Highway Planning

Introduction

Transportation planning, or Road planning, is involved with the evaluation, assessment, design and siting of transport facilities.

In other words it is the process of deciding in advanced the manner in which the transportation facilities will be made so that the demand of today and that of a foreseeable future can be satisfied

- Planning is a pre-requisite for any development work.
- Planning is the basic requirement for any new project or an expansion programme.
- Planning is the best utilisation of available funds in a systematic and planned way to derive maximum benefits out of the money spent.

Introduction

Highway road project can be defined as the discipline of planning, organizing, securing, and managing resources to bring about the successful completion of road project goals and objectives.

Thus highway planning is also a basic need for its development.

Specially planning is of great importance when the available resources are limited and the requirement is much higher.

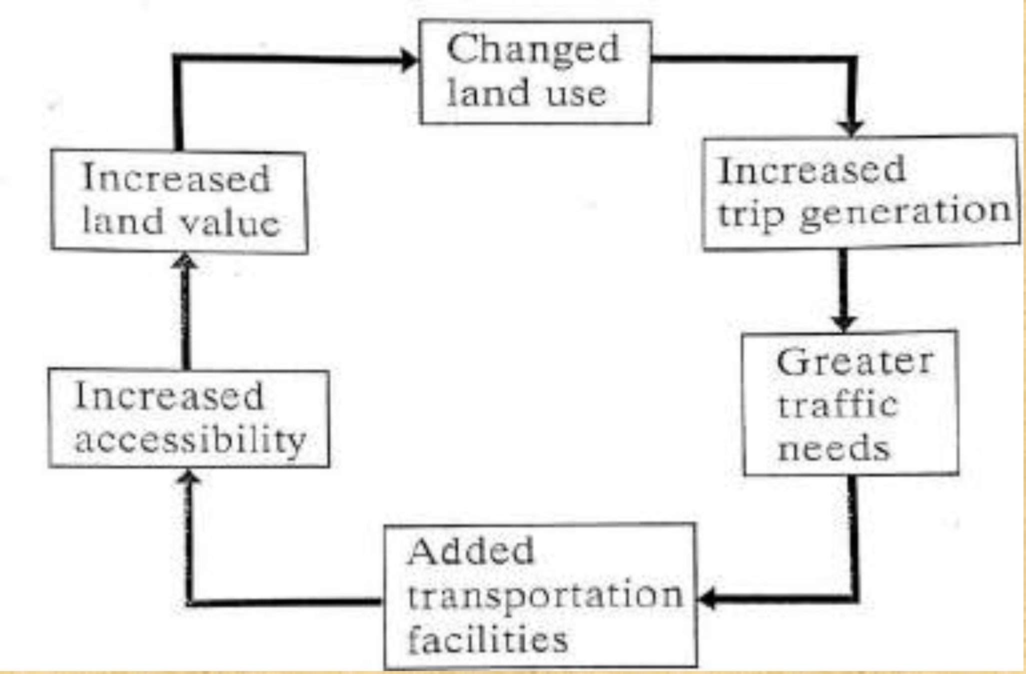
Approach of Highway Planning

The major steps in the planning process are:

- the articulation of goals and objects,
- data collection,
- data analysis and model development,
- travel forecasting, and
- systems analysis and evaluation.

Need of Transportation Planning

Transportation demand is a ever changing parameter and is dynamic in nature



Land use -Transportation Cycle

Need of Transportation Planning

- Transportation System requires a Continuous Planning to Optimally Satisfy the Mobility Requirement of the Society.
- Transport Planning is essential to set transport project priority for a country, region or locality and it becomes more significant when the resources available are limited and requirements are higher.
- The main objective of transport planning is to utilize the available resources in the best possible way and in a very systematic manner including project identification and decision of national priority area.
- e.g. 21 National Pride Projects of Nepal

Objectives of Highway Planning

To provide safe and efficient roads at minimum cost.

To plan for future requirements and improvements of roads in view of anticipated developments.

Defining the highway planning process, establishing necessary standards, and auditing performance;

Leading the development of the highway network system;

The highway should be as direct as possible between the cities to be linked, as it will result in economy in construction, maintenance and operation

To construct the best possible road system having maximum utility within the available resources.

Objectives of Highway Planning

To fix up the priorities for future development on utility basis.

To work out the financing system.

Articulate the goals and objects of the planning effort.

Define study constrains, e.g , time, cost, available resources, etc.

Employ basic systems analysis procedures to select the most appropriate method of approach

Use the selected approach to produce probable impacts of alternative systems.

Evaluation the various alternatives, using the basic systems analysis approach in construction with previously agreed upon performance measures to select the best available alternative.

Translate the best alternative into an implementation plan including individual project statements.

The Phases of Road Planning

The planning of road projects is a process becoming more detailed stage by stage.

At each stage, the level of planning accuracy and decision making is adapted in accordance with land use planning.

The planning process has four stages:

- Feasibility study,
- Preliminary engineering planning,
- Final engineering planning and
- Construction planning.

In minor road projects with limited impacts, planning and decision-making stages can be combined.

When a new highway or the improvement of an existing highway is planned, the planning must be based on a land use plan meeting the requirements of the Land Use and Building Act.

A road project is given its form and details during a planning process which becomes more and more detailed in phases, adjusted to correspond to land use planning.

Dividing project-specific planning into phases makes specifying the order and time of road project implementation easier.

Factors in Planning

Types of Planning

- Short Term Planning
- Medium Term Planning
- Long Term Planning
- **Short/Medium term planning:**

Less complex, no great demand on construction activities so requires less fund and main objective is to obtain maximum efficiency or optimal operation from existing facilities

- **Long Term Planning:**

Complex in nature because of comprehensive and strategic transportation planning, require huge financial expenditure and involve large and extensive construction programs which affect the Economic, Social and Natural Environments. Policy making, government role, administration, and forecasting are crucial to achieve the desired solution. System Approach is the Best way of getting solution.

Evaluation of Alternatives
(Establishing Economic and Environmental Viability)

A particular alignment shall be recommended if it is the best alternative solution among the various alternative road projects

Economic Viability:

Criteria for comparison-

- Benefit/ Cost ratio
- IRR
- Payback
- Social benefit

Evaluation of Alternatives
(Establishing Economic and Environmental Viability)

Environmental Viability:

Positive Effects

Negative Impacts

- Socio-Economical Impacts
- Biological Impacts
- Chemical Impacts
- Physical Impacts

A road projects is viable when the benefits due to the positive impacts are significant than the losses in terms of bio diversity , ecology and environmental parameters

Road Classification
Administrative/Functional Classification

National Highways

- Main arterial roads connecting East to West and North to South
- Longer distance travel, higher the inter- community mobility.
- designated by letter “H” followed by a two- digit number.

Feeder Roads

- Connect District Headquarters, Major economic centers, Tourism centers to National Highways or other feeder roads.
- They are designated by letter “F” followed by 3-digit number

District Roads

- Roads connecting district headquarters to village or village to village
- Serves rural area of production , market centers service centres etc.

Urban Roads

- The roads serving within the urban municipalities. Except highways and feeder roads
- Designed to maintain flow as well to provide modern facilities and also to maintain the city aesthetics
- **Design Speed 40-50kmph**

Road Networks of Nepal
National Road Network of Nepal

Strategic Road Network (SRN)

- **Consist of the main national arteries, which provide inter-regional connections and links to district headquarters, international borders, key economic centers and the major urban roads**
- **Comprises of National Highways, Feeder Roads and Roads having a specific objective.**
- **Road having highly dense daily traffic, roads connected with the possibility and investment of project as electricity, tourism, industry, roads concerning with important vehicle in urban area and the roads necessary to be built by central level as: road in side district or feeder roads connecting district headquarters and important roads connecting more than one districts**
- **The classification and name of any particular road shall be prescribed from time to time by Government of Nepal through a notice published in the Nepal Gazette such roads shall be operated by the central bodies.**

Road Networks of Nepal
National Road Network of Nepal

Strategic Road Network (SRN)

- The roads under strategic road system shall be evaluated in every three years regularly.
- Under the jurisdiction of DoR under MoPIT

Local Road Network (LRN)

- Comprising of Roads those are not the parts of the central road system and where project formulation, construction, maintenance and repair have to be done by local institution shall be classified as the local road system.
- Constructed and maintained by the local governments (DDCs, VDCs & municipalities) with the support from DoLIDAR, functioning under MoFALD)
- Road within district, road within village, main trails, mule track, and village trails and tracks shall be operated. Roads connecting one or more main development centre or connecting VDC's directly to the headquarters of the same district or other district or through important road system fall under local roads

Urban Road Network of Nepal

- Roads within a Municipality, excluding those under central road system, are under urban road system. The construction maintenance and repairing of these roads shall be done by the Municipality.
- Those works shall be conducted by peoples' participation.
- More over the construction and operation of permanent parking places including pavement within urban area shall be the responsibility of the respective municipalities.
- The constructions, maintenance, repair and operation of bus terminals shall be under the working scope of municipality.
- Identification, conservation of green belt in the urban area shall be the responsibility of the municipality itself.
- These works shall have to be done by the municipality in coordination with various authorities of Government of Nepal.

Road Network Planning

- It should establish an integrated road network capable of accommodating all road travel in an orderly, safe, efficient and economical way. Also it shall develop roads in such a way that roads aid the development of suitable models of other means of transportation
- For this 3 Processes should be followed:

1)Forecast the future requirements of roads needed.

2)Set up priorities and schedules of construction and renewal program in accordance with the available resources.

3)Financial planning and management.

Types of Road Network Planning in Nepal

1) National road network planning
- Strategic Road Network Planning
- Local Road Network Planning

2) Urban/City road network planning

Strategic Road Network Planning

- Strategic Road Network Planning (National and Feeder roads)
- Linear pattern (East to west such as East West Highway, Mid Hill road , North to south – Kathmandu Terai Fast track, Karnali Highway)
- Economic prosperity, national integrity , social justice and political balance

Local Road Network Plan

- To provide access to all District Headquarters to strengthen social, economic, administrative linkages
- Poverty reduction and accessibility
- District Transport Master Plan

Urban Road Network Planning

- **Should consider the extent of the town, future expansion possibilities etc.**
- **In old towns/cities**
  - no plan
  - roads are developed along a well used track way.
  - linear pattern
  - These trends no more use in modern towns, and require modern practices with models capable to deal with grater amount of traffic more efficiently

Road Transport and Development in Nepal

Road Transport and Development in Nepal

During Rana regime, there was a road office named "Bato Kaj Goshwara“

"Naya Bato Kaj Goshwara" and "Purano Bato Kaj Goshwara" were merged into a new office as Public Works Department (PWD), in 2007 BS.

Under PWD two sections were created - one as road section and the other as building section (for all kinds of civil engineering works other than that of roads)

"Bagmati valley Road Project " was set up to carry out the detail survey and construction of Kanti Rajpath in 2011.

In 2017 BS, Rajdal Army Battalion completed the construction of 70 Kms. of 91 Km. long Kanti Rajpath.

In 1958 The Tribhuwan Rajpath was constructed with the help of Indian army

In 2017 BS, three sub-sections, named as Construction, Planning and Maintenance, were created under road section of PWD.

Department of Roads (DoR) was Established along with Department of Building after splitting from Public Works Department (PWD) in 2027 B.S.

Historical Development in Road Construction in Nepal

Fiscal Year		Black top	Gravel	Earthen	Total
1950	2007	Year of Democracy			360
1974-75	2031-32	1575	516	1182	3173
1979-80	2036-37	2044	564	2332	4940
1984-85	2041-42	2724	918	2283	5925
1989-90	2046-47	2899	1621	2516	7036
1994-95	2051-52	3533	2662	4529	10724
1999-2000	2056-57	4522	3646	7140	15308
2004-05	2061-62	4911	4707	7661	17279
2009-10	2066-67	4952.11	2065.15	3817.76	10835.02
2011-12	2068-69	5573.55	1888.49	4173.55	11635.58 + 50,994 LRN
2013-14	2070-71	5573.55	1888.49	4173.55	11635.58 + 50,994 LRN

HIGHWAY ALIGNMENT , ENGINEERING SURVEY and FEASIBILITY

HIGHWAY ALIGNMENT

- **Alignment** is the layout of the central line of highway on the ground.

Includes two parts:

- **Horizontal alignment**
- **Vertical alignment**

- Horizontal alignment in road design consists of straight sections of road, known as tangents, connected by circular horizontal curves. Circular curves are defined by radius and deflection angle (extent). The design of a horizontal curve entails the determination of a minimum radius (based on speed limit), curve length, and objects obstructing the view of the driver.

- Projection of highway in vertical plane is the vertical alignment consists of gradients and vertical curve

- It consists of three major drawings:

- **Plan of the road**
- **Longitudinal Profile**
- **Cross Section**

ALIGNMENT SELECTION

- It is the process of selecting the best suited alignment among the possible alternatives
- Alignment decision is important because a bad alignment will increase the construction, maintenance and vehicle operating costs.
- Once an alignment is fixed and constructed, it is not easy to change it due to increase in cost of adjoining land and construction of costly structures by the roadside.

Requirements of Highway Alignment

- **SESEC**
  - Short
  - Easy
  - Safe
  - Economical
  - Comfort

Requirements of Highway Alignment

- **Short:** The alignment between two terminal stations should be short and as far as possible be straight, but due to some practical considerations deviations may be needed.
- ***Easy***: The alignment should be easy to construct and maintain. It should be easy for the operation of vehicles. So to the maximum extend easy gradients and curves should be provided.
- ***Safe:*** It should be safe both from the construction and operating point of view especially at slopes, embankments, and cutting. It should have safe geometric features.

Requirements of Highway Alignment

- ***Economical:*** The alignment should be economical and it can be considered so only when the initial cost, maintenance cost, and operating cost are minimum.
- **Comfort:** it should provide comfort to the users.
- **The alignment should be such that it would offer maximum utility by serving maximum possible population and products**

Factors Controlling Highway Alignment

- The various factors that control the alignment are as follows:
- Government Requirement
- Obligatory Points
- Traffic
- Geometric design
- Economics
- Other considerations

Factors Controlling Highway Alignment

- **Government Requirements:**

  Government should be clear about the road requirement due to heavy investment in the project.

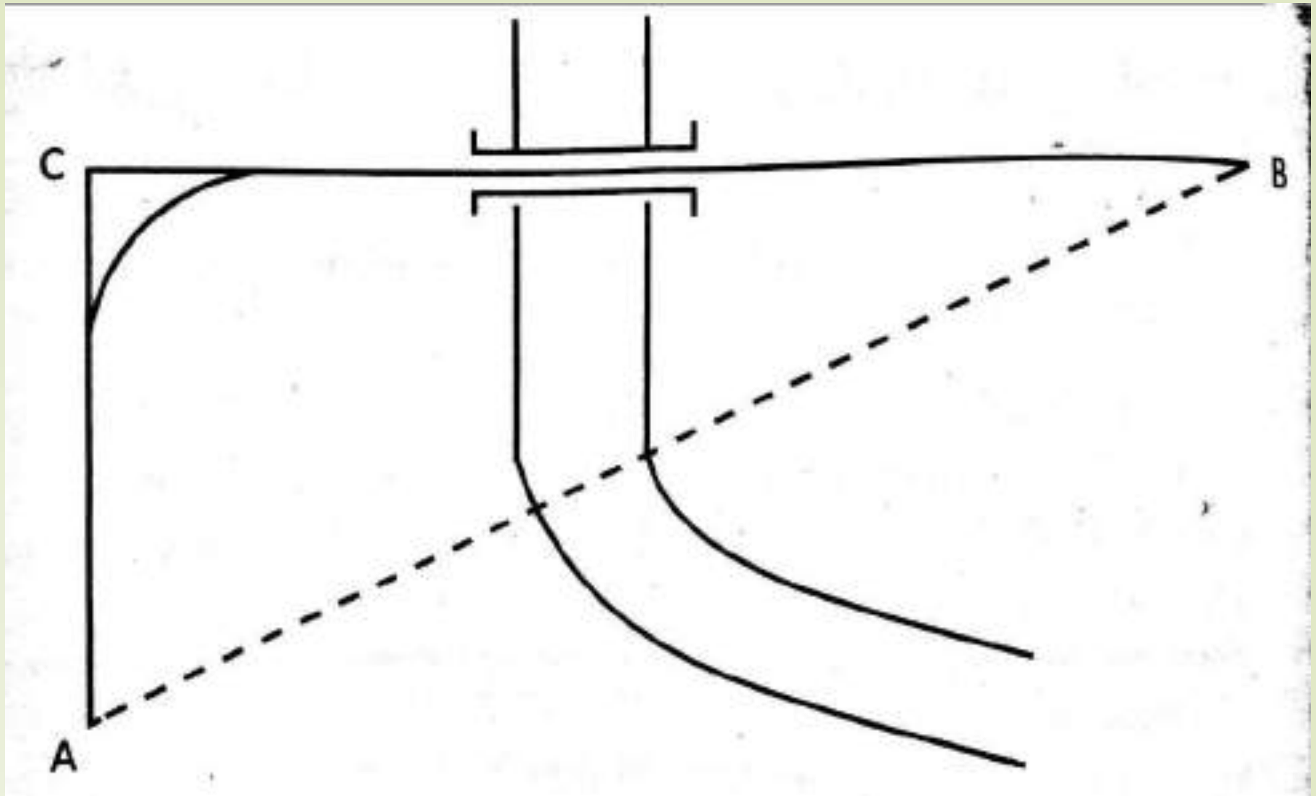
- They should be prepared for when to construct, what type of road to construct, how to construct and why to construct.

- **Obligatory Points:**
- These are the control points governing the highway alignment. These points are classified into two categories.
- (i) Points through which it should pass (Positive Obligatory Point)
- (ii)Points through which it should not pass. (Negative Obligatory Points)

Factors Controlling Highway Alignment

- Obligatory points through which the road alignment has to pass may cause the alignment to often deviate from the shortest or easiest path.
- **Examples of positive obligatory points:**
- *Bridge site*: The bridge can be located only where the river has straight and permanent path and also where the abutment and pier can be strongly founded. The road approach to the bridge should not be curved and skew crossing should be avoided as possible. Thus to locate a bridge the highway alignment may be changed.

Factors Controlling Highway Alignment



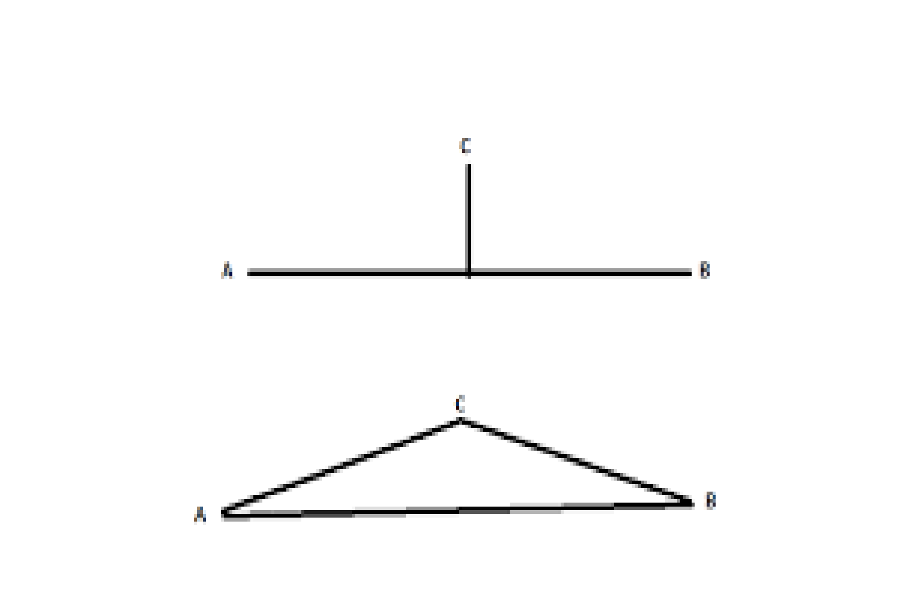
Factors Controlling Highway Alignment

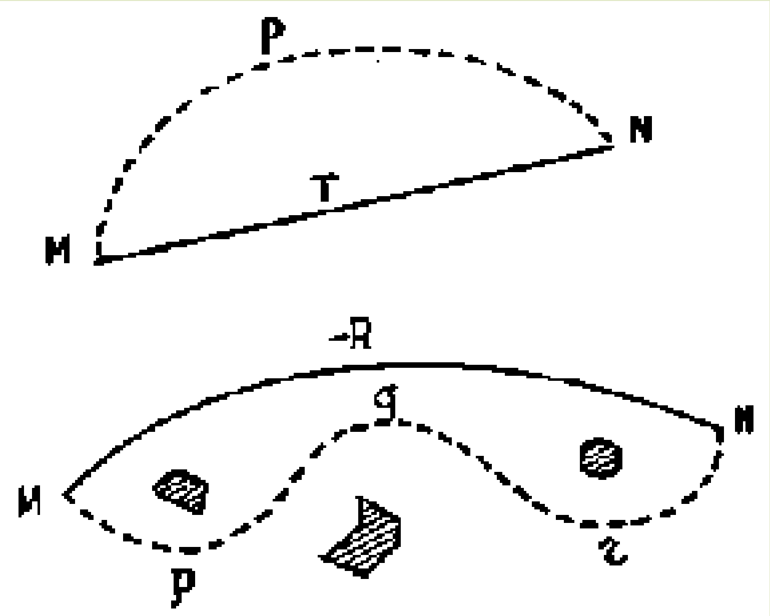
- ***Mountain***: While the alignment passes through a mountain, the various alternatives are to either construct a tunnel or to go round the hills.
- The suitability of the alternative depends on factors like topography, site conditions and construction and operation cost.

Factors Controlling Highway Alignment

Factors Controlling Highway Alignment

- ***Intermediate town:*** The alignment may be slightly deviated to connect an intermediate town or village nearby.

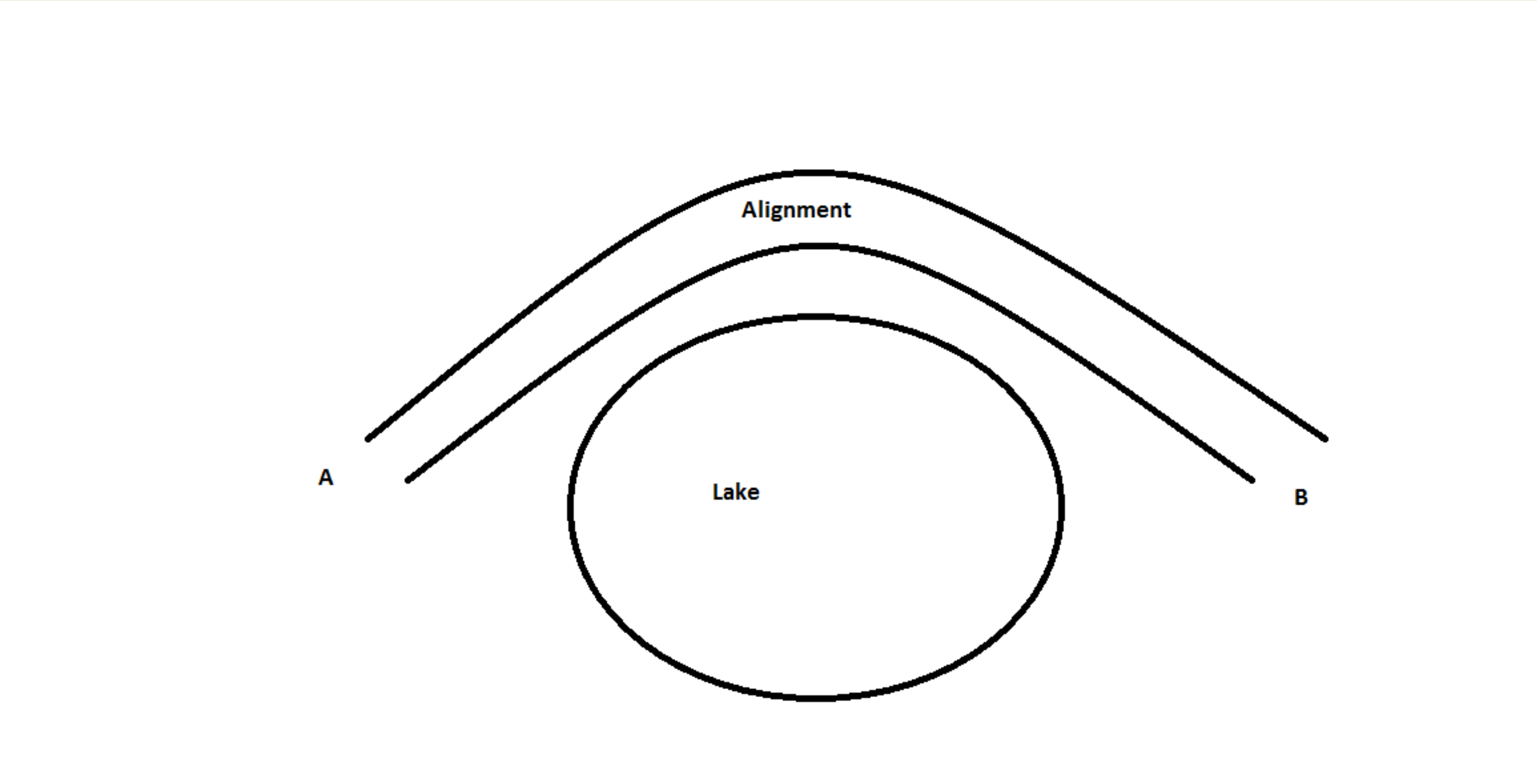




Factors Controlling Highway Alignment

- **Examples of negative obligatory points:**
- ***Religious places***: These have been protected by the law from being acquired for any purpose. Therefore, these points should be avoided while aligning.
- ***Very costly structures***: Acquiring such structures means heavy compensation which would result in an increase in initial cost. So the alignment may be deviated not to pass through that point.
- ***Lakes/Ponds etc***: The presence of a lake or pond on the alignment path would also necessitate deviation of the alignment.
- Marshy place, waterlogged areas
- Historically and archeologically important property
- Restricted zone for defense, national security
- Densely populated area

Factors Controlling Highway Alignment



Factors Controlling Highway Alignment

- **Traffic**:
- The alignment should suit the traffic requirements. Based on the origin-destination data of the area, the desire lines should be drawn. The new alignment should be drawn keeping in view the desire lines, traffic flow pattern etc.

- **Geological Condition:**
- Alignment should pass through the stable slopes and if not the area should be properly stabilized or treated with engineering aspects.

Factors Controlling Highway Alignment

- **Geometric design**: Geometric design factors such as gradient, radius of curve, sight distance etc. also govern the alignment of the highway. To keep the radius of curve minimum, it may be required to change the alignment. The alignments should be finalized such that the obstructions to visibility do not restrict the minimum requirements of sight distance. The design standards vary with the class of road and the terrain and accordingly the highway should be aligned.

- **Economy**: The alignment finalised should be economical. All the three costs i.e. construction, maintenance, and operating cost should be minimum. The construction cost can be decreased much if it is possible to maintain a balance between cutting and filling. Also try to avoid very high embankments and very deep cuttings as the construction cost will be very higher in these cases.

Factors Controlling Highway Alignment

- **Other considerations**: Various other factors that govern the alignment are drainage considerations, political factors, monotony and hydrological factors..
- Drainage: Deviation of highway to minimize cross drainage structures
- Political: If a foreign territory comes across a straight alignment, we will have to deviate the alignment around the foreign land.
- Resisting Length: keep the ineffective rise and excessive fall to minimum.

The route Location Process

Route Location

- Region
- Bands 8-16 Km
- Corridors 3-10 Km
- Route Strips 1-1.5 Km
- Alignments 30-50m

Engineering Survey and its Stages
(Finalization of the alignment)

- Out of all possible alignments the best alignment has to be selected
- The best alignment is selected based on socio-economical and environmental considerations for which detailed engineering survey has to be carried out i.e. Before a highway alignment is finalised in highway project, the engineering surveys are to be carried out.
- The survey may be completed in four stages i.e.
- (a) Map study
- (b) Reconnaissance
- (c) Preliminary surveys
- (d) Final location and detailed surveys

Engineering Survey and its Stages

- **Map study:** With the help of topographic map it is possible to analyze the likely routes of the road. In India, topographic maps are available from the survey of India with 15 of 30 m contour interval(In Nepal they are available in scale of 1:25000). The :main features like rivers, hills, valleys, etc., are also shown on these maps.
- Alignment avoiding valleys, ponds or lake.
- When the road has to cross a row of hills; mountain pass
- Approximate location of Bridges

Engineering Survey and its Stages

Engineering Survey and its Stages

- **Reconnaissance(Fact finding Survey):** It is a rapid and rough survey. During the survey, the physical characteristics of the areal are inspected and the proposed route is thoroughly examined. it is done without accurate instruments. Clinometers are used to determine the slopes of the ground. It provides additional information not available in top sheets.

- **Objectives: -**
- i)To study the feasibility or practicability of the proposed route
- ii)To reduce the number of alternative routes to the minimum to select the best 2 or 3 routes.
- iii) Source of construction materials, water and location of stone quarries.
- iv) Number and type of cross drainage structure, maximum flood level and natural ground water level along the probable routes.

Engineering Survey and its Stages

- The different date to be observed in this stage are
  - Valley, Ponds, Lakes, marshy land, other obstructions along the route which are not available on the map
  - Approximate grade values, lengths, and radius of curves
  - No. and type of cross drainage structures, HFL, Natural GWL
  - Soil type
  - Sources of Materials, water and stone quarries location
  - Geological formations, types of rocks, dip, seepage etc

Engineering Survey and its Stages

- **Preliminary Survey**: This survey can be started on the basis of reconnaissance. It consists of detailed survey of the alternative routes selected. After reconnaissance. It is done by using the instruments such as chain, compass, tape, level & theodolite. This stage aims to select the best possible alignment from the available one using the evaluation techniques and data obtained
  - Objectives: -
  - a. To select the best route.
  - b. To determine the centre line to be followed
  - c. To collect the additional information found necessary after reconnaissance.
  - d. To estimate quantity of earthwork materials and other construction aspects and to work out the cost of alternate proposals
  - E. to compare different proposals in view of requirement of a good alignment
  - F. To finalize the best alignment

Engineering Survey and its Stages

- **Preliminary Survey** Survey can be carried out by any one of the following ways:
- **Conventional Approach,** in which a survey team carries out surveys using the required field equipment, taking measurement, collecting topographical and other data and soil survey
- **Modern Rapid Approach,** by aerial photographs and photogrammetric methods and photo interpretation techniues

Procedure for conventional method:

- **Primary Traverse:**
- For alternate alignments either secondary traverse or independent primary traverses may be necessary
- Length of the center line should be measured by using very good and accurate method of chaining or tachometry.
- **Topographical Features:**
- All geographical and man made features along the traverses and for certain width on either side are surveyed and plotted

Procedure for conventional method:

- **Levelling:**
- Carried out side by side to give the center line profiles and typical cross sections

- **Drainage Studies and Hydrological Data:**
- Estimation of the type, number and approximate size of cross drainage structures

- **Soil Survey:**
- To work out details of earthwork, slopes, stability of materials, subsoil and surface drainage requirement, pavement type and its approximate thickness requirement
- Compare the data and analyse the results of all alternate alignments

Procedure for conventional method:

- **Material Survey:**
- Naturally occurring materials like sand, stones, aggregates and identification of quarries should be done
- Availability of manufactured materials like cement, lime, brick etc and their location Should be ascertained.

- **Traffic Survey:**
- Decision of number of traffic lanes, roadway width, pavement design, and economic analysis of project.

- **Determination of Final alignment center line:**
- It is decided in the office before final location survey.
- Preliminary survey maps consisting of contour plan, longitudinal profile, cross sections of the alternate alignments should be carefully studied to decide the best alignment which must satisfy the engineering and economic requirement

Modern Approach:

- Taking aerial photographs of various strips of land with required longitudinal and lateral overlaps.

- Photographs are examined under stereoscopes and control points are selected for establishing the traverses of all alternate proposals

- Using stereo-pair observations, the spot levels and subsequently contour lines may be obtained

- The photo interpretation methods are used to assess the geological features, soil conditions, drainage requirements etc

Modern Approach:

- The alignment finalized after the preliminary survey is to be first located on the field by established the centre line.
- This is done accurately by using instruments.

Final Location and Detailed Survey

- The final route selected after the preliminary survey is surveyed and located on the ground. And final survey is carried out with the purpose of implementation
- This provies further accurate quantities of works so that if any variations necessary can be done within time (In Nepal this is done post contracting and called construction survey)
- Objectives:
  - To establish temporary bench marks
  - To collect information required for
  - The preparation of working drawings
  - The preparation of detailed estimates
  - The design of road & bridges
  - Preparing specifications
  - Land acquisition

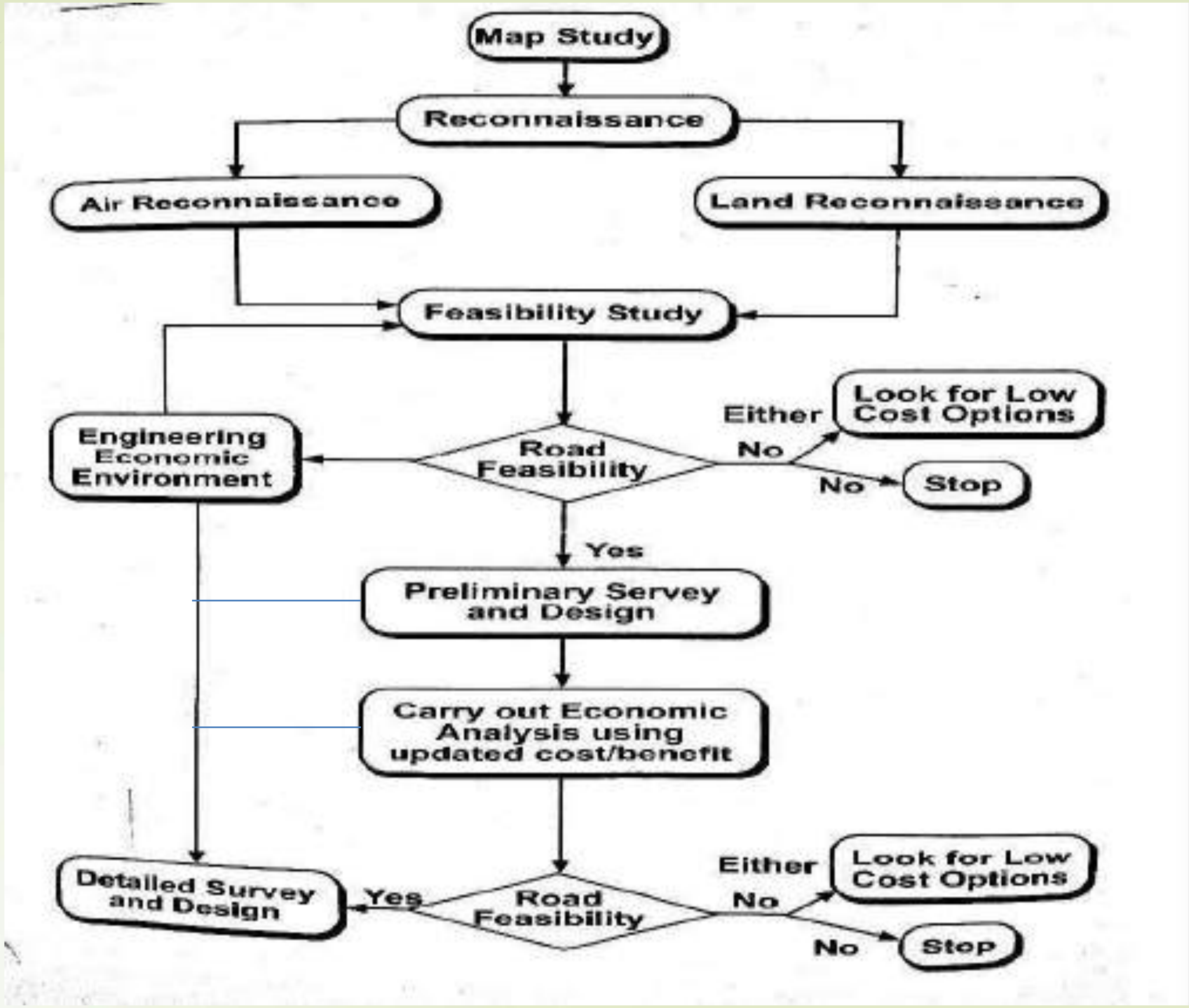
Final Location and Detailed Survey

- **Location:**
- The center line of the finalized road in the drawing needs to be translated on the ground
- Major and minor control points are established and central pegs are driven, checking the geometric design requirements
- If essential, modifications can be done after approval

- **Detailed Survey:**
- TBM are fixed at drainages and under pass structures.
- Levels along the center line is taken
- Vertical alignment, earthwork calculation and drainage details are to be worked out from the level noted.
- The cross sections are taken upto desired width
- River crossing valley should be surveyed in detail n either side

Final Location and Detailed Survey

- All topographical and hydrographical details are collected and recorded
- Soil profile depth upto 1.5 to 3 meters below the GL or finished grade line of the road whichever is lower.
- In case of high embankments, the depth should be upto twice the height of the finished embankment
- The detail survey should be elaborate enough for preparing detailed plans, designs and estimates

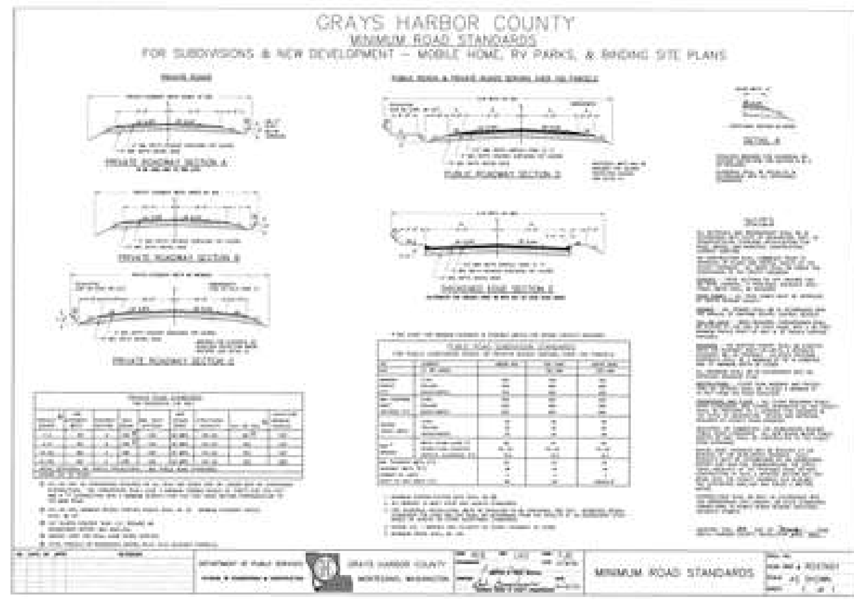


Map Study
Reconnaissance
Air Reconnaissance
Land Reconnaissance
Feasibility Study
Engineering
Economic
Environment
Road
Feasibility
Either
Look for Low
Cost Options
No
No
Stop
Yes
Preliminary Servey
and Design
Carry out Economic
Analysis using
updated cost/benefit
Detailed Survey
and Design
Yes
Road
Feasibility
Either
Look for Low
Cost Options
No
No
Stop

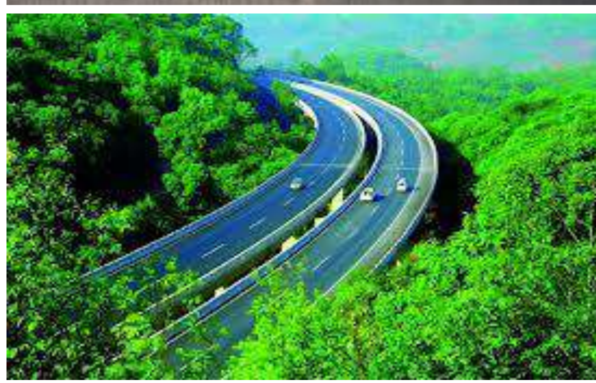
Asian Highways in Nepal, NRS 2045

ASTM INTERNATIONAL
Standards Worldwide

NEWS
AASHTO
THE VOICE OF TRANSPORTATION




RUSSIA
CHINA
INDIA
INDONESIA



Asian Highway (AH) Network

- The Asian Highway Network (or the Great Asian Highway) is a 141,000km network of roads running across 32 countries.
- It is being built with an intention to improve transport facilities throughout these nations and provide road links to Europe.
- The Asian Highway Network is a part of the Asian Land Transport Infrastructure Development (ALTID) project being supported by United Nations Economic and Social Commission for Asia and the Pacific (ESCAP).
- The Asian Highway project was initiated in 1959.

Asian Highway Network

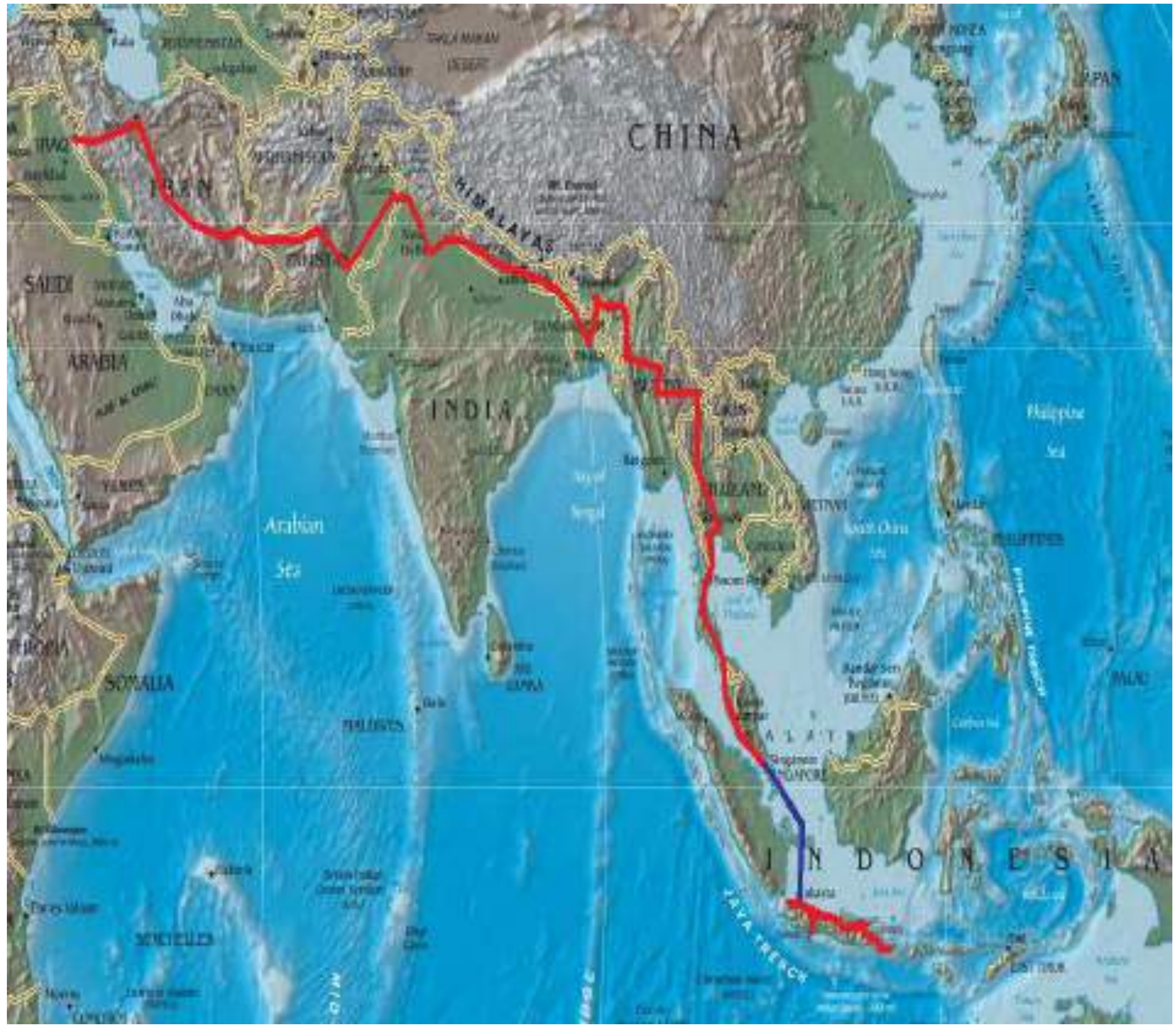
The Length of Asian Highway in different countries-

1. Afghanistan- 4,247km
2. Armenia- 958km
3. Azerbaijan- 1,442km
4. Bangladesh- 1,804km
5. Bhutan- 167km
6. Cambodia-1,339km
7. China - 25,579km
8. North Korea- 1,320km
9. Georgia- 1,154km
10. India- 11,432km
11. Indonesia- 3,989km
12. Iran km-11,152
13. Japan -1,200km
14. Kazakhstan- 13,189km
15. Kyrgyzstan- 1,695km
16. Lao PDR- 2,297km,,

1. Malaysia- 1,595km
2. Mongolia- 4,286km
3. Myanmar- 3,003km
4. Nepal -1,321km
5. Pakistan- 5,377km
6. Philippines- 3,517km
7. South Korea-907km,
8. Russia- 16,869km
9. Singapore- 19km.
10. Sri Lanka -650km
11. Tajikistan- 1,925km,
12. Thailand- 5,112km
13. Turkey- 5,254km,
14. Turkmenistan- 2,204km
15. Uzbekistan- 2,966km
16. Vietnam- 2,678km.

