of the pavement with CBR 5% and 4.73 msa (figure 3) = 575 mm

d) Pavement composition from (Annex III):

i. Bituminous wearing course: Asphalt Concrete 50 mm.

ii. Bituminous Binder course: DBM 50 mm

iii. Base course: Water Bound Macadam: 150 mm

iv. Sub-base: Granular sub-base 325 mm CBR not less than 30 %

v. Pavement cross section:

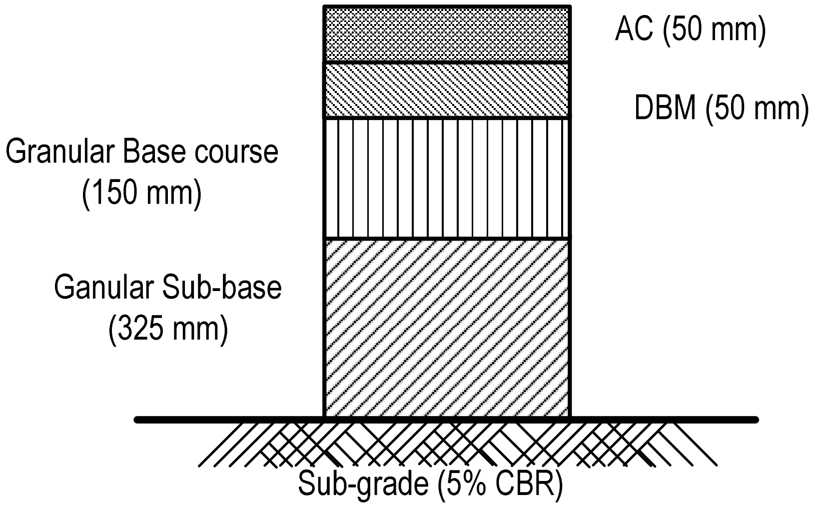

Figure 2 Cross section of the designed pavement

10. 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.

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11 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

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

13 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

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

15 Gudelines for Traffic Prediction on Rural Highways, IRC 1996

Annex-I: Failure Criteria

Failure criteria, relationship between number of cumulative standard axles, strains values and elastic moduli of materials:

a) Fatigue criteria

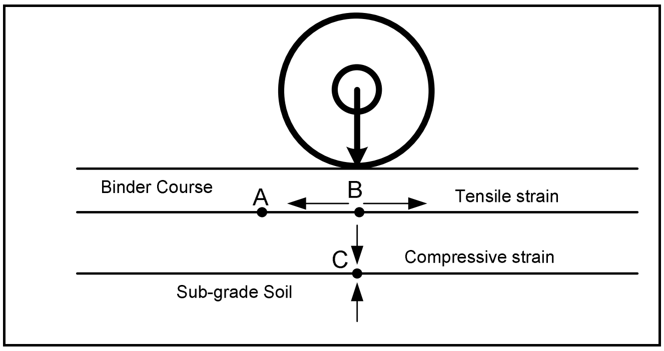


Figure 3 Critical Locations on Pavement

A and **B** are the critical locations for tensile strains **(ε_t)**. Thus the maximum value for tensile strain is adopted for design is **(εt). C** is the critical location for the vertical sub-grade strain (**ε_z**) since the maximum value of the **ε_z** occurs mostly at point C.

Bituminous surfacing of pavement displays flexural fatigue cracking if the tensile strain at the bottom of the bituminous layer is beyond certain limit. The relation between the fatigue life of the pavement and the tensile strain in the bottom of the bituminous layer can be obtained:

$$N_f = 2.21 * 10^{-4} * \left(\frac{1}{\varepsilon_t}\right)^{3.89} * \left(\frac{1}{E}\right)^{0.854}$$

Where, ***N_f*** is the number of cumulative standard axles to produce 20 percentage cracked surface area; (ε_t) is the tensile strain at the bottom of the bituminous concrete layer; ***E*** is the Elastic modulus of bituminous surfacing.

The values of the elastic moduli of Asphalt Concrete (AC), Dense Bituminous Macadam (DBM) and Bituminous Macadam (BM) meeting the requirements of the Standard specifications of DoR are given below.

Table 1: Elastic Modulus (MPa) of Bituminous materials

Mix Type	Temperature, ^{0}C				
	20	25	30	35	40
AC and DBM 80/100 Bitumen	2300	1966	1455	975	797
AC and DBM 60/70 Bitumen	3600	3126	2579	1695	1270
AC and DBM 30/40 Bitumen (75 blows compaction and 4 % air voids)	6000	4928	3809	2944	2276
BM 80/100 Bitumen	-	-	-	500	-
BM 60/70 Bitumen	-	-	-	700	-

The above fatigue equation was calibrated at 35^0 C for bituminous concrete surfacing having 80/100 bitumen and the equation was generalized by introducing the term containing the elastic modulus (**E**) of the bituminous layer so that pavement can be designed for temperatures from 20^0 C to 40^0 C using any grade of bitumen.

The Poisson's ratio of bituminous layer may be taken as 0.5 for pavement temperature of 35 ^{0}C and 40 ^{0}C. For temperature from 20 ^{0}C to 30 ^{0}C, a value of 0.35 may be adopted. Fatigue equation at any pavement temperature from 20 ^{0}C to 40 ^{0}C can be evaluated by substituting the elastic modulus of pavement temperature. Catalogue of design has been worked for temperature of 35 ^{0}C.

b) Rutting criteria

The rutting criteria as mentioned in IRC 37-2001 is the allowable rut depth as 20 mm, the rutting equation was obtained as:

$$N_r = 4.1656 * 10^{-8} * \left(\frac{1}{\varepsilon_z} \right)^{4.5337}$$

Where, N_r is the number of cumulative standard axles to produce rutting of 20 mm; ε_z is the vertical sub-grade strain.

c) Modulus of Elasticity of Sub-grade, Sub-Base and Base layers

Sub-grade	E = 10*CBR for CBR<5 E = 176*(CBR)$^{0.64}$ for CBR > 5
Granular Sub-base	$E_2 = E_3 * 0.2 * h^{0.45}$

Where, ***E_2*** is the composite Elastic Modulus of granular sub-base and Base (MPa); ***E_3*** is Elastic Modulus of Sub-grade (MPa); ***h*** is the thickness of granular layers (mm); Poison's ratio for both the granular layers as well as sub-grade layer may be taken as 0.4.

d) Calculation of equivalent modulus of elasticity

For two layered system of pavement system, equivalent modulus of elasticity can be found using empirical relationship:

$$E_{eq} = \frac{\left[1.05 - 0.1 \frac{h}{D} (1 - \sqrt[3]{E_2 / E_1}) \right] E_1}{0.71 \sqrt[3]{E_2 / E_1} \arctan\left(\frac{1.35 h_e}{D} \right) + \frac{E_1}{E_2} \frac{2}{\pi} \arctan \frac{D}{h}}$$

Where,
E1 - Modulus of elasticity of upper layer
E2 – Modulus of Elasticity of lower layer
h – Thickness of upper layer
D – Diameter of circular area of contact between transferring wheel loads to the pavement.

$h_{eq} = 2h \sqrt[3]{E_1 / 6E_{eq}}$ - equivalent thickness of materials of lower layer with E2

e) Substitution of Dense Bituminous Macadam (DBM):

Part of DBM can be substituted for BM on the basis of equal flexural stiffness given as:

$$\frac{E_1 H_1^3}{12(1-\mu_1^2)} = \frac{E_2 H_2^3}{12(1-\mu_2^2)}$$

Where, E_1, H_1, μ_1 and E_2, H_2, μ_2 are the parameters (Elastic modulus, Thickness and Poisson's ratio) of DBM and BM respectively. Based on the above equation, following equivalent thickness may be used:

Conversion factors for the thickness of pavement layers (i.e different constituent materials) can be done in terms of modulus of Elasticity. Considering the equal value of the Poisson's ration (μ) for both the layers, the equivalent thickness (H_1) of layer ***1*** is equal to:

$$H_1 = \left[\frac{E_2}{E_1}\right]^{\frac{1}{3}} H_2$$

Where, H_2 is the thickness of layer **2** ; E_1 and E_2 are Modulus of elasticity of layers.

Examples:

The vales of modulus of elasticity of Dense Bituminous Macadam (DBM) and Bituminous Macadam (BM) are 1695 and 700 MPa respectively.
The thickness of 180 mm DBM can be split into: 125 mm DBM + 75 mm BM.

The 55 mm thickness of DBM can be converted into 75 mm of BM using above relationship.

