Province Government

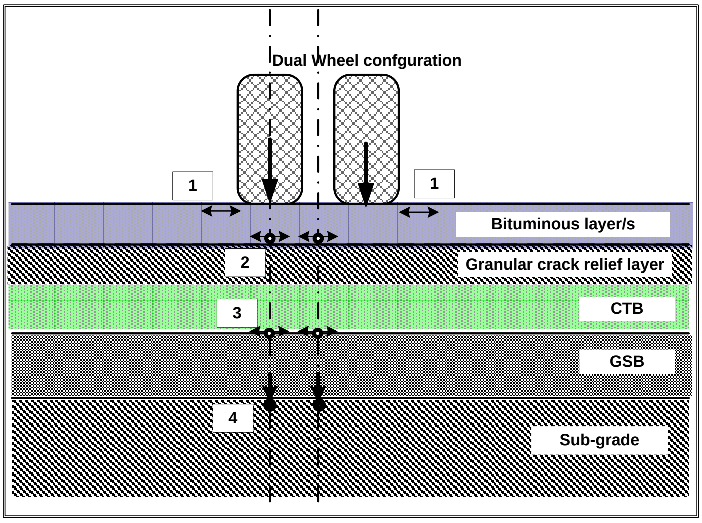
Ministry of Physical Infrastructure Development

Transport Infrastructure Directorate

Bagamati Province

Hetauda, Makwanpur

Flexible Pavement Design Guidelines for Provincial Roads



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Preface

Road Pavement is most important element for entire roadway 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.

TID was following different guidelines for the design of pavements such as: Guidelines for the Design of Flexible Pavement 2014 DOR, IRC 37: 2001, and Road Note 31 (TRL, UK). But, in the context of Provincial Road of Bagamati Province, Nepal, the design parameters may be different with respect to National Highways. The traffic condition, climatic condition, wheel load, availability of materials etc. may be different in Provincial Roads in comparison to Highways. Therefore, the TID has developed this**‘ Pavement Design Guidelines for Provincial Roads (Flexible Pavement)’** that will be acceptable for roads within the Bagamati Province. I hope the guideline will guide the TID, IDOs and PRDOs to follow rational and economic design of road pavements.

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

Thank You

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ACKNOWLEDGMENTS

This 'Pavement Design Guidelines (Flexible Pavement), is prepared as per the contract agreement between Transport Infrastructure Directorate, Ministry of Physical Infrastructure Development, Bagamati Province, and GRID Consult Pvt. Ltd. The Guidelines has been prepared for practicing engineers to understand design principle as well as carrying out the design of flexible pavement for the roads having moderate traffic flow for the provincial road network.

Consultant gratefully acknowledges the officials in the Ministry of Physical Infrastructure Development and the Transport Infrastructure Directorate. The consultant would like to highly appreciate Dr. Sahadev Bahadur Bhandari, Acting Director for his sincere understanding on the matter of pavement design and for entrusting the consultant's team for this assignment.

GRID Consult Pvt. Ltd.

September 2021

ABBREVIATIONS

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
BC	Bituminous Concrete
BM	Bituminous Macadam
BSD	Bituminous Surface Dressing
CBR	California Bearing Ratio
CFD	Cumulative Fatigue Damage
CTB	Cement Treat Base
CTSB	Cement Treated Sub-base
cvpd	Commercial Vehicle Per Day
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
GGRB	Gap Graded Rubberized Bitumen
GSB	Granular Sub Base
IDO	Infrastructure Development Office
IRC	Indian Road Congress
ITS	Indirect Tensile Strength
LCCA	Life Cycle Cost Analysis
MOPID	Ministry of Physical Infrastructure Development
MPa	Mega Pascal
msa	Million Standard Axles
PC	Premix Carpet

PRDO	Provincial Road Division Office
SAMI	Stress Absorbing Membrane Interlayer
SD	Surface Dressing
SDBC	Semi-Dense Bituminous Concrete
SMA	Stone Matrix Asphalt
SSRBW	Standard Specification for Road and Bridge Works
TID	Transport Infrastructure Development
UCS	Unconfined Compressive Strength
VDF	Vehicle Damage Factor
WBM	Water Bound Macadam
WMM	Met Mix Macadam
AADT	Average Annual Daily Traffic

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1. INTRODUCTION

1.1 Background

Bagamati Province is the most populous province playing a central role in the national economy. It has a leading position in the national economic sector with the largest contribution to the national economy with a share of 37.7% in the national Gross Domestic Product (GDP).

The status of development of physical infrastructure including road network is highest than other provinces. Similarly, vehicle registration in this Province is highest in comparison with other provinces.

The geographical extent covers the plain land in Chitwan District to the high Himalayas at the border with Tibet. Similarly, the climatic variations are associated with the diverse nature of its topography and altitude. It has sub-tropical climate in the southern plain and a tundra climatic zone in the northern Himalayan regions. The average annual temperature varies from 30^o C to -10^o C.

The diversity in the provincial topography, climatic zones, and other socio-economic indicators are very much related to the status of the transportation system in the province. The road transportation system is being dominant mode in the province it has a great role in the overall development.

The rationale behind the idea to prepare the 'flexible pavement design guidelines for provincial roads' is to consider specific provincial circumstances.

1.2 Provincial Road Network

Some sections of the most important National Highways pass/cross the Bagamati Province. Such as E-W Highway, Araniko Highway, BP Highway, and others. The provincial road network mainly consists of the roads connecting the district headquarters with the provincial and national capital. The provincial roads are providing the access to the major market, administrative and industrial center in the province. The physical connectivity and transport service is important feature for the economic prosperity of the province. The overall transport cost and transport efficiency depend on the pavement condition of the road network. The planning, design, construction, and maintenance of the road network needs huge investment. The existing road network of the province is shown in Figure 1.

1.3 Flexible Pavement Design Guidelines

Pavement is the uppermost and stable layer of the roadway. A complete task of 'Road Design' comprises of 'geometric design' and 'structural design'. Pavement is one of the important structural elements in road infrastructure. The structural behavior of the pavement is the major object of highway engineering. It is the most important element for the overall functioning of the road transport system. The pavement could be characterized in terms of its structural strength and surface conditions. The important indicator of the 'transport cost' mainly derives from the cost of 'vehicle-operation', which could be greatly affected by the pavement surface conditions. The design method of the flexible pavement shall consider several variables, such as the 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 base methods for the design of flexible pavement.

Figure 1: Road Network in Bagamati Province

In the context of Nepal,the Department of Roads (DoR)prepared the 'Pavement Design Guidelines (Flexible Pavements)' in 2014. Further, it has been recently revised as ***'Guidelines for the Design of Flexible Pavements-2014 (Second Edition 2021)'***. Basic design principles for these 'guidelines' were taken from the recent DoR documents as well as other relevant documents.

These Guidelines have been envisioned to incorporate the specific provincial context in terms of the road network, sub-grade strength, as well as traffic conditions.

This manual is prepared with the view to having a unified approach for working out the design of flexible pavement in the Bagamati Province. The manual could be taken as the design reference material for carrying out the specific roadway and traffic conditions.

1.4 Scope and Applicability

Technical concepts in these guidelinesare preferred for the design of flexible pavements for provincial roads as well as other types of roads such as urban roads and village roads having low traffic volume. After reviewing the recent development in the construction technology, materials, as well as 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 recent axle load pattern and trend have been incorporated in the vehicle Damage Factors,
- Mechanistic-empirical performance models have been taken for the rutting in sub-grade and bottom-up cracking in bituminous layers have been taken into considerations,
- Concepts for reliability for pavement performance equations as 80 % reliability for roads having traffic less than 20 msa and 90 % for roads having more than 20 MSA.

The Guidelines shall be updated with the change in the specifications for the road and bridge works as well as in the development of new concepts and numerical methods in this field.

1.5 Structure of the Guidelines

The first edition of the ‘Flexible Pavement Design Guidelines for Provincial Roads’ includes the following sections:-

- Section 1: Introduction
- Section 2: Pavement Design
- Section 3: Pavement Analysis
- Section 4: Traffic
- Section 5: Pavement Composition
- Section 6: Pavement Design Procedure
- Section 7: Pavement Design Catalogue
- Section 8: Quality control Tests during construction

2. PAVEMENT DESIGN

2.1 Overview

Pavement engineering has been gradually developed based on structural analysis in combination with the empirical results of the various efforts in this field. Before the early 1920s, the thickness of pavement was based purely on experience. The pavement thickness was designed without considerations of the sub-grade soil along the highway alignment. Later, various design methods have been developed by different agencies for determining the thickness of pavement required. Similarly, with the improvement of material properties and strength, various combinations are being practiced by engineers.

2.2 Environmental Consideration

The environmental factors are very prominent for the selection of pavement type. The performance of the particular type of pavement is greatly influenced by environmental factors. Therefore, pavement design shall be guided by the temperature and precipitation, of the site. In the context of Nepalese climatic zones, the temperature is dependent on altitude and seasonal variation. Therefore, a detailed analysis of the altitude, temperature, and precipitation should be considered while designing the pavement.

2.2.1 Temperature

The effect of temperature on bituminous pavements is different from that on concrete pavements. Temperature affects the resilient modulus of asphalt layers and induces the curling of concrete slabs. In cold climates, the resilient moduli of un-stabilizedmaterials also vary with the freeze-thaw cycles. The severity of cold climate is indicatedby the freezing index, which can be correlated with the depth of frost penetration.

Effect on temperature on the bituminous Layer is related to the elastic and viscoelastic properties of asphalt. Any mechanistic method of flexiblepavement design must consider pavement temperature, which can be related to air temperature. During the winter, when the temperature is low, the bituminous mix becomes rigid andreduces the strains in the pavement. However, stiffer asphalt concrete has less fatigue life, whichmay neutralize the beneficial effect of smaller strains. Low temperature can cause bituminous pavements to crack.

The severity of frost in a given region can be expressed as a freezing index in terms of degree days. A negative one-degree day represents one day with amean air temperature one degree below freezing; a positive one-degree day indicatesone day with a mean air temperature one degree above freezing. Analysis of the freezing index shall be conducted for the pavement design for the cold region.

The design of the pavement shall be confirmed with the temperature of the region during the cold season. The boundary of the cold region for a specific month of the cold season has been worked out in these guidelines. The map of the temperature gradient for November, December, January, and February has been illustrated as the general guide to the pavement designer. These temperature gradient maps can be considered for selecting the pavement type, designing, and construction methods of the bituminous pavement.

3. PRECIPITATION AND DRAINAGE

The precipitation in the form of rain and snow has a detrimental effect on any aspect of the pavement performance. It affects the quantity of surface water infiltrating into the subgrade and the location of the groundwater table. Every effort should be made to improve drainage and alleviate the damaging effect of water. If water from rainfalls can be drained out within a short time, its effect can be minimized, even in regions of high precipitation. The location of the groundwater table is also important. The water table should be kept at least 1.0 m below the pavement surface. In seasonal frost areas, the depth from the pavement surface to the groundwater table should be much greater. When water seeps through pavement cracks and joints, an open-graded base or sub-base course can carry it away to the pavement layers.

The pavement analysis for the design shall carefully consider the precipitation pattern and the existing ground table and its variation due to the precipitation. Furthermore, any roadside developments (construction of the building, diversion of natural drainage systems, etc.) may change the pattern of variation on the groundwater table which may negatively affect the pavement strength.