Asian Highway Network- AH2

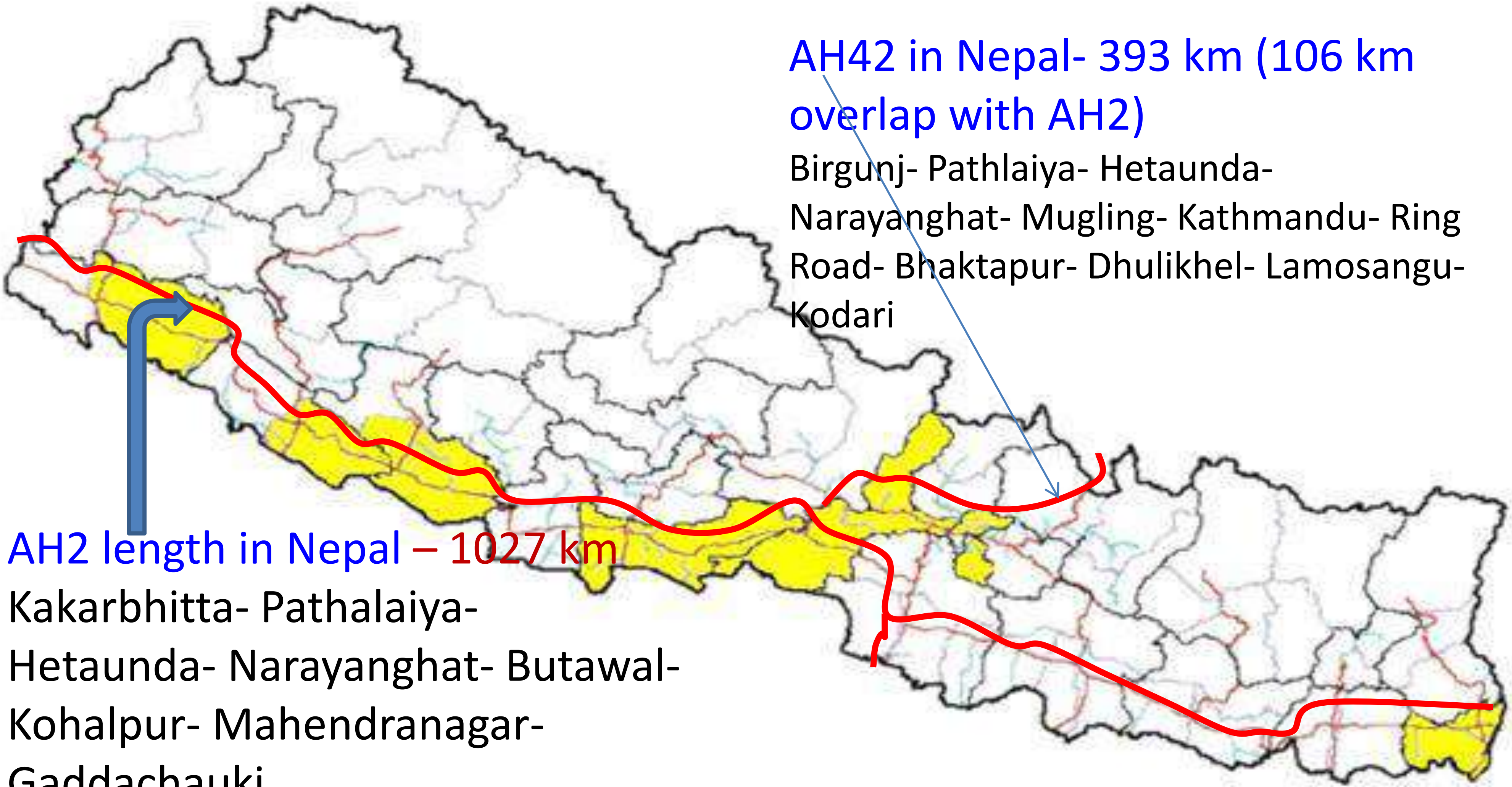
- AH2 is a 13,177km roadway from Denpasar in Indonesia to Khosravi in Iran.
- It passes through 10 countries-
- Indonesia, Singapore, Malaysia, Thailand, Myanmar, India, Bangladesh, Nepal, Pakistan and Iran.



Asian Highway Network- AH42

- AH 42 Total length- 1495 km
  - India: 457 km, Nepal: 393 km (106 km overlap with AH2) and China: 740.706 km, (2,134 km potential)
- Routes
  - China (Lanzhou – Xining – Golmud – Lhasa – Zhangmu) – Nepal (Kodari – Kathmandu – Narayanghat – Pathlaiya – Birgunj) – India (Raxaul – Piprakothi –Muzaffarpur – Barauni – Barhi)

Asian Highway Network in Nepal



AH42 in Nepal- 393 km (106 km overlap with AH2)

Birgunj- Pathlaiya- Hetaunda- Narayanghat- Mugling- Kathmandu- Ring Road- Bhaktapur- Dhulikhel- Lamosangu- Kodari

AH2 length in Nepal – 1027 km

Kakarbhitta- Pathalaiya- Hetaunda- Narayanghat- Butawal- Kohalpur- Mahendranagar- Gaddachauki

Road Standards being Adopted in Nepal

- **No Uniform Standards**
  - Department of Roads, "Nepal Road Standard 2027 1st Revision 2045”
  - Department of Roads, “Design standards for feeder roads (3rd revision)” (1997)
  - Nepal Road Standard 2070 approved and implemented

  - DoLIDAR, “Nepal Rural Roads Standards (2055) 1st revision”
  - DoLIDAR, Nepal rural road standard (2055) Annex II-2
  - RAIDP, Rural road technical design manual
  - Nepal urban road standards 2068 (draft)

Road Standard 2027 (Revision 2045)
and
Road Standard 2070

What's addition in Nepal Road Standard 2070

- Technical Classification of Roads
- Vehicle dimension
- Forward period(road capacity design period)- 20 yrs which was 10 years in 2045 version
- Provision of hair pin bend design
- Provision of set back distance in horizontal curve
- Other Provisions
  - Climbing lane and emergency escape ramps
  - Side slope in cutting and embankment
  - Guard rails and Safety barriers
  - Bicycle tracks, Side walks, Curbs and Bys lay bys
  - Intersection and Access control
  - Aesthetic and landscape design
  - Road side arboriculture and Environmental considerations
  - Road side service facilities

Thank you

Geometric Design of Highways

Introduction

- It refers to the **dimensioning of the elements of highways**, such as vertical and horizontal curves, cross sections, truck climbing lanes, bicycle paths, and parking facilities etc.
- Takes into concern the engineering principles as well as the **social and environmental impacts** of the highway geometry on the surrounding facilities

Necessities

- To decrease the cost of construction
- To Decrease the cost of operation
- To maintain consistency of traffic flow
- To ensure safety
- To maintain asthetics of highway allignment

Objectives of Geometric Design

- To **incorporate various physical features** of road alignment as per design standard
- To provide **optimum efficiency in traffic operation** with maximum safety at reasonable cost.
- To incorporate human behaviors
- To promote the environmental benefit
- To provide **a basis to evaluate** the construction of the proposed highway.

Scope of Geometric Engineering

1. Elements of Cross-Section

- Typical Cross Section
  - Traffic lane, Carriageway, Shoulder, Median-strips, Right of Way, Side Slope
- Camber
- Super elevation

2. Elements of Horizontal Alignment

- Tangent
- Horizontal Curves and its Elements
- Transition Curve and its Elements
- Extra widening of horizontal curves
- Laybys

3. Sight Distance across the road

- Stopping Sight Distance
- **Intermediate Sight distance**
- **Overtaking Sight distance**
- **Decision Sight Distance**

4. Elements of Vertical Alignment

- Grade
- Vertical Curves (Summit Curve and Valley Curves)

Design Control Criteria

- Road Classification
- Design Speed
- Design Vehicle
- Driver Characteristics
- Traffic Volume and Composition
- Level of Service
- Social and Environmental Considerations
- Topography
- Economy
- Safety

Road Classification

1. Administrative/Functional Classification

- National Highway
- Feeder Road
- District Road and Village Road
- Urban Road

National Highways

- Main arterial roads connecting East to West and North to South
- Longer distance travel, higher the inter- community mobility.
- designated by letter "H" followed by a two- digit number.

Feeder Roads

- Connect District Headquarters, Major economic centers, Tourism centers to National Highways or other feeder roads.
- They are designated by letter “F” followed by 3-digit number

District Roads

- Roads connecting district headquarters to village or village to village
- Serves rural area of production , market centers service centres etc.
- **Speed 50-60kmph (district road) , 40-50kmph (village roads)**

Urban Roads

- The roads serving within the urban municipalities. Except highways and feeder roads
- Designed to maintain flow as well to provide modern facilities and also to maintain the city aesthetics
- **Design Speed 40-50kmph**

In Nepal(Before Federalism)

1. National Highway + Feeder Roads = SRN = Department of Roads (DOR)
   - Has published Nepal Road Standard (NRS)

2. District Roads + Urban Roads = LRN
   - District Roads = Department of Local Infrastructure and Agricultural Roads (DoLIDAR) and गा.वि.स.
   - Has Published Nepal Rural Road Standard (NRRS)

   - Urban Roads = Municipalities and Department of Urban Development and Building Construction (DUDBC)

- Nepal Rural Road Standard (NRRS) has further classified district roads into two categories
  - District road core network : connects villages to district headquarter of to major economical centeres
  - Rural Road : Connecting Village to Village

2. Technical Classification

Class	ADT (PCU)
Class I	20,000 PCU
Class II	5000 – 20000 PCU
Class III	2000 – 5000 PCU
Class IV	<2000 PCU

Design Speed

- A selected speed to determine the various geometric features of the roadway.
- The maximum safe speed that can be maintained over a specified section of highway
- Design speed shall be taken as the 98th percentile value for traffic on the roadway the reference design speed depends on

 -- The functional classification of the highway,

  – The topography of the area (level, rolling, and mountainous terrain)
  – the land use of the adjacent area

Design Speed as per NRS 2070

Table 7-1 Design Speeds, km/h

Road Class	Plain	Rolling	Mountainous	Steep
I	120	100	80	60
II	100	80	60	40
III	80	60	40	30
IV	60	40	30	20

Design Vehicle

- Largest design Vehicle likely to use facility with considerable frequency as a design vehicle
- Design of critical features such as radii of horizontal curve, radii at intersections with respect to a vehicle with special characteristics

Relationships between vehicular and facility characteristics (1/2)

Vehicular characteristics	Related facility characteristics
Length	Park stall length Transit station platform length
Width	Lane width Parking stall width Lateral clearance
Height	Vertical clearance Minimum vertical curve length
Wheelbase (turning radius)	Lateral clearance on curves Intersection edge radii

Source: J. H. Banks Introduction to Transportation Engineering

Vehicle Dimension as Per NRS 2070

Maximum Width, m	2.50
Maximum Height, m	4.75
Maximum Length, m	18.00
Maximum single axle load, kN	100

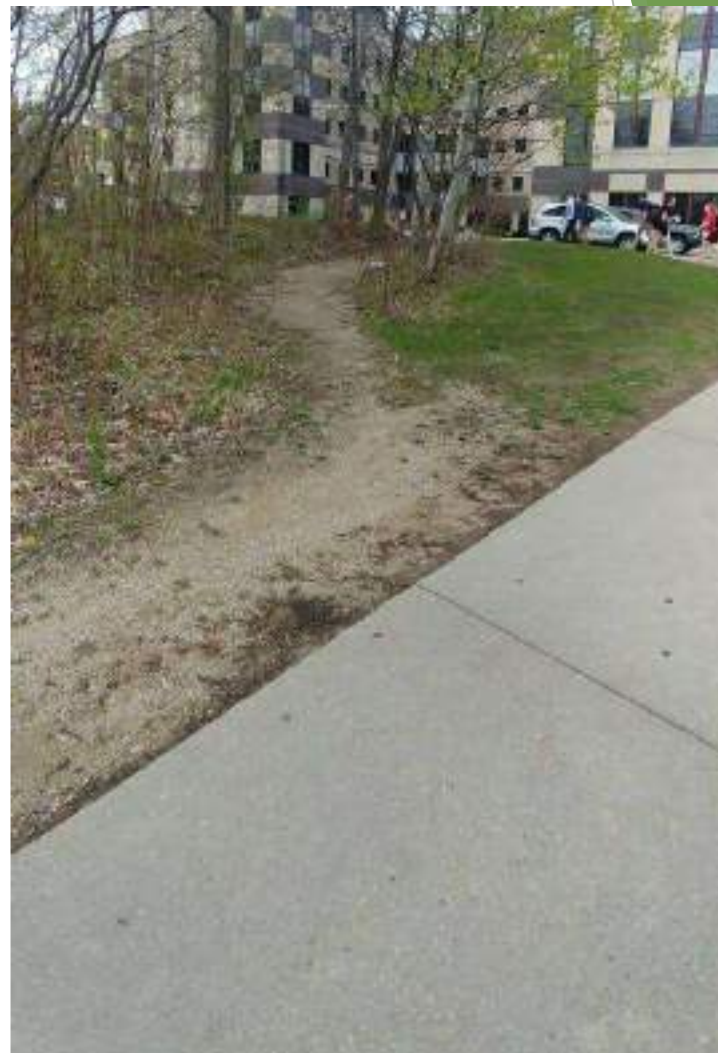
Topography

- As the topography becomes more extreme the design standards become more flexible
- The different types of topography are decided based on the cross slope and are as follows

Table 6-1 Terrain Classification

S.No.	Terrain Type	Percent Cross Slope	Degree
1	Plain	0-10	$0^{o} – 5.7^{o}$
2	Rolling	> 10-25	$> 5.7^{o} – 14^{o}$
3	Mountainous	>25-60	$> 14^{o} – 31^{o}$
4	Steep	>60	$> 31^{o}$

Driver's Characteristics



Driver's Characteristics

- **The driving task – control, guidance and navigation.**

- The various parameters like perception reaction time , psychological extra widening etc. are directly dependent on the drivers behavior
- Geometric Design must incorporate
  - Older drivers – capabilities and needs of older road users
  - Information handling (collects information, make numerous decisions, and perform necessary control actions and act timely i.e. - reaction time)
  - Driver error (insufficient experience, inappropriate risk taking, poor glare recovery, fatigue, sleep deprivation or prolonged exposure to monotonous environments)
  - The guidance task (lane placement, car following, passing maneuvers, merging & diverging, response to traffic control devices)

Level of Service

LOS		
A	Free flow	Completely unimpeded maneuver
B	Reasonable Free	Maneuver within traffic stream is slightly restricted
C	Stable	Maneuver within traffic stream is visibly restricted
D	Reaching Unstable	Speed decrease and drivers are in discomfort psycologically
E	Restricted	Vehicles are closely spaced, slight diruption result long queuing
F	Congested	Greater than capacity of road

Level of Service

- Recommended to adopt a LOS "B" for the design capacity of roads.
- Under this condition, traffic will experience congestion and inconvenience during some of the peak hours, which may be acceptable.
- At the level of service B, volume of traffic will be around 45 percent of capacity under mixed traffic condition

Social & Environmental Consideration

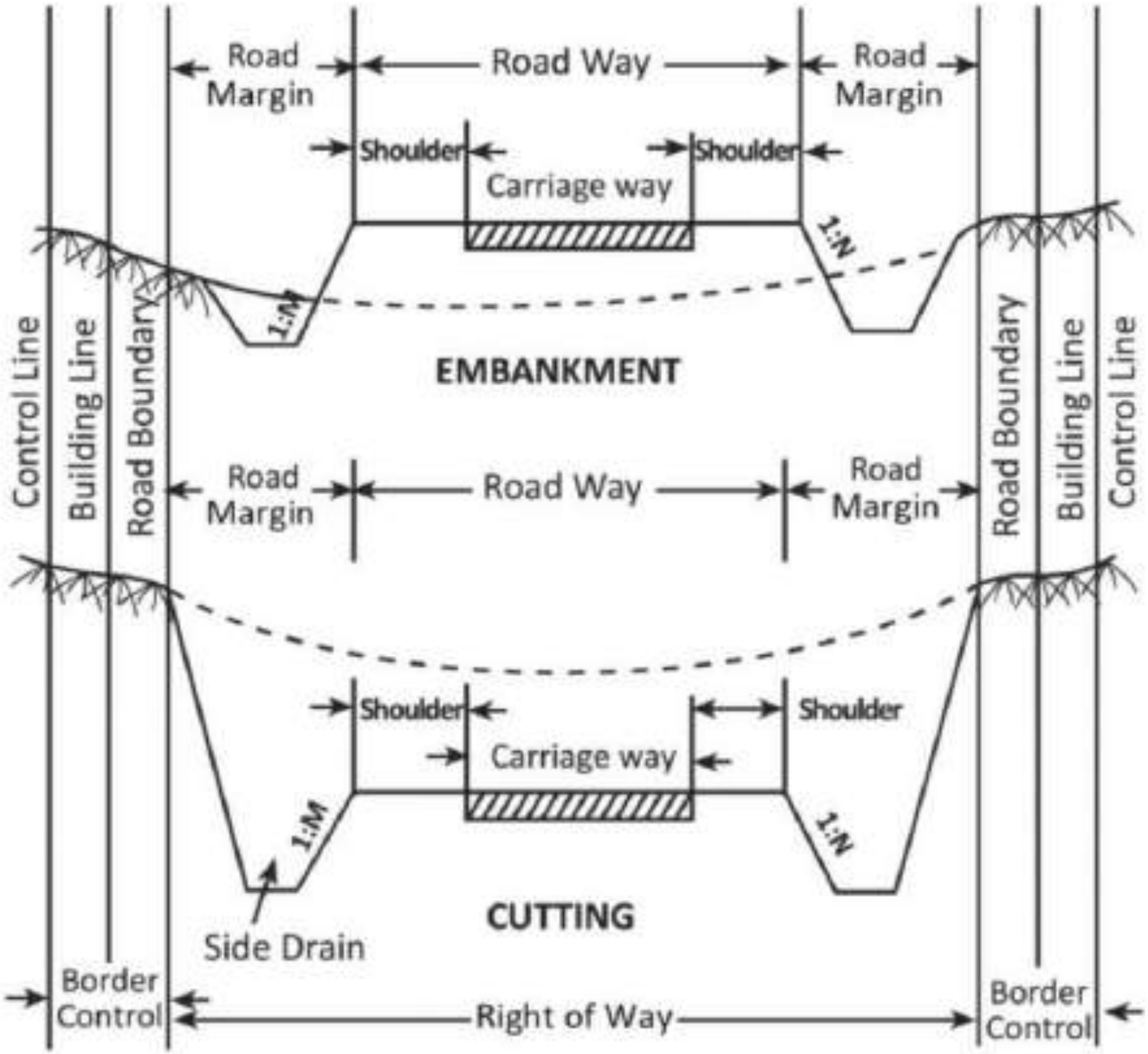
- Emits pollutants and transmits noise
- Pollutants emitted impact on land uses adjacent to highways
- Noise and pollutant affects distance to the highway from a residence or workplace
- Impact on natural and historic assets
- road side developments

Safety Consideration

- Highways should be designed to minimize driver decisions and to reduce unexpected situations.

- Some measures:
  - Access control
  - Safe Speed limit
  - Characteristics of expected drivers
  - Design of Curves, sufficient Radius
  - Wide median or Median barriers
  - Shoulder width
  - Sight distances
  - Treatment of obstacle (Remove, relocate or reduce severity)
  - Intersection Treatment (Channelization, refuse islands)

Typical Cross Section of Highway



- Traffic lane (TL): It is the strip of the carriageway occupied by vehicles moving in a single stream along the road.

  TL= (width of vehicle + safety clearance on either side)

- Carriage Way (CW) : It may be defined as that strip of road which is constructed for the movement of vehicular traffic. The carriageway generally consists of hard surface to facilitate smooth movement and is made of either hard bituminous treated materials or cement concrete. It is also called Pavement width. By definition

- Shoulder:
  - It is the portion of roadway on either side which is periodically used by vehicles during crossing, overtaking and parking maneuvers.
  - Shoulder is an important element of rural road.
  - Laybys are the intermittent shoulders provided in hill roads. Laybys are provided as continuous shoulder cannot be provided in hill roads.

Required Width

2 to 4 Lane	4 to 6m on either side
Single / Intermediate Lane	3 to 5 meter
Minimum	0.75 on each side

In practice in Nepal; width of shoulder = 0.5 to 1.5 m

- Advantages of Shoulder:

  i. Provides space for parking vehicles during repair etc

  ii. Capacity of road increased because of frequently available opportunity for overtaking

  iii. Sufficient space available for parking vehicles on rest

  iv. Provides space for fixing traffic signs away from the pavement

  v. Shady trees can be grown up away from the pavement

  vi. Provides sufficient space for confidence in driving

  vii. Proper drainage strengthen the life of the pavement

  viii. Increased effective width of carriageway

  ix. Lateral clearance increases the sight distance

- Side Slope of fill or cut:
  - 1:1 to 1:1.5 in cutting
  - 1:1.5 to 1:2 in filling
- Right of Way (ROW) or Land Width:
  - The strip of land on either side of road from its centre line acquired during road development and which is under the control of road authority (DoR Nepal)
  - i. National Highway =25 m on either side
  - ii. Feeder Roads = 15 m on either side
  - iii. District Roads = 10 m on either side

- Functions
  - Right of way may be used for the following purposes:

    i. to accumulate drainage facilities

    ii. to provide frontage roads/driveways in roads with controlled access

    iii. to develop road side arboriculture

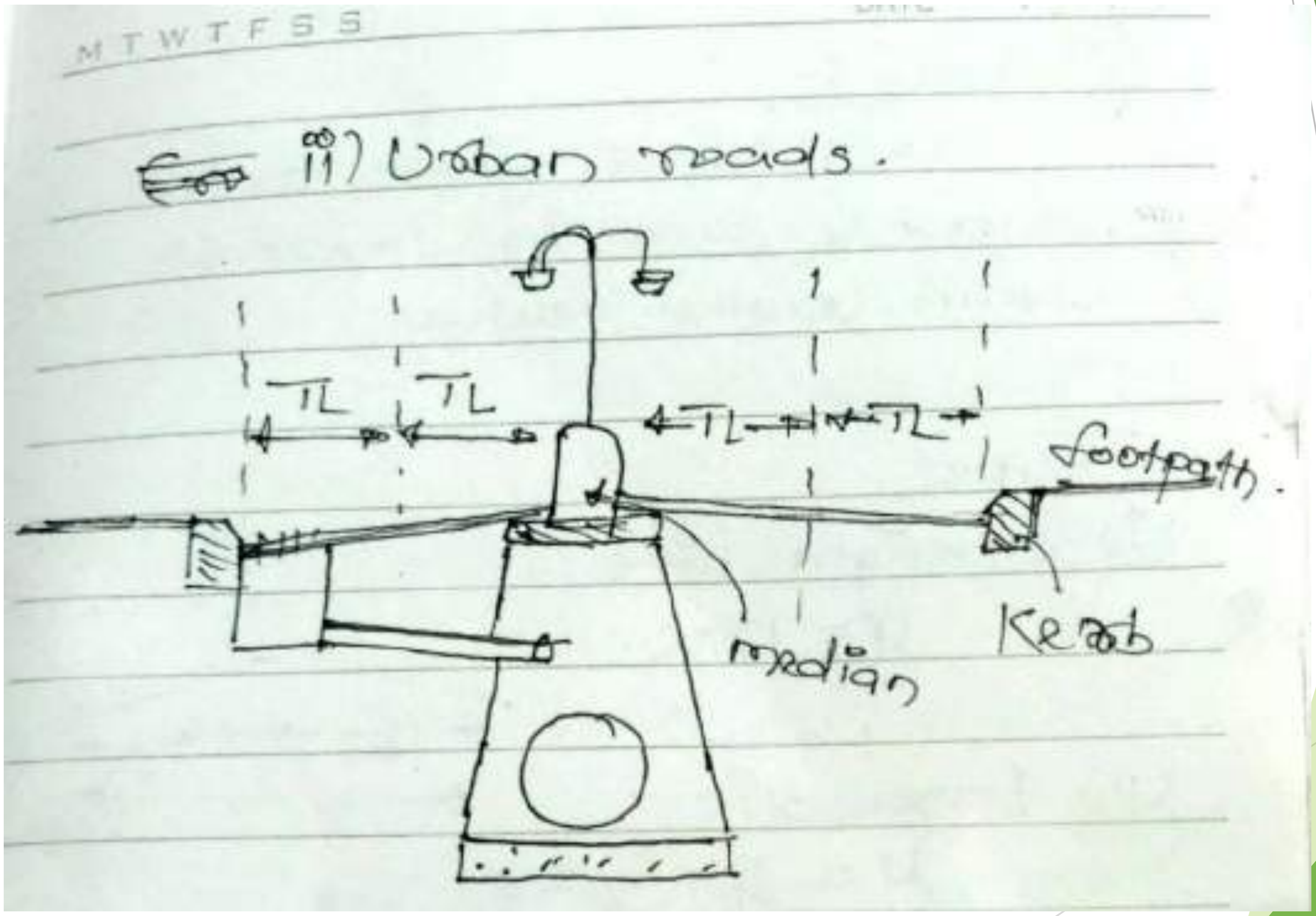
    iv. to open side burrow pits

    v. to improve visibility in curves

    vi. to accommodate various road ancillaries

    vii. to widen the road where required in future with no compensation for property

Typical Cross Section of Urban Roads



1. Traffic Lane
2. Carriageway
3. Sidewalk or Foot Path: It is that portion of urban road which is provided for the movement of pedestrian traffic where the intensity is high.
4. Kerb : It is that element of road which separates vehicular traffic from pedestrians by providing physical barrier (15-20 cm)
5. Median Strip (or Traffic Separator or Central Reservations): It is the raised portion of the central road strip within the roadway constructed to separate traffic following in one direction from the traffic in opposite direction.
6. Side Drain
7. Catch Pit and Cross Pipe

Camber

- it may be defined as the slope of the line joining the crown (topmost point) of the pavement and the edges of pavement.
- Camber is Expressed either as the ration of the rise to the half width of pavement(1:50 1:25 etc.) or as percentage (2% 4% etc.)
- Necessity/Advantages of Camber: -
  - to drain of surface water quickly
  - to prevent infiltration into underlying pavement layers and sub-grade
  - To give the driver a physiological feelings of the presence of two lanes
  - To improve the road appearance

- Disadvantages of providing heavy camber:-
  - Central portion of road is excessively eroded
  - Causes uncomfortable side thrust drag
  - Overtaking operations may be dangerous
  - especially in two lane roads
  - There is possibility of overturning and skidding of vehicles
  - Low cost surface and shoulder will be excessively eroded due to increase velocity of water. This may leads to formation of cross ruts.
  - Tendency of driver to travel through centre line of road. So centre line area undergoes more wear and rear.

- Types of Camber
  - 1. Straight line camber $Y = nX$
  - 2. Parabolic camber $Y = (2n/W)\, x^2$
  - 3. Composite camber

Numerical Example

The centerline of a two lane highway has an elevation of 320.5m as recoreded from the L-Profile , if the carraigeway has a camber of 2.5 and the shoulder has a camber of 5% , calculate the RL of

(i) The center of carriageway

(ii) The edge of carriageway

(iii) The edge of shoulder

If the camber provided is

<u>(A) Parabolic Camber</u>

<u>(B) Straight line camber</u>

SUPERELEVATION

- The outer edge of the pavement is raised with respect to the inner edge in order to provide a transverse slope throughout the length of the curve. This transverse slope is known as superelevation.
- Superelevation can be described in the form of ratio of the rise to the width of pavement (1:15 , 1:20 etc.) or as percentage (5% 4% etc.)
- **Design Superelevation**
- The value of superelevation that is required to be adopted in the field to sustain the design speed or tha allowable speed is called design superelevation
- The maximum/Limiting value of design superelevation are as follows
  - In Plain and rolling terrain 7%
  - In Snow bound areas 7%
  - In Hilly areas not bounded by snow 10%

- Expression for design superelevation

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

Calculation of Design Superelevation

- 1. In order to overcome the effect of combined equation , 75% of design speed is taken neglecting f
- $e = \frac{0.75v^2}{127R}$ If the calculated e is less than 0.07 (7%), the value obtained is provided. If the valued of e exceeds 0.07, then provide maximum superelevation i.e. e=0.07 or 7%
- 3. Check the coefficient of friction developed for the selected value of e at the full value of design speed $f = \frac{v^2}{127R} - e$ If the value is less than 0.15, calculated value is provided. And the given conditions are sufficient to handle the design velocity. If the value of f exceeds 0.15, the given section cannot sustain the design speed and given designed speed is reduced to allowable speed.
- 4. The allowable speed (V_a kmph) at the curve is calculated by considering the design coefficient of lateral friction and the maximum superelevation:

$$v_a = \sqrt{127R(e + f)}$$

Numerical Example

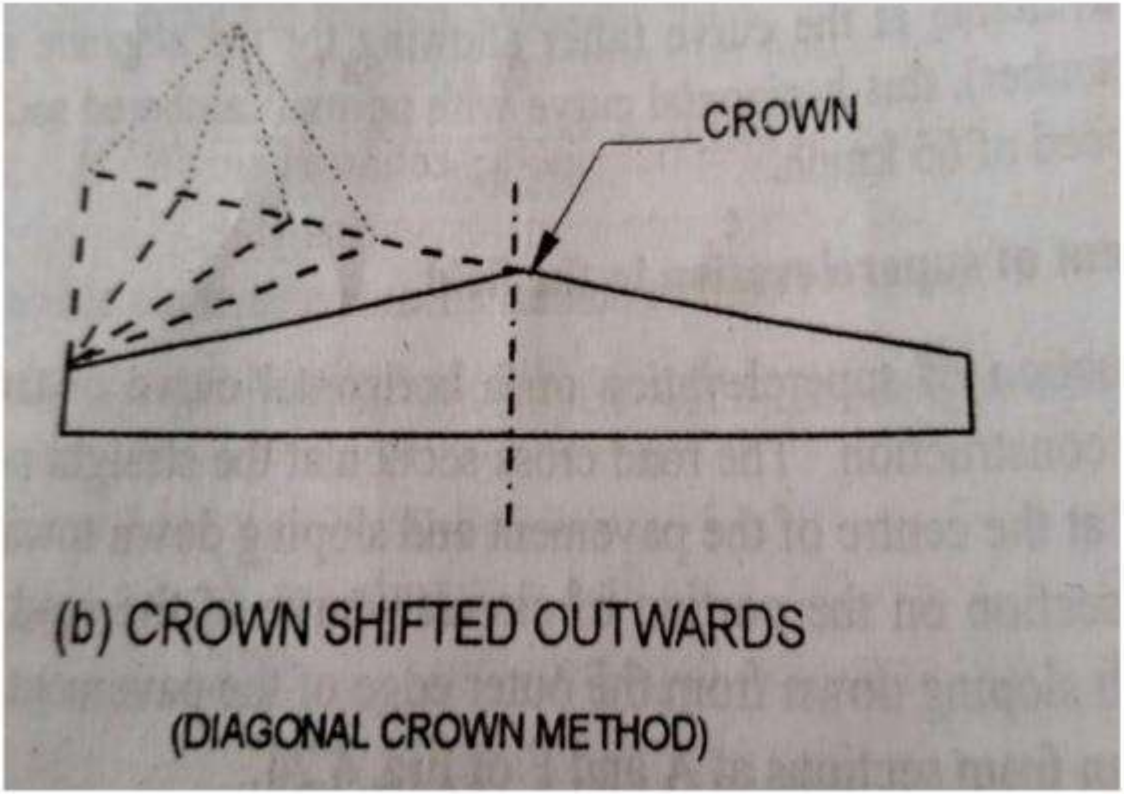
The design velocity of a highway is 80 Kmph , there is a horizontal curve of radius 100m.

Calcualte the design superelevation and check weather the velocity can be sustained or not , if not determine the allowable velocity

Take maximum cant as 1 in 15 and maximum allowable coefficient of friction as 0.15

Method of Providing Superelevtion

1. By Elimination of Crown



2. By rotation of pavement

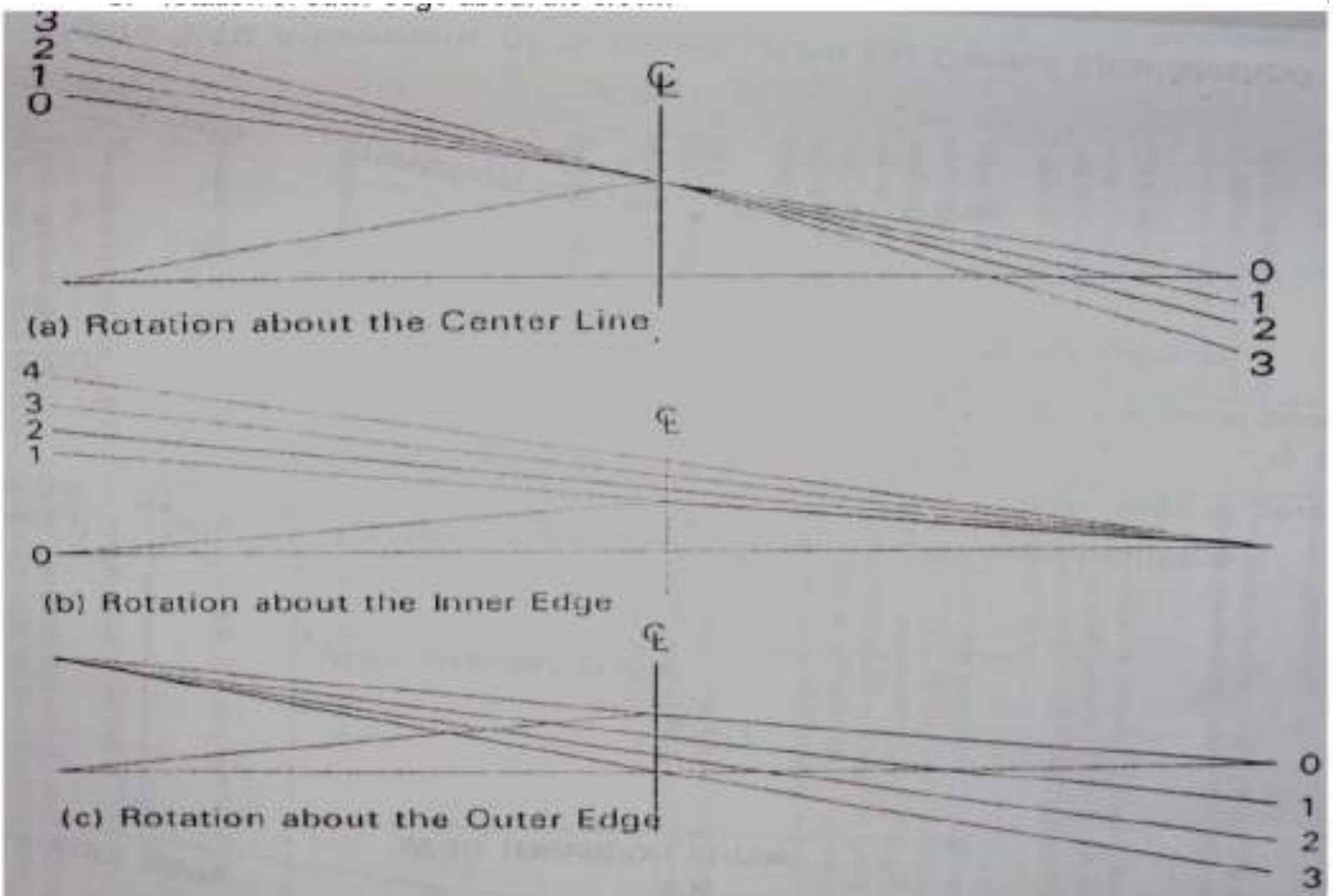
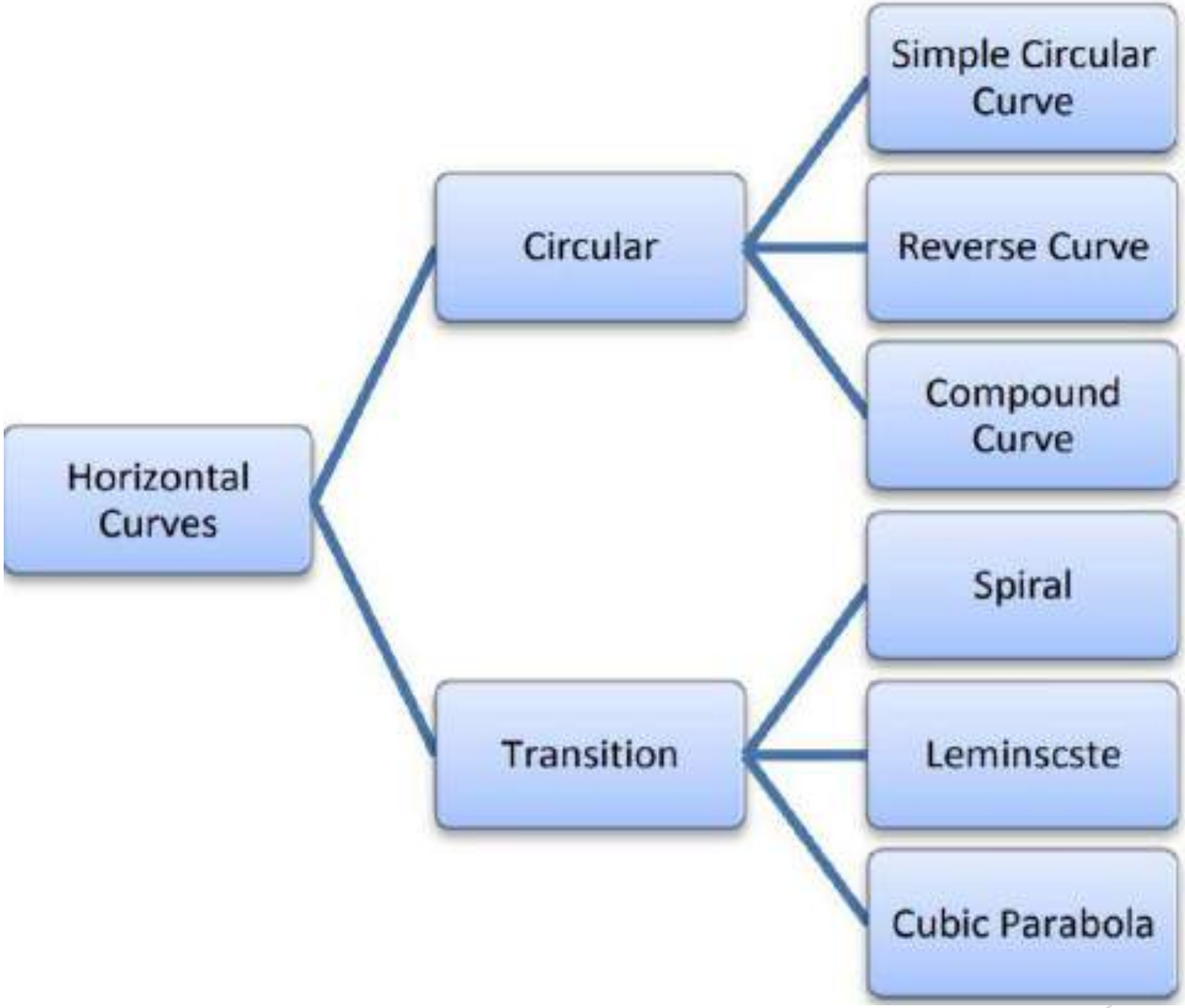


Figure 3.15 Methods of Attaining Maximum Superelevation

Elements Of Horizontal Alignment

- It includes tangents and curves
- Deviations in horizontal alignment are encountered due to various reasons as:
  - 1. Topography of the terrain
  - 2. Restrictions imposed by property
  - 3. Minimizing quantity of earthwork
  - 4. Need to provide access o the particular locality
  - 5. Other factors controlling highway alignment
  - 6. Maintaining consistency with existing topographical features of the terrain blending with existing topographical or other features)
  - **7. Reduce mental strain produced by travelling monotonously along the straight route.**
- Curves are provided in each and every points of intersection of two straight alignments of roads in order to change the direction.
- Provision of horizontal curves at deviation points allows the vehicle to turn
- Radius additional to the minimum radius enhances comfort to the passenger by avoiding sudden change in direction.


Horizontal Curves
Circular
Transition
Simple Circular Curve
Reverse Curve
Compound Curve
Spiral
Leminscste
Cubic Parabola

Elements of simple circular Curve

R = Radius of Curve

BC = Beginning of curve

EC = End of curve

PI = Point of Intersection

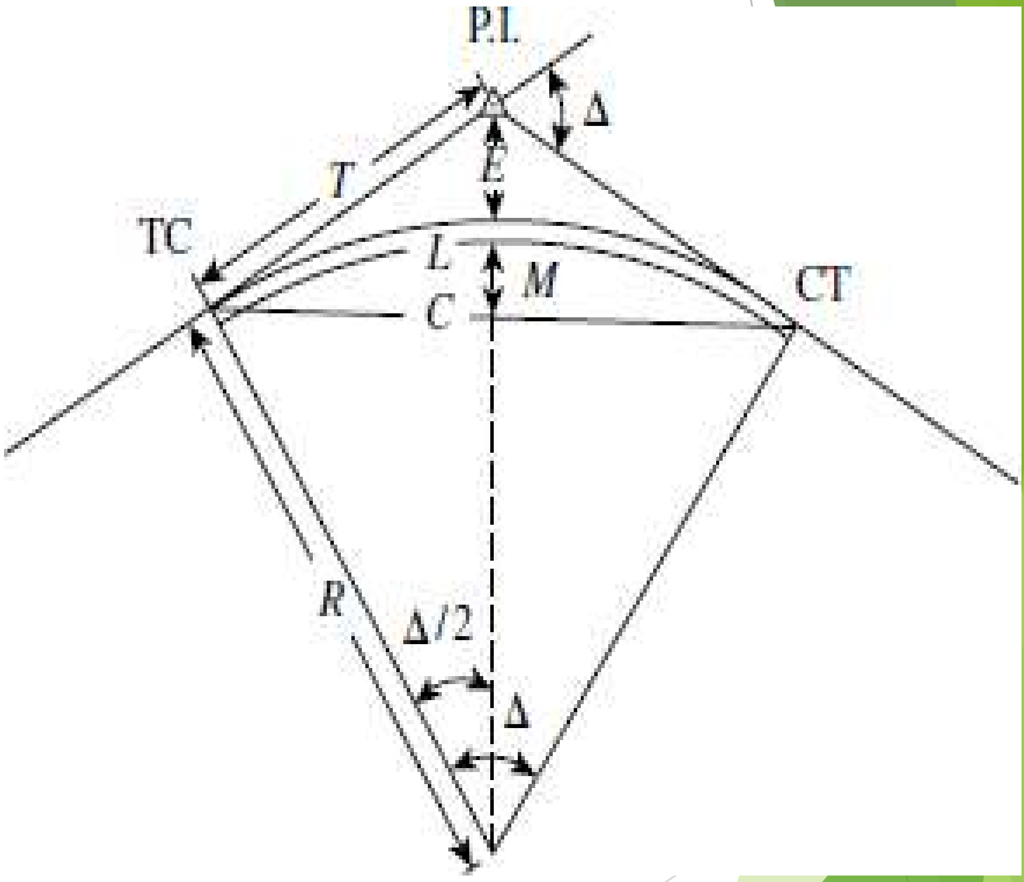
T = Tengent length

L = Legth of curve

Δ=Deflection angle

E = External distance

M= Mid ordinate



Elements of Circular Curves

Radius of Curve	**$R = 1718.9 / D$**
Length of Curve	**$L = \pi R \Delta / 180^{o}$**
Tangent:	**$T = R \tan(\Delta/2)$**
Chord:	**$C = 2R \sin(\Delta/2)$**
Mid Ordinate:	**$M = R – R \cos(\Delta/2)$**
External Distance:	**$E = R \sec(\Delta/2) - R$**

Numerical

- The intersection angle of a 4° curve is 55°25, and the PC is located at station 238 + 045. Determine the length of the curve, the station of the PT.