Annex-II: Pavement Design Chart

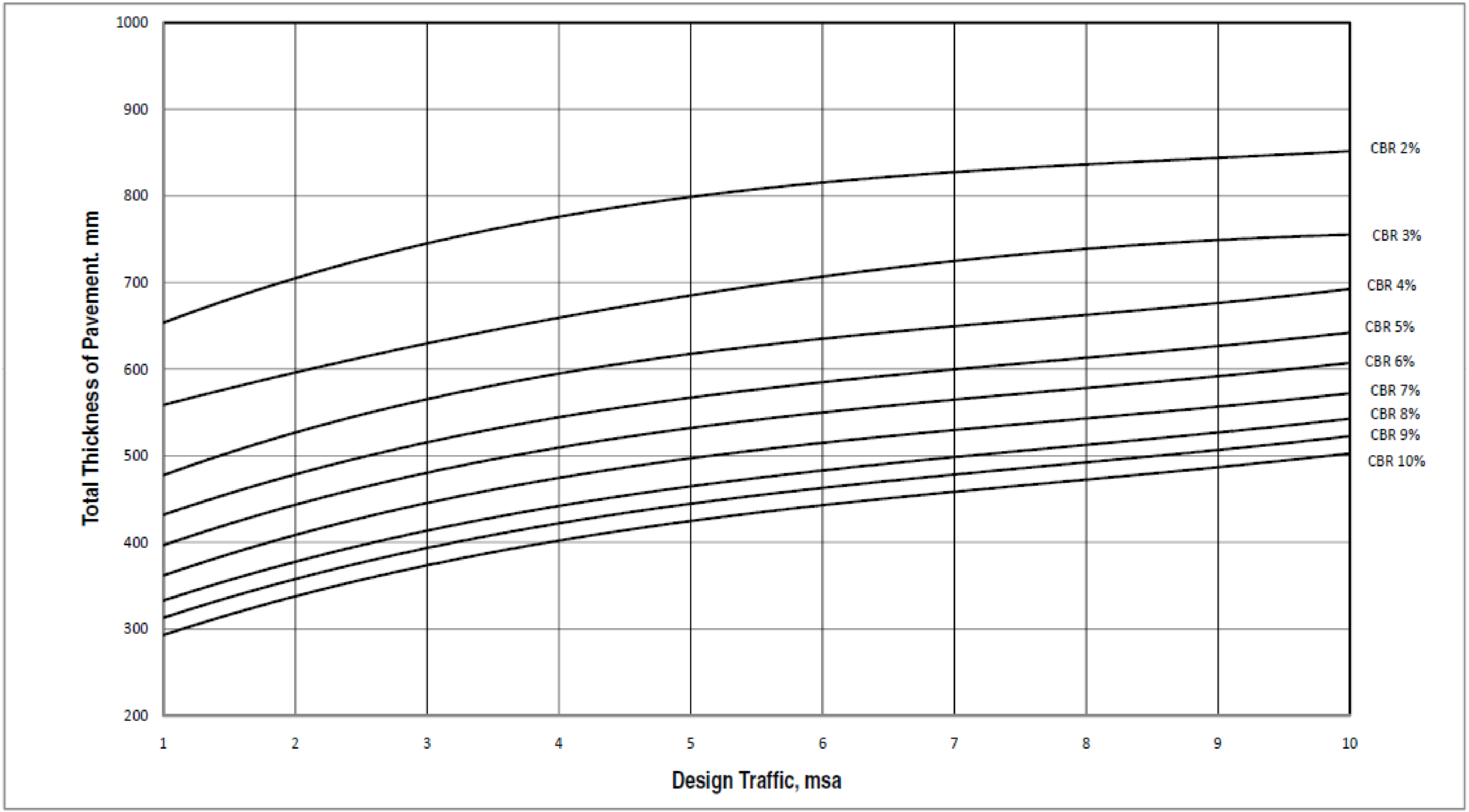


Figure 4 Pavement Thickness Design Chart 1-10 msa

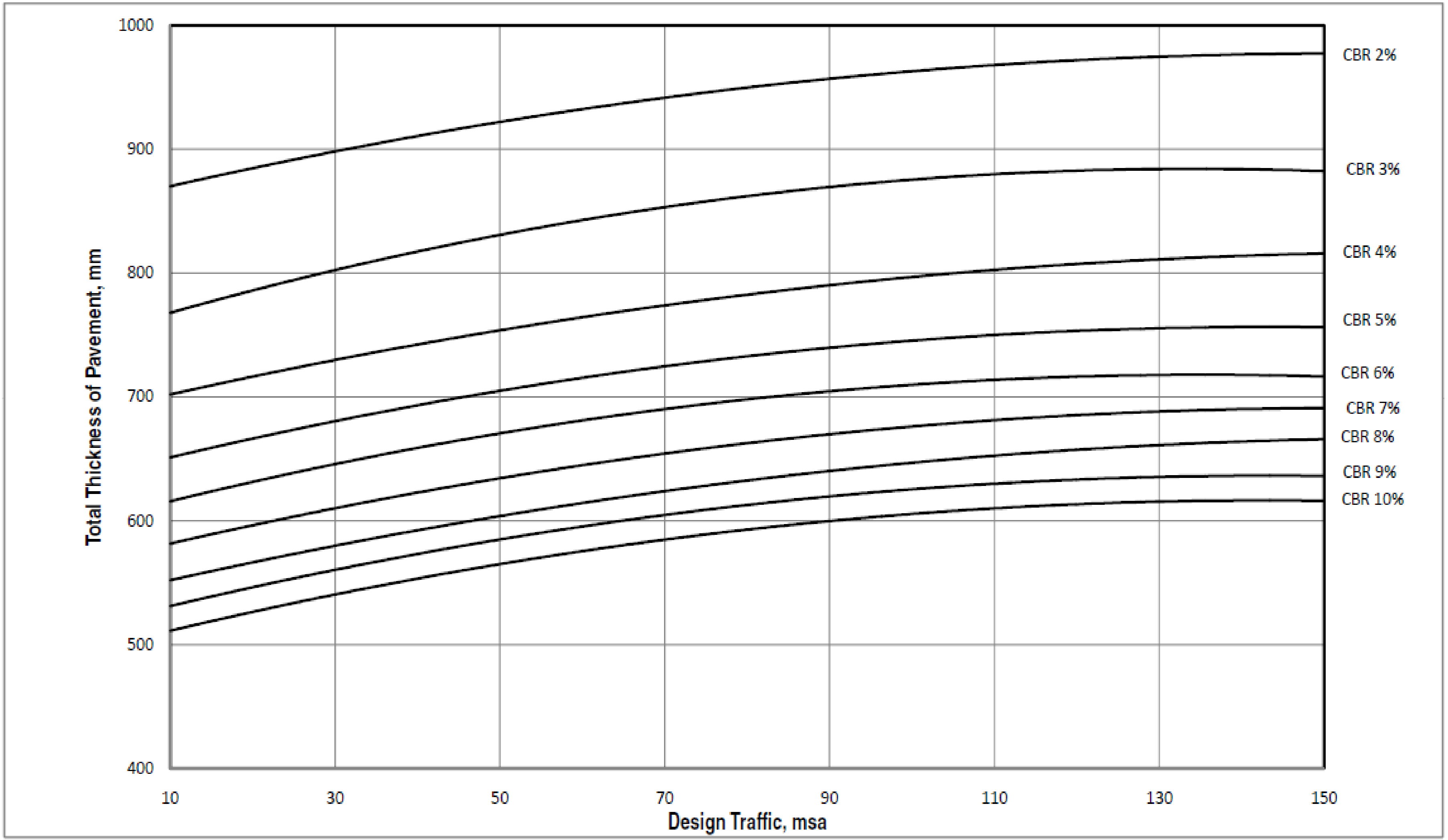
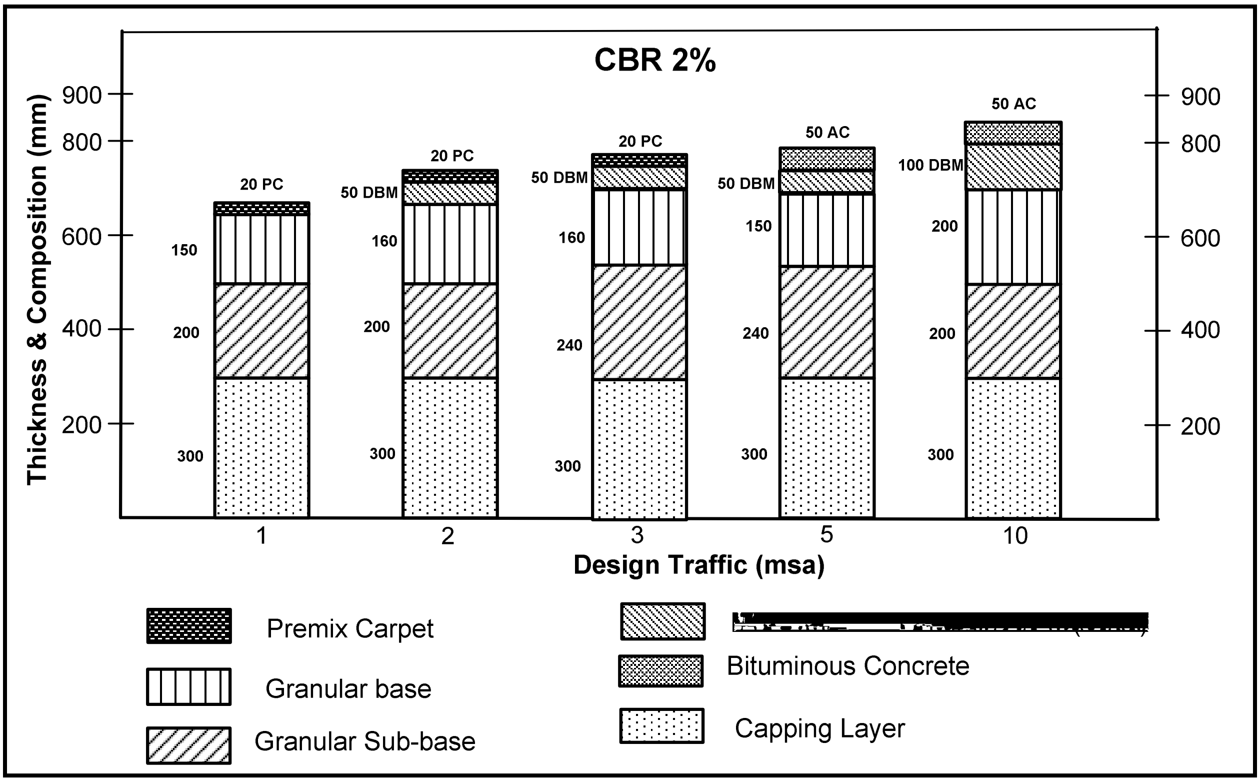


