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# Guidelines on Design, Construction and Maintenance of Road Infrastructure incorporating Climate-resilient Features

(December 2019)

Department of Roads, MoWHS



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**Royal Government of Bhutan**  
**Ministry of Works & Human Settlement**  
**Department of Roads**

*"Construction Industry: Solutions through innovation & improved technology"*

## Foreword

The Department of Roads, Ministry of Works and Human Settlement is pleased to bring out the *"Guidelines on Design, Construction and Maintenance of Road Infrastructure incorporating Climate Resilient Features"* for the benefit of all the engineers.

Road is the primary means of transportation in Bhutan and plays a vital role in all its developmental activities. Due to factors such as the difficult geographical terrain, quality of construction and frequency of maintenance, Bhutan's road network remains vulnerable to failures. In addition, effects of Climate Change on roads provide new challenges and causes premature failure.

This Guidelines has been developed in line with the existing *Environmental Friendly Road Construction (EFRC)* manuals and it will serve as an enhanced version of it. The EFRC manuals took into consideration only the bio-engineering and farm road construction aspects. This document, however, focuses on design, construction and maintenance of roads taking in consideration the effects of climate change in addition to the EFRC considerations. It clearly outlines the studies and tests that are required to be carried out before construction of roads. It comprehensively covers the different stages of road design and construction and guides on the maintenance aspect of the road. It suggests measures to be adopted in order to incorporate climate change in roads during the road design and construction phases. It is also intended to guide the engineers on quality control and measures to be taken at sites. References are also made to relevant codes and standards for further information.

I am optimistic that this document prepared in-house by our own professionals will have positive impact in road sector for all times to come. I sincerely hope our engineers will read and refer this document in their daily activities.

Tashi Delek!

**Tenzin**  
**Director General**  
**Department of Roads**

## Acknowledgement

First and foremost, the Department of Roads would like to express our sincere thanks to the Global Environment Facility (GEF) and the Least Developed Countries Fund (LDCF) for funding this project. The initiative of building climate resilient roads carried out under the National Adaptation Programme of Action III (NAPA – III) project titled *Enhancing Sustainability and Climate Resilience of Forest and Agricultural Landscape and Community Livelihood in Bhutan* is the right intervention required at this hour. The developed guidelines will not only help the engineers from the department, but also the engineers from various sectors, in incorporating climate resilience in road design, construction and maintenance.

The Department would also like to thank our development partner United Nations Development Partner (UNDP) and the Project Management Unit (PMU) based with Gross National Happiness Commission (GNHC), for supporting the Department throughout the development of this guideline.

The Department would also like to acknowledge the efforts and inputs of the core group members, Mr. Lungten Jamtsho, Mr. Karma Wangdi, Mr. Karma Tenzin, Ms. Sonam Choden and Ms. Shreenita Chhetri, who dedicated their time and effort in development of this guideline.

Finally, the Department would like to thank all the stake holders for their active participation in all the stake holder meetings. The inputs from various stake holders were crucial and beneficial in development of this guideline.

## Project Background

Countries all over the world are facing challenges of climate change and Bhutan remains no exception to such effects. Sustainable Environment is accorded the highest priority by the Royal Government of Bhutan (RGoB). Like many other countries around the world, Bhutan is considered highly vulnerable to the impacts of climate change. There are several climate induced hazards which will severely impact the livelihood sources of the rural communities and disrupt key infrastructures like roads that will immensely affect the access to food and other basic necessities.

National Adaptation Programme of Action (NAPA) – III Project titled ‘**Enhancing Sustainability and Climate Resilience of Forest and Agricultural Landscape and Community Livelihoods**’ is funded by Global Environment Facility and Least Developed Countries Fund (GEF-LDCF) and supported by UNDP. The project focuses on three landscapes that cover 38 gewogs across 12 dzongkhags in the central belt of the country. The project has three components; Institutional Capacity for Integrated Landscape Management (ILM) and Climate Change Resilience, Implacment of Biological Corridor (BC) System Governance and Management System at Pilot Corridors and Climate Adaptive Communities.

The Department of roads is mandated to fulfil an output under the component, Climate Adaptive Communities, with the outcome *‘Livelihood options for communities are more climate-resilient through diversification, Sustainable Land Management (SLM) and Climate Smart Agriculture and supported by enhanced climate resilient infrastructure.’* The Department’s output under the above stated outcome is *‘Transformation of market access demonstrated for selected rural communities to enhance their climate-resilience’*. Under this outcome the Department has two broad activities and they are, Activity 3.3.1 - Develop Climate Resilience Guidelines for Road Infrastructure adapting to Existing Environmental Friendly Road Construction (EFRC) Guidelines and Standards and Activity 3.3.2 - Improve and Upgrade Prioritized Gewog Connectivity (GC) Road Stretches for Enhanced Climate Resilience. The guideline has been developed in house and is allocated with a budget of USD 94,000.00, which also included the capacity development of engineers in the Department. For improvement of GC road, among various roads proposed, Shingkar GC road was prioritized keeping the project landscapes in view. Shingkar GC road is being taken up as the pilot climate resilient road with a budget of USD 1,130,000.00.

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## Acronyms and Abbreviations

The following acronyms & abbreviations are used.

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ALD	Average Least Dimension
ASTM	American Society of Testing and Materials
BOQ	Bill of Quantities
BS	British Standards
BSR	Bhutan Schedule of Rates
CBR	California Bearing Ratio
c/c	centre to centre
Cum	Cubic metre
CR	Crushing Ratio
DCP	Dynamic Cone Penetrometer
DoFPS	Department of Forestry and Park Services
DoR	Department of Roads
DGM	Department of Geology and Mines
Dia	diameter
ECOP	Environment Code of Practice for Highways and Roads
EMP	Environmental Management Plan
FI	Flakiness Index

GCC	General Conditions of Contract
HMAC	Hot mix asphalt concrete
IRC	Indian Road Congress (i.e. Recommended Code of Practice by IRC)
IS	Indian Standards
ISO	International Organization for Standardization
LAA	Los Angeles Abrasion Value
LS	Linear Shrinkage
MC	Moisture Content
MDD	Maximum Dry Density
min	minute
NEC	National Environment Commission
No	Number (units), as in 6 no.
No	Number (order) as in No 6
OMC	Optimum Moisture Content
OPC	Ordinary Portland Cement
PCC	Particular Conditions of Contract
PI	Plasticity Index
PL	Plastic Limit
PM	Plasticity Modulus (PI x % passing 0.425 mm sieve)
QA	Quality Assurance
PS	Provisional Sum
QC	Quality Control
RGoB	Royal Government of Bhutan
RROW	Road Right of Way
SE	Sand Equivalent
sec	second
SG	Specific Gravity
SI	International Standard Units of Measurements
SSS	Sodium Sulphate Soundness test, loss on 5 cycles
STV	Standard Tar Viscosity
Sqm	Square metre
UC	Uniformity Coefficient
UCS	Unconfined Compressive Strength
VIM	Voids in Mix
w/c	Water cement ratio
Wt	Weight
%	Percent

## INTRODUCTION

Bhutan being a mountainous and a land locked country, the road network system plays an important role in all its developmental activities. It is used as primary means of transportation due to absence of rail connections and limited air connectivity. The main objective of Department of Roads (DoR) is to achieve the national goal of poverty reduction and economic growth through provision of reliable and resilient road infrastructures. It is being realized that the reliability and quality of Bhutan's road and bridge network plays an important role in poverty reduction and the subsequent boost in economic prosperity. Despite the above fact, Bhutan's road network remains vulnerable to the premature failures and susceptible to increasing threats from climate change hazards and extreme events such as flash floods, floods, rainfall, glacial lake outburst (GOLF), etc. This is being attributed by many factors: geography, initial design, quality of construction, performance of the planned preventive maintenance activities and limitations on other mode of transportation.

As per “The Road Act of Bhutan 2013” the Department of Roads is the National Road Authority responsible for planning, construction, maintenance and improvement of roads. Currently, roads and road infrastructures are designed, constructed and maintained using conventional method. Most of the existing road networks constructed in 1970-80s without proper design and construction techniques has become obsolete and outlived its design lives. The road geometrics, pavement and carriageway width are inadequate to the needs of growing traffic and the existing specifications and standards. In addition, the performance of road network is severely hampered by climate change effects. Climate change is real and its consequences observed in the form of severe weather conditions worldwide including Bhutan.

The future climate change projections for Bhutan indicate that as compared to the 1980-2009 periods the mean annual temperature is projected to increase by 0.8°C to 1.0°C by 2010-2039 and further by 2.0°C to 2.4°C for the period 2040-2069. The summer temperatures are projected to increase by 0.8°C in 2010-2039 and further increase by 2.1°C by 2040-2069. The winter temperature is projected to increase by much higher range of 1.2°C rise for 2010-2039 and by 2.8°C for the period 2040-2069. With regard to the precipitation, the mean annual precipitation is expected to increase by 10% for the period 2010-2039 and, further by 20% for the period 2040-2069.

The most prominent and increasing climate change induced hazards relevant to road and transport sector are landslides, flash floods and soil erosion. Highways and roads get damaged by excessive heat. Other impacts include temporary or permanent flooding of roads and bridges; increased maintenance costs due to damage or increased wear and tear; and service disruption. Its impacts are projected to intensify in the decades to come and as such it is timely that climate change adaptation is mainstreamed in the transport sector.

Measures to adapt to climate change in the transport sector range from making adjustments to engineering specifications (design standard) to alignment and master planning, and include environmental measures, such as bio-engineering works. This publication, *Guidelines on Design, Construction and Maintenance of Climate Resilient Road Infrastructures*, presents a

step-by-step methodology to help road engineers incorporate climate change adaptation measures starting from planning, design, and construction to maintenance of roads.

The methodology presented in this *Guidelines* is based on the existing procedures for design, construction and maintenance of roads. In addition, climate proofing measures has been incorporated based on literature review and relevant international best practices.

The first chapter is on road infrastructure planning which mainly covers surveying, geo-technical studies and other data collections. In this chapter more emphasis is on hydrological data collection and its analysis in addition to the conventional method. For the road infrastructure project, in order to account for climate change, in-depth hydrological studies, catchment analysis and presence of ground water, etc. has to be accounted for. These studies will assist in design of drainage structures particularly with regard to design discharges at various return periods and additional estimation to account for climate change induced precipitation-runoff events.

The second chapter is on design of road infrastructure. Designs are generally carried out using Indian Road Congress (IRC) standards. In addition, the design works are carried out keeping into consideration the Environmental Code of Practice (ECOP) and Environmental Friendly Road Construction (EFRC) methods. To account for climate change, geometric, pavement and drainage designs are improved. The number of cross drainages and its sizes are enhanced to account more water discharge and avoid choking with debris. The design of V-shaped drains would be avoided as much as possible and replaced with box-shaped drains. Discharge of water from the outlets of cross drainages would be managed in order to prevent scouring of existing surfaces.

The third chapter is on construction aspects of road infrastructure. The construction works are generally carried out as per ECOP and EFRC methods in Bhutan. The climate change adaption for construction of roads are provision of gentle slopes compared to conventional batter slopes, bench cutting, temporary restraining walls like log/timer barriers & boulder barriers to protect from slides, temporary earthen drains & cross drainages to protect valley slope and washing away of road formation. The retaining structures are to be constructed with rich cement mortar of not less than 1:4 in order for the structures to be stronger and durable due to severe climate actions. In addition, subsurface drains and materials like geo-cells and gabion cells are to be provided below the pavement for the purpose of better drainages.

The final chapter is on maintenance of road infrastructure. With the design and construction of road infrastructure carried out incorporating climate change adaption techniques, the performance of road infrastructures is expected to be improved. The recurrent cost would be reduced bringing in overall economy in construction and maintenance of road infrastructure, which is the ultimate aim for development of this guideline. In order to further enhance the performance and design life of pavement, the resurfacing works would be carried out using asphalt concrete of minimum 30 mm instead of premix carpet and also encourage new techniques of resurfacing. The old asphalt concrete would be removed and recycled. While

various aspects of climate change adaption measures have been incorporated and recommended in this guidelines, considering the cost factors, it may not be possible to adopt all for a particular road work. Design and construction of climate resilient road infrastructure is only to guide the road engineers and an in-depth analysis and economics has to be worked out before its adoption.

# CHAPTER 1 – SURVEY, GEOTECHNICAL STUDIES & DATA COLLECTION

## 1.1 Survey

The three major steps involved in the survey of roads are as follows:

1. Desktop Study
2. Pre-feasibility Study
3. Technical feasibility

### 1.1.1 Desktop Study

The term 'desktop study' refers to a study that is carried out purely through research, rather than physical investigations. Desk studies are an essential part of the site investigation process. These reports are invaluable in assessing the requirements of a ground investigation not only from an environmental perspective, but also for road designs and geotechnical purposes. A well-executed desk study can help to formulate investigation work, targeting specific areas of contamination or geotechnical parameters, culminating in a cost effective and targeted investigation.

The design engineers are responsible for carrying out the desk study and it is done using Google Maps and topography sheets. With the advancement in technology, it is also done using drones and survey scanning features.

### 1.1.2 Pre-feasibility Study

Pre-feasibility study is a preliminary study undertaken to determine, analyse, and select the best alignment for roads. In this study, we assume we have more than one alternative alignments, then we want to know which one is the best, both technically and financially. In pre-feasibility, the best alignment is selected among several alignments. It will be hard and takes time if we explore each scenario in depth. Therefore, shortcut method deems acceptable in this early stage.

If the selected scenario is considered feasible, it is recommended to continue the study to get deeper analysis of the selected alignment of a road. It mainly involves verification of desktop study using GPS. Strategic points like river crossings, saddles, old slide areas, marshy areas, rocky cliffs, etc. can be marked with their coordinates. A temporary batter pegging can be done to mark the coordinates.

A team comprising the following should take up the task:

- Design Engineer (Road and Bridge)
- Surveyor
- Geotechnical Engineer

As a part of the pre-feasibility study, Environmental and Social Clearances must be processed. For roads likely to pass through important parks and preserved areas, EIA report (Environmental Impact Assessment) should be prepared. For details, Environmental Clearance Guideline from NEC shall be referred.

### 1.1.3 Technical Feasibility

After the pre-feasibility study is done, a suitable alignment is selected and detailed survey and geotechnical studies are carried out for the selected alignment.

#### 1.1.3.1 Detailed Topographic Surveying

A Topographic Survey is a survey that gathers data about the elevation of points on a piece of land and presents them as contour lines on a plot. The purpose of a topographic survey is to collect survey data about the natural and man-made features of the land, as well as its elevations.

Topographic survey is used for determining the relative locations of points on the earth's surface by measuring horizontal distances, differences in elevation and directions. A Topographical Survey is a 2-D representation of the features present in the real world (3-D). The characteristics of a topographical survey can vary, but some of the most common elements include:

- *Contours* - A contour line shows the peaks and the valleys of the land. For example, if there is a significant slope on a property, contour lines can be shown on the drawing to represent every time there is a drop of 5 vertical feet. A drop of 3 feet, 2 feet or even 1 foot can be shown as well; it is all based on the data that the surveyor obtains while at the project. The smaller the cumulative drop, more detailed the survey becomes.
- *Vegetation and physical attributes* - If there is a stream or creek, or an easily identified wooded area, those attributes are identified by the surveyor and data regarding the location of those attributes is obtained. The surveyor can locate individual trees and bushes, the outer perimeter of a “brushy” area, and more information at the request of the client.
- *Utilities* - Any visible improvement on the lot can be identified and shown on the topographical survey. Overhead utility lines, street lights, electric boxes, pipeline markers and any visible evidence can be shown on the drawing. The surveyor can then show those markings on the drawing.

#### 1.1.3.2 General principles of Surveying

*Boundaries* - It is important in topographic surveys to record the boundaries of survey, both so that the data can be spatially located, but also, for the management of point collection.

More often than not, survey boundaries are defined by field boundaries, and it is a good practice to record these immediately after instrument setup and orientation. 15 m on either sides of the proposed road centreline is marked except for cliffs and rocky areas. It is proposed to go for tunnelling (half or full) in case of negative slope areas.

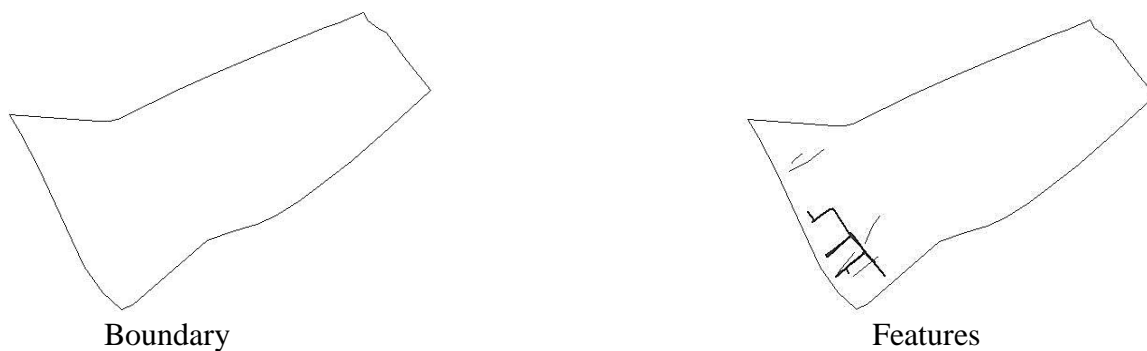


Figure 1: Boundary and Features of Surveying

*Features* - Often the survey area comprises certain features which you do not want to include with the topographic data. Points associated with these features should be recorded separately and assigned point IDs which are different from the ID of Topographic points.

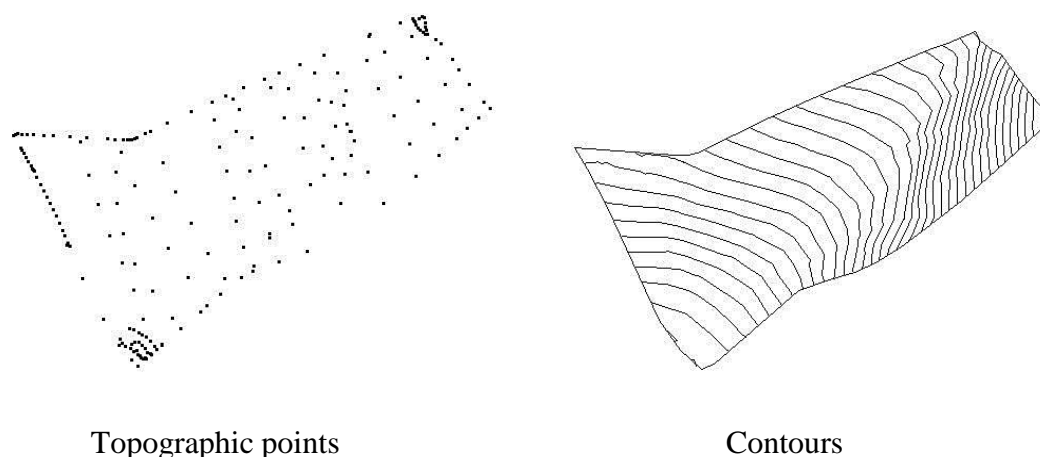


Figure 2: Topographic points and Contours

*Topographic points* - The idea behind collecting topographical points is simply to record elevation data for the entire area of survey. Important points to keep in mind:

- Ideally points will be recorded at a high density (close together) over the entire area of the survey.
- In practice this is not often possible and different strategies have to be chosen. Two possibilities are as follows:
  - i. Even coverage over survey area - In this option, point spacing should be approximately equal over the entire area of the survey.

*Pros:* The theory behind this method is that with a full and even coverage, a true representation of the topography of the survey area will be generated.

*Cons:* The drawback is that in practice, it is often hard to record a density of points over the entire area that will accurately reflect the detailed surface of the ground. Rather, this method often gives a general idea of the surface of the ground.

- ii. Feature oriented Topographic survey - If the survey area covers a number of areas of significance, a strategy which concentrates on these areas may be chosen. In this type of survey, points are collected at a high density in the area of the particular feature, while the surrounding area is surveyed at a lower density.

*Pros:* This strategy relies on the judgment of the surveyor and has the potential to be very accurate (the human eye is left to judge where more points are needed based on the complexity of the ground surface).

*Cons:* Features which escaped initial observation by the surveyor may be missed. Areas with very few points can be misinterpreted. Areas which are left out of the survey for whatever reason must be marked by survey boundaries.

*Break lines* - Features which have clear boundaries or edges are often surveyed with a specific point sequence called a Break line. This allows us to accurately reconstruct the surface of the feature in the office. Surfaces created with topographical points only can sometimes dull the effects of boundaries or edges. Break lines define edges, boundaries, and sharp changes of terrain.

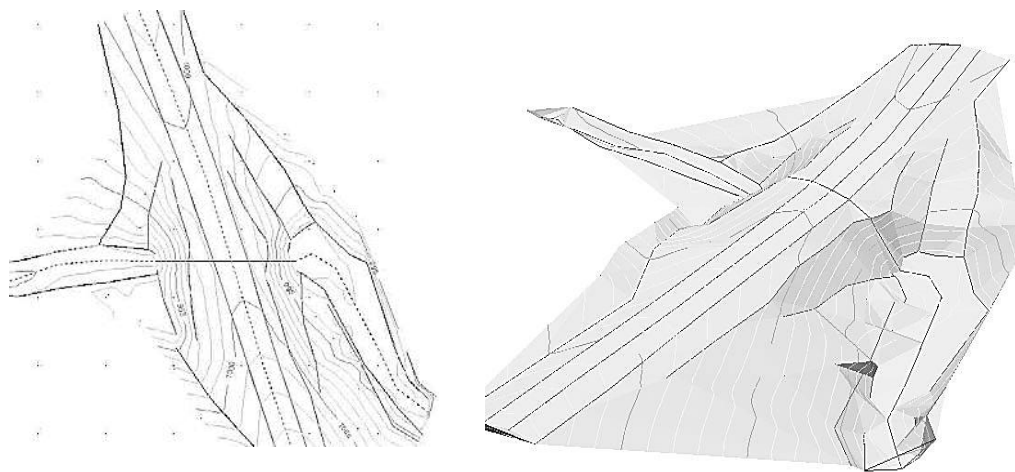


Figure 3: Break-lines

## 1.2 Geo-technical studies

The purposes of a geotechnical investigation are to investigate the soil and geologic conditions of a property and to provide recommendations and design criteria for construction. The scope of a geotechnical investigation includes review of available literature; conducting on-site exploration, mapping/logging and sampling; and laboratory testing of samples obtained in the field. The collected data is analysed. The criterion chiefly consists of the load bearing capacities and anticipated lateral forces from the onsite soil and rock. The culmination of the investigation is a report summarizing the field and laboratory findings; conclusions regarding the geotechnical impacts of the site; and recommendations for the most geo-technically suitable road construction.

The depth and seasonal fluctuations of water table also form an important component of data required for landslide investigations. This information may be obtained from local enquiries, or by noting the presence of springs, etc. Sometimes, it may be desirable to make borehole and install a piezometer, to observe the water level over a cycle of seasons.

The causes of slope movements could be geological factors, change in the slope gradient, surcharge, shocks and vibrations, changes in the water content, changes due to weathering, influence of developmental activities, etc.

**Landslide investigations** – Investigation and study of landslide broadly comprises field and laboratory investigations. Both geological and geotechnical aspects, in the broad sense of terms, need to be studied. The objective of these studies is to collect data for the evaluation of the stability of the slope, determine the conditions under which failure may occur and base the remedial measures on a rational footing. Pro-forma for keeping record of landslides is given in **Annexure I**.

### **1.2.1 Field Investigations**

Field investigations may be divided into three stages:

- i) Mapping of the area
- ii) Geological investigations
- iii) Geotechnical investigation

#### ***1.2.1.1 Topographical mapping of the area***

The slide area should be mapped in detail. Field maps should be prepared giving the plan of the affected area and typical cross-sections, which can be used for ability analysis. If possible, the topography may be determined by aerial surveys (photogrammetry) which provides an overall view of the site features. General observations should be made concerning the condition of the slope, covering such aspects as the extent and nature of vegetation cover, surface runoff characteristics, presence of springs, etc. Erosion of the toe and tension cracks in the crown area may be observed in detail. Topography sheets of the area should be studied as a part of the field investigation. Any signs or evidences for locating surfaces of failure should be carefully noted. Data concerning rainfall and intensity should be obtained as a part of field investigation.

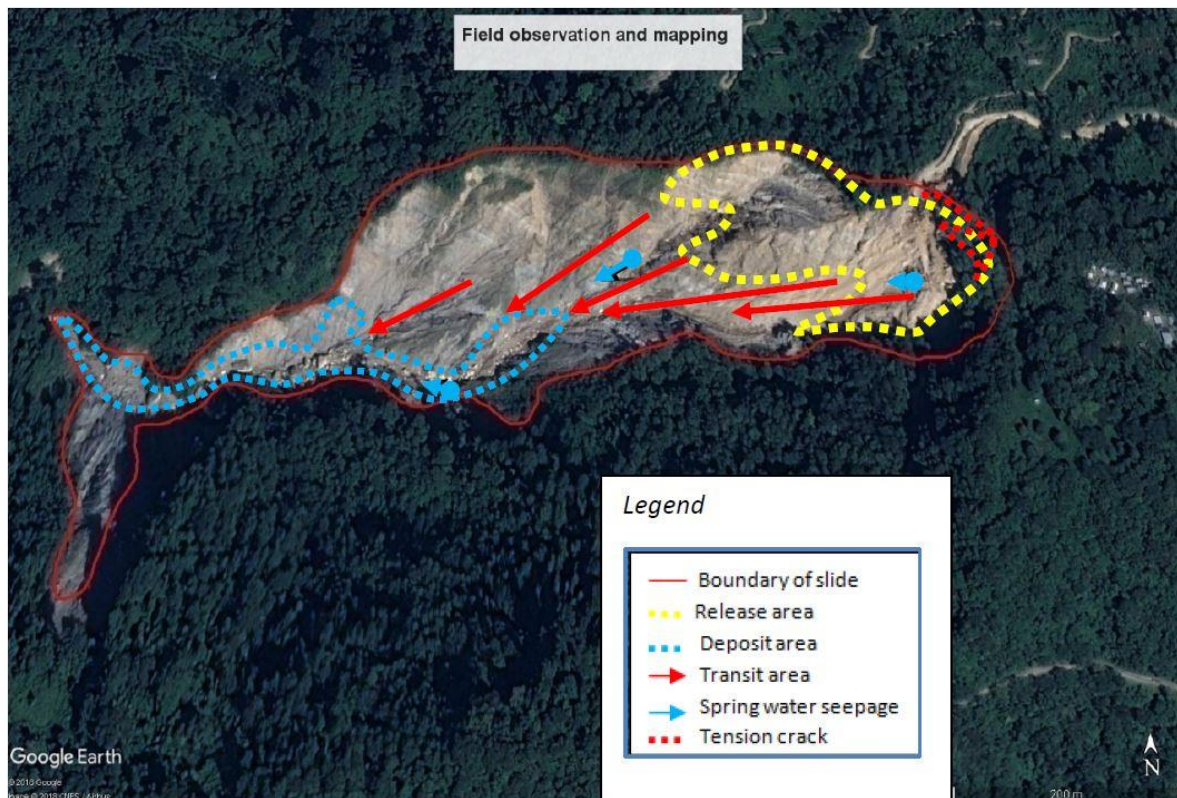
#### ***1.2.1.2 Geological investigations including geological & geomorphological mapping***

Geological map of the area, if available should be studied carefully. Plan of the landslide area must be prepared incorporating geological data. Structural geological features such as bedding planes, joint planes, faults, folds, shear zones, unconformity, etc. should be studied in the field in detail and plotted on the geological map. The influence of these structural geological features on the stability of the affected slope can be evaluated with the help of stereo nets, etc. The rock types in the slide area should be identified and their qualities assessed wherever possible. The minerals in the rocks and their alteration products should be taken into consideration. The investigation must carefully observe for the presence of any soft pockets or beds or interlayers. In some instances, geophysical studies may help in detecting such layers or pockets. On the plan of the area already prepared or on a separate map, the geomorphological features should

be marked. These include such features as elevated and depressed zones, break in slope, erosional and depositional zones, mass movement vectors, etc.

### 1.2.1.3 Geotechnical investigation

Geotechnical investigations shall be carried out with the objective of determining the nature and strength characteristics of the material comprising the slope. If the slope is predominantly made up of soil or a mixture of soil and rock, disturbed and undisturbed samples should be collected at a few locations covering the affected area. Soil samples are often categorized as being either disturbed or undisturbed; however, undisturbed samples are not truly undisturbed. A disturbed sample is the one in which the structure of the soil has been changed sufficiently and the tests of structural properties of the soil will not be representative of in-situ conditions. The only properties of the soil grains (e.g., grain size distribution, Atterberg limits, and possibly the water content) can be accurately determined. An undisturbed sample is the one where the condition of the soil in the sample is close enough to the conditions of the soil in-situ. Therefore, the tests of structural properties of the undisturbed soil can be used to approximate the properties of the soil in-situ. Undisturbed samples may be collected from open pits or from boreholes, using appropriate type of sampling tubes. In debris covered slopes, as is very often the case in landslides affected areas of Himalayas, undisturbed samples of good quality can be collected only from open pits. Good quality undisturbed samples are a basic requirement for reliable evaluation of shear strength parameters.



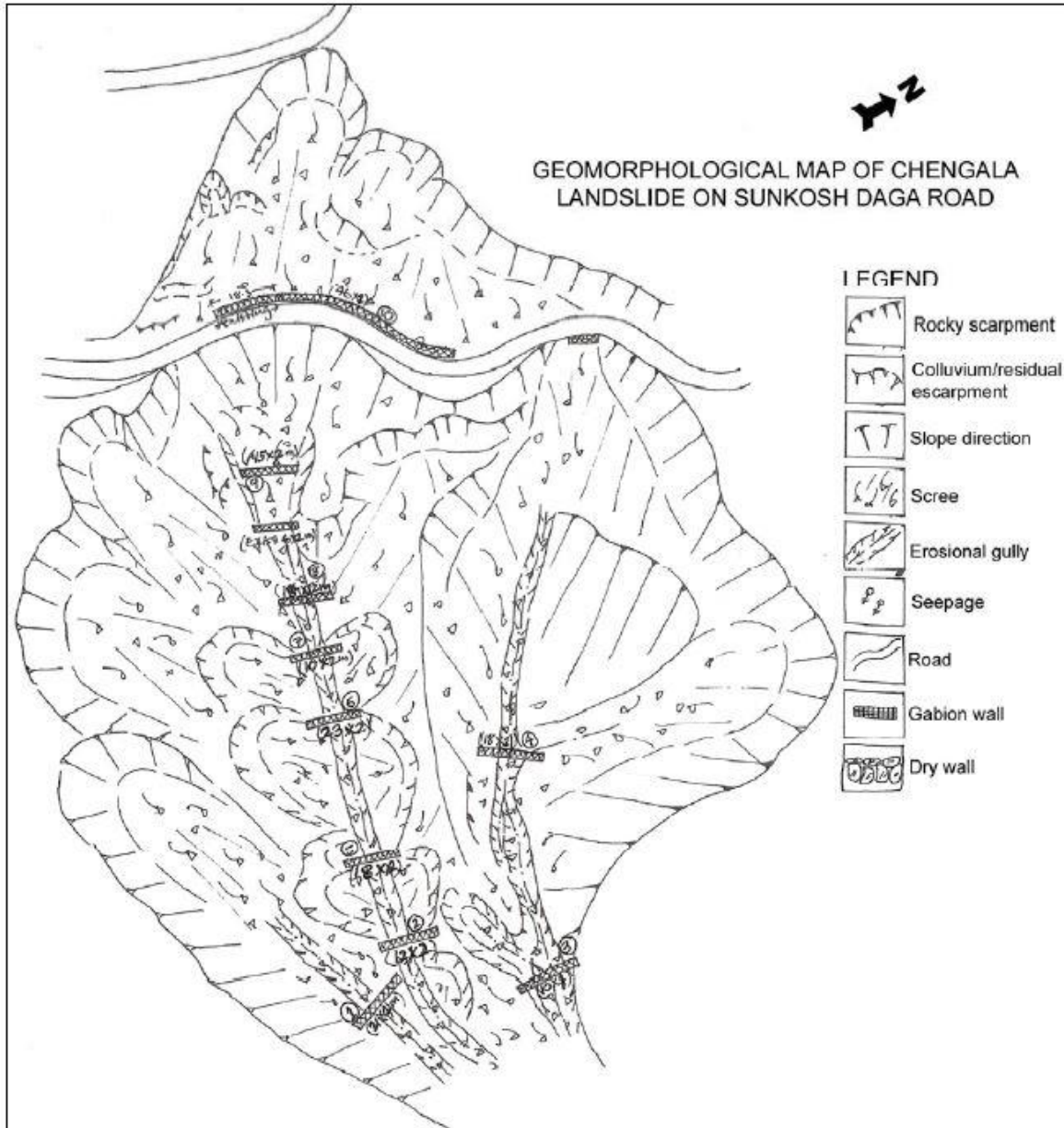


Figure 4: Examples of a Geological Map

## 1.2.2 Laboratory Investigations

The following represents some of the basic tests that need to be carried out on the soil and rock samples collected from the slide area.

- i) Determination of index properties in case of soil samples.
- ii) Determination of shear characteristics of slope material by appropriate type of shear tests. If the material is by and large, fine-grained, tri-axial shear test may be suitable. If sample contains relatively high content of gravel or rock fragments, direct shear test could be conducted more easily on such samples.
- iii) Rock sample should be examined to find out the nature of rock, extent of weathering, presence of any weak inter layer etc. If suitable samples are obtained, strength of rock samples may also be determined.

The above data are used for stability analysis and formulation of corrective measures.

To obtain information about the soil conditions below the surface, some form of subsurface exploration is required. Methods of observing the soils below the surface, obtaining samples, and determining physical properties of the soils and rocks include test pits, trenching (particularly for locating faults and slide planes), boring, and in situ tests.

### *1.2.2.1 In-situ Tests*

Among the many types of in-situ tests, following are the most commonly used:

- A standard penetration test is an in-situ dynamic penetration test designed to provide information on the properties of soil, while also collecting a disturbed soil sample for grain-size analysis and soil classification.
- A dynamic cone penetrometer test is an in-situ test in which a weight is manually lifted and dropped on a cone which penetrates the ground. The number of millimetre per hit are recorded and this is used to estimate certain soil properties. This is a simple test method and usually needs backing up with laboratory data to get a good correlation.
- A Cone Penetration Test (CPT) is performed using an instrumented probe with a conical tip, pushed into the soil hydraulically at a constant rate. A basic CPT instrument reports tip resistance and shear resistance along the cylindrical barrel.

A wide variety of laboratory tests can be performed on soils to measure a wide variety of soil properties. Following are the important tests to be performed to analyse the soil properties:

- 1.2.2.1.1 **Atterberg Limit** - The Atterberg limits define the boundaries of several states of consistency for plastic soils. The boundaries are defined by the amount of water a soil needs to be at one of those boundaries. The boundaries are called the plastic limit and the liquid limit, and the difference between them is called the plasticity index. The shrinkage limit is also a part of the Atterberg limits. The results of this test can be used to help predict other engineering properties. Atterberg limits must be obtained using **IS: 2720 (Part 5)**
  - 1.2.2.1.2 **California Bearing Ratio**- A test to determine the aptitude of a soil or aggregate sample as a road subgrade. A plunger is pushed into a compacted sample, and its resistance is measured. CBR values must be obtained using **IS: 2720 (Part 16)**
  - 1.2.2.1.3 **Direct Shear Test** - The direct shear test determines the consolidated, drained strength properties of a sample. A constant strain rate is applied to a single shear plane under a normal load, and the load response is measured. If this test is performed with different normal loads, the common shear strength parameters can be determined. This test is carried out using **IS: 2720 (Part 13)**.
  - 1.2.2.1.4 **Hydraulic Conductivity Tests** - There are several tests available to determine a soil's hydraulic conductivity. They include the constant head, falling head, and constant flow methods. The soil samples tested can be any type including remoulded, undisturbed, and compacted samples. This test is carried out as per **IS: 2720 (Part 17)**.

- 1.2.2.1.5 **Oedometer Test** - This can be used to determine consolidation and swelling parameters. This test is carried out as per **IS: 2720 (Part 15)**.
- 1.2.2.1.6 **Particle-size Analysis** - This is done to determine the soil gradation. Coarser particles are separated in the sieve analysis portion, and the finer particles are analysed with a hydrometer. The distinction between coarse and fine particles is usually made at 75 µm. The sieve analysis shakes the sample through progressively smaller meshes to determine its gradation. The hydrometer analysis uses the rate of sedimentation to determine particle gradation. This test is carried out as per **IS: 2720 (Part 4)**.
- 1.2.2.1.7 **Soil-compaction Tests** - Standard Proctor, Modified Proctor, and CBR tests. These tests are used to determine the maximum unit weight and optimal water content a soil can achieve for a given compaction effort. This test is carried out as per **IS: 2720 (Part 8)**.
- 1.2.2.1.8 **Tri-axial Shear Test** - This is a type of test that is used to determine the shear strength properties of a soil. It can simulate the confining pressure a soil would see deep into the ground. It can also simulate drained and un-drained conditions. This test is carried out as per **IS: 2720 (Part 11)**.
- 1.2.2.1.9 **Unconfined compression test** - This test compresses a soil sample to measure its strength. The modifier "unconfined" contrasts this test to the tri-axial shear test. This is to be carried out using **IS: 2720 (Part 10)**.
- 1.2.2.1.10 **Water Content** - This test provides the water content of the soil, normally expressed as a percentage of the weight of water to the dry weight of the soil. This test is carried out as per **IS: 2720 (Part 2)**.

### 1.3 Data Collection

#### 1.3.1 Rainfall, flood discharge and temperature data

The design of the most appropriate drainage infrastructure at a particular location is dictated by hydrological conditions and the design criteria. A necessary preliminary data that an engineer would look for in designing drainage facility is the determination of the quantity of water (technically called design discharge) the facility must carry or convey. This involves some hydrologic analysis to establish the quantity of runoff or “design discharge”.

The choice of analytical method is a challenging decision as each hydrologic problem has its own peculiarity and complexity. Questions such as “What level of hydrologic analysis is justified?”, “What data are available or must be collected?” as the level of effort depends on available field data, and “What methods of analysis are available including the relative strengths and weaknesses in terms of cost and accuracy?” are always a challenge. Unlike many other aspects of engineering design, the quantification of runoff is not a precise science. Nonetheless, it is possible to obtain solutions which are functionally acceptable to form the basis for design of highway drainage facilities.

Precipitation on roads may be in two forms:

- (a) Liquid precipitation i.e. rainfall
- (b) Frozen precipitation such as

- (i) Snow
- (ii) Hail
- (iii) Sleet
- (iv) Freezing

Run-off is that portion of precipitation which does not get evaporated like surface run-off, interflow or sub-surface run-off and ground water flow or base flow.

#### ***1.3.1.1 Measurement of rainfall***

The amount of precipitation is expressed as the depth in centimetre which falls on a level surface and is measured by rain gauge which may be automatic or non-automatic type. Rainfall data can be obtained from National Center for Hydrology and Meteorology (NCHM).

#### ***1.3.1.2 Snow***

Run-off from snow varies with its physical characteristics. Snow is classified as crystalline, granular, powdery pallet snow or mixtures. For run-off purposes, it will be appropriate to classify snow as dry, damp and wet according to moisture content/density. Snow density varies from 0.40-0.45 (fresh snow) to 0.70-0.80 (wet snow). The snow with low density is termed as dry whereas snow having moderate and high density are termed as damp and wet snow respectively.

#### ***1.3.1.3 Specific Tasks to Obtain Rainfall Data***

- Collect past and current data on rainfall levels in the specific area including occurrence of extreme rainfall events for 1 in 50 and 1 in 100 years;
- Collect primary and secondary (past and current) data on the river flow, pattern, speed, flood level, geomorphology and others for all streams, rivers and water bodies that exist in and around the specific area;
- Based on the information on future climate scenario in the particular area, assess changes in future (next 50 and 100 years) rainfall and hydrological patterns in the project area in comparison with the current conditions;
- Analyse the data collected and assess the implications for the design, performance and maintenance of the roads, bridges and other structures in consultation with the experts.

#### ***1.3.1.4 Average Recurrence Interval (ARI)***

The ARI which is in units of years, is defined as the average (or expected) period of time between exceedance of a given rainfall (or discharge) amount over a given duration and location. For example, 100 mm of rain in 24 hours at a particular location is equivalent to an ARI of 100 years. This means that 100 mm of rain in 24 hours is expected to occur, on average, every 100 years. Since ARI is an average, a similar or even larger rainfall (or discharge) could occur this year, next year or any other year. As such, ARI is approximated as a probability or percent chance of occurring in any given year. For example, 100-year ARI should be interpreted as having a 1 in 100 chance or 1% chance of occurring in any given year.