EXTRAWIDENING AT THE CURVED PATH

- It is the additional width required of the carriageway that is required on a curved path than the width required on the straight path.
- Reasons:
  - i. Rigidity of the wheel base i.e when rear wheels go out while the front wheels are within the pavement
  - ii. Preferential use of the outer lane since visibility is enhanced when the vehicle moves along the outer lane
  - iii. More clearance between opposing vehicles
- Consists of two parts
  - i. Mechanical Extrawidening(W_{me}) : Due to rigidity of wheel base
  - ii. Psychological Extrawidening (W_{pe}) : Because of tendency of vehicle to move towards outer direction

Expression For Extrawidening

$$W_e = W_{me} + W_{pe}$$

$$W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

Where

W_e = Extrawidening

W_{me} = Mechanical extrawidening

W_{pe} = Psychological extrawidening

Transition Curve

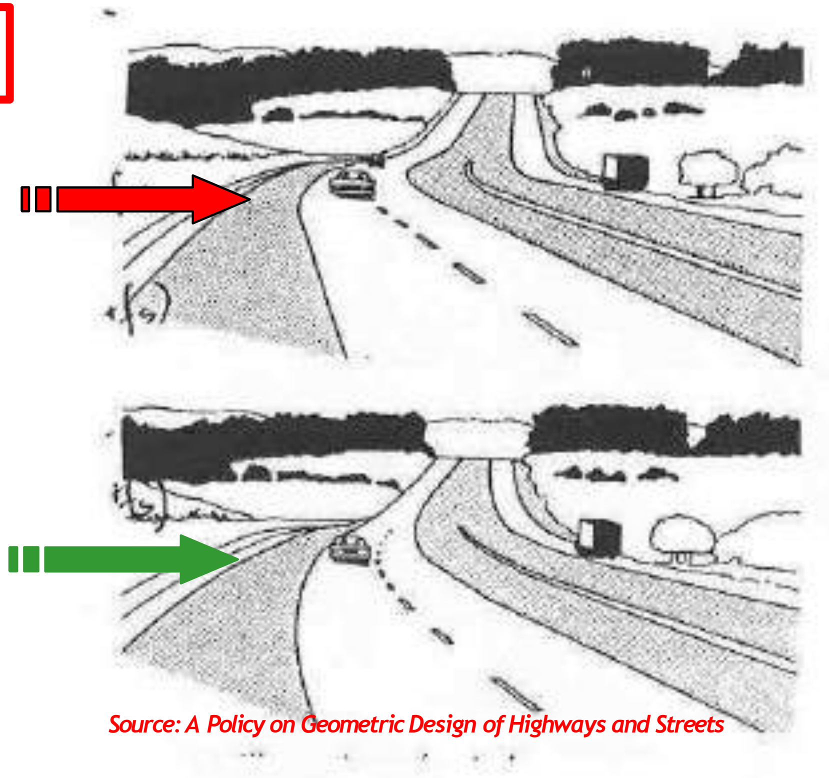
- Definition
- a curve of varying radius (R c between straight and circular path provide in order that the application of centrifugal force would be gradual.

- Objectives:
  - i. to introduce centrifugal force gradually in order to avoid a sudden jerk or discomfort to the passengers.
  - ii. to introduce superelevation at a desirable rate
  - iii. to enable the driver to turn his vehicle slowly and comfortably.
  - iv. to introduce extrawidening at the desirable rate.
  - v. to fit the road alignment in a given topography and also to improve the appearance of road.

Visual effect of Transition Curve

The sharp corners at the beginning of curve

Smooth transition from tangent to curve



Source: A Policy on Geometric Design of Highways and Streets

- Types of Transition Curve:
  - i. Spiral or clothoid
  - ii. Bernolli's leminscate or lemniscate
  - iii. Cubic parabola

Fig: Spiral

- r = aθ
  - a = R/2π
- Co ordinates at any point (Origin at the intersection of transititon and circulat curve)

$$x_c = R\left(\sin\frac{l_c}{R}\right) \qquad y_c = R\left(1-\cos\frac{l_c}{R}\right)$$

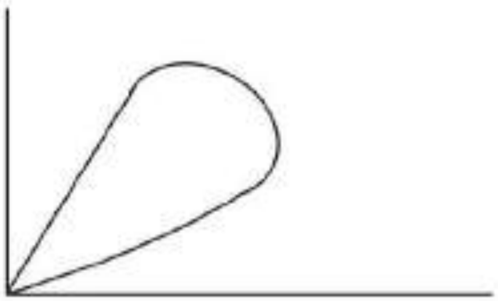


Fig: Lemniscate

- **r = a sin2θ**

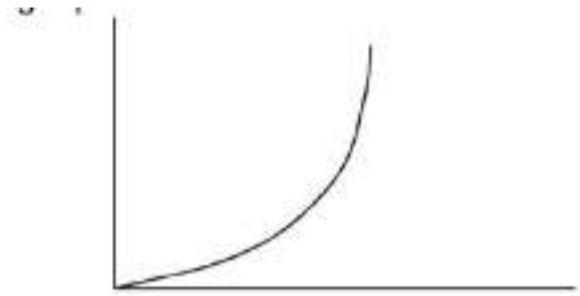


Fig: Cubic Parabola

$$y = x^3$$

Spiral is considered as ideal transition curve because

1. It satisfies that rate of change of centrifugal acceleration is constant i.e., $L_s.R$ = constant. Where L_s = length of transition curve R = radius of curve.
2. The calculation and field implementation of spiral curve is simple and easy.
3. It enhances aesthetics also.

Length of Transition Curve

1. Based on Rate of Change of centrifugal acceleration

- $$L_s = \frac{v^3}{CR}$$

- Where C = Rate of change of centrifugal acceleration

$= \frac{80}{75+v}$

V = velocity in kmph

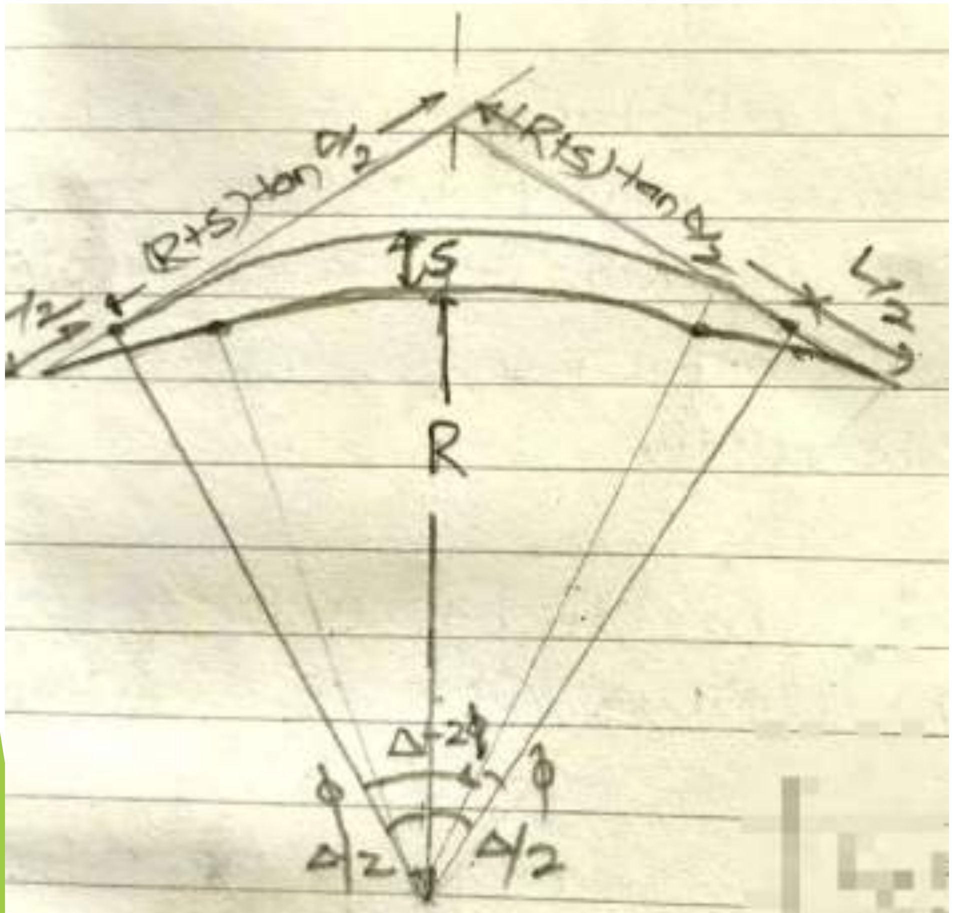
2. Based on Rate of introduction of superelevation

- $L_s = ne(w + we)$ **for rotation about inside or outside**

- $L_s = \frac{ne(w+we)}{2}$ **for rotation about center**

- By Empirical formula
  - Plain and rolling terrain $L_s = \frac{2.7v^2}{g}$
  - For mountainous and steep terrain $L_s = \frac{v^2}{g}$

Elements of transition curve



- Shift (S) = $\frac{L_s^2}{24R}$
- Tangent Length

  $$T = (R+S)\tan\frac{\Delta}{2} + \frac{L_s}{2}$$

- Spiral angle

  $$\Phi = \frac{L_s}{2R}$$

- Length of circular curve

  $$L_c = \frac{\pi R(\Delta - 2\Phi)}{180}$$

- Length of total curve

  $$L_T = L_c + 2L_S$$

NUMERICAL EXAMPLE

A national highway in plain area has a curve of 525m radius is set out to connect twi straights. The maximum speed of the moving vehicles on this curve is restricted to 90 kmph . Transition curve are to be introduced at each end of the curve . Calculate

a. A suitable length of transition curve is
b. The necessary shift of the circular curve
c. The Chainage at the beginning and end of the curve

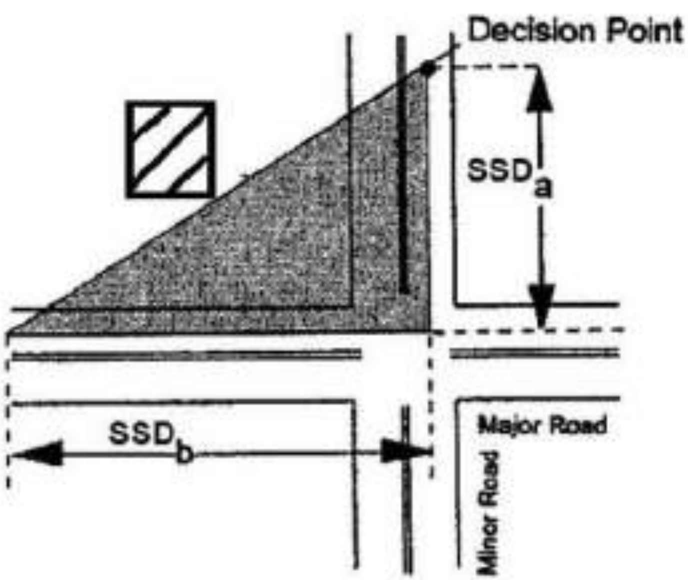
Given that

Angle of intersection = $130^o 24'$, Rate of change of centrifugal acceleration = 0.52 m/sec3 , Chainage at point of intersection = 1092.5 m , Lane width = 3.5m , Rate of introduction of superelevation = 1:120 , length of wheel base = 6.1 m

Sight Distance

- Visibility : The distance upto which there is clear vision in the highway alignment is called visibility
- Sight distance : The minimum visibility requirements for various maneuvering operations in highway is called sight distance. The different sight distances for roadway alignment are as follows
  - Stopping sight distance (SSD) : Distance upto which the driver shall be able to see clearly so as to avoid collision upon seeing a stationary obstruction
  - Overtaking Sight Distance (OSD) : The distance upto which the driver shall see clearly so as to avoid collision or **uncomfortable return back** if the overtaking operation has commenced.
  - Intermediate Sight Distance (ISD) : Distacne more than SSD and less than OSD provided for better safety or when there is chance of head on collision.

- Decision sight distance (DSD) : Distance upto which the driver shall be able to see clearly so as to safely carry out complex maneuvering operations like Transit to a ramp etc.
- Sight distance at intersection :
  - The SSD for minor and major roads varies as the velocity vary
  - The required sight distances are computed and the sight triangle is ensured
  - In case sight triangle cannot be ensured restrictions on minor like **slow and pass , stop and pass** etc can be applied



Stopping Sight Distance

SSD Contains two parts

1. Perception Distance/Lagging Distance (l_1) :

It is the distance travelled from the instant the obstruction/hazard is identified to the point at which brakes are applied,

According to PIEV theory the total reaction can be divided into four parts **Percepetion Intellect Emotion Volition** . The combined time from perception to volition is called perception reaction time.

It is equal to desigh velocity multiplied by the perception reaction time

2. breaking distance (l_2) :

It is the distance travelled from the instant the brakes are applied till the vehicle comes to a hault position

Analysis of SSD

$$\mathbf{SSD = l_1 + l_2}$$

$$\mathbf{SSD = 0.278vt + \frac{v^2}{254\Phi}}$$

$$\mathbf{SSD = 0.278vt + \frac{v^2}{254\acute{\eta}(\Phi \pm i)}}$$

v = design velocity

Φ = coefficient of longitiditional friction

t = perception reaction time

NUMERICAL EXAMPLE

Compute the minimum SSD required to avoid a head on collision of two busses approaching from the opposite directions. The speed of both the buses is 70 *kmph* . Assume a total perception and brake reaction of 2.5 Sec. Coefficient of friction is 0.4 , brake efficiency of 50% and a upgrade of 4%

Set Back

- It is the clearance from the centerline of the highway curve required to provide adequate sight distance
- Case I : Length of Curve(S) > Sight distance (S)

$$m = R - (R - d)\cos\frac{\alpha}{2}$$

R = Radius of circular curve

d = distance of center of innermost lane from center of highway

α = angle subtended at the center by the sight distance

$$\alpha = \frac{180S}{\pi(R - d)}$$

Numerical Example

A four lane divided highway has a curve of 1000m long, a radius of 550m, and a safe SSD of 250m. Caclculate the minimum set back distance from the inner edge of the curve to a building to ensure safe visibility. Take pavement width per lane as 3.5m

- Case II : Sight distance (S) > Length of Curve(S)

$$\boldsymbol{m = m1 + m2}$$

$$\boldsymbol{m1 = R - (R - d)\cos\frac{\alpha}{2}}$$

$$\boldsymbol{m2 = \frac{(S - L)}{2}\sin\frac{\alpha}{2}}$$

R = Radius of circular curve

d = distance of center of innermost lane from center of highway

α = angle subtended at the center by the curve

$$\alpha = \frac{180L}{\pi(R - d)}$$

Numerical Example

On a two lane highway there is a horizontal curve of radius 550 m and length of 225 m. Compute the setback distance required from the center line of the inner side of the curve so as to provide for Safe OSD of 350 m

Gradient : Definition and Types

- Gradient shall be the rate of rise or fall. Gradient shall be expressed as one of the following ways:

  1. In percentage; example 10%,20%, 33% etc (n%)

  - 10% means the rise/fall of 10 units per 100 units of horizontal distance travel .

  2. in fraction; example 1in 40, 1 in 200, 1 in 2000 etc. (1 in N) 1 in 40 means the 1 unit of rise/fall (vertical dist.) per 40 units of horizontal dist. travel.

- Based on Function, Gradient shall be of following 5 types

  1. Ruling gradient: It is the maximum gradient within which the designer attempts to design the vertical profile of a road.

  it is that maximum gradient over which a vehicle can be hauled with one locomotive without the application of additionally higher gears

  The value of ruling gradient per IRC the recommended value of ruling gradient is 1 in 30, 1 in 20 and 1 in 16.68 in plane/rolling, mountainous and steep terrain.

2. Limiting gradient

If ruling gradient requires huge amount of earthwork for e.g. topography of a place has steeper gradients then in such case we provide limiting gradient which is more than ruling gradient.

The length of limiting gradient is limited considering safety. The limiting gradient is broken either by providing level road or road with a ease gradient.

As per IRC the recommended value of limiting gradient is 1 in 20, 1 in 17.7 and 1 in 14.3 in plain/rolling, mountainous and steep terrain respectively. It shall not be provided for lengths greater than 300m and shall be followed by at least 300m of resting gradient.

3. Exceptional gradient

In some cases its quite impossible to provide ruling /limiting gradient.

Under this condition exceptional gradient is provided.The length of exceptional gradient is as less as possible. As per IRC the recommended value of exceptional gradient is 1 in 15, 1 in 14.3 & 1 in 12.5 in plain/rolling, mountainous and steep slope.

The exceptional gradient shall not be provided more than 60m/km of mild distance travelled and shall not be more than 100m at a time and shall be provided with at least 300m of resting gradient of 300m

4. Minimum gradient :

A minimum value of gradient is also required along the direction of the road because of the drainage purpose. As per IRC the minimum gradient of 0.5% to 1.0% should be provided considering various situation.

5. Momentum Grade

If the vehicle has just travelled a downgrade then the upgrade slightly higher than ruling gradient can be provided without any compensations. The grade is such that the inetrria gained by the vehicle is equal to the load imposed by additional gradient

According to NRS

Ruling Gradient 7%

Limiting Gradient 10%

Exceptional Gradeint 12%

Definition and Types of Vertical Curve

- It is a curve provided between two tangents to ease the change in gradient
- Necessity:
  - i. to obtain adequate visibility and safe driving
  - ii. to secure comfort to the passengers
- Types:
  - i. Vertical Summit Curve
  - ii. Vertical Valley Curve

Design of Summit Curve

- Length of Curve(L)

  Decided so as to provide minimum sight distance (S)

  L > S

  $$L = \frac{NS^2}{200(\sqrt{h1}+\sqrt{h2})^2}$$

  L < S

  $$L = 2S - \frac{200(\sqrt{h1}+\sqrt{h2})^2}{N}$$

  Where N = [g_2-g_1] = Change in grade

  h_1 = Height of Drivers eye from ground = 1.2m(unless specified else)

  h_2 = Height of Obstruction = 0.15m(unless specified else)

- Position of Highest Point

$$X_h = \frac{L}{N} * g_1$$

- Tangential Correction at any point

$$\mathrm{T} = \frac{Nx^2}{200L}$$

NUMERICAL EXAMPLE

A vertical summit curve is to be designed when two grades +1/60 and -1/45 meet each other at an RL of 1220.15m so that a ISD of 420m is to be ensured calculate

a. Length of the curve

b. RL of the beginning highest point and lowest point

Assume h1 = 1.2m , h2 = 0.15m

Design of Valley Curve

- Length of Curve(L)

  Decided so as to provide minimum sight distance (S) under head lights

  Case I : L > S

  $$L = \frac{NS^2}{200h + 200S\ tan\alpha}$$

  Case II: L < S

  $$L = 2S - \frac{200h + 200S\ tan\alpha}{N}$$

  Where N = $[g_2 - g_1]$ = Change in grade

  h_1 = headlight height = 0.75 m (unless specified else)

  α = beam angle = 1® (unless specified else)

- Position of Lowest Point

$$X_l = \frac{L}{N} * g_1$$

- Tangential Correction at any point

$$\mathrm{T} = \frac{Nx^2}{200L}$$

NUMERICAL EXAMPLE

A valley curve is formed by descending grade of 1 in 30 meeting an ascending grade of 1 in 40. Design the length of vertical curve to provide a sight distance of 72 m

If the RL of the apex is 98.5m determine the

(i) RL of BVC and EVC

(I)RL of the Lowest point

Grade Compensation

Grade Compensation

The reduction in grade due to the horizontal curve associated with gradient is termed as grade compensation,

- Grade compensation= $\frac{30+R}{R} \Rightarrow Maximum\ vaue = \frac{75}{R}$
- Compensation is not required when the grade is flatter that 4%

<u>Problem</u>:

If gradient =6%, R=75 m; how much compensation is preferred in this curve?

<u>Solution:</u>

grade compensation= $\frac{30+R}{R} = \frac{30+75}{75} = 1.4\ \ and\ \ \frac{75}{R} = \frac{75}{75} = 1$

the optimum value for grade compensations = 1%.

Factors affecting Selection of Grade

- Characteristics of dominating traffic
- Physical Factors like drainage , access to property , appearance , safety etc.
- Road Intersection , Bridge etc.
- Topography of the country

Criteria for alignment selection

- **Horizontal alignment**
  - Long tangents
  - Large Radius
  - Shall avoid hair pin bend
  - Shall avoid reverse curve

- **Vertical alignment**
  - Long tangents (short tangents create saw tooth arrangement which shall be avoided)
  - Vertical curve shall be of high radius
  - Vertical alignment shall blend well with the locality
  - Shall avoid box cutting

Highway Drainage

4.1 Introduction and important of highway drainage

- **Effects of Moisture**
- Moisture has the following effects on a highway

i. The bearing capacity of different layers of soil is reduced as a result of which the pavement may not be able to take the design loads

ii. The strength of various layers of pavement is reduces hence roadway may undergo permanent deformation

iii. The water flowing over the slopes may cause erosion

iv. Seepage of water along the roads may cause slope instability leading to landslides

v. There is a chance of slippage of vehicles running at high speed

vi. Rain water takes away with it the precious road material away

highway drainage is a set of engineering structures and techniques which ensures water is kept as far away from the surface i.e. ground water, seepage and infiltration is kept as low as possible and rain water is drained as soon as possible

Highway drainage ensures the following

- The flow of water which takes place for short period of time which shall not damage the road surface
- Seepage and other sources of ground water are be kept far away from the surface of the road
- The highest level of ground water is at least 1.2m below the top of road surface
- In water logged areas it is ensured that special precautions are taken

4.2. Causes of moisture variation in subgrade soil

- There various sources through which water may be introduced to the road surface some of them are as follows
- 1. By free water
- Seepage from higher ground
- Penetration through pavement
- Transfer from shoulder and pavement edges\
- 2. By Ground water
- Rise and fall of water
- Capillary rise from lower soil level
- Transfer of water vapor through soil

Sources of Moisture in Highway

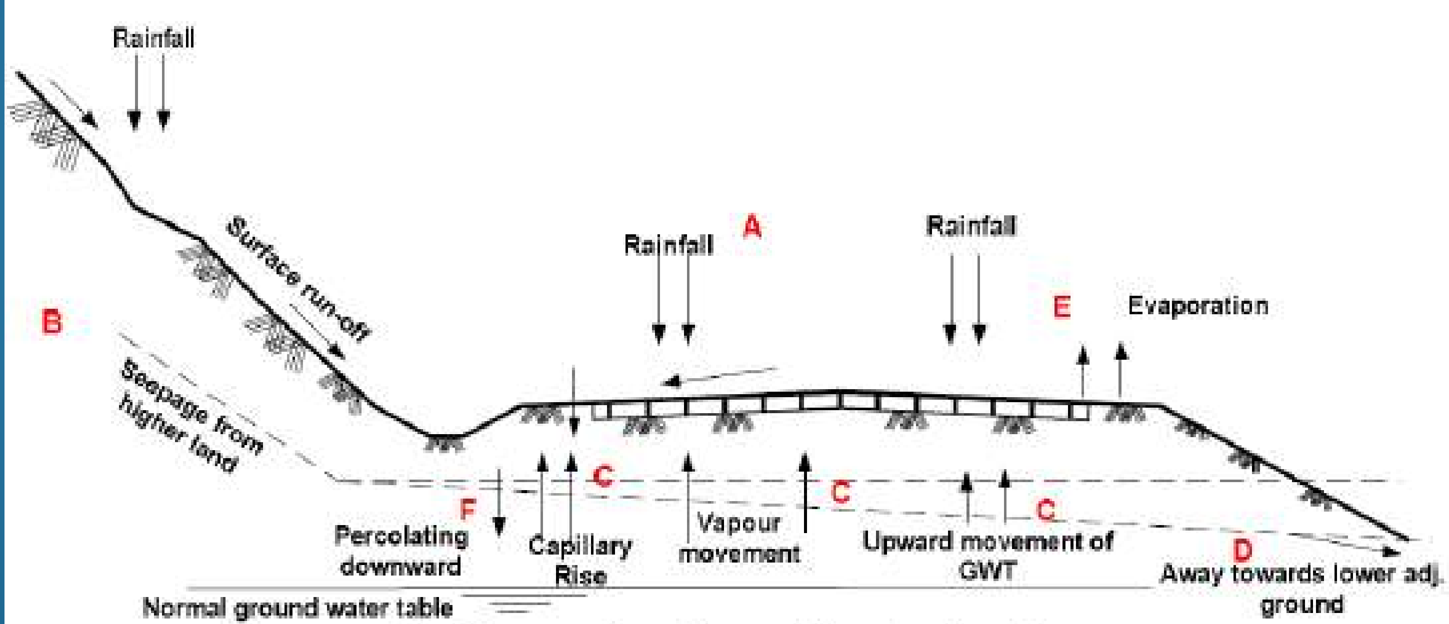


Fig. Sources of moisture variation in sub-grade

4.3. Requirements of good drainage system

- In general a good drainage shall fulfill the following requirements
  - i.The surface water from the carriageway and shoulder should be effectively drained off without allowing it to percolate through subgrade
  - ii.The surface water from adjacent land and natural drainages should be prevented from entering the roadway
  - iii.The side drain should have sufficient capacity and slope to carry away the water coming to the surface

4.4. Classification of highway drainage system

- Surface Drainage system
- The components which removes water from road and road side ground is called surface drainage

- Sub-Surface Drainage
- The components which removes water Below the road surface is called the sub surface drainage system

- Cross Drainage Structure
- When a stream has to cross the road way, special precautions have to be taken in order to cross the stream the structure thus formed is called cross drainage structure
- Some if the common cross drainage structures are bridge , culvert , cause way etc

- Energy dissipating structures
- Water flowing along the side drains have tremendous energy due to their Flow and might erode the canal away
- Those structures which are constructed in order to dissipate the energy carried by the water is like falls road rapids etc are called energy dissipating structures

4.5 Surface drainage system

- The removal of water from the road surface and road side pavement is called surface drainage
- It contain two components

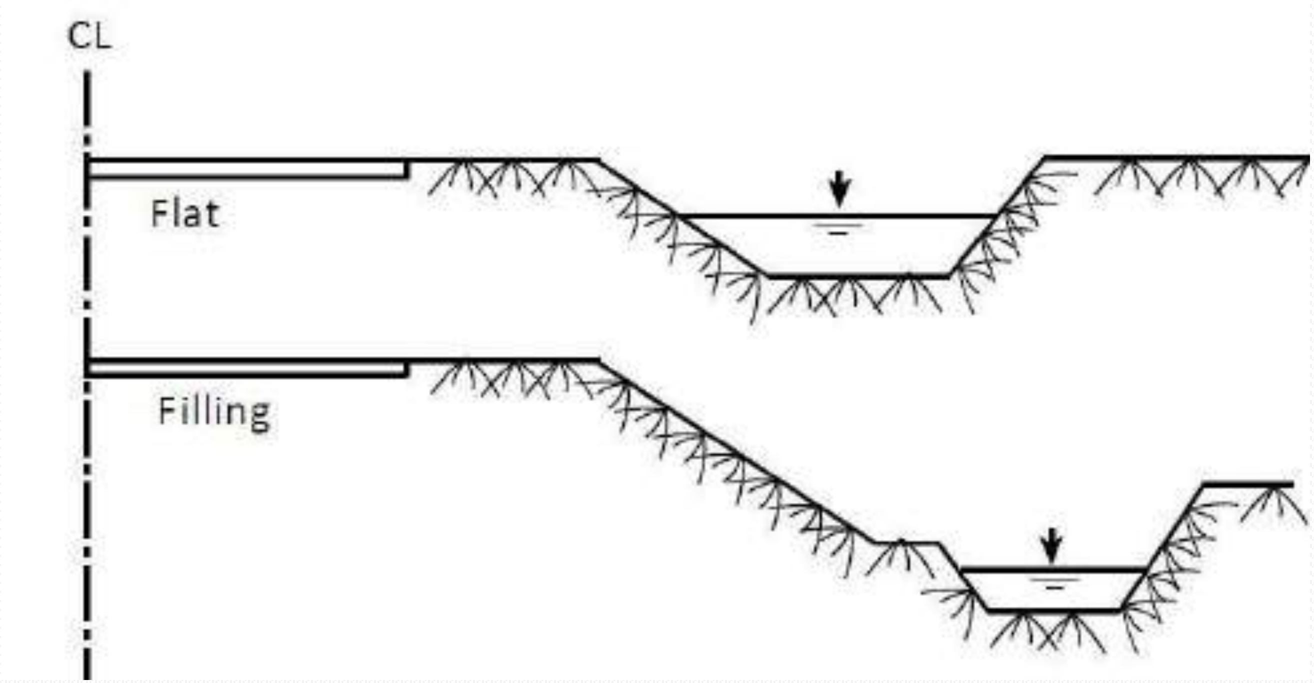
Transverse drainage

- It is used to provide the continuity of natural water lines, intercepted by the road. It is designed to avoid the flooding of the platform and surrounding areas.

- **Longitudinal channels**
  - Ditches along side of road to collect surface water after run-off

- The combination of these are used in the following configrations

- **A. Drainage In Plain Highway/Roads**
- The water from shoulder and the pavement is collected by the side drains
- The side drains are provided at the base of the shoulder or at the base of the embankement as per the nature of the cross section of the road
- Sometimes when the space is restricted and open drains are not safe to administered , under such circumstances covered drain closed by layers of pervious sand and gravel are used


CL
Flat
Filling

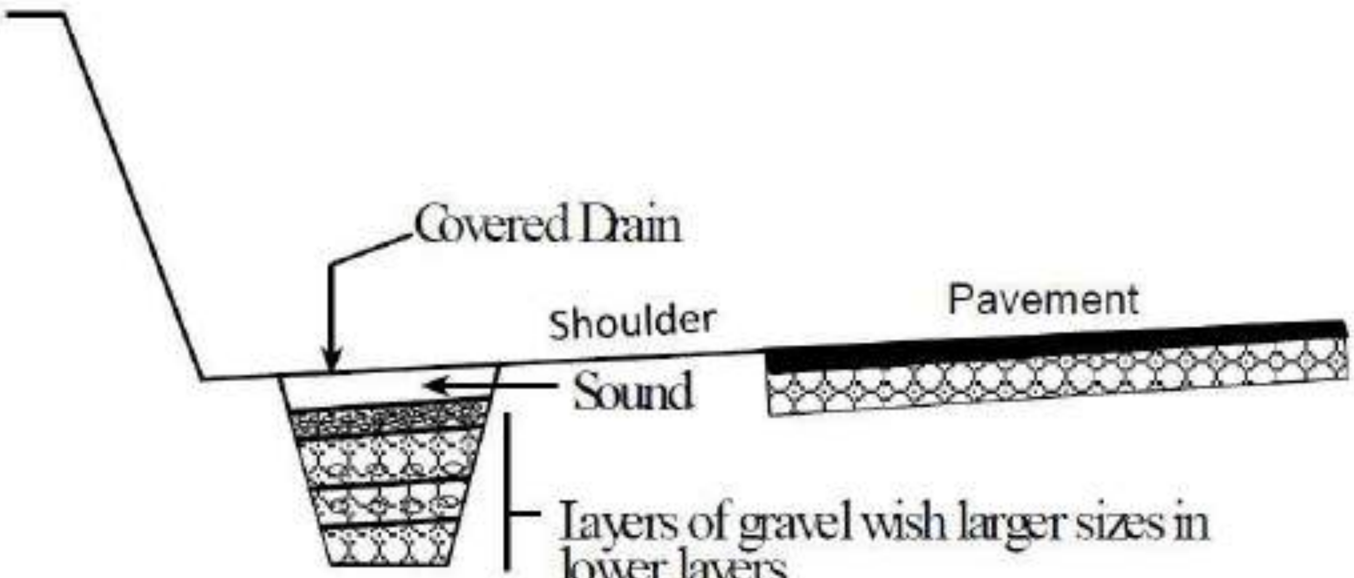
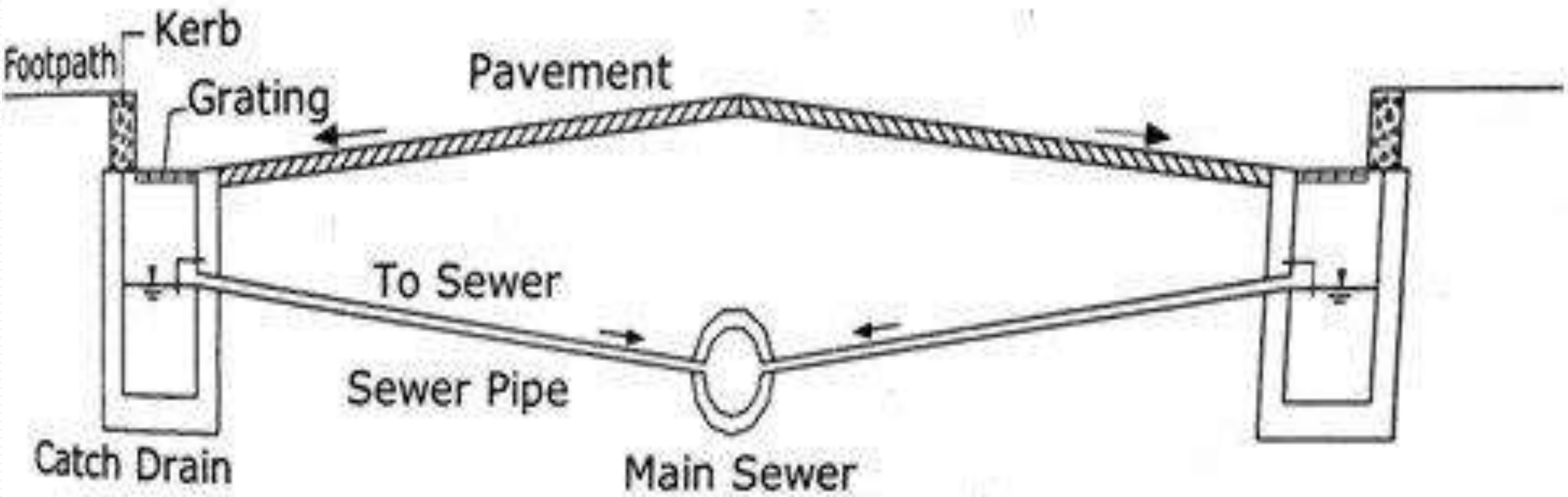
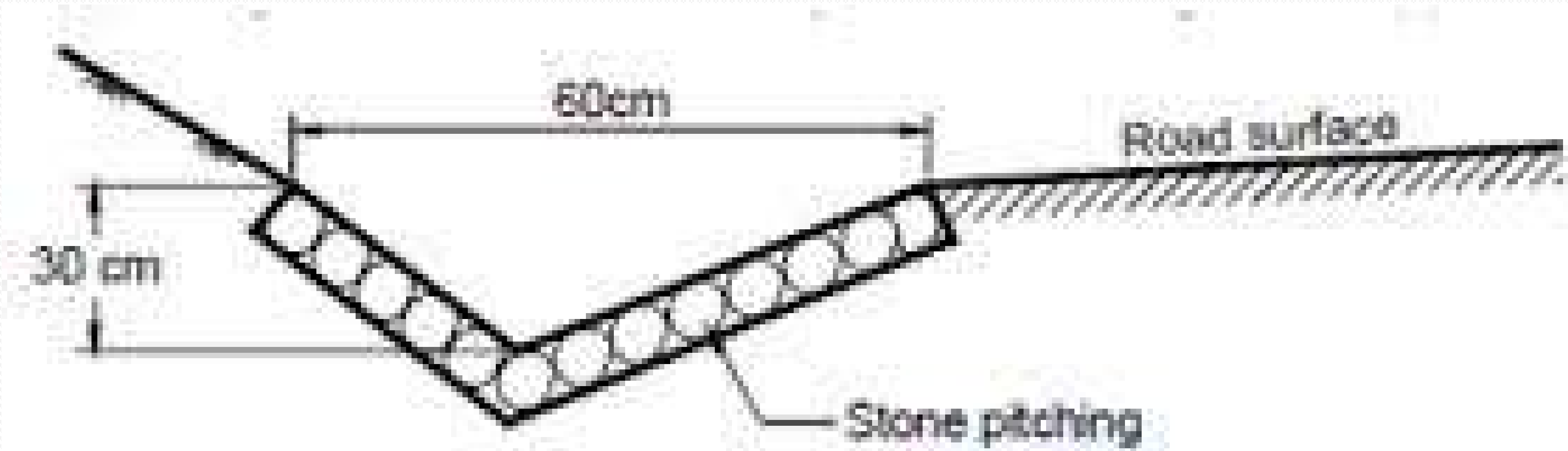


Fig. Filled drain

- **B. Drainage In Urban streets**
- In case of urban streets due to the presence of footpath , dividing island , other feature and lack of land underground drains have to be provided
- Water from pavement and footpath is collected by the kerb or gutter outlet and is deposited into the catch pits suitably placed
- The water is laid to main sewer by means of the sewer pipe


Kerb
Footpath
Grating
Pavement
To Sewer
Sewer Pipe
Catch Drain
Main Sewer

- **C. Drainage in Hill roads**
- In hill roads side drains are provided in the form of triangular drains
- Along with this there is additional water collected due to the presence of huge slopes
- If this water is not drained properly then the slippage of the road surface ultimately leading to the blockage may take place therefore the water flowing from the slopes is intervened by means of catch drains
- **Apart from this the water coming from the rivers which bring about a huge amount of water in the rainy seasons are a major problems**
- **Therefore proper cross drainage structure shall be established**


60cm
Road surface
30 cm
Stone pitching

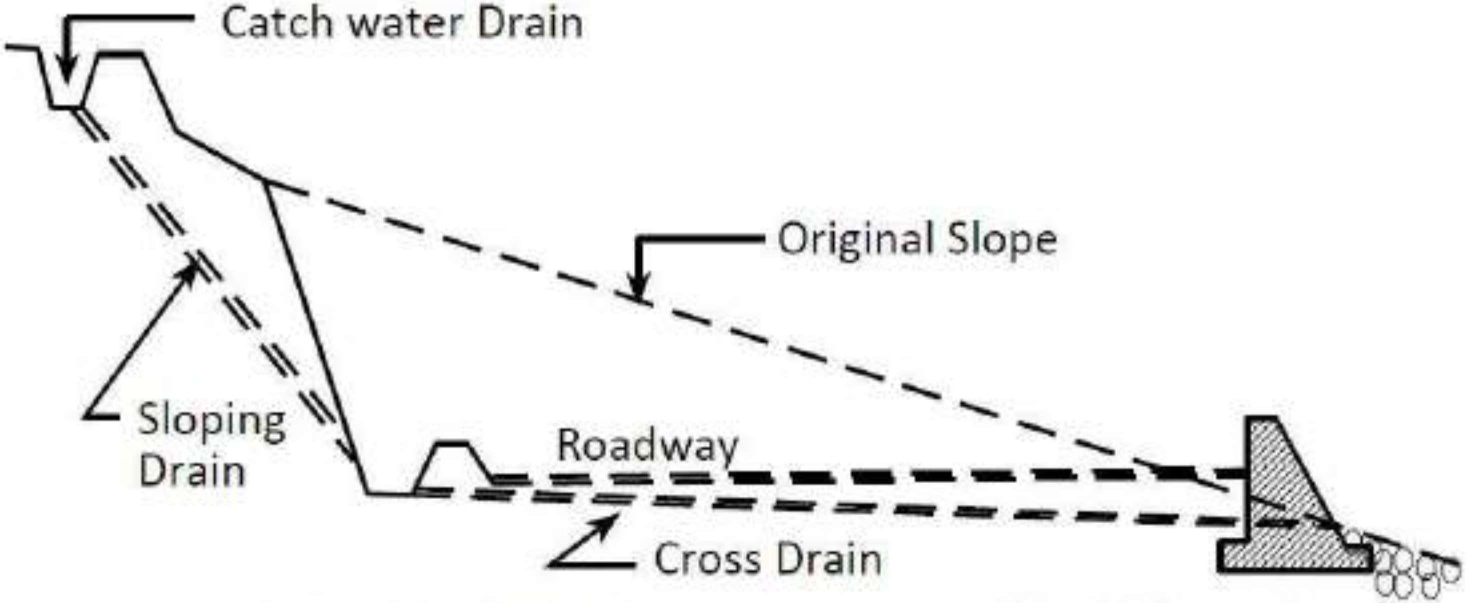


Fig. Catch drain arrangement for hill roads

4.6. Design of surface drainage

- The design process involves the following steps

(i) Hydrological analysis :

- The main objective of this phase is the estimation of the maximum quantity of water expected to reach the drainage system.
- When rain falls on the ground some portion is infiltrated along the ground, some is evaporated while the rest of it flows above the ground, this portion is called surface runoff
- The main objective of surface drainage is to drain off this surface runoff
- There are a no of formulas which utilize the catchment area and the nature of soil, in order to calculate the amount of runoff
- The most popular is the rational formula

$$Q = \frac{C * i * A}{360}$$

Where

i = rainfall in mm/hr

A = Area in Ha.

C = Coefficient of Impermeability

Run-off Coefficient

- It is the fraction of rainfall that becomes runoff
- Depends on
  - Characteristics of soil
  - Shape of drainage area
  - Existing moisture conditions
  - Slope of watershed
  - Amount of impervious soil
  - Land use
  - Duration and intensity of rainfall

Run-off Coefficient

Steep, bare rock. Also city pavements ...	0.90
Rock, steep but wooded ...	0.80
Plateaus, lightly covered ...	0.70
Clayey soils, stiff and bare ...	0.60
-do- lightly covered ...	0.50
Loam, lightly cultivated or covered ...	0.40
-do- largely cultivated ...	0.30
Sandy soil, light growth ...	0.20
-do- covered, heavy brush ...	0.10

Runoff Coefficient (AASHTO)

Table 16.2 Values of Runoff Coefficients, *C*

Type of Surface	*Coefficient*, C*
Rural Areas	
Concrete sheet asphalt pavement	0.8-0.9
Asphalt macadam pavement	0.6-0.8
Gravel roadways or shoulder	0.4-0.6
Bare earth	0.2-0.9
Steep grassed areas (2:1)	0.5-0.7
Turf meadows	0.1-0.4
Forested areas	0.1-0.3
Cultivated fields	0.2-0.4

Run-off Coefficient

- When a drainage area has distinct parts with different C values

Use the weighted average

$$C = \frac{C_1 A_1 + C_1 A_1 + \cdots + C_n A_n}{A_1 + A_1 + \cdots + A_n} = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i}$$

Watershed (Drainage) Area

- The drainage area is the area of land that contributes to the runoff at the point where the channel capacity is to be determined. i.e. combined area of all
  surfaces that drain to a given intake or culvert inlet

Drainage Area is determined from:

- Topographic maps
- Aerial photos
- Digital elevation models
- Drainage maps
- Field reviews

Rainfall

- Three properties of rainfall
  - The rate of fall, known as **intensity**;
  - The length of time for a given intensity, known as **duration**;
  - The probable number of years that will elapse before a given combination of intensity and duration will be repeated, known as **frequency (return period)**

Design Period

- Overdesign (longer return period) is costly and Under design (shorter return period) may be inadequate

  Factors usually considered in making this decision include,

  - the importance of the highway,
  - the volume of traffic on the highway, and
  - the population density of the area.