Figure 5 Pavement Design Chart, 10-150 msa

Annex III: Pavement Design Catalogue

Pavement Design Catalogue
Plate I - Recommended Design for Traffic Range 1 - 10 msa

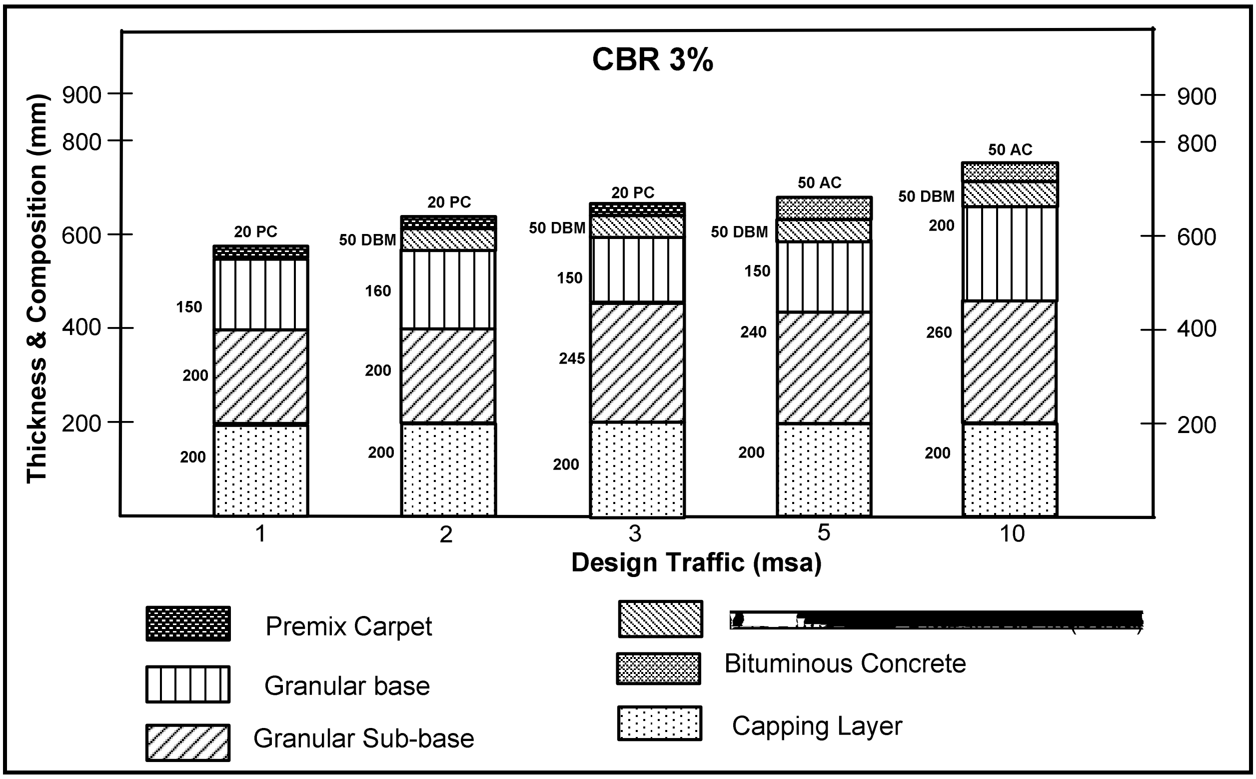
CBR 2%						
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition				
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm	Capping Layer, mm
		Wearing Course, mm	Binder Course, mm			
1	650	20 PC		150	200	300
2	710	20 PC	50 DBM	160	200	300
3	750	20 PC	50 DBM	160	240	300
5	790	50 AC	50 DBM	150	240	300
10	850	50 AC	100 DBM	200	200	300



Pavement Design Catalogue

Plate I - Recommended Design for Traffic Range 1 - 10 msa

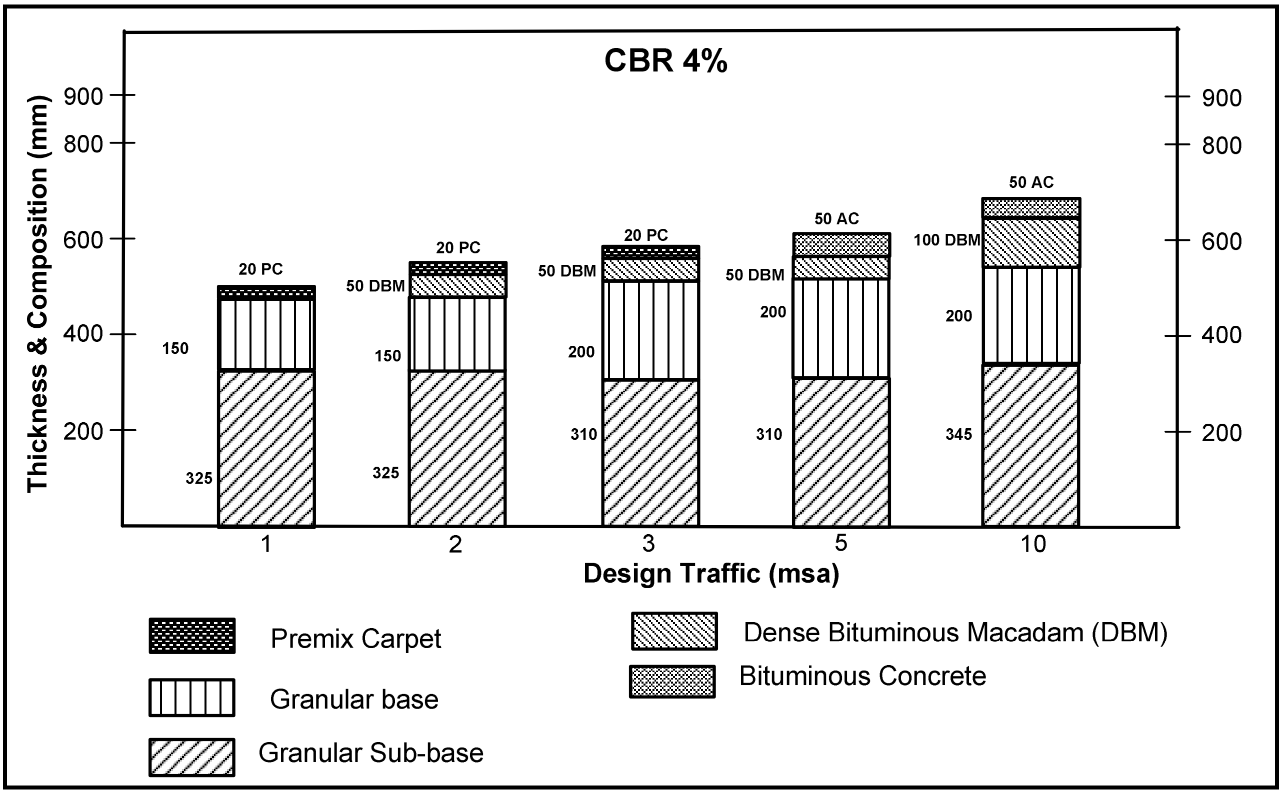
CBR 3%						
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition				
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm	Capping Layer, mm
		Wearing Course, mm	Binder Course, mm			
1	550	20 PC		150	200	200
2	610	20 PC	50 DBM	160	200	200
3	645	20 PC	50 DBM	150	245	200
5	690	50 AC	50 DBM	150	240	200
10	760	50 AC	50 DBM	200	260	200