*Recommended Design ARI* - Most highway design standards have segregated flood immunity criteria in two categories, viz. urban and rural. Highways are generally designed to pass 50 to 100 years ARI flood. In rural areas where traffic densities are low, a reduced standard has been adopted. Table below suggests the design ARI that could be adopted as a standard.

Guideline	Category	ARI
Based on Best Practices	Major Road Design - Urban	100 years
	Major Road Design - Rural	50 years
	Kerb and Channel Flow – Major Road	20 years
	Cross Drainage (Culverts) – Major Road	
	Kerb and Channel Flow – Minor Road	10 years
	Cross Drainage (Culverts) – Minor Road	

Table 1: Recommended Design ARI

### 1.3.1.5 Hydrological Methods for finding Design Discharge

The choice of an approach and a method for design discharge and estimation depends on several factors, such as available data, importance of the project, and available resources, time and expertise. A particular method may be good for one case and quite unsuitable for another. It should be noted that all design discharge estimates are burdened with some amount of uncertainty, regardless of the method of their estimation.

In general, there are several ways to obtain design discharge estimates and to relate them to some probability (frequency) of occurrence.

*Statistical analysis of observed flows* is the basic approach for estimation of flood-frequency relationship when adequate data on observed flows are available. If only a short record of stream-flow is available or none at all, it is possible to establish a regional relationship with flows from neighbouring gauged stations and to use such relationship to perform frequency analysis. The alternative is to obtain flood estimates using a *rainfall-runoff model*. In general, rainfall-runoff models provide flood runoff estimates for a given rainfall input for a gauged station. Depending on the type of rainfall input, there are two possible approaches involving rainfall-runoff modelling:

- **Design storm approach** is the approach in which a design storm represents the input for rainfall-runoff model, and the design flow is the model output. Design storms themselves are obtained by statistical analysis of observed rainfall. The key issue in this approach is the assumption that the frequency of the design flow is equal to the frequency of the design storm. However, having in mind that the rainfall-runoff relationship is neither linear nor straightforward, such an assumption is not always very realistic.
- **In the observed storms approach**, rainfall-runoff model is applied to observed rainfall data in order to obtain corresponding simulated flows. Characteristics such as intensity or rate of rainfall, duration of rainfall and frequency or how often rainfall will occur and watershed characteristics which are necessary parameters in the estimation of runoffs from

rainfall events are difficult to obtain and calibrate and are also very sensitive to changes in input and parameters.

The suggested approach for such assignment is outlined in Figure 5. In the figure, the process of design discharge estimation begins with the determination of catchment area. This can be determined from topographical maps using a planimeter (or GIS) after delineating the catchment boundary with reference to a stream or river of interest. Topographical maps in the scale 1:50,000 are available for most parts of Bhutan.

### 1.3.1.6 Run-off

The run-off of catchment area in any specified period is the total quantity of water draining into a stream or into a reservoir in that period. The principal factors affecting the flow from a catchment area are: -

- a) Precipitation characteristics
- b) Shape and size of the catchment
- c) Topography
- d) Geological characteristics
- e) Meteorological characteristics
- f) Character of the catchment surface
- g) Storage characteristics

#### 1.3.1.6.1 Computation of run-off

Run-off can be computed either by empirical or rationale formulae.

##### i. Empirical formulae:

- (a) Dicken's formula:  $Q = CM^{3/4}$

Where, Q is the peak run-off in cum/sec and M is the catchment area in square km, C is a constant depending upon the rainfall.

- (b) Ryve's formula:  $Q = CM^{2/3}$

##### ii. Rational formula (velocity area method):

$$V = (1/N) \times (R)^{2/3} \times (S)^{1/2}$$

Where

V = Mean velocity of flow in m/sec

R = Hydraulic mean depth = A/P

A = Cross sectional area in square meter

P = Wetted perimeter in meter

S = Bed slope

N = Co-efficient of Rugosity

*Note: The rational formula is the most commonly used in the determination of discharge*

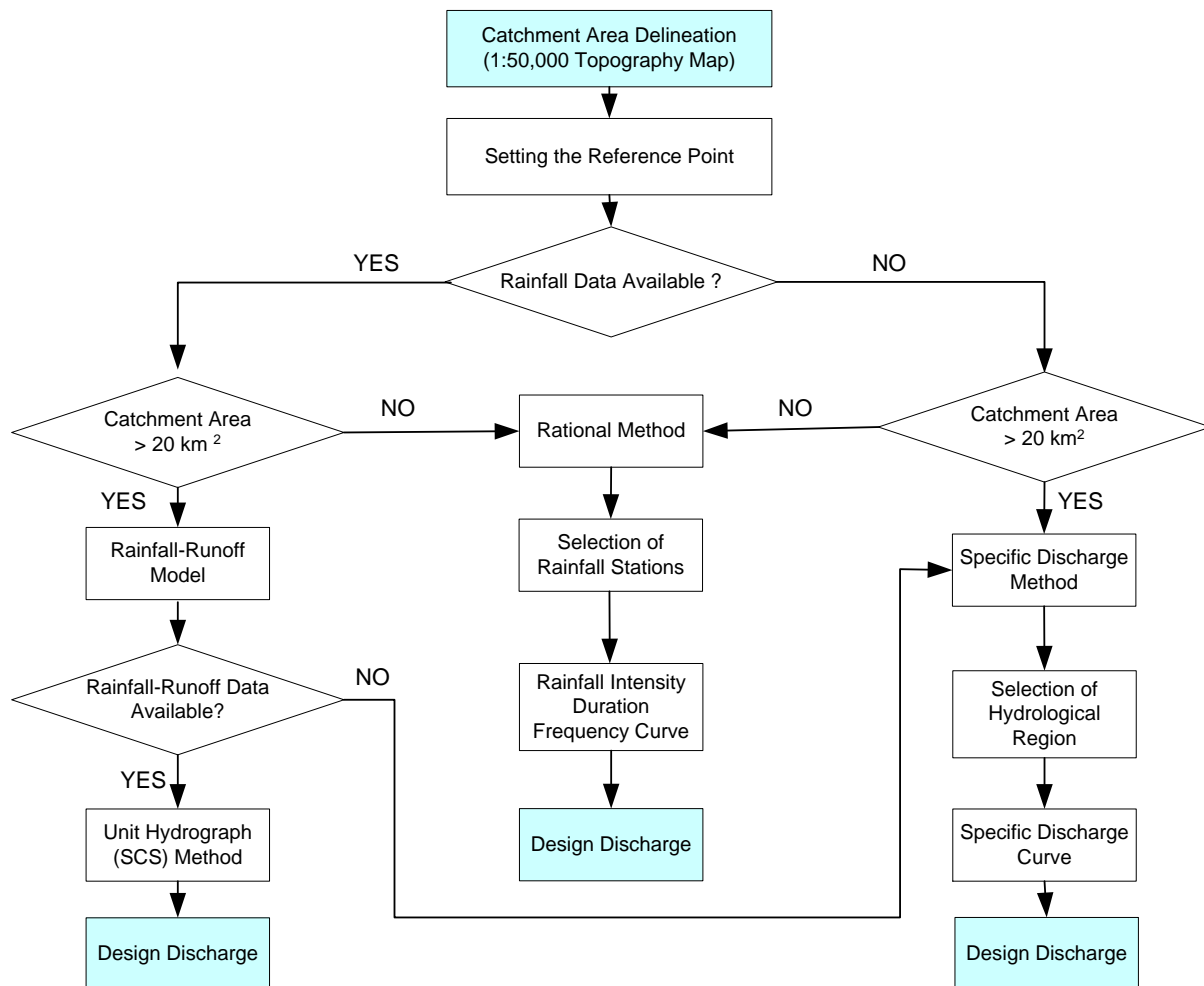


Figure 5: Hydrological Methods for finding Design Discharge

A suitable reasoning to adoption of the specific discharge method for drainages above 20 km<sup>2</sup> lies in the fact that as the basin size increases, storage or detention effects and unfamiliar dynamic flow effects dampen the peak flow in a non-linear relationship. It has been recognized that as the catchment size increases, the specific discharge decreases. For flood frequency study, only the annual maximum discharges are taken into account.

For regional justification of the hydrology of river flow require methodologies that search for similarities of physical geographical features. A recognized procedure is by hierarchical grouping which allows catchments to be classed into relatively homogeneous groups. A procedure to homogenization would be to segregate drainages by climatic and terrain spatial variations. For instance, in the subtropical belts of the Himalayas, monsoon is the main cause of extreme precipitation due to orographic effects of the Himalayas and as such the subtropical belt is the wettest. The terrain in this region is geologically fragile and is characterized by steep and unstable mountain slopes which facilitate mass wasting more frequently when intense precipitation occurs. Rock avalanches and landslides cause this belt to be vulnerable in economic and ecological terms. Most drainages originating from the Siwalik belt are small and are rain-fed and dry up during the dry winter months (ephemeral). Medium sized drainages (100 km<sup>2</sup> ~ 1000 km<sup>2</sup>) are perennial and originate from the lesser Himalayas. There are no

glaciers in the lesser Himalayas and as such risks from glacial lake outburst are not present. However, landslide dams and their resulting outburst floods (LDOF) are possibilities.

### **1.3.1.7 Discharge Analysis**

The drainage pattern of Bhutan is principally segregated into three hydrological regions and are tagged as basins I, II and III. These are main rivers flowing north to south, originating from perennial glaciated regions lying in the north of the country at altitudes over 7000 m. Besides the main basins, there are several sub-basins with north-south orientation, whose headwaters lie in the interior of the country and where glaciation has minimal influence. All others are east-west tributaries of the main drainages that contribute greatly to water budget of the country. The current knowledge of snow-cover and rainfall distribution in Bhutan is imprecise due to low density of gauge networks and due to the fact that gauging in scattered locations are recent.

#### **1.3.1.7.1 Discharge Data**

There are quite a number of rivers that are gauged on a daily basis. Rainfall data can be obtained from National Center for Hydrology and Meteorology (NCHM).

## **1.3.2 Traffic data**

Traffic Data Collection and projections thereof of traffic volumes are basic requirements for planning of road development and design purposes.

The most common method of collecting traffic flow data is the manual method, which consist of assigning a person to record traffic as it passes. This method of data collection can be expensive in terms of manpower, but it is nonetheless necessary in most cases where vehicles are to be classified with a number of movements recorded separately, such as at intersections.

At intersection sites, the traffic on each arm should be counted and recorded separately for each movement. It is of paramount importance that traffic on roads with more than one lane are counted and classified by direction of traffic flow.

According to the current practices, traffic count is recorded twice a year for all types of roads and it is found sufficient for design and other purposes.

The recommended method considers design traffic in terms of the cumulative number of standard axles (80 KN) to be carried by the pavement during the design life. Axle load spectrum data are required where cementitious bases are used for evaluating the fatigue damage of such bases for heavy traffic. Following information is needed for estimating design traffic:

- (i) Initial traffic after construction in terms of number of Commercial Vehicles per day (CVPD).
- (ii) Traffic growth rate during the design life in percentage.
- (iii) Design life in number of years.
- (iv) Spectrum of axle loads.
- (v) Vehicle Damage Factor (VDF).
- (vi) Distribution of commercial traffic over the carriageway.

Only the number of commercial vehicles having gross vehicle weight of 30 kN or more and their axle-loading is considered for the purpose of design of pavement.

Assessment of the present day average traffic should be based on seven-day-24-hour count made in accordance with IRC: 9-1972 “Traffic Census on Non-Urban Roads”.

#### **1.3.2.1 Traffic Growth Rate**

The present day traffic has to be projected for the end of design life at growth rates ( $r$ ) estimated by studying and analysing the following data:

- i) The past trends of traffic growth; and
- ii) Demand elasticity of traffic with respect to macro-economic parameters like GDP and expected demand due to specific developments and land use changes likely to take place during design life.

The annual growth rate of commercial vehicles is considered as 7% to 7.5%.

### **1.3.3 California Bearing Ratio (CBR) values**

The CBR test is a penetration test meant for the evaluation of subgrade strength of roads and pavements. The results obtained by these tests are used with the empirical curves to determine the thickness of pavement and its component layers. This is the most widely used method for the design of flexible pavement.

The harder the material, the higher the CBR value. A CBR value of 2% is usually found for clay, high-quality sub-base will have CBR values between 80% and 100%, and some sands may have values around 10%. The CBR testing can be applied to soils with a maximum particle size of 20 mm. For soils with bigger particles, other types of bearing capacity can be used like the Plate Bearing Test. The coarse-grained soils can reach higher CBR values when compared with those of the fine-grained soils. As expected, with bigger particles the soil may have bigger CBR values.

For design, the subgrade soil strength is normally assessed in terms of CBR for use in the flexible pavement design method. The design subgrade strength depends upon the type of soil, degree of compaction, moisture content and the climatic conditions that the subgrade would attain during the design life of the road.

The subgrade soils normally vary from hard rock to soft shale with intermediate types having gravel with different percentage of binder, silty gravels, silty clays, silty sands and boulders mixed with varying proportions of silty and clayey soils, etc.

The CBR value is ascertained as per a standard test procedure described in **IS: 2720 (Part XVI) “Methods of Test for Soils”**.

The subgrade, whether it is in cut or fill should be well compacted to attain thickness of pavement required. For pavement design, the sub-grade strength in terms of CBR of the sub-grade soil at the most critical moisture condition likely to occur in-situ is considered. The pavement design is based on CBR of the sub-grade which is compacted to a stipulated density.

If during construction, the field compaction is lower than stipulated, the pavement thickness may be reviewed and any extra thickness required provided by an increased thickness of sub-base.

If the type of soil used in different stretches of the subgrade varies along the length of the pavement, the CBR value of each type of soil should be the average of at least three specimens prepared using that soil. 90<sup>th</sup> percentile subgrade CBR value should be adopted for the design of high volume roads such as Expressways, National Highways and Urban roads. For other categories of roads, the design can be done based on the 80<sup>th</sup> percentile CBR value if the design traffic is less than 20 msa and based on 90<sup>th</sup> percentile CBR if the design traffic is 20 msa or more. CBR values must be obtained for every 250 m in case of National Highways and for every 500 m in case of other categories of roads.

## CHAPTER 2 – DESIGN OF ROAD & PAVEMENT

### 2.1 Geometric Design

Geometric design has to be carefully done to align the road to provide comfort and safety. The following parameters have to be considered for design:

1. Classification of Road
2. Design Speed
3. Horizontal Alignment
4. Formation & Cross Section
5. Sight Distance
6. Super elevation
7. Vertical Alignment
8. Grade

In the geometric design, environment friendly approaches have been adopted through optimization of cut and fill methods in the earthworks. Environment friendly road design aptly demonstrates that a slight shift of the centreline to the valley side can result in substantial reduction of earthworks and height of hill side cut.

#### 2.1.1 Terrain Classification

The terrain is generally classified as follows:

- |    |             |   |                  |
|----|-------------|---|------------------|
| 1) | Plain       | - | 0 to 10°         |
| 2) | Rolling     | - | 10°to 25°        |
| 3) | Mountainous | - | 25° to 60°       |
| 4) | Steep       | - | Greater than 60° |

#### 2.1.2 Design Speed

While driving along a road the drivers drive at a certain speed at which they feel that they can overcome any possible obstruction. The speed at which a driver feels most comfortable is considered as the design speed.

The class of the road and the terrain influence the design speed for the particular section of the road. The following design speeds are recommended to be used for design.

Class of Road	Minimum Design Speed in km/hr for Terrain Type (Minimum Curve Radius in meter)			
	Plain	Rolling	Mountainous	Steep
Primary National Highway	80 (280)	70 (200)	60 (120)	50 (75)
Secondary National Highway	80 (280)	70 (200)	60 (120)	50 (75)
Dzongkhag Road	70 (200)	60 (120)	50 (75)	40 (45)
Farm Road	50 (75)	40 (45)	30 (25)	20 (15)

Table 2: Design speed for different category of Roads

The minimum radius of horizontal curve at a hair pin bend should be 15 m for highways and 10 m for other categories of roads.

### 2.1.3 Horizontal Alignment

The horizontal alignment of a road comprises of usually a series of straight and circular curves connected by the transition curves. The radius of the curve is determined by the formula given below:

$$e + f = \frac{v^2}{127R}$$

Where	$e$	=	Super-elevation
	$f$	=	Coefficient of friction
	$V$	=	Speed in Km/Hr.
	$R$	=	Radius in meter

The maximum super-elevation of 0.08 (8%) may be adopted in the steep sections and 0.07 (7%) in flat section. The maximum value of the coefficient of friction varies from 0.19 at 20 to 40 Km/hr, down to 0.12 at 100 km/hr. The minimum radius of horizontal curves to the design speed is as follows:

Sl. No.	Design Speed km/hr	Radius (m)
1	20	15
2	30	25
3	40	45
4	50	75
5	60	120
6	70	200
7	80	280

Table 3: Minimum radius of horizontal curves to the design speed

## 2.1.4 Road Formation

The width of the pavement and formation is determined by the lane width which depends on:

- The dimension of the vehicle
- Speed of travel
- Traffic volume
- Width of shoulder

The desirable minimum width is 3.5 m and this is adopted as the standard width for the single lane and for two lanes the minimum width is 3.0 m for one lane.

The shoulder is measured from the pavement edge to the end of the usable formation. Wide shoulders have the following advantages:

- Space is available for vehicle to stand clear of the pavement.
- Space is available to avoid colliding with other vehicles and to regain control of vehicle.
- In cuttings on curves a wide shoulder gives a longer sight distance.
- The shoulder can be used for widening the road without cutting in future to widen the road
- The Shoulder can also be used to place the snow cleared from the pavement in snow bound areas.
- Shoulder can be used to park stranded vehicle.

## 2.1.5 Road Classification & Specifications

Following are the types of roads we have in Bhutan and their specifications:

ROAD CLASS (Design traffic volume)		DESIGN FORMATION (m)
Primary National Highway (Double Lane)	Pavement	7.5
	Shoulder (Valley side)	1.0
	Drain (On hill side)	1.0
	Debris collection	1.0
	Formation	10.5
Secondary National Highway (Double Lane)	Pavement	5.5
	Shoulder (Valley side)	1.0
	Drain (On hill side)	1.0
	Debris collection	1.0
	Formation	8.5
Dzongkhag Road (Single Lane)	Pavement	3.5
	Shoulder (Valley side)	1.0
	Drain (On hill side)	1.0

	Debris collection	1.0
	Formation	6.5
Farm Road (Single Lane)	Pavement	3.5
	Shoulder	0.5 X 2
	Drain (On hill side)	0.6
	Formation	5.1

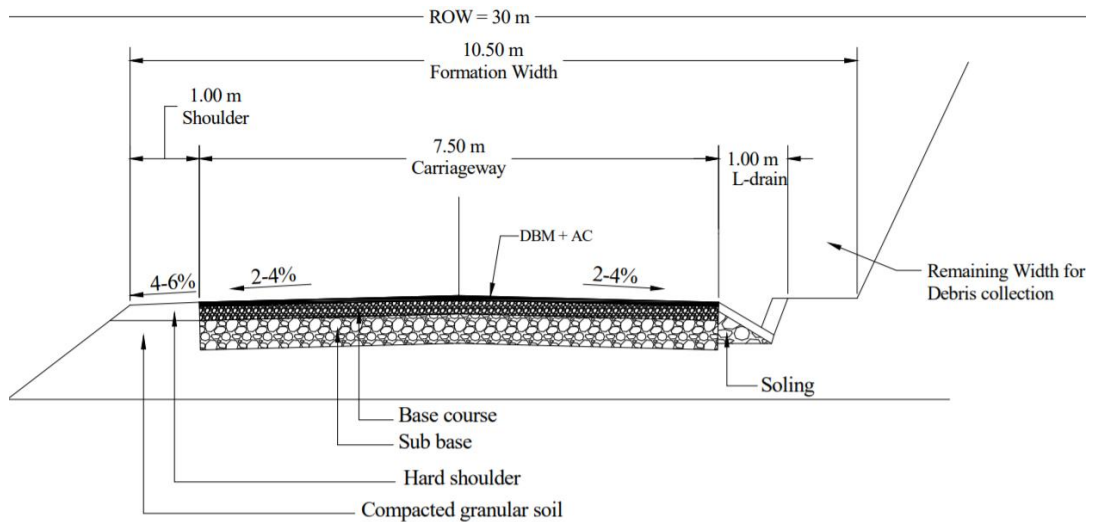
Table 4: Road Formation Width

### 2.1.6 Cross Section

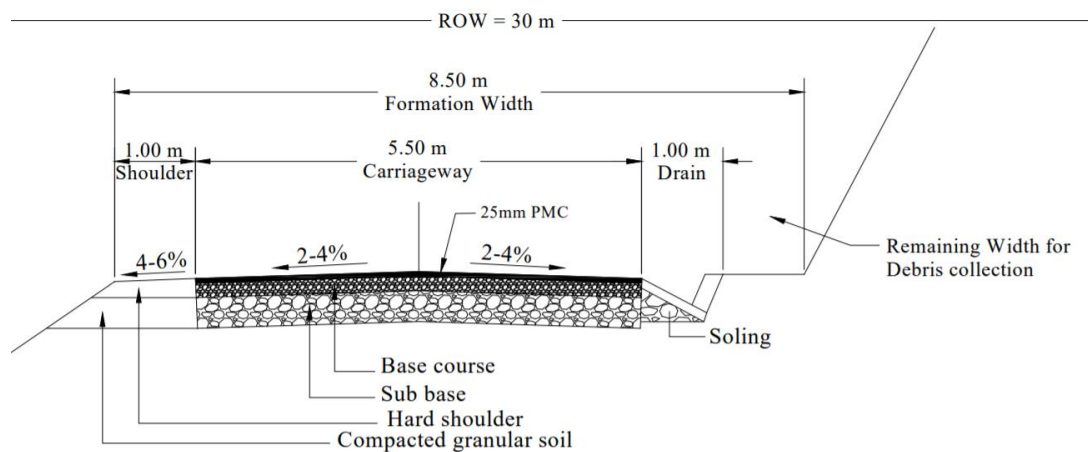
Cross fall is the slope of the surface of the formation/carrigeway measured at right angle to the horizontal alignment. It is essential to maintain cross fall in order to drain out the surface water from the carriageway.

Material Surface Type	Pavement Cross-fall	Shoulder Cross-fall
Earth, Loam	5 %	6 %
Gravel, Wet Mix Macadam	3 - 4 %	5 %
Asphalt Concrete (AC)	2.5 - 3 %	4 %
Ridge pavement	2 - 3 %	4 %

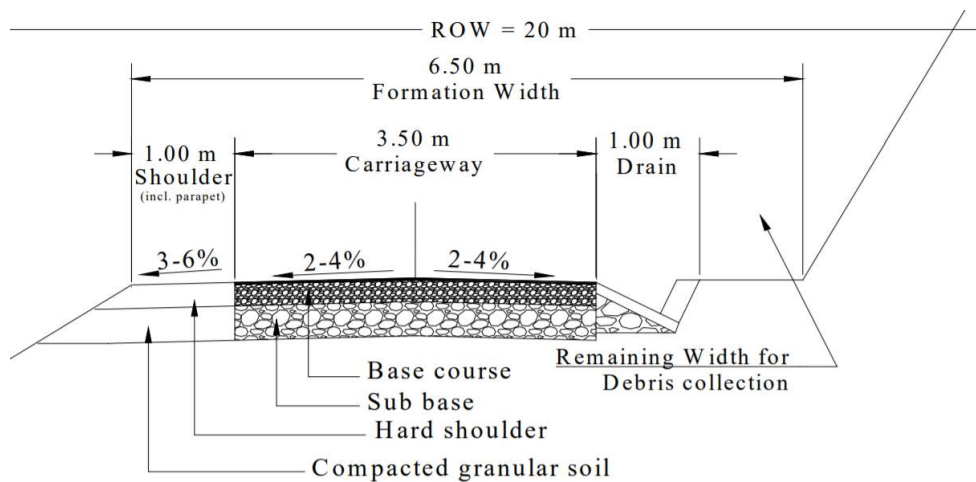
Table 5: Pavement and Shoulder cross-fall



Primary National Highway



Secondary National Highway



Dzongkhag/GC Road

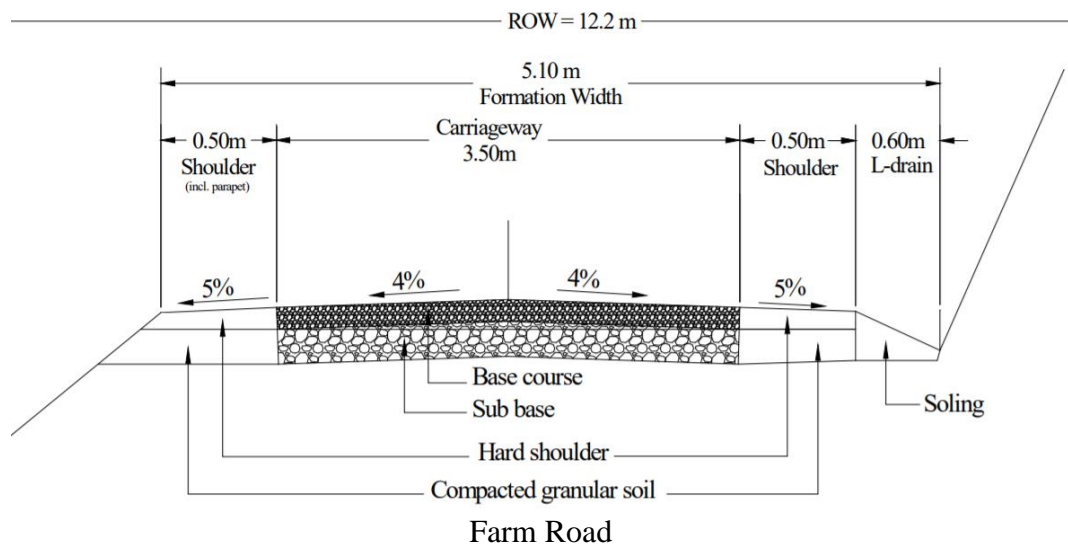


Table 6: Road Classification and its basic components

## 2.1.7 Sight Distance

Sight distance is the distance at which the driver of a vehicle can see an object of specified height on the road ahead of him. For detail calculation of sight distance refer *Survey & Design Manual* published by the Department of Roads in June 2005.

### 2.1.7.1 Stopping sight distance

Stopping sight distance provides stopping distance for a driver approaching the object on the road. The following table shows stopping distance (rounded up) value against the speed and the coefficient. (Reference *Survey & Design Manual* published by the Department of Roads in June 2005.)

Design Speed (km/hr)	Coefficient of Friction	Stopping Distance (m)
20	0.56	15
30	0.54	25
40	0.52	40
50	0.50	60
60	0.47	80
70	0.45	100
80	0.43	120

Table 7: Sight distance according to stopping distance

## 2.1.8 Super-Elevation

The figure below shows the method of development of super elevation and horizontal curve transitions. It also shows the positioning of transitions.

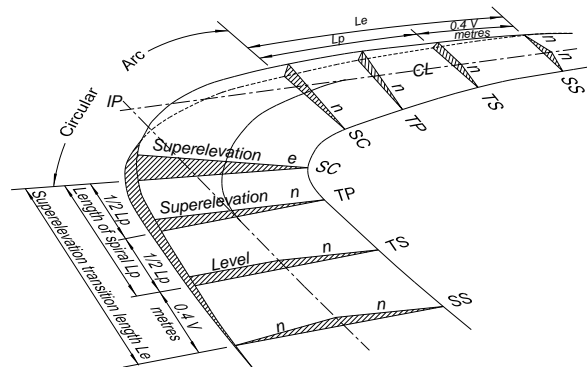


Figure 6: Super-elevation and horizontal curve transition

Legend:

IP	Point of intersection of the main tangents
TS	Tangent Spiral, common point of tangent and spiral
TP	Tangent point, common point of tangent and Circular curve
SS	Start of super-elevation transition
SC	Spiral curve, common point of spiral and circular curve
Lp	Length of spiral between TS and SC
La	Length of super-elevation transition
n	Norma pavement cross-fall – tangent of angle
e	Pavement super-elevation – tangent of angle
V	Design speed (Km/Hr.)

## 2.1.9 Widening

Widening is the extra width that is given to the curve of the pavement during its construction. While negotiating a horizontal curve, the driver has a tendency to follow the inner lane of the pavement. This reduces the effective width of the pavement at curves. In order to have a smooth operation at curves, you need to provide an extra widening at the curve of the road.

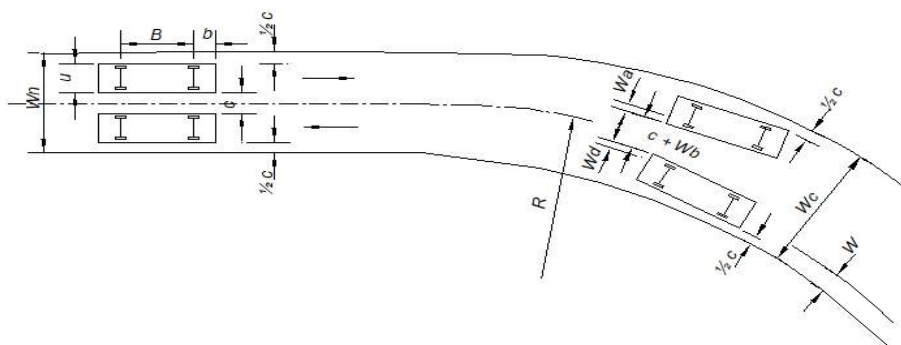


Figure 7: Pavement widening at a curve

## 2.1.10 Vertical Alignment

The longitudinal section of a road consists of straights (grade) joined by curves. The curves are known as vertical curves and are provided to smoothen the junction between two grades and to increase the sight distance. The convex vertical curves are known as summits or crests and the concave vertical curves are called sags.

### 2.1.10.1 Grade

General maximum grades for each design speed are the steepest grades that the majority of cars can travel in a high gear without loss of speed up hill and without gain downhill. It also varies with the design speed and with the terrain also. The following table shows the length and the value of maximum grade.

Design Speed km/hr	General Maximum Grade (%)	Absolute Maximum Grade (%)	Allowable Length of Grade Steeper than General Maximum	
			(%)	(m)
20 - 40	10	*	-	-
50	7	9	8	500
			9	350
60	7	9	8	900
			9	600
70-80	7	9	8	1000
			9	700

Table 8: Length and value of maximum grades

**Note:** No absolute maximum grade is shown for design speeds of 20 to 40 km/h as in some circumstances a length of very steep grade may be necessary. The length of grade steeper than 10 % should be kept as short as possible.

### 2.1.11 Horizontal Alignment

Following are the criterion that need to be looked into in order to achieve a suitable horizontal alignment:

Radius (m)	Speed (Km/h)	Super- elevation (%)	Sight Distance		Transition Super elevation (m)	Widening  Single lane (m)	SD offset	
			Stopping (m)	Over-taking (m)			Stopping (m)	Double stopping (m)
15	20	8	15	-	20	0.9	5	15
25	30	8	25	110	30	0.6	5	16
40							3	11
45	40	8	40	140	45	0.6	5	17
70							3	12
75	50	8	60	200	60	-	5	20
110								14
120	60	7	80	300	70	-	6	23
160							5	17
200							4	14
240							3	12

SD - Sight Distance

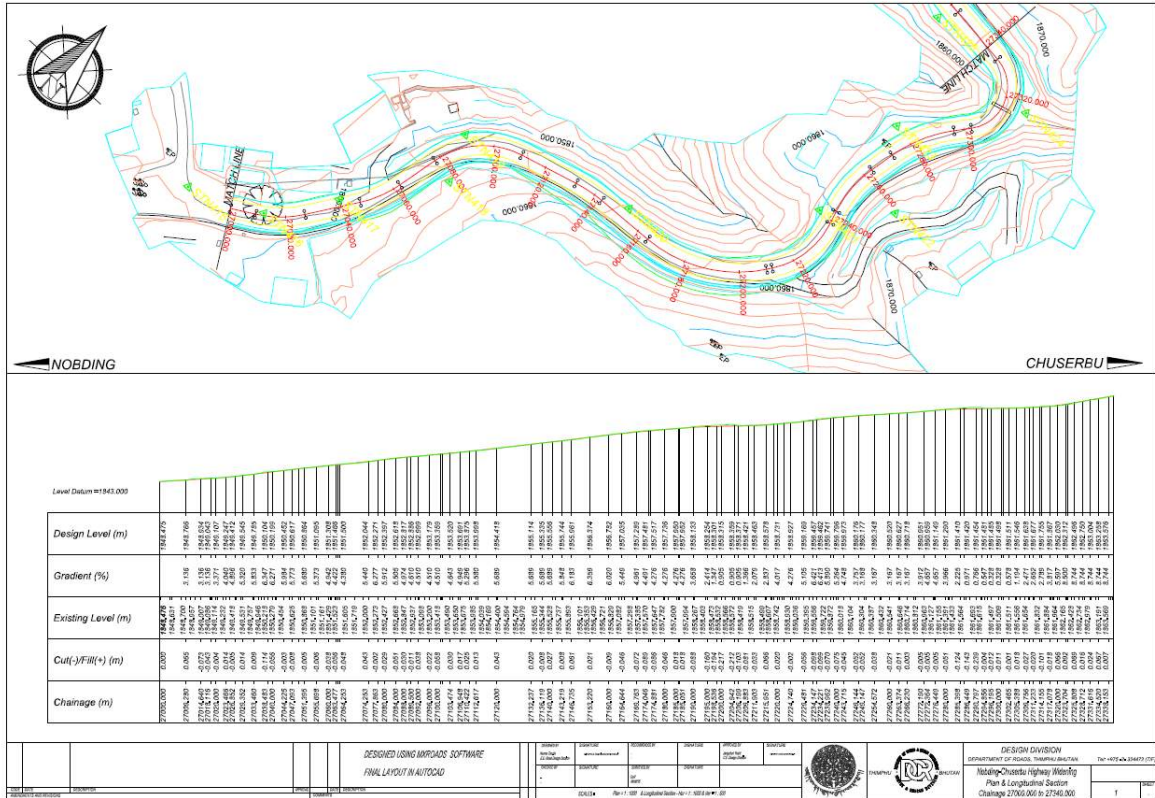
*Table 9: Horizontal Sight Distances*

The Road Geometric design is carried out using different Road Design Software such as:

- GEOCOMP,
- Micro Station 4.1.
- AutoCAD Civil 3D. 4.2.
- Bentley MX Roads.
- SkyCiv Structural 3D
- AutoTURN. 4.3
- Autodesk InfraWorks 360
- Site3D. 4.2
- RoadEng Civil Engineer. 4.5

After completion of the Road design the following drawings are produced:

1. Plan (usually at 1: 1000 scale)
2. L-Section (at Horizontal 1:1000 and vertical 1:500 scale)



3. Cross Section (the cross sections are produced at 20m interval on straight lengths and with cross sections at start of the curve, centre of the curve and at end of the curve at 1:500 scale)

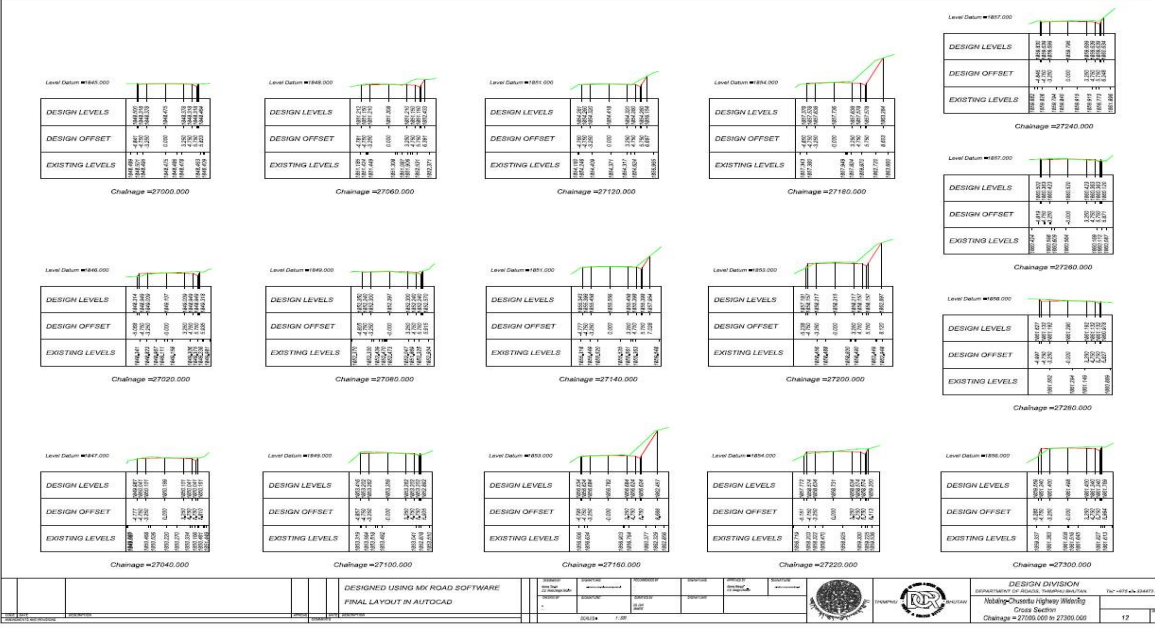


Table 10: A sample design showing the plan, longitudinal section and cross sections of a road section

## 2.2 Pavement Design

With the rapid growth of traffic plying on our road network, the pavements are required to be designed for heavy volume of traffic. *An ideal pavement design procedure is one which will predict a thickness and composition which, without being conservative, ensures that the pavement will not deteriorate beyond a tolerable level of serviceability in less than the design period.*

Pavement design is defined as the process of developing the most economical combination of pavement layers in relation to both thickness and material type to suit the soil foundation and the cumulative traffic to be carried during the design life. The different types of pavement are:

1. Flexible Pavement
2. Rigid Pavement and
3. Composite Pavement

### 2.2.1 Flexible Pavement

Flexible pavement is composition of a bituminous material surface course and underlying base and sub-base courses. The flexible pavement design (IRC: 37, IRC: 81) is based on the load distribution characteristics of a layered system; it transmits load to the subgrade through a combination of layers. The flexible pavement can be either in the form of surface treatment, such as bituminous surface treatments generally used on low volume roads or, asphalt concrete surface courses used on high traffic volume highways.

#### 2.2.1.1 Components of a Flexible Pavement

A flexible pavement consists of asphalt surface course built over a base course and sub base course resting on the sub grade soil.

*Sub-grade* - The sub grade is normally the in-situ soil over which the pavement is being constructed. It can also refer to the top of embankment or fill over which the pavement is laid.

*Sub-base* - The sub base usually consists of granular material either naturally occurring, stabilised or prepared from crushed aggregates. This can be considered as a layer of weaker quality and hence cheaper than base course, but in any case sufficiently stronger than sub grade to help the distribution of wheel load. In certain instances, sub base helps as a drainage layer.

*Base course* - The base course which is the main load bearing layer is normally the thickest layer of the flexible pavement underlying the surface course. The materials used in this layer are invariably of high quality. The base course can be constructed by well graded aggregates in order to provide mechanical interlocking action and properly compacted. This can be of wet mix macadam type, water bound macadam type or well graded dry aggregates type. For the well graded dry aggregate base course, the prime coating should be applied 48 hours prior to laying of surface course so as to keep the finer aggregates intact. New technologies like cementitious road base are also used in order to reduce the thickness of the pavement and where the bearing capacity of the soil is very low.

*Surface course* - The main purpose of surface course is to provide a smooth, skid resistant riding surface which is of utmost importance from the user point of view. It protects ingress of water to the underlying pavement layers. The surface course must carry high stresses induced by the traffic without unacceptable deformation. Normally the surface course is formed by dense bituminous macadam, asphaltic concrete and premix carpet with seal coat.