3.1 Pavement Type Selection

There are mainly rigid and flexible types of road pavement. The selection of appropriate type is an important and foremost step of the pavement design procedure for identifying the most favorable type of pavement structure for a given set of traffic, subgrade soils, climate, and other factors. The selection process may be a very simple process that considers only the anticipated traffic volume. The type selection process could be carried out based on multi-criteria methods which may consider various factors with the relative weights for indicating the importance for given conditions.

A general process for the selection of pavement type selection could consider the primary and secondary factors as shown in Figure 2.

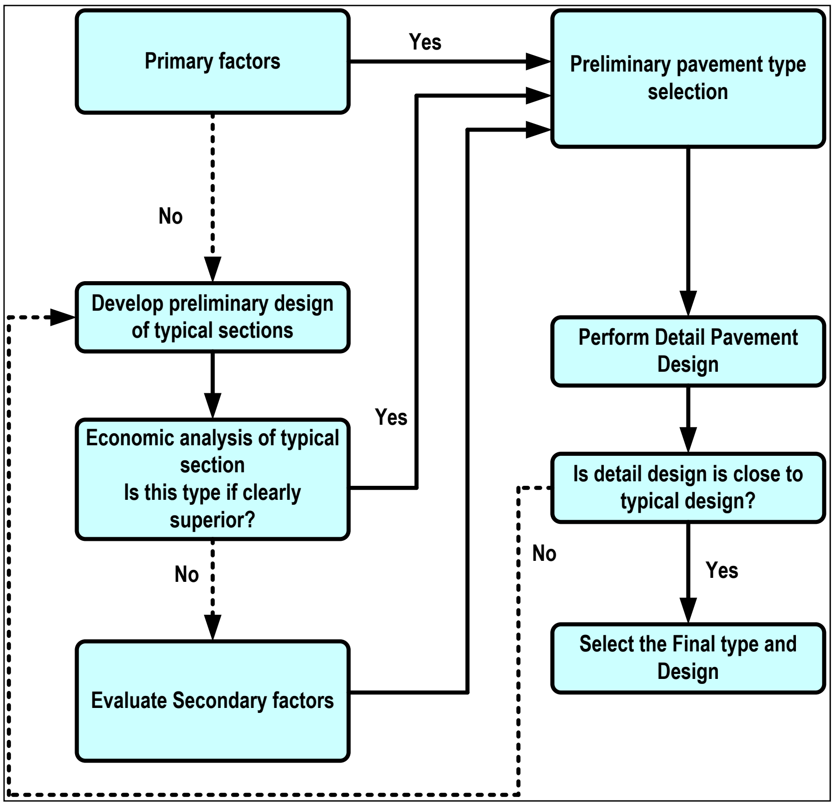


Figure 2: Pavement type Selection Process

3.1.1 Primary Factors

Primary factors for the selection pavement type can be taken as traffic volume, sub-grade soil, construction methods, weather, cost, and opportunity for recycling. A brief explanation of the primary factors is listed below.

- Traffic: the basic principle of the geometric design of roads is to consider the traffic volume. However, only the commercial traffic can be taken into consideration for the design of pavement structure.
- Soil characteristics: The load-carrying capability of a native soil, which forms the sub-grade for the pavement structure, is a dominant factor in pavement performance. The uniform character of the soil even in a small area can exhibit different behavior due to the influence of different weather factors such as precipitation, temperature, etc.
- Weather: it affects sub-grade 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 the pavement material from an existing roadway section or other sources may dictate the use of one pavement type. Similarly, the opportunity of recycling in the future 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

Secondary factors are mainly related to the local skill or technology, functioning of existing pavement types, environmental aspects, safety, as well as the availability of construction materials. The secondary factors to be considered for the pavement type are listed as:

- Performance of the similar pavement type in the area: The experience and judgment of the highway engineer must be based on the performance of pavements in the adjacent area of his jurisdiction. Past performance is a valuable guide, provided there is a good correlation between conditions and service requirements between the reference pavements and the designs under study.
- Existing pavement type constructed in the adjacent roadway: if there is no radical change in conditions, the choice of paving type on the highway may be influenced by adjacent existing sections, which have given an 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 require less energy consumption.
- Availability of local materials: The availability and adaptability of local materials may influence the selection of pavement type. In addition, 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 non-skid surface as affected by the available materials may each influence the paving type selection in specific locations.
- 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 taken as the selection preference for the pavement type.

3.1.3 Life Cycle Cost Analysis

Life Cycle Cost Analysis (LCCA) is important for the overall economic aspects of pavement type selection. It is referred to as an engineering economic analysis that allows engineers to quantify the differential costs of alternative investment options for a given pavement type. It can be used to compare alternate pavement types (flexible versus rigid) on new construction projects and rehabilitation projects.

LCCA takes into account the expenditures during the entire life of the facility, not just the initial investment for keeping the facility into the acceptable service condition. The analysis allows for a cost comparison of options with varying design lives and potentially differing user costs to be compared on an equivalent basis. Furthermore, this analysis is not limited to the simple cost comparison, but it contains the methods to determine and demonstrate the economic merits of the selected alternative in an analytical and fact-based manner. The LCCA shall be focused on the following aspects of the pavement type selection:

- The lowest total cost to the authority over the life of the project,
- The details of the alternative types to be compared,
- The user-cost impacts of alternative types over the design period.

LCCA shall be conducted within the framework of an approved or well-discussed and well-structured methodology. The process shall be based on reliable data for each type of alternatives.

3.2 Types of Flexible Pavement

Flexible pavement is generally constructed with the application of bituminous binder in the surface layers including wearing courses.The types of bituminous pavements are taken as per the Standard Specifications for Road and Bridge Works, 2073 (SSRBW, 2073). Basic types of the construction of flexible pavement are described as below:

3.2.1 Surface Dressing

This type of construction is referred to as the application of one or more coats of surface dressing, each coatconsisting of a layer of bituminous binder sprayed on a base prepared previously,followed by a cover of stone chipping properly rolled to form a wearing course to theirrequirements of Clause 1303 of SSWBW, 2073.

3.2.2 Penetration Macadam, Semi-grout

This type of construction consists of compacted crushed coarse aggregates with the application of a bituminous binder and choke aggregate by the requirements of Clause 1304 of SSRBW, 2073.

3.2.3 Sand Seal

A sand seal is referred to as the application of a bituminous binder covered with aggregate asspecified in Clause 1305 of SSRBW. The aggregates shall consist of sands or fine aggregates passing 100 percent from 9.50 mm.

3.2.4 Slurry Seal

This type of construction is the mixture of bitumen emulsion, fine aggregate, cement or lime and, water prepared in a mixer and then spread on the road surface. The construction and requirements shall comply with Clause 1306 of SSRBW.

3.2.5 Bituminous Macadam

Bituminous Macadam (BM) may be constructed in a single course having 50 mm to 100 mm thickness or in multiple courses of compacted crushed aggregates premixed with a bituminous binder on a previously prepared base. Bituminous macadam is an open-graded mix, there is a potential that it may trap water or moisture vapor within the pavement system. Therefore, the adjacent layer (shoulders) shall have proper drainage quality to prevent moisture-induced damage to the BM. The requirements and construction shall be followed as Clause 1307 of SSRBW.

3.2.6 Dense Bituminous Macadam

Dense Bituminous Macadam, (DBM), mainly used as base/binder and profile corrective courses. The work shall consist of construction in single or multiple layers of DBM on a previously prepared base or sub-base. The thickness of a single layer shall be 50 mm to 100 mm. The bitumen content required shall be determined by the Marshall Mix design procedure contained. The requirements for the materials and construction shall comply with Clause 1308 of SSRBW.

3.2.7 Asphalt Concrete

This type of construction is used as wearing courses. This work shall consist of construction in a single layer on a previously prepared bituminous bound surface. A single layer shall be 30 mm/40 mm/50 mm thick.

The bitumen shall be viscosity grade paving bitumen complying with the Indian Standard Specification IS: 73, modified bitumen complying with IS: 15462, or as otherwise specified in the Contract document. The requirements for the materials and construction shall comply with Clause 1309 of SSRBW.

3.2.8 Close Graded Premix Surfacing

This type of construction consists of the preparation, laying, and compaction of a close graded premix surfacing material of 20 mm thickness composed of graded aggregates premixed with a bituminous binder on a previously prepared surface, by the requirements of these Specifications, to serve as a wearing course.

Close graded premix surfacing shall be of Type A or Type B as specified in the Contract Documents. Type A grading is recommended for use in areas having rainfall more than 150 cm per year. In other areas, Type B grading may be used. The requirements for the materials and construction shall comply with the Clause 1310 (A) of SSRBW.

3.2.9 Open-Graded Premix Surfacing

This type of bituminous surfacing consists of preparation, laying, and compaction of an open-graded premix surfacing material of 20 mm thickness composed of small-sized aggregate premixed with a bituminous binder on a previously prepared base, by the requirements of the SSRBW 1310 (B).

3.2.10 Sand Asphalt

This method of bituminous construction is referred to as the controlled, hot-mixed, hot-laid, plant mixture of sand andpenetration grade bitumen. It shall be constructed as per the requirements of the SSRBW clause 1312.

3.2.11 Bituminous Cold Mix

Cold Mixed Bituminous Macadam (CMBM)shall involve construction of one or more courses of compacted mixture prepared withbitumen emulsion and mineral aggregate, laid immediately after mixing to requiredgrade and camber using appropriate machinery.

Bitumen emulsion for preparation of CMBM shall be Medium Setting (MS), SlowSetting (SS-2) grade or a tailor made for compatibility with available mineralaggregates, conforming to IS: 8887 or another international standard (ASTM orAASHTO). Requirements for the Cold mix shall comply with the clause 1313 and 1314 of SSRBW.

3.2.12 Otta Seal

Otta seal may be applied in a single or double coat with orwithout sand cover seal, each layer consisting of bituminous binder sprayed on apreviously prepared base/sub-base surface, followed by graded aggregates properlyrolled to form a wearing course to the requirements of these Specifications. A singleOtta Seal means an application of bituminous binder to the road surface followedimmediately by a single layer of graded aggregates.

A double Otta Seal means two Otta Seal surfacing placed over base/sub-base. Sandcover seal is normally applied over single Otta seal surfacing.

A double Otta Seal means two Otta Seal surfacing placed over base/sub-base. Sandcover seal is normally applied over single Otta seal surfacing.Requirements for the Otta seal shall comply with the clause 1317 of SSRBW.

4. PAVEMENT ANALYSIS

4.1 General

The philosophy of pavement design involves designing pavements for satisfactory functional and structural performance of the pavement during its intended service life period. Roughness caused by variation in surface profile, cracking of layers bound by bituminous or cementitious materials, rutting (permanent or plastic deformation) of unbound/unmodified or partially modified subgrade, granular layers, and bituminous layers are the primary indicators of the functional and structural performance of pavements. Performance of the pavement is explained by performance models which are either (a) purely empirical (only based on experience) or (b) mechanistic-empirical, in which the distresses/performance are explained in terms of mechanistic parameters such as stresses, strains, and deflections calculated using a specific theory and as per a specified procedure.

Most of the current pavement design methods follow the mechanistic-empirical approach for the design of bituminous pavements. In these methods, for each of the selected structural distresses, a critical mechanistic parameter is identified and controlled to an acceptable (limiting) value in the design process. The limiting values of these critical mechanistic parameters are obtained from the performance models.