Pavement Design Catalogue

Plate I - Recommended Design for Traffic Range 1 - 10 msa

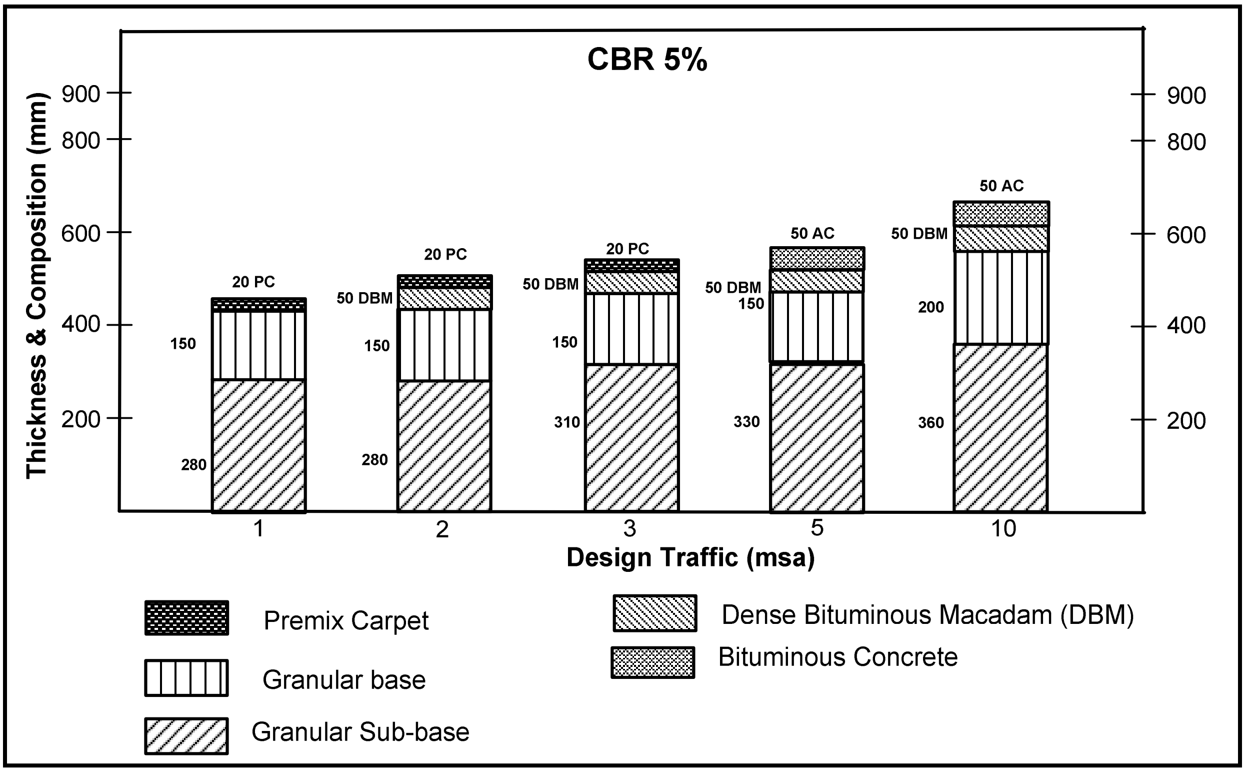
CBR 4%					
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition			
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm
		Wearing Course, mm	Binder Course, mm		
1	475	20 PC		150	325
2	525	20 PC	50 DBM	150	325
3	560	20 PC	50 DBM	200	310
5	610	50 AC	50 DBM	200	310
10	695	50 AC	100 DBM	200	345



Pavement Design Catalogue

Plate I - Recommended Design for Traffic Range 1 - 10 msa

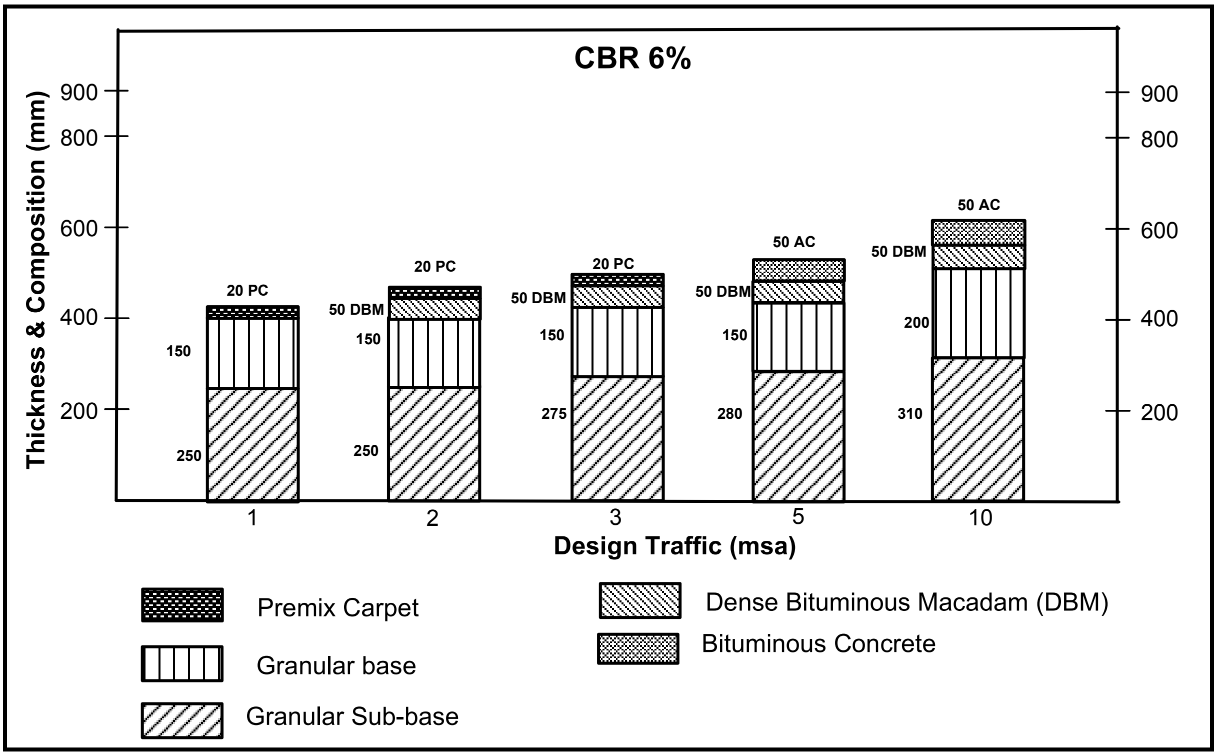
CBR 5%					
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition			
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm
		Wearing Course, mm	Binder Course, mm		
1	430	20 PC		150	280
2	480	20 PC	50 DBM	150	280
3	510	20 PC	50 DBM	150	310
5	580	50 AC	50 DBM	150	330
10	660	50 AC	50 DBM	200	360



Pavement Design Catalogue

Plate I - Recommended Design for Traffic Range 1 - 10 msa

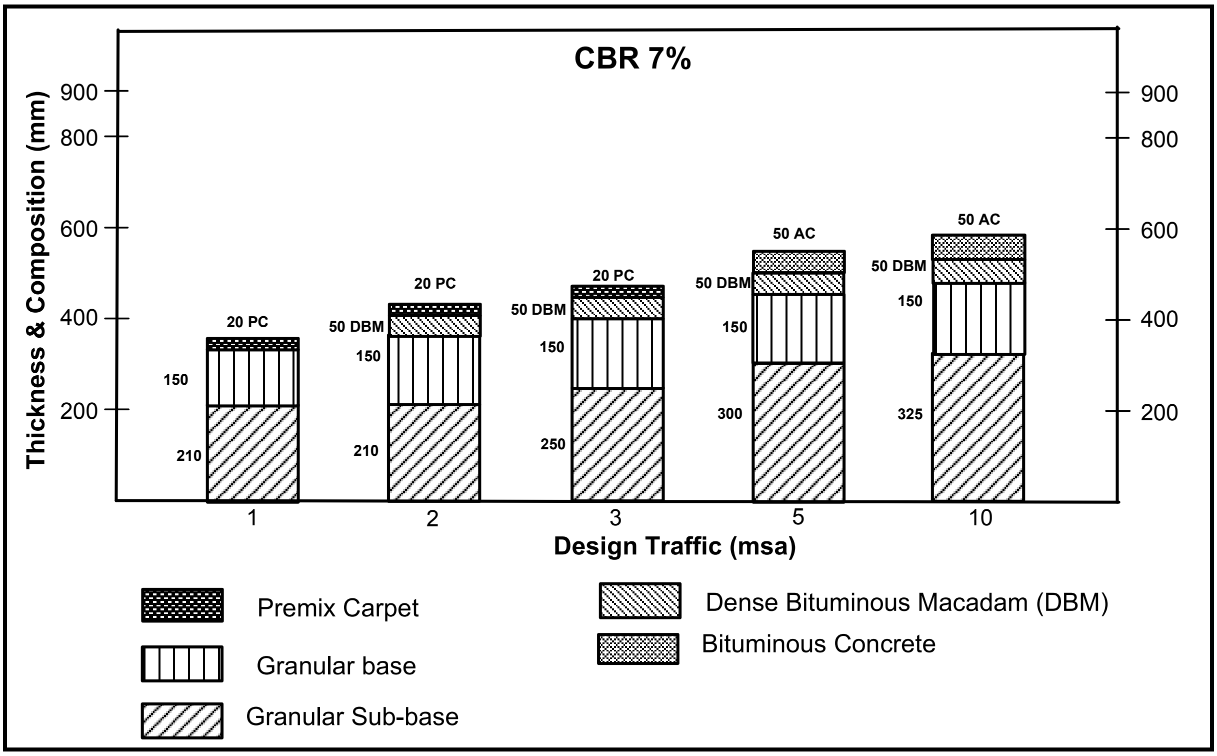
CBR 6%					
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition			
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm
		Wearing Course, mm	Binder Course, mm		
1	400	20 PC		150	250
2	450	20 PC	50 DBM	150	250
3	475	20 PC	50 DBM	150	275
5	530	50 AC	50 DBM	150	280
10	610	50 AC	50 DBM	200	310