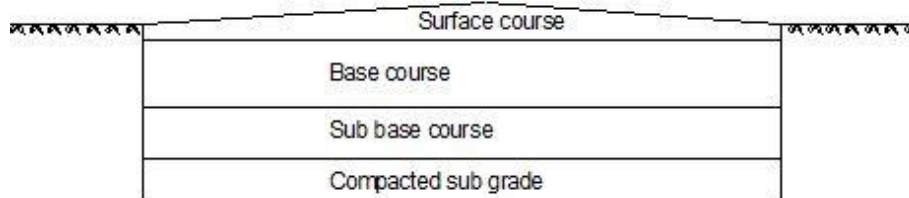
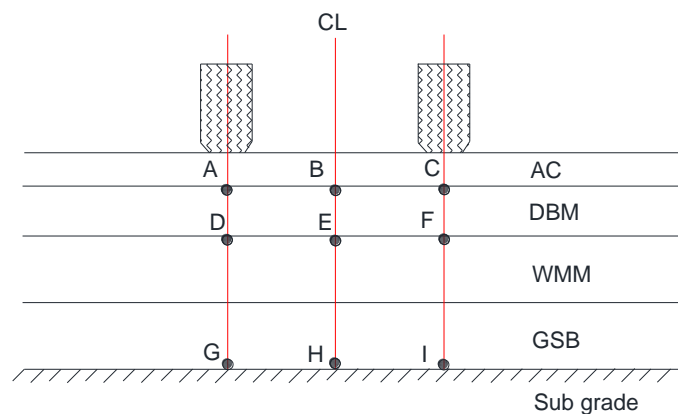


Figure 8: Components of a Flexible Pavement

An analytical design of flexible pavement is based on layered structure as per the strain at critical locations as shown below:



A, B, C, D, E & F are the critical locations for horizontal tensile strain at the base of asphalt layer ( $\epsilon_t$ ). This is because the bottom of bound layers is in tension under load. Large tensile strains cause fracture of bituminous layer during the design life. The maximum value of strain is adopted for design. G, H & I, are the critical vertical compressive strain at the top of sub grade of which maximum value is taken for design. If the strain is excessive, the sub grade will deform resulting in permanent deformation at the pavement surface during the design life. No stress/strain analysis is required for granular/gravel layers. Such stress/strain analysis is computed by using computer software such as CIRCLY.

The pavement deformation within the bituminous layer can be controlled by meeting the asphalt mix design requirement. Thicknesses of sub base, base and asphalt layers are selected using the analytical design approach such that strains at critical points are within the allowable limits for allowable number of load repetitions.

Based on the analytical design approach, simple design charts are developed to carry out the pavement design using the simple input parameter like traffic and soil strength.

### 2.2.1.2 Computation of Design Traffic ( $N_s$ )

The design traffic in terms of cumulative number of standard axles (8160kg) to be carried by the pavement during the design life is estimated by using the equation

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

Where,

- i)  $A$  = Initial traffic in the year of completion of construction in terms of number of commercial vehicles per day and  $A = P(1 + r)^x$

Where,

$P$  = Number of commercial vehicles as per last count,

$r$  = Annual growth rate of commercial vehicles. The growth rate should be estimated based on the past trends of traffic growth. If adequate data are not available, an average annual growth rate of 7 to 7.5% may be adopted. (for 7%,  $x = 0.07$ )

$x$  = Number of years between the last count and the year of completion of construction.

- ii)  $n$  = Design life of pavement in years. Design load is defined in terms of cumulative number of standard axles that can be carried before strengthening of the pavement is necessary. The following design life is recommended for various types of roads.

Expressways and Urban Roads - 20 years

National Highways and Dzongkhag Roads - 15 years

Others Roads - 10 years

- iii)  $F$  = Vehicle damage factor (VDF). It is defined as equivalent number of standard axles per commercial vehicle. In other words, it is a multiplier to convert the number of commercial vehicles of different axle load and axle configuration to the number of standard load repetition given in Table 11.

Initial traffic (CVPD)	Recommended VDF values		
	Unsurfaced	Thin surfacing	Thick surfacing
< 150	0.5	0.75	-
150 - 1500	-	1.00	1.25
>1500	-	1.25	1.50

Table 11: Vehicle Damage Factor vs Traffic

$D$  = Lane distribution factor. The assessment of commercial traffic by direction and by lane is necessary as it directly affects thickness design.

The following values are recommended.

Single-lane roads = 1.00

Double-lane roads = 0.75

### 2.2.1.3 Pavement Thickness Design

The design of roads shall basically consist of 3 layer pavements, namely Granular Sub Base layer(GSB), Wet Mix Macadam (WMM) and bituminous layer. Having calculated the design CBR and cumulative number of standard axles, the thickness of sub base and base course layer can be directly read off from the figure below. It is to note that the minimum thickness of sub base should not be less than 150mm for design traffic less than 10 msa and 200mm for design traffic of 10 msa and above. The recommended minimum thickness of granular base should be 200 mm for traffic up to 2 msa and 250mm for traffic exceeding 2 msa. For CBR value of 9% and above, the minimum thickness of base should be 200 mm. Where the CBR value of sub grade is 2 percent or less, a capping layer of 150mm thickness of material with minimum CBR of 10% shall be provided in addition to the sub base. However, the thickness design shall not be based on the strength of capping layer and it should be based on the original sub grade CBR.

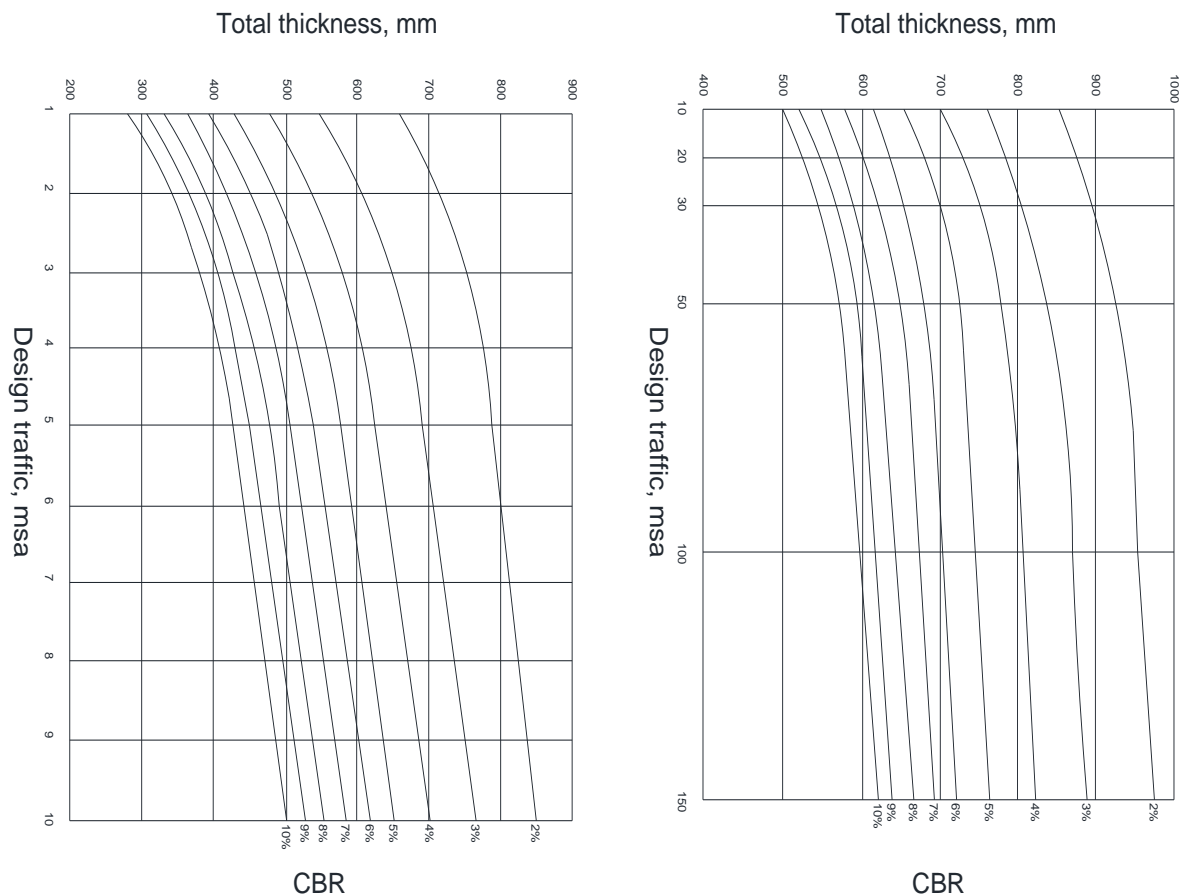


Figure 9: Pavement Thickness Graph

**Bituminous Layer Thickness:** The minimum thickness of bituminous surface shall be as per the table shown below:

Traffic (msa)	Wearing course	Binder course	Remarks
0-0.5	30 mm PMC/AC	-	Wearing course = surface layer
0.5-2	30 mm PMC/AC	-	Binder course = Bituminous course immediately below wearing course
2-5	30 mm AC	50 mm DBM	PMC = Pre Mix Carpet
5-10	40 mm AC	60 mm DBM	AC = Asphalt Concrete
10-15	40 mm AC	65 mm DBM	DBM = Dense Bituminous Macadam
15-20	40 mm AC	80 mm DBM	
20-30	40 mm AC	100 mm DBM	

Table 12: Minimum thickness of bituminous surface

The Charts adopted by the Department are as below:

### For Road with AC and DBM

CBR	TRAFFIC IN MILLION STANDARD AXLES											
	3 - 6			6 - 10			10 - 17			17 - 30		
3 - 4%	AC	40		AC	40		AC	50		AC	50	
	DBM	60		DBM	60		DBM	75		DBM	100	
	WMM	200		WMM	200		WMM	225		WMM	250	
	GSB	200		GSB	225		GSB	225		GSB	250	
5 - 7%	AC	40		AC	40		AC	50		AC	50	
	DBM	60		DBM	60		DBM	75		DBM	100	
	WMM	200		WMM	200		WMM	225		WMM	250	
	GSB	225		GSB	250		GSB	250		GSB	275	
8 - 14%	AC	40		AC	40		AC	50		AC	50	
	DBM	60		DBM	60		DBM	75		DBM	100	
	WMM	200		WMM	200		WMM	225		WMM	250	
	GSB	150		GSB	175		GSB	175		GSB	175	
15 - 29%	AC	40		AC	40		AC	50		AC	50	
	DBM	60		DBM	60		DBM	75		DBM	100	
	WMM	200		WMM	200		WMM	225		WMM	250	
	GSB	100		GSB	100		GSB	100		GSB	100	
30% +	AC	40		AC	40		AC	50		AC	50	
	DBM	60		DBM	60		DBM	75		DBM	100	
	WMM	200		WMM	200		WMM	225		WMM	250	

**Note**

AC = Asphaltic Concrete (mix design required)

WMM = Wet Mix Macadam (40 mm down aggregates, mix design required)

GSB = Granular Sub Base (63 - 40 mm aggregate or 70mm down aggregates)

SR = Soil Replacement (preferably quarry materials)

For shoulders 150mm thick GSB to be applied which shall be flushed with BT surface

If Traffic is <3msa, use thickness adopted for 3-6 msa against design CBR.

### For Road with AC only

CBR	TRAFFIC IN MILLION STANDARD AXLES											
	0.7 - 1.5			1.5 - 3			3 - 6			6 - 10		
3 - 4%	AC		50	AC		50	AC		50	AC		50
	WMM		175	WMM		175	WMM		175	WMM		200
	GSB		175	GSB		225*	GSB		275*	GSB		300*
	SR		200	SR		200	SR		200	SR		200
5 - 7%	AC		50	AC		50	AC		50	AC		50
	WMM		175	WMM		175	WMM		175	WMM		200
	GSB		225	GSB		275*	GSB		325*	GSB		350*
8 - 14%	AC		50	AC		50	AC		50	AC		50
	WMM		175	WMM		175	WMM		175	WMM		200
	GSB		150	GSB		200	GSB		250	GSB		275*
15 - 29%	AC		50	AC		50	AC		50	AC		50
	WMM		150	WMM		175	WMM		175	WMM		200
	GSB		100	GSB		125	GSB		150	GSB		175
30% +	AC		50	AC		50	AC		50	AC		50
	WMM		150	WMM		175	WMM		200	WMM		225

**Note**

AC = Asphaltic Concrete (mix design required)

WMM = Wet Mix Macadam (40 mm down aggregates, mix design required)

GSB = Granular Sub Base (63 - 40 mm aggregate or 70mm down aggregates)

SR = Soil Replacement (preferably quarry materials)

\* = up to 100mm of SB may be substituted with SR provided the SB is not reduced to less than WMM thickness or 200mm whichever is greater

For shoulders 150mm thick GSB to be applied which shall be flushed with BT surface

### For Roads without bituminous surface

CBR	TRAFFIC IN MILLION STANDARD AXLES														
	0.3 - 0.7			0.7 - 1.5			1.5 - 3			3 - 6			6 - 10		
3 - 4%	WBM		150	WBM		150	WBM		200	WBM		200	WBM		200
	SB		150	SB		200	SB		175	SB		225*	SB		275*
	SR		200	SR		200	SR		200	SR		200	SR		200
5 - 7%	WBM		150	WBM		150	WBM		200	WBM		200	WBM		200
	SB		200	SB		250	SB		225	SB		275*	SB		325*
8 - 14%	WBM		150	WBM		150	WBM		200	WBM		200	WBM		200
	SB		125	SB		175	SB		150	SB		200	SB		250
15 - 29%	WBM		150	WBM		150	WBM		175	WBM		200	WBM		225
	SB		100	SB		100	SB		100	SB		125	SB		250
30% +	WBM		150	WBM		150	WBM		175	WBM		200	WBM		225

**Note**

WBM = Water Bound Macadam (50 - 20 mm aggregate)

SB = Sub Base (63 - 40 mm aggregate)

SR = Soil Replacement (preferably quarry materials)

\* = up to 100mm of SB may be substituted with SR provided the SB is not reduced to less than

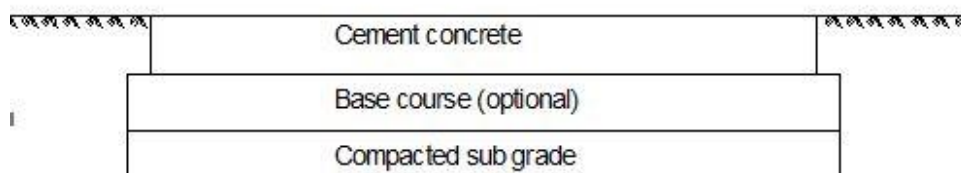
WBM thickness or 200mm whichever is greater.

Figure 10: Design Charts adopted by DoR for Road Design

## 2.2.2 Rigid Pavement

A rigid pavement is constructed from cement concrete or reinforced concrete slabs. The design of rigid pavement is based on providing a structural cement concrete slab of sufficient strength to resist the loads from traffic. IRC: 58, IRC: 15, IRC: 76 and IRC: SP62 shall be referred to for design and construction of rigid pavement.

A “Rigid Pavement” is cement concrete pavement, plain or reinforced laid over a base course. While using plain concrete, some reinforcement becomes necessary at joints, provided to relieve stresses due to expansion, contraction, warping or to facilitate construction. On the other hand, reinforcement may also be used to take due care of the stresses arising due to temperature fluctuation. In that case it is known as temperature reinforcement. Heavy reinforcement used without breaks or joints is usually known as continuously reinforced concrete where the reinforcement is expected to take care of both temperature stresses and also load stresses to some extent.



*Figure 11: Components of a Rigid Pavement*

As the name implies, rigid pavements are rigid i.e., they do not flex much under loading like flexible pavements. They are constructed using cement concrete. In this case, the load carrying capacity is mainly due to the rigidity and high modulus of elasticity of the slab (slab action). H. M. Westergaard is considered the pioneer in providing the rational treatment of the rigid pavement analysis.

### 2.2.2.1 Design of Slab Thickness

The factors commonly considered for design of pavement thickness are traffic load and temperature variations. For purpose of analysis, three regions are recognized in a pavement and they are slab corner, edge and interior which react differently from one another to the effect of temperature differentials as well as load applications.

The concrete pavement undergoes a daily cyclic change of temperature differentials and more so due to climate change, the top of the pavement remains hotter than the bottom during day, and cooler during night. The consequent tendency of the pavement slabs to warp upwards (top convex) during the day and downwards (top concave) during the night, and restraint offered to this warping tendency by self-weight of the pavement induces stresses in the pavement, commonly referred as temperature stresses. These stresses are flexural in nature being tensile at the bottom during the day and at top during the night. The restraint is maximum in the slab interior and somewhat less at the edge. Consequently, the temperature stresses induced in the pavement are negligible in the corner regions and maximum in the interior.

Under the action of load application, maximum stress is induced in the corner region as the corner is discontinuous in two directions. The edge being discontinuous in one direction only, has lower stress while the least stress is induced in the interior where the slab is continuous in all directions. Furthermore, the corner tends to bend like a cantilever, giving tension at the top, interior like a beam giving tension at bottom. At the edge, main bending is along the edge like a beam giving maximum tension at the bottom.

The maximum combined tensile stresses in the three regions of the slab will thus be caused when effects of temperature differentials are such as to be additive to the load effects. This would occur during the day in case of interior and edge regions, at the time of maximum temperature differential in the slab. In the corner region, the temperature stress is negligible, but the load stress is maximum at night when the slab corners have a tendency to lift up due to warping and lose partly the foundation support. Considering the total combined stress for three regions, viz., corner, edge and interior, for which the load stress decreases in that order while the temperature stress increases, the critical stress condition is reached in the edge region where neither of the load and temperature stresses are the minimum. It is, therefore, felt that both the corner and the edge regions should be checked for total stresses and design of slab thickness based on the more critical condition of the two.

#### 2.2.2.1.1 Calculation of Stresses

##### Edge Stresses

- a) Due to load: The load stress in the critical edge region may be obtained as per Wertergaard analysis and modified by Teller and Sutherland from the following correlation (metric units):

$$\sigma l_e = 0.529 \frac{P}{h^2} (1 + 0.54 \mu) \left[ 4 \log_{10} \frac{1}{b} - \log_{10} b - 0.4048 \right]$$

With  $\sigma l_e$  = load stress in the edge region, kg/cm<sup>2</sup>,

P = design wheel load, kg,

h = pavement slab thickness, cm,

$\mu$  = Poisson's ratio for concrete,

E = modulus of elasticity for concrete, kg/cm<sup>2</sup>,

K = reaction modulus of the pavement foundation, kg/cm<sup>3</sup>,

$l_e$  = radius of relative stiffness, cm

$$= 4 \sqrt{\frac{Eb^3}{12(1-\mu^2)K}}$$

b = radius of equivalent distribution of pressure

$$= a \text{ for } \frac{a}{h} > 1.724$$

$$= \sqrt{16a^2 + h^2} - 0.675h \text{ for } \frac{a}{h} < 1.724$$

And a = radius of load contact, cm, assumed circular

The values of  $l$  and  $b$  can be ascertained directly from the tables below:

$h$ (cm)	Radius of relative stiffness $l$ (cm) for different values of $K$ (kg/cm <sup>3</sup> )				
	$K = 6$	$K = 8$	$K = 10$	$K = 15$	$K = 30$
15	61.44	57.18	54.08	48.86	41.09
16	64.49	60.02	56.76	51.29	43.31
17	67.49	62.81	59.40	53.67	45.14
18	70.44	65.56	62.01	56.03	47.07
19	73.36	68.28	64.57	58.35	49.06
20	76.24	70.95	67.10	60.63	50.99
21	79.08	73.59	69.60	63.89	52.89
22	81.89	76.20	72.08	65.13	54.77
23	84.66	78.80	74.52	67.33	56.62
24	87.41	81.35	76.94	69.31	58.45
25	90.13	83.88	79.32	71.68	60.28

Table 13: Radius of relative stiffness,  $l$ , for different values of pavement slab thickness,  $h$ , and foundation reaction modulus,  $K$ , for concrete  $E = 3.0 \times 10^6$  kg/cm<sup>3</sup>

$a/h$	$b/h$	$a/h$	$b/h$
0.0	0.325	1.0	0.937
0.1	0.333	1.1	1.039
0.2	0.357	1.2	1.143
0.3	0.387	1.3	1.250
0.4	0.446	1.4	1.358
0.5	0.508	1.5	1.470
0.6	0.580	1.6	1.582
0.7	0.661	1.7	1.695
0.8	0.747	1.724	1.724
0.9	0.840	>1.724	$a/h$

Table 14: Radius of equivalent distribution of pressure section,  $b$ , in terms of radius of contact,  $a$ , and slab thickness,  $h$

- b) Due to temperature: The temperature stress at the critical edge region may be obtained as per Westergaard analysis, using Bradbury's coefficient, from the following correlation:

$$\sigma t_e = \frac{E\alpha\Delta t}{2} * C$$

With  $\sigma t_e$  = temperature stress in the edge region

- $\Delta t$  = maximum temperature differential during day between top and bottom of the slab
- $\alpha$  = coefficient of thermal expansion of concrete,
- $C$  = Bradbury's coefficient, which can be ascertained directly from Bradbury's chart against values of  $L/l$  and  $W/l$ ,
- $L$  = Slab length, or spacing between consecutive contraction joints,
- $W$  = Slab Width, and
- $l$  = radius of relative stiffness

Values of the coefficient  $C$ , based on the curves given in Bradbury's chart, are given in the table below:

<i>L/l or W/l</i>	<i>C</i>
1	0.000
2	0.040
3	0.175
4	0.440
5	0.720
6	0.920
7	1.030
8	1.075
9	1.080
10	1.075
11	1.050
12 and above	1.000

*Table 15: Values of Co-efficient 'C' based on Bradbury's Chart*

Corner Stresses: The load stress in the corner region may be obtained as per Westergaard's analysis, as modified by Kelley, from the following correlation:

$$\sigma l_c = \frac{3P}{h^2} \left[ 1 - \frac{(\alpha\sqrt{2})^{1.2}}{1} \right]$$

With  $\sigma l_c$  = load stress in the corner region, other notations remaining the same as in the case of the edge load stress formula.

The temperature stress in the corner region is negligible as the corners are relatively free to warp, and may be ignored.

### 2.2.2.2 Design Charts

Figures below give ready-to-use design charts for calculation of load stresses in the edge and corner regions of rigid pavement:

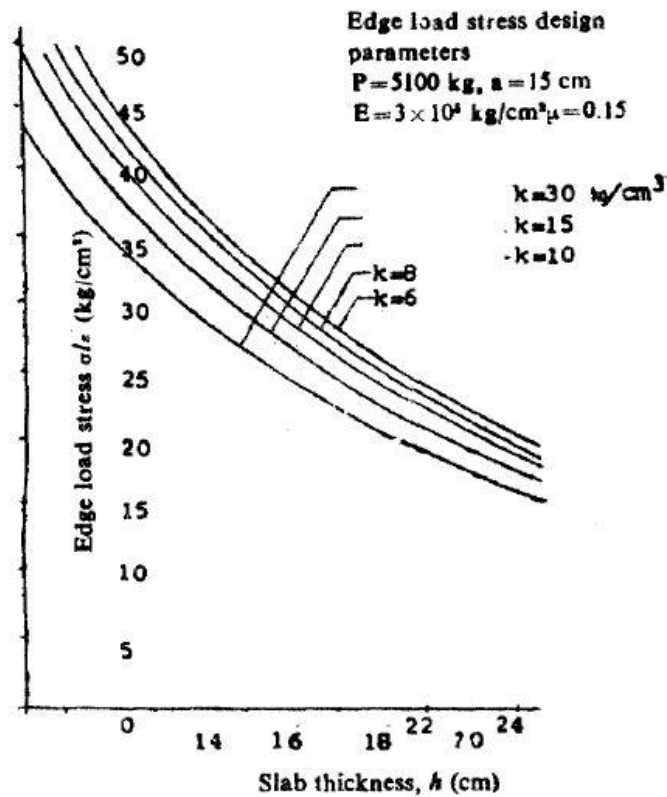


Figure 12: Design chart for calculation of edge load stress

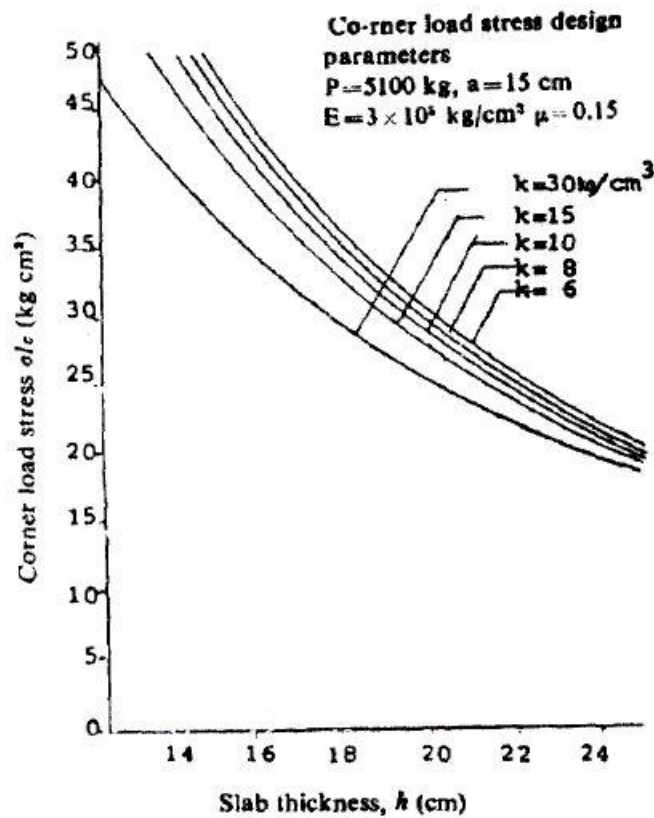


Figure 13: Design chart for calculation of corner load stress

### 2.2.2.3 Design of Joints

The maximum recommended spacing of expansion joints are given in the table below:

Expansion Joint Spacing (based on CRRI study) (for 25 mm wide expansion joints)

Period of Construction	Degree of foundation roughness	Maximum expansion joint spacing (m)		
		Slab thickness (cm)		
		15	20	25
Winter (Oct – March)	Smooth	50	50	60
	Rough	140	140	140
Summer (Apr – Sept)	Smooth	90	90	120
	Rough	140	140	140

Table 16: Maximum recommended spacing of expansion joints

Slab thickness (cm)	Maximum contraction joint spacing (m)	Weight of reinforcement in welded fabric (for reinforced pavements only) (kg m <sup>2</sup> )
Unreinforced Slabs		
10	4.5	-
15	4.5	-
20	4.5	-
Reinforced Slabs		
10	7.5	2.2
15	13.0	2.7
20	14.0	3.8

Table 17: Contraction Joints Spacing (Based on IRC: 15-1981)

#### 2.2.2.4 Load Transfer at Transverse Joints

Load transfer to relieve part of the load stresses in edge and corners regions of pavement slab at transverse joints is provided by means of mild steel dowel bars. The method of design of dowel bars as per Bradbury's analysis is recommended.

##### 2.2.2.4.1 Design of Dowel Bars

The dowel bar system may be designed on the basis of Bradbury's analysis which gives the following formulae for load transfer capacity of a single dowel bar in shear, in bending and in bearing on concrete:

$$P_s = 0.785 d^2 F_s \dots \dots \dots \text{Shear}$$

$$P_f = \frac{2d^3 F_f}{r+8.8\delta} \dots \dots \dots \text{Bending in the bar}$$

$$P_b = \frac{F_b r^2 d}{12.5 (r+1.5z)} \dots \dots \dots \text{Bearing on the concrete}$$

With P = load transfer capacity of a single dowel bar,

d = diameter of dowel bar,

r = length of embedment of dowel bar,

z = joint width,

F<sub>s</sub> = permissible shear stress in dowel bar,

F<sub>f</sub> = permissible flexural stress in dowel bar, and

F<sub>b</sub> = permissible bearing stress in concrete.

For balanced design, for equal capacity in bending and bearing, the length of embedment of dowel is first obtained by equating P<sub>f</sub> and P<sub>b</sub> values from the above equations as follows, for the assumed joint width z and dowel diameter d:

$$r = 5d \left[ \frac{F_f}{F_b} \frac{(r + 1.5z)}{(r + 8.8z)} \right]^{0.5}$$

Knowing  $z$ ,  $d$  and  $r$ , the load transfer capacity of a single dowel is determined from the equations  $P_f$  and  $P_b$  given above.

To calculate the spacing of dowel bars, the required capacity factor,  $n$ , is first determined from:

$$n = \frac{\text{load transfer capacity required from the dowel system}}{\text{load transfer capacity of a single dowel bar}}$$

The distance on either side of the load position up to which the dowel bars are effective in load transfer is taken as  $1.8l$ , where  $l$  is the radius of relative stiffness obtained using the formula

$$l = 4 \sqrt{\frac{Eb^3}{12(1-\mu^2)K}}$$

Dowel bars are not satisfactory for slabs of small thickness, and shall not be provided for slab less than 15 cm thick.

Design loading	Slab thickness (cm)	Dowel bar details		
		Diameter (mm)	Length (mm)	Spacing (mm)
5100 kg	15	25	500	200
	20	25	500	250
	25	25	500	300

Table 18: Design details of dowel bars for rigid pavement

Typical dowel bar designs for use in 20 mm wide expansion joints for highway pavements, for 40 per cent load transfer is given in the above table.

### 2.2.2.5 Tie Bars for Longitudinal Joints

In case of heavy traffic and expansive subgrades, tie bars must be provided in accordance with the recommendations from IRC: 15-1981.

#### 2.2.2.5.1 Design of Tie Bars

The area of steel required per m length of joint may be computed by using the following formula:

$$A_s = \frac{bfW}{S}$$

Where,  $A_s$  = area of steel in  $\text{cm}^2$  required per m length of joint.

$b$  = distance between the joint in question and the nearest free joint or edge in m,

$f$  = coefficient of friction between pavement and the subgrade (usually taken as 1.5)

$W$  = weight of slab in  $\text{kg/m}^2$ , and

$S$  = allowable working stress of steel in  $\text{kg/cm}^2$ .

The length of any tie bar should be at least twice that required to develop a bond strength equal to the working stress of the steel. It is obtained using the formula:

$$L = \frac{2SA}{BP}$$

Where, L = length of tie-bar (cm)

S = allowable working stress in steel (kg/cm<sup>2</sup>),

A = cross-sectional area of one tie bar (cm<sup>2</sup>),

P = perimeter of tie-bar (cm), and

B = permissible bond stress in (i) deformed tie bars – 24.6 kg/cm<sup>2</sup>, (ii) Plain tie bars – 17.5 kg/cm<sup>2</sup>

To permit warping at the joint, the maximum diameter in case of tie bars may be limited to 20 mm, and to avoid concentration of tensile forces, they should not be spaced more than 75 cm apart. The calculated length, L, may be increased by 5-8 cm to account for any inaccuracy in placement during construction.

Typical tie bar details for use at central longitudinal joint in a double-lane rigid pavement with a lane width of 3.5 m are given in the table below:

Slab thickness (cm)	Tie bar details			
	Diameter (mm)	Maximum spacing (cm)	Minimum length (cm)	
			Plain bars	Deformed bars
15	8	38	40	30
	10	60	45	35
20	10	45	45	35
	12	64	55	40
25	10	30	45	35
	12	45	55	40
	14	62	65	46

Table 19: Typical tie bar details for use at central longitudinal joint

### 2.2.2.6 Design of Reinforcement

Reinforcement in concrete slabs is designed to counteract the tensile stresses caused by shrinkage and contraction due to temperature or moisture changes. The maximum tension in the steel across the crack equals the force required to overcome friction between the pavement and its foundation, from the crack to the nearest joint or free edge. This force is the greatest when the crack occurs at the middle of the slab. Reinforcement is designed for this critical location. However, for practical reasons, reinforcement is kept uniform throughout the length, for short slabs.

The amount of longitudinal and transverse steel required per m width or length of slab is computed by the following formula:

$$A = \frac{LfW}{2S}$$

Where, A = area of steel in cm<sup>2</sup> required per m width or length of slab,

L = distance in m between free transverse joints (for longitudinal steel) or free longitudinal joints (for transverse steel)

f = coefficient of friction between pavement and subgrade (usually taken as 1.5),

W = weight of slab in kg/m<sup>2</sup>

S = allowable working stress in steel in kg/cm<sup>2</sup> (usually taken as 50 to 60 percent of the minimum yield stress of steel)

Since reinforcement in the concrete slabs is not intended to contribute towards its flexural strength, its position within the slab is not important except that it should be adequately protected from corrosion. Since cracks starting with higher tensile stress at the top surface are more critical when they tend to open, the general preference is for the placing of reinforcement about 50 mm below the surface.

#### *2.2.2.7 Recommended Design Procedure*

Step 1: Stipulate design values for the various parameters.

Step 2: Decide joint spacing and land-widths

Step 3: Select tentative design thickness of pavement slab.

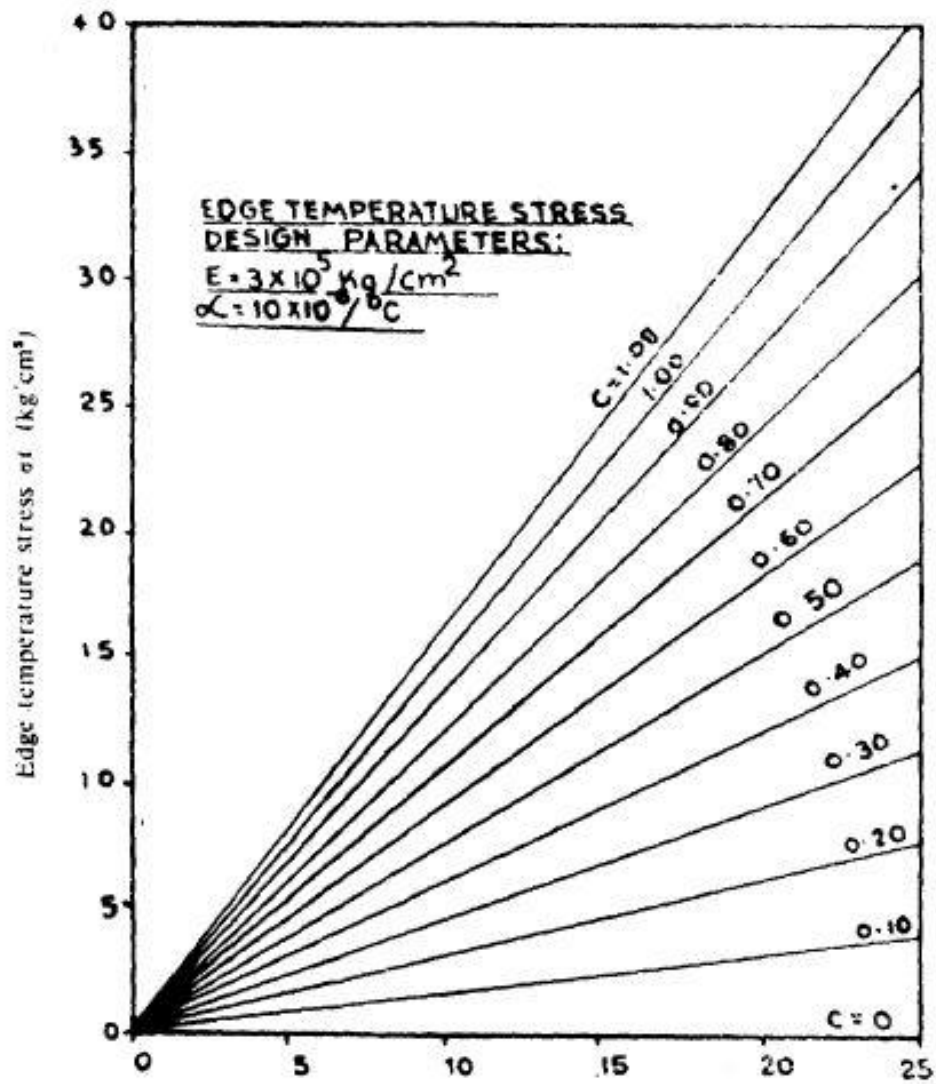
Step 4: Ascertain maximum temperature stress for the critical edge region using

$$\sigma t_e = \frac{E\alpha\Delta t}{2} * C$$

Step 5: Calculate the residual available strength of concrete for supporting traffic loads.

Step 6: Ascertain edge load stress using

$$\sigma l_e = 0.529 \frac{P}{h^2} (1 + 0.54 \mu) \left[ 4 \log_{10} \frac{1}{b} - \log_{10} b - 0.4048 \right]$$



Temperature differential  $t$  °C  
 Chart for determination of coefficient  $C$

$L/l$ or $W/l$	$C$	$L/l$ or $W/l$	$C$
1	0.000	7	1.030
2	0.040	8	1.077
3	0.175	9	1.080
4	0.440	10	1.075
5	0.720	11	1.050
6	0.920	12	1.000

Figure 14: Design chart for calculation of edge temperature stress

Step 7: In case the available factor of safety is less than or far in excess of 1, adjust the tentative slab thickness and repeat steps 3 to 6 till the factor of safety is 1 or slightly more. Denote the corresponding slab thickness as  $h_s$ .

Step 8: Check for adequacy of thickness in the corner region by ascertaining corner load stress

using  $\sigma l_c = \frac{3P}{h^2} \left[ 1 - \frac{(a\sqrt{2})^{1.2}}{1} \right]$  and readjust the thickness  $h_s$  if inadequate.

Step 9: Adjust  $h_s$  for traffic intensity. The adjusted design thickness,  $h$ , maybe obtained from

$$h = h_s + h_t$$

The values of  $h_t$  may be taken from the table below:

Traffic classification	A	B	C	D	E	F	G
$h_t$ (cm)	-5	-5	-2	-2	0	0	+2

Table 20: Traffic classification

Traffic classification for rigid pavement design is as follows:

Traffic classification	Design Traffic Intensity: Vehicles (laden weight >3 tonnes) per day at the end of design life
A	0-15
B	15-45
C	45-150
D	150-450
E	450-1500
F	1500-4500
G	Above 4500 and all expressways

Table 21: Traffic classification for Rigid Pavement

### 2.2.3 Composite Pavement

A composite pavement (IRC: SP 68) is a type of pavement that utilizes both concrete and asphalt. Typically, a concrete base layer provides structural capacity while the asphalt surface layer provides a wearing surface. Geo-cell and geo-grids are also used together with asphalt for constructing road pavement in unstable areas.

### 2.3 Drainage Design

Drainage is the process of interception and removal of water from over and under the vicinity of the road surface. Drainage can be surfaced or sub-surface. Surface drainage or pavement drainage includes the disposal of all water present on the surface of the pavement and adjacent ground. While the sub-surface drainage includes such as French/trench drains, generally built below the subgrade to reduces the moisture content so as to keep the moisture as minimum as possible.

Surface and subsurface drainage of roads critically affect the structural integrity, safety of users, and is thus important during road design and construction. Road designs therefore have to provide efficient means for removal of water. Drainage facilities are required to safeguard the road against damage from surface and subsurface water. Traffic safety is very important as poor drainage can result in dangerous conditions like hydroplaning. Poor drainage can also compromise the structural life of the pavement. Drainage system combines various natural and man-made facilities like open drain, pipe drain and culverts to convey the water safely.

### 2.3.1 Principles of Good Drainage

Some of the basic principles of drainage design are briefly outlined below

- The surface runoff over the pavement surface and the shoulders should be drained away as quickly as possible, preventing the water from finding entry into the pavement layers from the top and into the subgrade from the bottom and the sides.
- Precipitation over the open land adjoining the road should be led away from the pavement structure through natural drainage channels or artificial drains. Suitable cross-drainage channels should be provided to lead the water across the road embankment which may be cutting across to the natural drainage courses.
- Consideration should be given to deal with the precipitation on the embankment and cut slopes so as to prevent erosion.
- Seepage and subsurface water is detrimental to the stability of cut slopes and bearing power of subgrades. An effective system of subsurface drainage must be provided to accelerate slope failures.
- Landslide-prone zones deserve special investigations for improving drainage.
- Relatively poor embankment soils can perform satisfactorily if drainage is considered in the design.
- Water-logged and flood-prone zones demand detailed consideration for improving the overall drainage pattern of the area through which the road is aligned.

**The study has found that the dimensions of the drains and cross drainages need to be increased by about 20%-25% to incorporate high intensity of rainfall due to climate change.**

### 2.4 Provision of Surface Drainage

For an effective surface drainage system, it must be ensured that the following measures are taken on all roads:

- a) Cross-fall or camber on the carriageway must be ensured at all times as per the specifications. The cross-fall of the shoulder should be 1% steeper than the cross-fall of the carriageway, subject to a minimum of 4%.
- b) Sub-surface drains should be provided at marshy areas for better internal drainage of pavement layers, especially for granular materials. Similarly, along vertical curves, the sub-surface drainage considerations are of great importance and in some cases, the length of the vertical curve may have to be adjusted to satisfy drainage requirements. For most conditions, a minimum of 1% longitudinal gradient should be provided.

- c) Side drains should be provided to collect the surface water from the carriageway and lead it to an identified outlet to prevent saturation of pavement layers. Side drains should be constructed and maintained in accordance with the following:
- provide enough area to accommodate storm flow and deep enough to drain the base course
  - protect the surface of side drains from erosion with turf cover or other suitable lining
  - keep velocities low enough to prevent erosion but great enough to prevent deposition or silting
  - maintain a continuous and unobstructed waterway
  - ***provide stable outlets for natural channels or by constructing cascade/rip-rap/check dams for other areas***

The design of the side drains can be done in the following step-by-step manner:

- From the known soil type, arrive at the value of Manning's Rugosity coefficient, side slopes and the maximum permissible velocity.
- Determine the slope from the topography.
- The design discharge should be enhanced by at least 20% to account for climate change effects.
- For the given discharge, calculate the hydraulic mean depth from Manning's formula.
- Find out the cross-sectional area from the given discharge and the maximum permissible velocity.