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 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 the calculation of stresses, strains, and deflections produced by a load applied at the surface of the pavement.

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. In the case of application of Cement Treated Base (CTB), it 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 the rutting of the bituminous layer is taken as the plastic deformation of these layers due to the repeated application of wheel loads. The pavement analysis is proposed based on the following aspects:

a. Fatigue cracking and moisture damage resistant mixes for the bottom (base) bituminous layer,

b. Rut and moisture damage resistant bituminous mixes for the intermediate (binder) bituminous layer (if provided),

c. Rut, moisture damage, fatigue cracking, and age-resistant surface course, and

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

4.2 Reliability and performance

Reliability is defined as the probability that the design will perform its intended function over its design life. There are two methods of pavement design: deterministic and probabilistic. In the deterministic method, each design factor has a fixed value based on the factor of safety assigned by the designer. Using judgment, the designer usually assigns a higher factor of safety to those factors that are less certain or that have a greater effect on the final design. Application of this traditional approach based on the factors of safety can resulting overdesign or under-design, depending on the magnitudes of the safety factors applied and the sensitivity of the design procedures. A more realistic approach is the probabilistic method, in which each design factor is assigned a mean and variance.

Generally, 90% reliability is adopted for the performance equations of sub-grade rutting and fatigue cracking of the bottom bituminous layer for all important roads such as Expressways, National Highways, State Highways, and Urban Roads. Similarly, 90 % reliability is recommended for design traffic of 20 msa or more. All categories of roads with the anticipated traffic less than 20 msa 80 % reliability are considered for performance models.

4.3 Analysis of Pavement Slayers

Pavement has been considered as the linear elastic layered system for the calculation of stresses, strains, and deflections. The vertical compressive strain on top of sub-grade and the horizontal tensile strain at the bottom of the bituminous layer is considered to be the critical mechanistic parameters that 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 strain at the bottom of the CTB layer are considered to be critical for the performance of the CTB bases.

The various pavement compositions and the locations of the different critical mechanistic parameters to be calculated are shown in Figure 3,Figure 4and Figure 5.

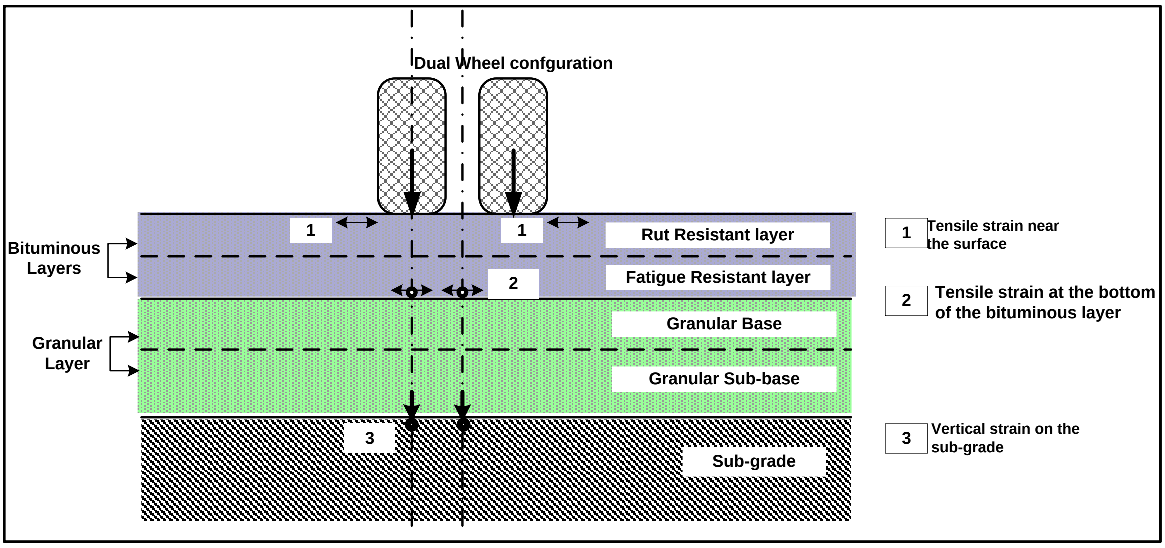


Figure 3: Bituminous Layers with GB and GSB

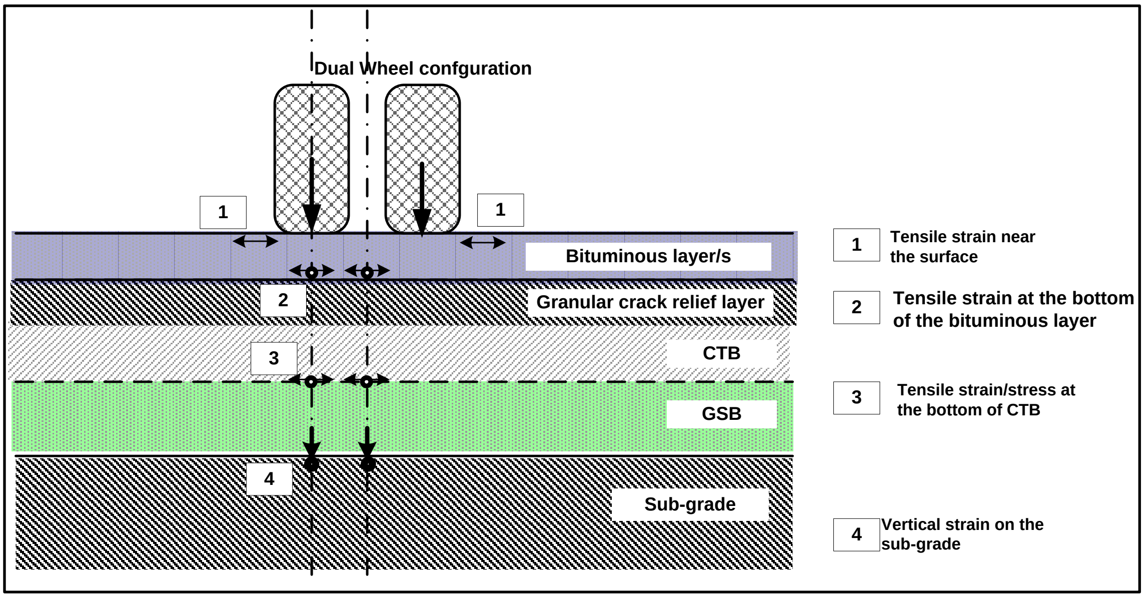


Figure 4: Bituminous Layer(s) with Granular Crack Relief Layer, CTB, and GSB

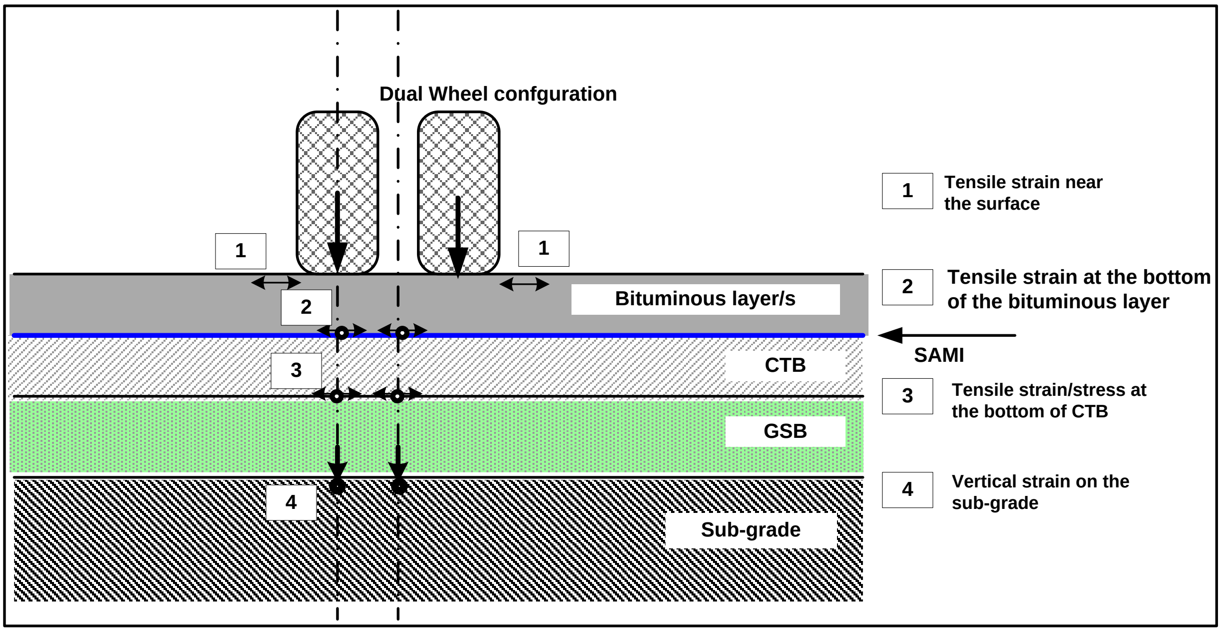


Figure 5: Bituminous Layer(s), SAMI, CTB and GSB

4.4 Performance of Pavement Layers

Sub-grade rutting criteria, fatigue criteria of bituminous layers, and fatigue performance of the CTB (incase of CTB layer) have been taken into consideration for design analysis of the pavement layers.

4.4.1 Sub-grade Rutting Criteria

An average rut depth of 20 mm or more, measured along the wheel paths, is considered in these guidelines as a critical or failure rutting condition. 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.

a) For the reliability of 80 % (design traffic of fewer 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.

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 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 isotropic.

4.4.2 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. 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 3and Equation respectively for 80 % and 90 % reliability levels[1].

a) For the reliability of 80 %:

$$N_f = 1.6064 * C * 10^{-4} \left[\frac{1}{\varepsilon_t}\right]^{3.89} \left[\frac{1}{M_{Rm}}\right]^{0.854} \qquad \textbf{Equation 3}$$

b) For the reliability of 90 %:-

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

Where,

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

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

V_{be} = percent volume of effective bitumen in the mix used in the bottom bituminouslayer,

N_f = fatiguelifeofbituminouslayer(cumulativeequivalentnumberof80kNstandard axle loadsthatcanbeservedbythepavementbeforethecriticalcrackedareaof20 % or more of the paved surface area occurs)

ε_t = maximumhorizontaltensilestrainatthebottomofthebottombituminouslayer (DBM)calculatedusinglinerelasticlayeredtheorybyapplyingstandardaxleload at the surface of the selected pavementsystem.

M_{RM} = resilientmodulus(MPa)ofthebituminousmixusedinthebottom bituminous layer, selected as per the recommendations made in theseguidelines

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.

4.4.3 Fatigue performance for Cement Treated Base

The fatigue performance check for the CTB layer should be carried out using Equation 5. 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 againstfatigue (for Expressways, National Highways, Sate Highways, and Urban Roads RF = 1 whereas for other categories of roads if the design traffic is more than 10msa,RF = 2 for all othercases

N = No of standard axle load repetitions which the CTB cansustain

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 the axle load of class ***'i'*** during the design period, is given by Equation 6 [1].

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

Where,

N_{fi}= Fatigue life of CTB material which is the maximum repetitions 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

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

For 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. 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.