Rainfall Intensity

- Average intensity for a selected frequency and duration over drainage area for duration of storm

  Based on values of :

  - time of concentration
  - recurrence interval or design frequency

Design Rain Fall (IRCSP13method)

- The rainfall intensity is,

Where,

$$I = F\,\frac{\left(1+\frac{1}{T}\right)}{\left(t_c+1\right)}$$

- F=the of rainfall in cm dropped by severest storm over a period of T hours

- t_c =time of concentration (Time for water to flow from most distant point in drainage area to the drain inlet) in hours

$$t_c = \left(\frac{0.87L^3}{H}\right)^{0.385}$$

Where, 'L' is the distance from the critical point to the culvert in km, and 'H' is the fall in level from the critical point to culvert in m

Time of Concentration (tc)

- Depends on:
  - Size and shape of drainage area
  - Type of surface
  - Slope of drainage area
  - Rainfall intensity
  - Whether flow is entirely overland or whether some is channelized

(i) Hydraulic Design

- This phase involves the process of determining the size of the drain based on the slope , amount of runoff and the nature of drainage material.
- It utilized manning's formula

$$Q = \frac{1}{n} * A * R^{2/3} S^{1/2}$$

$$A = Area \text{ of catchment}$$

$$\text{R} = \text{Hydraulic Radius} = \frac{\text{A}}{\text{P}}$$

- The steps involved are as follows

(i) Determine the hydraulic radius using permissible velocity V

$$R = \left(\frac{nV}{S^{1/2}} \right)^{3/2}$$

(ii) Determine the required area using

$$A = \frac{Q}{V}$$

(iii) Determine the perimeter using

$$P = \frac{A}{R}$$

(iv) Determine the dimensions solving

$$A = Bd + Sd^2 \text{....................}(i)$$

$$P = B + 2\sqrt{1+m^2}\,d \text{............}(ii)$$

(v) Determine the actual velocity(V') from area calcualted by rounded off dimensions

(iv) Check For critical depth using d >V^2 /2g if ok the design is ok else change dimesnions and review

4.7. Subsurface drainage system

- Subsoil(Sub Surface) drainage can be achieved through the following

- **A. Lowering of water table**
- Water table must be at least 1.2m away from the road surface
- If depth is more than that it is ok else it is shall be lowered
- The best way is to keep the top surface of the road above the natural the natural ground till the depth is satisfactory
- For relatively Granular (Permeable soils) Water table can be lowered by the construction of longitudional drains filled with filter sand
- The depth of these drains depends upon the type of drain the spacing of drains and the type of soils
- If soil is relatively less permeable the lowering of ground water may not be adequate at the center therefore additional transverse drains may have to be provided in order to effectively drain off the water and thus to lower the water table

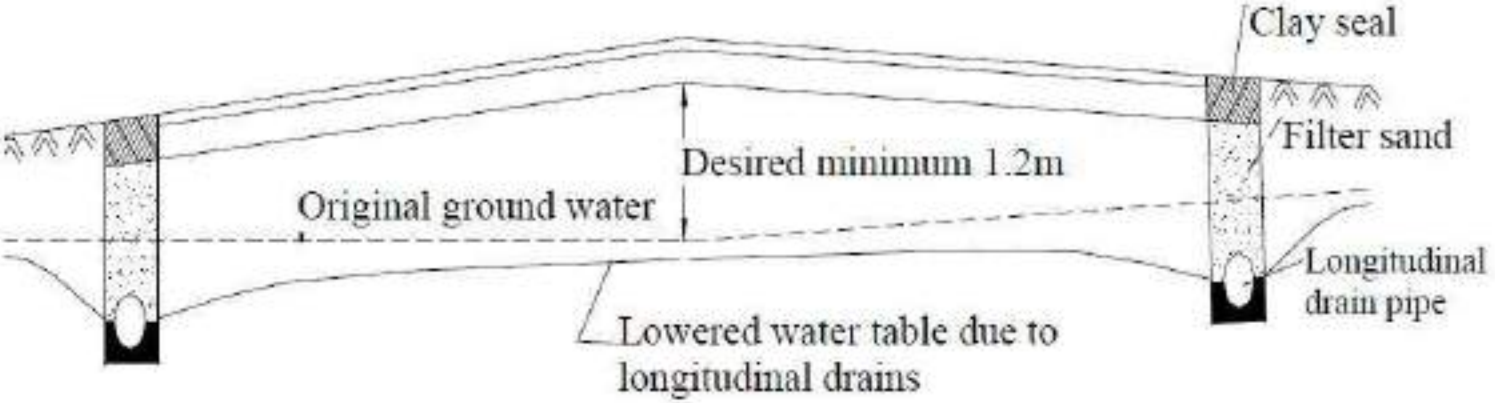
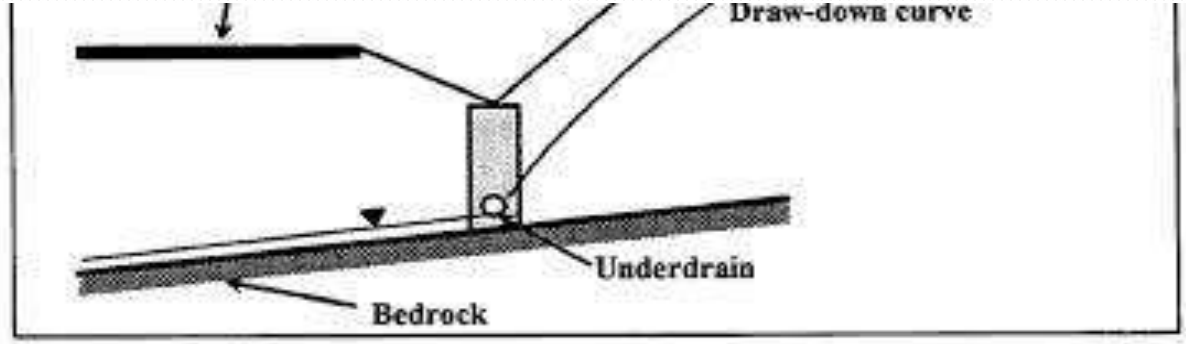



Fig. Lowering of ground water table

- **B. Control of Seepage flow**
- Where ground slope as well as the impervious layer is slopping towards the road surface the seepage from higher grounds is likely to reach the road surface the seepage is likely to damage the road and reduce he strength of the road
- If the depth of seepage gets lower then 60 to 90 cm from the road surface then it has to be intervened to keep the seepage fairly below the ground level
- This is achieved by introducing a perforated drain pipe in between the slope and the road
- The pipe is covered by a layer of filter material like coarse gravel sand etc
- The top of the pipe is sealed by a clay seal so that the outside water may not enter the drain pipe


Draw-down curve
Underdrain
Bedrock

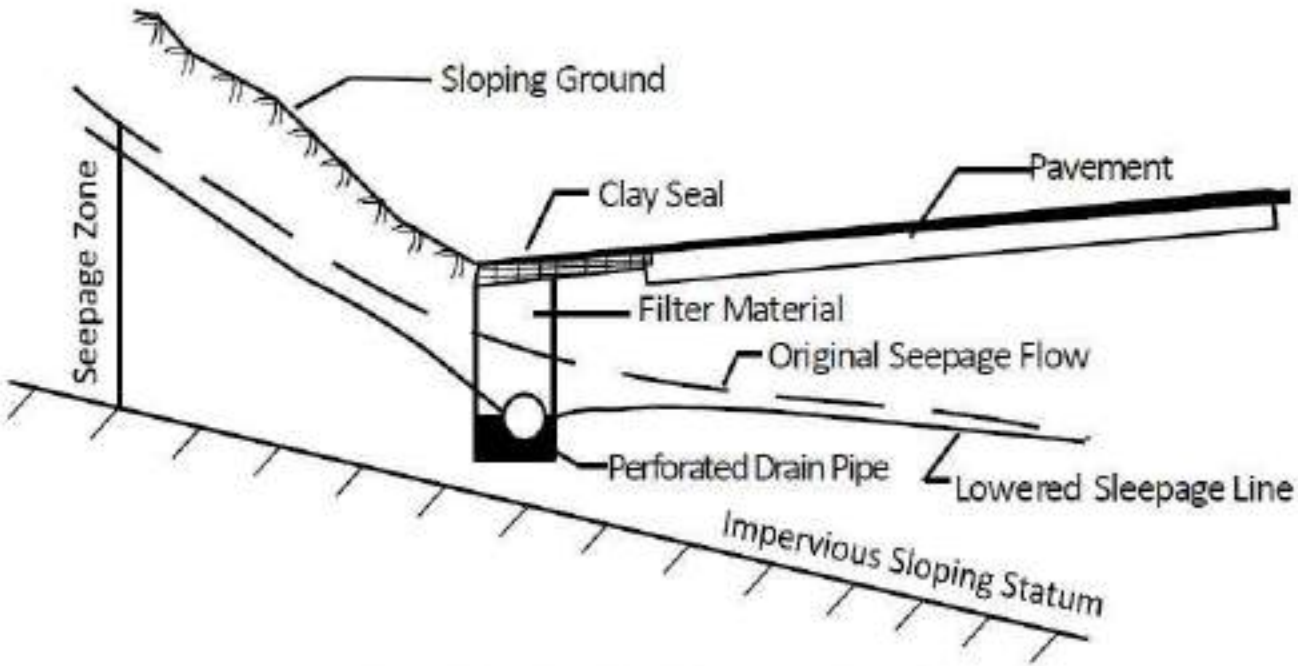
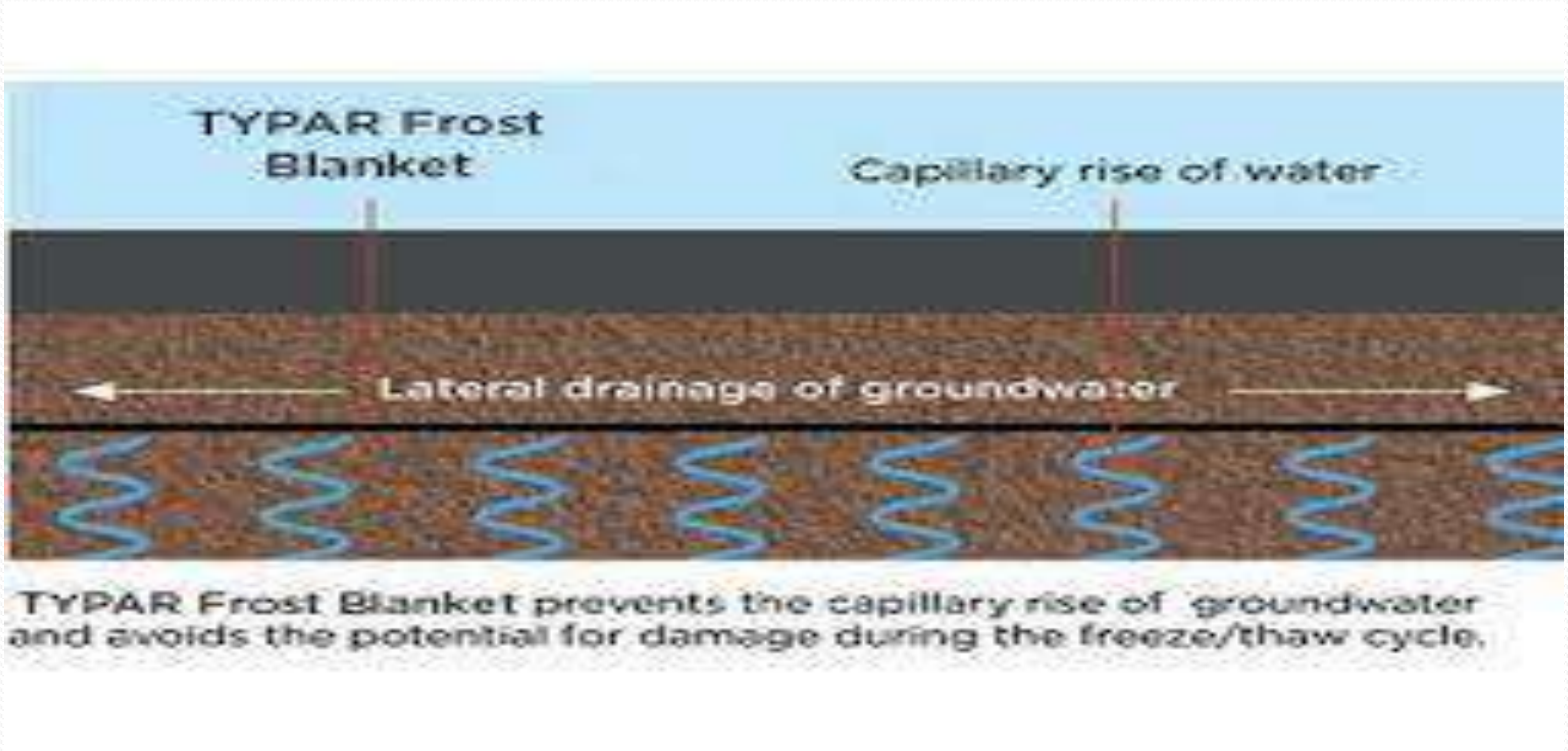


Fig. Control of seepage flow

- **C. Control of Capillary rise**
- If capillary rise water is fairly near the road surface then it may affect the strength and durability of the road
- Under such conditions, steps should be taken to arrest the capillary rise of water
- For sub grade soil is permeable the lowering of water table is more proffered but for impermeable soils the drainage is too costly therefore a capillary cut off is proffered

- **1.** By providing a layer of granular material during the construction of the road embankment
  - The thickness of the granular capillary cut off shall be sufficiently higher than the anticipated capillary rise
  - The capillary rise is intervened by the granular layer and cannot reach beyond it

- **2.** By inserting a impermeable layer in the place of granular layer for eg a layer of bitumen



4.8 Cross Drainage Structure

- They are structures formes at the junction of road embankement and natural drain in order to drain the water flow efficiently
- The different type of cross drainage structures used in highway are as follows
- (i)Culvert
- (ii) Causeway
- (iii) Bridge

Culvert

- It is a conduit placed under the embankment to carry water. It is of following types
- **Pipe culvert**

  This type of culvert is used when stream carries low discharge and the cover over the drain is sufficiently high

  It consists of a RCC Pipe laid over a concrete base of 15cm provided such that there is a minimum cover of 50cm above the top of pipe

  The pipe size ranges from 60cm to 3m and are available in langths of 2.5 to 3m

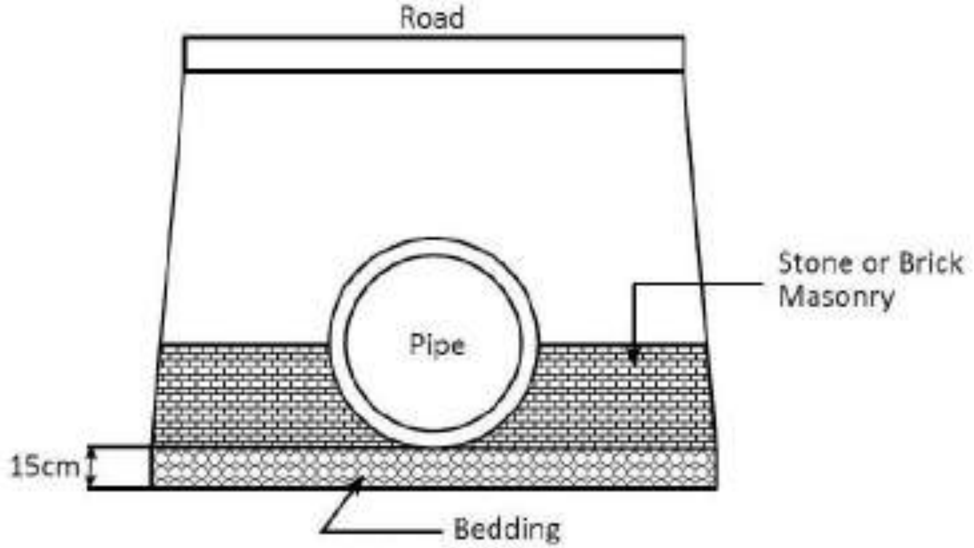
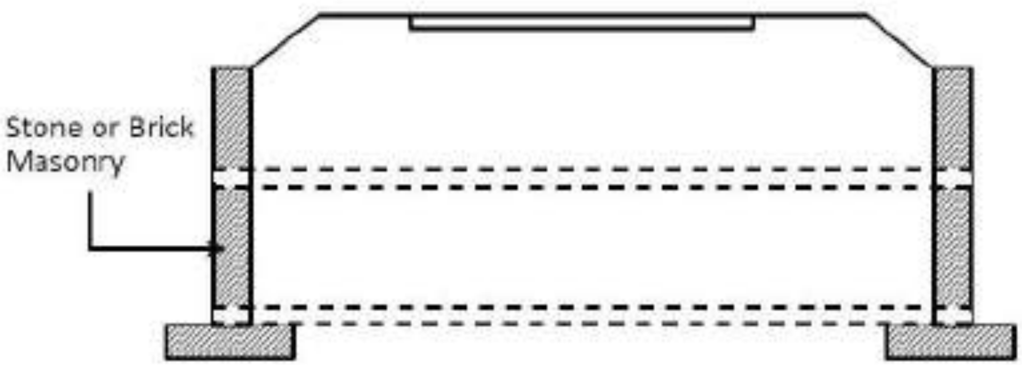


Fig. Pipe culvert

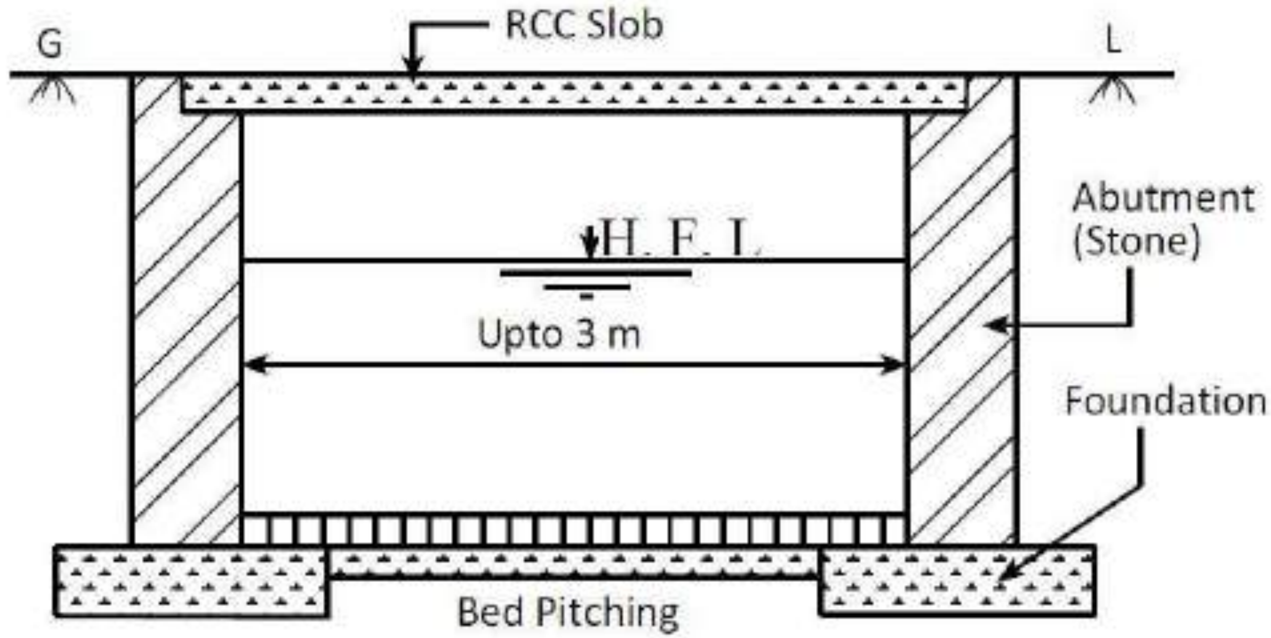


- **Slab Culvert**

  This kind of culvert has two stone masonry abutements on either side over which a slab is provided

  The abutements are made by stone masonry in places where stone is available abundantly and from brick masonry in other places

  These type of culvert span from 2.5 to 3m and can economically discharge moderate flows


RCC Slob
G
L
H. F. L.
Abutment
(Stone)
Upto 3 m
Foundation
Bed Pitching

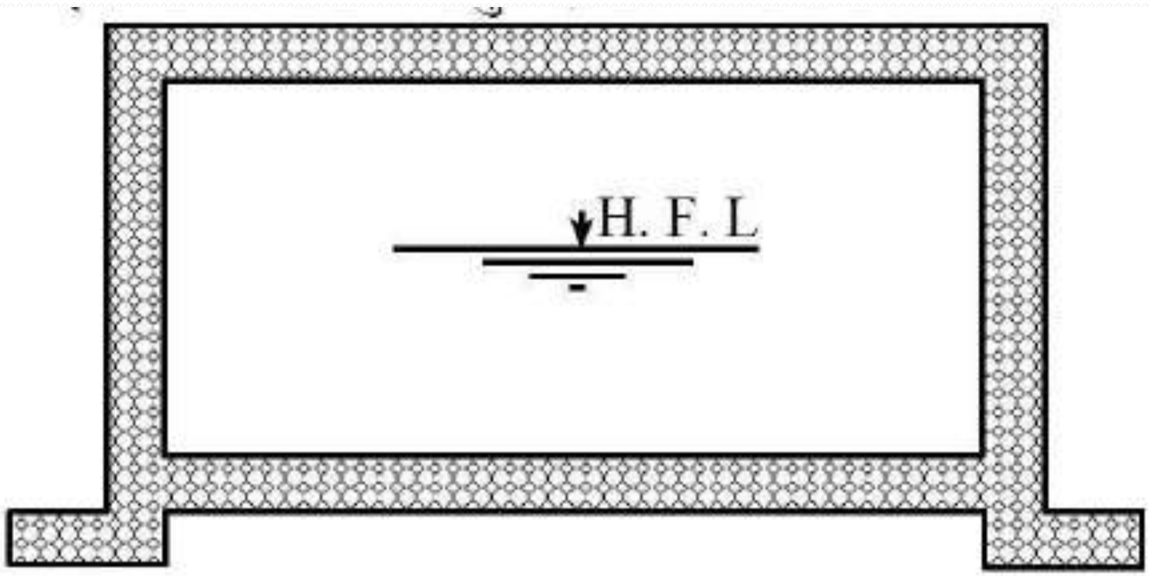
- **Box culvert:**

  If the soil is not suitable for the individual fottings of a slab culvert then a complete RCC box is provided in the form of culvert this is called box culvert.

  This does not require a high cover and can even be aligned with the road surface.

  This kind of culvert contains a complete RCC box of minimum size 60X60cm and can be upto 3mX3m

  This kind of culvert has grater resistance to damage due to debris


H. F. L

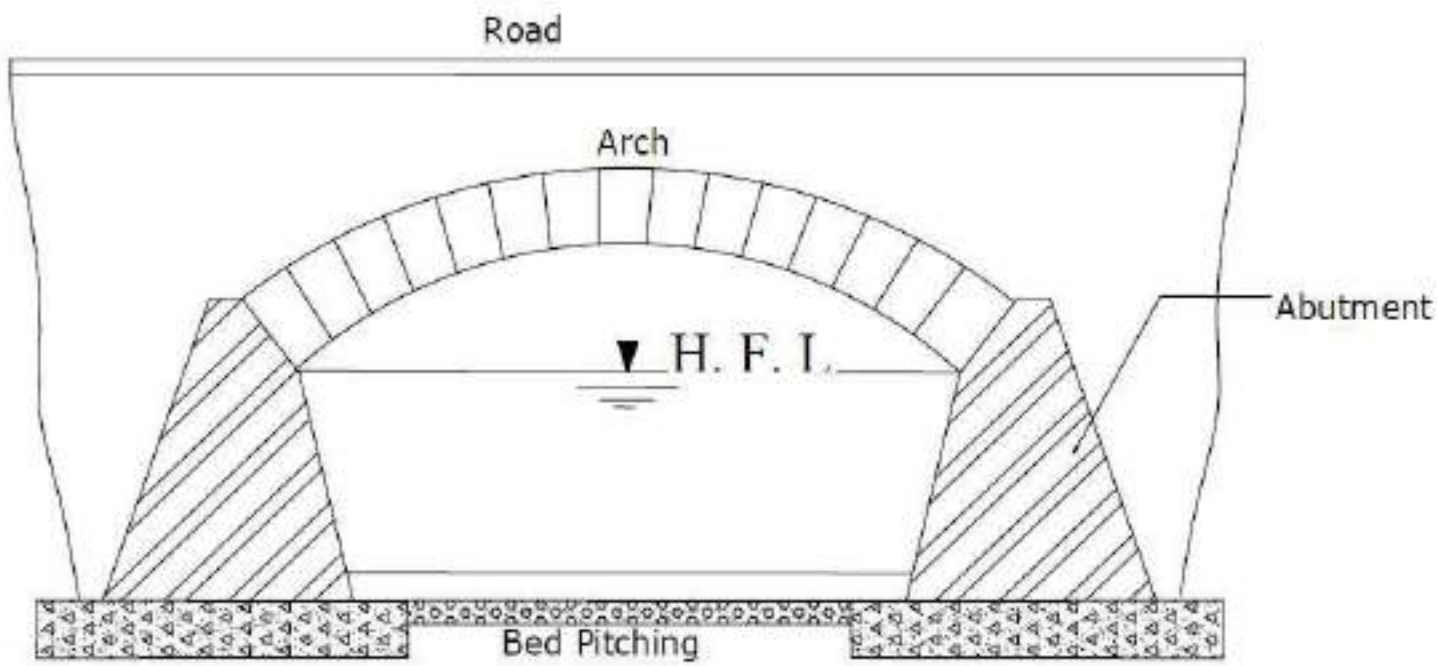
- **Arch Culvert**

  This kind of culvert is made when huge amount of loads are occurs

  It contains two masonry abutements over which a arch is provided, deck is provided over the arch

  The arch is generally made RCC or Stone masonry

  The span of arch is limited to 3m


Road
Arch
Abutment
H. F. L.
Bed Pitching

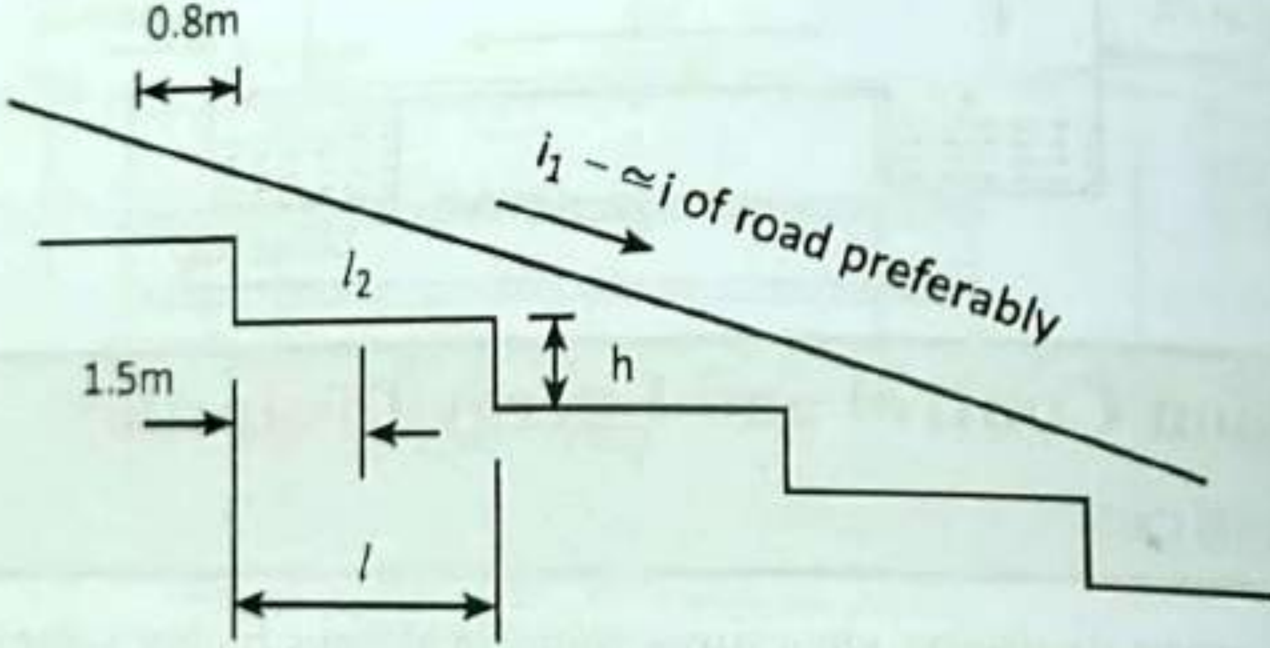
Causeway

- They are submersible bridges i.e. are inundated in when heavy flow occurs
- These are provided in less important roads where depth of flow does not exceed 1.5m.
- When flood occurs traffic is stopped at both the ends and continued when flood recedes
- They are of two types
- Low level type which can run only during dry conditions
- High level type which can pass a certain magnitude of flood

4.9 Erosion control and Energy Dissipation

- At the outlet and other critical points the velocity of water is higher than the non-scouring velocity, which causes erosion under normal conditions and therefore special precaution shall be applied they are

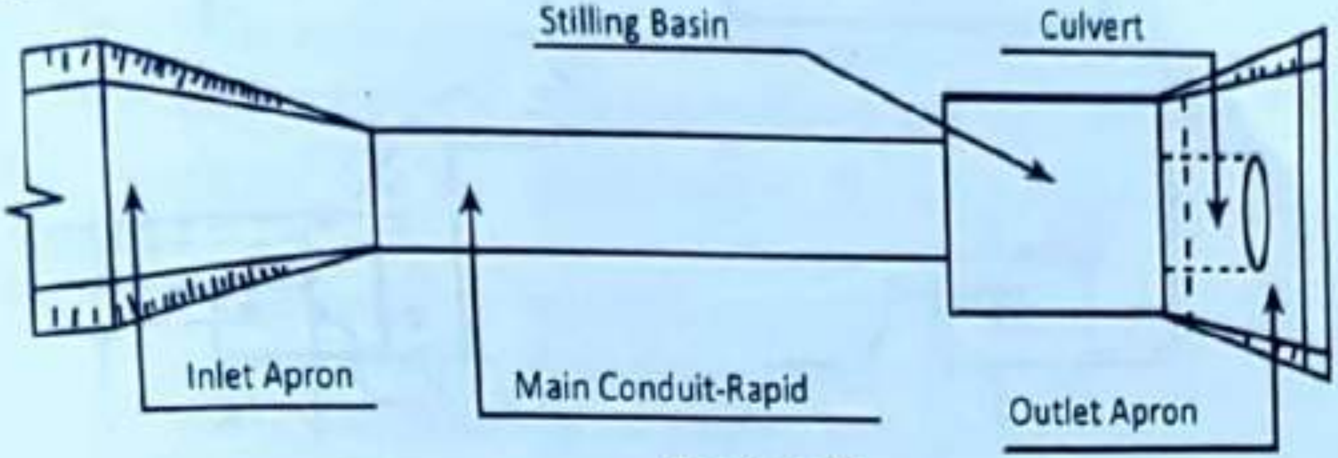
- **Lining Of drains and Ditch checks**
- In order to reduce erosion the slopes are covered with turf and bottom with gravel or cobble of desired size
- If the flow is too high then the turf can be replaced by stone masonry,RCC or Lining based on the flow and budget availability
- Simillarly if the grade of the bottom is too high for ordinary measures then series of steps are formed these are called ditch checks



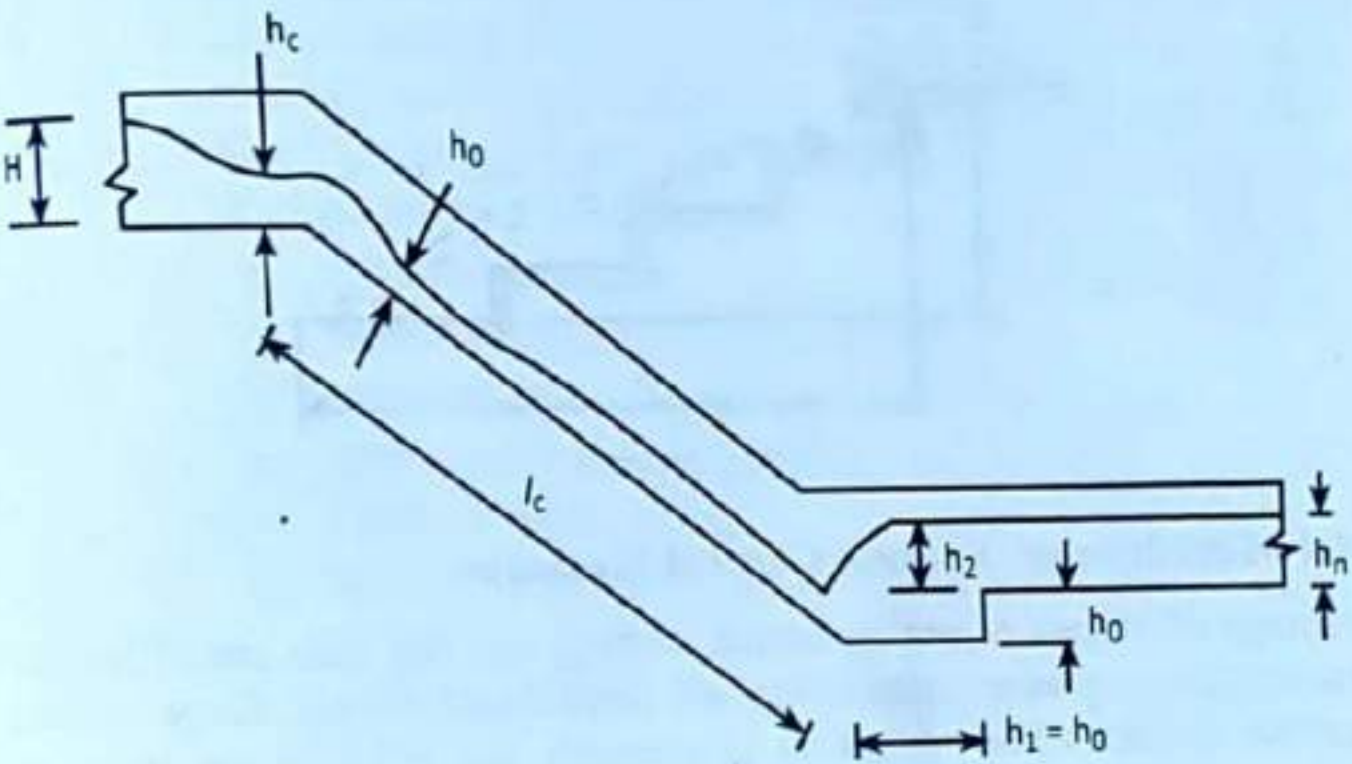
Ditch check

- **Road Rapids**
- These are structures provided at the inlet and outlet of cross drainage on order to dissipate energy
- It contains three parts inlet outlet and stilling basin

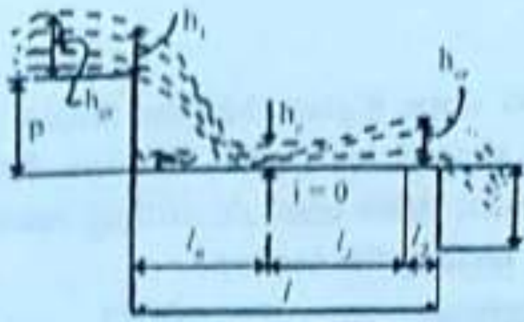
- **Fall or Drop Structure**
- They are provide in hill slopes where the bed slope of the existing drainage is too high
- They are provided at the inlet and the outlet of the cross drainage

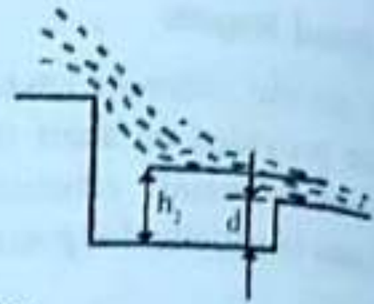


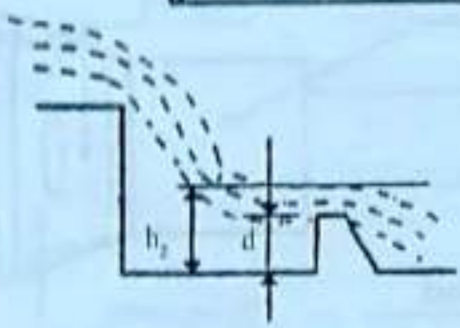
Road rapid



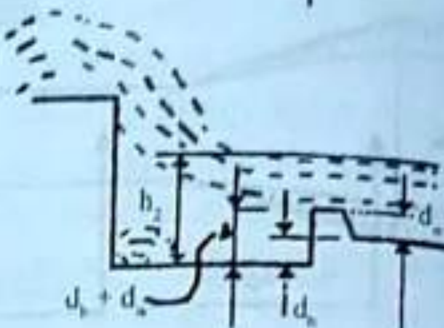
Scheme for the design of rapid



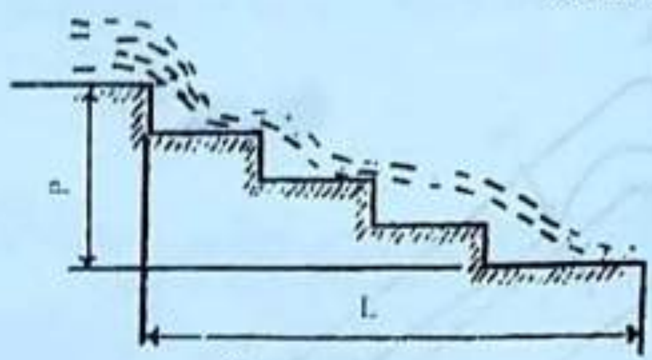




With friction wall (blocks)



With stilling basin and fraction wall (blocks)



Drop structures

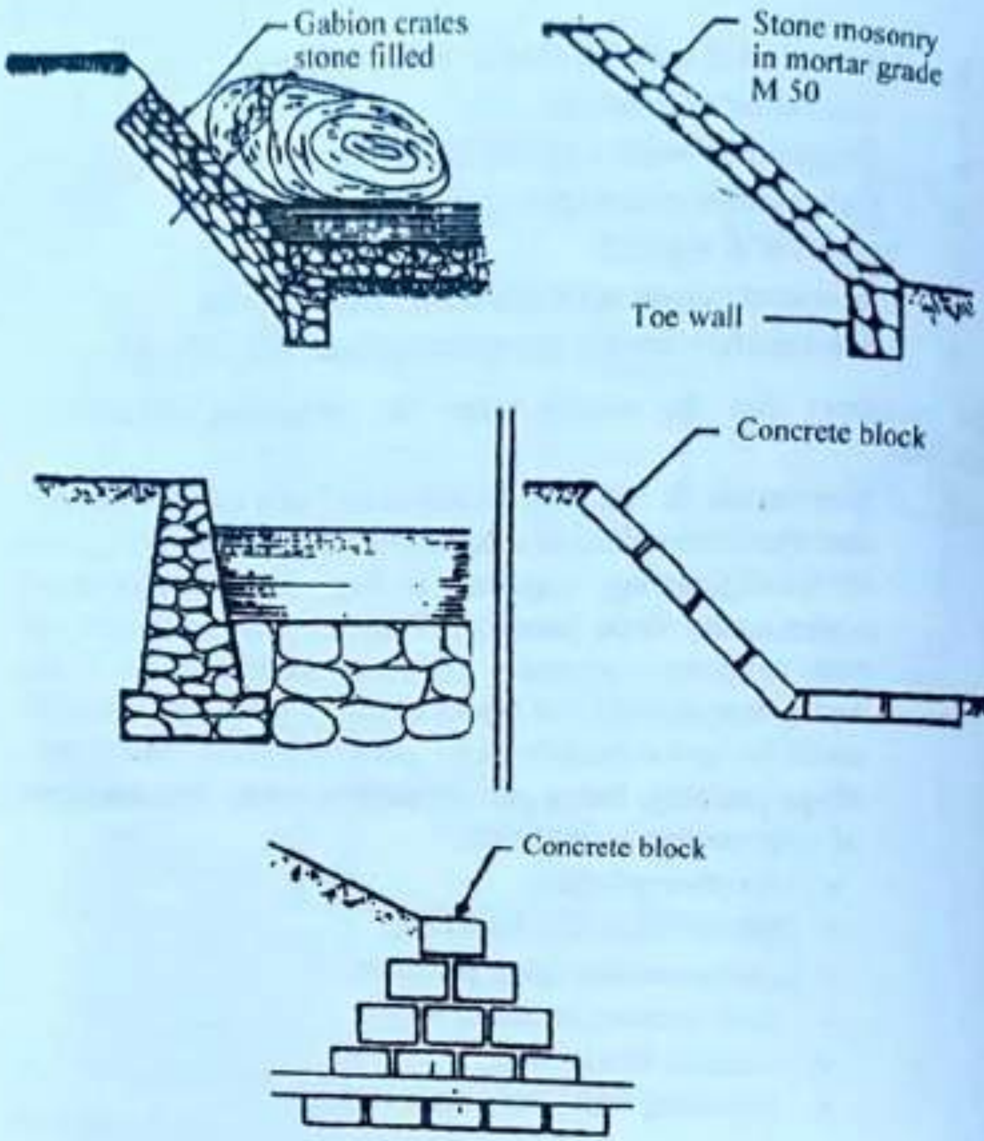
- **Miscellaneous Erosion Control Measures**
- The flow of water over the shoulders and hill slopes causes erosion.
- Erosion also occurs on the surface of earthen roads
- This may be tackled through

(i) Vegetation

- Vegetation performs protective as well as aesthetical functions.
- It is dealt under the topics of road side arboriculture or bioengineering
- Turfing is the most economical method
- In this process turfs are transferred to critical sites which stabilizes the slopes and control erosion

(ii) Slope pitching

- Slopes can also be stabilized by pitching
- Pitching can be done by following methods
- Dry Stone pitching
- Gabion crate pitching
- Cocnrete lining
- Retaining wall



Slope protection work

Unit 5: Highway Materials

5.1. Classification of highway materials

- A highway consists of a number of layers namely
- Sub-Grade = The soil Supporting the roadway
- Sub base = The soil Supporting the Base,bridges base and subgrade
- Base = The soil which transfers stress from pavement to the subgrade and is supported by sub base
- Pavement = The strongest and the most expensive material used to directly bear the load of the veichle and wear and tear through it

These layers require different materials like soil stone tar bitumen concrete etc these materials are called highway materials

Highway materials can be classified as follows

- 1. Minerals such as sub grade soil, sand stone chips ,gravel,pit sand,blast furnace slag ,pebble, stone etc
- 2. Common building materials like reinforcing steel , Timber , Bricks , etc
- 3. Binding materials like bitumen , tar etc.They can be classified as

  a. Stone dust or cohesive soil Semi Rigid Binding

  b. Cement lime and other inorganic binder Rigid Binding

  c. Bitumen tar and other organic binder Flexible Binding

5.2. Subgrade soil

- **Uses**
- Soil is an integral part of the pavement
- It is used to form embankments as well as the base of road
- Usually pavement layers are constructed over compacted soil layer in some cases modified soil is also used extensively in forming the Sub base and base of the highway
- Soil is also used as the surface of the low cost pavements like gravel road , soil stabilized roads
- It supports the load of the pavement
- Its Strength and other properties highly influence the design of the road pavements as well as the success of the road

- **Requirements of soil as a highway material**
- The desirable properties of soil as highway materials are as follows

1. **Stability :** soil should offer resistance to permanent deformation under loads, resistance to weathering and ability to provide support to the pavement
2. **Incompressibility :** Soil shall not compress under the loads of vehicle
3. **Permanency of Strength :** The strength of soils shall not vary with time(This occurs due to weathering sub grade moisture movements etc) i.e it shall provide the same degree of support the soil below
4. **Good drainage :** Soil should have good drainage i.e. water shall not be logged into the soil
5. **Ease of Compaction :** It shall be compacted easily so as to provide higher dry density so that the strength of the highway is ensured

- **California Bearing Ratio test of soil**
- It is the method of determining the stability or strength of the soil(Sub grade) as well as that of other highway materials factor in the design of pavements.
- California Bearing Ratio (CBR) is defined as the ratio of it is defined as the force required for desired penetration in the given medium(Soil) to the force required for peneration in Standard medium(Compacted Stone) provided by a cylindrical plunger of 50mm dia applied at the rate of 1.25mm/min
- The desired penetration values are 2.5mm and 5mm.