Figure 15: V-shaped and Box drain

## 2.5 Cross Drainage

Cross drainage requires careful design and construction. Functionally, they must

- allow for passage of the maximum amount of water which can reasonably be expected to occur within the lifetime of the structure and
- not degrade water quality or endanger the structure itself or any downstream structures. It should be pointed out that most road failures are related to inadequate water passage structures and fill design and placement as well as poor construction practices in such locations.

The cross drainages are of two types:

- a) Submersible

b) Non-submersible.

The appropriate choices of cross drainages depend upon:

(a) Technical

- Nature and width of stream and flood flows;
- Velocity of flow and bed slope;
- Maximum and minimum depth of flow;
- Presence of floating sediments and boulder movement.

(b) Economical

- Cost of initial construction;
- Cost of maintenance or reconstruction;
- Cost of delays to vehicles (in case of submersible).

Normally experience and local practice will be helpful in the choice of the appropriate cross drainages. The table below provides a guideline for the choice of appropriate cross drainages.

Sl.	Type of Structure	Locations of cross drainages
1	Vented Causeway	Shallow streams having permanent dry weather flow exceeding 0.6m in depth
2	Submersible Causeway or Hume pipe Culvert	In case where a culvert or bridge is too expensive to construct
3	Box Culvert	Areas where there is a clear span up to 6m.
4	Bridge	Areas where the clear span is greater than 6.0 m.

Table 22: Locations of Cross Drainages

If there are existing roads in the watershed, examination of the performance of existing culverts often serves as the best guide to determining the type, size, and accompanying inlet/outlet improvements needed for the proposed stream crossing. For estimating streamflow on many forest watersheds, existing culvert installations may be used as "control sections". Flow can be calculated as the product of water velocity (V) and cross-sectional area (A):

$$Q = A * V$$

Cross-sectional area of water flowing in a round- culvert is difficult to measure, however a rough estimate can be calculated from the following equation:

$$A = \left[ \frac{(\pi r^2 \beta)}{180} \right] - (r^2 - rd) \sin \beta$$

where:

r = culvert radius

d = measured depth of flow

β = angle (°) between radial lines to the bottom of the culvert and to the water surface =  $\cos^{-1} [(r-d) / r]$

## 2.6 Slope Stabilization (Bio-engineering)

Slope stability is the potential of soil covered slopes to withstand and undergo movement. Stability is determined by the balance of shear stress and shear strength. A previously stable slope may be initially affected by preparatory factors, making the slope conditionally unstable. Triggering factors of a slope failure can be climatic events which can then make a slope unstable, leading to mass movements. Mass movements can be caused by increase in shear stress, such as loading, lateral pressure, and transient forces. Alternatively, shear strength may be decreased by weathering, changes in pore water pressure, and organic material.

The field of **slope stability** encompasses static and dynamic stability of slopes of earth and rock-fill dams, slopes of other types of embankments, excavated slopes, and natural slopes in soil and soft rock. Slope stability investigation, analysis (including modelling), and design mitigation is typically completed by geologists, engineering geologists, or geotechnical engineers. Geologists and engineering geologists can also use their knowledge of earth process and their ability to interpret surface geomorphology to determine relative slope stability based simply on site observations.

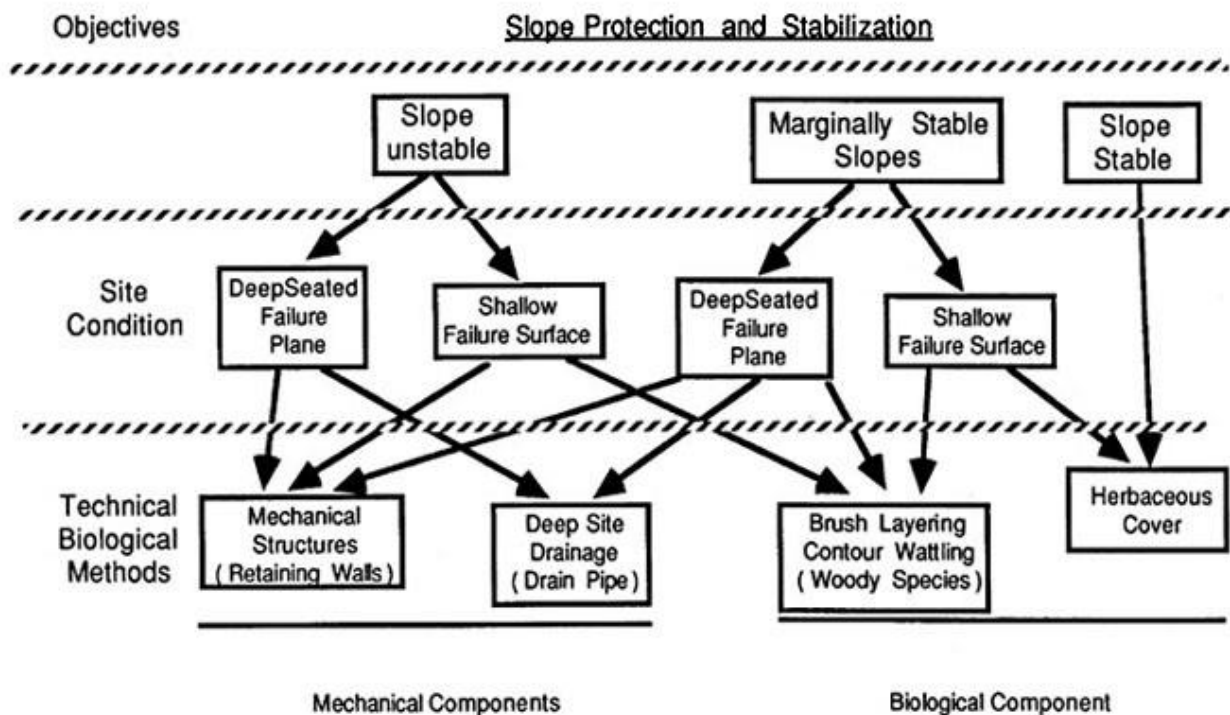


Table 23: Selection criteria for slope stabilization methods

For protection of slope the following types of mitigations can be provided:



Bioengineering



Gabion Wall



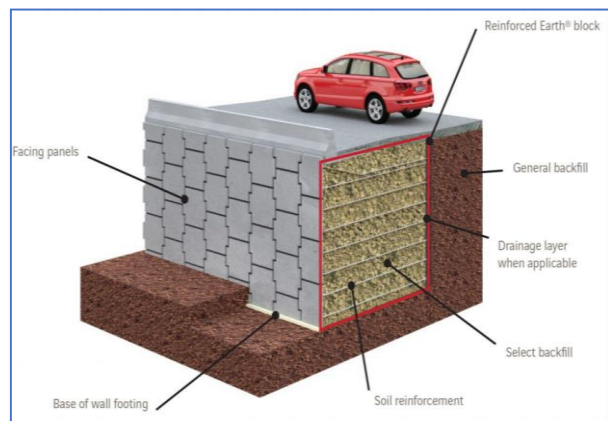
RRM Wall



RCC Wall



Concrete Crib Wall



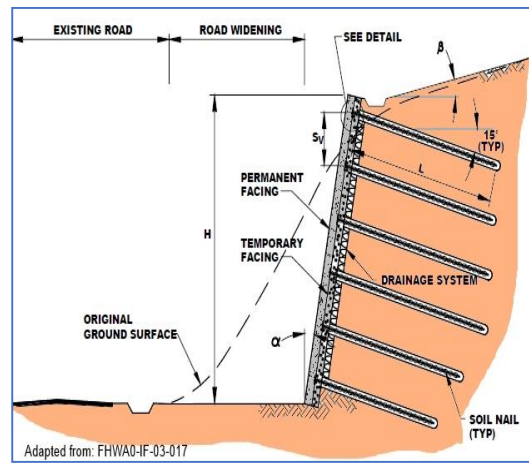
Reinforced Earth Structures



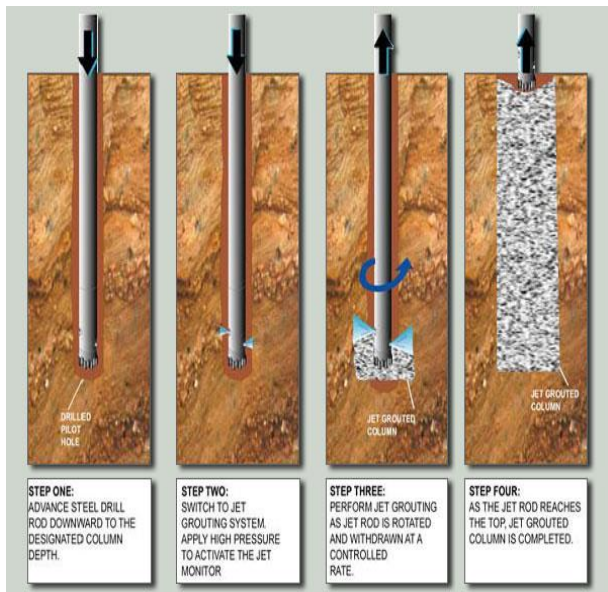
Boulder Wall – Innovative and effective drainage system



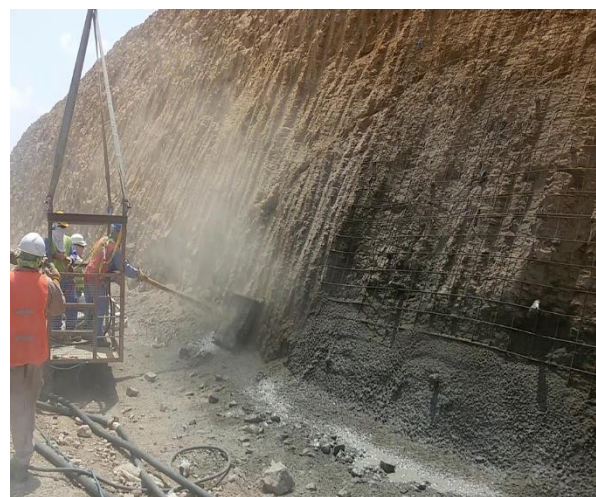
Non-Frame Structure



Soil Nailing



Grouting



Shot-creting

Figure 16: Various Slope Stabilization Measures

## CHAPTER 3 – ROAD CONSTRUCTION

For any new road project, EIA shall be carried out and Environmental Clearance processed with the National Environment Commission/Dzongkhag Environment Section. Proper EMP shall be prepared to avoid damages to the environment. The road shall be constructed using appropriate machines such as excavator, back-hoe loader etc. Bull dozer shall be used only if the road alignment passes through the plain area.

Adequate labour camps, site office with toilet facilities, stores, etc. shall be built at the work site in line with the TS and the contract document.

### 3.1 Construction staking

Prior to the construction activity, the design has to be transferred from the design drawings/plan to the ground. It is done by staking-out and through the batter pegging. Permanent Reference points (RPs) and Bench Marks (BMs) shall be set-up at such locations/points where there is no disturbance. RPs should be established at least 3 to 5 m behind the uphill clearing limits. In case of inevitable disturbance due to the site condition, the permanent points shall be shifted in accordance with the standard survey procedures and process.

### 3.2 Environmental Friendly Road Construction (EFRC) Approach

The cost of road construction is comparatively higher than other construction activity. Due to limited funds, there is a need to adopt “low cost construction approach” and road for all weather. The modern road construction technique should adopt the climate change effect and apply the Environmental Codes of Practice (ECoP). EFRC guideline shall be strictly referred for the construction of roads in the country.

The climatic conditions vary due to the mountainous nature of the country. The country has monsoon rain in summer, with relatively dry winters. About 70% of the land area is covered with forest of temperate and sub-tropical varieties that are a natural habitat of a diversity of flora and fauna. Bhutan has chosen the ‘*middle path*’ where economic development takes place while preserving natural resources and preventing environmental degradation. The Environment Assessment Act of 2000 and the regulation for Environmental Clearance of Projects, 2002 to ensure that environment assessments are conducted for all development activities that have potentially significant environmental impact.

Road construction has a large potential negative impact on the environment. Inadequate road construction techniques cause significant damage to forest, land and water sources and reduce the quality and lifetime of the road. A maximum effort therefore needs to be made to prevent and mitigate the negative impacts of roads. Figure below shows the economic comparison between EFRC & traditional construction method

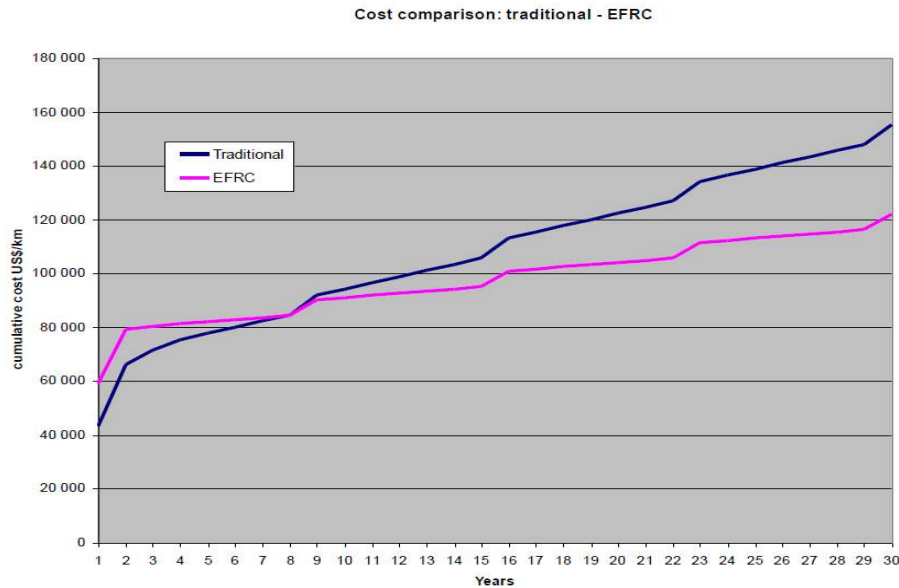


Figure 17: Economic comparison between EFRC & traditional construction method

There are three methods of road construction as below: -

i) Cut and fill method

- creates little or no slope stability problems
- for slope angles of not more than 30 degrees (to avoid retaining structures)

ii) Full fill method

- for areas with rock joints or when bedding or foliation planes dip out of the slope
- In highly erodible soils
- In shallow loose scree or similar deposits
- In slopes with high water table

iii) Full Cut method

- for slope without stability problem
- For steep slope angle
- For areas where the dipping of surplus material is no problem

### 3.3 Clearing and Grubbing of Road Construction Area

Preparing the road right-of-way or construction area is referred to as clearing and grubbing. During the clearing phase, trees are cut and felled. Grubbing refers to the clearing and removal of stumps and organic debris. For felling of trees, prior approval of the forest department needs to be obtained. Trees should be felled and cleared a minimum of 1 to 3 m from the top of the cut or toe of the hill. Figure below shows the minimum clearance to be maintained

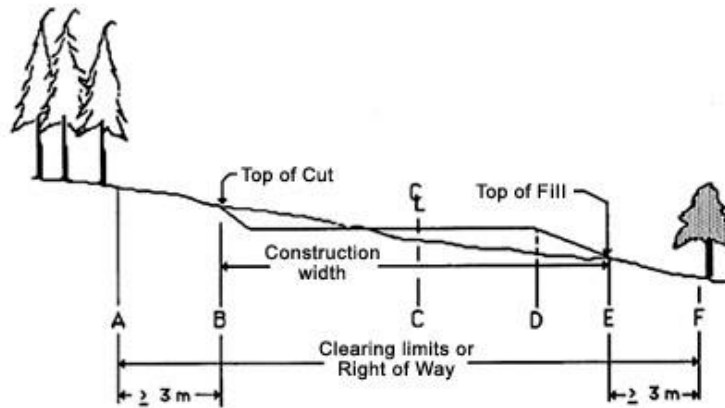


Figure 18: Minimum clearance of 1 to 3m to be maintained

Organic overburden or top soil has to be removed over the full construction width in order to prevent uneven settlement and potential side cast failure. During the grubbing phase or preparation stage, a pioneer/bypass road is often constructed to facilitate the movement of equipment and delivery of materials, such as the construction of bridges and culverts. When pioneer/bypass road is required, they are often built at the top of the construction width with restricted width, just good enough for machine to manoeuvre. Figure below shows that the pioneer/bypass road location at bottom of proposed fill provides a bench for fill materials of completed road.

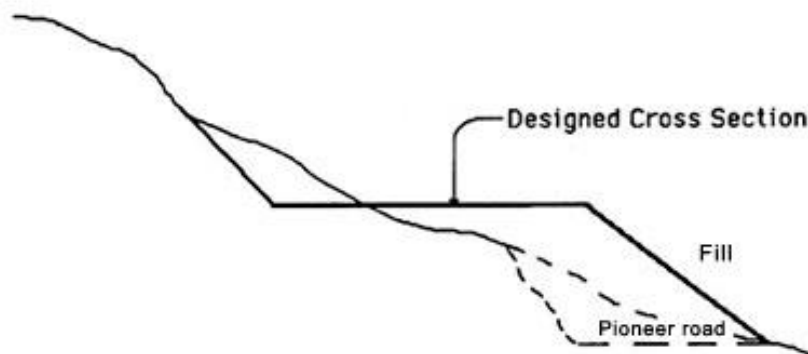


Figure 19: Bypass road serving as a bench for fill materials

### 3.4 General Equipment Considerations

The method and equipment used in road construction is an important economic and design factor in road location and subsequent design. Table 4.1 lists down common road construction equipment and their suitability for different phases of road construction. For example, bulldozer can be used in all phases of road construction from formation cutting until final grading in plain area where the material spillage is not a big concern from the environment aspect. Front-end loader performs well in soft materials while excavator is very effective in hilly areas. The table below shows a list of common road construction equipment and their suitability.

Criteria	Bulldozer	Front end loader	Hydraulic excavator	Dump trucks or scrapers	Farm tractors
<b>Excavation mode (level of control of excavated materials)</b>	Digs and pushes; adequate control (depends on blade type)	Minor digging of soft material; good for lift and carrying	Digs, swings & deposits with excellent control; controls better in avoiding mixing of materials	Scrapers can load themselves and used for small quantities	Minor digging and good in carrying materials
<b>Suitability for fill construction</b>	Adequate	Good	Good and excellent control in levelling the materials	Good for transportation and larger fills	Not suitable
<b>Clearing and grubbing</b>	Good	Adequate	Excellent	Not suitable	Handles only smaller materials
<b>Operating cost per hour</b>	Moderate depending upon machine size	Relatively low	Moderate to high, but excellent productivity	Very high	Low
<b>Special limitations or advantages</b>	Widely available and can do all required works with good operator	Cannot dig hard materials	Widely available and good for roads on steep hill slopes and can do all required jobs	Limited to moving materials long distance	Low and depends on site conditions

*Hydraulic Excavator is usually used for road formation cutting due to its capability to swing and power to load the excavated materials.*

*Table 24: Lists of common road construction equipment and their suitability*

### 3.5 Road Formation

Formation is the finished profile of the road, ready for construction of protective/drainage works, carriageway/pavement, shoulders, drains, parapets etc. Construction of formation on roads generally comprises of the following items of works:

- Jungle Clearance
- Earthwork in excavation
- Earthwork in embankment with suitable materials including protection of slopes
- Temporary structures like drains, stone revetment, soling in weak soil etc. during initial construction

### 3.5.1 Formation Cutting

Environmental friendly method aims to minimize cuts in mountain slopes. Where the slopes are fragile and prone to landslides, a part of the road width shall be made in fill, by constructing retaining walls. The “balance cut and fill method” is normally adopted for road construction. Box cuts are to be avoided as much as possible, unless providing box cut can significantly reduce the road length. Box cut increases the volume of cut and the height of cut as shown in the figure below.

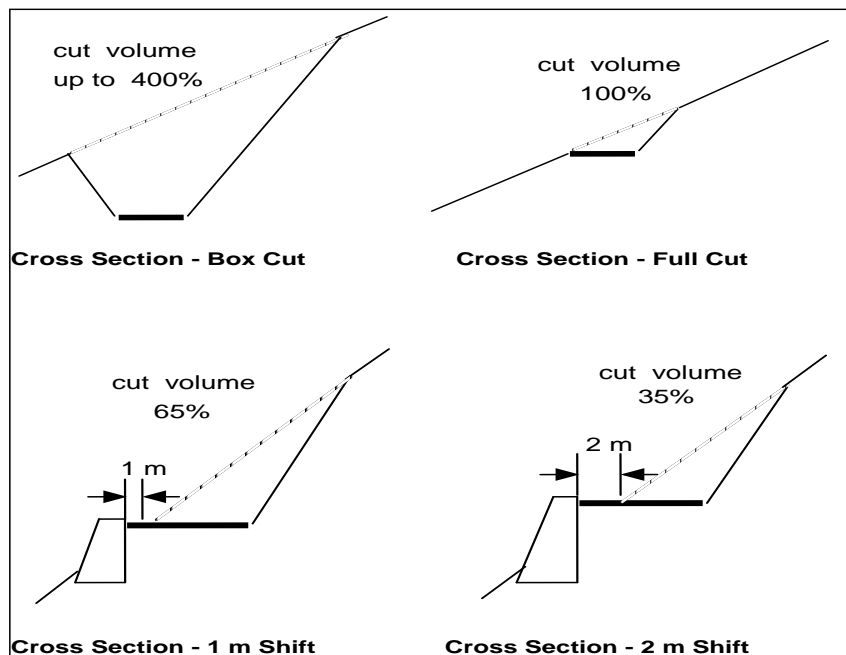


Figure 20: Volume of cut of different methods

Marshy areas are drained-out before excavation is allowed through the construction of gravel drains and other temporary water management structures such as catch drains, earthen drains, etc.

Barriers to be constructed out of logs or boulders at about 10-15 meters below the road to catch falling materials and in some cases to allow for controlled dumping of excavated materials. Wherever possible, trenches are to be built for same purpose and to prevent damage to natural slope further down.



Figure 21: Timber Log barriers to catch falling materials

*In terms of climate change, side slope should be adjusted from 1:0.5 to 1:1 or flatter to prevent flood damage and erosion from road surface runoff. Adjusting side slopes from 1:0.5 to 1:1 will also increase traffic safety of the road. Adjusting side slopes normally requires more land, and if the existing right of way is not sufficient, it might be difficult to acquire additional land. If it is not possible to flatten the slope to 1:1, other measures could be considered, such as protection of slopes with rip-rap or gabion mattresses especially in areas with erosion problems.*

*When the slope height is more than 5m benching of 1m must be provided. A slope angle of 75 degrees must be maintained in rocky slopes and 60 degrees must be maintained in slopes which are composed of soil and gravel.*

### 3.5.2 Blasting Operation

Road construction in the mountainous areas normally requires blasting of hard boulders. In order to minimize damage to the surrounding hill, environment and to prevent destabilization of the slopes, controlled blasting techniques are to be adopted. Blasting operation is to be carried out by a certified and an experienced blaster. The purchase, transport, storage and use of explosives shall be carried out in accordance with **Department of Roads (DoR) “Blasting Manual”** and the by-law issued by the Ministry of Home & Cultural Affairs. Shot hole blasting is not allowed except when explicitly approved as an exception by the engineer. Slopes shattered or loosened by blasting shall be taken down and falling of blasted materials along the valley slope shall be minimized. Only approved explosives brand shall be used.

#### 3.5.2.1 Blasting Plan

**The blasting plan is the basis for:**

- Good blasting work
- Safety at site
- High economy
- Less accidents

### The blasting plan contains:

- Drilling scheme (pattern) - It is the relation of drilled holes to each other and any free faces as part of the blast design.
- Loading scheme (pattern) - It is the charge that is loaded into the drilled holes and determined by the type of blasting.
- Ignition scheme (pattern) - It is the initial energy source required to detonate an explosive used for rock blasting. It is also a distribution network to deliver the energy to each blast hole.

#### 3.5.2.2 Bench Blasting

Bench blasting can be defined as drilling of vertical or angled holes in one or several rows from a free surface. Bench blasting is the most common and basic method of surface rock excavation. The Blasting Manual shall be referred for its parameters, explosives charging calculation, firing method and firing sequences.

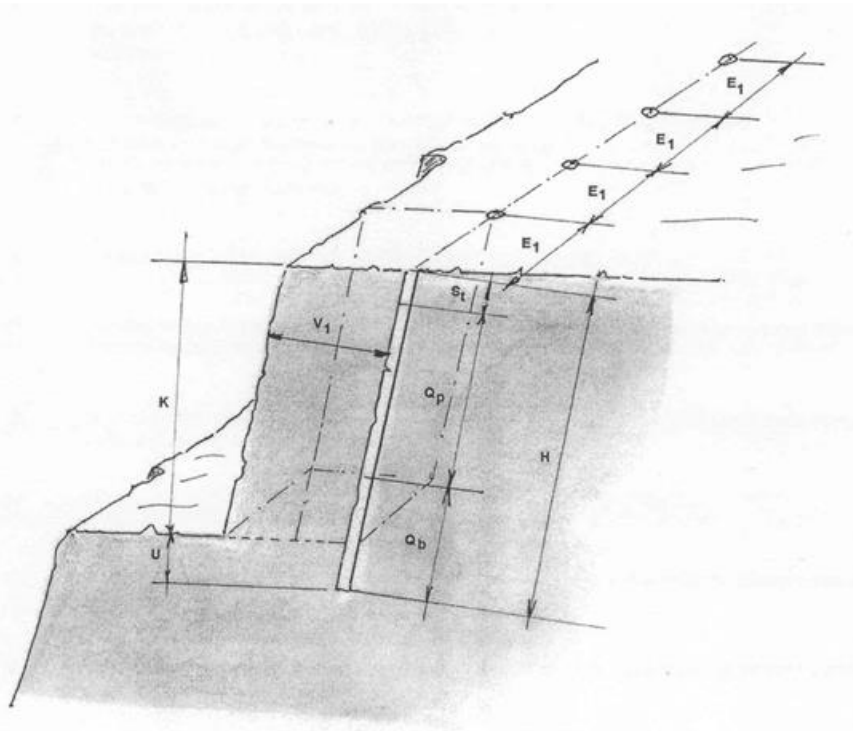


Figure 22: Bench Blasting Plan

#### 3.5.2.3 Boulder Blasting

The breaking down of large stones at quarries by small explosive charges is called boulder blasting. A minimum of 300 m distance needs to be maintained between the structures and site of blasting operation as shown in the figure below:

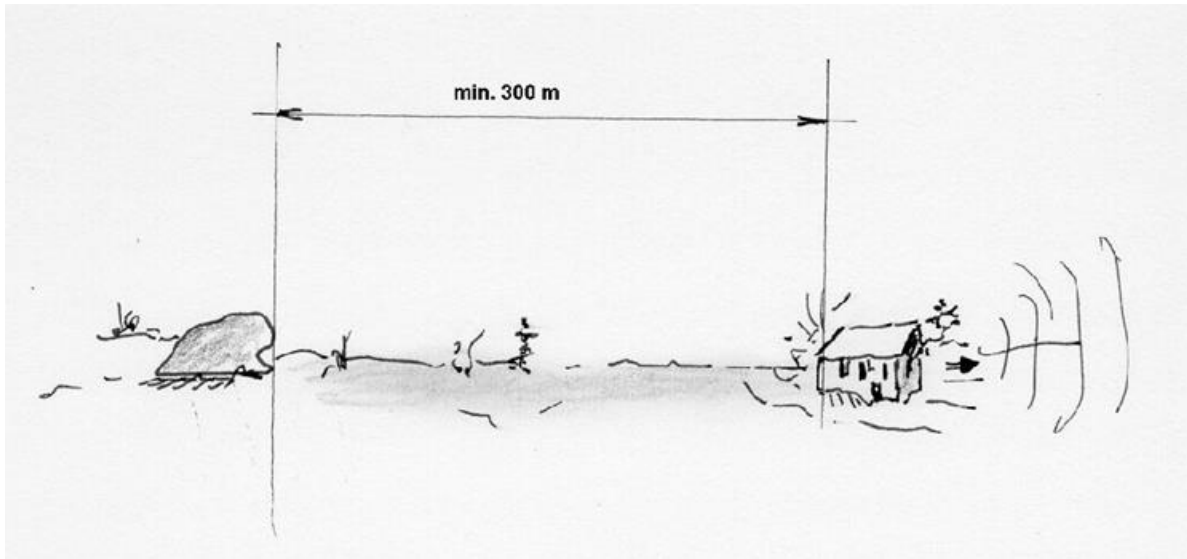


Figure 23: Minimum safe distance to be maintained

#### 3.5.2.4 Controlled Blasting Techniques

Controlled blasting will attempt to modify the type of explosives, or the placement of particular explosives, such that the damage zone created by the perimeter holes does not exceed the damage zone produced by the holes within the perimeter, or vice-versa.

##### 3.5.2.4.1 Conventional Smooth Blasting

Smooth blasting is a special blasting method to protect the surface of the remaining and surrounding rock. The idea is not only to obtain a smooth (regular) surface but also to protect the remaining rock from cracking and to keep it as compact as possible.

Conventional smooth blasting (sometimes also called contour blasting) is carried out **after** the main blasting work by using an explosive with a low charge concentration per metre and other characteristics, which result in a "mild" effect.

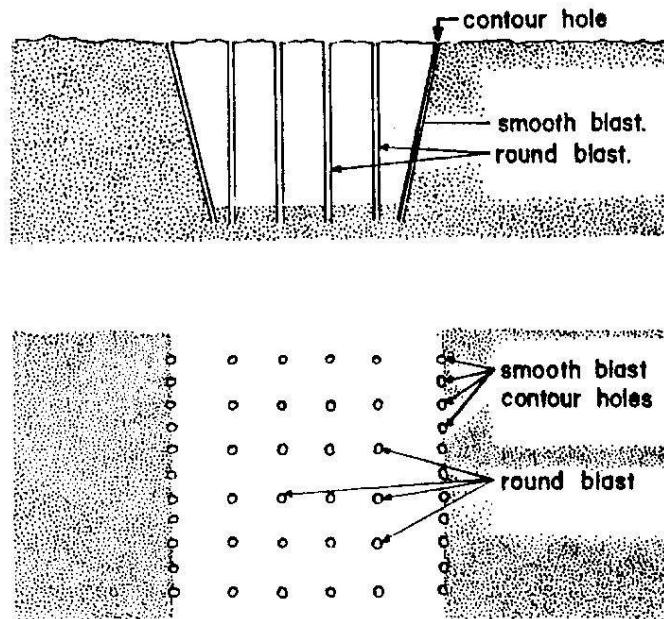


Figure 24: Smooth Blasting Plan

#### 3.5.2.4.2 Presplitting

As opposed to smooth blasting, presplitting is used to blast the contour holes **before** the actual round is fired. Presplitting produces a crack in the rock between the closely spaced contour holes. This crack acts like a shock absorber for the ground vibrations, which cannot travel beyond the crack and, thus, cannot disturb the surrounding rock.

When presplitting is being carried out, it is extremely important to determine the right hole spacing and charges for the type of rock concerned.

Drill hole Ø [mm]	Charge concentration [kg/m drill hole]	Explosive	Burden $V_1$ [cm]	Hole spacing $E_1$ [cm]
25 - 32	0.080	Detonating cord	-	25 - 50

Table 25: Drill hole against charge concentration

Before drilling many holes for a long distance, it is advisable to carry out a sample blasting over a short distance of about five metres. If cracking is too poor, there is usually the possibility to load the drill holes again for a second round of presplitting with a higher charge. The remaining presplitting will then be carried out with the adjusted, higher charge.

Controlled blasting methods are used to control blast induced effects such as over-break, fractures within rock walls and ground vibration. For climate change, controlled technique shall be adopted in order have minimal effects to the ground and rock surfaces. Some of the controlled blasting techniques are: (i) Line Drilling (ii) trim blasting, (iii) buffer blasting, (iv) smooth wall blasting and (v) presplitting and air decking.

### 3.6 Road Embankment Construction

Filling and embankment construction includes the preparation of areas for embankment, to be constructed. All materials used for the construction of fillings and embankments shall be approved by the engineer. Areas to receive fillings and embankments shall be cleared and grubbed, and all existing structures and other obstruction shall be demolished and cleared away. Where groundwater or seepage is encountered, proper measures to be taken as specified in the Technical Specification (TS). Prior to the placing of fill, the sub grade shall be compacted to 95% of the maximum dry density.

Embankment shall be built up evenly over the full width in layers of not more than 200mm compacted thickness and shall be maintained at all times with a sufficient cross-fall and even surface to enable surface water to drain readily. All materials used in embankments shall be compacted as soon as practicable after deposition. Each layer shall be compacted to a density of not less than 98% of the maximum dry density as determined by the Modified Standard Proctor Test. The finishing of the road embankment shall be in accordance with the levels and dimensions provided in the design drawings, including the provision of the temporary side drains.

### 3.7 Climate Change Adaptation Road Construction

Climate change is affecting road infrastructure or the level of service, one way or another. Risk is always there and therefore, proper and effective mitigations need to be incorporated during the construction phase. Following are the salient features of climate resilience in construction phase:

- Special emphasis must be given to hydrological analysis and geotechnical studies.
- Design discharge must be increased by 20 to 25 percent to address increase in rainfall intensity as a result of climate change.
- For proper record keeping of landslides, a Pro-forma (format) has to be maintained regularly and the format is attached in Annexure I.
- A minimum of 5 numbers of cross drainages must be provided per kilometre of road and the minimum size of the cross drainage to be provided is 1200 mm. This must be done in order to account for more discharge and to avoid choking with debris.
- Discharge of water from the outlets of the cross drainages must be managed by providing cascading structures in order to prevent scouring of existing surfaces.
- Controlled blasting techniques must be adopted as far as possible.
- One-sided cross fall shall be provided in single-laned roads to improve drainage of water from pavement.
- Provision of gentle slopes compared to conventional batter slopes, bench cutting, temporary restraining walls like log/timer barriers & boulder barriers shall be made to protect the road from slides. Temporary earthen drains & cross drainages shall be provided to protect valley slope and the washing away of road formation.
- The retaining structures are to be constructed with rich cement mortar of not less than 1:4 in order for the structures to be stronger and durable due to severe climate actions.
- Subsurface drains and materials like geo-cells, gabion cells and geo-synthetics are to be provided below the pavement for the purpose of better drainages especially at marshy areas.

- All road side drainages must be constructed using plum concrete.
- Wherever flexible pavements are not feasible, it is encouraged to check the possibilities of constructing rigid pavement and due procedures must be adopted in design and construction of rigid pavement.
- As far as possible, all excavation shall be carried out during dry weather.
- In case of marshy areas, ground water table needs to be lowered by constructing sub-surface drains.
- Temporary earthen drains are to be constructed for effective draining of excess water.
- The road formation cutting shall be executed true to levels, slopes, shape and pattern as per the design drawings.
- The sides of the excavation shall be dressed or trimmed and bottom shall be levelled or graded and rammed.
- When the cutting has reached to the formation width, temporary V-shaped earthen drain of size 600mm wide and minimum 300mm deep shall be built and maintained till the construction of permanent drain is initiated.
- For safety of workers, machines and commuters, rock netting and temporary gabion walls wherever necessary are to be constructed.
- During construction, environmental management plans prepared and approved are to be used to prevent and mitigate environmental hazards.
- Animal passing places must be provided in embankment and cut slopes where ever possible.
- Special emphasis on bio-engineering must be given.
- In terms of climate change, side slope should be adjusted from 1:0.5 to 1:1 or flatter to prevent flood damage and erosion from road surface runoff wherever possible.
- When the slope height is more than 5m benching of 1m must be provided wherever possible. A slope angle of 75 degrees must be maintained in rocky slopes and 60 degrees must be maintained in slopes which are composed of soil and gravel.
- Wherever open graded carpet is proposed, a seal coat should be provided.
- In areas where annual rainfall is higher than 300cm the entire formation width should be surfaced without leaving any gap between edge of pavement and drain/parapet.
- If sub-grade is salt infested, 225mm sand blanket should be laid on sub-grade before sub-base is considered.
- The resurfacing works must be carried out using asphalt concrete of minimum 30 mm instead of premix carpet.
- The possibilities of recycling and reusing the old asphalt concrete must be explored and carried out as far as possible.

### **3.8 Structures and Protective Works**

Roads in Bhutan are generally constructed by cutting into the hills and thereby disturbing natural stability of slopes. Water and soil movement along the slopes tend to disturb the road formation. The disturbance to the road formation is therefore, protected by provision of structures to act as retaining, restraining and protective structures.

### 3.8.1 Drainage

Drains and cross drainages are must for roads due to numerous watercourses, continuous road gradient and rainfall. Uncontrolled water is the primary cause of problems like soft surfaces, potholes, rutting, and even complete failure of complete sections of roadway structures. A road is good if the degree of drainage achieved is good. The drains and cross drainages shall be built taking into account the effect of climate change.

Drainage problems are generally considered in two categories: surface and sub-surface. Surface drainage or pavement drainage includes the disposal of all water present on the surface of the pavement and adjacent ground. While the sub-surface drainage includes such as French/trench drains, generally built below the subgrade to reduces the moisture content so as to keep the moisture as minimum as possible.

The cost of controlling water is a significant part of total highway construction cost. It is therefore, important to plan and develop adequate facilities for drainage and erosion control. A key rule while planning drainage would be least interference with natural drainage. Minimum interference with natural drainage will mean stable earth face/surface with some kind of vegetative cover preventing erosion and allowing free drainage. Water flowing towards the road surface may be diverted and guided to follow a definite path and the flow on the valley side controlled so that stability is not affected.

A network of drains helps in confining and controlling flow of water and thus checks adverse effect on road structures.

### 3.8.2 Roadside Drains

Roadside drains are very much required on a road. The drains should be invariably taken about 300mm below the road surface. Where cross-fall and super-elevation oppose each other in valley side curves, proper layout of the drain has to be done. Roadside drains should be generally of uniform section throughout irrespective of the location of the road on the hill slope. Road on ridge alignment may not require the same section of drains due to lesser quantity of flow of water. Roadside drains are constructed to parabolic, trapezoidal, triangular, V-shape, L-shaped kerb and channel or U-shaped/box cross sections.

L-shaped drain gives extra road width in case of emergencies for vehicles to use. U-shaped/box drains are generally deep drains and are provided where higher discharge has to be catered and adequate road width is available. As far as practicable, these drains are to be kept free of debris or any foreign matters at all times. Soil debris from the drains should be disposed of properly.

The most commonly adopted roadside drains are shown below: -

- i) V-shaped drain
- ii) Box drains

### 3.8.3 Sub-surface drains:

Increase in the moisture content of subgrade reduces its strength and bearing capacity and hence it should be ensured that the moisture content in the sub-grade is kept as minimum as possible. The entrance of water into the sub-grade soil could be due to one or more of the following situations:

- Water directly percolating through the road surface from above or through the shoulders;
- Seepage from higher ground or natural springs;
- Water rising from below by capillary action in low lying grounds or swamps;
- Leakages from water pipes and irrigation channels and spillages from paddy fields.

### 3.8.4 Transverse trench/French drains

Transverse trench drains are generally provided below the road pavement in a sinking area to facilitate the drainage of seepage water from the hill slopes without damaging the road structure. Sausage blocks of 1.2m x 1.2m in a trench of 1.8m width are constructed on uphill and downhill site. In between these blocks, boulders are properly packed to take the load of road structure and traffic over the transverse trench.

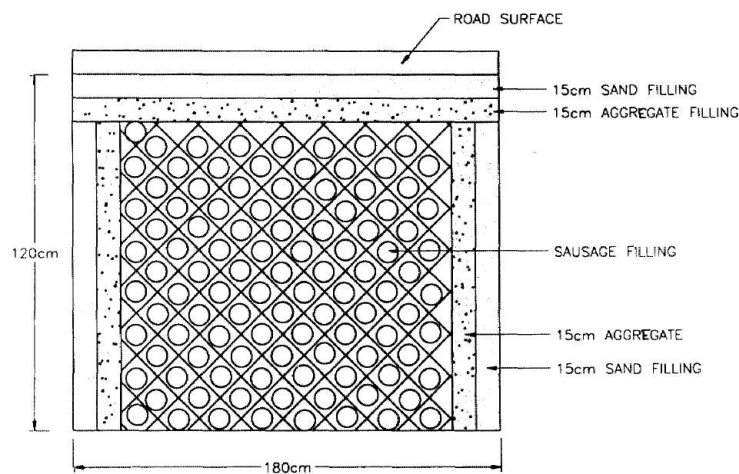


Figure 25: Transverse Trench

### 3.8.5 Cross-Drainage

Cross Drain/culvert is primarily required to reduce overflow of water in the drains and breaking flow velocity. The surface water from the drains is disposed through the cross drains/culverts in order to divert the water away from the road to a water-course or valley. Adequate drains in the form of catch water drains are essential for stability of road. Similarly, the cross drainage structures have to be provided at the location of streams and seasonal gullies.