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

Where,

n_i = expected (during the design life period) repetitions of the 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**.**

5. TRAFFIC

5.1 General

Traffic loading is the main cause of pavement failure, which is related to the magnitude of the individual wheel loads and the number of times these loads. 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 relative structural damage due to the different types of axle-loads is considered by using the Vehicle Damage factor (VDF) in the estimation of the design traffic.

Future traffic forecasting is one of the important steps for pavement design. It is related to the determination of a cumulative number of standard axles anticipated during the design period. 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.

- initial traffic (two-way) 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),
- average traffic growth rate(s) during the design life period,
- design life in several years,
- spectrum of axle loads, and
- factors for the estimation of the lateral distribution of commercial traffic over the carriageway.

5.1.1 Traffic Growth Rate

The determination of a cumulative number of standard axles expected to use the pavement over the design period shall be based on the estimated traffic growth rate of the commercial vehicles over the design period. The estimation of growth rates shall be determined based on the following:

- Past trends of traffic growth, and
- Demand elasticity of traffic with respect to macroeconomic parameters (such as the gross domestic product and state domestic product) and the demand expected due to specific developments and land-use changes likely to take place during the design life period.

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** should be used for commercial vehicles for estimating the design traffic.

5.1.2 Design Period

The time duration of the pavement without major rehabilitation can be considered as the design period. However, the failure criteria shall be considered for this purpose. It is recommended that the structural design of the pavement for provincial highways as 15 years. The design period for the case flow-volume roads may be taken as 10 years.

5.1.3 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, Cumulative Fatigue Damage (CFD) is carried out based on the 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 the dual wheel on either side are given in the equations below:

a) Single axle with single wheel on either side:

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

b) Single axle with the dual wheel on either side:

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

c) Tandem axle with the dual wheel on either side:

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

d) Tridem axle wtheith dual wheel on either side:

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

The 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 to be considered for the axle load survey is given in Table 1. 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 a class interval of the axle load survey data of 10 kN, 20 kN, and 30 kN for single, tandem, and tridem axles respectively.

Table 1: Minimum Sample Size of the Axle Load Survey [1]

Commercial traffic volume(CVPD)	Min.%ofCommercialTraffictobesurveyed
<3000	20 percent
3000 to6000	15 percent t(subject to a minimum of 600cv)
>6000	10 percent (subject to a minimum of 900cvs)

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 the recently conducted axle load survey VDF values can be used to convert volume of commercial traffic into the number of standard axles for each category of vehicle types as shown in Table 2.

Table 2: Indicate Values of VDF

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

5.1.4 Lateral Distribution of Commercial Traffic over the Carriageway

The Annual Average Daily Traffic (AADT) is distributed over the whole carriageway for the 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 a particular project, it is recommended that the following distribution may be assumed for design.

- **Single lane roads:** traffic tends to be more channelized single-laneroads than two-lane roads and to allow for this concentration of wheel load repetitions, the design should be based on the total number of commercial vehicles in both directions.
- **Intermediate lane roads of width 5.5 m:** Design traffic based on 75 percent of the two-way commercial traffic.
- **Two-lane two-way roads:** the design should be based on 50 percent of the total number of commercial vehicles in both directions.
- **Four-lane single carriageway roads:** the design should be based on 40 percent of the total number of commercial vehicles in both directions.
- **Dual carriageway roads:** The design of dual two lane carriageway roads should be based on 75 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.

5.2 Traffic Estimation

5.2.1 Base Year Traffic Flow

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.

5.2.2 Traffic Forecasting

The anticipated future traffic flow depends on 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:

- **Normal Traffic:**The traffic, which would pass along the existing road or track even if no new pavement were provided. The commonmethod 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.

- **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.
- **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 it canbe ignored.

5.2.3 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 determined 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.

6. PAVEMENT COMPOSITION

The design of Flexible pavement mainly consists of determination of thickness of various layers. These layers 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

6.1 Sub-grade

6.1.1 General

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 generally should not 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. The Standard Specification for Road and Bridge Works (SSRBW), 2073 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.

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. The design can be based on the 80th percentile CBR value for Provincial Roads with the design traffic of less than 20 msa.

6.1.2 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 (***M_{RS}***) can be estimated from its CBR value by using the following equations.

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

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

Where,

- M_{RS} = 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.

6.1.3 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.

- 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 layers 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.
- Effective Resilient Modulus ($\boldsymbol{M_{RS}}$) of an equivalent layer can be calculated by using Equation 15.

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

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

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.

For the purpose of design, the resilient modulus ($\boldsymbol{M_{RS}}$), 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.

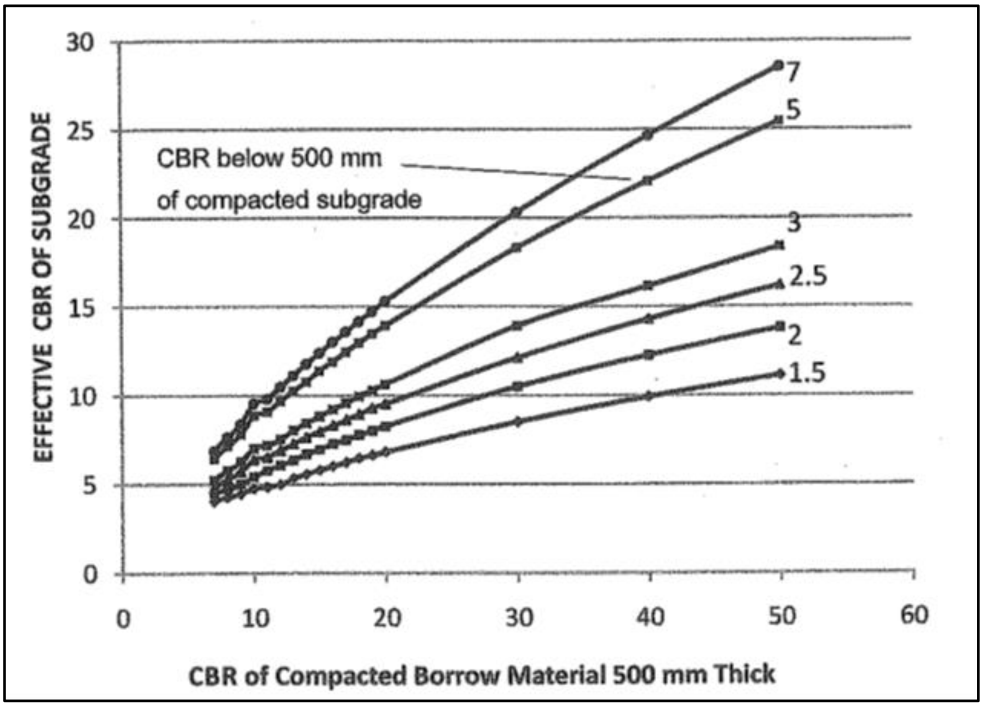


Figure 6: Determination of Effective CBR

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%.

6.2 Sub-base

6.2.1 Granular Sub-base Layer

Sub-base layer is mainly provided for supporting for 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. Grading-III and Grading - IV shall preferably be used in lower sub-base. Grading-V and Grading-VI shall be used as sub-base cum drainage layer. The minimum thickness of the granular sub-base shall be as:

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

6.2.2 Resilient Modulus of 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)

6.2.3 Cement Treated Sub-base 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 (SSRBW, 2073). It shall have a uniformity coefficient not less than 5, capable of producing a well closed surface finish. For use in a 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.

6.2.4 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

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

Where,

- UCS =28-day unconfined compressive strength (MPa) of the cementitious granular material. It should be ensuredthat 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.

6.3 Base Course

6.3.1 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.

6.3.2 Cement Treated 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 standard specification. 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 7.0 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-bases, 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 elastic modulus of cementitious bases depends upon the quality of materials. Elastic Modulus (ECTB) can be estimated by using Equation 17 from the 28 days 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 days unconfined compression strength values ranging between 4.5 to 7.0 MPa.

6.3.3 Flexural Strength (Modulus of Rupture) of CTBMaterial

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)， subjected to the following limiting values:

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

6.3.4 Crack Relief Layer

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.

6.4 Bituminous Layers

6.4.1 Functioning of Bituminous Layers

Bituminous surfacing may 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 durable surfacing course, aging resistant and crack resistance surface can be recommend as below:

- Stone Matrix Asphalt (SMA),
- Gap Graded mix with rubberized bitumen (GGRB), and
- Bituminous Concrete (BC) with modified binders,

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.

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

Table 3.

Table 3: Summary of Bituminous Layer Options Recommended in these Guidelines [1]

S/N	Traffic Level	Surface course		Base/Binder Course	
		Mistype	Bitumen type	Mix type	Bitumen type
1	>50 msa	SMA	Modified bitumen orVG40	DBM	VG40
		GGRB	Crumb rubber modified bitumen		
		BC	With modified bitumen		
2	20-50 msa	SMA	Modified bitumen orVG40	DBM	VG40
		GGRB	Crumb rubber modified bitumen		
		BC	With modified bitumen orVG40		
3	<20 msa	BC/DBC/PMC/MSS/Surface Dressing	VG40 orVG30	DBM/ BM	VG40orVG 30

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.

6.4.2 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 4.

Table 4: Indicative Values of Resilient Modulus (MPa) of Bituminous Mixes [1]

Mix type	AverageAnnualPavement Temperature °C				
	20	25	30	35	40
BC and DBM for VG10bitumen	2300	2000	1450	1000	800
BC and DBM for VG30bitumen	3500	3000	2500	2000	1250
BC and DBM for VG40bitumen	6000	5000	4000	3000	2000
BCwithModified Bitumen (IRC: SP:53)	5700	3800	2400	1600	1300
BM with VG10bitumen	500 MPa at35°C				
BM with VG30bitumen	700 MPa at35°C				

The design shall be carried out in considerations of the factors below:

- 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,
- The same indicative maximum modulus values are recommended for BC (surface course) as well as DBM (binder/base course) with unmodified binders,
- 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 arerecommended for arriving at a reasonable estimation of the resilient modulus value.

- Resilient Modulus of 150 mm diameter DBM specimens at 35^0C:

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

- Resilient Modulus of 102 mm diameter specimens with elastomeric polymer modified binder mixes at 35^0C

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

7. PAVEMENT DESIGN PROCEDURE

7.1 Design Steps

7.1.1 Selection of Pavement Composition

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

7.1.2 Mix Design and Resilient Modulus

The ingredients, for the mix have to be decided and the physical requirements and properties of the sourced materials should be checked for their conformity with the provisions of applicable Specifications and these Guidelines. The right proportioning of the mix ingredients or the design mix should be arrived at 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.

7.1.3 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.

7.1.4 Structural Analysis

The structural analysis of the pavement layers could be done with the application of relevant software and other computer applications. Inputs for using analysis are layer thicknesses, the layer moduli, the layer Poisson's ratio values and the standard axle load of 80 kN distributed on four wheels (20 kN on each wheel). The tyre pressure taken as 0.56 MPa for the analysis of bituminous layers and 0.8 MPa is taken for cement treated bases. The analysis gives the 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 5 gives the details of different inputs to be considered for the analysis.