- **Apparatus:**
- A mould 15 cm internal dia and 175mm height with a base plate 10 mm thick and collar 50mm in height
- A loading frame that can move vertically at the rate of 1.25mm/min with a cylindrical plunger 50mm in dia and 100mm long
- Dial gauges for measuring the penetration or deflection
- A metal spacer disc disc of 148mm dia and 47.7mm high
- One annular weight and one slotted weight each of weight 2.5 kg and 147mm dia with a central hole of 53 mm dia
- Miscalenous appartus like mixing bowl straight edge scale etc

AIM 120-MS

- **Preperation Of Specimen**
- **1) Undisturbed Specimen**
- Fit steel cutting edge of dia 150mm
- Push the mould into the ground gently till it is full of soil
- Remove the excess soil from top and bottom after removing the collar the sample is ready

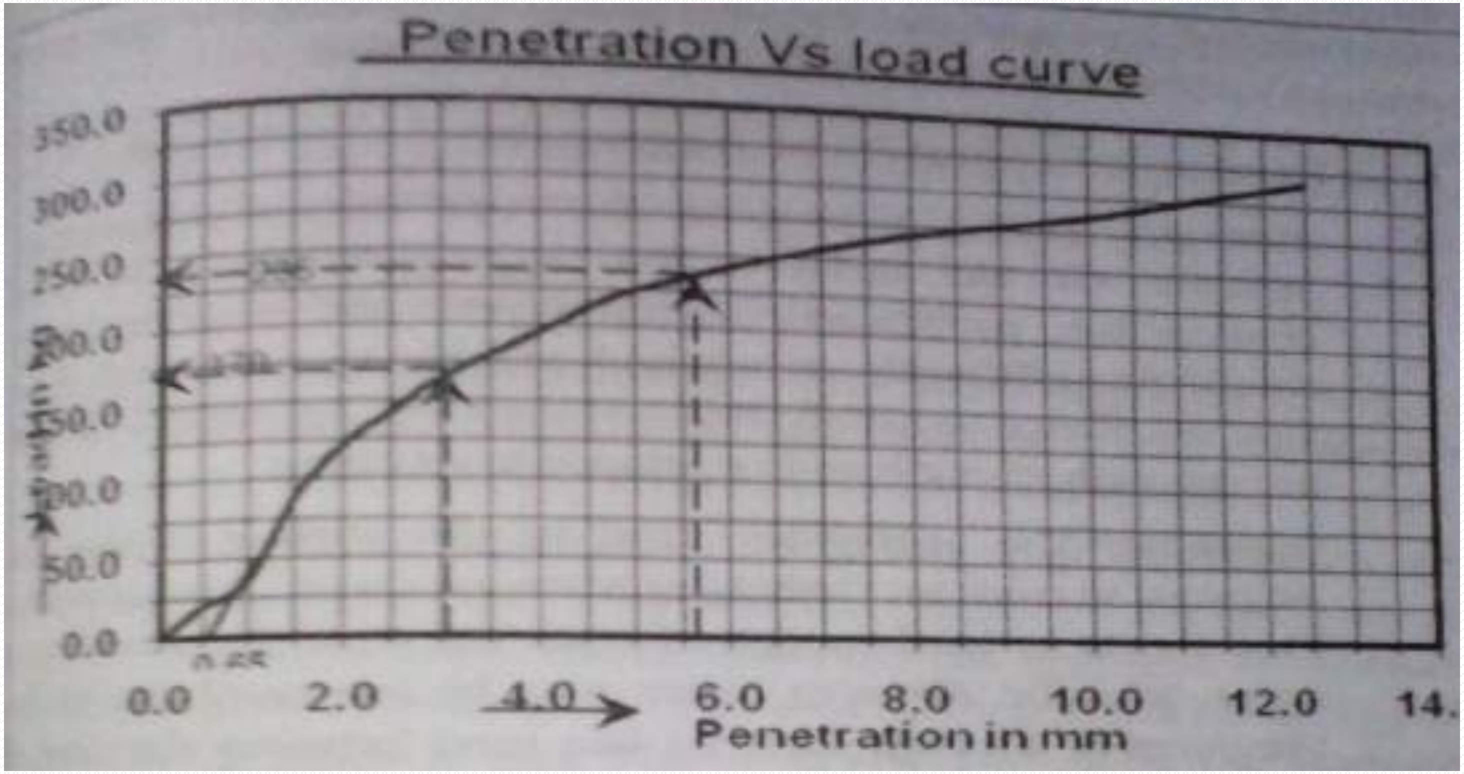
- **2) Remolded(Disturbed) sample**
- **A. Statically Compacted**
- Calculate the amount of soil required for static compaction
- Calculate the amount of water and mix thoroughly with water
- Fit the extension collar with the vessel
- Place a spacer disc and apply compaction load
- Fill the mould with soil gently pressing it with hands
- Place a coarse filter paper on the leveled soil

- **A. Dynamically Compacted**
- Sieve the material through 20mm IS Sieve
- Take 4.5 kg of sample for fine and 5.5 for coarse grained soil
- Add required amount of water and mix throughly
- Clamp the extension collar with the mould
- Place the spacer and filter paper
- Pour soil into the mould such that $1/5^{th}$ of it is fillled at a time
- Compact each layer with 56 blows of 2.6 kg hammer falling from 310mm for light and 4.89kg hammer falling from 450mm for light compaction and heavy compaction respectively
- Repeat the process till sample is finished
- Remove collar and trim the excess sample off
- Remove spacer and push the soil to bottom

- **Testing**
- Place the mould on the machine
- Place the annular weight of 2.5kg on the top surface of the soil
- Place the plunger on the soil surface and apply a seating load of 4kg so that a full contact between the plunger and the soil is established
- Place the reminder of the weight so that total weight is 5.0 kg
- Apply load at the rate of 1.25mm/min and take reading for penetration of 0 0, 0.5, 1,1.5,2,2.5,3,4,5,7.5,10,12.5
- Collect 20 to 50 gm to determine the water content

- **IRC** Recommendation For **Soaked** specimen
- For soaked test a filter paper and then surcharge is applied over the weight
- Then the sample is soaked for 4 days
- After 4 days the sample is allowed to drain off water and finally test is performed

- **Computation of test results**
- Plot the load vs. Deformation curve
- The initial portion is concave upwards due t surface irregularities under this case draw a tangent at the point having the greatest slope the point where it meets the abscissa is the new zero
- Take the load value corresponding to 2.5mm and 5mm penetration



- CBR= $\dfrac{\text{load sustained by sample for 2.5mm and 5mm penetartion}}{\text{load sustained by compacted stone for 2.5mm and 5mm penetartion}}$
- Greater of the two is taken
- Standard load for 2.5mm=1370kg and for 5mm=2055kg
- Generally 2.5 mm value is dominant if 5mm comes to be grater than another test is conducted and if the same result persists the 5mm penetration value is taken

5.3. Stone aggregates

- **Definition**
- It is a hard mineral substance obtained by quarrying breaking and(or) dressing of natural stones.
- Stones are responsible for bearing stress coming to the roads and also for resisting wear due to abrasive action of the vehicle

- **Classification**

A. Based on nature of Rocks

- ***Igneous*** Formed by cooling of magma
- ***Sedimentary*** Formed By the erosion transportation sedimentation and ***petrifaction*** *of other rocks* *Not preffered*
- ***Metamorphic*** formed by the alternation of the crystalline structure of the parent rock by the action of heat magma etc *Not preffered*

B. Based on Grain size

- ***Coarse*** Particle having size more than 4.75mm i.e. retained on a 4.5mm sieve
- ***Fine*** Particle having size less than 4.75mm i.e. passing on a 4.5mm sieve

- **B. Based on surface texture**
- Granular ,smooth , serrated etc

- **B. Based on shape**
- Angular flaky rounded etc

- Desirable properties of road aggregates
- **1. Strength** traffic moving on the surface of the road causes compressive stress on the pavement the aggregate used shall be sufficiently strong and capable to withstand these stresses
- **2. Toughness** The irregularities in the road surface causes the vehicles to jump as a result of which the pavement is subjected to a impact this impact of the vehicles tend to break the stones therefore the aggregate shall be strong enough to withstand huge amount of impact loads without breaking
- **3. Hardness** the aggregate used in the road are subjected to constant rubbing due to moving traffic therefore shall be strong enough to resist the abrasive action of the moving traffic

- **4. Durability** : External weather conditions tend to disintegrate the aggregates, therefore it is necessary for the aggregate to withstand the adverse effect of weather like rain water frost etc which is called the durability of the aggregate
- **5. Shape of Aggregate** : Shape of the aggregate influence the workability and the strength if the road surface

  The shapes of aggregate may be rounded flaky elongated etc

  Generally Angular particles provide a better bond as a result are prefer in WBM and bitumen concrete roads

  Rounded particle provides a good workability hence comparatively rounded aggregates are prefered in the cement concrete roads
- **6. Adhesion with Bitumen** : Aggregate may be hydrophobic i.e. in which the bitumen is not stripped off when in contact with water of Hydrophilic in which bitumen is stripped in the long time prescience of water

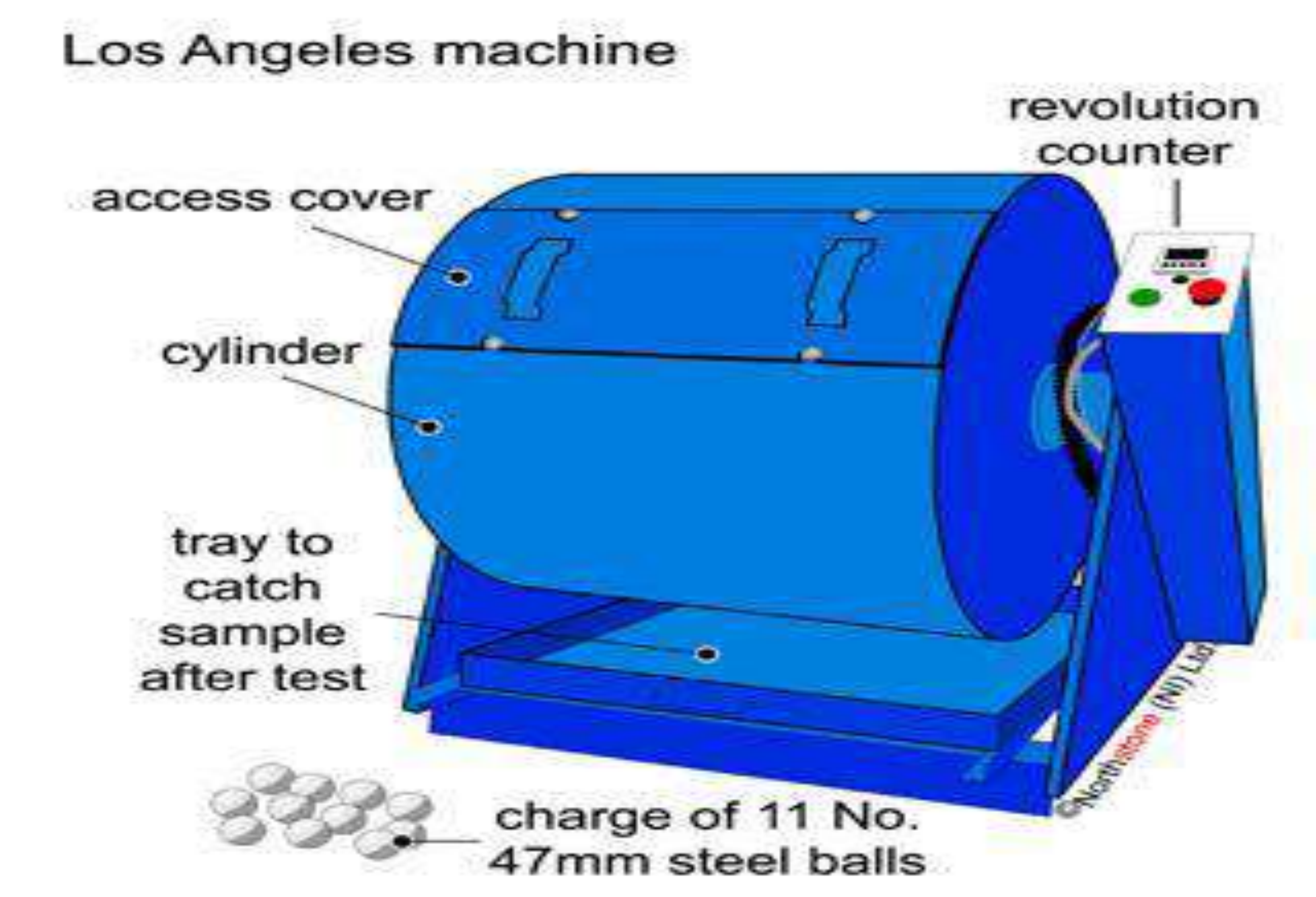
  Since the bitumen should bond with the aggregate and strip away the aggregate shall be selected properly also the bonding can be increased by taking high porosity aggregate

Tests on road aggregate

Los Angeles Abrasion (LAA) test :

- Aggregated are exposed the abrasive action of traffic therefore it is necessary that they resists wear and tear due to the traffic
- The resistance to wear and tear is called hardness
- The hardness of the aggregate can be tested by using los angles abrasion test
- This test is based on abrasive action rapidly by rotating mixture of standard steel balls and aggregate

- Apparatus
- It consists of closed cylinder of inside dia 700mm and length 500mm mounted about its axis so that it can rotate about the horizontal axis
- The charge consists of a iron ball of dia 48mm and weight 250 to 450gm


Los Angeles machine
revolution counter
access cover
cylinder
tray to catch sample after test
charge of 11 No. 47mm steel balls
©Northstone (NI) Ltd

- Procedure
- Take specified amount of the aggregate and fed it into the machine containing the balls
- Rotate the machine at 30 to 33rpm for 500 to 1000 rotations
- Sieve the material trough a IS 1.75 mm sieve and weigh the residue
- LAA Value= $\dfrac{\text{Weight of residue}}{\text{Weight of sample taken}}$

Aggregate Impact test

- Aggregate are exposed to impact loads due to jerking of vehicle which tend to break them
- Aggregate therefore should be sufficiently strong against the impact loads this is called toughness
- The toughness of the aggregate s tested using the Aggregate Impact test

- Apparatus
- The apparatus contains a testing machine having a 45 to 60 kg weight and base minimum 0f 30 cm is dia
- A Cylindrical steel cup of internal dia 102m depth 50mm and thickness 6.3mm
- A hammer 13.6 to 14.1 kg in weight the lower portion of which is in the shape of 50mm long and 100mm dia cylinder falling freely from a height of 380mm
- A cylindrical metal measure of internal dia 75mm and depth 50mm
- Tamping rod

- Procedure
- Heat the aggregate at 100 to 110c for 4 hour
- Take materials passing through 12.5mm seive and retained on 10mm seive
- Fill the measuring vessel by three layer tamping each by 25 blows
- Transfer the contents into the cup and apply 25 blows
- Raise the hammer 38cm and provide 15 blows
- Seive throught 2.36mm seive and weight the residual
- Aggregate Impact value = $\dfrac{Weight\ of\ residue}{Weight\ of\ sample\ taken}$

Specific Gravity and Water absorption test

Specific Gravity :

- it is the ratio of the density of aggregate to the density of water at 4°C
- Specific Gravity of an aggregate is the measure of it's strength
- Aggregates having a low specific gravity are generally weaker than those having a higher value

Procedure :

- Take 2kg of aggregate in a basket and immersed in water for 24 hours
- The sample is weighed in air and water and the dry and buoyant weight is found
- The sample is weighted after allowing sufficient drainage and wet weight is found
- Sample is now taken out and dries in an oven at 100 to 110c for

Let

M_d =Dry mass Of aggregate

M_b = Bouyant weight of sample

M_w = Weight after allowing sufficient drainage

V_n =Net volume of aggregate excluding the voids

$= (M_{d\,-}\,M_w)/\rho_w$

ρ_W =Density of water

V_R =Total Volume Including The volume of absorbed Water

The specific gravity is calculated as follows

Apparent Specific Gravity

- It is Computed on the basis of net volume of the aggregate that is the volume excluding the volume of the volume of voids

- $G_d = \dfrac{\frac{Md}{Vn}}{\rho W}$

Bulk Specific Gravity

- It is computed on the basis of the total volume including the water permeable voids

    - $$G=\frac{\frac{Md}{VR}}{\rho W}$$

Percentage Water Absorption

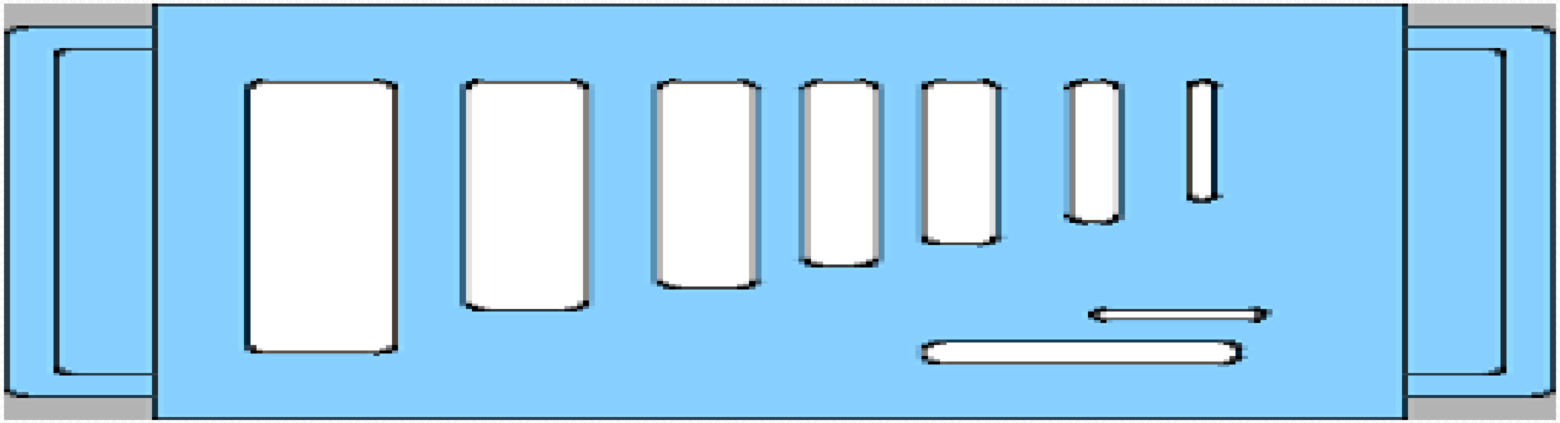
- The ratio of difference in mass of aggregate in saturated and dry condition to the mass of aggregate in dry condition is defined as the water absorption
- Percentage water absorption= $\frac{Ms-Md}{Md}$

Shape Test

- The shape of a particle is evaluated by percentage of flaky elongated and angular particles, these are evaluated as follows

Flakiness Index :

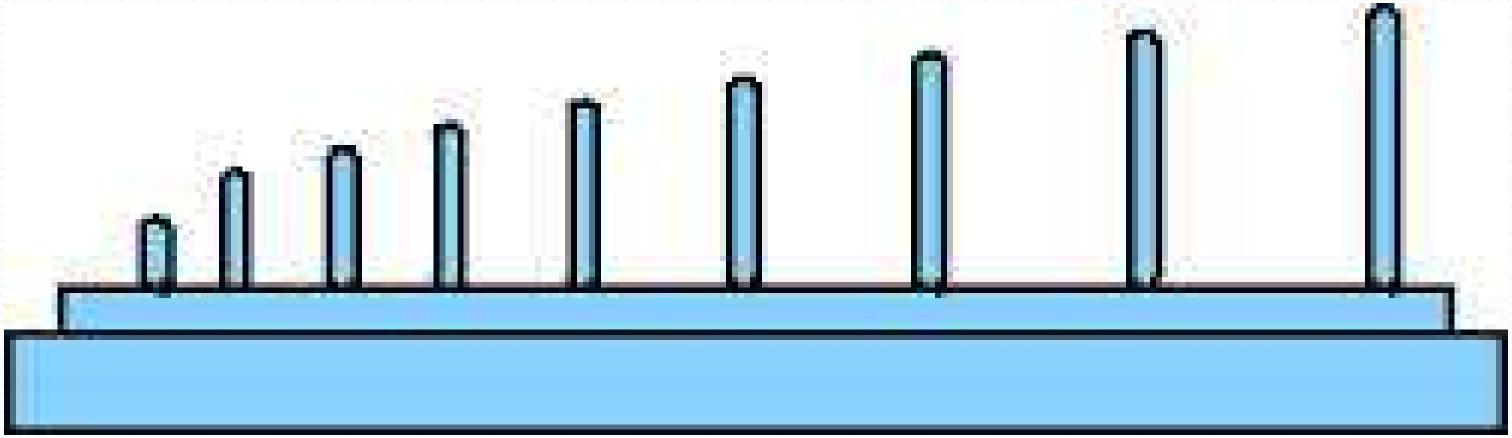
- It is the percentage by weight of the aggregate whose least dimension is less than 0.6 times the mean particle size
- This test is applicable to particles having size larger than 6.3mm
- The particles are separated into sizes by sieving through sieves
- Then they are passed through the appropriate slots of standard sizes(0.6 times standard)
- The weight of total passing material is evaluated
- Flakiness Index= $\frac{W1}{W2}$ X 100%



Elongation Index

- Those particled having mean size more than 1.8 times the mean Dia are called elongated particles
- Elongation Index is It is the percentage by weight of the mean sze of aggregate
- This test is applicable to particles having size larger than 6.3mm
- The particles are seperated into sizes by seiving through seives
- Then they are passed through the appropriate slots of standard sizes(1.8times standard)
- The weight of total passing material is evaluated

- Flakiness Index= $\frac{W1}{W2}$ X 100%



Angularity number

- The angular voids have more voids than rounded ones
- The least voids are in the rounded particles
- The rounded particles leaves a void of 33% and solids 67%
- Angularity number is the voids in excess of that of perfectly rounded particles i.e. 33%
- The apparatus consists of Metal Cylinder of 3 liter capacity and tamping rod
- Aggregate is filled in the cylinder in 3 layers providing 100 blows from tamping rod
- The cylinder is weighed and then emptied
- The cylinder is now filled with water and weighed again

    - Angularity Number = 67- $\frac{W_a/\rho_a}{W_w/\rho_w}$ X100%

5.4. Binding materials (bituminous material)

- They are materials which provide a binding action to the road surface
- It might be **bitumen** or **tar**
- **Bitumen** is Petroleum product obtained by the distillation of petrol crude
- **Tar** is obtained by the destructive distillation of wood and charcoal

Bitumen

- It is viscous liquid material in liquid or solid Stage having adhesive properties consisting essentially of hydrocarbons
- Derived naturally or by the the fractional distillation of the crude oil
- Bitumen is classified as follows

A. Natural Bitumen : They are found naturally in asphalt form

A.1 Native lake asphalt

- Found in dispersions of earth accumulated by the action of springs
- They are almost pure or nearly pure in nature

A.2 Natural Rock Asphalt

- They are associated with large proportions of mineral matter
- They are found embedded in deposits of sandstone and

B. Artificial Bitumen

- It is obtained by the fractional distillation at petroleum refinery plant
- It is also called straight run bitumen,refinery bitumen etc.

Artificial Bitumens are classified as follows

- **A) Cutback Bitumen**
- They are bitumen whose viscosity is reduce by the addition of volatile substances like gasoline kerosene etc to decrease the boiling point
- It is used when there is need of fluid binder which can sprayed at low temperature
- It is used for surface dressing , soil stabilization ,Bitumen Macadam
  - Substitute of heating
  - Suitable for direct application
  - Good mixing
  - Provides grater haul i.e. Transporting time

- **Types Of cutback**

Slow curing :- It is obtained by blending bitumen with high binding (low volatile) liquids

- They are used in fine cold asphalt palliative materials

Medium curing :- It is obtained by blending bitumen with medium volatile liquids such as kerosene

- They are used in Dense grade roads surfacing and in soil stabilization

Rapid curing :- It is obtained by blending bitumen with highly volatile such as naphtha

- They are used in Dense grade roads when semisolid binding medium is required

- **B) Bitumen emulsions**

- Emulsion is relatively stable dispersion of one liquid, minutely sub-divided into another liquid which are not soluble into each other
- In Bituminous emulsion bitumen is the disperse phase and water is the continuous phase
- Stability of emulsion is obtained by mixing an emulsifying agent contained in aqueous phase
- Bitumen particles can be charges positively or negatively according to the type of emulsifier
- Emulsion having negatively charged bitumen are called anionic emulsion and those having positively charged bitumen are called cationic emulsion
- Emulsifier for anionic emulsion=Fully acidic derived from wood by reacting with sodium or potassium hydroxide
- Emulsifier for cationic emulsion=amine salts made by reacting amine with hydrochloric or acetic acid

- Bituminous emulsion are of following type

Slow Setting :

- It does not break down easily in contact with stone aggregate
- It is suitable for fine aggregates coating and for soil stabilization

Rapid setting:

- Break rapidly in contact with aggregates and used in surface dressing and penetration macadam

Medium Setting :

- It breaks with medium speed. It is used in premixing with coarse aggregates for retreating with old road surface

Tar

- Tar is a viscous material made by destructive distillation of materials like wood coal etc in the absence of air
- Based on the material from which the tar is obtained it is classified as Wood tar and Coal tar

The Production of tar can be classified as follows

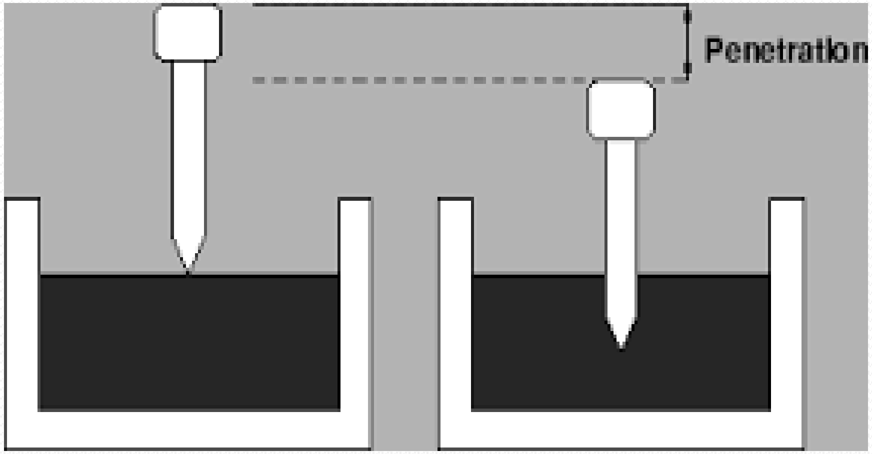
- i) Carbonization of coal to produce crude tar
- ii) Refining or distillation of crude tar
- iii) Blending of distillation residue with distillate oil fraction to give the desired road tar

- Tar is divided into five groups as follows
- RT – 1 has low viscosity and used for surface painting at cold regions
- RT – 2 for standard surface painting
- RT – 3 for surface painting and premixing chips for top courses
- RT – 4 premixing macadam in base courses
- RT – 5 Used for grouting as it has highest viscocity among road tars

5.5. Tests on bitumen:

- **Penetration test:**
- It is a measure of the hardness or consistency of the bitumen
- It us the vertical distance traversed or penetrated by a standard needle for 5 seconds under standard temperature conditions
- The value is obtained is called the penetration value and is used for the selection of the bitumen for the road work

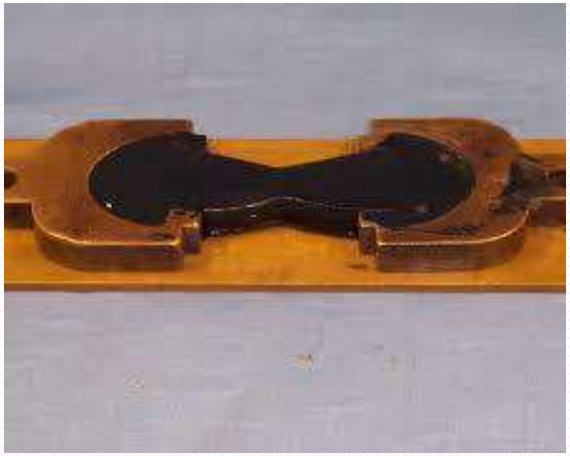
- **Apparatus**
- Needle assembly of total weight 100gm and device for releasing and locking he needle
- A graduated dial gauge for reading the penetration upto the value of 0.1mm
- Thermometer of range 0 c to 44c of accuracy 0f 0.2C


Penetration

- **Procedure:**
- Heat the bitumen to softening point and pour it into the cylindrical can unto a depth 15mm grater than the expected penetration value.
- Place sample container at a temperature of 25c for an hour
- After 1 hour take the sample out and bring the needle in contact with the bitumen surface
- Set reading of dial gauge to zero
- Press the release button for 5 seconds and read the final dial gauge reading this gives the penetration value
- Generally penetration is given in ranges for eg a 80/100 bitumen will indicate that the penetration is between 80mm to 100mm
- The Grading is used to access suitably for climatic conditions
- For bituminous and penetration macadam IRC Suggests 60/70 and 80/100 mm for warmer and 180/200 for colder regions

- **Ductility Test**
- The pavement forms a thin film around the aggregate , which as a result of which ductility is impaired to the pavement
- In flexible pavement it is necessary that the pavements is flexible enough in another word the bitumen shall be elastic
- The flexibility is measured by observing the Elasticity property of bitumen which is measured by the ductility test
- The ductility of a specimen is measured in terms of the length upto which bitumen sample made into a bracket can be stretched at a standard speed

- **Apparatus**
- Briquette of standard dimension
- Pulling device with distance meter
- Water bath arragement



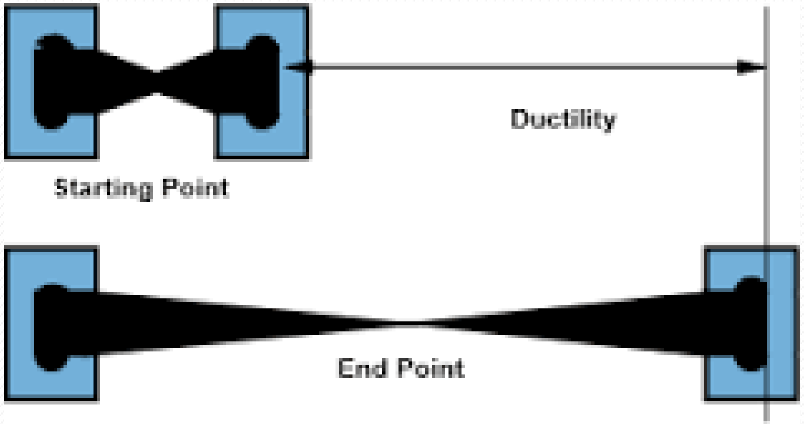


Figure 23:2: Ductility Test

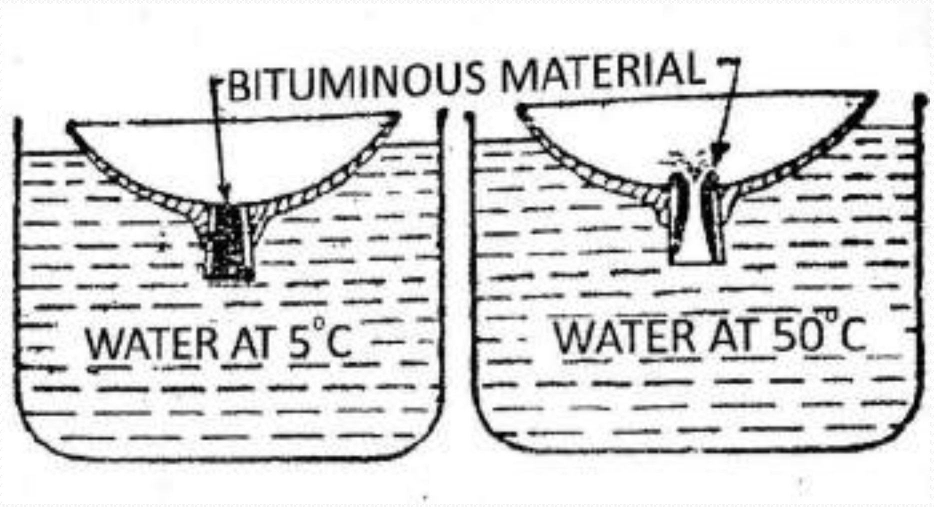
- **Procedure**
- Heat the bitumen to liquid stage and pour in a briquette assembly
- Allow the briquette to cool in air
- Cut the excess bitumen with a knife
- Keep the assembly in water bath at 27c for 85 to 95 min
- Remove the cover to the mould and set initial reading to zero
- Apply strain at the rate of 50 mm/min
- The Distance at which the thread breaks is called the ductility
- The ductility may range from 5 to 100 but for satisfactory performance it should not be less than 50(Preferable 80 for cold regions)

- **Viscosity Test**
- Viscosity is the property by virtue of which the offers resistance to flow, higher the viscosity slower will the movement be
- Binder(Bitumen) shall spread uniformly all over the aggregate Viscosity effect this tendency
- A highly viscous binder may not fill up the voids completely while a low viscosity binder may not hold the aggregate therefore viscosity of the bitumen shall lie within suitable range for it to be used as road binder
- Viscosity is measured by the time taken by 50cc of the bitumen to flow through a standard orifice at specified temperature

- **Apparatus**
- Viscosity apparatus having orifice of size 10mm
- Sample Collector
- Thermometer

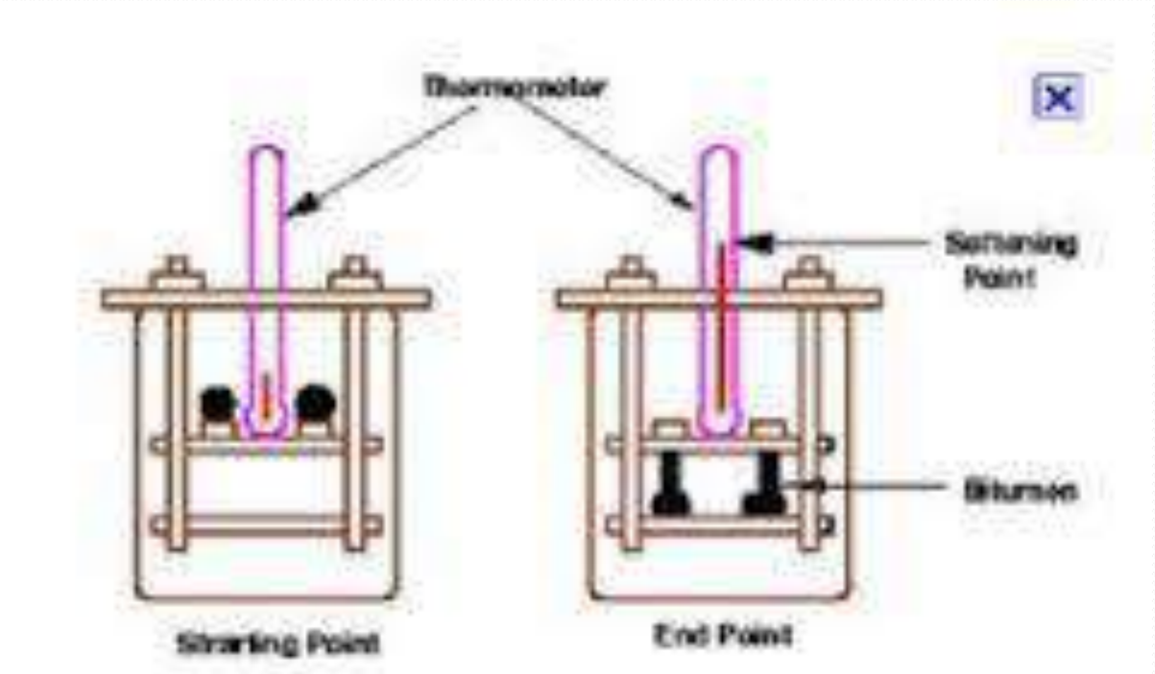
- **Procedure**
- Pour the sample into the Apparatus
- Note the tie taken for 50cc of the material to flow through it
- The time gives an indirect measure of the viscocity greater the tie higher is the viscosity
- The Low viscosity bitumen can be used in cold weather
- High viscosity shall be used in hot places and if used in cold places shall be heated

- **Float test**
- For consistencies in which penetration test cannot be performed float test is applied
- The apparatus contains a float with a central hole
- The hole is filled with bitumen ,the float is kept in water and temperature is slowly increased
- Time required for float to sink is measured this goves the measure of hardness of bitumen



- **Softening point test**
- The bitumen used for road application shall be heated well before its application tll it gets soft the softening point s determined to know the temperature upto which the bitumen shall be heated so that it attains sufficiently fluidity
- Softening point Test Of aggregate
- It is the temperature at which the bitumen turns from hard to soft state
- It is the temperature at which standard ball penetrate the bitumen sample and falls through a height of 2.5cm when heated in glycerin under standard rate

- **Apparatus**
- Brass ring , steel ball , holding arrangement



- **Procedure**
- Put heated bitumen in the brass ring
- Place it into the holder
- Place the ball into the ring and heat @ 5c/min
- Note the temperature at which the ball just touches the lower ball i.e. falls through 2.5cm heght

- **Flash and Fire Point Test**
- Flash pipe is the lowest temperature at which the application of test flame causes the vapors from the materials to catch fire momentarily
- Fire point is the lowest temperature at which the application of test flame causes the material to ignite and burn continuously
- At high temperature there is a chance of fire hazard therefore flash and fire point test are used to determine the temperature at which the material can be safely used

- Procedure

(i) Fill the material in cup , place the lid, close

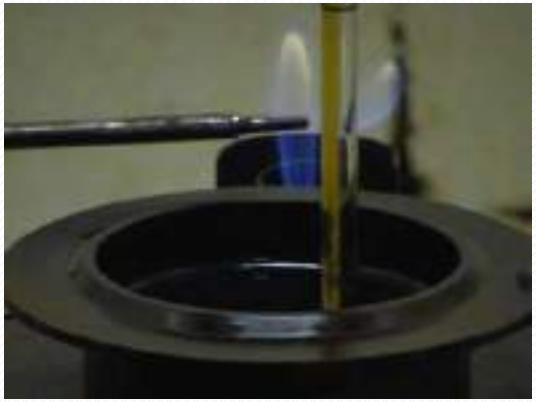
(ii) Fit the thermometer

(iii) heat bitumen and increase temperature @ 5 deg per minute

(iv) At the anticipated flash point bring the flame near and heat @ 1Deg per minute

(v) At a moment application of flame causes a bright flash inside this is the flash point

(vi) Similarly the moment at which application of flame causes the sample to burn is called fire point



- **Solubility Test**
- Pure bitumen is completely soluble in solvents like carbon disulphate , carbon tetrachloride etc. Any impurities present thus can be detected by dissolving bitumen into any of the two solvents
- Procedure
- The sample is disolved in carbon disulphate

5.6 Bituminous Mixes

- They are readymade mixture composed of binder materials combined with Coarsed and fine aggreage with or without filler materials
- They are of two type

1. Closed Graded Mixes:

- Composed of hot mix, hot laid mixture of aggregates and high viscosity binder
- Used in high category roads in the construction of top layer

2. Open Graded Mix:

- Laid in hot or cold mix form
- Used in medium category roads

Ingredients of Bituminous Mixes

1. **Coarse aggregates**: Materials retained on 2.36 mm Sieve

- **Function**:
  - Imparts stability to the mix by mechanical interlock between the particles and friction between the particles
  - Resist the abrasive action of traffic and withstand wear.

2 Fine aggregates: Materials passing through 2.36mm and retained on 75 micron sieve

- **Function:**
  - Add stability by increasing interlock
  - Helps to secure density by filling of voids
  - facilitate greater load transfer

- 3. **Filler:** Materials passing through 600 micron sieve.
- **Functions:**
  - Acts as final void filling medium and completes the process of making the mixture as impermeable and dense as possible
  - Lowers the temperature susceptibility of binder
  - Helps retaining its stability and hardness
- **4. Binder : They are materials which bind together the different materials of the mix**
- **Functions :**
  - Lubricate all aggregate and facilitate compaction
  - Impart cohesion to the mixture and incresase its safety
  - Serves to waterproof layer
  - Provide flexibility

Method of Bituminous Mix Design

- Bituminous mix design should aim an economical blend with proper gradation of aggregates and adequate proportion of bitumen
- The desirable property of good bituminous mix are stability, durability, flexibility, skid resistance and workability
- Mix design should have following properties:
  - Sufficient stability satisfying the service requirements of pavement and traffic conditions
  - Sufficient bitumen to ensure a durable pavement by bonding aggregates together and water proofing
  - Sufficient voids in compacted mix to provide a reservoir space for slight amount of additional compaction avoiding flushing, bleeding and loss of stability
  - Sufficient flexibility even in coldest season and prevent cracking
  - Sufficient workability while placing and compacting of the mix
  - Economical that would produce stable, durable and skid resistance pavement

- Design of bituminous mix primarily consists of following steps:
  - **Selection of aggregates**
  - **Selection of binders**
  - **Determination of optimum binder content**

- **1. Selection of Aggregate**
  - Density and stability of mix highly depends on the aggregate and size distribution. Bigger size give higher stability.
  - Aggregates with sufficient strength, hardness and soundness shall therefore be selected
  - Crushed aggregates and sharp sands produce high stability compared to gravel and rounded sands therefore are preferred

- The table illustrates the specification of material proposed for bituminous mix.

	Maximum %
Impact and LAA Value	24% and 30%
Combined Flakiness and Elongation Index	30%
Stripping Value	5%
Soundness (MgSo4/Na2So4 5 cycles)	18 % and 12 %
Water Absorption	2%

- The gradation required depends upon the type of mix 37.5mm down aggregate are used for dense graded mixes while 45mm down are used for open graded mixes

2. Selection of Binders:

- Depends upon the nature of traffic and climatic condition, penetration grade is considered

USE	Climate			
	Hot	Hot Humid	Moderate	Cold
A. Highway		60/70	80/100	80/100
1. Heavy and very heavy traffic	30/40 or 60/70			
2. Medium and light Traffic	80/100	80/100	80/100	120/150
B. Street				
1. Heavy and very heavy traffic	30/40 or 60/70	60/70	80/100	80/110
2. Medium and light Traffic	80/100	80/100	80/100	80/100

3. Determination of Optimum Binder Content (OBC)

- Done to ensure maximum stability defined as resistance of paving mix to deformation under load
- It can be done by
  - Surface area concept and
  - Void concept method

1. Surface area Concept:

- Stability of bituminous mixes is obtained by interlocking of mineral particles
- Binder must be enough to form thin film around all mineral particles
- It provides required cohesion to make particles together

- It should not take more space in voids available
- Excess of bitumen cause flow of the mix and various surface distortions

- Usually used for determining binder content of open graded mixes
- Also used in preliminary estimates of binder in the mixes intended for design by void concept method

- Nebraskan formula
  - P=AG(0.002a)+0.06b+0.1c+Sd
    - P- % by wt of bitumen residue in mix prior to laying
    - A- absorption modifying factor based on the percentage of materials passing ASTM 50 (300 Micron) sieve
    - G- Specific Gravity correction = 2.62/apparent specific gravity
    - a- % by wt. of aggregate passing through ASTM 50
    - b- % by wt. of aggregate passing through ASTM 50 and retained on ASTM 100
    - d- % by wt. of aggregate passing through ASTM 200
    - S- experimental factor depending upon the fineness and absorptive characteristics of material passing ASTM 200

2. Void Concept Method:

- Void in mineral mass must be minimized to improve the stability by the selection of appropriate well graded materials
- All mineral particles would be coated with thin film of binders and minimum voids are filled
- Amount of binder content is controlled by voids space and this method can be applied for design of dense bituminous mix and not to open graded ones

- **MIX DESIGN METHOD (MARSHALL METHOD)**
- This method helps in designing a mix and determination of strength and flexibility
- Strength is measured in terms of **Marshall Stability** of mix which is the maximum load carrying capacity of a compacted specimen at standard test temperature of 60^{o}C which represents the weakest condition for a bituminous pavement
- Flexibility is measured in terms of **Flow Value** which is measured by change in diameter of the sample in direction of load application between start and maximum loading time.