### 3.8.6 Retaining walls

Masonry structures built to support the downhill side unstable strata or fills are called 'retaining walls'. Depending on the ground condition and its intended purpose, the retaining walls can be constructed in stone masonry, cement concrete, reinforced cement concrete, gabion, wooden/timber/poles etc. Reinforced earth is the latest technology being used now. While the retaining walls shall be constructed as per the design drawings issued, it is very important to take special care of the backfill and its materials, size and slope of the weep holes, bond stone in case of Random Rubble Masonry (RRM).

Based on the types of material, the retaining walls be classified as below:

- i) Random Rubble Masonry
- ii) Composite wall (DRM and RRM)
- iii) RCC

- iv) Timber wall
- v) Gabion wall
- vi) Reinforced Earth wall
- vii) Reinforced mesh wall

### 3.8.6.1 Random Rubble Retaining (RRM) Wall

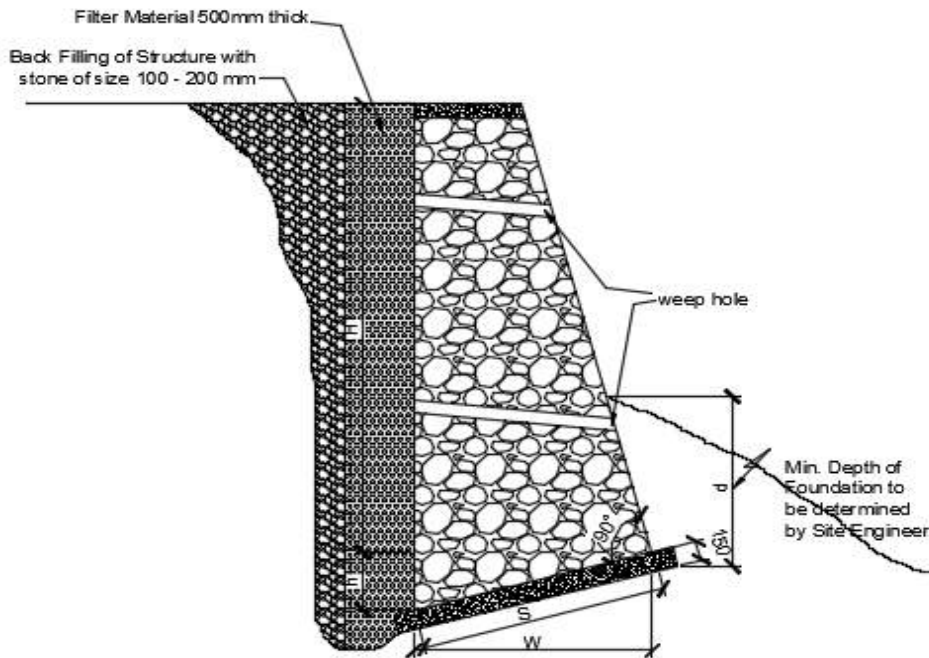


Figure 26: A typical RRM drawing

The retaining wall shall be constructed as per the design drawings and adjusted as per the site soil condition; the adjustment to be endorsed by the site/design engineer. Depth of foundation shall be at least 500mm below the firm ground level. Drainage is an important aspect of retaining wall construction and therefore, weep holes of 100x100mm opening shall be provided at 1.5m interval and staggered both horizontally and vertically. Alternatively pipes of equivalent area may be used. Filter layer of 400-500mm width behind the wall should be provided for effective drainage and it is normally composed of good quality stones of 50-100mm sizes. Geo-textile or bamboo mats shall be substituted in absence of good filter media.

A dip of foundation base (6:1 horizontal to vertical) towards hill side increases the factor of safety against sliding significantly and shall be provided during the construction phase. The longer wall shall be broken down into 10m panels and a gap of 50-100mm maintained. All joints to be cut and staggered. Large size stone shall be used at the corner as the corner stone for stability and aesthetic. Bond or through stone shall be provided at every 1.0m interval both horizontally and vertically throughout the length and height of the wall. Where there is no single stone of large size is available, reinforced concrete blocks of 100x100mm size shall be used as the bond stone.

The retaining wall can be of combination of Dry Random Masonry (DRM) and Random Rubble Masonry (RRM). For DRM, the stones are to be chiselled dressed and placed closely and tightly to avoid collapse of wall under the pressure.

### 3.8.6.2 Timber Crib Wall

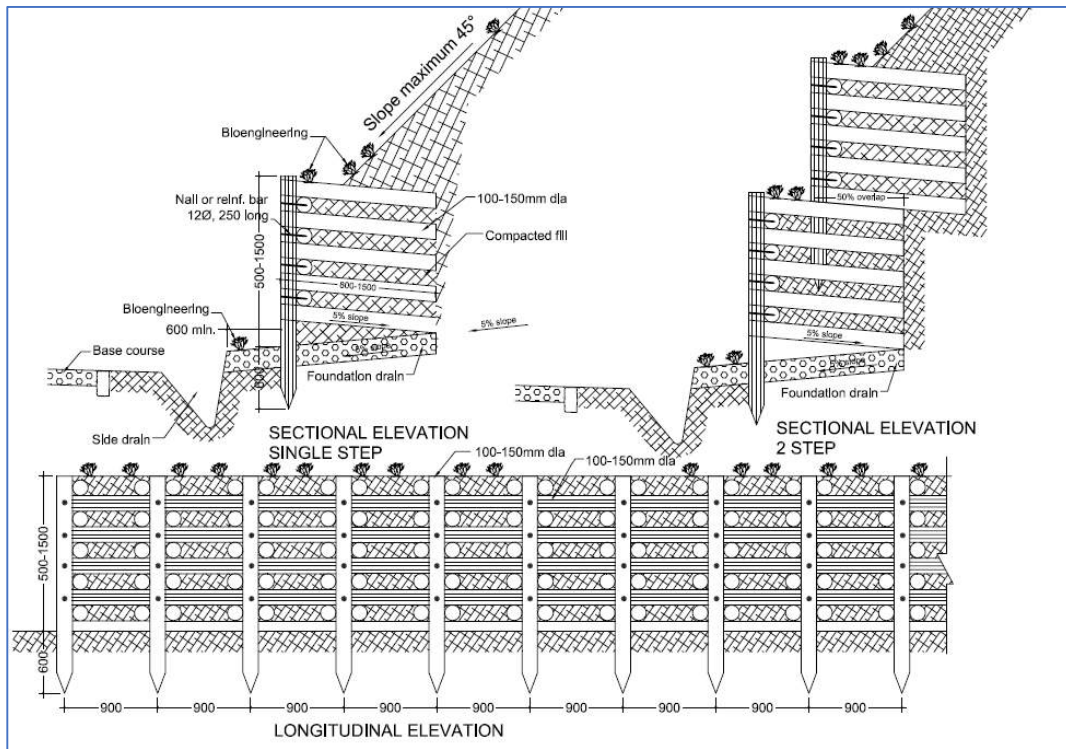
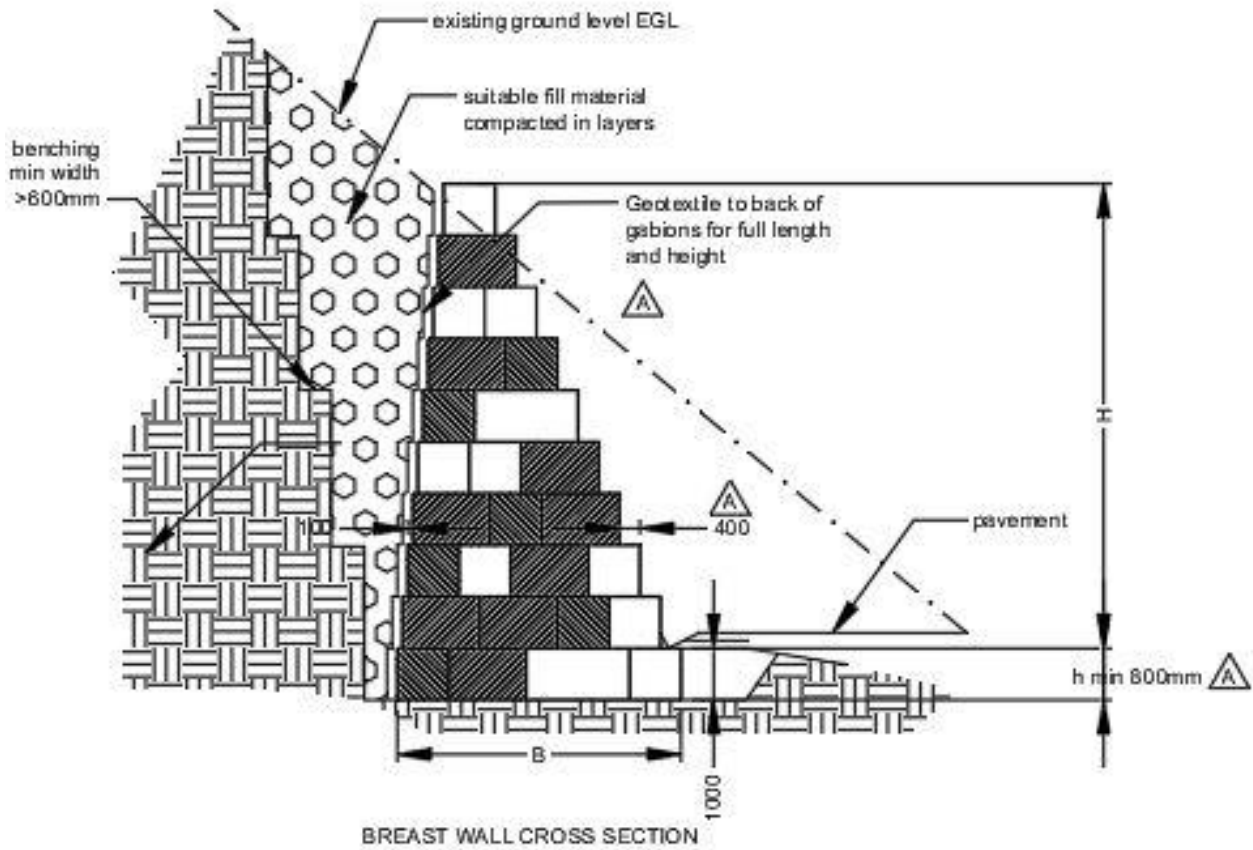






Figure 27: Timber Crib wall

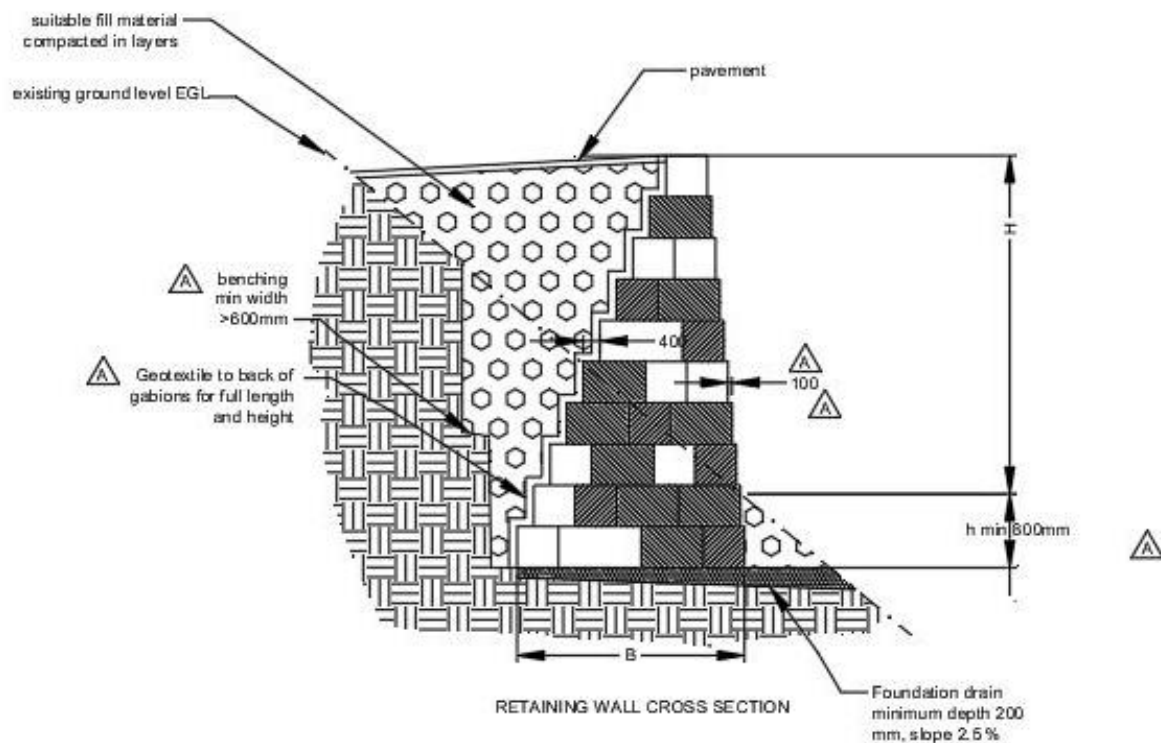
Timber crib wall is a temporary wall constructed using timbers, placed both horizontally and vertically. The maximum single height of timber wall shall be limited to 1.5 – 2.0 m and width of not less than 1m. The gaps between the timbers to be filled in with selected materials of soil and gravels and compacted manually at every layer.

### 3.8.6.3 Gabion Wall



Total Height H+h	2	3	4	5	6	7	8	9	10	11	12
Base Width B	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50

-  1m x 1m x 1.5m gabion
-  1m x 1m x 2m gabion
-  1.5m x 1m x 1m gabion
-  2m x 1m x 1m gabion



**Note**

1. All dimensions in millimetres unless otherwise specified
2. Foundation surfaces are to be approved by the Project Manager
3. Suitable fill shall conform to the Technical Specification Section D9 and D10
4. All gabions shall conform to Technical Specification Section E4
5. All geotextiles shall conform to Technical Specification Section G13
6. Any gap remaining between the edge of the excavation and the last gabion basket at either end, shall be filled with hand packed Dry Rubble Masonry to prevent scouring/erosion at the ends of the wall.

Figure 28: Gabion Wall

Gabion wall is retaining structure made of stacked stone-filled gabions tied together with wire. For stability the gabion walls to be constructed sloped backward and stepped back with the slope. For proper bond and cutting of the joints, regular shaped stone of size not more than 200mm to be used for gabion and all voids filled with smaller sizes. Rounded shaped boulder or stone is not recommended for gabion wall due to large voids and improper cutting of the bed joints. The maximum single height of gabion shall be 1 m and then stepped with a gap of minimum 100mm. 1 m crate box gabion is normally used for gabion wall and the wires are tied properly with the lacing wire.

Reinforced earth/mesh is a composite material formed by the friction between the earth and the reinforcement. This type of wall is fairly new technique available in the 21<sup>st</sup> century and constructed where there is limited space for normal wall construction. The wall consists of RCC panels at the outer and geotextile materials laid across the width and anchored to the

compacted soil. The filling between the outer RCC panels are done with the selected materials and compacted to 95% MDD. This type of wall is normally constructed near the bridge abutment for approaches.

### 3.9 Road Pavement

Design of road pavement for roads, whether in plains or hills follows the same basic principles like soil and traffic parameters as also climate change considerations. However, while designing pavement for roads, specific aspects relevant to the hill regions like terrain and topographic conditions, extreme of weather conditions, altitude effects etc. have also to be duly considered and suitably incorporated in the design so that the pavement is able to perform well for the designed traffic and service life. The different layers of the pavement shall be constructed as per the designed drawings within permissible tolerances given in the table below:

Layer	Level (mm)	Straight edge (mm)	Slope or cross fall (%)
DBM/Bituminous wearing course	+/- 10	6*	+/- 0.25
Bituminous binder course	+/- 10	6	+/- 0.25
Base (WMM layer)	+/- 10	6	+/- 0.25
Sub-base (GSB layer)	+/- 15	10	+/- 0.50
Gravel wearing course	+/- 15	15	+/- 0.50
Formation (subgrade)	+0 -25	20	+/- 0.50

\* *In case of asphalt concrete surface it shall be 4 mm*

Table 26: Tolerances for level and surface regularity

#### 3.9.1 Flexible Pavement

Flexible pavement is composition of a bituminous material surface course and underlying base and sub-base courses. The flexible pavement designed (IRC: 37, IRC: 81) is based on the load distribution characteristics of a layered system; it transmits load to the subgrade through a combination of layers. The flexible pavement can be either in the form of surface treatment, such as bituminous surface treatments generally used on low volume roads OR, asphalt concrete surface courses used on high traffic volume highways.

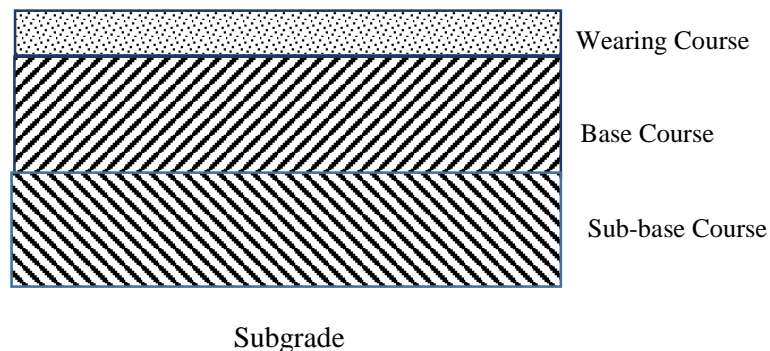


Figure 29: Components of Flexible Pavement

### 3.9.1.1 Subgrade:

It is the native soil compacted underneath a constructed road pavement. It is also called formation level. Sometimes, a **capping layer** (Capping layers are layers of specified materials to be laid and compacted in the subgrade and below, as required, in replacement of in-situ materials to achieve CBR). The subgrade soil strength is normally assessed in terms of the CBR. The conventional procedure for evaluating the sub-grade strength is by determining its laboratory CBR, an empirical index value representing the resistance to penetrate of the subgrade soil. The Dynamic Cone Penetrometer (DCP) test is also conducted to determine the CBR value of the subgrade. For DCP test procedure, refer ASTM-D6951-3 (2003).

In absence of test equipment and result, CBR values of the subgrade can be generally adopted from the table below:

Sl. No	Type of Subgrade	Strength Designation (CBR etc) Range
1	Rocky subgrade, conglomerates, slate	High strength – CBR not the criterion
2	Gravel with binder soil less than 20%, hard slate	Soaked CBR 8-15
3	Gravel with binder soil more than 20%, shale of medium hardness, silty sands	Soaked CBR 5-10
4	Silty clays and soft shale	Soaked CBR 2-5

Table 27: CBR value for different soil strata

Preparation and surface treatment of formation (subgrade) shall be carried out only after completion of all drainage works unless otherwise agreed by the Engineer and prior to laying the sub-base or the base where no sub-base is required.

The sequence of operations shall be as follows:

#### a) Formation of Loose Untreated Materials

Materials for use in the subgrade shall not contain particles larger than 60 mm. In addition, the material shall have a CBR of not less than 5% measured after a 4-day soak on a laboratory mix compacted to 95% MDD (heavy compaction), a swell of less than 1%, a plasticity index of less than 40% and an organic matter content less than 3%. In-situ material in the subgrade in cutting that does not meet these requirements shall either be spoiled or, if suitable, placed in the embankment. The spoiled material shall be replaced with material meeting the requirements for loose material in the subgrade.

The material shall be broken down to the above specified grading and any oversize material that cannot be broken down to the required size shall be removed and disposed of. The material shall be scarified and the moisture content shall be adjusted by either uniformly mixing in water or drying out the material such that the moisture content during compaction is between 95% and 100% of the Optimum Moisture Content. The moisture content shall be kept within these limits until compaction is complete except where otherwise instructed by the Engineer.

- Each layer shall be compacted to a dry density equal to at least 95% MDD (heavy compaction).

- Testing to be carried out during the construction of subgrade shall include the following:
  - The MDD (heavy compaction) and OMC shall be determined for each new material encountered and in every 3000m<sup>2</sup> or part of it of each layer of compacted subgrade.
  - The field dry density shall be determined at least once per 500m<sup>2</sup> or part of it of each layer of compacted subgrade. The test of field density shall be conducted in staggered manner i.e. at left, at crown and at right in the carriageway.
  - The soaked CBR of material in the subgrade shall be determined at least in every 3000m<sup>2</sup> or part of it of each layer.

**b) Formation of Loose Treated Materials**

Where in-situ material in the subgrade in cuttings does not meet the requirements, in-situ materials shall be replaced with selected material from cuttings or borrow pits. Where materials of differing quality are available for placing in the embankments, the Engineer may also instruct that certain materials be excluded from the subgrade and that certain materials be set apart, or obtained from borrow pits for use in the upper layers.

When materials for subgrade are extracted from borrows to form the capping layers shall be natural material complying with the following requirements:

Materials used in capping layers shall be selected among soils classified as GW, GP, GC, SW in the Unified Soil Classification. Materials for use in the capping layers shall not contain particles larger than 60 mm and their percentage passing by weight the 0.075 mm sieve shall be less than 15%. The grading requirement for capping layer materials shall be as shown in the table below:

Sieve Size (mm)	Percent passing by dry weight
50	100
37.5	80 – 100
20	60 – 100
4.75	30 – 100
1.18	15 – 75
0.3	9 – 5
0.075	5 – 15

*Table 28: Grading Requirements for Capping Layer Materials*

**c) Laying and Compaction of subgrade**

The material shall be deposited in the layer of 150 mm compacted depths. Each layer shall extend over the full width of the embankments or cuttings, and shall be compacted in accordance with the Technical Specification issued.

**d) Proof rolling and Tolerances**

All subgrade shall be proof rolled with a power roller of 8 to 12 tonnes. The roller shall run over the subgrade until the soil is evenly and densely consolidated and behaves as elastic mass (the roller shall pass a minimum of five runs on the subgrade). All the undulations in the surface that developed due to rolling shall be made good with material or quarry spoils and the subgrade is re-rolled.

**e) Formations in Rock Cuttings**

The subgrade in rock cuttings shall be regulated after trimming the rock excavation. The finished surface shall be uniform and conform to the lines, grades and typical cross-sections shown in the drawings. When tested with the template and straight edge, the variation shall be within the tolerances specified in the table below:

<b>Longitudinal Profile</b> Maximum permissible undulation when measured with a 3m straight edge	24 mm
<b>Cross Profile</b> Maximum permissible variation from specified profile when measured with a camber template	15 mm

*Table 29: Permissible tolerances of surface regularity*

**3.9.1.2 Sub-base:**

This consists of a well-drained material placed on the subgrade. The granular sub-base (GSB) may be made up of granular materials like natural sand, moorum, gravel, crushed stone or combination of thereof or other materials like stabilized soil which remain static under saturated conditions. Soil aggregate mixes also are suitable for use in sub-base. The sub-base may be in more than one layer and in such case nomenclature as lower sub-base and upper sub-base may be used. Refer pavement design chart of DoR for appropriate thickness of sub-base in the road pavement.

**3.9.1.2.1 Source of materials**

Granular Sub base materials shall be obtained from approved roadside excavation in borrow or cut or from such other sources of supply as may be specified or approved from time to time for use.

**3.9.1.2.2 Material requirement and potential processing**

The source may be river bed or pit gravels, rock quarry, alluvial deposits, crusher-run, or other naturally occurring granular materials meeting the requirements of the Specifications. The

material shall be free from organic or other deleterious constituents and conform to one of the two grading given in the table below:

IS Sieve Designation	% by weight passing the IS Sieve	
	Grading I	Grading II
75.00 mm	100	
53.00 mm	80-100	100
26.50 mm	55-90	70-100
9.50 mm	35-65	50-80
4.75 mm	25-55	40-65
2.36 mm	20-40	30-50
0.425 mm	10-25	15-25
0.075 mm	3-10	3-20
Min Strength of GSB in terms of CBR value after compaction	30	25

Table 30: Grading envelope for GSB materials

**Note:** The material passing 425-micron sieve for all the three grading when tested shall have liquid limit and plasticity index not more than 25 and 6% respectively.

The materials shall have 10% fines value of 50 KN or more (for soaked sample condition) when tested in compliance with BS: 812 (part 111). The water absorption value of the coarse aggregate shall be determined as per IS: 2386 (part 3); if this value is greater than 2%, the soundness test shall be carried out on the materials delivered to the site as per IS: 383.

#### 3.9.1.2.3 Compaction Trials

Before commencing construction and from time to time as may be considered necessary compaction trials shall be carried out on each main type of materials to be compacted in the Works. The length of the trial section shall be minimum 100 m.

#### 3.9.1.2.4 Preparing Underlying Course

Immediately prior to laying of GSB, the subgrade already finished shall be checked for any damage or deficiencies. If necessary, the damage shall be rectified, lightly sprinkled with water and rolled with two passes of 80-100KN smooth wheeled roller.

#### 3.9.1.2.5 Laying

The GSB material shall be spread on the prepared subgrade with the help of a motor grader of adequate capacity, its blade having hydraulic controls suitable for initial adjustment and for maintaining the required slope and the grade during the operation or other means. When the GSB materials consist of combination of materials mentioned above, mixing shall be mechanically done using Pug mill. Manual mixing shall be permitted only where the width of laying is not adequate for mechanical operations, as in small sized jobs. Every reasonable effort

shall be made to prevent segregation during mixing, dumping, spreading, trimming and compacting operations. Moisture content of the loose material shall be checked in accordance with IS: 2720 (part 2) and suitably adjusted by sprinkling additional water.

#### 3.9.1.2.6 Compaction

The minimum layer thickness shall be 100 mm. For minimum thickness, a smooth wheeled roller of 80 to 100 KN weigh may be used for compaction. For a compacted single layer up to 225mm the compaction shall be done with the help of a vibratory roller of a minimum 80 to 100Kn static weight or heavy pneumatic tyred roller of minimum 200 to 300 KN weight. Rolling shall commence at the lower edge and proceed towards the upper edge longitudinally for portions having unidirectional cross fall and super-elevation and shall commence at the edges and progress towards the centre for portions having cross fall on both sides. The speed of the roller shall not exceed 5km per hour. Rolling shall be continued till density is at least 98% of the maximum dry density (MDD) for the material determined as per IS: 2720 (part 8).

On completion of compaction, the surface shall be tight and free from movement under compaction plant and free from compaction planes, ridges, cracks, loose or segregated material. All loose, segregated or otherwise defective areas shall be made good to the full thickness of layer and re-compacted.

#### 3.9.1.2.7 Setting out and Tolerances

The layer shall be set out and constructed to the appropriate tolerances specified in the table 8.3.

#### 3.9.1.2.8 Drainage of subgrade and sub-base

The subgrade and sub-base shall be kept continuously drained and any damage caused by water accumulating on or running off the surface shall be made good. Water accumulated on any part of the subgrade or sub-base, shall be removed and disposed off. Any material which becomes saturated, or cannot then be compacted to the required density, shall be replaced as specified.

#### 3.9.1.2.9 Testing

The minimum testing frequency for the purpose of process control shall be as given in Table 4.9. The GSB generally make up the greatest thickness for the pavement structure and provide bearing strength and drainage for the pavement structure. Hence, proper size, grading shape and durability are important attributes to the overall performance of the pavement structure.

The compaction test shall be carried out at the field at regular interval to ensure required MDD is achieved.

Tests	One test in Every:	Minimum no of tests per section
<b>Material:</b>	200 m <sup>3</sup> or part thereof, and change in source	2
Gradation	200 m <sup>3</sup> or part thereof, and change in source	
Atterberg Limits, Shrinkage	1000 m <sup>3</sup> or part thereof, and change in source	

Maximum Dry Density and Optimum Moisture Content	500 m <sup>2</sup> of each layer	2
Field Density and Moisture Content		2
		2
<b>Construction Tolerances:</b>		
Surface Levels	10 m	-
Thickness	25 m	-
Width	200 m	-

Table 31: GSB - Minimum Testing Frequency

### 3.9.1.2.10 Routine Inspection and Testing

Routine inspection and testing shall be carried out by the Engineer to test the quality of materials and workmanship for compliance with the requirements of this section. Any materials or workmanship not complying with the specified requirements shall be replaced with materials and/or workmanship complying with the specified requirements or be repaired to comply with the specified requirements.

### 3.9.1.3 Base Course:

The base course consists of granular unbound course placed above sub-base and transmits load and shear stress on pavement to sub-grade through sub-base. The base may be water bound macadam (WBM) and wet-mix macadam (WMM).

The work shall consist of laying and compacting clean, graded crushed stone aggregate material, premixed with water, to a dense mass on a prepared subgrade/sub-base/base or existing pavement as the case may be in accordance with the requirements of the Technical Specifications. The material shall be laid in one or more layers as necessary to lines, grades and cross-sections shown on the Drawings or as directed by the Engineer. The thickness of a single compacted Wet Mix Macadam layer shall not be less than 75 mm. When vibrating or other approved types of compacting equipment are used, the compacted depth of a single layer of the sub-base course may be increased to 200mm upon approval of the engineer.

#### 3.9.1.3.1 Materials

##### (i) Aggregates

The aggregate shall be either crushed stone or crushed gravel. The fine aggregate shall be screenings obtained from crushed stone or gravel. The crushed aggregate shall consist of hard, sound, durable and un-weathered stone, rocks, and boulders crushed to specified sizes and shall be free from dirt or other objectionable matter and shall not contain soft or disintegrated pieces. If crushed gravel is used, not less than 90 per cent by weight of the gravel/shingle pieces retained on 4.75 mm sieve shall have at least two fractured faces. The aggregates shall conform to the physical requirements set forth in the table below:

Test	Test Method	Requirements
1 *Los Angeles Abrasion value or *Aggregate Impact value	IS: 2386 (Part 4) IS: 2386 (Part 4) or IS:5640	Maximum 40 per cent Maximum 30 per cent
2 Flakiness & elongation Indices (combined)	IS : 2386 (Part 1)	Maximum 30 per cent**
3 California Bearing Ratio	IS : 2720 (Part 16)	Minimum 80 per cent
4 Crushing Ratio	Manual counting & weighing	Minimum 80 percent

Table 32: Physical Requirements of Coarse Aggregates for WMM Base Course

\* Aggregate shall satisfy requirements of either of the two tests.

\*\* To determine this combined proportion, the flaky stone from a representative sample should first be separated out. Flakiness index is weight of flaky stone divided by the weight of stone sample. Only the elongated particles be separated out from the remaining non-flaky stone metal. Elongation index is the weight of elongated particles divided by total non-flaky particles. The value of flakiness index and elongation index so found are added up.

If the water absorption value of the coarse aggregate is greater than 2 per cent, the soundness test shall be carried out on the material delivered to the site as per IS: 2386(Part-5).

**Grading requirements** - The aggregates shall conform to the grading given in the table below:

Sieve Size (mm)	Per cent by weight passing
50	100
37.5	95-100
20	60-80
12.5	40-60
4.75	25-40
2.36	15-30
0.600	8-22
0.075	0-8

Table 33: Grading Requirements of Aggregates for Wet Mix Base Course

At least 40% of particles retained on a 12.5 mm screen must be angular, irregular or crushed faces.

- Aggregate Hardness Criteria - Aggregate shall have a minimum soaked (overnight) Ten Percent Fines Value of 50KN or a maximum soaked Aggregate Impact Value of 40.
- Plasticity of Fines - The fraction passing the 0.425 mm sieve shall have Plasticity Index (PI) not more than 6 %. As an alternative to testing of PI, a maximum Linear Shrinkage of 3% is applicable.

If the PI approaches the upper limit of 6% ( $4.5 < PI < 6.0$ ), the fines content shall be restricted to the lower end of the grading range given in a) in accordance with the following criteria:

- i) A maximum PP (PI x percentage passing the 0.075mm sieve) of 60, and

- ii) A maximum PM (PI x percentage passing the 0.425mm sieve) of 90.
- California Bearing Ratio (CBR) - The CBR of the material, after 4 days soaking, shall not be less than 40% at 95% MDD (Heavy Compaction).

#### 3.9.1.3.2 Crushing, Screening and Mixing

Crushing shall be carried out in two stages. The crushing, screening and proportioning of materials and their subsequent mixing shall be carried out using methods and machines acceptable to the Engineer. To avoid segregation, graded crushed stone shall be moistened when being handled and shall not be stockpiled in heaps higher than 5 m.

Wet Mix Macadam shall be prepared using Pug mill, and shall be mixed to required moisture content prior to loading and transporting to site.

Optimum moisture for mixing shall be determined in accordance with IS:2720 (Part - 8) after replacing the aggregate fraction retained on 20 mm sieve with material of 4.75 mm to 20 mm size. While adding water, due allowance should be made for evaporation losses, However, at the time of compaction, water in the wet mix should not vary from the optimum value by more than agreed limits. The mixed material should be uniformly wet and no segregation should be permitted.

#### 3.9.1.3.3 Preparation of Sub-layer

The surface of the subgrade/sub-base to receive the WMM shall be prepared to the specified lines and cross fall and made free of dust and other extraneous material. Any ruts or soft yielding places shall be corrected in an approved manner and rolled until firm surface is obtained if necessary by sprinkling water.

#### 3.9.1.3.4 Provision of Lateral Confinement of Aggregates

While constructing WMM, arrangement shall be made for the lateral confinement of wet mix. This shall be done by laying materials in adjoining shoulders along with that of WMM layer and following the sequence of operations described in the subsequent sections that follow.

#### 3.9.1.3.5 Transportation of Wet Mix

Wet mix crushed stone base materials shall be transported and dumped in such a way that no segregation occurs.

#### 3.9.1.3.6 Compaction Trials

The Contractor shall carry out compaction trials in the presence of the engineer on each main type of materials to be compacted in the works. The length of the trial section shall be minimum 100m unless otherwise specified by the engineer. Following completion of the compaction trials, the contractor shall submit to the engineer for his approval to go ahead with the work.

#### 3.9.1.3.7 Laying of Wet Mix

The material shall be deposited in such quantity and spread in a uniform layer across the full width required, so that the final compacted thickness is nowhere less than shown on the Drawings or instructed by the Engineer. Every reasonable effort shall be made to prevent segregation during transportation, dumping, spreading, trimming and compacting operations. In no case should the mix be dumped in heaps directly on the area where these are to be laid nor shall their hauling over a partly completed stretch be permitted.

The wet mix may be spread either by a paver or a motor grader. The motor grader shall be capable of spreading the material uniformly all over the surface. The surface of the aggregate shall be carefully checked with templates and all high or low spots remedied by removing or adding aggregate as may be required. The layer may be tested by depth blocks during construction. No segregation of larger and fine particles should be allowed. The aggregates as spread should be of uniform gradation with no pockets of fine materials.

#### 3.9.1.3.8 Compaction of Wet Mix

After the mix has been laid to the required thickness, grade and cross fall/camber the same shall be uniformly compacted, to the full depth with suitable roller.

The compacted thickness of any layer laid, processed and compacted at one time shall not exceed 150 mm and when a greater compacted thickness is required, the material shall be laid and processed in two or more layers. The minimum compacted layer thickness shall be 75 mm. In portions having unidirectional cross fall/super elevation, rolling shall commence from the lower edge and progress gradually towards the upper edge. Thereafter, roller should progress parallel to the centre line of the road, uniformly over-lapping each preceding track by at least one third width until the entire surface has been rolled.

In portions in camber, rolling should begin at the edge with the roller running forward and backward until the edges have been firmly compacted. The roller shall then progress gradually towards the centre parallel to the central line of the road uniformly overlapping each of the preceding tracks.

Rolling should not be done when the subgrade is soft or yielding or when it causes a wave like motion in the sub-base/base course or subgrade. If irregularities develop during rolling which exceed 12 mm when tested with a 3 metre straight edge, the surface should be loosened and premixed material added or removed as required before rolling again so as to achieve a uniform surface conforming to the desired grade and cross fall. In no case should the use of unmixed material be permitted to make up the depressions.

Rolling shall be continued till the density achieved is at least 98% of the maximum dry density (heavy compaction) for the material as determined by the method as per IS 2720 Part 8.

After completion, the surface of any finished layer shall be well closed, free from movement under compaction equipment or any compaction planes, ridges, cracks and loose material.

#### 3.9.1.3.9 Testing

The minimum testing frequency for process control shall be as given in the table below:

Tests	One test in every	Min. no of tests per section
<b>Materials:</b>		
Gradation	200 m <sup>3</sup> or part of it and change in source	2
Flakiness Index	200 m <sup>3</sup> or part of it and change in source	2
Los Angeles Abrasion	200 m <sup>3</sup> or part of it and change in source	Section 300

Aggregate Impact Value	200 m <sup>3</sup> or part of it and change in source	Section 300
Crushing Ratio	200 m <sup>3</sup> or part of it and change in source	Section 300
California Bearing Ratio	500 m <sup>3</sup> or part of it and change in source	Section 300
Sodium Sulphate Soundness	500 m <sup>3</sup> or part of it and change in source	Section 300
MDD, OMC	1000 m <sup>3</sup> or part of it and change in source	2
Field Density	500 m <sup>2</sup> of each layer	
<b>Construction Tolerances:</b>		
Surface Levels	10 m	-
Thickness	25 m	-
Width	200 m	-
Smoothness	40 m <sup>2</sup>	-

Table 34: Minimum Testing Frequency

### 3.9.1.4 Shoulders

The term "shoulder" means the part of the road falling between the edge of the pavement and the side ditch or embankment slopes above the formation level.

#### 3.9.1.4.1 Material for Construction of Shoulders

Material for construction of shoulders shall be as shown on the Drawing or instructed by the Engineer. It may consist of and include:

- (i) Gravel wearing course or sub base material;
- (ii) Wet mix crushed stone material;
- (iii) Surface of the shoulder may be sealed with bituminous course.

#### 3.9.1.4.2 Construction of Shoulders

Shoulders shall be constructed concurrently with construction of the adjacent pavement layers and with the same materials, except in case the base course is a bituminous mix, the "upper shoulder" shall be constructed subsequent to the base course. Shoulders shall not be constructed ahead of adjacent pavement layers and the Contractor shall ensure that the method of construction is such that at no time water gets prevented from draining off the pavement layers.

#### 3.9.1.5 Wearing Course (Bituminous Binder)

All bituminous binders shall comply with the relevant requirements or ASTM D.

In high rainfall areas, where open graded bituminous surface is done, an appropriate seal coat using ant-stripping agent of 1-1.2% by weight of bitumen to be used;

### Heavy Rainfall Areas – Provision (Climate Change Consideration)

In heavy rainfall areas provision should be made for adequate drainage.

- ✓ Wherever open graded carpet is proposed, a seal coat should be provided;
- ✓ In areas where annual rainfall is higher than 300cm the entire formation width be surfaced without leaving any gap between edge of pavement and drain/parapet;
- ✓ If sub-grade is salt infested, 225mm sand blanket should be laid on sub-grade before sub-base is considered;

Selection criteria for bitumen binder shall be in accordance with IRC: SP:53 and given in the table below:

Lowest Daily Mean Air temperature, °C	Highest Daily Mean Air Temperature, °C		
	Less than 20°C	20 to 30°C	More than 30°C
More than -10°C	VG-10	VG-20	VG-30
-10°C or lower	VG-10	VG-10	VG-20

Table 35: Selection Criteria for Viscosity – Grade (VG) Paving Bitumen Based on Climatic Conditions

Both the highest daily mean air temperature and the lowest daily mean air temperatures can be obtained for the weather station nearest to the project site.

#### 3.9.1.5.1 Storage and Handling of Bituminous Binder

When carried in bulk containers, records of binder temperature during and at the time of storage shall be kept in a manner acceptable to the Engineer. During storage the temperature of the bituminous binder shall be kept as low as possible, consistent with reasonable pumping ability.

Where bitumen emulsions are stored on site in drums, the drums shall be regularly "rolled" to ensure mixing of the contents. Prior to using, all bituminous emulsion drums shall be "rolled" just before opening and use. Emulsions shall be protected against frost and temperatures below 3<sup>0</sup> C.

The bitumen storage area and heating station shall be cleared of vegetation, kept neat and tidy. The drums shall be stacked on their sides in small quantities with gaps between each stack to reduce fire risk.