Table 5: Recommended Material Properties for Structural Layers

Material Type	Elastic/Resilientmodulus(MPa)	Poisson’s
Bituminous layerwith VG40orModifiedBitumen	3000ortestedvalue (whichever isless)	0.35
Bituminouslayerwith VG30	2000ortestedvalue (whichever	0.35
Cement treatedbase	5000	0.25
Cold recycledbase	800	0.35
Granularinterlayer	450	0.35
Cement treatedsub-base	600	0.25
Unbound granularlayers	Use**Equation 16**	0.35
Unboundgranularbaseover CTSBsub-base	300 for naturalgravel 350 for crushedaggregates	0.35 0.35
Sub-grade	Use **Equation 13** and **Equation 14**	0.35

7.1.5 Calculation of 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 performancemodels 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.

7.1.6 Doing the Iterations

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

7.1.7 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.

7.1.8 Minimum Thickness

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

8. PAVEMENT DESIGN CATALOGUES

Two alternatives have been considered for the determination of minimum thickness of pavement layers. The thickness corresponding to the sub-grade effective CBR and design traffic (msa) have been recommended in the tables below.

8.1 Alternative I

This alternative consists of granular sub-base, granular base and bituminous layer (consisting of binder and surface course) as shown in Figure 7. Design table for this alternative is given in the tables below for the effective CBR from 5 to 15% and design traffic from 5 msa to 150 msa.

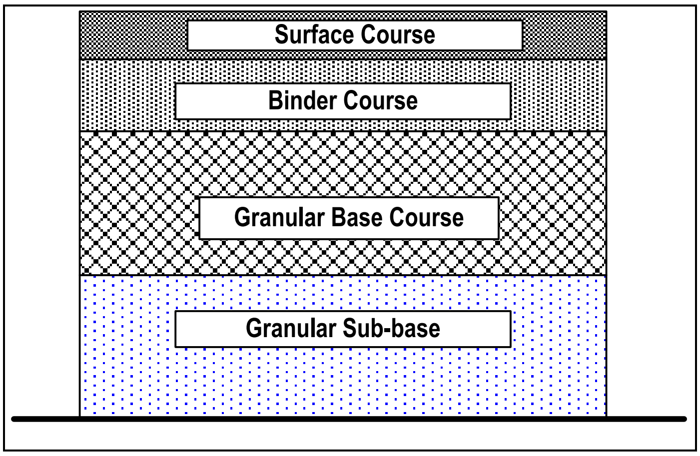


Figure 7: Bituminous Surface and Binder Courses with Granular Base and Sub-base

Table 6: Pavement Thickness for Effective CBR 5%

Design Traffic, msa	GSB,mm	Granular Base, 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

Table 7: Pavement Thickness for Effective CBR = 6%

Design Traffic, msa	GBS,mm	Granular Base, 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

Table 8: Pavement Thickness for Effective CBR=7%

Design Traffic, msa	GBS,mm	Granular Base,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

Table 9: Pavement Thickness for Effective CBR = 8%

Design Traffic, msa	GBS,mm	Granular Base, 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

Design Traffic, msa	GBS,mm	Granular Base, mm	DBM, mm	AC, mm
120	300	300	80	50
130	300	300	80	50
140	300	300	85	50
150	300	300	85	50

Table 10: Pavement Thickness for CBR = 9%

Design Traffic, msa	GBS,mm	Granular Base, 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

Table 11: Pavement Thickness for Effective CBR = 10%

Design Traffic, msa	GBS,mm	Granular Base, 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

Table 12: Pavement Thickness for Effective CBR = 11%

Design Traffic, msa	GBS,mm	Granular Base, 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

Table 13: Pavement Thickness for Effective CBR = 12 %

Design Traffic, msa	GBS,mm	Granular Base, 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

Table 14: Pavement Thickness for Effective CBR = 13 - 15%

Design Traffic, msa	GBS,mm	Granular Base, 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

Design Traffic, msa	GBS,mm	Granular Base, mm	DBM, mm	AC, mm
120	300	250	60	40
130	300	275	60	40
140	300	275	60	40
150	300	300	65	40

8.2 Alternative II

This alternative consists of granular sub-base, cement-treated base, and granular crack relief layer (aggregate inter-layer) with the bituminous wearing course and binder course (as shown in Figure 8). The design thickness for this alternative is given in the tables below for various design traffic and subgrade effective CBR.

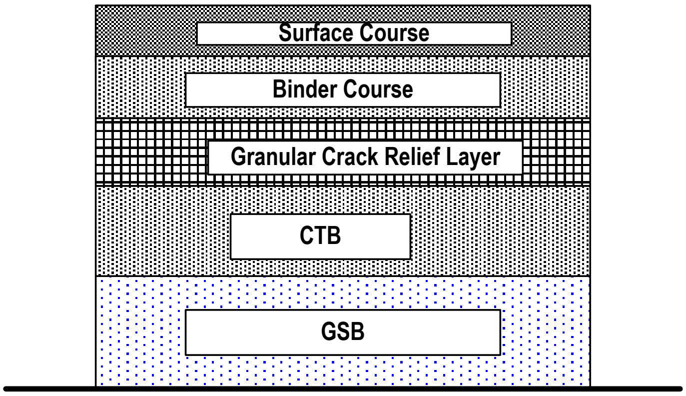


Figure 8: Pavement Alternative with Granular Sub-base, CTB with Bituminous Courses

Table 15: Pavement Thickness for Effective CBR = 5 %

Design Traffic, msa	GBS,mm	Cement-treated Base, mm	Granular crack relief layer	DBM, mm	AC, mm
5	200	160	100	50	30
10	200	170	100	50	30
20	200	190	100	50	30
30	200	175	100	60	40
40	200	180	100	60	40
50	200	185	100	60	40
100	250	200	100	60	50
150	250	210	100	65	50

Table 16: Pavement Thickness for Effective CBR = 6 %

Design Traffic, msa	GBS,mm	Cement-treated Base, mm	Granular crack relief layer	DBM, mm	AC, mm
5	200	155	100	50	30
10	200	165	100	50	30
20	200	185	100	55	30
30	200	170	100	60	40
40	200	175	100	60	40
50	200	175	100	60	40
100	250	190	100	60	50
150	250	200	100	65	50

Table 17: Pavement Thickness for Effective CBR = 7 %

Design Traffic, msa	GBS,mm	Cement-treated Base, mm	Granular crack relief layer	DBM, mm	AC, mm
5	200	155	100	50	30
10	200	165	100	50	30
20	200	185	100	55	30
30	200	165	100	60	40
40	200	170	100	60	40
50	200	175	100	60	40
100	250	185	100	60	50
150	250	190	100	65	50

Table 18: Pavement Thickness for Effective CBR = 8 - 9 %

Design Traffic, msa	GBS,mm	Cement-treated Base, mm	Granular crack relief layer	DBM, mm	AC, mm
5	200	145	100	50	30
10	200	155	100	50	30
20	200	170	100	55	30
30	200	155	100	60	40
40	200	160	100	60	40
50	200	165	100	60	40
100	250	170	100	60	50
150	250	180	100	65	50

Table 19: Pavement Thickness for Effective CBR = 10 %

Design Traffic, msa	GBS,mm	Cement-treated Base, mm	Granular crack relief layer	DBM, mm	AC, mm
5	200	135	100	50	30
10	200	145	100	50	30
20	200	155	100	50	30
30	200	150	100	60	40
40	200	155	100	60	40
50	200	160	100	60	40
100	250	180	100	60	50
150	250	190	100	65	50

Table 20: Pavement Thickness for Effective CBR = 12 %

Design Traffic, msa	GBS,mm	Cement-treated Base, mm	Granular crack relief layer	DBM, mm	AC, mm
5	200	130	100	50	30
10	200	140	100	50	30
20	200	150	100	50	30
30	200	140	100	60	40
40	200	145	100	60	40
50	200	150	100	60	40
100	250	170	100	60	50
150	250	180	100	60	50

Table 21: Pavement Thickness for Effective CBR = 15 %

Design Traffic, msa	GBS,mm	Cement-treated Base, mm	Granular crack relief layer	DBM, mm	AC, mm
5	200	120	100	50	30
10	200	130	100	50	30
20	200	140	100	50	30
30	200	130	100	60	40
40	200	135	100	60	40
50	200	140	100	60	40
100	250	160	100	60	50
150	250	170	100	60	50

9. QUALITY CONTROL TESTS DURING CONSTRUCTION

The recommendations mentioned in Clauses of Section 500 of Standard Specifications for Road and Bridge Works about different tests along with their frequencies for different types of specifications to ensure quality in the construction are to 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 ofConstruction	Test	Frequency
1	Bituminousconstruction	Resilient modulusdesired from indirecttensile strengthtestonspecimens prepared using fieldmix	Threespecimensforeach400 tonnes ofmix or minimum 2 tests perday.
2	Cementtreated/stabilized base andsub-base	Unconfinedcompressive strength	Threespecimensforeach400 tonnes ofmix or minimum 2 tests perday.
3	Cementtreated/stabilized base andsub-base	Binder/cement content	Threespecimensforeach400 tonnes ofmix or minimum 2 tests perday.
4	Cementtreated/stabilized base andsub-base	Flexuralstrength/Indirect tensile strengthtest	Threespecimensforeach400 tonnes ofmix or minimum 2 tests perday.
5	Cementtreated/stabilized base andsub-base	Soundnesstest (BIS 4332 PartIV)	Onespecimenforeachsource andwheneverthereisthe change in the quality ofaggregate
6	Cementtreated/stabilized base andsub-base	The density of compactedlayer	Onespecimenoftwo testsper 500 sqm.
7	Emulsion/ Foambitumen	Indirect tensile strengthtest	Threespecimensforeach400 tonnes ofmix or minimum 2 tests perday.
8	Emulsion/ Foam bitumen	Density of compactedlayer	One specimen per 1000 sqm.

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.

10. REFERENCES

1 IRC:37-2018, 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 Rubberized 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 Road Note 3 A Guide to Surface Dressing in Tropical and Subtropical countries

ANNEX A: Worked out Examples for Pavement Design

1. Design of bituminous pavement with granular base and sub-base

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%

2. Solution

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

$$N = \frac{2500x365x(1+0.06)2500x365x(1+0.06)^{20}-1)}{0.06}x0.75x5.2 = 131\ msa$$

a. Effective CBR of sub-grade = 7 %

- Effective resilient modulus of Sub-grade = $17.6x(7.0)^{0.64}$ = 62 MPa (less than 100MPa, the upper limit)
- Since the design traffic is more than 50 msa, provide a SMA/GGRB or BC withmodified bitumen surface course and DBM binder/base layer with VG40 withviscosity more than 3600 Poise (at 60^{0}C)
- Select a trial section with 190 mm total bituminous layer (provide 40 mm thicksurface layer, 70 mm thick DBM-II, 80 mm thick bottom rich DBM-I); 250 mmthick granular base (WMM) and 230 mm thick granular sub-base (GSB). Totalthickness of granular layer = 480 mm
- Resilient modulus of the granular layer = 0.2 x (480)0.45x 62 = 200 MPa
- Adopting 90 % reliability performance models for sub-grade rutting and bituminous layercracking (design traffic > 20 msa)
- 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 X 10^{-03})

- Allowable horizontal tensile strain at the bottom of bituminous layer for 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 (0.150×10^{-03})
- Analyzing the pavement usingIITPAVE 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
- Computed vertical compressive strain = 0.000243 < allowable strain of 0.000301. Hence OK

ANNEX B: Design of Flexible Pavement for Low Volume Roads

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 this annex.