- **Objectives:**
  - Determination of density
  - Determination of strength and flexibility
  - Determination of suitability of bituminous mix

Apparatus:

- Cylindrical mould of 101.6mm dia and 63.5mm height with a base plate and collar
- Hammer of 4.54 Kg
- Sample extractor to extrude the compacted specimen from mould
- Dial gauge to measure deformation
- Proving ring to measure load

Sample Preparation:

- Measure 1.2 Kg of aggregates and heat upto $154^o – 160^o$
- Add bitumen at mixing temperature producing viscosity of 170 ± 20 centistokes at various % for both above and below the expected optimum content
- Mix the material in heated pan
- Return the mixture to oven and reheat it to compacting temperature producing viscosity of 280±30 centistokes
- Place the mixture in heated marshall mould with a collar and base. Spade the mixture around the sides, place filter paper under and on top of the sample
- Place the mould in marshall compaction pedestal and compact the material with 50 blows of hammer, invert and repeat the process
- After compaction invert the mould, with collar on bottom remove the base and extract the sample and allow to stand for few hours to cool

- Obtain the sample's mass in air and submerged to measure density of specimen
- At least three specimens for each combination of aggregates should be prepared
- For surface courses with 12mm aggregate, expected OBC may be made at 5.5%, 6%, 6.5%, 7% and 7.5% bitumen content

Testing

- Specimens are heated upto 60 ± 10 (57.80 ± 1 for specimens with tar) either in water bath for 30-40 mins or in oven for minimum 2 hrs
- Remove the specimen and place in lower segment of the breaking head. Then place the upper segment of breaking head on the specimen and place the complete assembly in position on the testing machine
- Place flow meter over one of the post and adjust it to read zero
- Apply load at 50mm/min until maximum load reading is obtained
- Record the maximum load reading in N at the same instant obtain the flow as recorded on flow meter in mm

- Calculation

Determination of Bulk Unit Weight of each Specimen

Bulk unit weight of each specimen is estimated from the following expressions:

a) for well compacted and smooth surface

$d = W_A / V = W_A / (W_A - W_W)$

Where, d = bulk unit weight (gm/cm ^{3}); W_A = weight of specimen in air (gm);
V = volume of specimen (cm ^{3}); and W_W = weight of specimen in water (gm);

b) for open and porous surface, paraffin coating is required.

$d = W_A / V = W_A / \{ W_{PA} - W_{PW} - (W_{PA} - W_A) / G_P \}$

Where, W_{PA} = weight of specimen plus paraffin coating in air (gm)
W_{PW} = weight of specimen plus paraffin coating in water (gm)
G_P = specific gravity of paraffin.

Calculations of the Percentage of Air Voids (VTM)

This is accomplished in three steps as follows. First maximum theoretical unit weight is determined then voids in total mixture (VTM) and voids in mineral aggregate framework (VMA) are determined using the following expressions

a) Calculate the maximum theoretical unit weight

$$y_t = W_A / (V_b + V_c + Vf + V_{mf}) = W_A / \left\{ \frac{W_b}{G_b} + \frac{W_c}{G_c} + \frac{W_f}{G_f} + \frac{W_{mf}}{G_{mf}} \right\}$$

Where,

y_t = maximum theoretical unit weight, gm/ cm^3

W_A = weight of the specimen, gm.

V_b; V_c; V_f; Vmf = volume of binder, coarse aggregates, fine aggregates and mineral filler respectively, cm^3.

W_b; W_c; W_f; W_{mf} = weight of binder, coarse aggregates, fine aggregates and mineral filler respectively, gm.

Gb; Gc; Gf; Gmf = specific gravity of binder, coarse aggregates, fine aggregates and mineral filler respectively.

b) Calculate percentage of air voids (VTM) in the compacted specimen

$$\% V.T.M. = \{ (\gamma_t - d)/\gamma_t)\} \times 100$$

Where,

% V.T.M. = voids in the total mix i. e. in the specimen.

γ_t = maximum theoretical unit weight, gm/ cm ^{3}.

d = bulk unit weight, gm/cm ^{3}

c) Calculate voids in mineral aggregates framework

Voids in aggregates framework (V.M.A.) is calculated simply by

$$V.M.A. = V - V_c - V_f - V_{mf} = (W/d - W_c/G_c - W_f/G_f - W_{mf}/G_{mf})$$

Accordingly, $\% V.M.A. = (V.M.A./V) \times 100$

Where,

$\% V.M.A.$ = voids in the mineral aggregate framework, % of total mix.

$V.M.A.$ = voids in the mineral aggregate framework, cm ^{3}.

The percentage of voids in the aggregate framework, which is filled with binder is determined either from

$$\% V.F.B. = (V_b / VMA) \times 100$$

or

$$\% V.F.B. = \{(\% VMA - \% VTM) / \% VMA$$

Where, V.F.B = Voids filled with binder

Determination of Marshall Stability and Flow

The Marshall stability is defined as the maximum load in Newton required producing failure. Marshall flow is defined as the vertical deformation corresponding to failure load. Both stability and flow are determined under when the specimen is placed in the special testing machine as shown in **figure 3.1**.

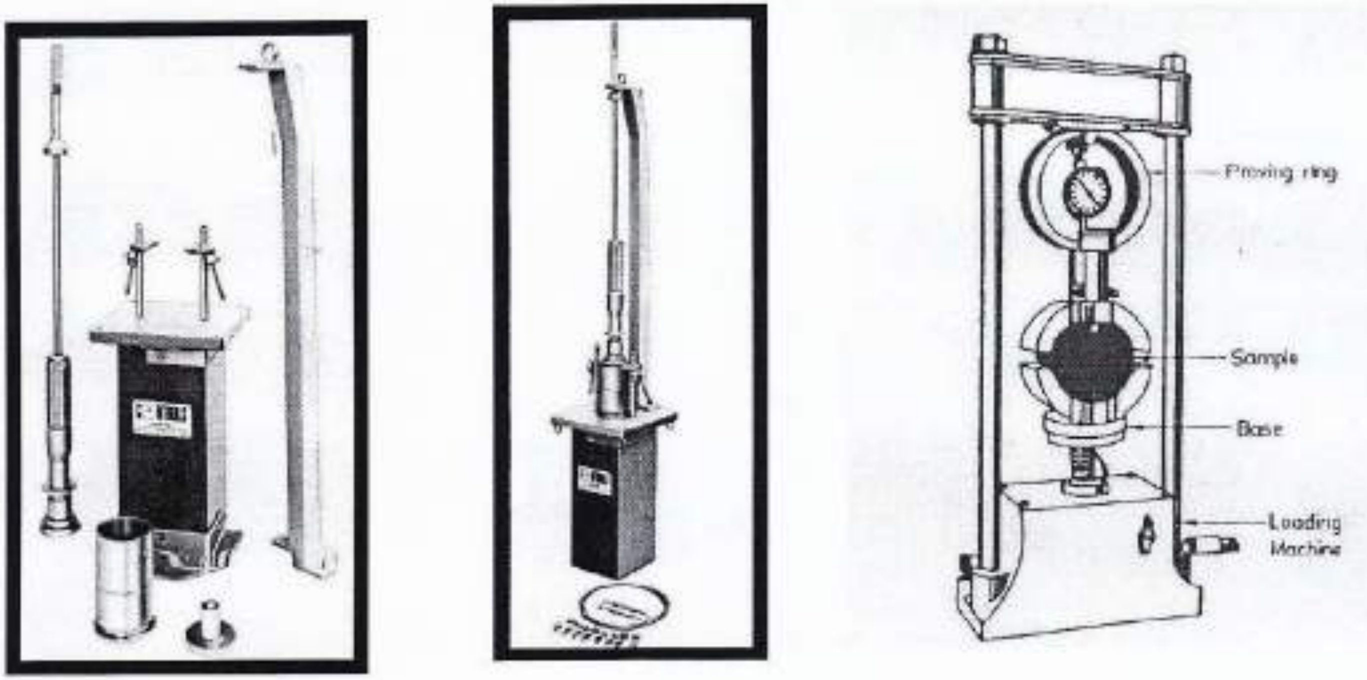


Figure 3.1 Mould with collar and base plate; extraction plate; compaction table; hammer and Marshall Stability testing machine

Corrections in Measured Stability

This is needed when specimen height is not standard (63.5 mm). This is done by using correlation factors chart as given in **table 3.1.**

Table 3.1 Marshall Stability correlation values

Volume of specimen, cm^3	*Approximate thickness of specimen, cm*	*Correlation ratio*	*Volume of specimen, cm^3*	*Approximate thickness of specimen, cm*	*Correlation ratio*
200 – 213	25.4	5.56	421 – 431	52.4	1.39
214 – 225	27.0	5.00	432 – 443	54.0	1.32
226 – 237	28.6	4.55	444 – 456	55.6	1.25
238 – 250	30.2	4.17	457 – 470	57.2	1.19
251 – 264	31.8	3.85	471 – 482	58.8	1.14
265 – 276	33.3	3.57	483 – 495	60.3	1.09
277 – 289	34.9	3.33	496 – 508	61.9	1.04
290 – 301	36.5	3.03	509 – 522	63.5	1.00
302 – 316	38.1	2.78	523 – 535	65.1	0.96
317 – 328	39.7	2.50	536 – 546	66.7	0.93
329 – 340	41.3	2.27	547 – 559	68.3	0.89
341 – 353	42.9	2.08	560 – 573	69.9	0.86
354 – 367	44.5	1.92	574 – 585	71.5	0.83
368 – 379	46.0	1.79	586 – 596	73.0	0.81
380 – 392	47.6	1.67	597 – 610	74.6	0.78
393 – 405	49.2	1.56	611 – 625	76.2	0.76
406 – 420	50.8	1.47			

Preparation of separate graphical plots

The following graphical plots are prepared in order to establish the relationships between binder content and different parameters. These include:

- Binder content versus corrected Marshall Stability.
- Binder content versus Marshall Flow.
- Binder content versus percentage of voids in the total mix
- Binder content versus percentage of voids in the mineral aggregate framework filled with binder
- Binder content versus unit weight

Determination of optimum binder content (OBC)

Optimum binder content is determined corresponding to maximum stability, maximum unit weight, and to appropriate percentage of voids in total mix and aggregates voids filled with binder from **figure 3.2.** Binder content for each of these cases may be different. The design binder content is taken as the average of these four values.

Comparison of sample parameters with the given specification

It is very usual that the sample with selected OBC may not meet the requirements such as stability, flow, % VTM and %VFB. The parameters are compared with the specification of the bituminous mix required for the work. If the sample meets all the requirements the mix design is over and if not the mix is redesigned with using new aggregates.

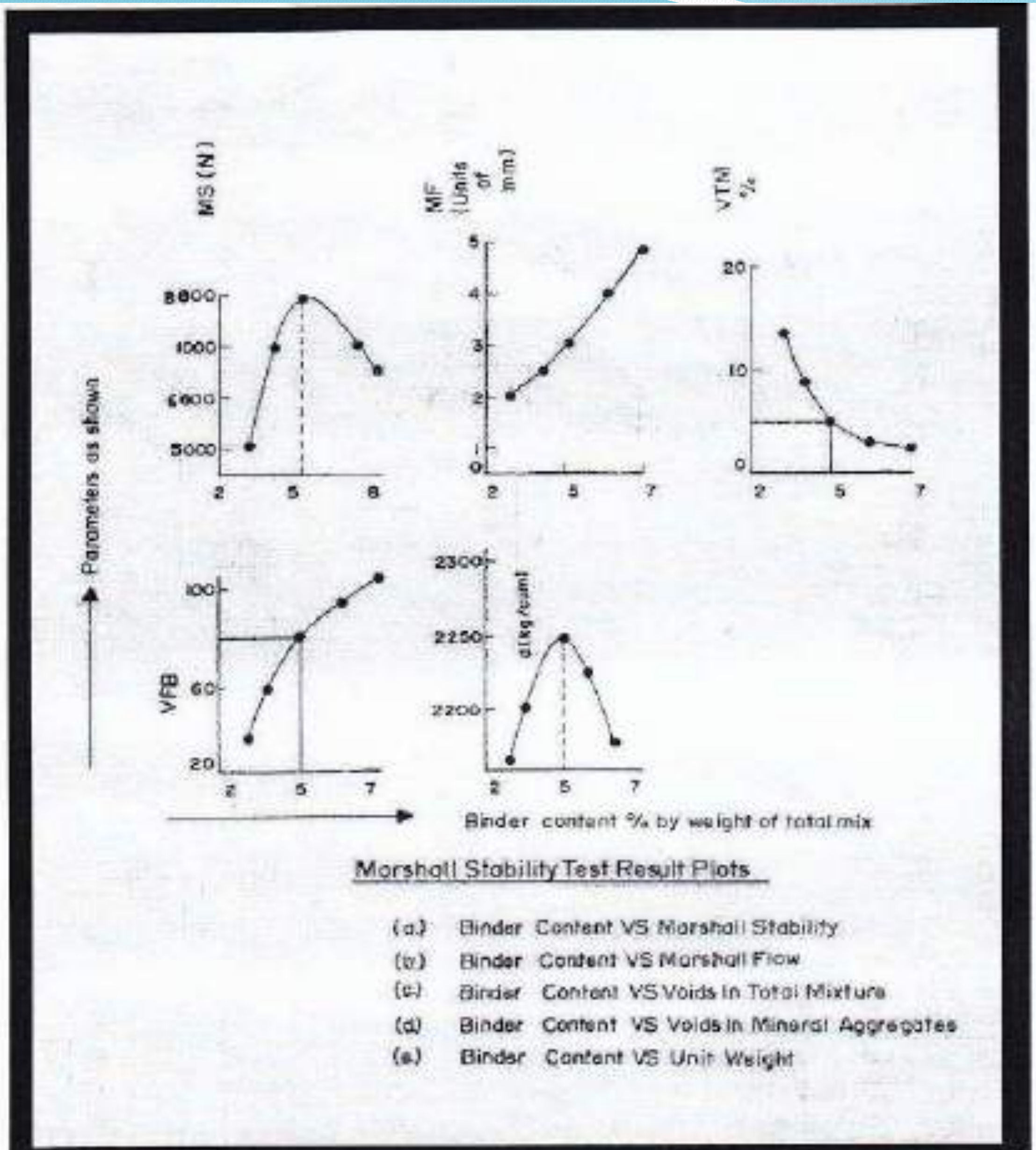


Figure 3.2 Graphs plotted with Marshall test data.

Hill Roads

Topics As Per Syllabus

1. Introduction
2. Special Consideration in Hill Road
3. Alignment of Hill Road Design: General Consideration, Route Location in Hills
4. Special Structures in Hill Roads
   - Retaining Structures, River Training Structures, Landslide Stabilization Structures and Gully Control Structures
5. Geometric Design(Gradietents, Sight Distance Design and Types of Hair Pin Bends, Different Types of Hill Road Cross-sections)

1. Introduction

- A hill road is usually defined on the basis of terrain.
- As per NRS the cross slope may be classified as:

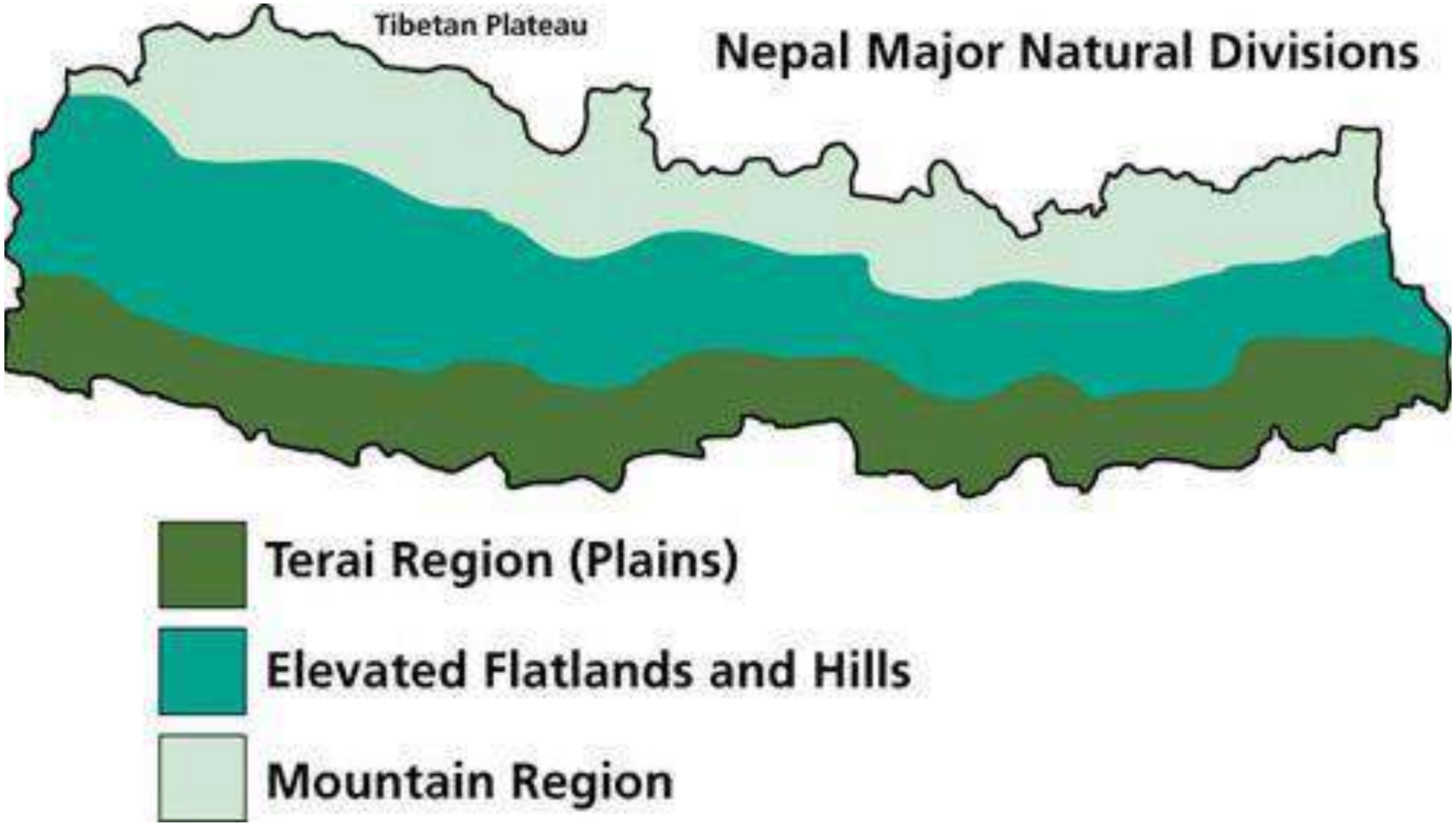
Type of Terrain	1. Level or plain	2. Rolling	3. Mountainous	4. Steep
Cross Slope (%)	0 – 10	10 – 25	25 – 60	> 60

- Hill road-one which passes through terrain with cross slope of 25% or more i.e. mountainous or steep.

- There are sections along hill road with cross slope less than 25%, esp. when the road follows river route.

Why Hill Road in Nepal?

- Nepal area = 140,000 sq. km approx.



- **66% covered with thinly/sparsely populated hills, mountains.**

- **90% population reside in hilly areas and depends on agro products ,for which transportation is a must**






- Hilly Areas Rich: in Natural Resources, Flora and Fauna → Important to launch development Projects (e.g. Hydropower, etc.), tourism, etc.










- **Hilly Regions → Extremes of Climatic Conditions, Difficult and Hazardous Terrain, Topography and Vast High Altitude Areas**



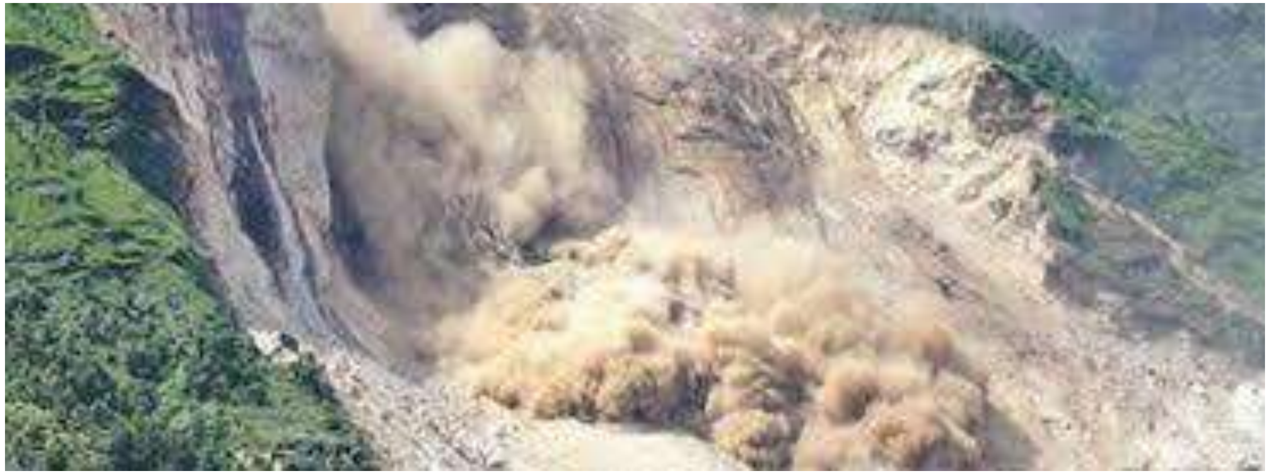




- **Challenges of Hilly Areas: Floods, Landslides, Snowfall, etc. → Fairly Weathered Roads Possible**







- **Waterways, Railways, Airways → Even Not Possible or Very difficult**

- **Where Tunnels, Viaduct → Possible but Not Economical**

- **For Transport, Economy, Social Reasons → Justify the Construction of Hill Roads in the Hilly Regions.**

Why Hill Road in Nepal?

- Nepal area = 140,000 sq. km approx.
- 66% covered with thinly/sparsely populated hills, mountains.
- 90% population reside in hilly areas and depends on agro products.
- But Hilly Areas Rich: in Natural Resources, Flora and Fauna → Important to launch development Projects (e.g. Hydropower, etc.), tourism, etc.
- Hilly Regions → Extremes of Climatic Conditions, Difficult and Hazardous Terrain, Topography and Vast High Altitude Areas
- Challenges of Hilly Areas: Floods, Landslides, Snowfall, etc. → Fairly Weathered Roads Possible
- Waterways, railways, airways → difficult
- Tunnels, Viaduct → Possible but Not Economical
- For Transport, Economy, Social Reasons → Justify the Construction of Hill Roads in the Hilly Regions.

Design and Construction Problems of Hill Roads

1. Characterized by a highly broken relief with Widely Differing Elevations and Steep Slopes, Deep Gorges and Several Watercourses → Unnecessari increase in Road Length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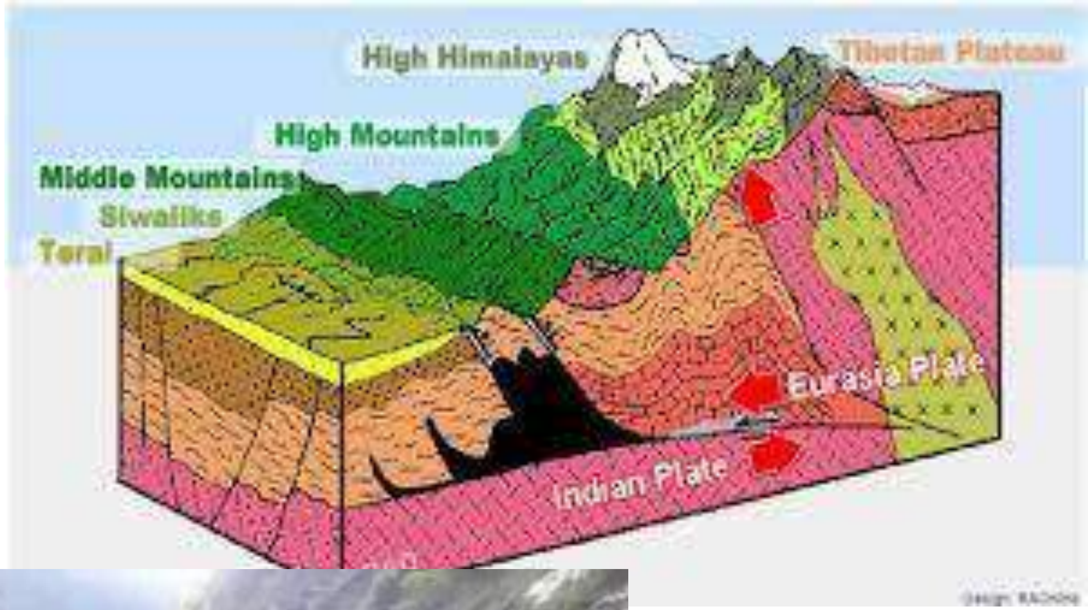
2. Complex Geology → Different Rock Bed → Geology differs from place to place → Assessment for road foundation is not easy



3. Environmental impact → removal of vegetation etc. → stable slope may change to unstable slope after road construction

4. Great Variation in hydrological condition → vary from place to place → landslides, soil erosion → may lead to damages after road construction











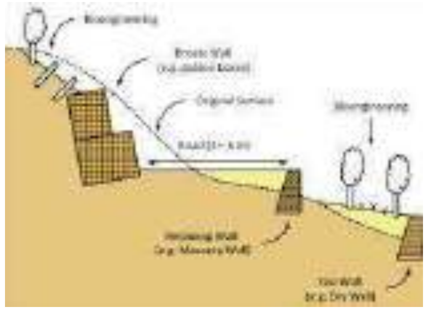
5. New earth fill for road embankment may overload the relatively weak underlying soil layer on hill slope → may trigger new andrecurrent slides

6. Requires installation of various types of special various road structures → cost may rise upto 50 - 60% of total construction










7. Steep slopes → high speed of surface runoff → provision of erosion protection works









8. Construction along relatively small approach stretches → different construction technology may be needed

9. Need of special safety precaution during hill road construction

10. Frequent blasting

11. Design of hairpin bends to get heights

Special Consideration in Hill Roads

1. Selection of Road Alignment
2. Special Geometric Standards
3. Cross-section Design
4. Design of Drainage Structures
5. Stability of Slopes

Allignment Of Hill Roads

- The main objective of alignment selection is to establish safe , easy , short and economical line of travel between two points considering physical features and topography
- The alignment bewtween the selected points is decided based on the administrative needs , develpemental needs and obligatory points like bridge , Valleys , Saddles passes etc
- Allingnment shall be based on the following

Factors Affecting Selection of Alignment

1. Temperature

- Parts with lower temperature variation are preferred. Valleys are the best choice as the temperature is very favorable.
- North facing slopes have low temperature and cold conditions but can be adopted with rigid pavements

- South and south west facing slopes have movement of warm and cold air streams which caused unequal temperature fluctuation(Bad for pavements)
- Also these slopes have rapid rise of temperature causing fast melting of snow and thus huge damage by flow therefore shall be avoided

2. Rainfall

- Areas where rainfall water accumulates like low lands etc. shall be avoided
- Roads shall preferably passed through region of low rainfall
  - The region from 1500 to 2500 have very heavy rainfall and thus leads to rapid erosion landslide etc. this shall be avoided as far as possible

3. Atmospheric Pressure and Winds

- Atmospheric pressure decreases with increase in elevation
- For altitudes above 3000m multiple problems arises like
  - High wind velocity
  - Very low temperature
  - Depth of frost penetration
- Above conditions leads to intensive rock weathering and damage to normal pavements therefore this elevation shall be avoided if possible and if not special precaution shall be adopted

4. Geological Conditions

- Shall pass through stable rocks
- Avoid strata with Horizontal dip or with a dip towards the cut slope

Route Location : a) River Route

- The location of a route along the river valley is known as river route.
- River route is frequently used in hill road due to comparatively gentle gradient.


Chris Winter

Steep valley between tatopani and jomsom (nepal), annapurnas, cliff, dirt road

- **Characteristics**

1. Location: along a river valley
2. Most frequent case of hill road alignment
3. Comparatively gentle gradient

Merits

a. Serves the rural settlement
b. Low vehicle operating cost, availability of water and other construction materials

Demerits

a. Numerous horizontal curves
b. Construction of special retaining and protection of walls on the hill sides
c. Extensive earthwork
d. Construction of large number of cross drainage structures
e. Steep sloping hill side may be insufficiently stable
f. Massive river training and protection works on the river side.

b) Ridge Route

- The road usually follows the top section of the hill system and crosses successively mountain pass.
- Geologically stable and comparatively mild slope sections are selected for the artificial development of the route.
- A ridge route is characterized by very steep gradient, numerous sharp curves including hair pin bends and the expensive rock works.




Ridge Route

Advantages

- Less amount of drainage structures
- Are most stable

Demerits

- Steep gradient, sharp curves including hair pin bends
- Expensive rock works, successive mountain pass
- Route climbs up continuously from the valley till mountain pass and descends down
- Construction of special structures, tunnels, snow fences etc.

Geometric Design

Cross-section Design

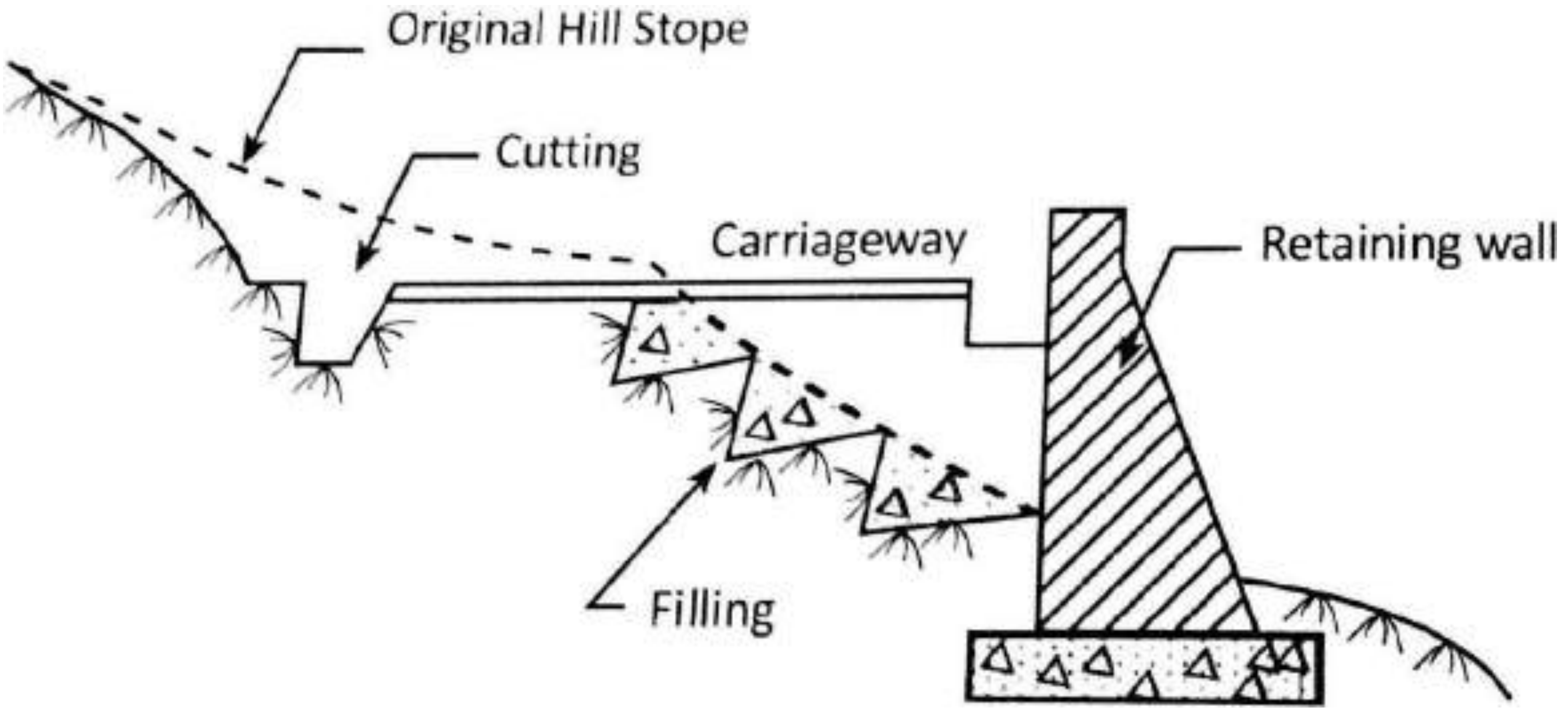
- Cross section of a road in hilly terrain is determined by:

o original ground slope of site,

o slope of the road formation,

o width of roadway,

o side drain size and



Various Configurations of Hill Road Cross Sections

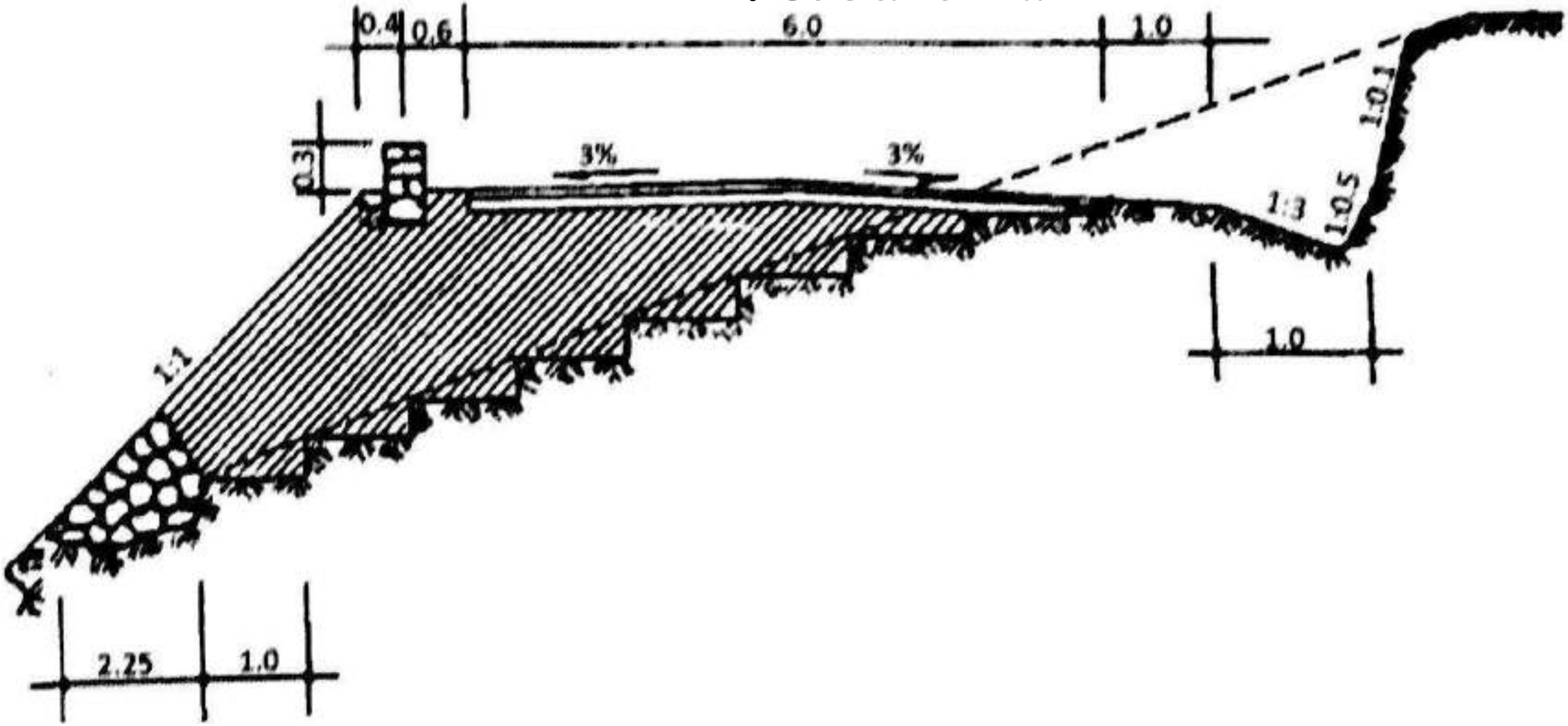
1. Cut and fill
2. Bench type
3. Box cutting
4. Embankment with retaining walls
5. Semi bridge
6. Semi tunnel
7. Platforms

1) Cut and Fill

- With a hill side slope of over 2%, a cut and fill road bed is the cheaper and environment friendly type of construction.
- The fill mass is obtained from the cut material at the same location or within free haul distance.

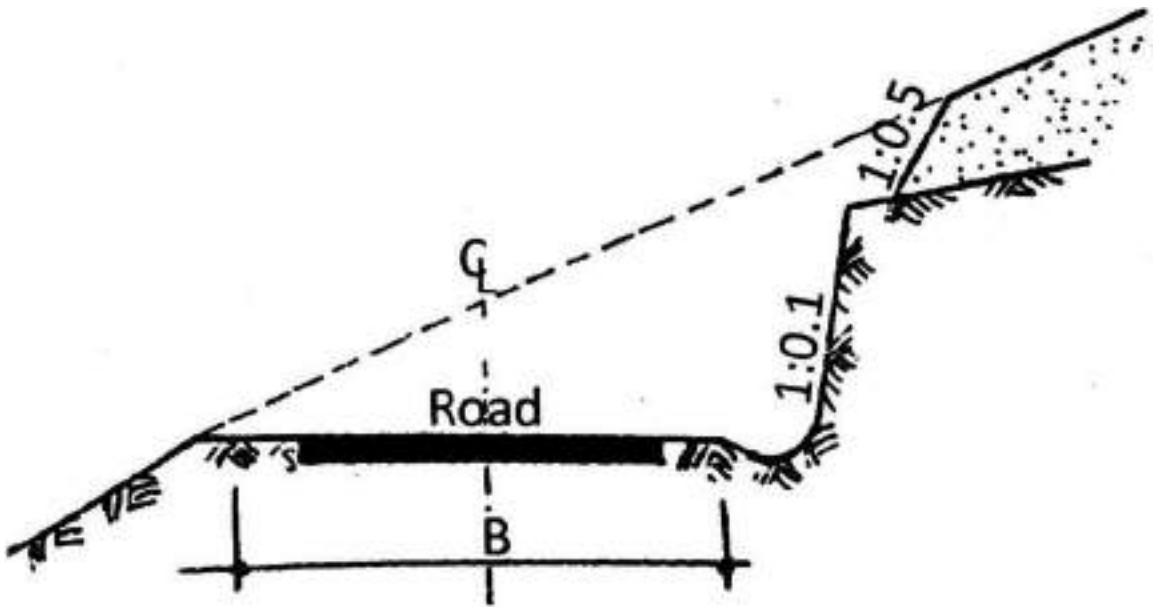
- To ensure adequate stability of embankment, benches are made on the surface of the hill side with a height of 0.5 m and a length varying 1.5 m to 3.0 m depending on the slope.
- The settlement of the fill portion of road bed sometimes causes the appearance of longitudinal cracks in the pavement.

1. Cut and Fill



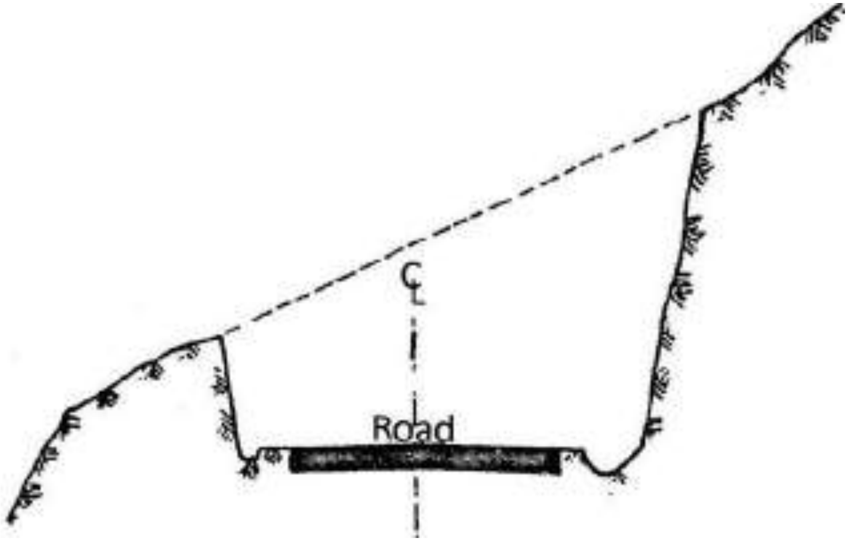
2) Bench Type

- A cross section of the bench type although entailing some increase in earthwork ensures the complete stability of the road bed, if hill side itself is stable.
- To avoid cracks in the pavement as result of settlement and consolidation it is preferred to locate roads on stable hills cross slope exceeding 1 in 3 entirely in a cutting at the higher cost of making full bench.
- Roads with hard and costly pavement structures are to be preferably located in full bench while those with low cost surface (WBM, gravel, earthen) be made with cut and fill road bed.

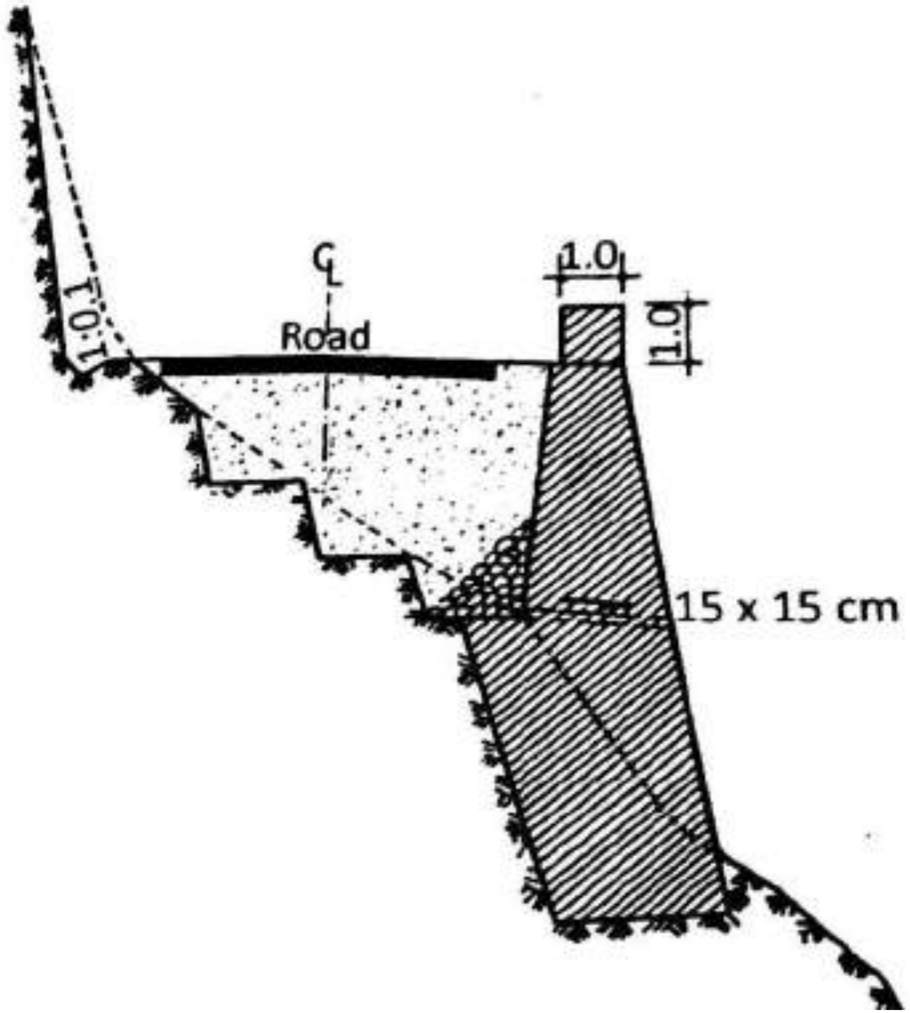


3) Box Cutting

- When the location of road bed is unstable or unstable along the hill side due to one or other reason, the road bed is designed as trench type of cross section.
- In some cases It is introduced in order to meet the geometric design standards for given category of road.
- Also when a road is ascending up the grade , the grade is reduced substantially by raising formation line at the beginning with fill and lowering the same at the following section with box cutting.
- This type of road bed increases earthwork to a large extent.
- This way, the length of road may be substantially reduced.