Bitumen distributors and boilers shall be kept clean at all times. When changing the grade of bitumen and at the end of each day's work, all boilers and distributors shall be thoroughly cleaned out with a solvent. The flushing from boilers and distributors shall not be poured anywhere indiscriminately, but shall be led by drainage channels to disposal pits. Care shall be taken that flushing does not find their way into storm water ditches or streams. All boilers, pre-heating pits, tools, and plant shall be kept scrupulously clean.

When filling the bitumen distributor from the boilers or bulk containers, the bitumen shall be passed through a filter of fine wire mesh having opening of not more than 0.6 mm.

On completion of the works, the disposal pits and drainage channels shall be filled in and top soiled. The site shall be left clean and tidy.

### 3.9.1.5.2 Heating of Bituminous Binder

Pre-mixed bituminous materials shall be prepared in a hot mix plant of adequate capacity and capable of yielding a mix of proper and uniform quality with thoroughly coated aggregates. Appropriate mixing temperatures are given in the table below. The difference in temperature between the binder and aggregate shall at no time exceed 14°C.

Bitumen Viscosity Grade	Bitumen Temperature	Aggregate Temperature	Mixed Material Temperature	Laying Temperature	*Rolling Temperature
VG-30	150-165	150-170	150-165	140 Min	90 Min
VG-20	145-165	145-170	145-165	135 Min	85 Min
VG-10	140-160	140-165	140-160	130 Min	80 Min

Table 36: Mixing, Laying and Rolling Temperatures for Bituminous Mixes (Degree Celsius)

\*Rolling must be completed before the mat cools to these minimum temperatures.

If a continuous type mixing plant is used, the Contractor must demonstrate by laboratory analysis that the cold feed combined grading is within the grading limits specified for that bituminous bound material. In the case of a designed job mix, the bitumen and filler content shall be derived using this combined grading.

### 3.9.1.6 Prime Coat and Tack Coat

A prime coat means a thin layer of low viscosity bituminous binder applied to an absorbent non-bituminous surface. If the prime coat is to be trafficked, it shall be covered with blinding material. While a tack coat means a thin layer of bituminous binder applied to a bituminous surface.

For tack coat, the binder shall be a penetration grade bitumen applied hot immediately prior to laying the bituminous mixture or alternatively a rapid curing cutback RC-800 or medium curing cutback MC30, MC70 or MC-800 applied at sufficient time before laying the bituminous mixture to allow the evaporation of the cutter (solvent).

The choice of a bituminous primer shall depend upon the porosity characteristics of the surface to be primed as classified in IRC: 16.

#### 3.9.1.6.1 Preparation of Surface

The surface to be sprayed shall be thoroughly cleaned by sweeping with mechanical brooms and/or washing or other approved means. All laitance of soil or binder material, loose and foreign material shall be removed. No traffic shall be allowed on the prepared surface.

#### 3.9.1.6.2 Spraying of Prime Coat and Tack Coat

Soon after the surface to be sprayed has been prepared, the edges of the area shall be marked out with a line of string or wire pegged down at intervals not exceeding 15 m on straights or 7.5 m on curves. The prime coat or tack coat shall be sprayed on to it at the specified rate. Spraying shall be carried out not later than 12 hours after the surface has been prepared. The primer shall

be cationic bitumen emulsion SS1 grade conforming to IS :8887 as specified in the Contract. Quantity of SS1 grade bitumen emulsion for various types of granular surface shall be as given in the table below :

Type of Surface	Rate of Spray (kg/sqm)
WMM/WBM	0.7-1.0
Stabilized soil bases/Crusher Run Maccadam	0.9-1.2

Table 37: Quantity of bitumen emulsion for various types of granular surfaces

Type of Surface	Rate of Spray of Binder in kg per sqm
Bituminous surfaces	0.20-0.30
Granular Surfaces treated with primer	0.25-0.30
Cement concrete pavement	0.30-0.35

Table 38: Rate of Application of Tack Coat

#### 3.9.1.6.3 Curing of Tack Coat

The tack coat shall be left to cure until all the volatiles have evaporated before any subsequent construction is started. No plant or vehicles shall be allowed on the tack coat other than those essential for the construction.

The correct quantity of primer shall be decided by the Engineer and shall be such that it can be absorbed by the surface without causing run-off of excessive primer and to achieve desired penetration of about 8-10mm.

#### 3.9.1.6.4 Weather and Seasonal Limitations

Primer shall not be applied during a dust storm or when the weather is foggy, rainy or windy or when the temperature in the shade is less than 10°C. Surfaces which are to receive emulsion primer should be damp, but no free or standing water shall be present. Surface to be just wet by very light sprinkling of water.

Surfaces which are to receive emulsion primer should be damp but no free or standing water shall be present. Surface can be just wet by very light sprinkling of water.

#### 3.9.1.6.5 Construction Methodology

**Equipment** - The primer shall be applied by a self-propelled or towed bitumen pressure sprayer equipped for spraying the material uniformly at specified rates and temperatures. Hand spraying shall not be allowed except in small areas, inaccessible to the distributor, or in narrow strips where primer shall be sprayed with a pressure hand sprayer, or as directed by the Engineer.

**Preparation of Road Surface** – The granular surface to be primed shall be swept clean by power brooms or mechanical sweepers and made free from dust. All loose material and other foreign material shall be removed completely. If soil/moorum binder has been used in the WBM surface, part of this should be brushed and removed to a depth of about 2mm so as to achieve good penetration.

**Application of Bituminous Primer** - After preparation of the road surface, the primer shall be sprayed uniformly at the specified rate. The method for application of the primer will depend on the type of equipment to be used, size of nozzles, pressure at the spray bar and speed of forward movement. The Contractor shall demonstrate at a spraying trial, that the equipment and method to be used is capable of producing a uniform spray, within the tolerances specified.

No heating or dilution of SS1 bitumen emulsion shall be permitted at site. Temperature of bitumen shall be high enough to permit the primer to be sprayed effectively though the jets of the spray and to cover the surface uniformly.

**Curing of Primer/tack coat and Opening to Traffic** - A primed surface shall be allowed to cure for at least 24 hours or such other higher period as is found to be necessary to allow all the moisture/volatiles to evaporate before any subsequent surface treatment or mix is laid. Any unabsorbed primer shall first be blotted with a light application of sand, using the minimum quantity possible. A primed surface shall not be opened to traffic other than that necessary to lay the next course.

#### 3.9.1.6.6 Tolerances

The actual rate of application of bituminous binder across the width of each spray run shall not vary by more than  $\pm 5\%$  of the rate ordered and the actual rate of application of binder for each single run of the spray shall not vary from this specified rate by more than 0.03 litre per square metre.

#### 3.9.1.7 Dense Bituminous Macadam (DBM)

DBM is used as a road base material. The thickness of a single layer shall be 50mm to 100 mm

##### 3.9.1.7.1 Materials

**Bitumen** –The bitumen shall be viscosity grade paving bitumen complying with the Indian Standard Specification IS:73 or as otherwise specified in the Contract.

The type and grade of bitumen to be used shall be specified in the Contract.

**Coarse Aggregates** - The coarse aggregates shall consist of crushed rock, crushed gravel or other hard material retained on 2.36 mm sieve. They shall be clean, hard, and durable, of cubical shape, free from dust and soft or friable matter, organic or other deleterious substances. Where the Contractor's selected source of aggregates has poor affinity for bitumen, the Contractor shall produce test results that with the use of anti-stripping agents, the stripping value is improved to satisfy the specification requirements. The Engineer may approve such a source and as a condition for the approval of that source, the bitumen shall be treated with an approved anti-stripping agent, as per the manufacturer's recommendations, at the cost of the Contractor. The aggregates shall satisfy the requirements specified in the table below:

Where crushed gravel is proposed for use as aggregate, not less than 90 percent by weight of the crushed material retained on the 4.75 mm sieve shall have at least two fractured faces.

Property	Test	Specification	Method of Test
Cleanliness (dust)	Grain size analysis	Max 5% passing 0.075mm sieve	IS:2386 Part I
Particle shape	Combined Flakiness and Elongation Indices*	Max 35%	IS:2386 Part I
Strength	Los Angeles Abrasion Value or Aggregate Impact Value	Max 35% Max 27%	IS:2386 Part IV
Durability	Soundness either Sodium Sulphate or Magnesium Sulphate	Max 12% Max 18%	IS:2386 Part V
Water Absorption	Water Absorption	Max 2%	IS:2386 Part III
Stripping	Coating and Stripping of Bitumen Aggregate Mix	Minimum retained coating 95%	IS:6241
Water Sensitivity	Retained Tensile Strength**	Min 80%	AASTHO 283

*Table 39: Physical requirements for coarse aggregate for DBM*

\* To determine this combined proportion, the flaky stone from representative sample should first be separated out. Flakiness Index is weight of flaky stone metal divided by weight of stone sample. Only the elongated particles are separated out from the remaining (non-flaky) stone metal. Elongation index is weight of elongated particles divided by total non-flaky particles. The values of flakiness index and elongation index so found are added up.

\*\* If the minimum retained tensile test strength falls below 80%, use of anti- stripping agent is recommended to meet the requirement.

**Fine Aggregates** - Fine aggregates shall consist of crushed or naturally occurring mineral material, or a combination of the two, passing the 2.36 mm sieve and retained on the 75-micron sieve. These shall be clean, hard, durable, dry and free from dust, and soft or friable matter, organic or other deleterious matter. Natural sand shall not be allowed in binder courses. However, natural sand up to 50 percent of the fine aggregate may be allowed in base courses. The fine aggregate shall have a sand equivalent value of not less than 50 when tested in accordance with the requirement of IS:2720 (Part 37). The plasticity index of the fraction passing the 0.425mmsieve shall not exceed 4, when tested in accordance with IS:2720 (Part 5).

**Filler** – Filler shall consist of finely divided mineral matter such as rock dust, hydrated lime or cement approved by the Engineer. The filler shall be graded within the limits indicated in the table below:

The filler shall be free from organic impurities and have a plasticity Index not greater than 4. The Plasticity Index requirement shall not apply if filler is cement or lime. Where the aggregates fail to meet the requirements of the water sensitivity test in Table 39, then 2 percent by total weight of aggregate, of hydrated lime shall be used and percentage of fine

aggregate reduced accordingly.

IS Sieve (mm)	Cumulative % by weight of total aggregate
0.6	100
0.3	95 - 100
0.075	85 - 100

Table 40: Grading of filler material

### Aggregate Grading and Binder Content

- When tested in accordance with IS:2386 Part 1 (wet sieving method), the combined grading of the coarse and fine aggregates and filler for the particular mixture shall fall within the limits given in the table below for grading 1 or 2 as specified in the Contract. To avoid gap grading, the combined aggregate gradation shall not vary from the lower limit on one sieve to higher limit on the adjacent sieve.

Grading	1	2
Normal aggregate size*	37.5 mm	26.5 mm
Layer thickness	75 – 100 mm	50 – 75 mm
IS Sieve (mm)	Cumulative % by Weight of total	
45	100	-
37.5	95 - 100	100
26.5	63 - 93	90 - 100
19	-	71 - 95
13.2	55 - 75	56 - 80
9.5	-	-
4.75	38 - 54	38 - 54
2.36	28 - 42	28 - 42
1.18	-	-
0.6	-	-
0.3	7 - 21	7 - 21
0.15	-	-
0.075	2 - 8	2 - 8
Bitumen content % by mass of total mix	Min. 4 **	Min. 4.5 **

Table 41: Grading limits

- \* The nominal maximum particle size is the largest specified sieve size upon which any of the aggregate is retained.
- \*\* Corresponds to specific gravity of aggregates being 2.7. In case aggregate have specific gravity more than 2.7, the minimum bitumen content can be reduced proportionately. Further the region where highest

daily mean air temperature is 30°C or lower and lowest daily air temperature is - 10°C or lower, the bitumen content may be increased by 0.5 percent

**Mixture Design** - Requirement for the mixture: Apart from conformity with the grading and quality requirements for individual ingredients, the mixture shall meet the requirements set out in the table below:

Properties	Viscosity Grade Paving Bitumen	Modified bitumen		Test Method
		Hot climate	Cold climate	
Compaction level	75 blows on each face of the specimen			
Minimum stability (KN at 600C)	9.0	12 .0	10 .0	AASTHO T245
Marshall flow (mm)	2-4	2. 5- 4	3.5-5	AASTHO T245
Marshall Quotient ( $\frac{Stability}{Flow}$ )	2-5	2.5-5		MS-2 and ASTM D2041
% air voids	3-5			
% voids filled with bitumen (VFB)	65-75			
Coating of aggregate particle	95% minimum			IS:6241
Tensile strength ratio	80% minimum			AASTHO T283
% Voids in Mineral Aggregate (VMA)	Minimum percent voids in mineral aggregate (VMA) are set out in Table 12.10			

Table 42: Requirements for Dense Bituminous Macadam

Nominal Maximum Particle Size	Minimum VMA Percent Related to Design Percentage Air voids		
	3.0	4.0	5.0
26.5	11.0	12.0	13.0
37.5	10.0	11.0	12.0

Table 43: Minimum percent voids in mineral aggregate (VMA)

Note: Interpolate minimum voids in the mineral aggregate (VMA) for designed percentage air voids values between those listed.

### 3.9.1.7.2 Job mix formula:

The contractor shall inform the engineer in writing, at least 20 days before the start of the work, of the job mix formula proposed for use in the works. While establishing the job mix formula, the contractor shall ensure that it is based on a correct and truly representative sample of the materials that will actually be used in the work and that the mixture and its different ingredients satisfy the physical and strength requirements of these specifications.

The approved job-mix formula shall remain effective unless and until a revised job mix formula is approved. Should a change in the source of materials be proposed, a new job mix formula shall be forwarded to the engineer for approval before placing of the material.

**Plant trials – permissible variation in job mix formula:** Once the laboratory job mix formula is approved, the plant trials at the mixer to establish that the plant can be set up to produce a uniform mix conforming to the approved job mix formula. The permissible variations of the individual percentages of the various ingredients in the actual mix from the job mix formula to be used shall be within the limits. Once the plant trials have demonstrated the capacity of the plant and the trials are approved, the laying operation shall commence.

Bitumen penetration	Bitumen mixing (° C)	Aggregate mixing (° C)	Mixed Material(° C)	Rolling (° C)	Laying (° C)
35	160 – 170	160 – 175	170 Max.	100 Min.	130 Min.
65	150 – 165	150 – 170	165 Max.	90 Min.	125 Min.
90	140 – 160	140 – 165	155 Max.	80 Min.	115 Min.

Table 44: Manufacturing and rolling temperatures

**Laying Trials:** Suitable area which is not to form part of the works, unless specifically approved in writing, by the Engineer. The area of the laying trials shall be a minimum of 100 sqm of construction similar to that of the project road, and shall be in all respects, particularly compaction, the same as the project construction, on which the bituminous material is to be laid.

The plant trials shall then establish if the proposed laying plant, compaction plant, and methodology is capable of producing satisfactory results. The density of the finished paving layer shall be determined by taking cores, no sooner than 24 hours after laying, or by other approved method.

Once the laying trials have been approved, the same plant and methodology shall be applied to the laying of the material on the project, and no variation of either shall be acceptable.

**Weather and Seasonal Limitations:** Laying shall be suspended while freestanding water is present on the surface to be covered, or during rain, fog and dust storms. After rain, the bituminous surface, prime or tack coat shall be blown off with high pressure air jet to remove excess moisture, or the surface left to dry before laying shall start. Laying of bituminous

mixture shall not be carried out when the air temperature at the surface on which it is laid is below 10<sup>0</sup>C, or when the wind speed at any temperature exceeds 40 km/h at 2m height.

**Preparation of Base, prime coat and tack coat:** The base on which the dense Graded bituminous material is to be laid shall be thoroughly swept clean by a mechanical broom and the dust removed by compressed air

**Mixing and Transportation of the mixture:** The premixed bituminous material for DBM/AC shall be prepared in a hot-mix plant of adequate capacity and capability of yielding a mix of proper and uniform quality with thoroughly coated aggregates at appropriate mixing temperatures.

The bituminous material should be transported in clean insulated vehicles, and unless otherwise agreed by the engineer, shall be covered while in transit or waiting tipping.

**Spreading:** Except in areas where a mechanical paver cannot access, bituminous materials shall be spread, levelled and tamped by an approved self-propelled paving machine. As soon as possible after arrival at site, the materials shall be supplied continuously to the paver and laid without delay. The rate of delivery of material to the paver shall be regulated to enable the paver to operate continuously. The travel rate of the paver, and its method of operations, shall be adjusted to ensure an even and uniform flow of bituminous material across the screed, free from dragging, tearing and segregation of the material.

Bituminous material shall be kept clean and uncontaminated. The only traffic permitted to run on bituminous material to be overlaid shall be that engaged in laying and compacting the next course or, where a binder course is to be sealed or surface dressed, that engaged on such surface treatment.

**Rolling:** Bituminous materials shall be laid and compacted in layers which enable the specified thickness, surface level, regularity requirements and compaction to be achieved. Compaction of bituminous materials shall commence as soon as possible after laying. Compaction shall be substantially completed before the temperature falls below the minimum rolling temperature. Rolling of the longitudinal joints shall be done immediately behind the paving operation. After this, rolling shall commence at the edges and progress towards the centre longitudinally except that on super-elevated and uni-directional cambered portions, it shall progress from the lower to the upper edge parallel to the centre line of the pavement. Rolling shall continue until all roller marks have been removed from the surface.

**Opening to traffic:** The newly laid surface shall not be open to traffic for at least 24 hrs after laying and completion of compaction, without the express approval of the Engineer in writing.

#### **3.9.1.8 Asphalt Concrete (AC)**

This work shall consist of construction in a single layer of bituminous concrete on a previously prepared bituminous macadam surface. A single layer shall be 30mm minimum and 80mm maximum as the wearing course.

### 3.9.1.8.1 Materials

**Bitumen:** The bitumen shall be viscosity graded paving bitumen complying with Indian Standard Specification for paving bitumen, IS:73 or as specified in the Contract. The type and grade of bitumen to be used would depend upon the climatic conditions and the traffic.

**Coarse Aggregates:** The coarse aggregates shall consist of crushed rock, crushed gravel or other hard material retained on 2.36 mm sieve. It shall be clean, hard, durable and cubical shape, free from dust and soft organic and other deleterious substances. Before approval of the source, the aggregates shall be tested for stripping. Where the Contractor's selected source of aggregates has poor affinity for bitumen, as a condition for the approval of that source, the bitumen shall be treated with approved anti-stripping agents, as per the manufacturer's recommendations, without additional payment.

The coarse aggregates shall satisfy the physical requirements given in the table below and where crushed gravel is proposed for use as aggregate, not less than 95 percent by weight of the crushed material retained on the 4.75 mm sieve shall have at least two fractured faces.

Property	Test	Specification	Method of Test
Cleanliness (dust)	Grain size analysis	Max 5% passing 0.075 mm sieve	IS:2386 Part I
Particle shape	Combined Flakiness and Elongation Indices	Max35%	IS:2386 Part I
Strength	Los Angeles Abrasion Value or Aggregate Impact Value	Max30% Max 24%	IS:2386 Part IV
Durability	Soundness either Sodium Sulphate or Magnesium Sulphate	Max 12% Max 18%	IS:2386 Part V
Polishing	Polished Stone Value	Min 55	BS:812-114
Water Absorption	Water Absorption	Max2%	IS:2386 Part III
Stripping	Coating and Stripping of Bitumen Aggregate Mix	Minimum retained coating 95%	IS:6241
Water Sensitivity	Retained Tensile Strength*	Min 80%	AASHTO 283

Table 45: Physical Requirements for Coarse Aggregate for Bituminous Concrete

If the minimum retained tensile test strength falls below 80 percent, use of anti-stripping agent is recommended to meet the requirement.

**Fine Aggregates:** Fine aggregates shall consist of crushed or naturally occurring mineral material, or a combination of the two, passing the 2.36 mm sieve and retained on the 75-micron sieve. These shall be clean, hard, durable, dry and free from dust, and soft or friable matter, organic or other deleterious matter. Natural sand shall not be allowed in binder courses. However, natural sand up to 50 percent of the fine aggregate may be allowed in base courses. The fine aggregate shall have a sand equivalent value of not less than 50 when tested in accordance with the requirement of IS:2720 (Part 37). The plasticity index of the fraction passing the 0.425 mm sieve shall not exceed 4, when tested in accordance with IS: 2720 (Part5).

**Filler:** Filler shall consist of finely divided mineral matter such as rock dust, hydrated lime or cement. The filler shall be free from organic impurities and have a Plasticity Index not greater than 4. The Plasticity Index requirement shall not apply if filler is cement or lime. Where the aggregates fail to meet the requirements of the water sensitivity test, then 2 percent by total weight of aggregate, of hydrated lime shall be used and percentage of fine aggregate reduced accordingly.

IS Sieve (mm)	Cumulative % by weight of total aggregate
0.6	100
0.3	95-100
0.075	85-100

Table 46: Grading of filler material

**Aggregate Grading and Binder Content:** When tested in accordance with IS:2386 Part 1 (Wet grading method), the combined grading of the coarse and fine aggregates and filler shall fall within the limits shown in the table below. The grading shall be as specified in the Contract.

Grading	1	2
Nominal aggregate size*	19 mm	13.2 mm
Layer thickness	50mm	30-40 mm
IS Sieve (mm)	Cumulative % by weight of total aggregate passing	
45		
37.5		
26.5	100	
19	90-100	100
13.2	59-79	90-100
9.5	52-72	70-88
4.75	35-55	53-71

2.36	28-44	42-58
1.18	20-34	34-48
0.6	15-27	26-38
0.3	10-20	18-28
0.15	5-13	12-20
0.075	2-8	4-10
Bit. content % by mass of total mix	Min 5.2*	Min 5.4**

Table 47: Aggregate Grading

- \* The nominal maximum particle size is the largest specified sieve size up on which any of the aggregate is retained.
- \*\* Corresponds to specific gravity of aggregate being 2.7. In case aggregate have specific gravity more than 2.7, the minimum bitumen content can be reduced proportionately. Further the region where highest daily mean air temperature is 30°C or lower and lowest daily air temperature is - 10°C or lower, the bitumen content may be increased by 0.5 percent

**Mixture Design:** Requirement for the mixture: Apart from conformity with the grading and quality requirements for individual ingredients, the mixture shall meet the requirements set out in the table below:

Asphalt Concrete	Wearing Course	Binder Course, Regulating/Levelling Course
Marshall Stability (75 blows/face, N)	Min 8000	Min 6000
Flow Value (mm)	2 - 6	2 – 6
Voids in total Mix (%)	2 - 6	3 - 7
Compression/Immersion Ratio <sup>2</sup>	>0.75	>0.75

Table 48: Requirements for Asphalt Concrete

### 3.9.1.8.2 Job mix formula

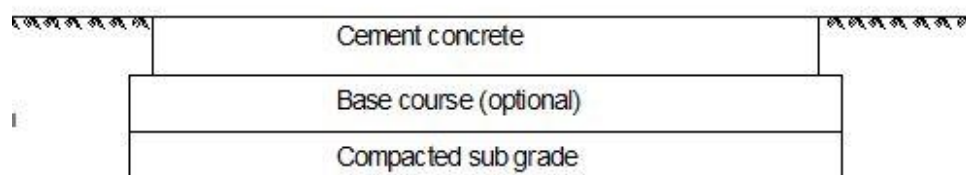
The contractor shall inform the engineer in writing, at least 20 days before the start of the work, of the job mix formula proposed for use in the works. While establishing the job mix formula, the contractor shall ensure that it is based on a correct and truly representative sample of the materials that will actually be used in the work and that the mixture and its different ingredients satisfy the physical and strength requirements of these specifications.

The approved job-mix formula shall remain effective unless and until a revised job mix formula is approved. Should a change in the source of materials be proposed, a new job mix formula shall be forwarded to the engineer for approval before placing of the material.

### 3.9.2 Rigid Pavement

A rigid pavement is constructed from cement concrete or reinforced concrete slabs. The design of rigid pavement is based on providing a structural cement concrete slab of sufficient strength to resist the loads from traffic. IRC: 58, IRC: 15, IRC: 76 and IRC: SP62 shall be referred to for design and construction of rigid pavement.

A “Rigid Pavement” is cement concrete pavement, plain or reinforced laid over a base course. While using plain concrete, some reinforcement becomes necessary at joints, provided to relieve stresses due to expansion, contraction, warping or to facilitate construction. On the other



hand, reinforcement may also be used to take due care of the stresses arising due to temperature fluctuation. In that case it is known as temperature reinforcement. Heavy reinforcement used without breaks or joints is usually known as continuously reinforced concrete where the reinforcement is expected to take care of both temperature stresses and also load stresses to some extent.

#### 3.9.2.1 Material

**Cement:** Any of the following types of cement capable of achieving the design strength may be used with prior approval of the Engineer, but the preference should be to use the 43 Grade:

- i. Ordinary Portland Cement 53 Grade, IS 1 2269
- ii. Ordinary Portland Cement 43 Grade, IS 8112
- iii. Portland-Pozzolana Cement IS 1489 (Part 1) (with fly ash content not more than 20 percent by weight of PPC)
- iv. Portland Slag Cement, IS 455 (with Granulated Blast Furnace Slag content not more than 50 percent by weight of Portland Slag Cement)

**Aggregates:** Aggregates for pavement concrete shall be natural material complying with IS383 but with a Los Angeles Abrasion Value not more than 35 percent. The limits of deleterious materials shall not exceed the requirements set out in IS 383.

The aggregates shall be free from chert, flint, chalcedony or silica in a form that can react with the alkalis in the cement. In addition, the total chlorides content expressed as chloride ion content shall not exceed 0.06 percent by weight and the total sulphate content expressed as sulphuric anhydride (SO<sub>3</sub>) shall not exceed 0.25 percent by weight.

Although IS 383 permits in the case of stone crushed sand, the fines passing 75 microns up to 15 percent. However, this provision should be used with caution when crushed stone sand is used as fine aggregate and when the mix produced in the Laboratory and the field is satisfactory in all respects and complies with the requirement of Specification. The grading zone of fine aggregates as per IS 383 shall be within the limits as given in Table below:

IS Sieve Designation	Percentage Passing for			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4.75 mm	90 - 100	90 - 100	90 - 100	95 - 100
2.36 mm	60 - 95	75 - 100	85 - 100	95 - 100
1.18 mm	30 - 70	55 - 90	75 - 100	90 - 100
600 micron	15 - 34	35 - 59	60 - 79	80 - 100
300 micron	5 - 20	8 - 30	12 - 40	15 - 50
150 micron	0 - 10	0 - 10	0 - 10	0 - 15

Table 49: Fine Aggregates Requirements of different Grading Zone

Note: -

- i) Where concrete of high strength and good durability is required, fine aggregates conforming to any one of the four grading zones may be used. From grading zones, I to IV, the fine aggregate grading becomes progressively finer and therefore the ratio of fine aggregate to coarse aggregate should be progressively reduced. In all cases concrete mix should be properly designed as per IRC:44 recommendations. Mix design shall be guided by the actual grading, particle shape and surface texture of both fine and coarse aggregate.
- ii) Where the grading in all Grading Zones falls outside the limits of any particular grading zone of sieves other than 600 microns IS Sieve by a total amount not exceeding 5 percent, it shall be regarded as falling within that grading zone. This tolerance shall not be applied to percentage passing the 600 micron IS Sieve or to percentage passing any other sieve size on the coarse limit of grading zone I or the final limit of grading zone IV.
- iii) For crushed stone sands, the permissible limit on 150-micron IS Sieve is increased to 20 percent. The use of crushed stone sand is permitted in PQC. However, its percentage of fines passing 75-micron sieve shall not exceed 8percent.

**Steel:** These shall conform to the requirements of IS 432, and IS 1786 as relevant. The dowel bars shall conform to Grade S 240 (with yield strength 240 MPa) and tie bars (deformed/plain) to Grade Fe 500 deformed steel bars as per IS 1 786/IS 432. Tie bars may be plain or deformed. If steel mesh is used, it shall conform to IS 1 566. The steel shall be coated with epoxy paint for protection against corrosion, wherever required.

**Temperature reinforcement:** Whenever the steel bars are used as temperature reinforcement bars, those shall be deformed steel bars as per IS 1786 and shall preferably be welded. Where spot welding is not possible these bars can be tied with binding wire to form the mesh. The size and spacing of bars depends on the design considerations, material properties and climatic condition of the region, but in any case the weight of the mesh shall not be less than 3.14 kg/sqm. The steel mesh may be placed in the upper half of the slab between say 50-75 mm below the top surface and to be sufficiently above the dowel bars such as not to cause any interference to their movement.

**Fibers:** Fibers may be used subject to the provision in the design/approval by the Engineer to reduce the shrinkage cracking and post-cracking. The fibers may be steel fiber as per IRC: SP:46 or polymeric synthetic fibers. The polymeric synthetic fibers will be within the following range of specifications:

- Effective Diameter 10 micron—1000 micron
- Length 6-48 mm

- Specific gravity more than 1.0
- Suggested dosage 0.6-2.0 kg/cu.m (0.2-0.6 percent by weight of cement in mix).
- Usage will be regulated as stipulated in IRC:44/IS 456.
- Water absorption less than 0.45 percent
- Melting point shall not be less than 160°C.
- The aspect ratio shall vary from 200 to 2000.
- Synthetic fibers shall have good alkali and UV light resistance.

When fibers are used, the mix shall be so designed that the slump of concrete at paving site shall be in the range of 25±10 mm and that in manual construction using needle vibrators for compaction, the slump shall not be more than 40 ±10 mm.

### 3.9.2.2 Proportioning of Concrete

#### 3.9.2.2.1 Proportioning on the basis of strength

In case of dry lean concrete, mix design shall be done as per IRC: SP:49 and in case of Pavement Quality Concrete (PQC), guidance for mix design, may be taken from IRC:44 for ascertaining the flexural/compressive strength of cement concrete required to match with the prescribed design strength of concrete. As the stresses induced in concrete pavements are mainly flexural, it is required that their design is based on the flexural strength of concrete in all major projects. The mix shall be so designed in the laboratory as to ensure the minimum flexural strength in the field with the desired tolerance level as per IS 516. To achieve the desired minimum strength in the field, the mix in the laboratory shall be designed for somewhat higher strength, making due allowance for the type and extent of quality control likely to be obtained in the field so as to ensure that minimum strength is achieved in the field. To achieve the desired minimum flexural strength  $f_{cr}$ , which is known as characteristic strength, the mix design strength is designed for a target strength  $f'_{cr}$

$$f'_{cr} = f_{cr} + Z \times \sigma$$

Where,

$f'_{cr}$  = Target average flexural strength at 28 days, N/mm<sup>2</sup>

$f_{cr}$  = Characteristic flexural strength (design strength) at 28 days, N/mm<sup>2</sup>

Z = Normal variate for the desired confidence level. The value of Z is given in Table

$\sigma$  = Standard deviation of field samples, N/mm<sup>2</sup>

Accepted Tolerance	Standard Normal Variate, Z	Degree of Control*
1 in 20	1.65	Fair to Good
1 in 40	1.96	Good to Very Good
1 in 100	2.33	Very Good to Excellent

Table 50: Values of Normal Variate for Different Values of Tolerance

\* **Fair to Good** means construction with semi-mechanized methods and site mixed/semi-automatic batching plant, insertion of tie bar/dowel bars and joint cutting by manual method/Joint cutting by machine (usually for low traffic roads).

**Good to Very Good** means construction with semi-mechanized/ fixed form paving machines and batch mixed concrete with semi-automatic/automatic batching plant insertion of tie bars and dowel bars by manual method usually for medium traffic roads.

**Very Good to Excellent** means construction with fixed form/slip form paving machines and batch mixed concrete with automatic batching plant insertion of tie bars and dowel bars by manual/automatic dowel/tie bar insertion mechanism method usually for heavy traffic roads/expressway

The value of Z shall depend upon the importance of the road. It may be chosen from Table 49. It is recommended that for National Highways, it may be kept as 1.96, for expressways, it may be kept as 2.33 and for lesser important roads, it may be kept as 1.65. The above are minimum recommended values. Higher values of variate may be adopted as per the quality requirement by the agencies concerned.

The mix design may be carried out by using compressive strength values and there after flexural strength will be determined as per correlation between flexural strength with compressive strength given in the equation below:

$$f_{cr} = 0.7 \sqrt{f_{ck}}$$

Where  $f_{cr}$  is the flexural strength in MPa or N/mm<sup>2</sup> and  $f_{ck}$  is the characteristic compressive strength in MPa or N/mm<sup>2</sup> as per IS 456-2000.

For design of cement concrete mixes, guidance may be taken from IRC: 44 “Guidelines for Cement Concrete Mix Design for Road Pavements”, or IS 10262.

#### 3.9.2.2.2 Cement Content

The minimum cement content for the mix corresponding to flexural strength of 4.5 MPa in the field at 28 days is given as under:

- When Ordinary Portland Cement (OPC) is used, the quantity of OPC shall not be less than 360 kg/cum.
- PPC quantity shall not be less than 425 kg/cum. However, in case, the target strength is not achieved, OPC shall be added in adequate quantity to achieve the target strength by the Contractor at his own cost. It is recommended not to increase the quantity of PPC prescribed as above, to avoid too much of fines, so that early strength and durability of concrete are ensured and not adversely impacted.

The laboratory mix designs should satisfy the requirement of workability when mix is produced through batching plant. Generally, further refinement of the mix becomes necessary in all project sites which may involve retesting of samples. Therefore, sufficient time should be allowed for developing a satisfactory mix design.

### 3.9.2.3 Tools, Equipment and Appliances

#### 3.9.2.3.1 List of tools, plants and equipment for fully mechanized concrete road construction:

- a) Subgrade
  - Compaction equipment (three-wheeled steel static roller or tandem roller, pneumatic roller, vibratory roller or any other suitable device)
  - Watering devices (water tanker, water carriers or watering cans)
  - Motor grader
  - Rotavator/disc harrow/tillers

b) GSB/WMM

- Pug-mill type mixing plant
- Tippers
- Paver finisher
- Motor grader
- Vibratory rollers
- Levelling instrument
- Rotavator, plougher, tiller

c) Dry Lean Concrete Sub-base

- Batching plant with more than 4-bin hoppers
- Tippers
- Paver finisher
- Vibratory roller
- Pneumatic roller
- Plate compactor
- Liquid curing compound sprayer
- Scabbler for correcting surface irregularity
- Levelling instrument

d) Paving Quality Concrete

- Batch mix plant with more than 4-bin hoppers
- Tippers
- Slip form paver for large projects and fixed form paver for small projects
- Side forms/side rails for fixed form pavers
- Joint cutting machine (concrete saw)
- Dowel bar inserter (DBI), if automatic dowel insertion system is adopted as in slip form paving
- Dowel cradles/chairs, for manual dowel placement
- Two nos. steel bulk-heads
- Tie bar supporting assembly or automatic tie bar inserter
- Guide-wires for slip-form pavers and stakes
- Finishing and texturing equipment
- Liquid curing compound sprayer
- Steel mobile bridges
- Sealant application extruder with flexible hose and nozzle
- Scabbler
- Edging tool
- Levelling instrument
- Digital Vernier callipers

3.9.2.3.2 List of tools, plants and equipment for semi-mechanized concrete road construction including fixed form paving

a) Subgrade

- Compaction equipment (three-wheeled steel static roller or tandem roller, pneumatic roller, vibratory roller or any other suitable device)

- Watering devices (water tanker, water carriers or watering cans)
  - Motor grader/Rotavator/tillers
- b) GSB/WMM
- Tippers
  - Motor grader
  - Vibratory rollers
  - Levelling instrument
  - Rotavator, plougher, tiller
  - Scratch templates or strike boards
  - Bulk heads
  - Pick axes, shovels and spades
  - Formwork and iron stakes
- c) Concrete Manufacture
- Shovel and spades
  - Sieving screens
  - Weigh batcher
  - Aggregate measuring boxes
  - Water pump
  - Water measures
  - Concrete mixer
- d) Transportation, laying and compaction of concrete
- Wheel barrows/iron pans
  - Rail, form work and wooden bridges
  - Spades
  - Concrete vibrators (pocker, surface and vibrating screed)
  - Wooden hand tampers
  - Tippers
- e) Finishing operation: surface and joints
- Wooden bridges
  - Floats (longitudinal and long handled wooden floats)
  - Templates
  - Three-metre long straight edges including one master straight edge
  - Graduated wedge
  - Mild steel sections and blocks for making joint grooves
  - Edging tools including double-edging tools
  - Canvas belts
  - Long handled brooms
  - Saw cutting machines
  - Scabblor (for grinding local high spots)
  - Levelling instrument theodolite and total station
- f) Curing
- Polyethylene sheeting
  - Watering devices
  - Liquid curing compound spraying machine

g) Cleaning and Sealing of Joints

- Iron raker
- Coir brush
- Cycle pump/pneumatic air blower/air compressor
- Kerosene stove
- Thermometer
- Transferring pot
- Double jacketed melter
- Painter's brush
- Pouring kettle
- Scraper
- Sand paper/sand blasting equipment
- Plywood planks to keep on both
- Gun for placing polysulphide

Semi-mechanized construction should be used only for small size projects. For major projects fully mechanized construction is recommended.

Specifications for different tools, equipment and appliances are given in IRC:43"Recommended Practice for Tools, Equipment and Appliances for Concrete Pavement Construction". This document also gives a list of other small tools, equipment and appliances, minimum balanced set of tools, equipment and appliances; their routine maintenance and upkeep; and details of field laboratory equipment.

### *3.9.2.4 Preparation of Sub-grade, Sub-base and Laying of Separation Membrane*

The cement concrete slabs (PQC) shall be constructed on two layers of sub-base. Granular Sub-base (GSB) acting as a lower sub-base and dry lean concrete (DLC) acting as upper sub base. GSB, the lower sub-base shall be laid over a subgrade of minimum 500 mm compacted thicknesses. Subgrade shall be of selected earth complying the following requirements:

- No soft spots are present in the subgrade.
- The subgrade shall be of coarse grained material and have a minimum CBR of 8 percent
- The camber and super-elevation of subgrade shall be same as that of the concrete slabs.

#### *3.9.2.4.1 Capillary Cut-off*

As a result of migration of water by capillarity from the high water table, the soil immediately below the pavement gets more and more wet and this leads to gradual loss in its bearing capacity besides unequal support. Several measures, such as, depressing the sub-soil water table by drainage measures, raising of the embankment and provision of a capillary cut-off are available for mitigating this deficiency and should be investigated for arriving at the optimum solution. However, where deleterious salts in excess of the safe limits are present in the subgrade soil, a capillary cut-off should be provided in addition to other measures.

The capillary cut-off may be a layer of coarse or fine sand, graded gravel, bituminised material, or an impermeable membrane.

Capillary cut-off/blanket layer, of required thickness may be placed over compacted subgrade layer. Layer thicknesses recommended for different situations are given in the table below. Whenever sand is used as cut-off layer, the layer shall not be provided at the edges but should

be replaced with suitable filter of graded granular material with or without non-woven geotextile material or it may be stabilized for preventing loss of fines.

Cut-off with bituminised or other materials may be provided in any of the following ways:

- Bituminous impregnation using primer treatment  
Bituminous emulsion applied at the rate of 6-15 kg per 10 sqm
- Heavy-duty tar felt  
Enveloping sides and bottom of the roadbed with heavy-duty tar felt.
- Bituminous/lime/cement/any other material stabilised soil  
Providing stabilised soil in a thickness of at least 40 mm
- Geo-filter layer  
Geo-filter fabrics recommended to function as capillary cut-off.

Sl. No	Situation	Minimum Thickness of layer (mm)			
		Graded gravel	Fine sand	Coarse sand	Stabilized layer
1)	Subgrade 0.6-1.0 m above HFL	150	350	150	150
2)	Subgrade 0.6-1.0 m above HFL, the subgrade soil being sandy in nature (PI<5; sand content not less than 50 percent)	150	300	150	150

*Table 51: Recommended thickness of graded gravel layer for capillary cut-off*

#### 3.9.2.4.2 Sub-Base

The Sub-base provided under the concrete slabs comprises Granular Sub base (GSB) as lower sub-base and Dry Lean Concrete (DLC) which is provided over GSB as upper sub-base. Permeability coefficient of GSB shall be at least 30 m/day.

The material to be used for the work shall be natural sand, crushed gravel, crushed stone, or combination thereof depending upon the grading required. The material shall be free from organic or other deleterious constituents and shall conform to the quality standards as prescribed in the specifications.

It shall be ensured prior to actual execution of sub-base that the material used in the sub-grade satisfies the requirements of minimum CBR of 8 percent along with other physical requirements like density (98 percent of the modified Proctor lab MDD) when compacted and finished.

#### 3.9.2.4.3 Modulus of Sub-Grade Reaction

Rigid pavement is designed by using the corresponding "k" value of subgrade/sub-base, as the case may be. "k" value is normally determined from plate load test as per details given in IRC

58. For the convenience of field engineers, correlation between CBR and 'k' value (the modulus of subgrade reaction) is given in the following table.