2. Design considerations

- 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 as mentioned in the previous chapters of these guidelines.
- 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 axle load survey is not available then VDF are used as per the previously mentioned factors in these guidelines
- Lane Distribution Factor (D) is taken as following:
  - D = 1 for Single and Intermediate Lane roads, traffic is total traffic per day in both direction
  - D = 0.75 for Double Lane roads, traffic is total traffic per day in both direction
- Cumulative number of standard axles (ESAL) is calculated using the**Equation 12**.
- Design Life is taken as 10 years for low volume roads.
- Traffic growth is taken as 6% for low volume roads.

3. Traffic Categorization

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

Table 1 : Traffic category

Traffic Code	Cumulative ESAL (For 10yr Design Life)
T1	10,000-30,000
T2	>30,000-60,000
T3	>60,000-1,00,000
T4	>1,00,000-2,00,000
T5	>2,00,000-3,00,000
T6	>3,00,000-6,00,000
T7	>6,00,000-10,00,000
T8	>10,00,000-15,00,000
T9	>15,00,000-20,00,000 (2 msa)

4. Sub-Grade

Sub-grade can be defined as a compacted layer, generally of naturally 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 the embankment. It should be well compacted to limit the scope of rutting in the pavement due to additional densification during the service life of the pavement. For poor sub-grade, a sub-grade improvement technique should be adopted.

Sub-grade shall comply with the specifications mentioned in the 'SSRBW' the publication of Department of Roads (always refer the latest publication).

5. Sub-Grade strength

Sub-grade strength is measured in terms of CBR. CBR test in Laboratory is desirable. However, Dynamic penetration Cone method can also be useful for the estimation of sub-grade strength.

- 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
- CBR can be determined by using the following chart.

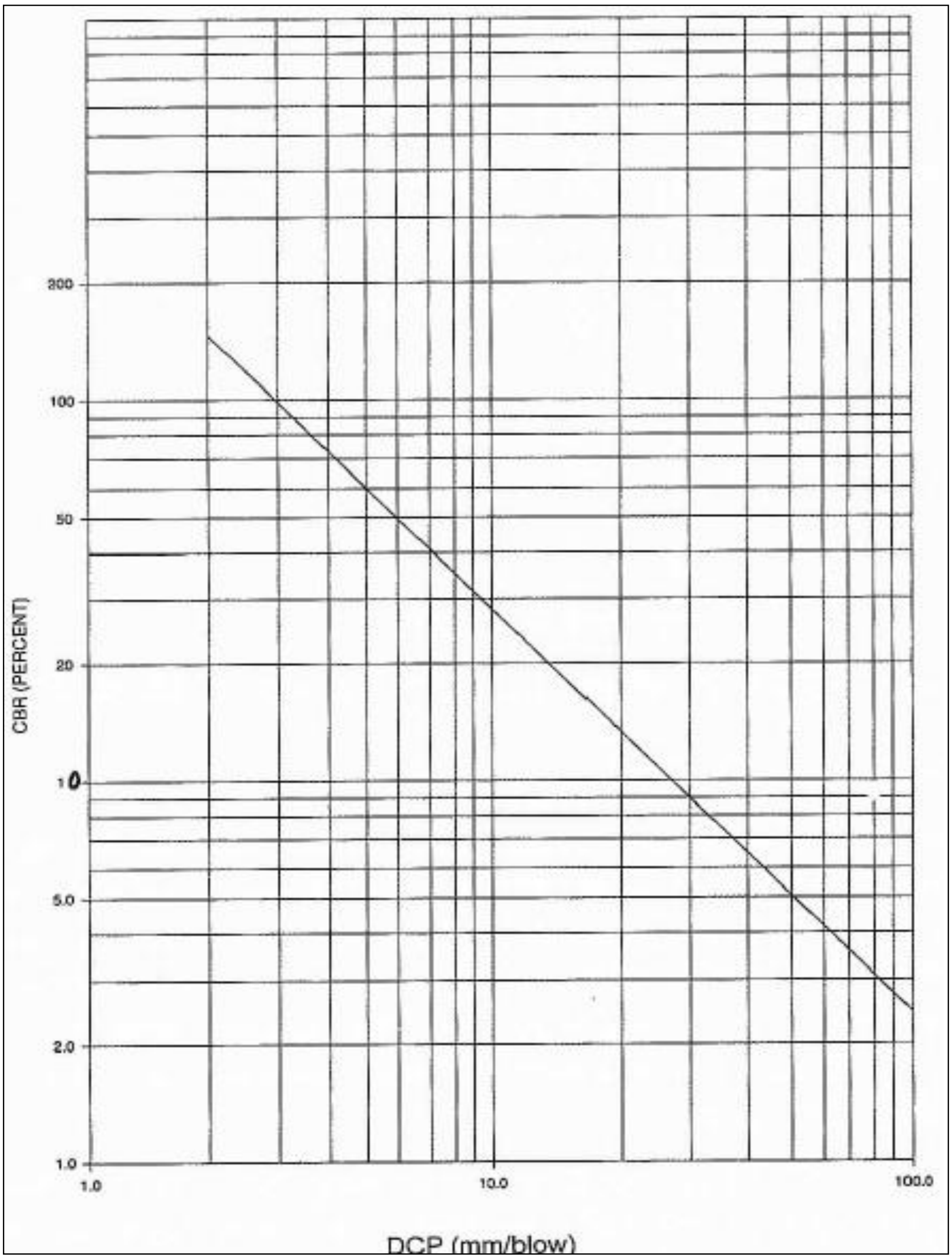


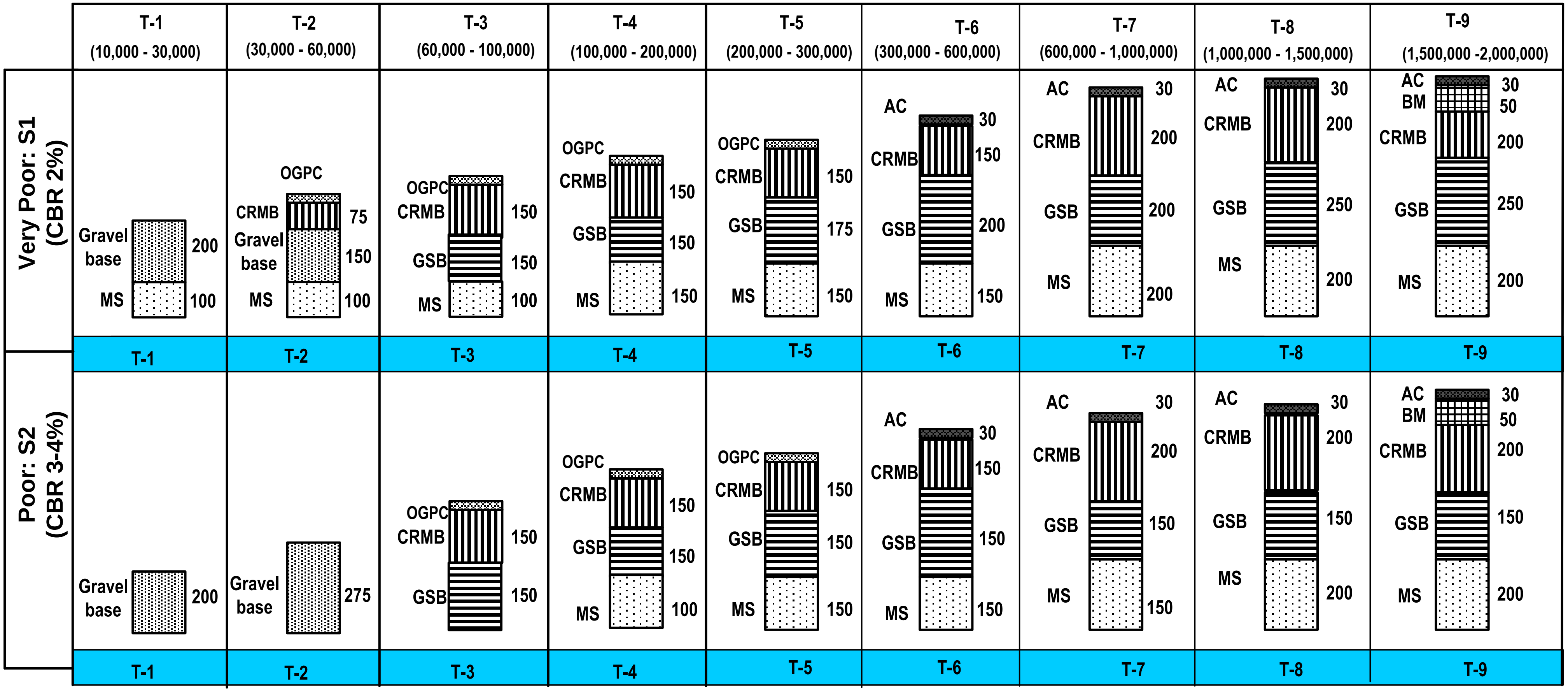
Figure 1 : CBR estimation from DCP result