Pavement Design Catalogue

Plate I - Recommended Design for Traffic Range 1 - 10 msa

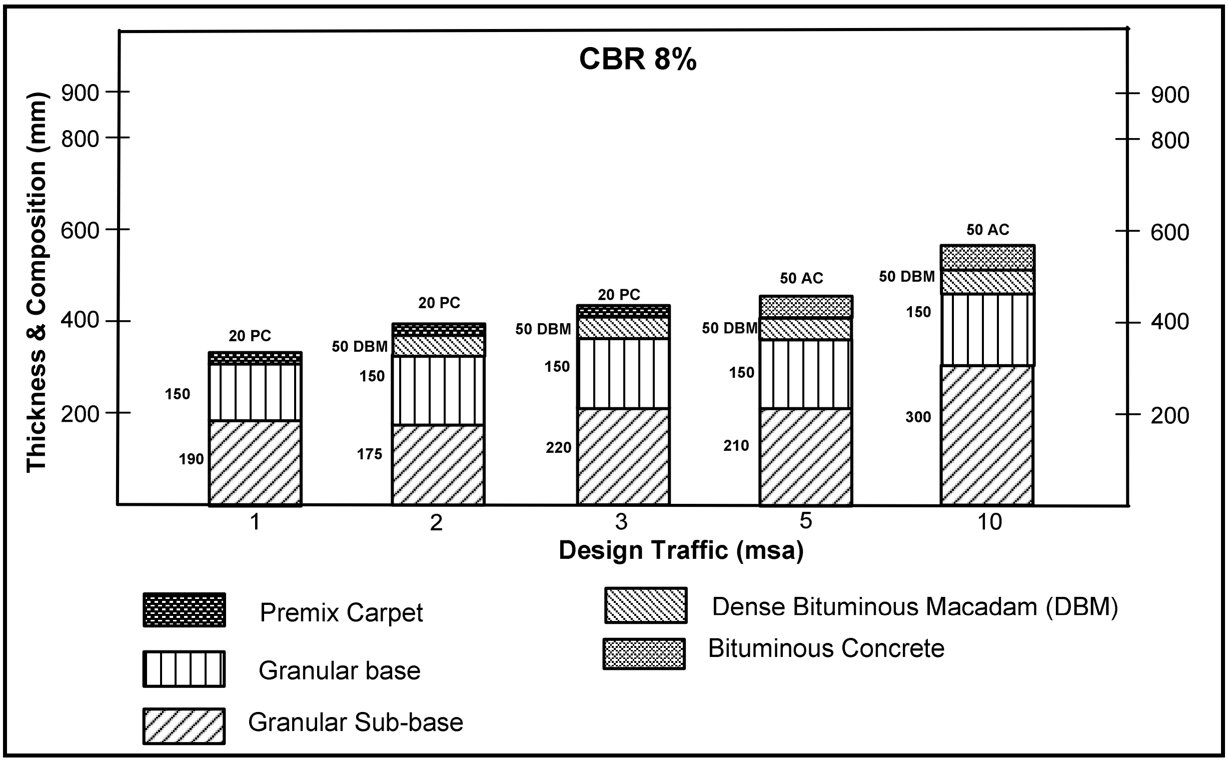
CBR 7%					
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition			
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm
		Wearing Course, mm	Binder Course, mm		
1	360	20 PC		150	210
2	410	20 PC	50 DBM	150	210
3	450	20 PC	50 DBM	150	250
5	500	50 AC	50 DBM	150	300
10	575	50 AC	50 DBM	150	325



Pavement Design Catalogue

Plate I - Recommended Design for Traffic Range 1 - 10 msa

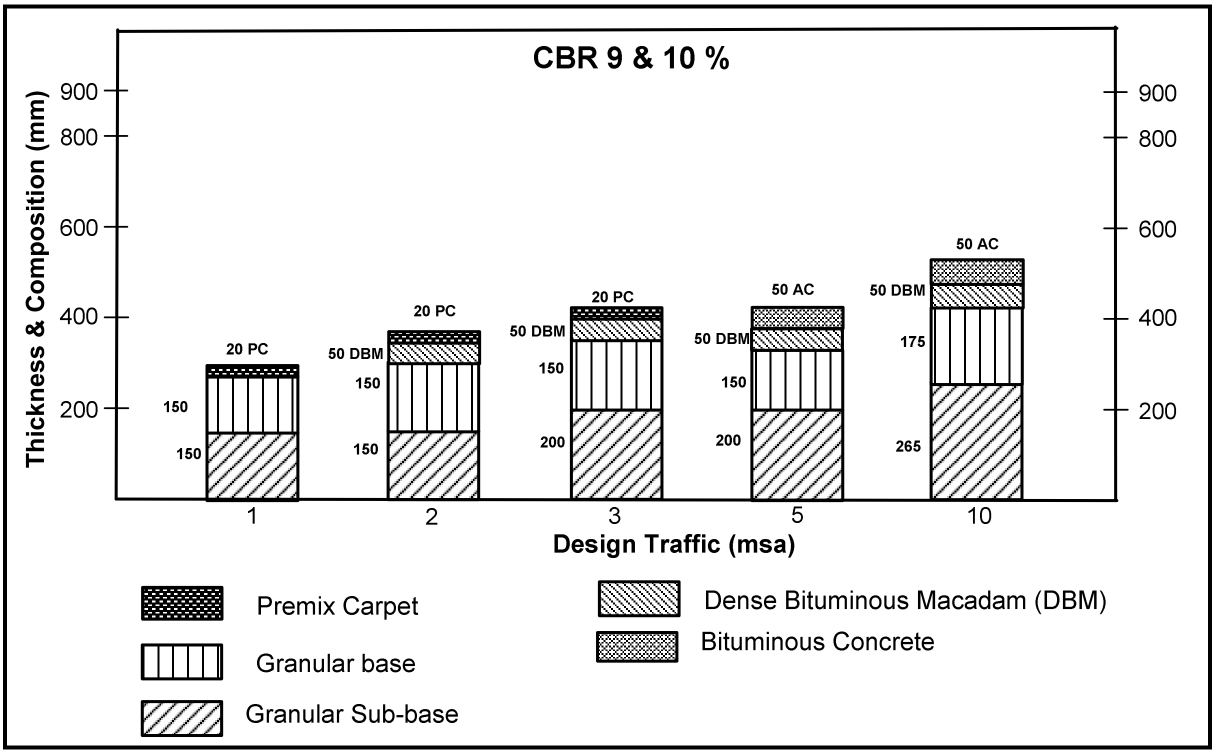
CBR 8%					
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition			
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm
		Wearing Course, mm	Binder Course, mm		
1	340	20 PC		150	190
2	375	20 PC	50 DBM	150	175
3	420	20 PC	50 DBM	150	220
5	460	50 AC	50 DBM	150	210
10	550	50 AC	50 DBM	150	300



Pavement Design Catalogue

Plate I - Recommended Design for Traffic Range 1 - 10 msa

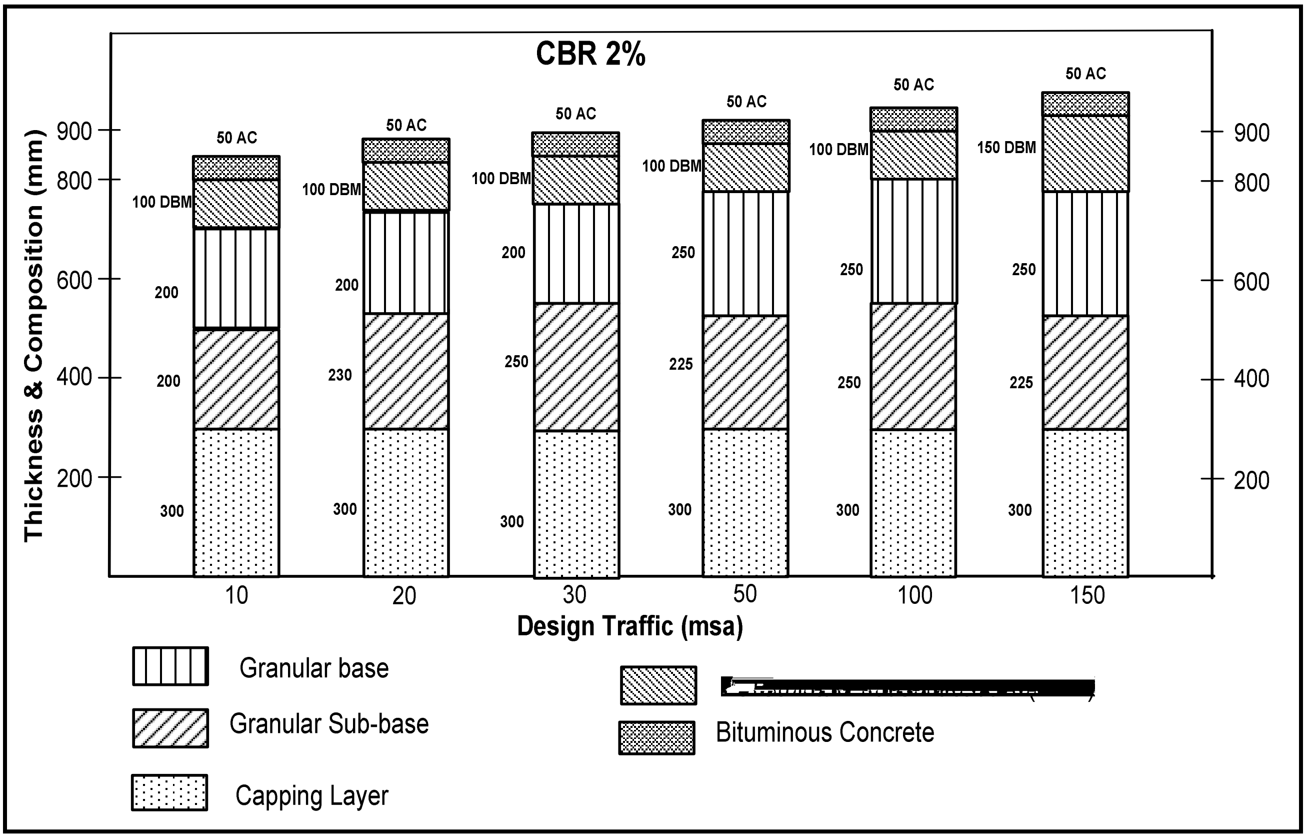
CBR 9 & 10%					
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition			
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm
		Wearing Course, mm	Binder Course, mm		
1	300	20 PC		150	150
2	350	20 PC	50 DBM	150	150
3	400	20 PC	50 DBM	150	200
5	450	50 AC	50 DBM	150	200
10	540	50 AC	50 DBM	175	265