<b>CBR Value (%)</b>	7	10	15	20	50	100
<b>'k' value (kg/cm<sup>3</sup>)</b>	4.80	5.50	6.20	6.90	14.00	22.00

Table 52: Approximate 'k' Value Corresponding to CBR Values for Homogeneous Soil Subgrade

#### 3.9.2.4.4 Dry Lean Concrete Sub-base, Modified "k" Value

A dry lean concrete (DLC) conforming to IRC: SP:49 is generally recommended as upper sub-base for modern concrete pavements, particularly those with high intensity of traffic. The use of granular sub-base or sub-base constructed out of semi rigid material is also being suggested for use at some locations. The equivalency of "k" value for different type of upper sub-bases (like DLC/semi rigid materials/cement treated or stabilized subbase/granular sub-base) corresponding to "k" value of the subgrade is required to be known for construction of rigid pavement.

Table below gives the 'k' values of granular and cement treated sub-bases for three types of subgrade soils.

'k' value of subgrade	Effective 'k' (kg/cm <sup>3</sup> ) over untreated granular layer sub-base of thickness in mm			Effective 'k' (kg/cm <sup>3</sup> ) over cement treated sub-base of thickness in mm		
	150	225	300	100	150	200
2.8	3.9	4.4	5.3	7.6	10.8	14.1
5.6	6.3	7.5	8.8	12.7	17.3	22.5
8.4	9.2	10.2	11.9	-	-	-

Table 53: 'k' values Over Granular and Cement Treated Sub-Base

Table below gives 'k' values for dry lean concrete (DLC) constructed as per IRC: SP:49 of 100 mm and 150 mm thickness. The thickness and the type of sub-base should be selected depending upon the 'k'.

'k' value of sub-grade kg/cm <sup>3</sup>	4.8	5.5	6.2
Effective 'k' over 100 mm DLC kg/cm <sup>3</sup>	20.8	27.8	38.9
Effective 'k' over 150 mm DLC kg/cm <sup>3</sup>	27.7	41.7	-

Table 54: 'k' Values Over Dry Lean Concrete Sub-Base

Thickness of DLC sub-base should be minimum 150 mm in case of National highways and for others it can be 100 mm, the surface finish of the sub-base shall be smooth.

Where the embankment consists of heavy clay (L.L.>50 percent), such as, black cotton soil, the subgrade should be soil stabilised with lime or any other approved stabilizer (having minimum CBR 15 percent) with a minimum thickness of 500 mm.

#### 3.9.2.4.5 Separation Membrane

A separation membrane shall be used between the concrete slab and the DLC sub-base. Separation membrane shall be impermeable PVC sheet 125 micron thick transparent or white in colour laid flat with minimum creases. Before placing the separation membrane, the sub-base shall be swept clean of all the extraneous materials using air compressor. Wherever overlap of plastic sheets is necessary, the same shall be at least 300 mm and any damaged sheathing shall be replaced at the Contractor's cost. The separation membrane may be nailed to the lower layer with concrete nails. Separation membrane shall be omitted when two layers of wax-based curing compound, bituminous seal coat is used. In summer (when ambient temperature is more than 25°C), before placing polythene membrane, the existing DLC surface shall be wetted with water.

#### 3.9.2.5 Weather Limitations

##### 3.9.2.5.1 Concreting in Hot Weather

No concreting shall be done when the temperature is above 30°C. The location of batching and mixing units should be as close as possible to the site of placement. The form work should be covered with earth or sand outside which can be kept wet continuously. The form work and sub-base shall be sprinkled with cold water, just prior to placement of concrete.

##### 3.9.2.5.2 Concreting in Cold Weather

No concreting shall be done when the temperature drops below 4°C. In regions where temperature is usually below the stated temperature, equipment to heat the aggregates (minimum 15°C and not exceeding 30°C) and water (should not exceed 66°C) shall have to be provided. In addition, use of calcium chloride as an accelerator when so indicated may be permitted. The amount of calcium chloride solution used shall not exceed about 2 to 3 litres per bag (50 kg) of cement and this solution shall be considered as a part of the mixing water. This solution shall be prepared by dissolving 45 kg of granulated or flaked calcium chloride in about 95 litres of water. Normally Ordinary Portland Cements of any grade alone shall be used, when calcium chloride is employed as an additive. Also it is recommended that when calcium chloride is proposed to be used, there should be no steel reinforcement in the concrete pavement. When concrete contains steel reinforcement, chlorides free accelerators e.g. calcium nitrite or calcium formate may be used.

During placement of concrete, tarpaulin covers or other readily removable coverings should closely follow the placing of concrete, so that only a few metres of the finished slab are exposed to the outside air at any point of time. The coverings may be so arranged that heated air, when provided, could be freely circulated on top of the pavement. The coverings may be further covered by layers of straw or other insulating materials; no sooner the wet concrete is strong enough to take their load.

Any concrete damaged by frost action shall be removed and replaced.

##### 3.9.2.5.3 Frost Affected Areas

In frost affected areas, the sub-base may consist of any of the specifications having the compressive strength of the stabilised or semi-rigid material cured in wet condition at least 1.7 MPa at 7 days in the laboratory. For moderate conditions, such as, those prevailing in areas at an altitude of 3,000 m and below, the thickness of frost affected depth will be about 450 mm.

For protection against frost, the balance between the frost depth (450 mm) and total pavement thickness should be made up with non-frost susceptible material. For extreme conditions, such as, those prevailing in areas above an altitude of 3,000 m, the foundation may be designed individually for every location after determining the depth of frost.

The suggested criteria for the selection of non-frost susceptible materials are as follows:

- i. Graded gravel: Not more than 8 percent passing 75-micron sieve.
- ii. Plasticity index not more than 6. Liquid limit not more than 25.
- iii. Poorly graded sands: Generally, 100 percent passing 4.75 mm sieve. Max. 10 percent passing 75-micron sieve.
- iv. Fine uniform sand: Generally, 100 percent passing 425-micron sieve: Max. 18 percent passing 75-micron sieve.

#### **3.9.2.6 Joints**

There are three general types of joints. These are:

- i. Expansion Joint: Such a joint provides the space into which pavement can expand thus relieving compressive stresses due to expansion and inhibiting any tendency towards buckling of concrete slabs.
- ii. Contraction Joint: Such a joint relieves tensile stresses in the concrete and prevents formation of irregular cracks due to restraint in free contraction of concrete. Contraction joints also relieve stresses due to warping.
- iii. Warping or Longitudinal Joint: Such a joint relieves stresses due to warping. These are commonly used for longitudinal joints dividing the pavement into lanes when width of the slab becomes more than 5 m.
- iv. Construction Joint: In addition, construction joints are provided whenever day's construction operations start and stops. These are full depth joints. Construction should be so planned that day's construction activity may end at the location of contraction joint.

Figure below shows the location of contraction and longitudinal joints. All joints shall be carefully installed in accordance with the location and details given in the plans. The details of different types of joints, sealing groove, their plan, cross section etc. are shown in IRC:57.

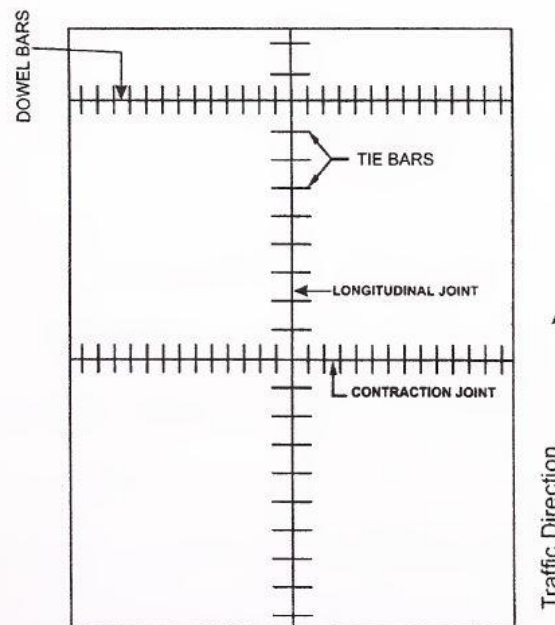


Figure 30: Location of contraction and longitudinal joints

### 3.9.2.6.1 Transverse Joints

Transverse joints can be expansion, contraction or construction joints and shall be placed across the traffic direction as indicated on the drawing. They shall make a right angle with the centre line of the pavement and surface of the sub-base/subgrade. Contraction, construction and expansion joints shall be continuous from edge to edge of the pavement through all lanes constructed at the same or different times. The maximum joint spacing shall be 5 m.

Dowel bars as per dimensions, location and spacing shown in the drawing are required at expansion joints to transfer wheel loads to the adjacent slab. For slabs of thickness less than 150 mm, dowel bars may not be provided (IS: 6509-1972). The pre-moulded synthetic expansion joint filler board, a compressible material shall be used to fill the gap between adjacent slabs at expansion joint. The height of the filler board shall be such that its top is 25 mm below the surface of the pavement. The accurate placing of dowels at the end of the day may be achieved by means of sufficiently placing the strong bulkheads made of steel sections with holes drilled along the centre line to accommodate the dowel bars in a mild steel section. The bulkhead shall be oiled or greased before placing in position to avoid bonding with concrete. The top and bottom edges of the bulkheads and mild steel section shall be shaped to correspond to camber of the pavements at the joint. If considered convenient, two-piece split bulkheads may also be used. When dowel bars are provided, bulkheads shall be designed such that they can hold the projecting ends of the dowel bars to maintain their alignment. A box section normally is adopted for such designs.

Sealing grooves can be formed by placing wooden strips of 20-25 mm x 25 mm sections above the filler board. This can be pulled out when concrete sufficiently hardens. For easy removal of the wooden strip without damaging the edges, the sides of the strips may be shaped suitably.

#### 3.9.2.6.2 Transverse Contraction Joints

These shall be placed as shown on the drawing and shall be of the weakened plane of "dummy" groove type. They shall be constructed by forming in the surface of the slab, a slot not less than 3 mm wide and having a depth equal to one-fourth to one-third the depth of the pavement at the thinnest part of its section. The groove is formed preferably by a joint cutting saw. This groove is subsequently widened and sealed with sealant. Alternatively, in manual construction and minor works, the slot may be formed in a manner approved by the Engineer-in-Charge, such as, by pushing into the concrete a flat bar or plastic strip or the web of a "T" bar using a suitable vibratory device, removing the bar subsequently, and keeping the slot open. It shall be ensured that no spalling of concrete occurs while removing the bar. Such manually formed grooves are found to affect the riding quality of the pavement.

#### 3.9.2.6.3 Transverse Construction Joints

These shall be placed whenever placing of concrete is suspended for more than 30 minutes. Except in the case of emergency, construction shall always be suspended at the regular site of expansion or contraction joint. If the construction joint is located at the site of an expansion joint, regular expansion joint shall be provided; if at the site of a contraction joint or otherwise, the construction joint shall be of butt type with dowels. In case of emergency the joint should be placed only in the middle third of the specified contraction joint interval. At all construction joints, bulkhead shall be used to retain the concrete and care shall be taken in striking off and finishing the surface to the top face of the bulkhead. When work is resumed, the surface of concrete laid subsequently, shall conform to the grade and cross section of previously laid pavement, and a straightedge 3 m in length shall be used parallel to the centre line, to check any deviation in the surface of the two sections. Any deviation from the general surface, in excess of 3 mm, shall be corrected.

#### 3.9.2.7 Dowel Bars

Dowel bars shall be mild steel rounds conforming to IS 432, of Grade S 240 and in accordance with details/dimensions as indicated in the drawing and free from oil, dirt, loose rust or scale. These shall be treated preferably by epoxy coating or any approved anti-corrosion treatment. They shall be straight, free of irregularities and burring restricting free movement in the concrete. The sliding ends shall be sawn or cropped cleanly with no protrusions outside the normal diameter of the bar. The dowel bar shall be supported on cradles/dowel chairs in pre-fabricated joint assemblies positioned prior to the construction of the slabs or mechanically inserted by a Dowel Bar Inserter (DBI) with vibration into the plastic concrete by a method which ensures correct placement of the bars besides full re-compaction of the concrete around the dowel bars.

Unless shown otherwise on the drawings, dowel bars shall be positioned at mid depth of the slab within a tolerance of  $\pm 20$  mm, and centred equally about intended line of the joint within a tolerance of  $\pm 25$  mm. They shall be aligned parallel to the finished surface of the slab and to the centre line of the carriageway and to each other within tolerances given hereunder:

For bars supported on cradles prior to the laying of the slab:

- a) All bars in a joint shall be within  $\pm 3$  mm per 300 mm length of bar.
- b) 2/3rd of the bars shall be within  $\pm 2$  mm per 300 mm length of bar.
- c) No bar shall differ in alignment from an adjoining bar by more than 3 mm per 300 mm length of bar in either the horizontal or the vertical plane.
- d) Cradles supporting dowel bar shall not extend across the line of joint, i.e., no steel bar of the cradle assembly shall be continuous across the joint.

For all bars inserted after laying of the slab:

Twice the tolerance for alignment as indicated above. Dowel bars, supported on cradles in assemblies, when subject to a load of 110 N applied at either end and in either the vertical or horizontal direction (upwards and downwards and both directions horizontally)

shall conform to be within the following limits:

- a) Two-thirds of the number of bars of any assembly tested shall not deflect more than 2 mm per 300 mm length of bar.
- b) The remainder of the bars in that assembly shall not deflect more than 3 mm per 300 mm length of bar.

### **3.9.2.8 Longitudinal Joints**

These joints known as warping joints can be formed by two different methods: (i) They can be of the plain butt type and shall be formed by placing the concrete against the face of the slab concreted earlier. The face of the slab concreted earlier, shall be painted with bitumen before placing of fresh concrete, (ii) When a pavement of width of more than one lane is laid, the longitudinal joint may be cut by a joint cutting machine (generally within 6-14 hours). Longitudinal joint becomes necessary to relieve warping stresses when the pavement width exceeds 5 m.

**Tie bars** - Tie bars are used across the joints of concrete pavements wherever it is necessary or desirable to ensure firm contact between slab faces or to prevent abutting slabs from separating. Tie bars are not required for structural reasons, but their only function being to prevent separation of the slabs, especially at fills or curves. Tie bars are not designed to act as load transfer devices. Tie bars are designed to withstand tensile stresses only.

Tie bars shall be laid automatically in a fully mechanised construction using slipform paving as being followed these days for most rigid pavement construction. For semi mechanised construction, tie bars in longitudinal joints shall be made up into rigid assemblies with adequate supports and fixings to remain firmly in position during the construction of the slab. Alternatively, tie bars at longitudinal joints may be mechanically or manually inserted into the plastic concrete from above by vibration using a method which ensures correct placement of the bars and re-compaction of the concrete around the tie bars (tie bar inserter). When the pavement is constructed in single lane width, tie rods are also inserted mechanically or manually from sides. During side insertion in fixed form paving, these may be bent so that half-length remains along the form. After removal of forms, bars shall be straightened using hollow G.I pipe so that they extend into the concrete placed on the other half of the concrete slab.

Tie bars shall be positioned to remain within the upper middle third of the slab depth as indicated in the drawings, approximately parallel to the surface and approximately

perpendicular to the line of the joint, with the centre of each bar on the intended line of the joints within a tolerance of + 50 mm, and with a minimum cover of 30 mm below the joint groove.

### ***3.9.2.9 Preparation of Joint Grooves for Sealing***

Joint grooves are usually not constructed in the first instance to provide the maximum width specified in the drawings when saw cut joints are adopted. They shall be widened subsequently by sawing before sealing. Depth/width gauges shall be used to control the dimensions of the groove during widening process.

### ***3.9.2.10 Sealing with Sealants***

When sealants are applied an appropriate primer shall also be used if recommended by the manufacturer and it shall be applied in accordance with the recommendation of the manufacturer. The sealant shall be applied within the minimum and maximum drying times of the primer recommended by the manufacturer. Priming and sealing with applied sealants shall not be carried out when the naturally occurring temperature in the joint groove to be sealed is below 7°C. Sealant shall be applied, slightly to a lower level than the slab with a tolerance of 3±1 mm. During sealing operation, it shall be seen that no air bubbles are introduced in the sealant either by vapours or by the sealing process.

Hot and cold sealants may be applied in accordance with IRC: 57.

### ***3.9.2.11 Construction***

#### ***3.9.2.11.1 Fully Mechanized Construction***

The batching plant shall include minimum four bins, weighing hoppers, and scales for the fine aggregate and for each size of coarse aggregate. If cement is used in bulk, a separate scale for cement shall be included. The weighing hoppers shall be properly sealed and vented to preclude dust during operation. Approved safety devices shall be provided and maintained for the protection of all personnel engaged in plant operation, inspection and testing. The batch plant shall be equipped with a suitable non-resettable batch counter which will correctly indicate the number of batches proportioned.

*Bins and Hoppers* - Bins with minimum four numbers of adequate separate compartments shall be provided in the batching plant. In addition, we may have another bin for any mineral admixture if used.

*Automatic weighing devices* - Batching plant shall be equipped to proportion aggregates and bulk cement by means of automatic weighing devices using load cells. The batching plant shall have facility for injecting at least two admixtures in the mixing pan. The discharging mechanism shall have appropriate chutes, down pipes, etc. so that the discharged mix will not get segregated.

*Control cabin* - An air-conditioned centralised control cabin shall be provided for automatic operation of the equipment.

Batching by weight only is recommended. However, if batching by volume is permitted, as a special case, separate measuring boxes shall be provided for the different aggregates. The boxes

shall be of strong construction provided with handles for convenient lifting and loading into the mixer. They shall be of such size that it should be possible to measure out the requisite quantity and capable of being lifted by two men. Each box shall be provided with a straight edge of required length for striking off after filling. In volume batching, suitable allowance shall be made for the bulking of fine aggregate due to the presence of water. For this purpose, the bulking shall be determined as per relevant Indian Standard Specification. The location of the batching plant is an important issue to be looked into while planning the project. As there is a limitation on using the concrete mix after adding the water within a stipulated time, the mix shall not normally be carried beyond 1.5 km of lead on a maintained road not requiring more than 40 minutes of travel time. Therefore, the location of the batching plant in a road project has to be decided carefully.

*Mixers* - Mixers shall be pan type, reversible type with single or twin shaft or any other mixer capable of combining the aggregates, cement, water and admixtures into a thoroughly mixed and uniform mass within the specific mixing period, and of discharging the mixture, without segregation. In twin shaft mixer, mixing time is normally very low (about 6 cubic materials may be mixed in 20-30 seconds). Facility i.e. hydrometers for the measurement of the density of the admixtures shall be available at site. Each stationary mixer shall be equipped with an approved timing device which will automatically lock the discharge lever when the drum has been charged and release it at the end of the mixing period. The device shall be equipped with a bell or other suitable warning device adjusted to give a clearly audible signal each time the lock is released. In case of failure of the timing device, the mixer may be used for the balance of the day while it is being repaired, provided that each batch is mixed for 90 seconds or as per the manufacturer's recommendation. The mixer shall be equipped with a suitable non-resettable batch counter which shall correctly indicate the number of batches mixed.

The mixers shall be cleaned at suitable intervals. The pick up and throw-over blades in the drum or drums shall be repaired or replaced when they are worn down 20 mm or more. The Contractor shall (1) have at the site a copy of the manufacturer's design, showing dimensions and arrangements of blades in reference to original height and depth, or (2) provide permanent marks on blade to show points of 20 mm wear from new conditions. Drilled holes of 5 mm diameter near each end and at midpoint of each blade are recommended. Batching plant shall be calibrated for each ingredient up to its maximum quantity being used in the mix at site in the beginning and thereafter at suitable interval not exceeding 1 month.

**Placing of Concrete:** Concrete mixed in central mixing plant shall be transported to the site without delay and the concrete which has been mixed too long before laying will be rejected and shall be removed from the site. The total time taken from the addition of the water to the mix, until the completion of the surface finishing and texturing shall not exceed 120 minutes when concrete temperature is less than 25°C and 100 minutes when the concrete temperature is between 25°C to 30°C. Trucks/Tippers delivering concrete shall not run directly on plastic sheet nor shall they run on completed slabs until after 28 days of placing of concrete.

**Construction by Slip form paver:** The slip form paving train shall consist of power machine which spreads, compacts and finishes the concrete in a continuous operation. The slip form paving machine shall compact the concrete by internal vibration and shape it between the side forms with either a conforming plate or by vibrating and oscillating finishing beams. The concrete shall be deposited without segregation in front of slip form paver across the whole width and to a height which at all times is in excess of the required surcharge. The deposited concrete shall be struck off to the necessary average and differential surcharge by means of the

strike off plate or a screw auger device extending across the whole width of the slab. The equipment for striking off the concrete shall be capable of being rapidly adjusted for changes of the average and differential surcharge necessitated by change in slab thickness or cross fall.

### **Surface Texture:**

*Tining* - After final floating and finishing of the slab and before application of the liquid curing membrane preferably two coats, the surface of concrete slabs shall be textured either in the transverse direction (i.e., at right angles to the longitudinal axis of the road) or in longitudinal direction (i.e., parallel to the centreline of the roadway). The texturing shall be done by tining the finished concrete surface by using rectangular steel tines. A beam or a bridge mounted with steel tines shall be equipped and operated with automatic sensing and control devices from main paver or auxiliary unit. The tining unit shall have facility for adjustment of the downward pressure on the tines as necessary to produce the desired finish. The tining rakes shall be cleaned often to remove snots of slurry. The tines will be inspected daily and all the damaged and bent tines shall be replaced before commencing texturing. Tined grooves shall be 3 mm wide and 3 to 4 mm deep. Before commencing texturing, the bleeding water, if any, shall be removed and texturing shall be done on a firm surface. Normally, transverse tining will be preferred.

- a) **Transverse Tining:** When the texturing is specified in transverse direction, a beam of at least 3 m length mounted with tines shall be moved in transverse direction to produce the texture. The grooves produced shall be at random spacing but uniform in width and depth. The spacing shall conform to a pattern shown below:

Random spacing in mm

10 14 16 11 10 13 15 16 11 10 21 13 10

- b) **Longitudinal Tining:** Longitudinal tining shall be done, if specified in the Contract. The texturing bridge shall be wide enough to cover the entire width of the carriageway but within 75 mm from the pavement edge. The centre to centre spacing between the tines shall be 18 to 21 mm. The width of tine texture shall be 3 mm and depth shall be 3 to 4 mm. The texture depth shall be measured with gauge and Vernier Calliper (simple/digital).

*Brush Texturing* - Alternatively on the instructions of the Engineer, the brush texturing may be applied. The brushed surface texture shall be applied evenly across the slab in one direction by the use of a wire brush not less than 450 mm wide but wider brushes normally of 3 m length are preferred. The brush shall be made of 32-gauge tape wires grouped together in tufts placed at 10 mm centres. The tufts shall contain an average of 14 wires and initially be 100 mm long. The brush shall have two rows of tufts. The rows shall be 20 mm apart and the tufts in one row shall be opposite the centre of the gap between tufts in the other row. The brush shall be replaced when the shortest tuft wears down to 90 mm length.

The texture depth shall be determined by the Sand Patch Test. This test shall be performed at least once for each day's paving and wherever the Engineer considers it necessary.

#### **3.9.2.11.2 Semi-Mechanized and Labour-Oriented Construction Technique**

Use of very sophisticated paving machines and high capacity concrete batch mixer may not be possible in small concrete road projects and also in remote hilly terrains or near bridge structures, although with the use of such machines and plants the end product is always of better quality. Without these advanced equipment, concrete roads can be constructed using

semi-mechanised and labour-oriented constructions but the resulting quality and surface may not be the same as achieved with mechanised constructions.

**Forms** - The fixed-forms made of steel channels or fabricated steel sections are generally made use of. Wooden forms, although, can be used, are liable to get damaged after each usage. Therefore, wooden forms are to be considered as a last resort. The steel forms shall be mild steel channel sections of depth equal to the thickness of the pavement or a few millimetres less than the thickness of the pavement to match with the plus level tolerances specified for sub-base. In the latter case, the forms shall be levelled by using metal wedges or shims. The thickness of flange and web shall not be less than 6 mm and shall be capable of resisting all loads applied in the paving process. The length of form shall not be less than 3 m except in the case of installations along curves.

Wooden forms may be used only when specifically permitted in the drawing with the exception that their use is herein approved for all curves having radii of less than 45 m, wooden forms shall be dressed and planed on the inside face. They shall have minimum base width of 100 mm for slab thickness up to 200 mm and a minimum base width of 150 mm for slabs over 200 mm thick. Their depth shall be equal or slightly less than the thickness of the pavement but it would be made up by metal shims. These forms when used on straights shall have a minimum length of 3 m. Forms shall be held by stakes set at intervals not exceeding 2 m. Two stakes, one on each side, shall be placed at each joint.

**Dowels** - Transverse joints shall be provided with dowels and of the dimension and at the spacing and location indicated on the drawing. They shall be firmly supported in place, accurately aligned parallel to the subgrade/sub-base, parallel to each other and parallel to the centre line of the pavement, by means of appropriate dowel supports/chairs.

**Tie bars** - Tie bars are provided in longitudinal joints to prevent opening of such joints and shall be bonded to the adjacent slabs on both sides of the longitudinal joint. These are installed by providing appropriate chair or these are installed by providing appropriate (drilled) holes in the side forms depending on the size and spacing of bars. These are sometimes bent aside temporarily to avoid obstruction to construction traffic and straightened later at the time of laying of slab in the adjacent lane.

**Hauling of mix** - Transporting of concrete mix from mixer to paving site with steel pans is not permitted in major works. However, these can be permitted in small size works only with the written permission of the Engineer. The mix tends to get segregated during such handling. It is desirable to use wheel-barrows or trolleys for carrying mix to the paving site. The workability of the mix can be controlled better with the use of wheel-barrows.

**Placing of concrete** - Where semi-mechanised construction technique is adopted, concrete shall be deposited between the forms directly from head loads or wheel barrows. Where a certain amount of redistribution is necessary, it shall be done with shovels and not with rakes. The concrete shall be compacted with needle vibrators and vibrating screeds in semi-mechanised construction where a paver finisher is not available. Use of vibrator near side forms is essential to eliminate honey combing. To achieve adequate compaction, the concrete shall be placed with appropriate surcharge over the final slab thickness. The amount of surcharge will depend on the mode of placement of concrete and shall be determined by trial. In general, the required surcharge is about 20 percent of the required slab thickness. Any portion of the

batch of concrete that becomes segregated while depositing it on subgrade/ sub-base shall be thoroughly mixed with the main body of the batch during the process of spreading.

**Compaction** - Where semi-mechanized and labour-oriented technique is adopted, compaction of the pavement shall be accomplished by a vibrating screed supplemented by plate/internal vibrators. For slabs of thickness more than 125 mm, vibrating screeds may be supplemented by portable needle vibrators. The vibrating screed shall rest on side forms. It shall be lowered vertically on to the concrete surface, evenly spread to the appropriate level above the base to provide the required surcharge for compaction; allowed to remain in position for a few seconds until compaction is complete, then lifted vertically and lowered to the adjacent strip of non-compacted concrete. The amplitude of vibration of the screed shall not be less than 1.5 mm and the speed of travel not more than 0.6 m per minute.

Forms shall not be removed from freshly placed concrete until it has set, or at least 12 hours, whichever is later. They shall be carefully removed in such a manner that no damage is done to the edges of the pavement. After the forms have been removed, the slab edges shall be cleaned and any limited honey-combed areas pointed with 1:2 cement and sand mortar, after which the sides of the slab shall be covered with wet hessian for curing. Slabs with excessive honey-combing as a result of inadequate compaction shall be removed between the nearest transverse joints and re-laid.

**Straight edging** - The slab surface shall be retested for trueness, before the concrete begins to set, with the 3 m long master straight edge and the graduated wedge gauge. The straightedge shall be placed on the surface in successive positions, parallel to the carriageway centre line. Irregularities shall be measured with the help of the wedge gauge moved transversely at various points until it touches both the straight edge and the concrete surface.

**Texturing** - Just before the concrete becomes non-plastic, the surface shall be textured with an approved long handled steel or fibre broom conforming to the stipulations laid down in IRC:43. The broom shall be pulled gently over the surface of the pavement from edge to edge. Adjacent strokes shall be slightly overlapped. Brooming shall be perpendicular to the centre line of the pavement and so executed that the corrugations thus produced will be uniform in character and width, and about 1.5 mm deep in case of texturing by broom/brush and 3-4 mm texture depth in case of texturing by tining method.

#### ***3.9.2.12 Widening of Road***

Where the width of the existing pavement falls short of the width to be concreted and the condition of the surface is sound enough for receiving the paving concrete, the extra width may be made up by placing at least 150 mm depth of dry lean concrete or lime-pozzolana concrete or lime-fly ash concrete or lean cement concrete in trenches of required width at the sides of the existing pavement after making sure that the bottom of such trenches is well compacted with 100 mm WBM or WMM layer. The soil below shall be watered to OMC and well compacted before placing of the new sub-base material. Normal tie bars shall also be used by drilling and inserting tie bars with epoxy and hardener in the existing PQC to be widened.

#### ***3.9.2.13 Work on Gradients***

The progress on gradient of all operations of placing, compacting and finishing of concrete should proceed from the lower to the higher reaches. The concrete mix shall be stiffer than that

used on level reaches. In case of very steep gradient, or where fill up areas/very weak subgrade is there, reinforcement in single layer or in two layers in the PQC may be provided. Slump of concrete mix in such situations should be adjusted from field trials.

#### **3.9.2.14 Curing**

Immediately after the finishing operations have been completed, the entire surface of the newly laid concrete shall be covered against rapid drying, and cured.

Curing can be done by one of the following two methods:

- a) By application of curing compound followed by spreading of wet hessian and moistening it regularly. In case of arid areas where water is extremely scarce, two applications of curing compound with moist curing by wet hessian may be allowed at the discretion of the Engineer. Curing compound shall be resin based aluminized reflective type.
- b) For small works, curing can be done by manual methods using wet hessian which is kept moist during curing period. Curing shall be done for a minimum period of 14 days. In case of blended cement curing shall be done for 16 days.

The water used for curing shall also be free from all injurious chemicals, like, chlorides and sulphates and shall meet the requirements of IS: 456.

#### **3.9.2.15 Opening to Traffic**

In general, traffic shall not use the newly constructed pavement for a minimum period of 28 days. The pavement shall be cleaned and the joints shall be properly sealed before the pavement is opened to traffic. In any case, the pavement will not be opened to traffic before it attains the strength of 32 MPa of equivalent cube compressive strength.

### **3.10 Bio-engineering**

Bio-engineering works like spreading of top soil, turfing, sprigging, preparation of seeds and plant cuttings, nursery construction and operation, slope preparation for planting, site planting and sowing, jute netting, gabion wire bolsters and wire netting helps in the soil stabilization.

#### **3.10.1 Sowing of Grasses on Site**

Immediately before sowing, the ground surface shall be lightly scarified using a rake to ease early root penetration. Seeds shall then be laid thinly over the surface. Under no circumstances shall they be broadcasted, because the lightness of perennial grass seeds and the steepness of the slopes to be treated give a poor cover using such a technique.

After sowing, a mulch of prepared and dried cut herbs shall be laid over the whole seeded area in a thin layer. If the mulch is too thick it will prevent light from getting to the seed and will inhibit germination

#### **3.10.2 Brush Layering, Palisades and Fascines**

The cuttings collected from the nursery and shall be transported in a wrapped Hessian jute. At all times, cuttings shall be kept moist and as cool as possible, and shall be wrapped in wet Hessian or in the thick blanket of mulch material (i.e. *Eupatorium adenophorum*) between all

operations such as cutting from the parent plant, trimming and planting. Under any circumstances, all plants supplied shall be planted the same day that they are lifted from the nursery.

### 3.10.3 Broadcasting

Seeds of grass and pioneer plants are broadcast on to the site. It allows easy vegetation coverage of large areas. This technique is often used in conjunction with mulching and jute or bamboo netting to aid establishment. The main engineering functions are to armour, and later also to reinforce.

Broadcasting is mostly used on any bare site with slopes up to  $45^{\circ}$  and on well-drained materials, where increased infiltration does not give rise to problems.



Figure 31: Broadcasting

### 3.10.4 Sodding/Turfing

Turf or sods, consisting of a shallow rooting plants and the soil they are growing in, are placed on the slope. A technique commonly used on gentle embankment slopes. Its only engineering function is to armour.

This technique can be used on any gently sloping site (less than  $30^{\circ}$ ). It is normally used on well-drained materials, where there is a minimal risk of slumping.



Figure 32: Sodding/Turfing

### 3.10.5 Shrub or tree planting

Shrubs or trees are planted at regular intervals on the slope. As they grow, they create a dense network of roots in the soil. The main engineering functions are to reinforce and, later, to anchor. In the long term, deeply rooting trees can also be used for slope support.

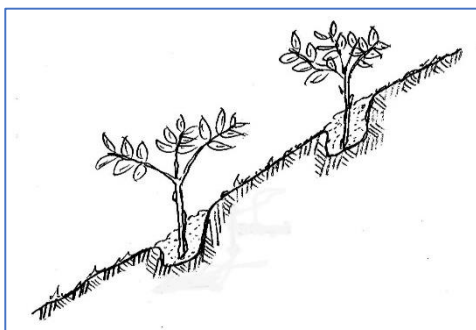


Figure 33: Spacing of plants



Figure 34: Tree planting

This method can be used without adverse effects on almost any slope up to 30°. With care, it can be used on slopes between 30° and 45°. It can be used on any material and in any site.

The spacing of plants is important. The main considerations are cost and the speed with which a full cover is required. In most bio-engineering sites a spacing of 1 × 1 metre is necessary, requiring 10,000 plants per hectare. Plants should be planted in off-set rows unless a different pattern is needed for specific bio-engineering requirements.

### 3.10.6 Bamboo Plantation

Large bamboos can reduce movement of material and stabilise slopes. Large bamboos are usually planted by one of two methods: (1) the traditional planting method or (2) to plant rooted culm cuttings from a nursery. Large clumps of the larger stature bamboos are one of the most substantial vegetation structures available to reinforce and support a slope. However, they do not have deeply penetrating roots and so do not have an anchoring function; also, they can surcharge upper slope areas. Mostly used at the base of slopes and in gullies, where the slope segment has an angle of less than 30°. Any fill site can be planted. Bamboos do not thrive on very dry or excessively stony sites.

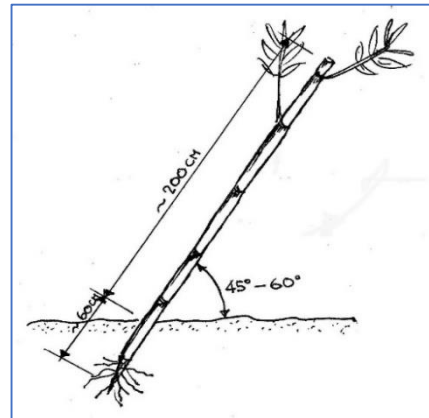


Figure 35: Bamboo plantation

### 3.10.7 Brush layering or hedge-brush layering

Woody cuttings and live branches are laid in lines across the slope, usually following the contour. They put out roots and shoots, forming a strong line of vegetation as a barrier, preventing the development of rills, and trap material moving down the slope. In the long term, a small terrace will develop. The main engineering functions are to catch debris, and to armour and reinforce the slope. In certain locations, brush layers can be angled to provide a drainage function.

This technique can be used on a wide range of sites up to about 45°. It is particularly effective on debris sites, fill slopes and high embankments. Avoid using the technique on materials that are poorly drained and are subject to high rates of small-scale slumping.



Figure 36: Brush layering

### 3.10.8 Live Check Dams

Large woody cuttings are planted across a gully, usually following the contour. These form a strong barrier and trap material moving downwards. In the longer term, a small step will develop in the floor of the gully. The main engineering functions are to catch debris, and to armour and reinforce the gully floor.

This technique can be used on a wide range of gully sites, on slopes of up to 45°. However, materials subject to high rates of small scale slumping should be avoided.

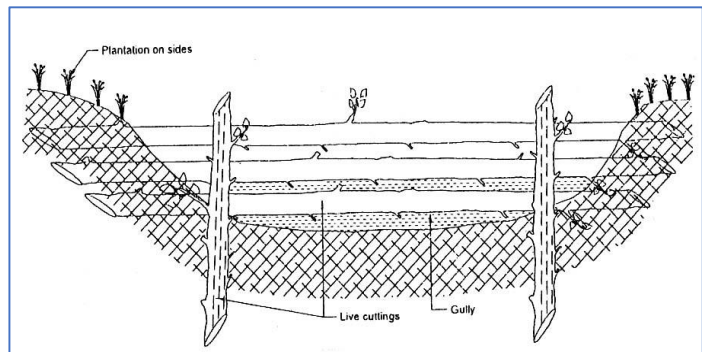


Figure 37: Check-dam

### 3.10.9 Fascines

The word “fascine” means a bundle of sticks. In this technique, bundles of live branches are laid in shallow trenches. After burial in the trenches, they put out roots and shoots, forming a strong line of vegetation. It is sometimes called live contour wattling. The main engineering functions are to armour and reinforce the slope, and to catch debris. In certain locations, fascines can be angled to provide drainage. Where time is at a premium, brush layers may be more appropriate as these are quicker to establish than fascines.

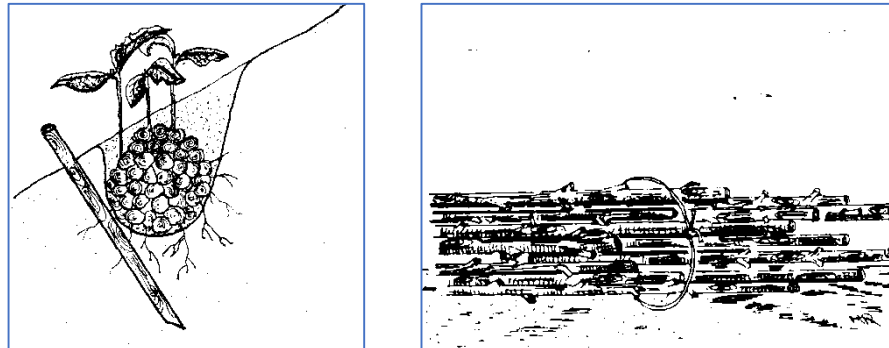


Figure 38: Fascines

Fascines are best used on consolidated debris or soft cut slopes. If the material is too hard, growth will be unacceptably slow. The maximum slope is about 45°. On well-drained materials, contour fascines are used; on poorly drained materials, a herringbone pattern (←←←←←) of fascines is used to improve drainage.

### 3.10.10 Bioengineering techniques to control slope failure phenomena

Bioengineering can be used to increase slope stability in a variety of ways), in particular

- mechanical reinforcement,
- controlling erosion,
- increasing the infiltration ratio.
- reducing runoff,

- and soil moisture adjustment.

#### **3.10.10.1 Reinforcement**

The dense network of coarse and fine roots from vegetation can work as a reinforcement mechanism on the slope by binding and stabilizing loose materials. The stabilizing effect of roots is even greater when roots are able to connect top soil with underlying bedrock, with the root tensile strength acting as an anchor. Small dense roots also contribute to the shear strength of a slope and thus reduce the risk of landslides and debris flows. Trees and bamboos can stabilize the whole soil layer in slope terrain, whereas bush and shrub roots mainly protect soil up to 1 m deep, and grasses can conserve top soil to a depth of around 25 cm.

#### **3.10.10.2 Erosion control**

Bare soil-covered slopes are easily affected by the splash effect of intense rain leading to heavy erosion. The surface runoff rate is also very high, and the flowing water can carry the soil particles away and trigger a debris flow. A dense cover of vegetation protects the soil from splash effects and reduces runoff velocity, while the roots bind the soil particles, thus hindering surface erosion.

#### **3.10.10.3 Soil infiltration**

As decayed roots shrink, they leave a gap which provides a passage for water seepage, which leads water away from the surface and reduces the likelihood of surface soil saturation. This reduces slope instability and hinders the development of debris flows.

#### **3.10.10.4 Reducing runoff**

Vegetation can be used to reduce runoff in a number of ways including trapping of moisture in leaves and branches, slowing the flow of water across the rough surface, increasing infiltration, and through structures designed to deflect flow away from the top of a slope and channel it along a desired pathway down the slope.

#### **3.10.10.5 Soil moisture adjustment**

Soil moisture is a key factor in slope stability. Vegetation can directly influence soil moisture through interception and evapotranspiration. In interception, precipitation is captured by the vegetation canopy and returned directly to the atmosphere through evaporation. The rate of interception varies according to various factors including leaf type and size, canopy density, temperature, and humidity. In evapotranspiration, the plants channel moisture from the soil to the leaves and stems, from where it returns to the air via evaporation. These two processes combine to reduce the overall soil moisture content.