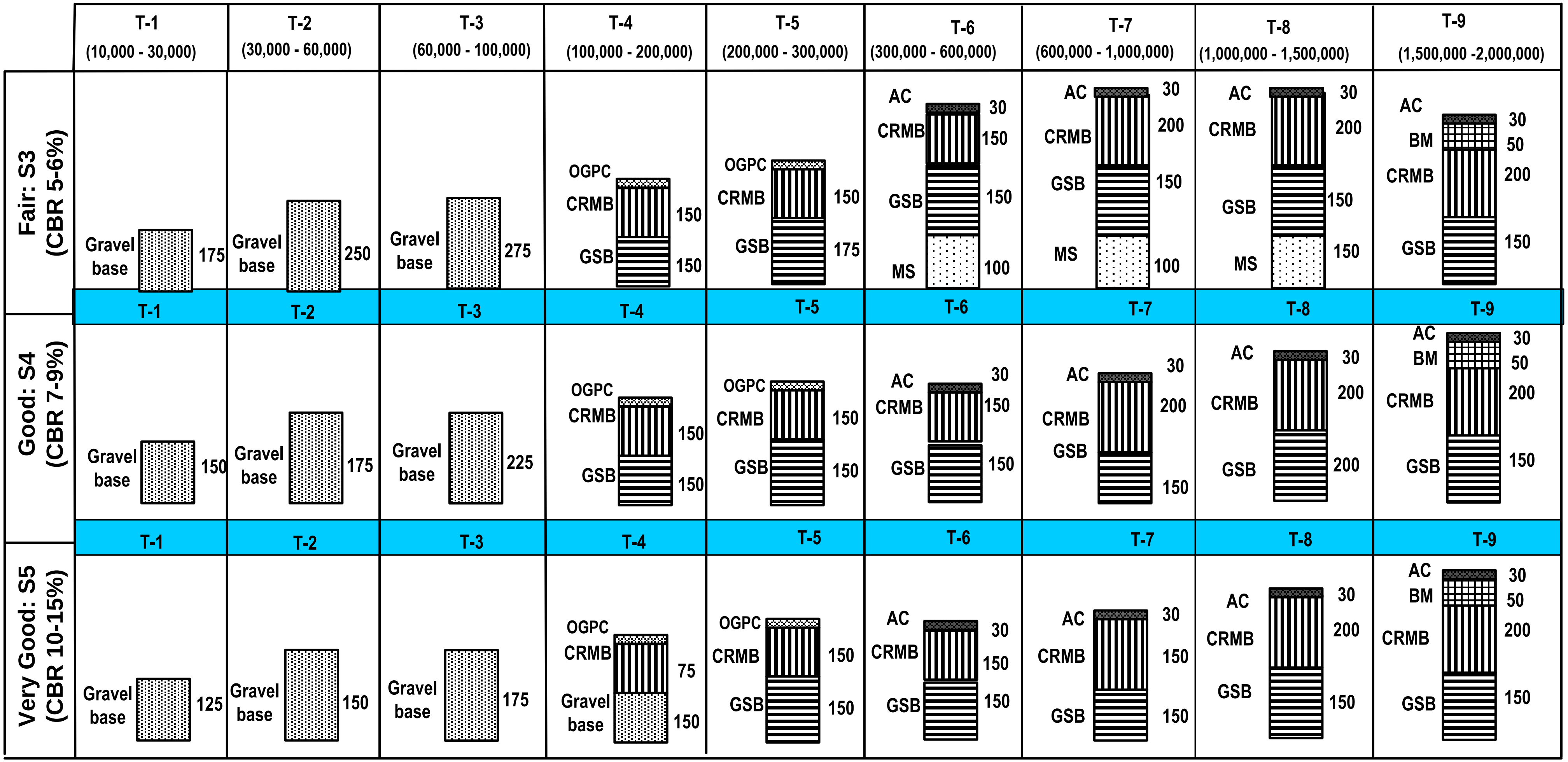
6. Sub-Grade Strength Classes

Table 2 : 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

7. Design Chart




T-1 (10,000 - 30,000)
T-2 (30,000 - 60,000)
T-3 (60,000 - 100,000)
T-4 (100,000 - 200,000)
T-5 (200,000 - 300,000)
T-6 (300,000 - 600,000)
T-7 (600,000 - 1,000,000)
T-8 (1,000,000 - 1,500,000)
T-9 (1,500,000 -2,000,000)
Fair: S3 (CBR 5-6%)
Gravel base 175
Gravel base 250
Gravel base 275
OGPC CRMB 150 GSB 150
OGPC CRMB 150 GSB 175
AC 30 CRMB 150 GSB 150 MS 100
AC 30 CRMB 200 GSB 150 MS 100
AC 30 CRMB 200 GSB 150 MS 150
AC 30 BM 50 CRMB 200 GSB 150
T-1 T-2 T-3 T-4 T-5 T-6 T-7 T-8 T-9
Good: S4 (CBR 7-9%)
Gravel base 150
Gravel base 175
Gravel base 225
OGPC CRMB 150 GSB 150
OGPC CRMB 150 GSB 150
AC 30 CRMB 150 GSB 150
AC 30 CRMB 200 GSB 150
AC 30 CRMB 200 GSB 200
AC 30 BM 50 CRMB 200 GSB 150
T-1 T-2 T-3 T-4 T-5 T-6 T-7 T-8 T-9
Very Good: S5 (CBR 10-15%)
Gravel base 125
Gravel base 150
Gravel base 175
OGPC CRMB 75 Gravel base 150
OGPC CRMB 150 GSB 150
AC 30 CRMB 150 GSB 150
AC 30 CRMB 150 GSB 150
AC 30 CRMB 200 GSB 150
AC 30 BM 50 CRMB 200 GSB 150

8. Gravel Base

The grading requirements for the gravel base is given in the table base.

Table 3 : Gradation for Gravel Base

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

9. 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 80 kN ESAL.
- 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 re-gravelling. Re-gravelling by adding gravel, before surface starts deteriorating rapidly, using only agricultural tractors and manual labour. Re-gravelling 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 the 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.The minimum gravel base material thickness should be 100mm.

Table 4 :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

10. Surface Gravel

The gravel road shall be covered with surface gravel material conforming **Table below.** 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 5 :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	

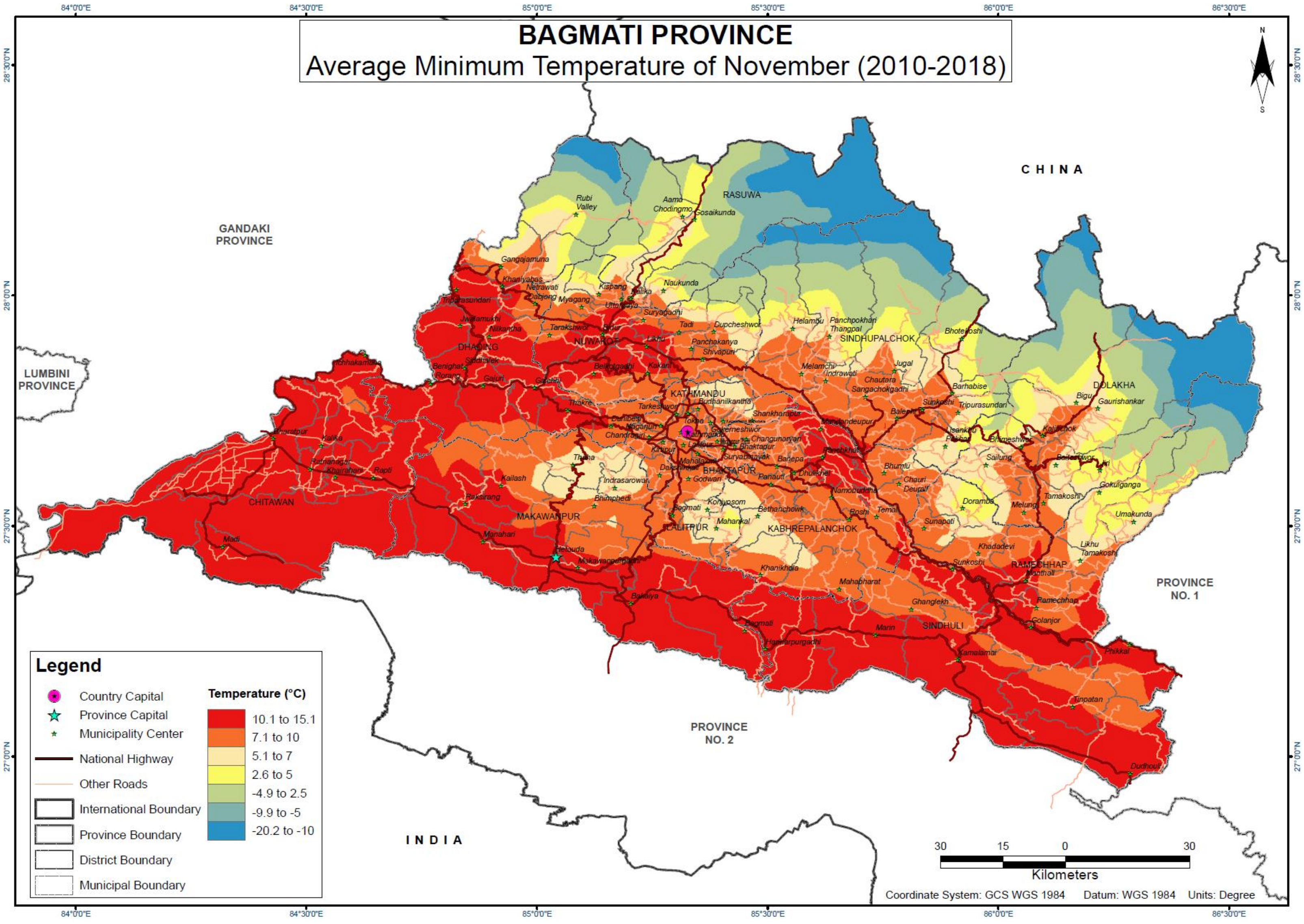
ANNEX C: Glossary of Pavement Terms

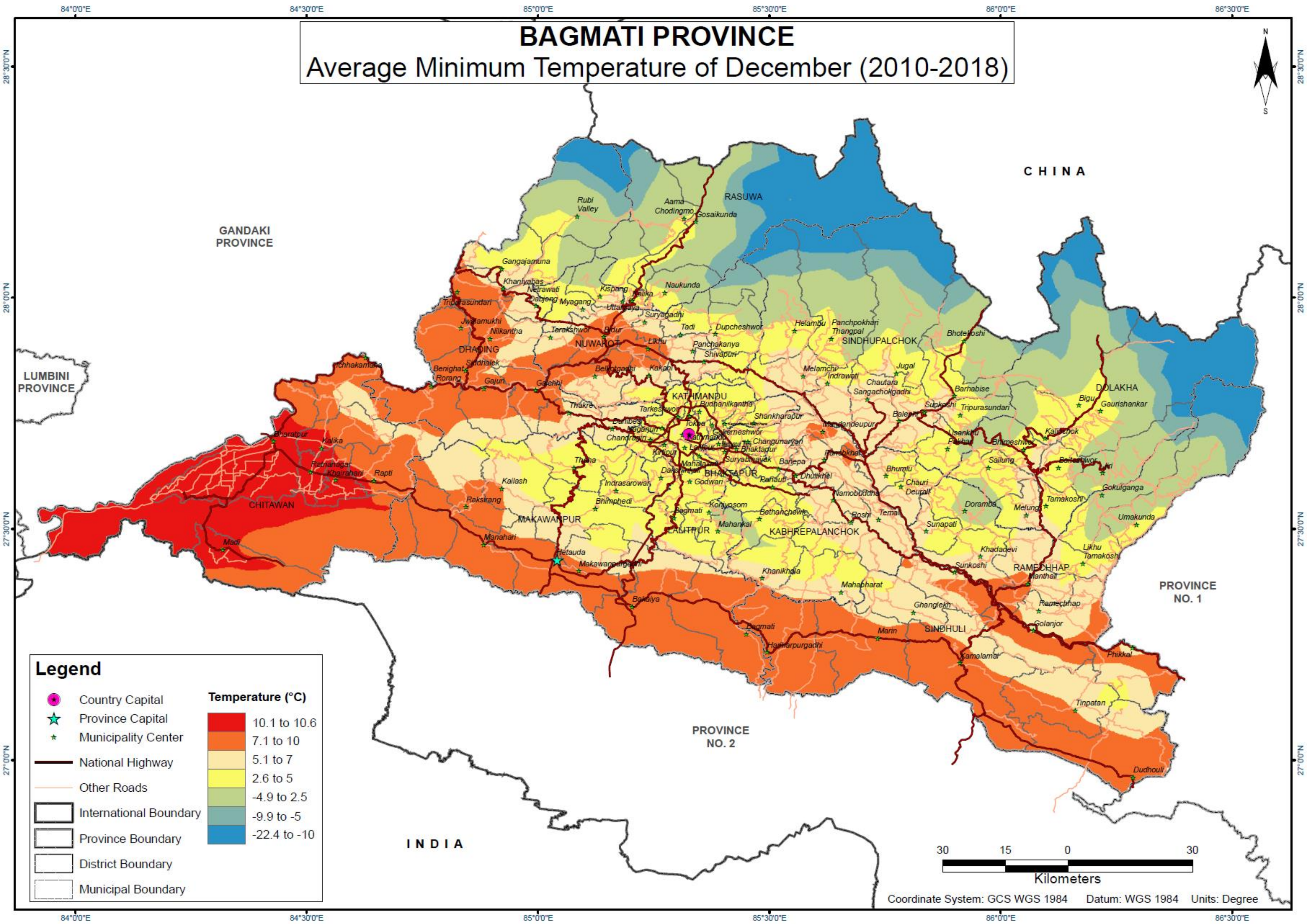
Asphalt Concrete	Bituminous concrete/ Asphalt Concrete is a dense-graded premixed bituminous mix that is well compacted to form a high quality pavement surface. The AC consists of carefully proportioned mixture of coarse aggregates, fine aggregates, mineral filler and bitumen and the mix is designed 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