Pavement Design Catalogue

Plate II - Recommended Design for Traffic Range 10 - 150 msa

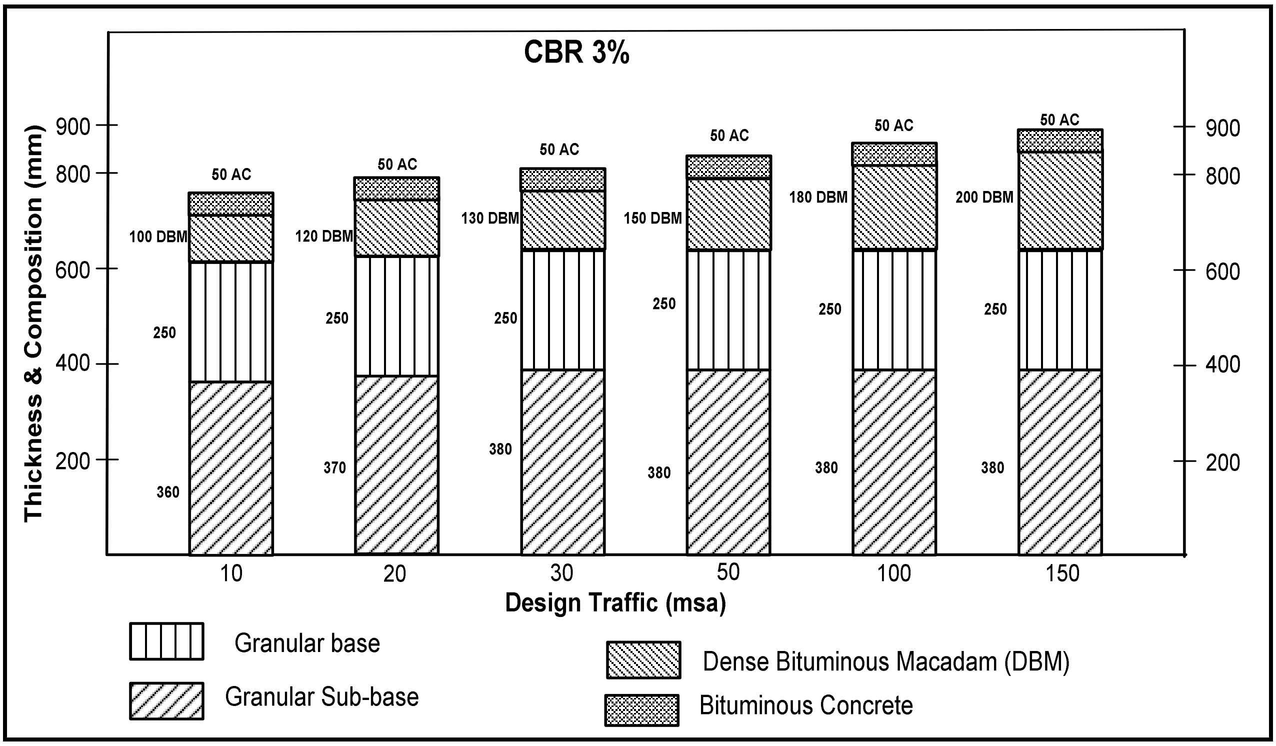
CBR 2%						
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition				
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm	Capping Layer, mm
		Asphalt Concrete	D B M			
10	850	50	100	200	200	300
20	880	50	100	200	230	300
30	900	50	100	200	250	300
50	925	50	100	250	225	300
100	950	50	100	250	250	300
150	975	50	150	250	225	300



Pavement Design Catalogue

Plate II - Recommended Design for Traffic Range 10 - 150 msa

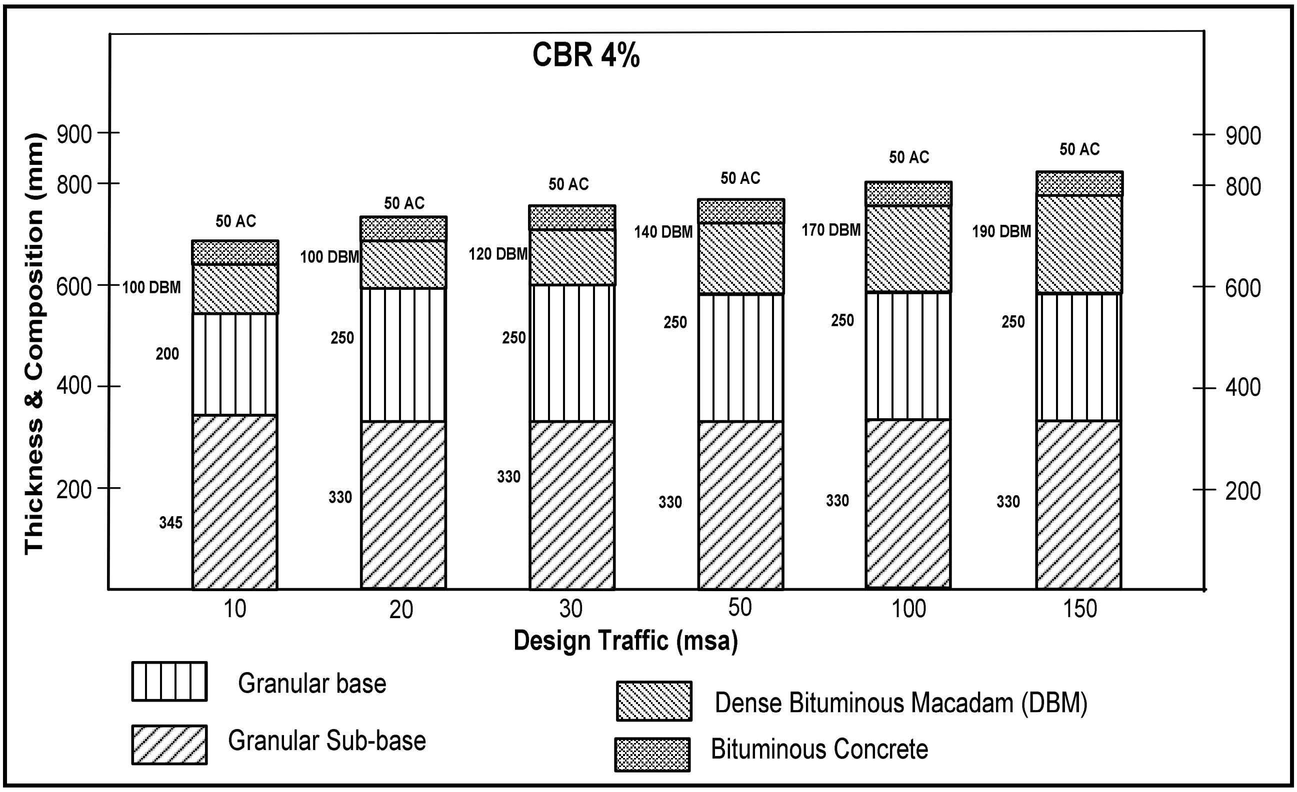
CBR 3%					
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition			
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm
		Asphalt Concrete	D B M		
10	760	50	100	250	360
20	790	50	120	250	370
30	810	50	130	250	380
50	830	50	150	250	380
100	860	50	180	250	380
150	880	50	200	250	380