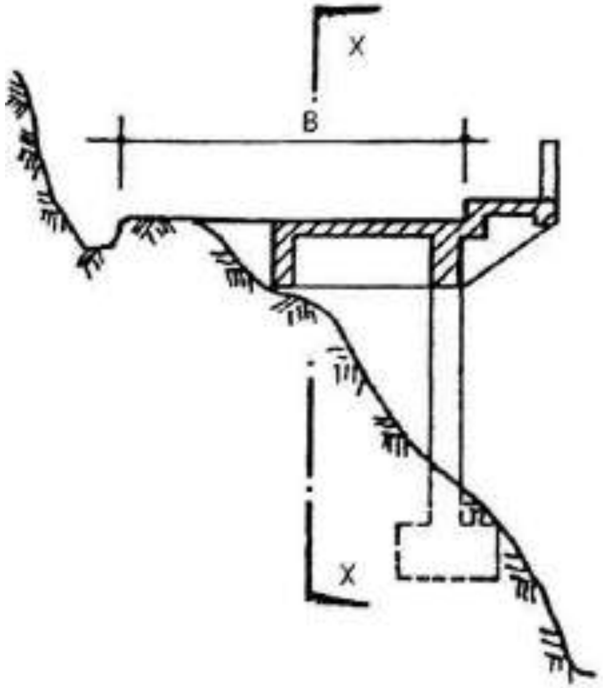
4) Embankment with Retaining Walls



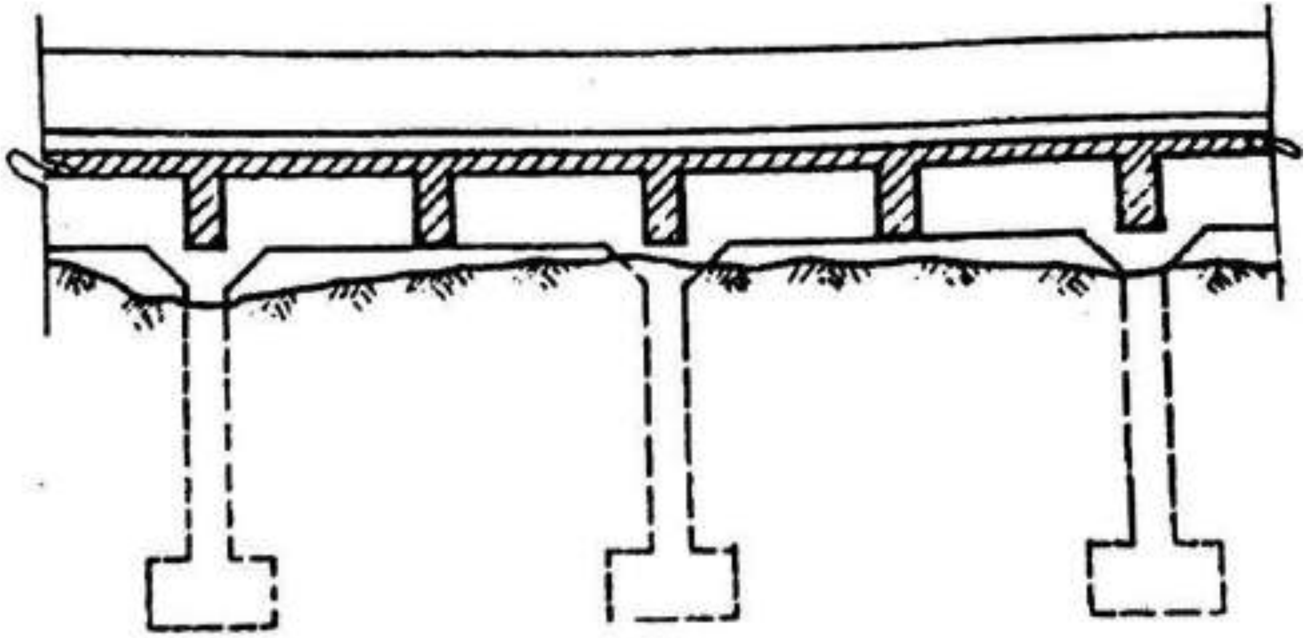
- If the natural cross slope of the ground is too high then it is preferred to form a retaining wall than an embankment (Sometimes the embankment might not be possible at all)
- Proper analysis of soil and materials properties shall be made to ensure adequate stability of the retaining structure

5) Semi Bridge

- If the road is located across a steep hill slope → retaining wall may have to be of substantial height.
- In such cases, in order to reduce the quantities of work, road bed with a semi bridge type of structure may be constructed.
- Part of the roadway is accommodated on bench cut and part on the semi bridge.



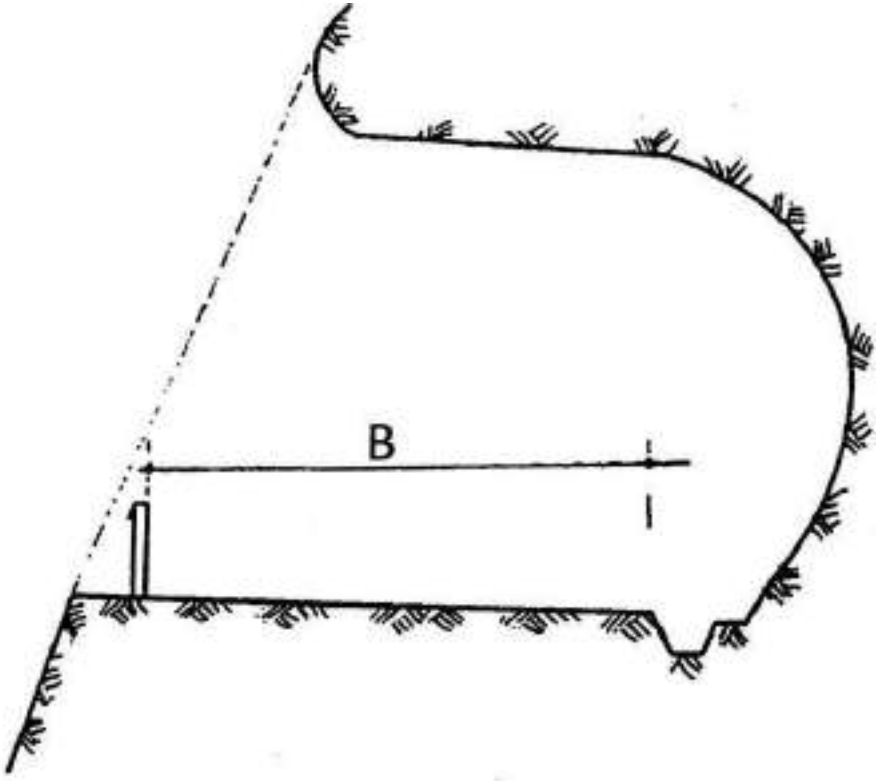
Cross - Section



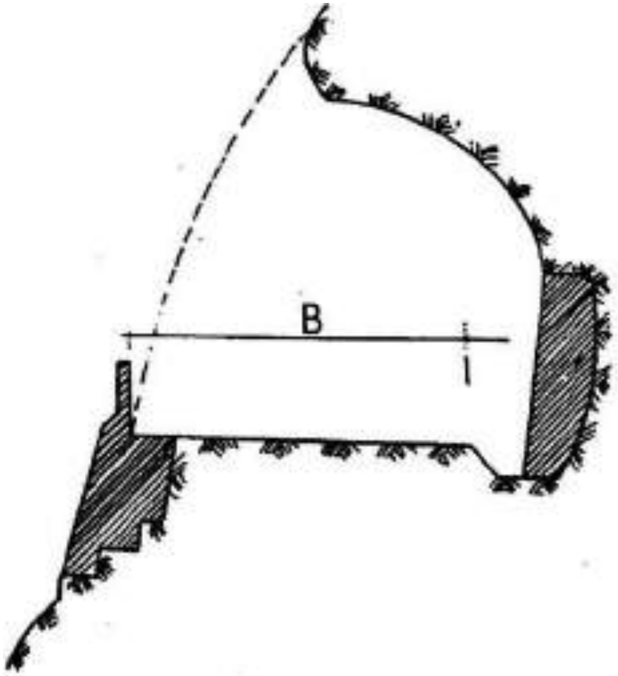
L-Section X-X

6) Semi Tunnel

- When cutting into steep hills in stable rock faces the rock may be permitted to overhang the road, reducing rock works.
- Such a cross section is called a semi tunnel.
- Road in half tunneling is advantageous for high altitude hill roads as they do not get blocked by snows.



With Accomodating Road-way Only



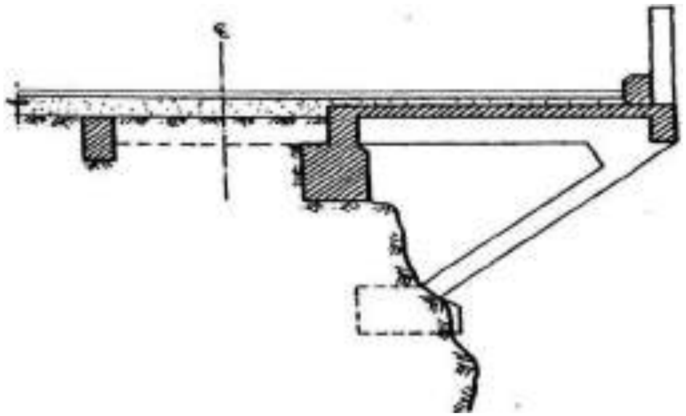
With Retaining and Breast Walls

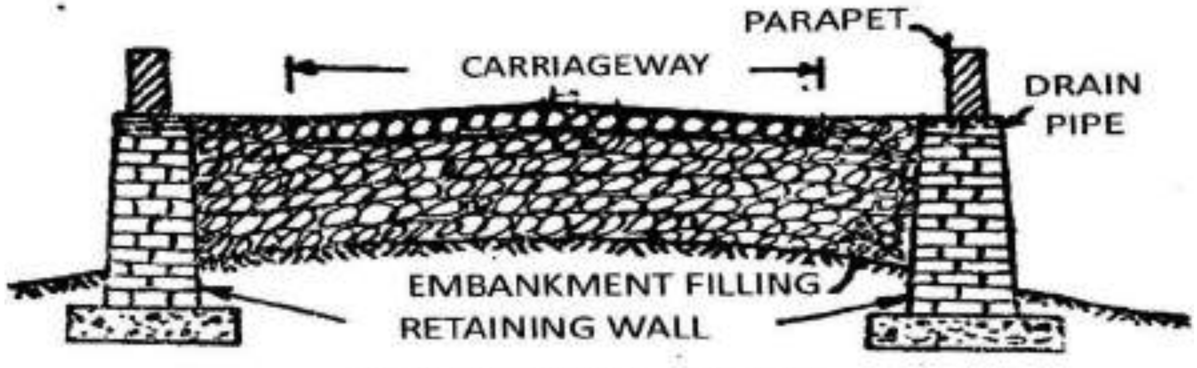
7) Platform

- On the precipitous/very steep slopes, where shifting of the route into the hill side will lead to enormous rock work, which would substantially increase the cost of road construction and where semi tunnel cannot be constructed due to the geological condition, platforms are usually cantilevered out of the rock on which road way is partially located.

8) Full Embankement

- When cross slope of the hill is very small, road may be in full embankment.
- Filling may be small or heavy.
- In case of heavy filling, retaining walls should be constructed on both the side of the formation.





Fully in embankment

Sight Distance

- On hill roads stopping sight distance is absolute minimum from safety angle and must be ensured regardless of any other considerations.
- It would be a good practice if this value can be exceeded and visibility corresponding to intermediate sight distance provided in as much length of road as possible.
- If this is the case then the driver will be able to get reasonable opportunities to overtake with caution and driving task becomes much easier.
- It is not normally feasible or practicable on hill roads to provide overtaking sight distance.

Speed(kmph)	Stopping sight distance (m)	Intermediate sight distance (m)
20	20	40
25	25	50
30	30	60
35	40	80
40	45	90
50	60	120

S.No.	Sight distance	Driver's eye height	Height of object
1	Safe stopping distance	1.2 m	0.15 m
2	Intermediate sight distance	1.2 m	1.2 m

Width of road

S.No.	Road classification	Open areas		Built up area	
		Normal	Exceptional	Normal	Exceptional
1	National and state highways	24	18	20	18
2	Major district roads	18	15	15	12
3	Other district roads	15	12	12	9

	Highway classification	Carriageway width (m)	Shoulder width (m)	Roadway width (m)
a	National highways and state highways Single lane Double lane	 3.75 7.00	 2×1.25 2×0.9	 6.25 8.8
b	Major district roads and other district roads	3.75	2×0.5	4.75
c	Village roads	3.00	2×0.5	4.00

Camber

a.	Urban road	3 to 4 percent (1 in 33 to 1 in 25)
b.	Gravel or WBM surface	2.5 to 3 percent (1 in 40 to 1 in 33)
c.	Thin bituminous surfacing	2.0 to 2.5 percent (1 in 50 to 1 in 40)
d.	High type bituminous surfacing	1.7 to 2.0 percent (1 in 60 to 1 in 50)

Superelevation

- The limiting value of super elevation is as under:

a) In snow bound areas = 7%

b) In hilly areas not bound by snow = 10%

- In attaining the required super elevation, it should be ensured that the longitudinal slope of the pavement edge compared to the center line (i.e. the rate of change of super elevation) is not steeper than 1 in 150 for roads in plain and rolling terrain and 1 in 60 in mountainous and steep terrain.

Gradient

- A study on dynamic characteristics for the truck indicates that:
  - If gradient is 4% the speed is 42 kmph
  - If gradient is 6% the speed is 32 kmph
  - If gradient is 8% the speed is 24 kmph

- If the gradient chosen is 4% instead of 8%, the route will be double in length but the speed will increase only 1.75 times. This indicates in spite of decrease in gradient there is no gain in travel time.
- Ruling Gradients of 7% , Limitng of 10% and Exceptional of 12% is used as standard value

Vertical Curve

- Designed as square parabola.

- Length of vertical curve is controlled by sight distance requirements but curves with greater length are aesthetically better.

- Curves should be provided at all grade change exceeding those indicated in the table below and for satisfactory appearance.

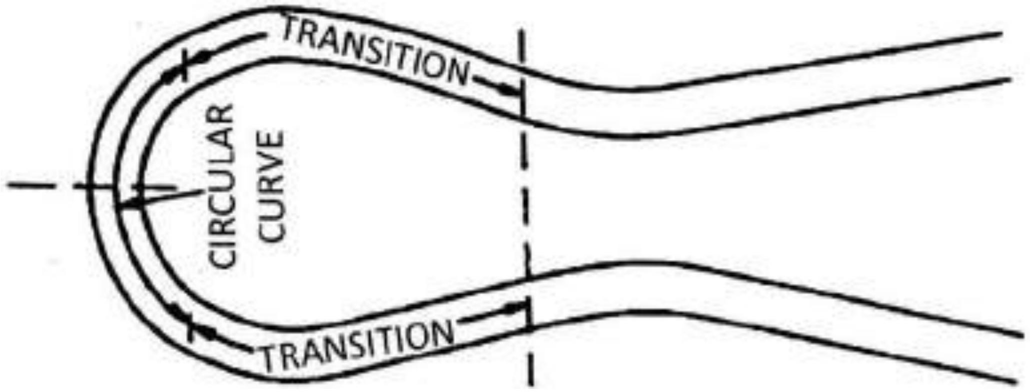
- Where horizontal and summit/crest curve overlap, the design should provide for the required sight distance both in the vertical direction along the pavement and in the horizontal direction on the inside of the curve.

Design of Hair Pin Bends

- In hilly regions →difficult to avoid bends →where direction of the road reverse.

- In hill road alignment, hair pin bends are introduced particularly → when necessary to attain height without covering substantial horizontal distance.

- Hair pin bends → designed either as a Circular Curve with Transition at each end or as a Compound Circular Curve.



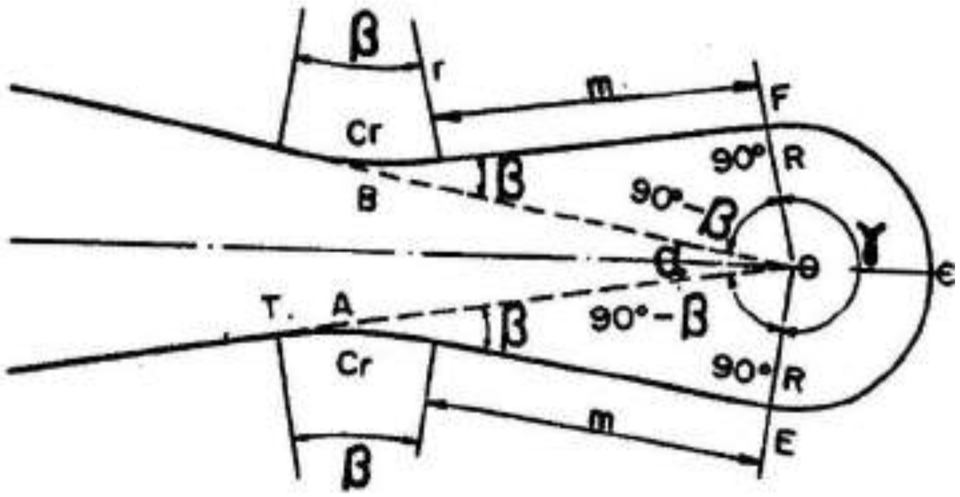
- Inner and outer edges of the roadway should be concentric with respect to the center line of the pavement.

- Where a number of hair pin bends have to be introduced, a minimum intervening distance of 60 m should be provided between the successive bends to enable the driver to negotiate the alignment smoothly.

- At hair pin bends preferably the full roadway width should be surfaced.

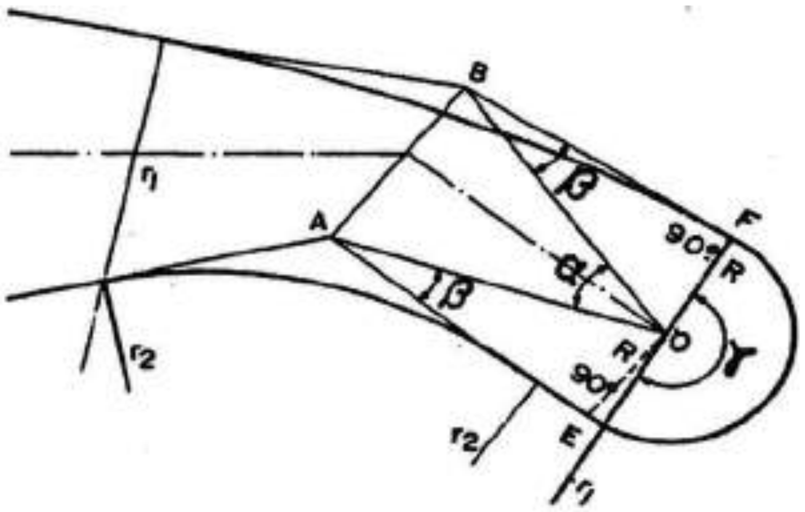
Types of Hair Pin Bends

1) Symmetrical Hair Pin Bend

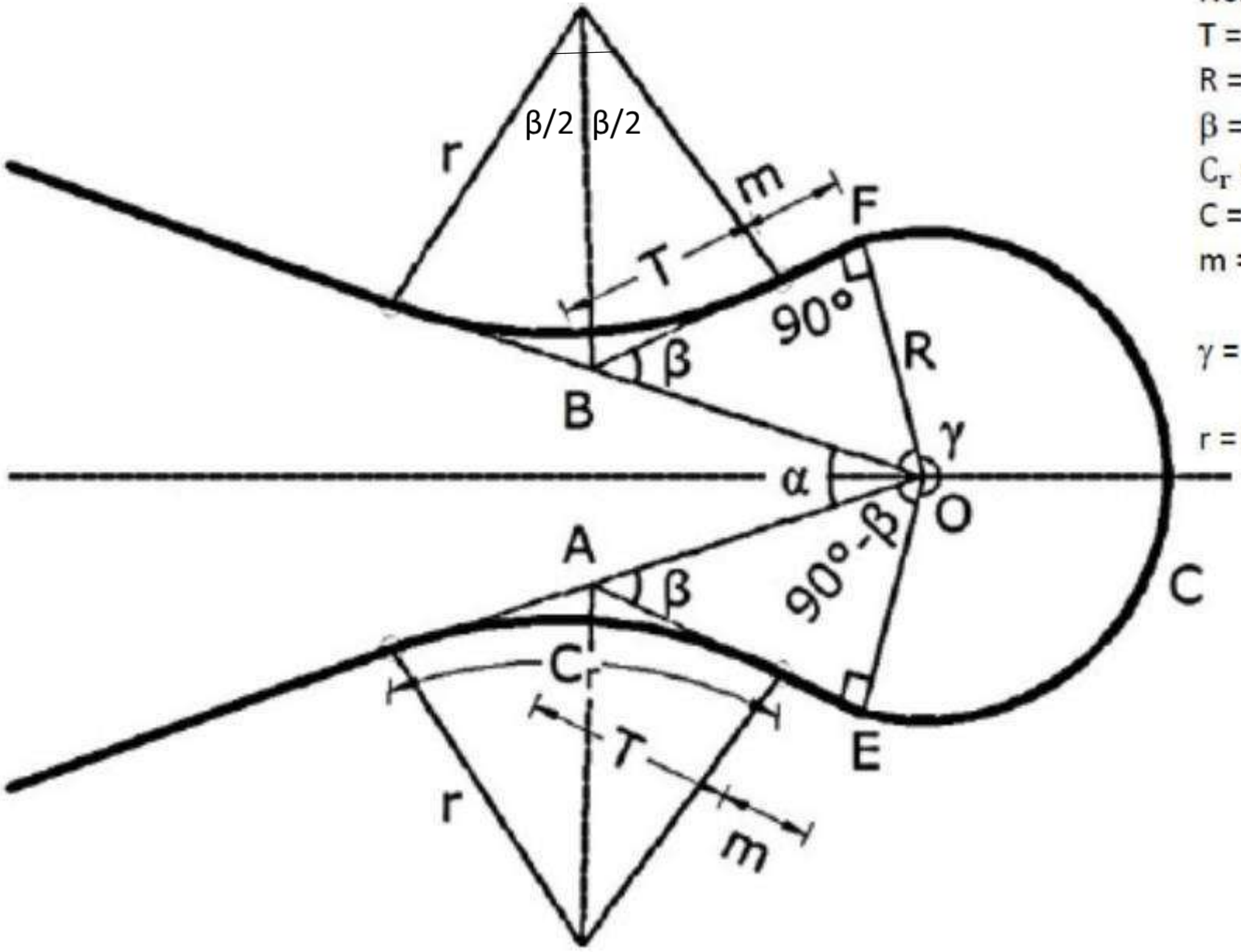


First Type

2) Asymmetrical Hari Pin Bend



Second Type



Here,

T = tangent length of reverse curve

R = radius of main curve

β = deflection angle

C_r = length of the reverse curve

C = length of the main curve

m = transition length between reverse and circular curve

γ = central angle at the centre of main curve

r = radius of reverse curve

Expression for Hair Pin Bends

- Simple expression may be derived based on the geometry of hair pin bends.

Tangent length of reverse curve = $r \tan \beta/2$ = T

In Rt. Angled ΔAEO

$$\because \tan\beta = \frac{OE}{AE} \qquad \text{Here,} \quad AE = BF = T + m \quad \& \quad OE = R$$

$$\therefore \tan\beta = \frac{R}{T+m} = \frac{R}{r\tan\beta/2 + m} \quad \ldots\ldots\ldots\ldots(i)$$

$$\text{from trigonometric law,} \quad \tan\beta = \frac{2\tan\beta/2}{1 - \tan^2\beta/2} \quad \ldots\ldots\ldots\ldots(ii)$$

Equating (i) and (ii)

$$\frac{R}{r\tan\beta/2 + m} = \frac{2\tan\beta/2}{1-\tan^2\beta/2}$$

$$\text{or,}\qquad 2\tan\beta/2 = \frac{R\,(1-\tan^2\beta/2)}{m + r\tan\beta/2}$$

$$\text{or,}\qquad 2\tan\beta/2\;(m + r\tan\beta/2) = R\,(1-\tan^2\beta/2)$$

$$\text{or,}\qquad 2\,m\tan\beta/2 + 2\,r\,\tan^2\beta/2 = R - R\,\tan^2\beta/2$$

$$\text{or,}\qquad 2\,r\,\tan^2\beta/2 + R\,\tan^2\beta/2 - R + 2\,m\,\tan\beta/2 = 0$$

$$\text{or,}\qquad (2\,r + R)\tan^2\beta/2 + 2\,m\tan\beta/2 - R = 0$$

This is a quadratic equation of $\tan\beta/2$.

$$\therefore\ \tan\beta/2 = \frac{-2\,m \pm \sqrt{(2m)^2 - 4\,(2\,r + R)\,(-R)}}{2\,(\,2\,r + R\,)} = \frac{-\,m \pm \sqrt{m^2 + R\,(2\,r + R)}}{2\,r + R}$$

Neglecting negative sign;

$$\tan \beta/2 = \frac{-\,m + \sqrt{m + R\,(2\,r + R)}}{2\,r + R}$$

After knowing the value of β,

In rt. angled Δ AEO, Cosβ = $\frac{AE}{AO} = \frac{T+m}{AO}$, Then AO = $\frac{T+m}{\text{Cos}\beta}$

In rt. angled ΔBFO, Sinβ = $\frac{FO}{BO} = \frac{R}{AO}$, Then BO = $\frac{R}{\text{Sin}\beta}$

$$AO = BO = \frac{T + m}{\cos \beta} = \frac{R}{\sin \beta}$$

Deflection angle at main curve, $\gamma = 360^0 - [\,2\,(90^0 - \beta) + \alpha\,]$

Length of reverse curve, $C_r = \dfrac{\pi\, r\, \beta}{180^0}$

Length of main curve, C $= \dfrac{2\,\pi\, R\, \gamma}{360°} = \dfrac{\pi\, R\, \gamma}{180°}$

∴ Total Length of Hair Pin Bend (S) = 2 (C_r + m) + C

Hill Side Drainage

- Adequate drainage facility should be provided across the road.
- Attempts should be made to align the roads in such a way where the number of cross drainage structures required are minimum.
- This will reduce the construction cost.

1) Drainage of water from hill slopes

Surface water flowing form the hill slope towards the roadway is one of the main problems in drainage of hill roads.

- It is desirable that the water from the hill side is not allowed to flow into the side drains due to the problems maintaining the side drains intended for water from roadway.
- In order to intercept and divert the water form hill slope catch water drains are provided and then it is diverted by side drain.

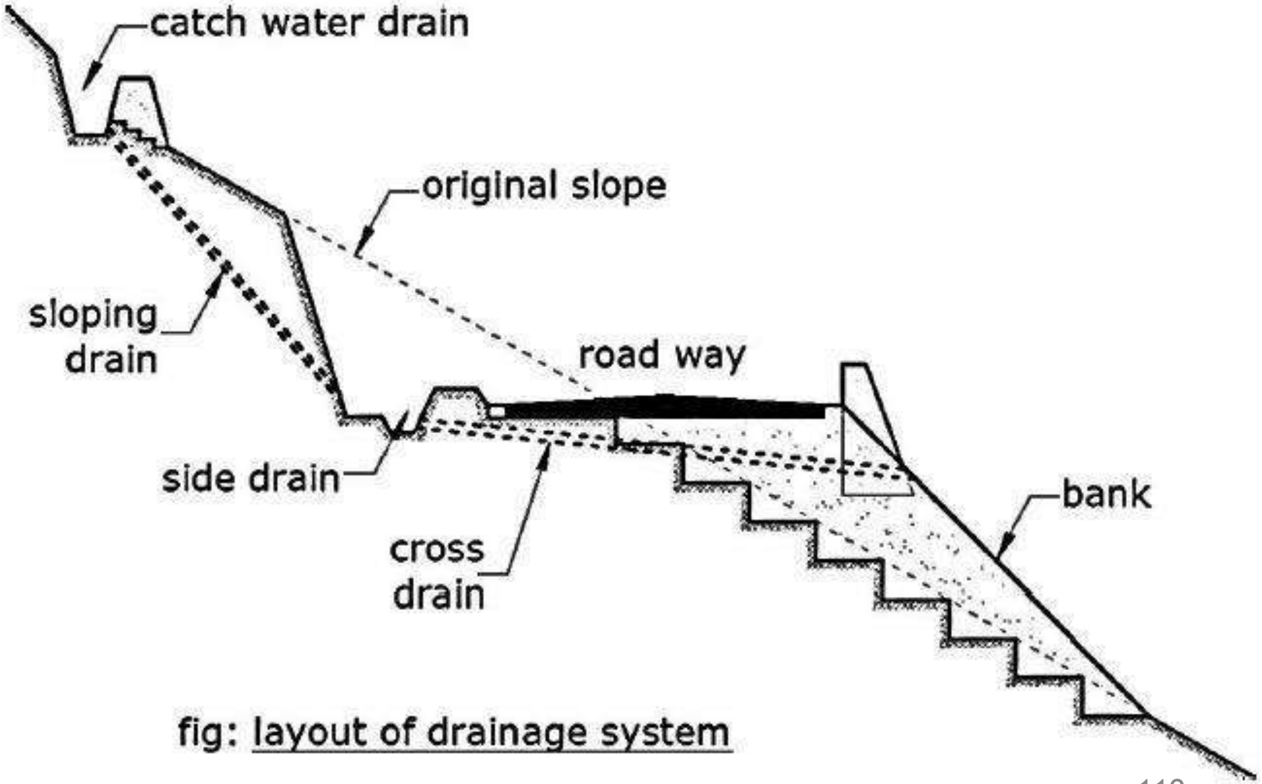


fig: layout of drainage system

2) Road-side drains

Side drain is provided only on the hill side of the roads and not on the both sides. Due to limitation of in the formation width, the side drains are constructed to such a shape that at emergency the vehicles could utilize the space for crossing at low speed or for parking.

3) Cross drainage

As far as possible, cross drainage should be taken under the road and at right angle to it.

- At the head of small cross drains catch pits must be provided to collect the stones and rubbish and to prevent scour.
- In hill roads where rainfall is heavy, it is recommended that culverts should be provided every 60 to 90 m, to facilitate drainage of water cross the roads.

4) Sub-surface drainage

The seepage flow of water on hill roads is one of the major problems during and after the monsoons.

- The seepage flow causes problems of slope stability as well as weakening of the road bed and the pavement.
- The seepage flow is controlled by suitable sub-surface drainage system i.e. by longitudinal pipe drain, by controlling of capillary rise, by lowering the water table.

Special Structures in Hill Roads

- Construction of hill roads involves many special structures.

- These may include wide range of structures which are used to retain soil mass to increase stability of road embankment slopes as well as natural hill slopes to accommodate road bed in steep slope to penetrate deep through mountain pass and so on.

- Special structures are also required to dissipate energy of surface water in the hill road drainage system to provide snow avalanche control and protection system, river training and erosion control to prevent scour under cutting and the cutting by the river.

The following types of special structures are most frequently used in the hill road in Nepal:

1. Retaining Structures
2. River Training Structures
3. Landslide Stabilization Structures/Slope Protection Structures/Slope Stabilization Structures
4. Gully Control Structures
5. Erosion Control Structures
6. Drainage Structures

1. Retaining Structures

- A retaining structure is usually a wall constructed for the purpose of supporting or retaining a vertical or nearly vertical earth bank which in turn may support vertical loads.
- Provides adequate stability to the roadway and to the slope.
- Constructed on the hill side of the roadway
- Also provided to retain the earth mass roads where the embankment slope or cut slope cannot be extended beyond roadway.
- Generally for hill slopes with gentle slope retaining structures may not be required.(Unless there is lack of land)
- For steeper slopes relative economy of cost of earth cutting and retaining structures has to be compared and decision shall be done accordingly.

Classification of Retaining Structure

Based on Materials Used:

i) Dry stone masonry
ii) Stone filled gabion wire crates
iii) Stone masonry with cement sand mortar
iv) Composite (Dry Stone Masonry Filled in Cement Sand Mortar Masonry Frame)
v) Plain Cement Concrete
vi) Reinforced Cement Concrete
vii) Timber (Crib walls)

Dry Wall

Gaboin Wall

Gabion Walls

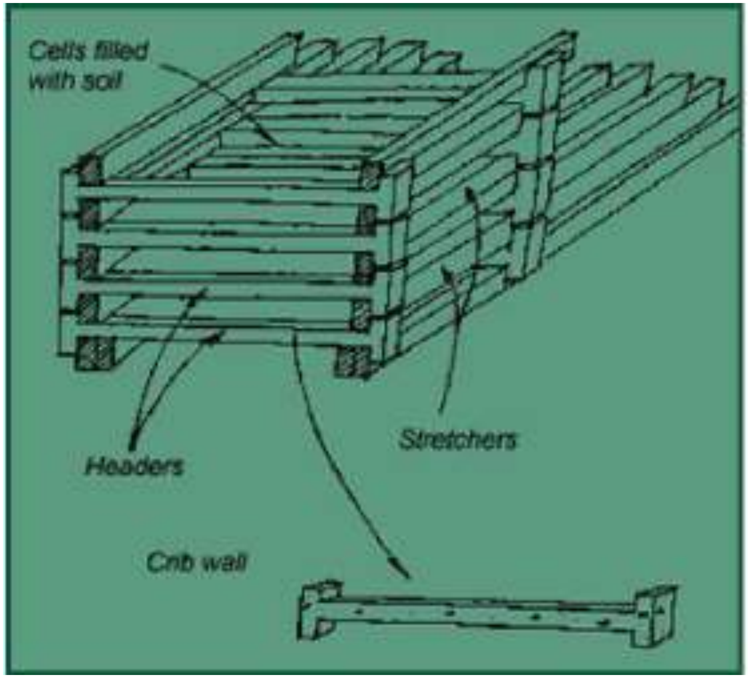
- Gabions are multi-celled, welded wire or rectangular wire mesh boxes, which are then rockfilled, and used for construction of erosion control structures and to stabilize steep slopes.
- Their applications include,
  - Retaining walls,
  - Bridge abutments,
  - Wing walls,
  - Culvert headwalls,
  - Outlet aprons,
  - Shore and beach protectionwalls, and
  - Temporary check dams.

RRM wall

RCC wall

Crib Walls

- Crib walls have been made of various materials including wood, concrete and even plastic.
- The cribs are made of interlocking headers and stretchers that are stacked like the walls of a log cabin.
- Crib walls are usually quite large and can be out of scale and character with the surrounding landscape.
- In addition, heavy construction equipment is required to lay the courses, possibly impacting sensitive areas.
- It can be used for moderate heights of 4m to 6m.



Based on Location with Respect to the Roadway

i) Hill Side or Valley Side Retaining Walls

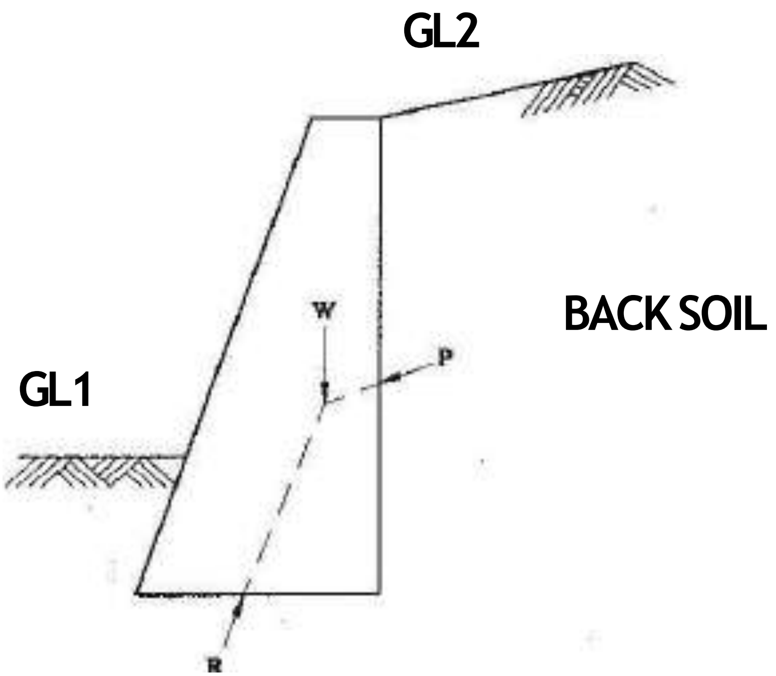
ii) Revetment Walls or Breast Walls, etc.

iii) Toe walls

iv) Cut off Walls

Retaining Walls

- Used to retain soil, rock or other materials.
- Designed and constructed to sustain the earth pressure and wheel load.
- Constructed along the valley side as well as the hill side



- Situations requiring the construction of retaining walls are:

i) In Valley sides to retain the embankment materials when where cutting into hill is not economical or has to be restricted due to other reasons

ii) Places where the valley side surfaces gets saturated in the monsoons and is likely to result in slip taking a part of road with it.

iii) In hill side when the soil is too loose or there is vehicle load coming from above

iv) Places where undercutting by a stream or other water course causes damage to the valley side and the road.

v) In valley point where water flows over the road

- Made of Dry Stone Masonry, Gabion, Stone Masonry with Cement Mortar or Concrete.
- No problem of backfill drainage → in case of Dry Stone or Gabion Box Retaining Walls
- In case of Stone Masonry in Cement Mortar Joint
- **Weeps Holes** → are provided at specific interval to facilitate backfill drainage
- Compacted Backfill with crushed aggregates or river gravel are provided for backfill to prevent choking of weepholes.

Revetment or Breast Walls

- Revetment walls are known as Breast Walls. They are not meant to take the road and retain the soil mass but to prevent the cut slope or fill slope made of loose eroding soils from further slip or erosion.
- These walls are sloped towards cut or fill slope and are not intended to resist overturning or sliding.
- Provided on the inner side of the road to give support to the loose and unreliable soil of the cut up hill side.
- Such walls perform the following functions:

a) Keep the road edge defined and also protect the drain to some extent.

b) The hill slope to the extent of breast wall height will remain protected from slips and any slide above this height will flow over the top of the breast wall.

c) It would not allow continuity of the flowing mass of soil and would thus facilitate the clearance of slides.

d) Assistance in drainage fro hill slope through weep holes in breast wall on to the side drain in front of wall.

Toe Wall

- If the sloping length is too long it is preferable to construct a toe wall as to support the embankment. Where the cutting slope is steep and contains loose soils, slips are likely to occur.
- Similarly When culverts/scuppers are constructed and waterfalls above the retaining walls on the valley side to a considerable height, in the form of free fall, there is considerable erosion at the toe of the retaining wall.
- In order to check this, one or a series of toe walls are constructed in order to break the water force so that the retaining wall does not get eroded.

Cut off walls

- In some cases, similar structures called Cut off walls/Check Walls are required in the stream bed on the upstream side of the road to reduce the flow of debris which blocks the road.