#### **3.10.10.6 Choice of techniques**

Different bioengineering techniques are used to control erosion and slope failure in different parts of the world. The techniques suitable for a particular area should be selected on the basis of availability of resources, site condition, and required function.

Basic techniques for bioengineering are given below:

Phenomenon	Erosion problem and condition	Suitable bioengineering techniques
Landslide	Deep-rooted landslide (>3 m depth)	Smoothing to a suitable slope gradient Diversion canals, channel lining, catch drains, waterways Stone pitching and planting of trees, shrubs, and grass slip Bamboo fencing with live poles, planting and seeding grass Terracing and planting with bamboo, trees, shrubs, grass Live peg fence, wild shrubs, live check dams Contour strips planted with grass, shrubs, and pegs Fascines, brush layering, and palisades Planting bamboo with or without a structure Check dams planted with deep-rooted species (e.g., bamboo, trees)
	Slumping	
	Planar sliding	
	Shear failure	
	Cut and fill area at deep and shallow-rooted landslide (<3m depth)	
	Bare and steep slope or newly exposed surface	
	Cracking zone	
Head scarp of landslide or slope failure	Slope excavated to an appropriate gradient and rounded (when high and steep) and planted with deep-rooted plants (e.g., bamboo, trees) Bamboo fencing, planting grass, seeding, and mulching Fascines, brush layering, and palisades Jute netting or straw mat covering soil, seeds, and compost mixture; turfing Stone pitching; planting of trees, shrubs, and grass slip Planting grass slip and seeding grass	
Debris flow	Sediment production zone	As for landslides
	Sediment transportation zone	Series of gabion check dams, retaining wall, and side wall planted with deep-rooted species (e.g., bamboo, trees) Bamboo fencing; grass planting, seeding, and mulching
	Sediment deposition zone	Diversion canal, channel lining, retaining wall, and side wall planted with trees, shrubs, and grasses Plantation of deep-rooted species (e.g., bamboo, trees)
Soil Erosion	Sheet and rill erosion	Planting of bamboo, trees, shrubs, and grass with or without terracing Live peg fence, wild shrubs, and live check dams Contour strips planted with grass, shrubs, trees, and pegs Fascines, brush layering, and palisades with wild and thorny shrub species.
	Gully erosion	Diversion canals, channel lining, catch drains, waterways, cascade retaining wall, and side wall, planted with trees, shrubs, and grasses Bamboo fencing with live pegs Planting of bamboo, trees, with or without check dams Series of retaining walls and plantation Vegetated stone pitching in small gullies and rill beds

Erosion on bare land, degraded steep sloped land, dry and burnt area	Planting of deep-rooted species (e.g., bamboo, trees) Bamboo and live peg fencing and live check dams Vegetated stone pitching in small sheets and rill beds Stone pitching and planting of trees, shrubs, and grass slip
Degraded shifting cultivation areas, newly excavated or exposed areas on terrace bund, degraded forest, and grazing land	Bamboo fencing with live poles, planting and seeding grass Planting of bamboo, trees, shrubs, and grass with or without terracing and structure Live peg fencing and live check dams Vegetated stone pitching in small gullies and rill beds Contour strips planted with grass, shrubs, trees, and pegs Planting fascines, brush layering, and palisades
Water induced degraded land (spring, water source damaged area, canal command area)	Planting of bamboo, trees, shrubs, and grass with or without terracing and structure Stone pitching and planting of trees, shrubs, and grass slip Planting of deep-rooted species (e.g., bamboo, trees) Live peg fences and live check dams Vegetated stone pitching and loose stone masonry walls or check dams
Cut and filled area or newly exposed area on slope*	Jute netting and straw mats covering soil, seeds, and compost Live peg fences and stone masonry walls Plantation, seeding, and planting grass Live wattling with terracing and seeding

Table 55: Basic techniques of bio-engineering

\*Exposed slope surfaces must be carefully maintained. A cut and newly exposed slope surface should usually be covered, depending on the type of soil material and other factors.

### 3.10.10.7 Benefits of soil bioengineering include:

- Erosion areas often begin small and eventually expand to a size requiring costly traditional engineering solutions. Installation of soil bioengineered systems while problems are small will provide economic savings and minimize potential impacts to the road and adjoining areas.
- Soil bioengineering work is often the only practical alternative on sensitive or steep sites where heavy machinery is not feasible.
- Many designs can be implemented by hand crews.
- Native plant species are usually readily available and adapted to local climate and soil conditions. Costs might be limited to labour for harvesting, handling, and transport to the project site.
- Soil bioengineering projects may be installed during the dormant season of late fall, winter, and early spring. This is the best time to install plants and it often coincides with a time when other construction work is slow.
- Years of monitoring have demonstrated that soil bioengineering systems provide limited initial benefits, but grow stronger with time as vegetation becomes established. Even if plants die, roots and surface organic litter continue to play an important role during reestablishment of other plants.
- Once plants are established, root systems remove excess moisture from the soil profile. This often is the key to long-term soil stability.

- Soil bioengineering provides improved environmental functions, such as slope stabilization, storm water retention, and habitat values.

## CHAPTER 4 – MAINTENANCE OF CLIMATE RESILIENT ROADS

To ensure road spending delivers the best possible return and brings lasting development benefits, it is critical that investment plans take into account the consequences of a changing climate, as **road assets are particularly vulnerable to climate stressors such as higher temperatures, increased precipitation, and flooding**. The damage and accelerated aging of roads caused by climate change will require **increased frequency of maintenance and rehabilitation**.

Climate-resilient roads tend to have higher upfront construction costs, but those are more than offset by the lower annual cost for maintenance, repairs, and rehabilitation.

Therefore, adequate road maintenance is the most critical and most efficient way of reducing the impact of a changing climate on the road system.

### 4.1 Basic objectives of Maintenance:

The basic objectives of maintenance function are to maintain and operate the highway system. It is done to ensure comfort and safety to the public. There are 3 major types of maintenance carried out for roads;

1. Routine Maintenance
2. Periodic Maintenance
3. Emergency Maintenance

#### 4.1.1 Routine Maintenance:

Routine maintenance is a set of recurrent activities which caters to the repair of faults and attention to the road structure and facilities to ensure the preservation of the asset and convenience and safety to the road users. Routine Maintenance shall be carried out on all roads including those which are in good and fair condition. Routine maintenance comprises of following major activities:

##### 4.1.1.1 Maintenance of Road Surface:

It is very important for the service length of a road that the surface of the road is maintained in a good manner. Road surfaces should be reworked only as necessary to provide a smooth running surface and a good crown or slope for drainage. All-season roads will require continual monitoring for surface and sub-grade wear or deterioration. Rutting and loss of ballast often occur during rainy season. Snow removal equipment can also destroy the road surface by removing or altering the crown and removing ballast. A plan should be in place to provide ballast when necessary to maintain continued use of the road.

- The surface of the road should be kept clean from foreign materials such as pebbles, debris etc. at all times.

- Rutting, potholes, corrugation, depressions, shoulder failures and other defects of the surface have to be repaired, especially at the end of the rainy season. Rutting which are the longitudinal depressions in the wheel paths caused by repeated heavy loads, or lateral movement of the material, can be corrected by adding suitable material to the surface. Paved roads are treated by surface dressing and if the ruts are deep, they should be patched before surface dressing is applied.
- Potholes are small depressions in the road surface often caused by poor drainage of the surface or weak sub grade. **Potholes must be fixed as soon as it occurs on road surface.** Potholes may be corrected by patching with well-graded materials and compacting. For paved roads, the patching shall be covered by surface dressing. Should the bitumen bleed in hot weather during the repair of potholes, application of grit/sand must be done.

#### *4.1.1.2 Clearing and Cleaning of Culverts and Drains:*

It is very important for roads to have a proper drainage system and to ensure that it functions well at all times.

- Culverts and drains must be maintained regularly so that no debris will block the flow of water. This is especially important close to forest areas where branches and other debris from trees can be brought by the water.
- In areas with slow water flow, the culverts can easily be blocked by sand deposits that can considerably reduce the flow area of the culvert. In order to facilitate cleaning of culverts, no cross-drainage structures **smaller than 1.2 m diameter** should be used.
- Growth of vegetation on culverts and drains must be prevented.
- Scouring of drains, culverts and culvert aprons must be prevented and the damages should be repaired promptly.
- Debris in and around culverts should be removed by hand or by tongs rather than by heavy equipment working directly in the stream.

#### *4.1.1.3 Other activities:*

Routine maintenance must also cater to other following activities:

- Repair and painting of road signs & markings.
- Care and control of roadside vegetation (trees, grasses, etc)
- Improve and preserve roadside appearance.
- Maintain smooth junction between pavements and decks of bridges, culverts and causeways/flood ways.
- Clear bushes, shrub, weeds and long grasses which interfere with sight distance.
- Maintain the sign posts, guide posts, parapet & guard rails and road markings.

#### 4.1.1.4 Routine Maintenance Calendar:

Sl#	Activity	Month											
		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
1	Vegetation Clearing												
2	Brooming of road surface												
3	Clearing of Side Drains												
4	Berms/Edge Clearing/Repairing												
5	Minor Slip Clearance up to 1.5 cu.m												
6	White washing												
7	Repair/Maintenance/Painting of road furniture												
8	Road marking												
9	Clearing of cross drainage												
10	Snow Clearance												
11	Patches/Potholes repairing												
12	Nursery maintenance												
13	Bio-engineering maintenance												

Figure 39: Routine Maintenance Calendar for High Altitude Roads

Sl#	Activity	Month											
		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
1	Vegetation Clearing												
2	Brooming of road surface												
3	Clearing of Side Drains												
4	Berms/Edge Clearing/Repairing												
5	Minor Slip Clearance up to 1.5 cu.m												
6	White washing												
7	Repair/Maintenance/Painting of road furniture												
8	Road marking												
9	Clearing of cross drainage												
10	Patches/Potholes repairing												
11	Nursery maintenance												
12	Bio-engineering maintenance												

Figure 40: Routine Maintenance Calendar for Low Altitude Roads

### 4.1.2 Periodic Maintenance:

Periodic maintenance is group of activities which can normally be predicted and planned based on its nature, location and extent and are carried out periodically. Periodic maintenance requires specific identification and planning for implementation as compared to the routine maintenance. Periodic maintenance comprises of following major activities:

#### 4.1.2.1 Resurfacing works:

Resurfacing is a road maintenance technique in which a new layer of asphalt is laid over the existing road surface. Resurfacing of the roads can be done in two major ways depending on the extent of damage caused to the road surface.

#### 4.1.2.1.1 Surface dressing:

Surface dressing is a cost-effective way of restoring the road surface and sealing it in one process. Surface dressing improves skidding resistance which makes the roads safer, it also allows the road to be waterproof and protects the road against frost and water damage.

A film of bitumen binder should be sprayed followed by a layer of 6mm to 10mm stone chippings for uniform coating and pressed into the surface by a roller. The process of surface dressing is as explained below;

##### 4.1.2.1.1.1 Construction Operations

###### *Preparation of Base:*

- The base on which the surface dressing is to be laid shall be prepared, shaped and conditioned to the specified lines, grade and cross section.
- Prime coat, where ever is needed, shall be provided. Where the existing surface shows signs of fattening up, the excess bitumen shall be removed by burning off, or manually, as specified.
- The bituminous surface to be dressed shall be thoroughly cleaned either by using a mechanical broom and/ or compressed air, or any other approved equipment/ method as specified. The prepared surface shall be dust free, clean and dry.

##### 4.1.2.1.1.2 Application of Binder

- The spraying of a uniform thin film of binder shall be provided by a Bitumen Sprayer, the type of Sprayer depending on the type of binder used.
- Immediately after application of the binder, clean, dry chips (in the case of emulsion binder the chippings may be damp) shall be spread uniformly on the surface so as to cover the surface completely with a single layer of chips.

##### 4.1.2.1.1.3 Rolling

- Rolling of the chips shall be carried out by 6/8T smooth-wheeled roller or preferably by a pneumatic tyre roller.
- Traditional steel wheeled rollers tend to crush the aggregates and if their use cannot be avoided their weight should be limited to 80 kN.
- Rolling shall commence at the edges and progress, towards the centre except in super elevated and unidirectional cambered portions where it shall proceed from the lower edge to the higher edge.
- Each pass of the roller shall uniformly overlap not less than one-third of the track made in the preceding pass.
- While rolling is in progress additional chips shall be spread by hand in necessary quantities required to make up irregularities. Rolling shall continue until all aggregate particles are firmly embedded in the binder and present a uniform closed surface.

##### 4.1.2.1.1.4 Application of Second Coat of Surface Dressing

- Where surface dressing in two coats is specified, the second coat should not be applied until the first coat has been open to traffic for 2 or 3 weeks.

- The surface on which the second coat is laid must be clean and free of dust. The construction operations for the second coat shall be the same as described above.

#### 4.1.2.1.1.5 Opening to Traffic

- Traffic shall not be permitted on any newly surface dressed area until the following day. In special circumstances, the road may be opened to traffic immediately after rolling, but in such cases, traffic speed shall be limited to 20km per hour until the following day.

#### 4.1.2.1.2 Overlay

Overlay of the bituminous surface involves placement of new layer of asphalt. For every stretch of road that is blacktopped, resurfacing with 30 mm asphalt is normally due in 4 to 5 years and may be lesser in extreme climatic conditions/heavy traffic areas.

Overlays make up a large portion of the roadway paving done today. The degree of surface preparation for an overlay is dependent on the condition and type of the existing pavement. Generally, the existing pavement should be structurally sound, levelled, clean and capable of bonding to the overlay. To meet these prerequisites, the existing pavement is usually repaired, levelled (by milling, pre levelling or both), cleaned and then coated with a binding agent. Before the overlay is carried out the following must be ensured:

- Repair
- Tack coats
- Levelling (both by applying a levelling coarse and by milling)

#### 4.1.2.1.2.1 Repair

Generally, pavement overlays are used to restore surface course characteristics such as smoothness, friction and aesthetics or to add structural support to an existing pavement. However, even a structural overlay needs to be placed on a structurally sound base. If an existing pavement is cracked or provides inadequate structural support these defects will often reflect through even the best-constructed overlay and cause premature pavement failure in the form of cracks and deformations. To maximize an overlay's useful life, failed sections of the existing pavements should be patched or replaced and existing pavement cracks should be filled.

At most, overlays are designed to add only some structural support; the remaining structural support must reside in the existing pavement. Therefore, small areas of localized structural failure in the existing pavement should be repaired or replaced to provide this structural support. Often, existing pavement failure may be caused by inadequate sub grade support or poor sub grade drainage. In these cases, the existing pavement over the failed area should be removed and the sub grade should be prepared as it would be for a new pavement.

Existing pavement crack repair methods depend upon the type and severity of cracks. Badly cracked pavement sections or severe cracks, must be patched or replaced because these distresses are often symptoms of more extensive pavement or subgrade structural failure. Existing cracks other than those symptomatic of structural failure should be cleaned out (blown out with pressurized air and/or swept) and filled with a crack-sealing material when the cracks are clean and dry. Cracks less than about 10 mm in width may be too narrow for crack-sealing

material to enter. These narrow cracks can be widened with a mechanical router before sealing. If the existing pavement has an excessive amount of fine cracks but is still structurally adequate, it may be more economical to apply a general bituminous surface treatment instead of filling each individual crack.

#### 4.1.2.1.2.2 Tack Coats

Before overlaying of bituminous layer is carried out, a tack coat should be placed on an existing pavement to ensure adequate bonding of the overlay to the existing pavement surface. Proper tack coat application can be critical to long-term pavement performance.

#### 4.1.2.1.2.3 Levelling

The existing pavement should be made as smooth as possible before being overlaid. It is difficult to make up elevation differences or smooth out ruts by varying overlay thickness. Therefore, before applying the final surface course the existing pavement is typically levelled by one or both of the following methods:

**Applying a levelling course** - The first lift applied to the existing pavement is used to fill in ruts and make up elevation differences. The top of this lift, which is relatively smooth, is used as the base for the wearing course.

**Milling** - A top layer is milled off the existing pavement to provide a relatively smooth surface on which to pave. Milling is also commonly used to remove a distressed surface layer from an existing pavement.

Levelling courses (or pre level) are initial lifts placed directly on to the existing pavement to fill low spots in the pavement. Typically, pavers are used for this purpose. The pavers are used to drive over a rough, uneven pavement yet place a relatively smooth lift with extra Hot Mix Asphalt (HMA) making up for low spots in the existing pavement. Levelling course lifts need to be as thick as the deepest low spot but not so thick that they are difficult to compact. Because it is not the final wearing course, levelling course elevation and grade are sometimes not tightly specified or controlled. However, contractors and inspectors alike should pay close attention to levelling course thickness because an excessively thick levelling course can lead to large overruns in HMA and thus large overruns in project budget. Although levelling courses can help produce a smoother pavement, they suffer from discussed differential compaction and therefore may not entirely solve the smoothness problem.

Milling can be used to smooth an existing asphalt pavement prior to overlays. Rather than filling in low spots, as a levelling course does, milling removes the high points in an existing pavement to produce a relatively smooth surface. For HMA pavements, milling can help eliminate differential compaction problems.

Milling machines are the primary method for removing old HMA pavement surface material prior to overlay. They can be fitted with automatic grade control to restore both longitudinal and transverse grade and can remove most existing pavement distortions such as rutting, bumps, deteriorated surface material or stripping. The primary advantages of milling:

- Eliminates the need for complicated levelling courses and problems with quantity estimates for irregular levelling course thicknesses used to fill existing pavement depressions.

- Provides Reclaimed Asphalt pavement option for recycling operations.
- Allows efficient removal of deteriorated flexible pavement material that is unsuitable for retention in the pavement structure.
- Provides a highly skid resistant surface suitable for temporary use by traffic until the final surface can be placed.
- Allows curb and gutter lines to be maintained or re-established before flexible overlays.
- Provides an efficient removal technique for material near overhead structures in order to maintain clearances for bridge structures, traffic signals and overhead utilities.

The basic components of a milling machine are a cutting drum to mill the existing pavement, a vacuum to collect the milled particles and a conveyance system to transport the milled particles to a dump truck for hauling.

After a pavement has been milled the resulting surface is quite dirty and dusty. The surface should be cleaned off by sweeping or washing before any overlay is placed otherwise the dirt and dust will decrease the bond between the new overlay and the existing pavement. When sweeping, more than one pass is typically needed to remove all the dirt and dust. If the milled surface is washed, the pavement must be allowed to dry prior to paving.

Milling also produces a rough, grooved surface, which will increase the existing pavement surface area when compared to an un-grooved surface. The surface area increase is dependent on the type, number, condition and spacing of cutting drum teeth but is typically in the range of 20 to 30 percent, which requires a corresponding increase in tack coat (20 to 30 percent more) when compared to an un-milled surface.

**Once the existing asphalt surface has been prepared, the asphalt overlay can be paved on top of the surface. The minimum thickness of asphalt overlay must be 30 mm.**

#### 4.1.2.2 Types of defects and their repair

**Deformation** - Following are the different types of deformation, their probable causes and remedies:

Sl.#	Defect	Description	Probable Causes	Type of remedies
1	Corrugations	Transverse undulations closely and regularly spaced wave action on the surface	Inadequate stability of the premix surface or pavement	Patch repair
2	Depressions	Localized area in a pavement which is lower than surrounding area	Consolidation of isolated areas of poorly compacted sub-grade. Settlement due to instability of embankment	Pothole repairs Strengthening of weak sections
3	Rutting	Longitudinal deformation in a wheel path of a road	Inadequate pavement thickness. Poor compaction of pavement or sub-grade	Patch repairs, potholes repairs
4	Shoving	Bulging of road surface and horizontal displacement of surfacing materials	Inadequate strength in pavement	Patch repairs

Table 56: Types of deformation, causes and remedies



Figure 41: Corrugation and Rutting on road surface



Figure 42: Shoving on road surface

**Cracks** - Following are the different types of cracks on road surface, their probable causes and remedies:

Sl.#	Defect	Description	Probable Causes	Repair methods
1	Block	Interconnected cracks forming a series of blocks approximately rectangular in shape and usually distributed over the full pavement	Shrinkage cracks in the asphalt surfacing. Fatigue cracking in hardened asphalt wearing course.	Crack Seal
2	Crescent	Half-moon or crescent shaped cracks	Poor bond between wearing course and pavement layers. Thin wearing course.	Patch repair
3	Alligator	Interconnected cracks resembling the skin of a crocodile generally in the wheel paths of a road.	Inadequate pavement thickness. Hardened wearing course.	Fog Seal if less severe Patch repair if highly severe
4	Diagonal	Unconnected cracks on diagonal across the road.	Differential settlement at embankments and cuttings.	Crack Seal
5	Longitudinal	Cracks running along the road in same direction as vehicles.	Differential settlement sometimes along the shoulder edge.	Crack Seal
6	Meandering	Unconnected irregular crack varying in direction.	Weakening of pavement edge. Entry of moisture. Reflection shrinkage crack. Differential settlement.	Crack Seal

7	Transverse	Unconnected crack running across the road	Construction joint or shrinkage crack in asphalt surfacing	Crack Seal
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*Table 57: Types of cracks, their causes and remedies*



*Figure 43: Block cracking and alligator cracking on road surface*



*Figure 44: Meandering and Diagonal cracking on road surface*

**Surface Texture deficiencies** - Following are the different types of surface texture deficiencies, their probable causes and remedies:

Sl. #	Defect	Description	Probable Causes	Repair methods
1	Delamination	Surface lifting seal break	Inadequate cleaning or insufficient tack coat on pavement before placing premix carpet.	Patch repair Fog Seal
2	Flushing	Black spot, fatty surface, excess bitumen on surface	Too much bitumen with respect to aggregate size.	Apply heated sand and roll
3	Polishing	Smoothing/rounding stone aggregates on wheel paths.	Stone aggregates too soft therefore polishing and rounding. Use of naturally smooth uncrushed stone aggregates.	Apply aggregate and sand seal coat
4	Ravelling	Disintegration of pavement surface by loss of bitumen and stone aggregates.	Deterioration of binder and/or stone aggregates. Inadequate compaction, construction during wet weather, insufficient binder, excessively open graded mix, fracture of stone aggregates during rolling.	Patch repair, Fog Seal
5	Stripping	Loss of stone aggregates in sprayed seal leaving only bitumen.	Insufficient bitumen application. Inadequate rolling of sprayed seal.	Patch repair
6	Potholes	Steep deep sided holes in pavement and wearing course.	Loss of surface dressing. Water entering pavement through cracks.	Pothole repair

*Table 58: Types of surface texture deficiencies, causes and remedies*

**Common Cross Drainages/culvert failures** - Following are the different types of common cross drainage or culvert failures, their probable causes and remedies:

Sl.no	Damage/Defect	Routine Maintenance	Periodic Maintenance
1	Siltation	Removal of silting materials and waste Occasional cleaning	
2	Fissures and cracks	-	Sealing of Fissures and cracks
3	Displacement/Dislocation	-	Relocation of misplaced elements
4	Joint Separation	-	Relocation of misplaced elements
5	Spalling	Repair of minor spalling	Repair of major spalling (including the passivation of reinforcement rods)
6	Break	-	Replacement of sections/elements
7	Collapse	-	Replacement of sections/elements
8	Corrosion	-	New protection treatment in the affected areas
9	Scouring	-	Repair and protection against scouring Embankment stabilization
10	Existence of vegetation	Clearing of Vegetation	Removal of harmful vegetation

*Table 59: Common cross drainage failures and remedies*

### 5.2.2 Emergency Maintenance:

Emergency maintenance is certain activities that is performed in order to restore the roadway following the damages caused by events such as monsoon rains resulting in floods or landslides which would be unpredictable.

Activities that have to be carried out as emergency maintenance are as follows:

- Snow clearance.
- Clearing of landslides.
- Repair of culverts and bridges.
- Reconstruction or rehabilitation of retaining wall based on the degree of damage caused.
- Construction of diversions.
- Repair of flood way.

- Restoration of road formation width.

#### *4.1.2.3 Snow clearance:*

Keeping the roads trafficable during snowfall is very important and challenging as well. Snow clearance can be done in several ways like:

- Clearance by men or machine
- Use of chemicals for clearance
- Use of grit

#### *4.1.2.4 Clearance by Men or Machine:*

The mechanical way of clearing snow is by blading it over the side of the road. The equipment used for snow clearing are:

- Motor grader
- Front end loaders

While deploying these machines for snow clearance, care must be taken that there is no damage caused to the pavement by the blades.

If there is formation of a film of ice on the surface of the road, which usually happens when snow freezes due to low temperature. Friction between the wheels of the vehicle and the road surface is lowered by ice on the road surface which causes the vehicle to lose control and slip off the road.

Ice on road requires treatment with chemicals (salt) to melt ice or by spreading grit (fine stone chippings) to provide traction for the wheels.

Sodium Chloride (Salt) or Calcium Chloride may be used to melt ice on road surfaces. De-icing salt works by creating a brine solution that has a lower freezing temperature than the temperature of the surrounding snow and ice. This brine gets in between the road surface and ice, preventing a bond that would make removal difficult. When salt is spread before snow fall or drop in temperature, it can prevent snow accumulation or ice formation. Application of salt is done manually by spreading it with hands. Though Calcium Chloride also has the same effect but Sodium Chloride is preferred since it costs lesser than the Calcium Chloride.

It must be noted that salt should not be used on roads under construction where bitumen sealing is to be carried out in the future, as the salt may damage the seal.

Where the use of salt as de-icing agent is not permissible, or the temperature is so low that a complete melt is not possible with salt application, grit should be spread to increase traction. The grit may be spread manually by hand if the area to be treated is small.

The table below provides a guidance for assignment of priorities for various operations and based on the priority it is identified as follows:

- Urgent for activities requiring top priority
- Special for activities which are in next order of priority

- Periodic for activities which occur recurrently and are next in line to special in order of priority and
- Routine for jobs which are to be attended to in a routine manner

Feature	Criteria	Action	Priority
Landslides/slips	Any type of slip or slides blocking the road and affecting the traffic flow	To be cleared immediately with available equipment at the site.	Urgent
Snowfall	Road affected by snowfall compelling suspension of traffic	To be cleared immediately with machineries or chemicals.	Urgent
Minor Cuts, ruts or blockades	Cuts or blocks that do not completely obstruct the traffic but endanger safety of traffic	Blockades to be removed and cuts to be repaired	Urgent
Cracking not accompanied by rutting	a) Cracking in local areas equal to or less than 25 percent of the total area b) Cracking in large areas exceeding 25 percent of the total area	a) Local sealing or filling of the cracks b) Binder @ 1.5kg/m <sup>2</sup> of 1 kg/m <sup>2</sup> of cutback for local sealing. c) Chippings(6-10mm) for local surface repairs which needs surfacing after local sealing	a) Routine b) Special attention c) Special attention.
Stripping	a) In local areas exceeding 25 percent of the total area. b) In larger areas exceeding 25 percent of total area.	Apply Local sealing. Apply surface dressing	a) Routine b) Special attention
Bleeding	a) In local areas not exceeding 25 percent of total area b) In local areas exceeding 25 percent total area.	a) Spread and roll over 6mm size aggregate heated to 60°C b) Apply surface dressing	a) Routine b)Special attention

Table 60: Priority for emergency maintenance

### 4.1.3 Maintenance of Bio- engineering

Bio-engineering is the use of vegetation, either alone or in conjunction with engineering structures to reduce instability and erosion. Bioengineering involves the use of live plant materials to perform engineering functions in stabilization of disturbed slopes. These vegetative structures are flexible and hence absorb movement; being live they recover from damage and ensure continued stability. The main aim of bio-engineering is to prevent all forms of erosion and shallow mass movement. Vegetation is carefully selected for the functions it can serve in stabilising roadside slopes and for its suitability to the site. In order to gain the maximum benefit, vegetation must be managed and taken care of. Bio-engineering becomes a part of Routine and periodic off-road maintenance.

Routine maintenance of bio-engineering must cater to simple protection and care of plants, such as watering, mulching and grass cutting.

Periodic maintenance of bio-engineering requires thinning and pruning of larger plants, repair of vegetation structures and vegetation enrichment. Vegetation on roadsides must be maintained on a long-term basis in order to maximize their engineering contribution.

## 4.2 Pavement Preservation Techniques

### 4.2.1 Fog seal

A fog seal is an application of a specially formulated asphalt emulsion (a thin liquid oil) to an existing asphalt pavement surface.

Asphalt emulsions used in fog seal applications contain globules of paving asphalt, water, an “emulsifying agent” or surfactant. Soap is a common form of a surfactant. In asphalt emulsions, the surfactant keeps the paving asphalt globules in suspension until it is applied to the pavement surface when the water in the asphalt emulsion starts to evaporate. A “rejuvenator” is an asphalt additive which when applied to the existing pavement will slightly soften the pavement it is applied to creating a better bond.

As asphalt pavement is subjected to traffic loads and as it ages, it oxidizes and cracks develop in the surface due in part to the pavement becoming more brittle. Oxidation is one of the reasons asphalt concrete pavement fades in color from the deep, rich black. Fog seal applications serve to seal narrow cracks, slightly restore lost flexibility to the pavement surface, provide a deep, rich black pavement surface color, and most importantly help preserve the underlying pavement structure.

On existing asphalt pavement, fog seals are typically applied on either an intermittent or cyclical basis. Location, weather, traffic loading, and pavement conditions are factors used to determine if a fog seal application is appropriate. Roadways selected for fog seal treatment are commonly those which have minor cracking, faded color, and where a fog seal would help extend the pavement life until resurfacing becomes necessary. Roadways chosen for cyclical fog seal applications would typically be treated every three to five years.

Fog seals are applied by a distributor truck. The distributor truck slightly heats the asphalt emulsion before spraying it onto the pavement. Once applied the surface has the appearance similar to the pavement having been spray painted black.

### 4.2.2 Micro-surfacing

Micro-surfacing is a method that consists of the application of a mixture of water, asphalt emulsion, aggregate (very small crushed rock), and chemical additives to an existing asphalt concrete pavement surface. Polymer is commonly added to the asphalt emulsion to provide better mixture properties.

Micro-surfacing is applied in order to help preserve and protect the underlying pavement structure and provide a new driving surface. Roads chosen for micro-surfacing application generally have low to moderate distress and narrow crack width.

Micro-surfacing is typically applied on an intermittent, project specific basis. Location, weather, traffic loading, and pavement conditions are factors used to determine if a micro-surfacing application is appropriate. Roadways selected for micro-surfacing treatment are commonly those which have slight to moderate distress, no rutting, generally narrow crack widths, and in which micro-surfacing treatment would help extend the pavement life until resurfacing becomes necessary. Roadways chosen for cyclical micro-surfacing applications would typically be treated every five to seven years.

Micro-surfacing is commonly mixed in, and applied using, a purposely built truck, generally referred to as a “slurry truck.” If the roadway segments to be micro surfaced are long and don’t contain sharp curves, a “continuous machine” is sometimes used. The continuous operation provides the benefit of having few if any seams in the roadway which occur when operation stops.

Slurry trucks and continuous machines contain various compartments which hold the aggregate (fine crushed rock), water, polymer modified emulsion, and other additives, which are mixed in the on-board mixer. The micro surfacing mixture flows out of the rear and onto the pavement within the confines of a rear-mounted box referred to as a “micro box.” This box contains an auger which turns to uniformly distribute the mixture across the width. Workers with squeegees follow behind and assist in spreading the mixture, correcting areas not properly covered.

A piece of burlap is often dragged behind in order to provide a smooth texture while applying the micro surfacing material. The texture of micro surfacing is different than that of asphalt pavement. The texture may have faint lines and be somewhat coarse. In addition, when the micro surfacing is first placed the surface is tender and can be marked up by sudden turning movements. These impressions on the pavement are temporary as seasonal weather and traffic smooth out these imperfections over time.

Once placed, micro-surfacing needs 1 to 2 hours to set or harden before the road is open for traffic.

### 4.2.3 Slurry Seal

A slurry seal is the application of a mixture of water, asphalt emulsion, aggregate (very small crushed rock), and additives to an existing asphalt pavement surface. A slurry seal is similar to a fog seal except the slurry seal has aggregates as part of the mixture. This combined mixture of the emulsion and aggregates represents “slurry.” Polymer is commonly added to the asphalt

emulsion to provide better mixture properties. The placement of this mixture on existing pavement is the “seal” as it is intended to seal the pavement surface.

Slurry seal is applied in order to help preserve and protect the underlying pavement structure and provide a new driving surface. Roads chosen for slurry seal applications generally have low to moderate distress and narrow crack width. Slurry seal applications serve to seal the cracks, restore lost flexibility to the pavement surface, provide a deep, rich black pavement surface color, and help preserve the underlying pavement structure.

Slurry seal is typically applied on either an intermittent or cyclical basis. Location, weather, traffic loading, and pavement conditions are factors used to determine if a slurry seal application is appropriate. Roadways selected for slurry seal treatment are commonly those which have slight to moderate distress, no rutting, and generally narrow crack widths, and where a slurry seal treatment would help extend the pavement life until resurfacing becomes necessary.

Roadways chosen for cyclical slurry seal applications would typically be treated every five to seven years.

The asphalt emulsion and the aggregates are mixed in, and applied using, a purposely built truck, generally referred to as a “slurry truck.”

Slurry trucks contain various compartments which hold the aggregate (fine crushed rock), water, polymer modified emulsion, and other additives, which are mixed in the on-board mixer. The slurry mixture flows out of the rear of the truck and onto the pavement within the confines of a box attached to the rear of the truck. The box serves to distribute the slurry mixture over the pavement. Workers with squeegees follow behind and assist in spreading the mixture, correcting areas not properly covered.

#### **4.2.4 Chip Seal**

A chip seal is a two-step process which includes first an application of asphalt emulsion and then a layer of crushed rock to an existing asphalt pavement surface. Asphalt emulsions used in chip seal applications contain globules of paving asphalt, water, an “emulsifying agent” or surfactant, polymer, and sometimes a “rejuvenator.” Soap is a common form of a surfactant. In asphalt emulsions, the surfactant keeps the paving asphalt globules in suspension until it is applied to the pavement surface when the water in the asphalt emulsion starts to evaporate. The chips (small crushed rocks) are immediately applied after the asphalt emulsion is applied to the pavement surface. The polymer in the asphalt emulsion is a “hardener” which serves to improve the adhesion to the crushed rock and to the pavement surface. A “rejuvenator” is an asphalt or additive which when applied to the existing pavement will slightly soften the pavement it is applied to creating a better bond.

As asphalt pavement is subjected to traffic loads and as it ages, it oxidizes, becomes more brittle and cracking develops in the pavement structure. A chip seal serves to seal the narrow cracks, help bind together cracked pavement, provide a wearing (driving) surface, and protect the underlying pavement structure. Chip seals used as interlayers serve to retard reflective cracking which develops from the bottom of the pavement structure towards the top.

Chip seals are typically applied on an intermittent or one-time basis. Location, weather, traffic loading, and pavement conditions are factors used to determine if a chip seal application is appropriate. Roadways selected for chip seal treatments are commonly those which have moderate block (or “alligator”) cracking which is not spalling (or “popping out”), no rutting, an acceptable ride quality, and in which a chip seal would help extend the pavement life until resurfacing or rehabilitation can be performed.

Roadways chosen for cyclical chip seal applications would typically be treated every seven to ten years.

A distributor truck first applies the asphalt emulsion to help seal the pavement surface. Using an asphalt emulsion is considered a “cold applied” chip seal even though the liquid temperature is typically between 110 and 150 degrees Fahrenheit. No smoke results from the application of emulsified asphalt. If modified paving asphalt is applied, it is considered a “hot applied” chip seal as the liquid application temperature is typically between 325 and 375 degrees Fahrenheit. Smoke will result from the application of modified paving asphalt but should not be of concern.

Immediately following application of the asphalt emulsion, a “chip spreader” follows and applies crushed rock to the top of the asphalt emulsion. A dump truck dumps crushed rock into the chip spreader as it travels. Following chip application, rubber tired rollers follow closely behind. The purpose of the rollers is to push the chips down into the binder and enhance the bond between them. A steel drum roller commonly follows the rubber tired rollers on “hot applied” chip seals.

After rolling and once the binder and chips have properly adhered, the surface is swept by power sweepers. The sweepers sweep the loose crushed rock which has not adhered to the underlying asphalt emulsion. Loss of crushed rock due to sweeping is a normal part of the operations. A chip seal would not be successful if the result was areas of the existing pavement not covered by crushed rock.

The final operation is placement of a “flush coat.” The flush coat consists of the application of a fog seal (see fog seal) followed by the application of very clean sand. The purpose of the flush coat is to help “lock down” the chips and absorb any excess asphalt emulsion. The result is a pavement surface that has a rough texture and a very deep, rich black in color.

## Annexure I

### Pro-forma for Collection of Data on Landslide Occurrence & Clearance

1. Location
  - i) Name of Road
  - ii) Type of Road
  
2. Location of the Slide:
  - i) Name of the place:
  - ii) At Km from:
  
3. Data to be collected regarding the slide when it is active:
  - i) Date of sliding:
  - ii) No. of times sliding has taken place in a year:
  - iii) Duration for which road was blocked by the slide (No. of days or hours):
  - iv) Damages to property or persons caused by the slide:
  - v) Quantity of material cleared:
  - vi) Method of clearance (Manual or by machine) and the time taken for clearing:
  - vii) Cost of clearance operation:
  - viii) Were any permanent stabilising measures executed since last sliding and if so, their efficacy:
  - ix) Is the slide preceded by rainfall or snowfall?
  - x) IS extent of area participating in sliding
  - xi) Confined to uphill slide of road only
  - xii) Confined to downhill side of road only
  - xiii) Covers both
  - xiv) Is the cause of slide due to man-made causes such as back-cutting, etc.
  - xv) Does the slide appear to be a surficial one or a deep seated one:

#### 5.3 Standard information/data to be collected about the slide:

- a. Prepare a sketch of the slide area covering the slopes both uphill and downhill of the road and include the following information;
- b. Length of the slide from crown to toe, indicating separately the length affected both above and below the road;
- c. Width of the slide (parallel to the road);
- d. Maximum depth (normal to the slide);
- e. General description of the slide area giving condition of the slopes, presence of erosion gullies, presence of water springs, tension cracks, etc.

#### 5.4 Geological Data

- a. Nature of rock – Indicate whether the slide material is predominantly rock or soil, decomposed rock or disintegrated rock or a mixture of both;
- b. Type of rock and formation;
- c. Indicate the type of rocks met within the formation

- d. Indicate whether there is any inter-bedding involving especially slide susceptible formation such as shale or sandstones
- e. Dip and strike – Indicate the dip and strikes of the rock formation and note whether they are favourable or unfavourable for slide formation with reference to the location of the road at the particular stretch.
- f. Weathering – Indicate whether the rock is subject to weathering or other degrading process due to natural or man-made causes.

## **5.5 Geotechnical data**

### **5.5.1 Nature of the soil**

- Give the classification of soil (or soil fraction of the mantle material) and identification data according to standard soil mechanics procedure
- Is there any pre-consolidated clay or shale met with?

### **5.5.2 Alteration of forces acting**

- Has there been any increases in the load due to construction of embankments or structures or accumulation of slide material?
- Has any construction work been carried out that adversely influences the stability, such as under-cutting the toe etc.?
- Has the slope been subject to vibrating action of either construction equipment or due to earthquakes or due to blasting?

### **5.5.3 Action of water**

- Has any water or seepage been noticed at the joint planes or along the slide surface or in clay strata?
- Give a brief description of the drainage conditions prevailing in the slide area.
- Are there any sources of water flow nearby, such as a lake or reservoir or a river, etc?

### **5.5.4 Causes of slide**

Landslides are usually caused by a number of factors rather than a single factor. Indicate which in your opinion are the predominant causes, and give, if possible, the order of their relative predominance.

### **5.5.5 Geological Causes**

Weathered rock, disintegrated and/or decomposed rock, due to various reasons like temperature changes, frost effects, other natural or man-made causes etc.

### **5.5.6 Geotechnical Causes**

Increase in load causing sliding due to any construction or accumulation of slide material or snow. Reduction in resisting forces caused by excavation at toe. Increase in water content of clayey layers due to rainfall or seepage, bad drainage, sudden draw-down, rise in water level in lake upstream. Inter-beds of clay or shale or micaceous matter that are susceptible of being softened by action of water

### **5.5.7 Classification of slide**

Give the classification of the slide according to the Varness system of classification

#### **Remedial measures**

- a. Has the slide area been studied for evolving remedial measures?
- b. If so, by which organization?
- c. Give a summary of the major recommendations
- d. Were any/all of the remedial measures implemented? If so, detail them
- e. What is the degree of success met with in stabilizing the slide area?

#### **Recommendations**

- a. Comment on future action you suggest
- b. Likely behaviour in future

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