Pavement Design Catalogue

Plate II - Recommended Design for Traffic Range 10 - 150 msa

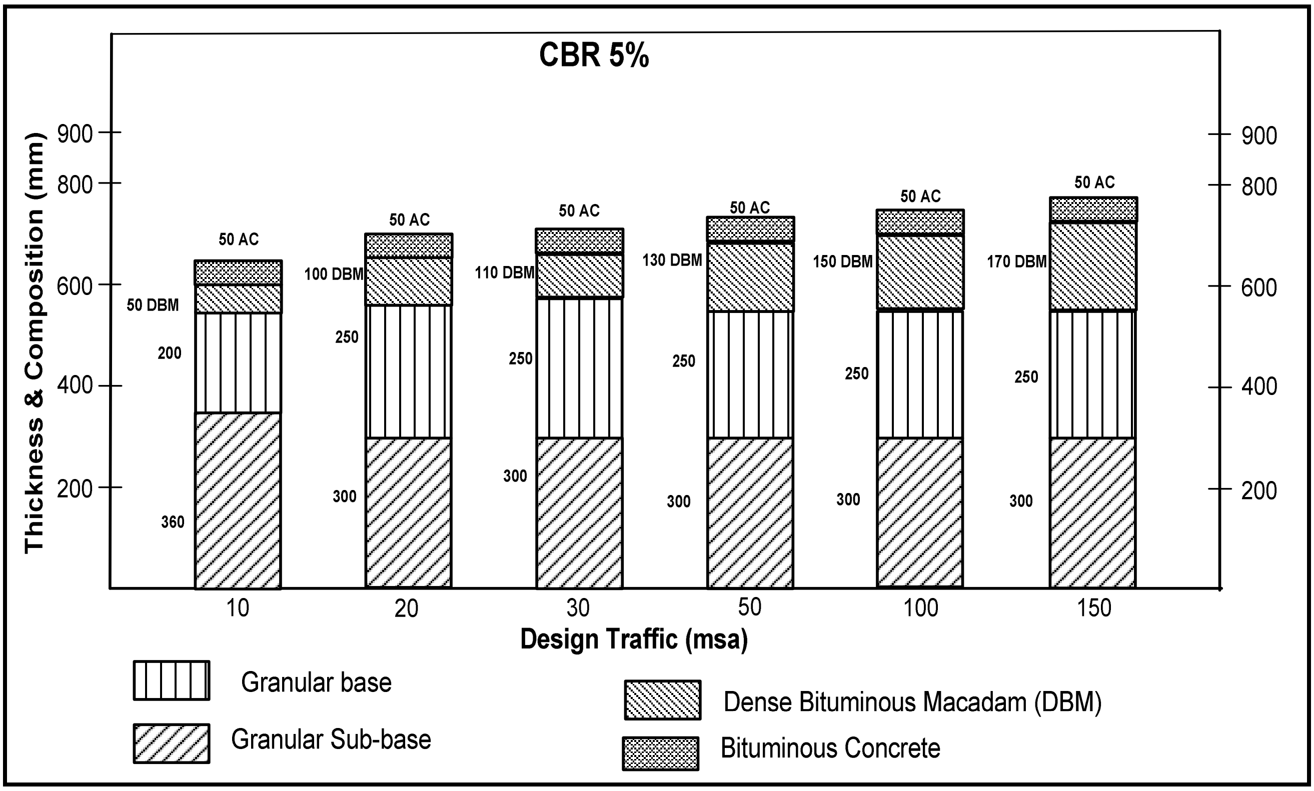
CBR 4%					
Cumulative Traffic, msa	**Total Pavement Thickness, mm**	**Pavement Composition**			
		Bituminous Surfacing		**Granular Base, mm**	**Granular Sub-base, mm**
		Asphalt Concrete	**D B M**		
10	695	50	100	200	345
20	730	50	100	250	330
30	750	50	120	250	330
50	770	50	140	250	330
100	800	50	170	250	330
150	820	50	190	250	330



Pavement Design Catalogue

Plate II - Recommended Design for Traffic Range 10 - 150 msa

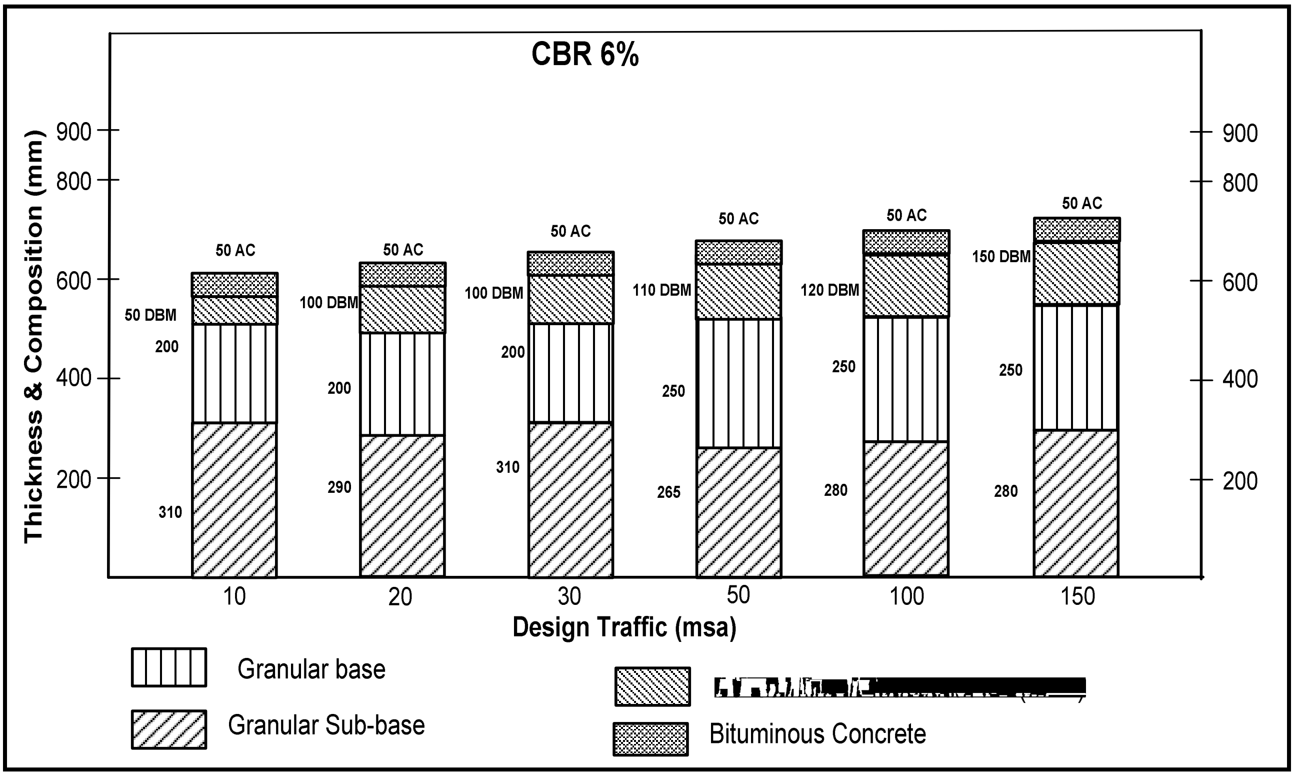
CBR 5 %					
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition			
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm
		Asphalt Concrete	D B M		
10	660	50	50	200	360
20	700	50	100	250	300
30	710	50	110	250	300
50	730	50	130	250	300
100	750	50	150	250	300
150	770	50	170	250	300



Pavement Design Catalogue

Plate II - Recommended Design for Traffic Range 10 - 150 msa

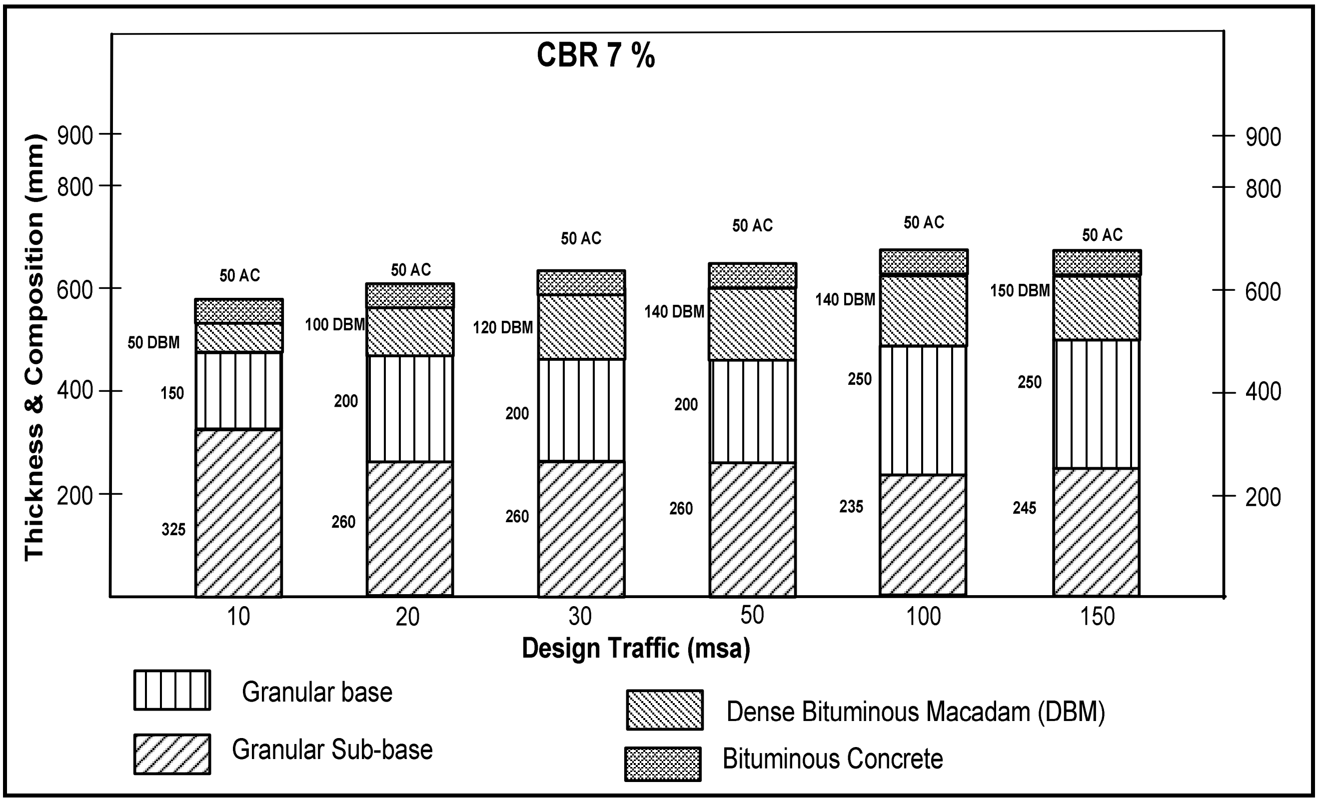
CBR 6 %					
Cumulative Traffic, msa	**Total Pavement Thickness, mm**	**Pavement Composition**			
		Bituminous Surfacing		**Granular Base, mm**	**Granular Sub-base, mm**
		Asphalt Concrete	**D B M**		
10	610	50	50	200	310
20	640	50	100	200	290
30	655	50	100	200	310
50	675	50	110	250	265
100	700	50	120	250	280
150	730	50	150	250	280