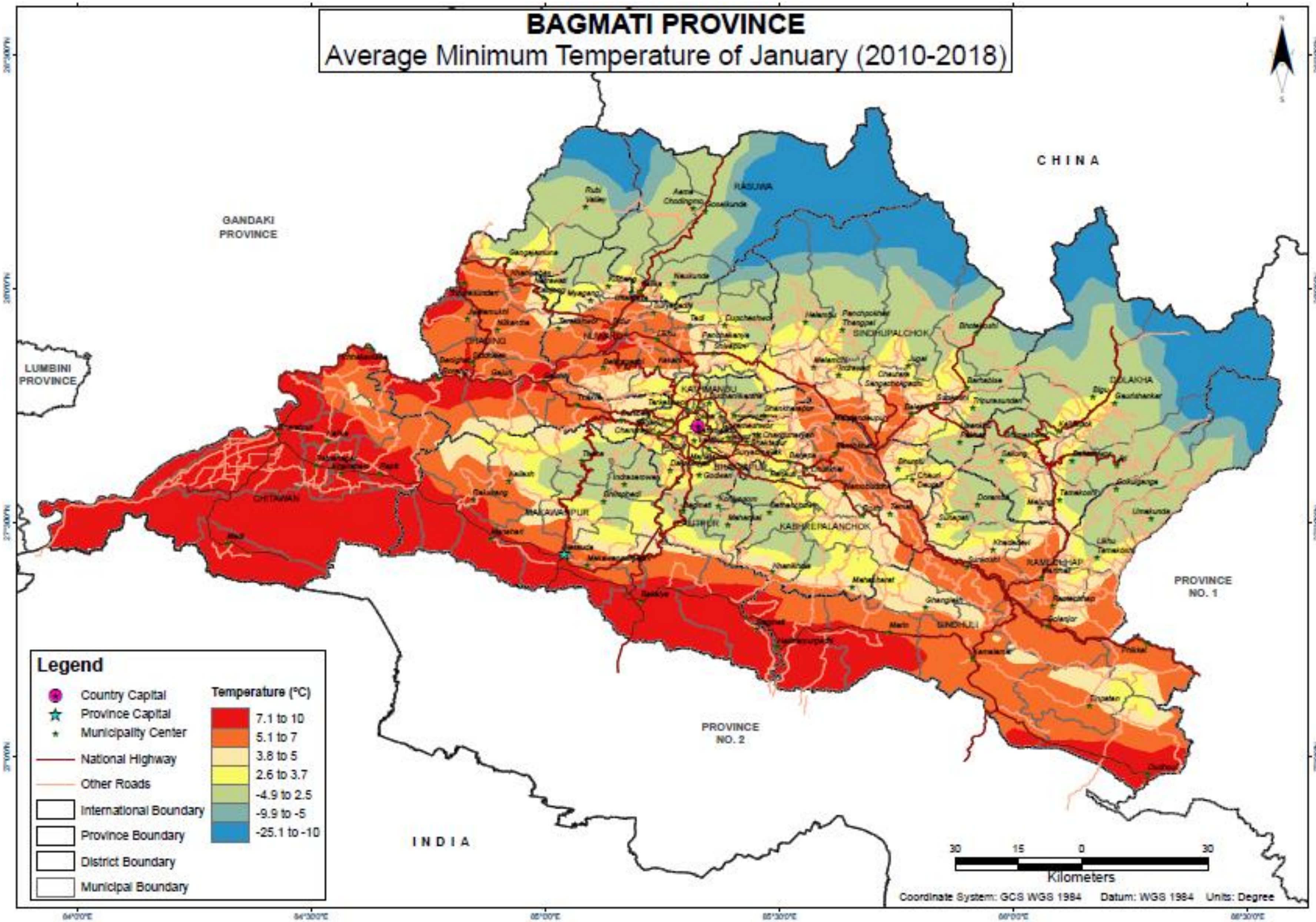
	composed of several layers of material. Each layer receives the loads from the above layer, spreads them out, and then passes on these loads to the next layer below. Thus, the further down in the pavement structure a particular layer is, the less load (in terms of force per area) it must carry.
Formation 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.

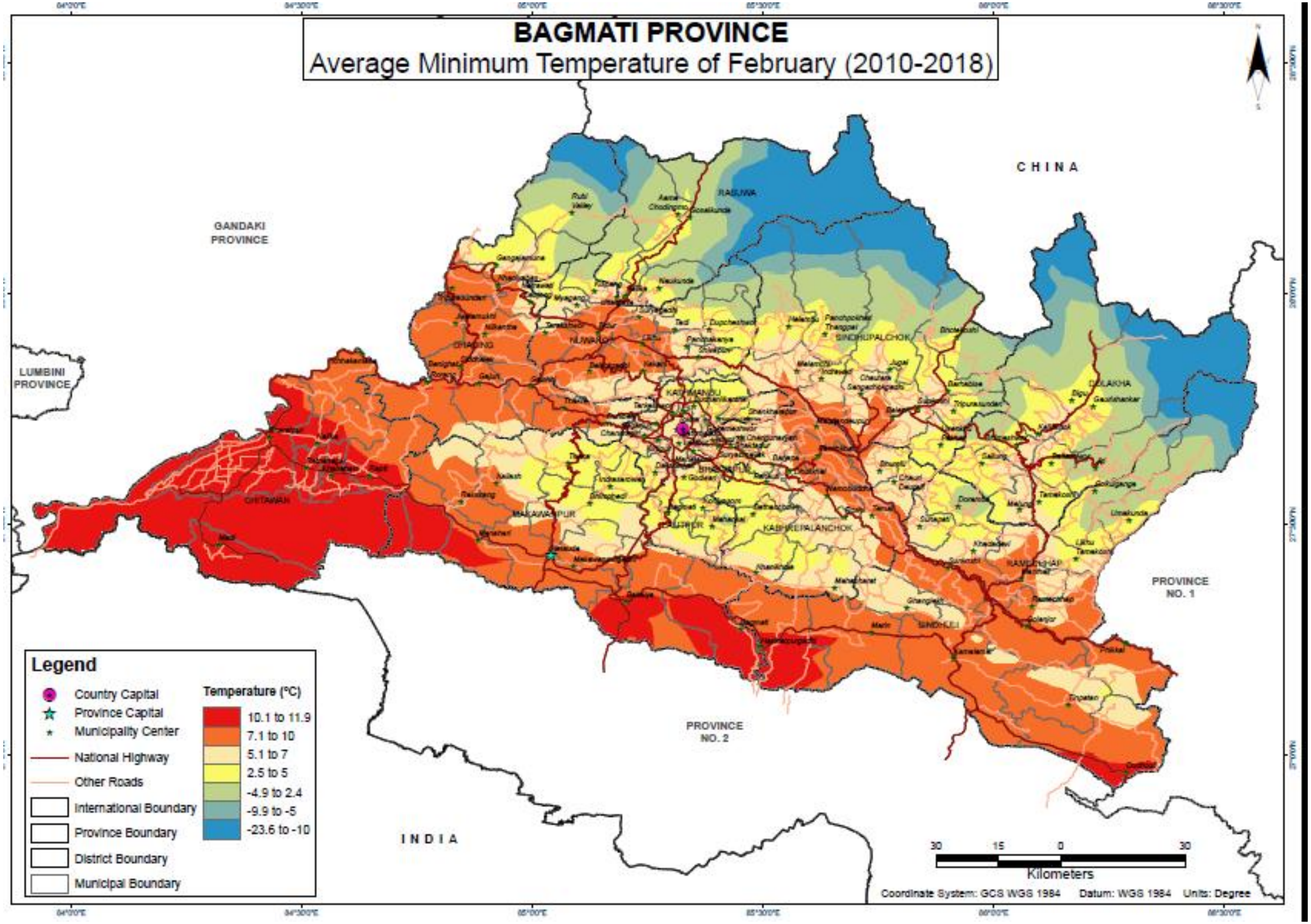
ANNEX D: Winter Seasonal Temperature Variation Maps




BAGMATI PROVINCE
Average Minimum Temperature of December (2010-2018)
CHINA
GANDAKI PROVINCE
LUMBINI PROVINCE
PROVINCE NO. 1
PROVINCE NO. 2
INDIA
RASUWA
NUWAKOT
DHADING
KATHMANDU
SINDHUPALCHOK
DOLAKHA
CHITAWAN
MAKAWANPUR
LALITPUR
BHAKTAPUR
KABHREPALANCHOK
RAMECHHAP
SINDHULI
Legend
Country Capital
Province Capital
Municipality Center
National Highway
Other Roads
International Boundary
Province Boundary
District Boundary
Municipal Boundary
Temperature (°C)
10.1 to 10.6
7.1 to 10
5.1 to 7
2.6 to 5
-4.9 to 2.5
-9.9 to -5
-22.4 to -10
30 15 0 30
Kilometers
Coordinate System: GCS WGS 1984 Datum: WGS 1984 Units: Degree



BAGMATI PROVINCE
Average Minimum Temperature of January (2010-2018)
CHINA
GANDAKI PROVINCE
LUMBINI PROVINCE
PROVINCE NO. 1
PROVINCE NO. 2
INDIA
RASUWA
NUWAKOT
DHADING
SINDHUPALCHOK
KATHMANDU
DOLAKHA
CHITAWAN
MAKAWANPUR
KABHREPALANCHOK
RAMECHHAP
SINDHULI
Legend
Country Capital
Province Capital
Municipality Center
National Highway
Other Roads
International Boundary
Province Boundary
District Boundary
Municipal Boundary
Temperature (°C)
7.1 to 10
5.1 to 7
3.8 to 5
2.6 to 3.7
-4.9 to 2.5
-9.9 to -5
-25.1 to -10
30 15 0 30
Kilometers
Coordinate System: GCS WGS 1984 Datum: WGS 1984 Units: Degree


BAGMATI PROVINCE
Average Minimum Temperature of February (2010-2018)
CHINA
GANDAKI PROVINCE
LUMBINI PROVINCE
PROVINCE NO. 1
PROVINCE NO. 2
INDIA
Legend
Country Capital
Province Capital
Municipality Center
National Highway
Other Roads
International Boundary
Province Boundary
District Boundary
Municipal Boundary
Temperature (°C)
10.1 to 11.9
7.1 to 10
5.1 to 7
2.5 to 5
-4.9 to 2.4
-9.9 to -5
-23.6 to -10
30 15 0 30
Kilometers
Coordinate System: GCS WGS 1984 Datum: WGS 1984 Units: Degree

ANNEX E: List of Participants in the Training / Interaction Program on Design of Flexible Pavement

यातायात पूर्वाधार निर्देशनालयको आयोजनामा संचालन गरिएको Design c' :ible Pavement सम्वन्धि मिति ०७८.०९.११ देखि ०७८.०९.१३ सम्म (ति ने) तालिममा सहभागीहरुको हाजिरी विवरण

सि.न	कार्यालय	सहभागीको नाम	पद	मोवाइलनं	इ मेल	०७८.०९.११	०७८.०९.१२	०७८.०९.१३
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२२	[illegible]	[illegible]	[illegible]	9855062300	sundarsbd1974@gmail.com			[illegible]