Pavement Design Catalogue

Plate II - Recommended Design for Traffic Range 10 - 150 msa

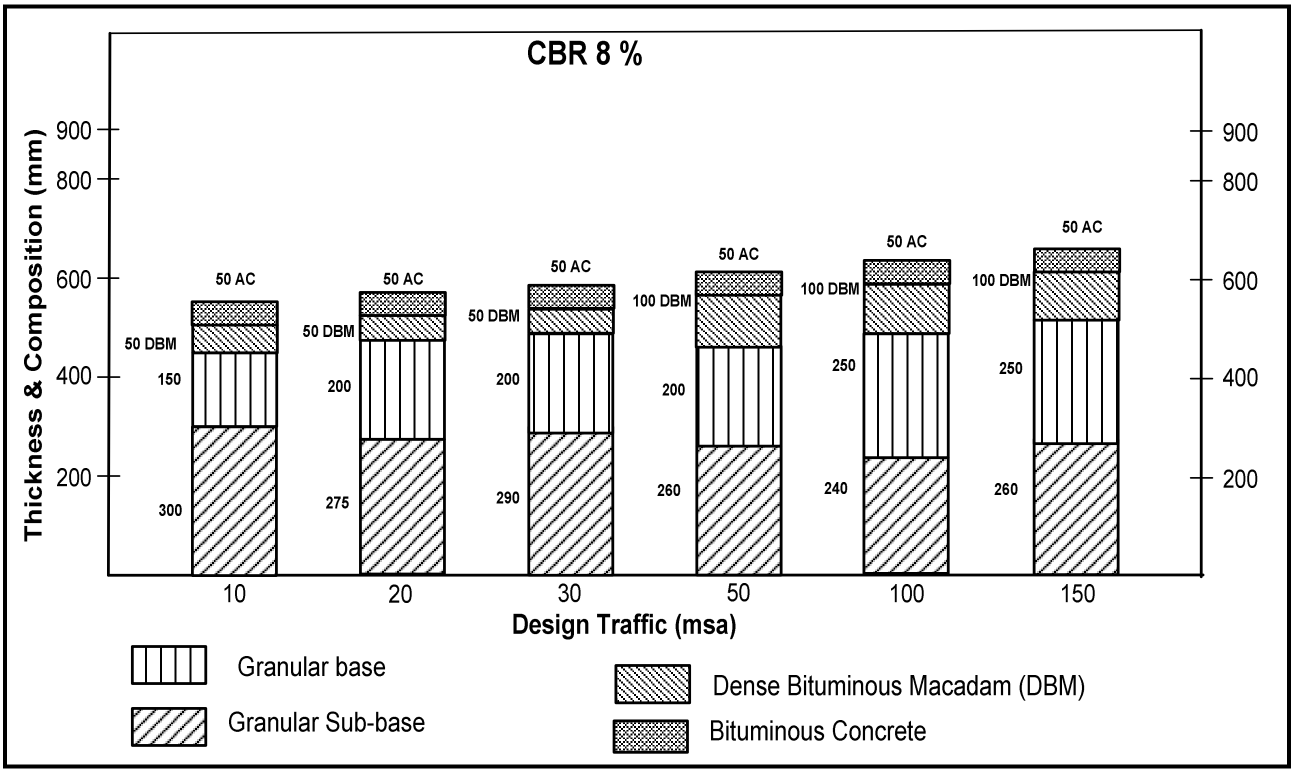
CBR 7 %					
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition			
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm
		Asphalt Concrete	D B M		
10	575	50	50	150	325
20	610	50	100	200	260
30	630	50	120	200	260
50	650	50	140	200	260
100	675	50	140	250	235
150	695	50	150	250	245



Pavement Design Catalogue

Plate II - Recommended Design for Traffic Range 10 - 150 msa

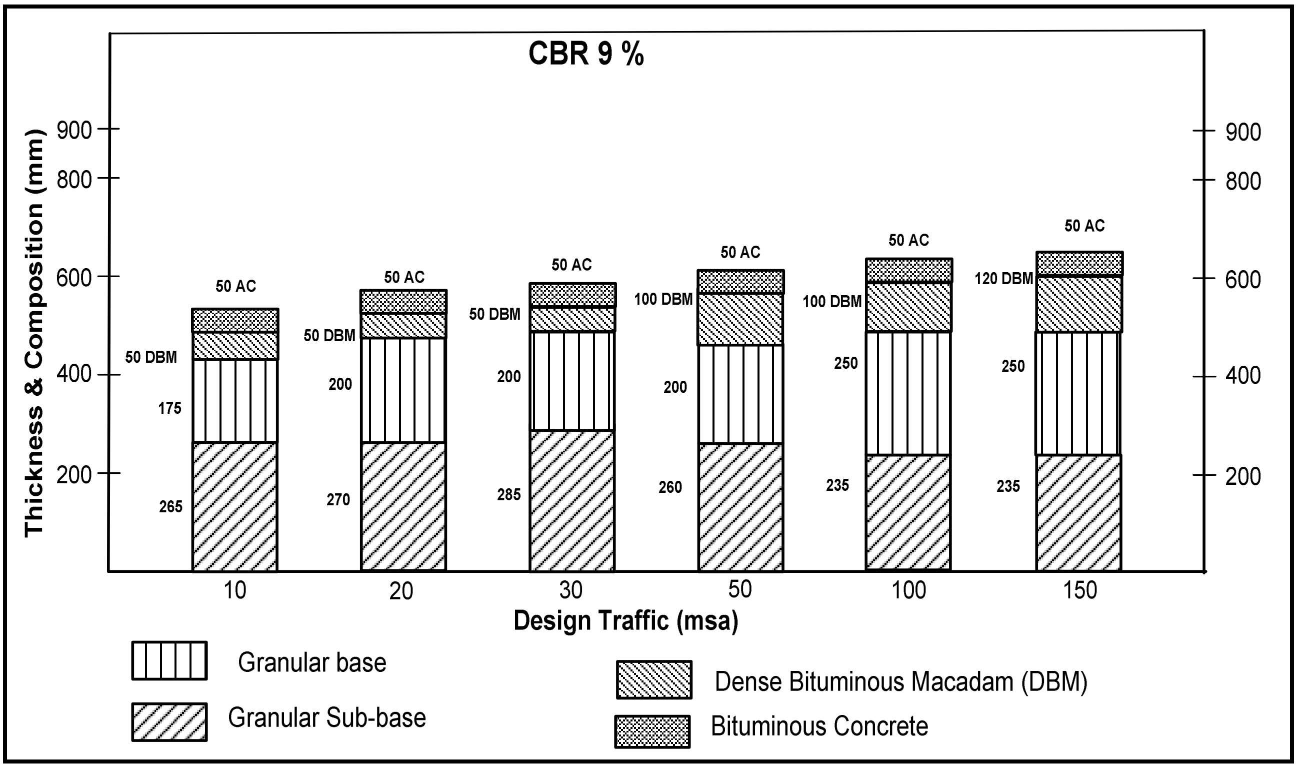
CBR 8 %					
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition			
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm
		Asphalt Concrete	D B M		
10	550	50	50	150	300
20	575	50	50	200	275
30	590	50	50	200	290
50	610	50	100	200	260
100	640	50	100	250	240
150	660	50	100	250	260



Pavement Design Catalogue

Plate II - Recommended Design for Traffic Range 10 - 150 msa

CBR 9 %					
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition			
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm
		Asphalt Concrete	D B M		
10	540	50	50	175	265
20	570	50	50	200	270
30	585	50	50	200	285
50	610	50	100	200	260
100	635	50	100	250	235
150	655	50	120	250	235



Pavement Design Catalogue

Plate II - Recommended Design for Traffic Range 10 - 150 msa

CBR 10 %					
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition			
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm
		Asphalt Concrete	D B M		
10	540	50	50	175	265
20	565	50	50	200	265
30	580	50	50	200	280
50	600	50	100	250	200
100	630	50	130	250	200
150	650	50	150	250	200