Embankement
TOE WALL
2013-4-1

Based on Structural Scheme (Principal Type of Retaining Walls)

(a)Conventional Retaining Walls

i) Gravity Walls

ii) Semi-Gravity Walls

iii) Cantilever Walls Counterfort Walls

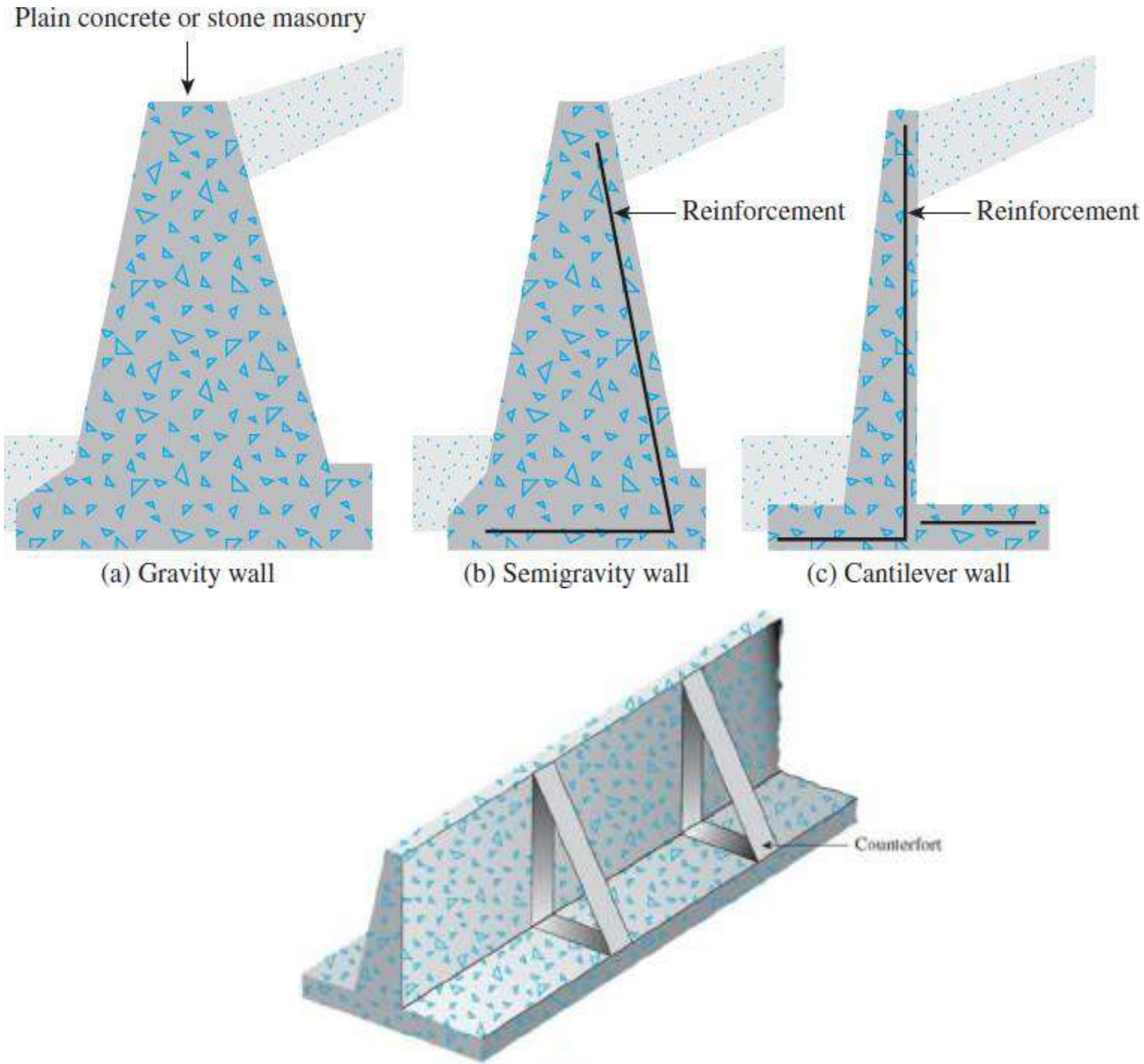
iv) Buttressed Walls

v) Crib Walls

(b) Mechanically Stabilized Earth (MSE) Walls

(c) Reinforced Soil Walls

Conventional Retaining Walls



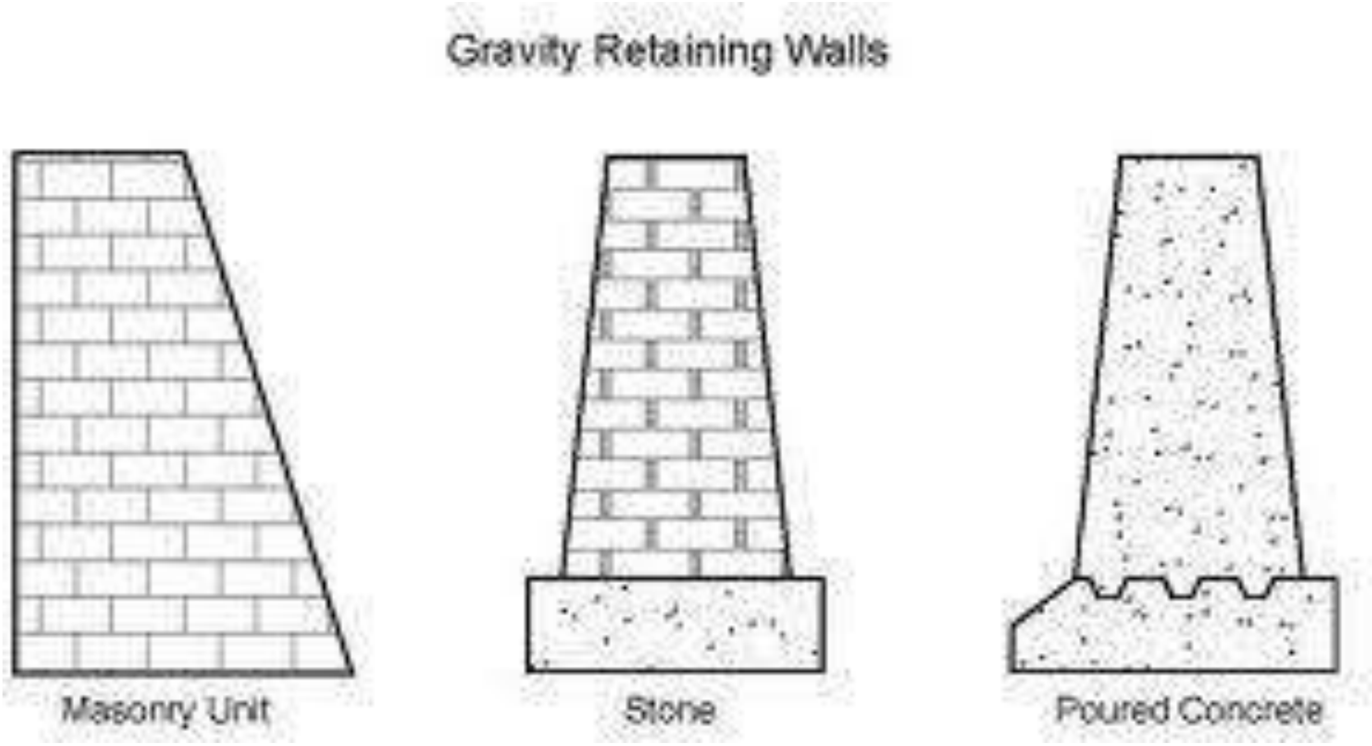
(d) Counterfort wall

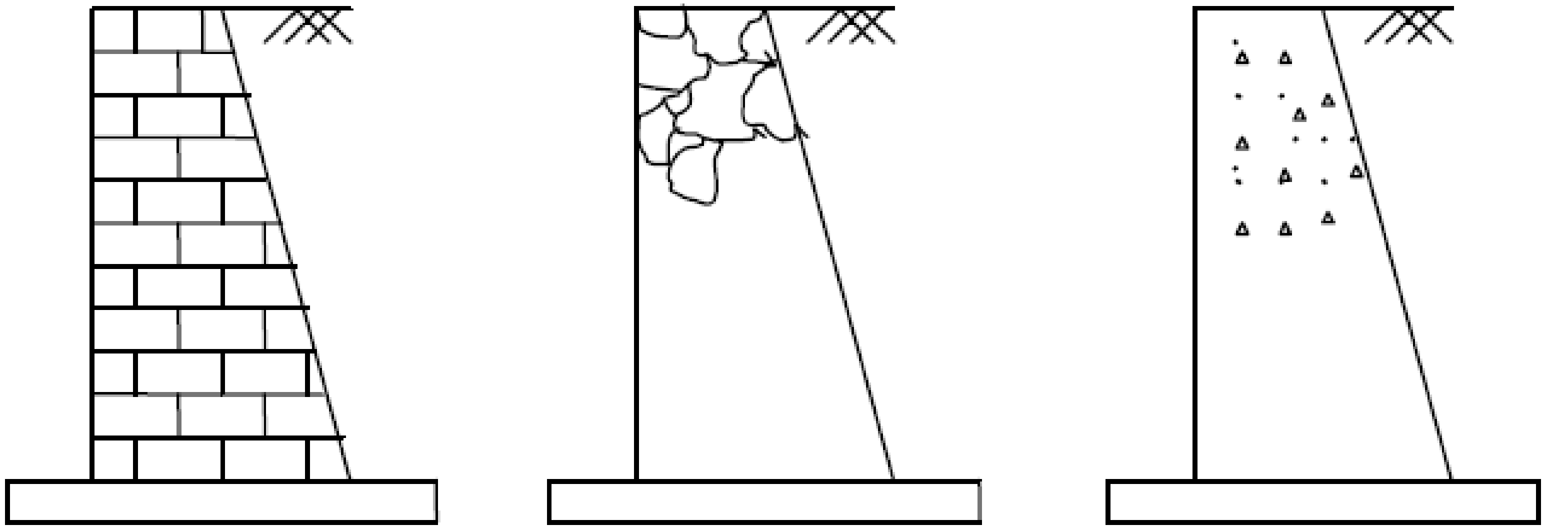
1. Gravity Retaining Walls

- Gravity walls are the earliest known retaining structures.
- Constructed with plain concrete or stone masonry. They are built from solid concrete or rock rubble mortared together.

- They depend on their own weight and any soil resting on the masonry for stability.
- This type of construction is not economical for high walls.
- Gravity walls are economical for heights up to 3 m (10 feet).

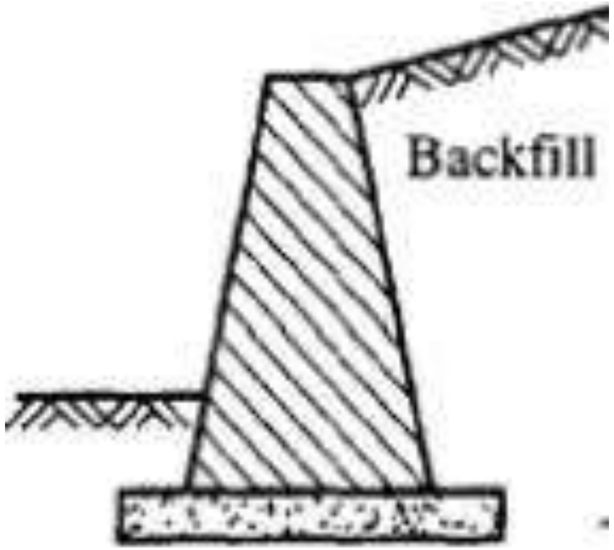
(a) Gravity wall

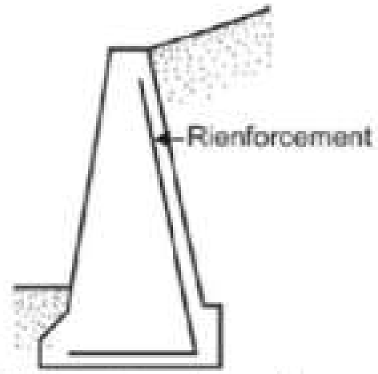

Gravity Retaining Walls
Masonry Unit
Stone
Poured Concrete



2. Semi-gravity Walls

- Not as heavy as gravity walls.
- A small amount of reinforcement is used for reducing the mass of concrete or minimizing the size of wall sections.
- A specialized form of gravity walls is a semi-gravity retaining wall.
- These have some tension reinforcing steel included so as to minimize the thickness of the wall without requiring extensive reinforcement.
- They are a blend of the gravity wall and the cantilever wall designs.



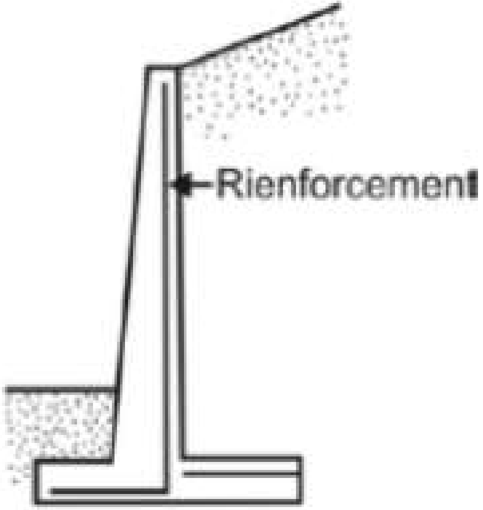


(b) Semigravity wall

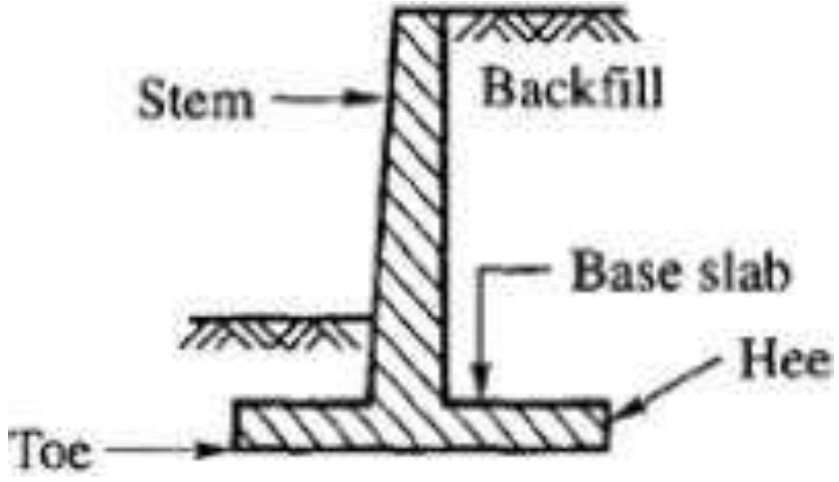
3. Cantilever Retaining Walls

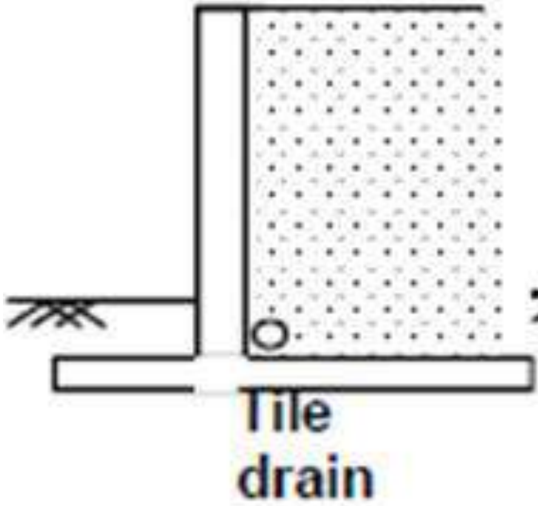
- Made of reinforced concrete and consist of a relatively thin *stem* and a *base slab*.
  - Base slab is the cantilever portion.
  - Base is also divided into two parts, the *heel* and *toe*.
  - Heel is the part of the base under the backfill.
  - Toe is the other part of the base.
  - Resists pressure due to its bending action.

- Use much less concrete than monolithic gravity walls, but require more design and careful construction.
- Generally economical up to about 8m (25 ft.) to 10m (32 ft.) in height.
- Can be precast in a factory or formed on site.
- More convenient and relatively economical for design.
- Rankine's and Coulomb's theories can be used to find active earth pressure on the wall.

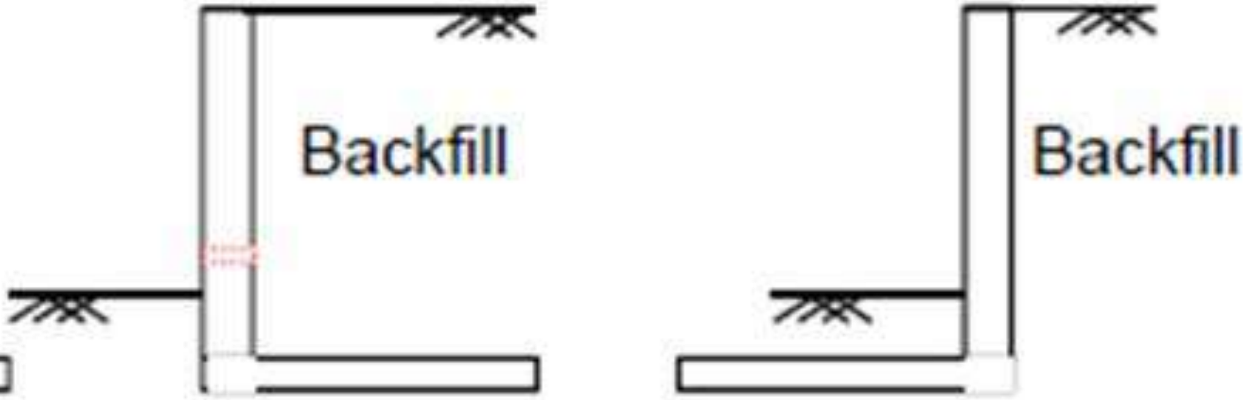


(c) Cantilever wall

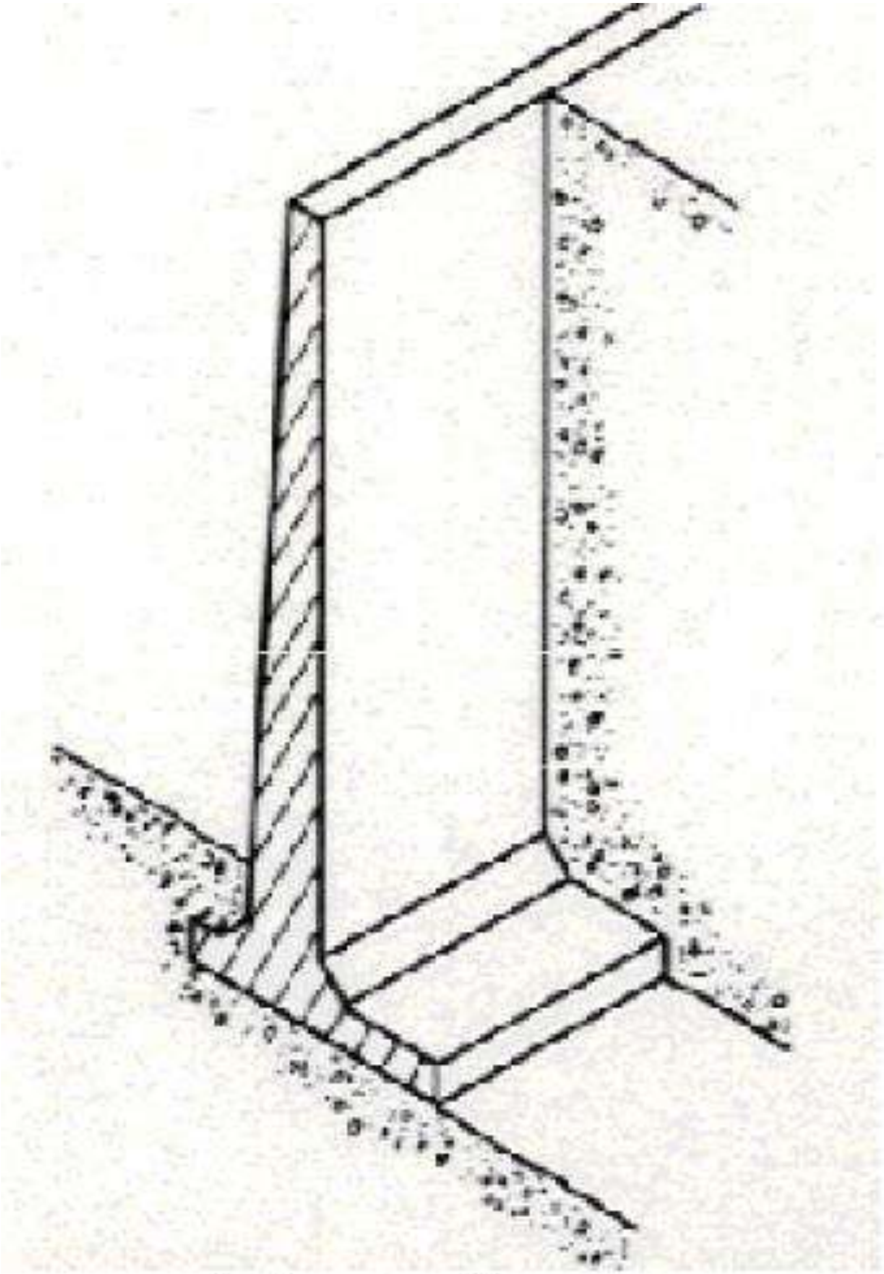




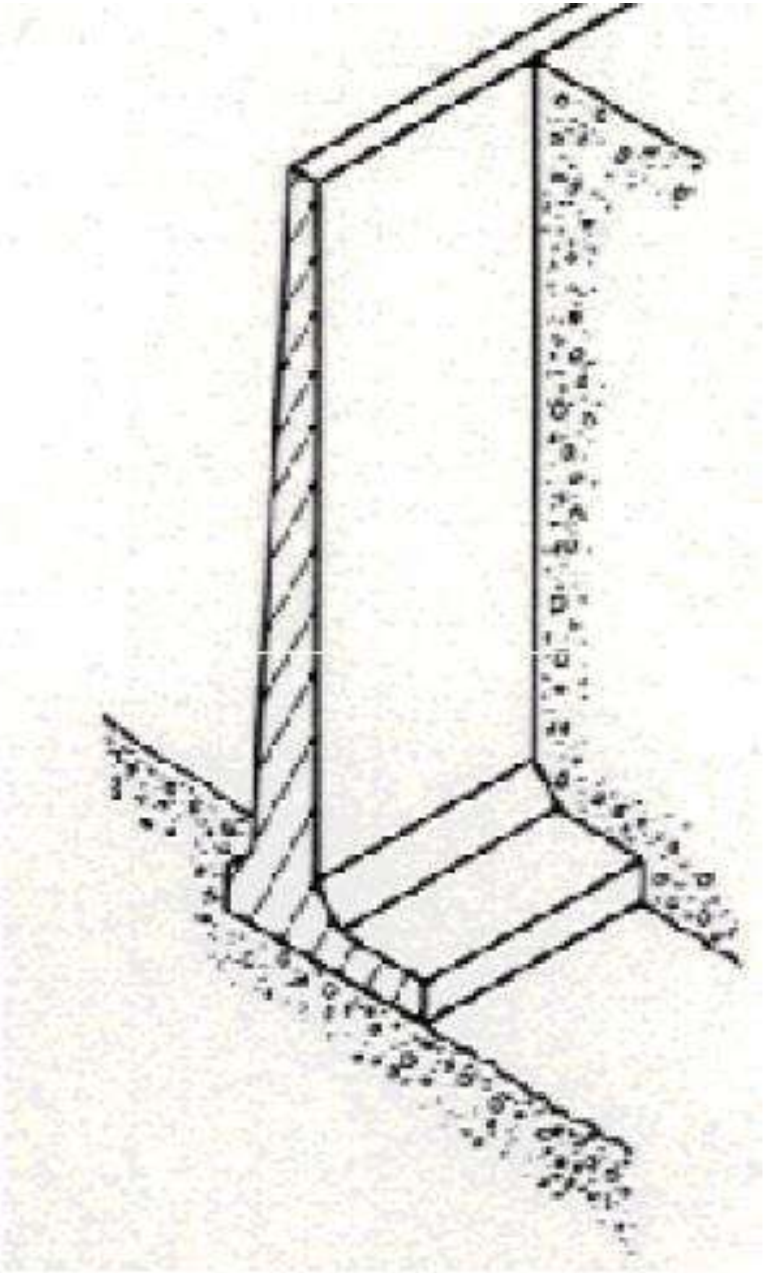
T-Shaped RW



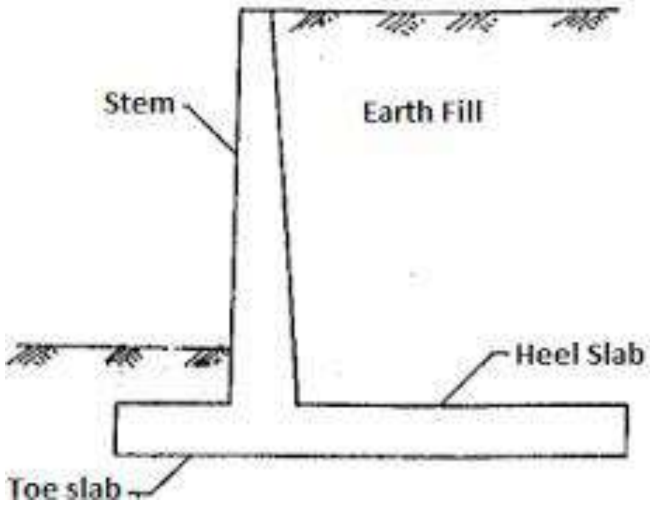
L-Shaped RW

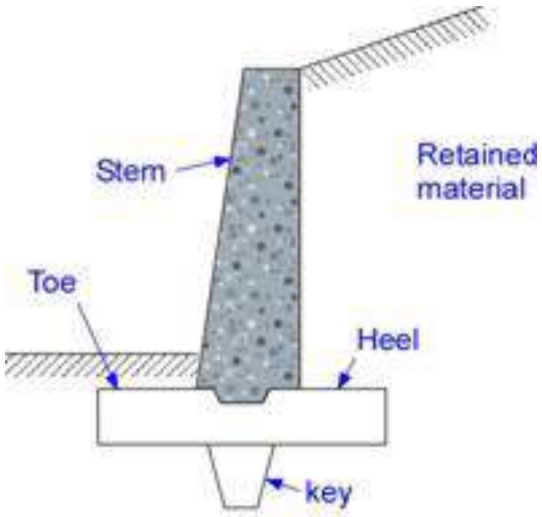


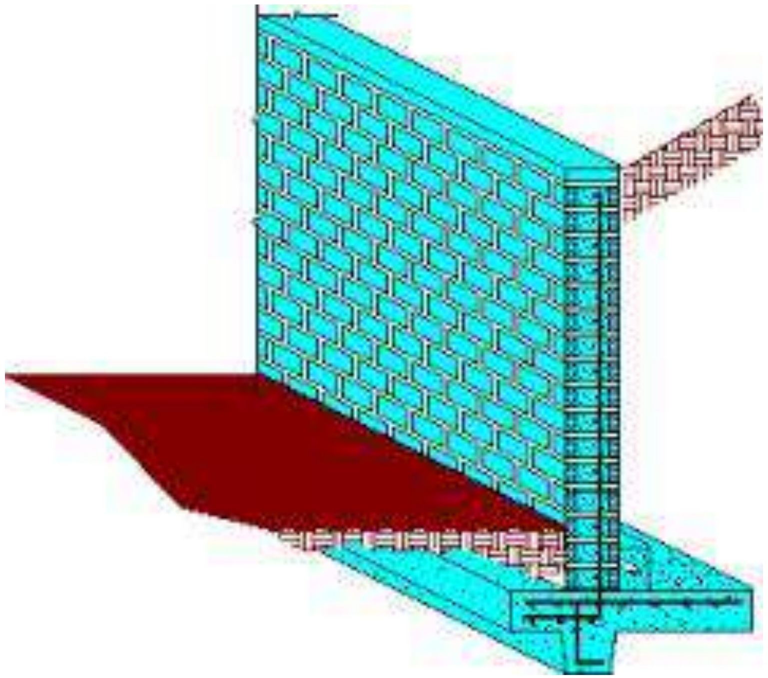
T-shaped walls.

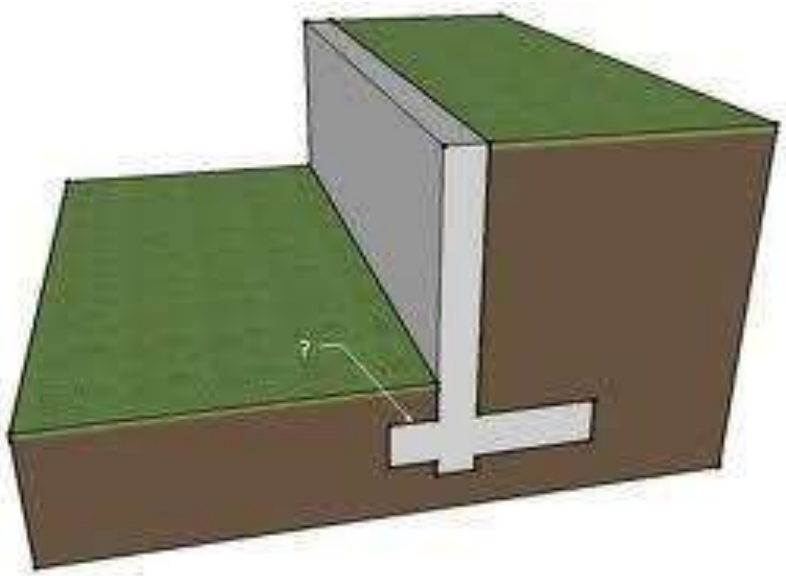


L-shaped walls.


Stem
Earth Fill
Heel Slab
Toe slab


Stem
Retained material
Toe
Heel
key
Cantilever retaining wall

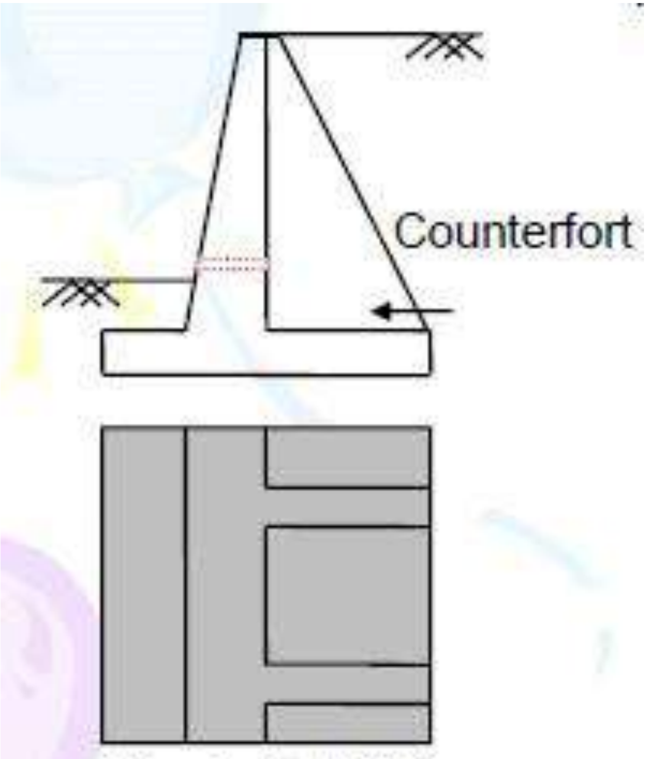




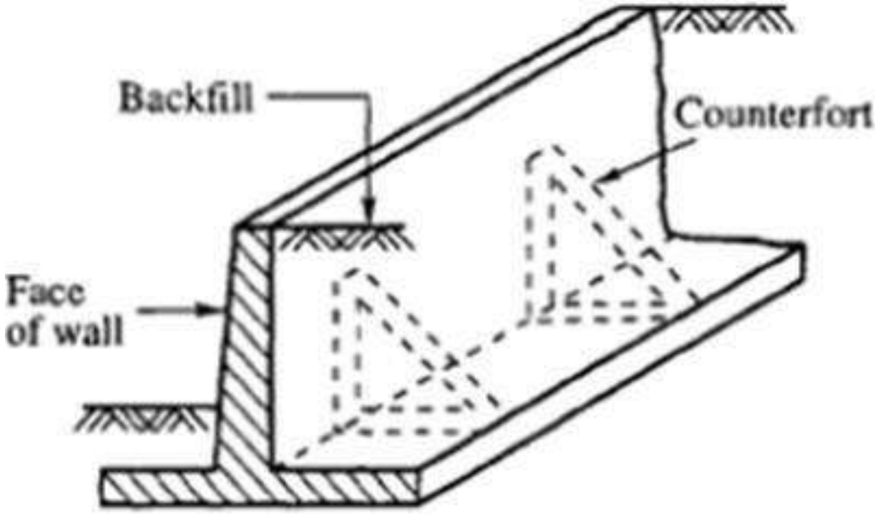
4. Counterfort Walls

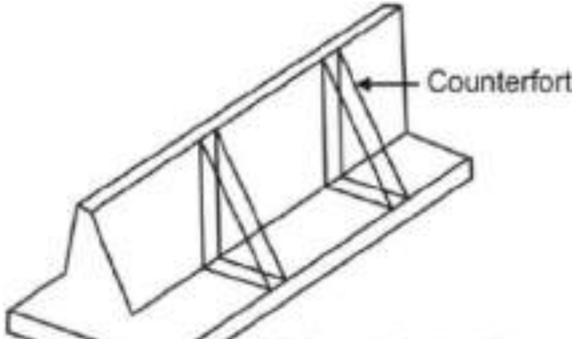
- Similar to cantilever walls except they have thin vertical concrete webs at regular intervals along the backside of the wall. These webs are known as *counterforts*.
- Counterforts tie the slab and base together, and the purpose of them is to reduce the shear forces and bending moments imposed on the wall by the soil. A secondary effect is to increase the weight of the wall from the added concrete.
- Can be precast or formed on site.
- More economical than cantilever walls for heights above 8 m (25 ft).
- Wall can be used for much longer lengths as compared to cantilever wall.

- It is just like a cantilever wall but much longer as compared to cantilever wall. If it is to be used for even longer distances some supports are provided to it at required intervals.
- Counterforts that tie the wall and the base slab together. The purpose of the counterforts is to reduce the shear and the bending moments.



Counterfort RW

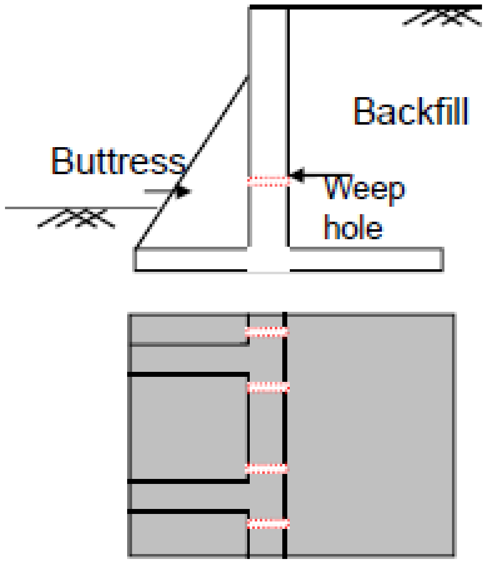




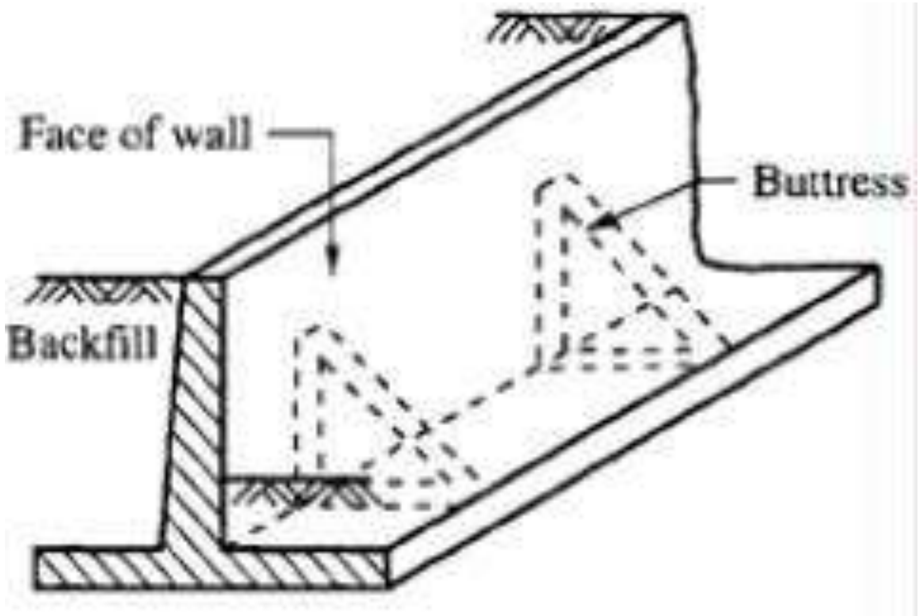
(d) Counterfort wall

5. Buttressed Walls

- o Similar to counterfort walls except the brackets or buttress walls are provided on the opposite side of the backfill.
- slab stems are used at some interval to tie the base slab and stem in order to reduce the shear force and bending moment for more economical design



Buttress RW



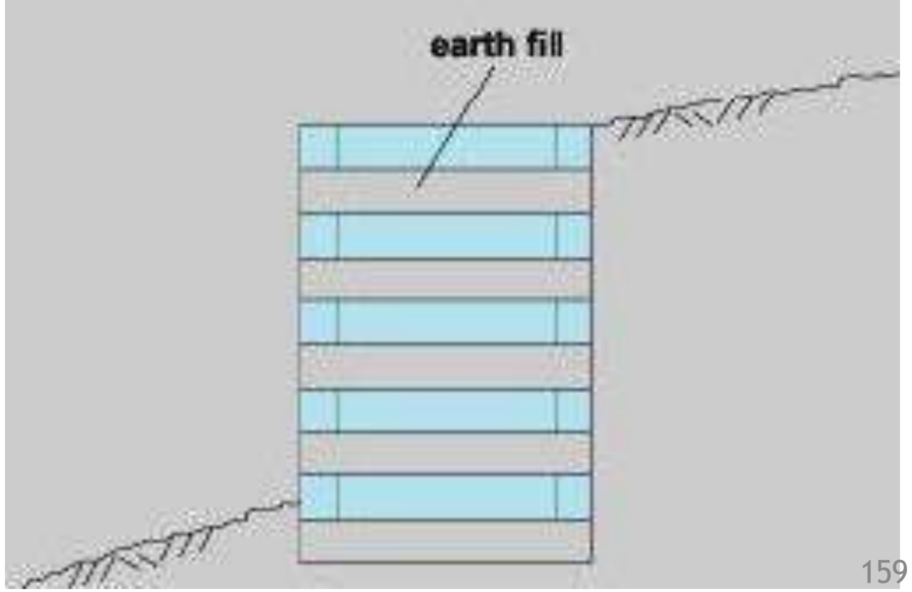
Mechanically Stabilized Earth (MSE) Walls

- These walls are among the most economical, and most commonly constructed.
- Contrary to other types, the MSE walls are supported by the soil, and not the other way around.
- They are supported by selected fills (granular) and held together by reinforcements, which can be either metallic strips or plastic meshes.
- The MSE Categories are

    A) Panel Walls,

    B) Concrete Block Walls, and

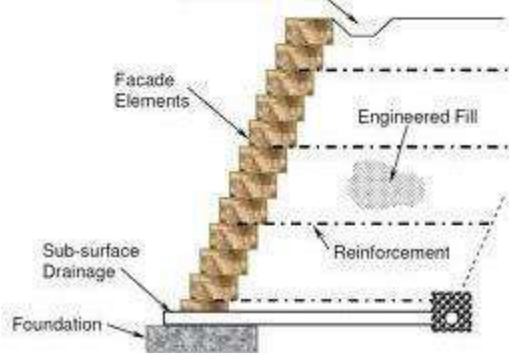
    C) Temporary Earth Walls

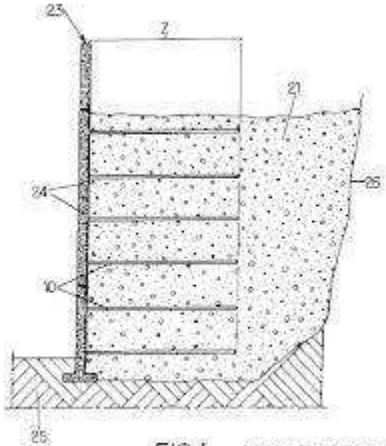


Panel Walls


Improvements to National Road 1 Section 2: 05-Mar-08 11:51:00 AM

Concrete Block walls





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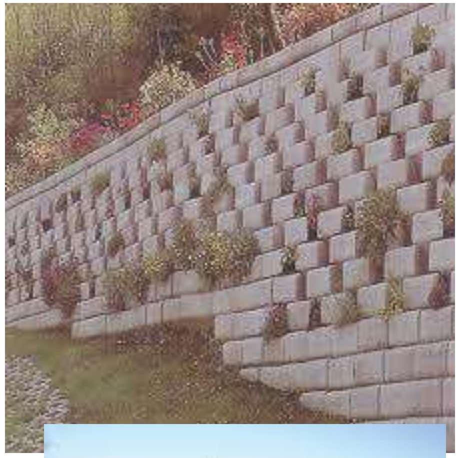
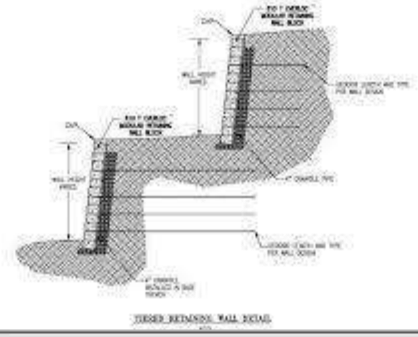
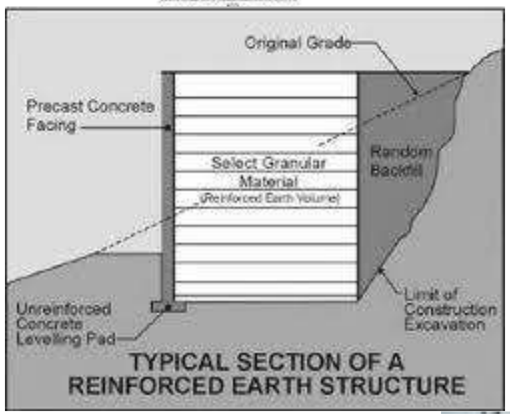
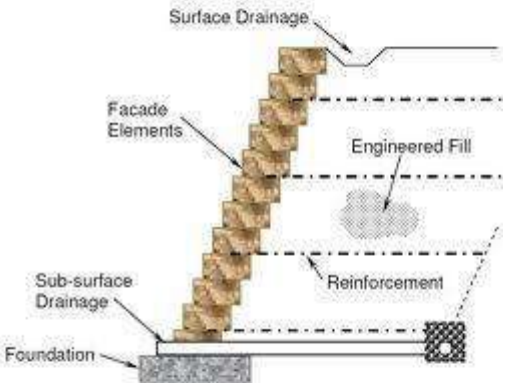
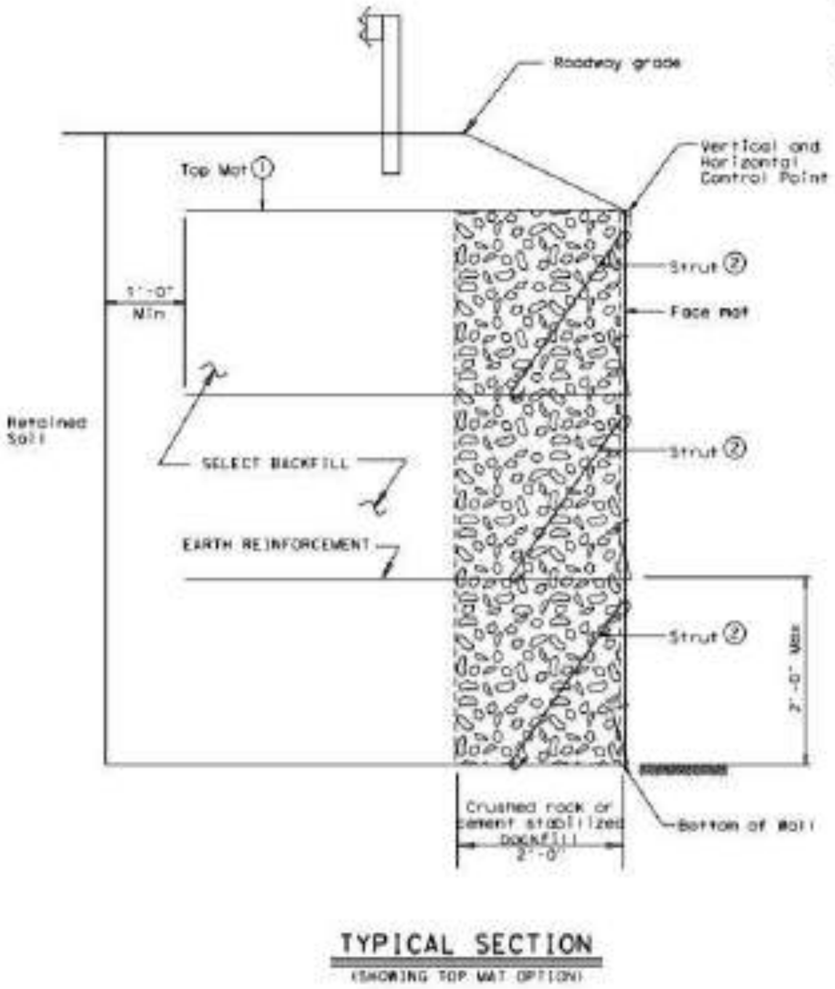


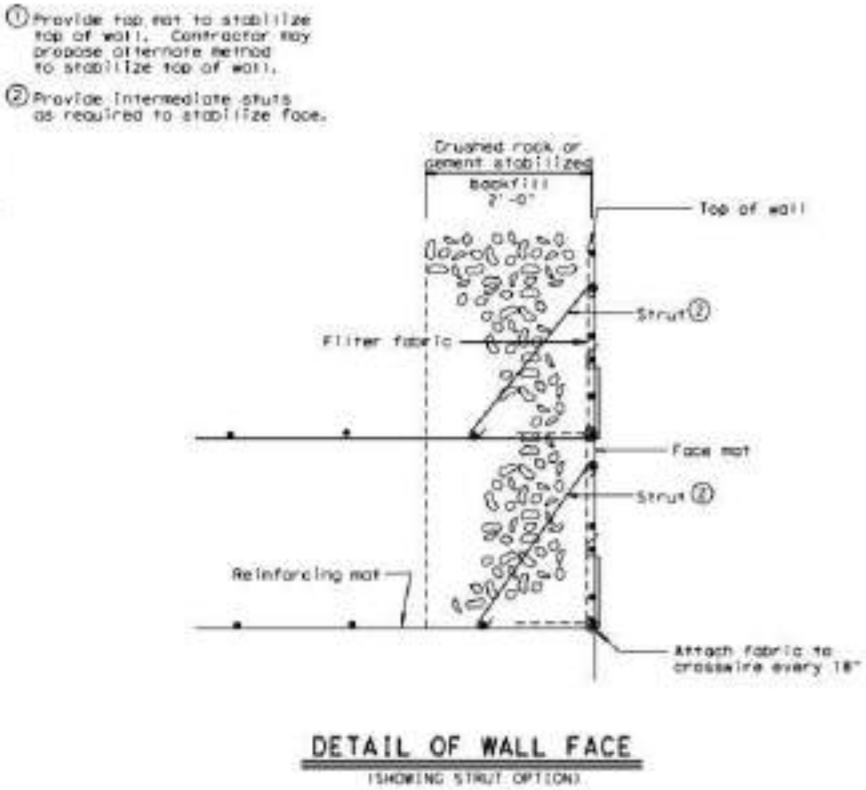



Original Grade
Precast Concrete Facing
Select Granular Material
(Reinforced Earth Volume)
Random Backfill
Unreinforced Concrete Levelling Pad
Limit of Construction Excavation
TYPICAL SECTION OF A REINFORCED EARTH STRUCTURE

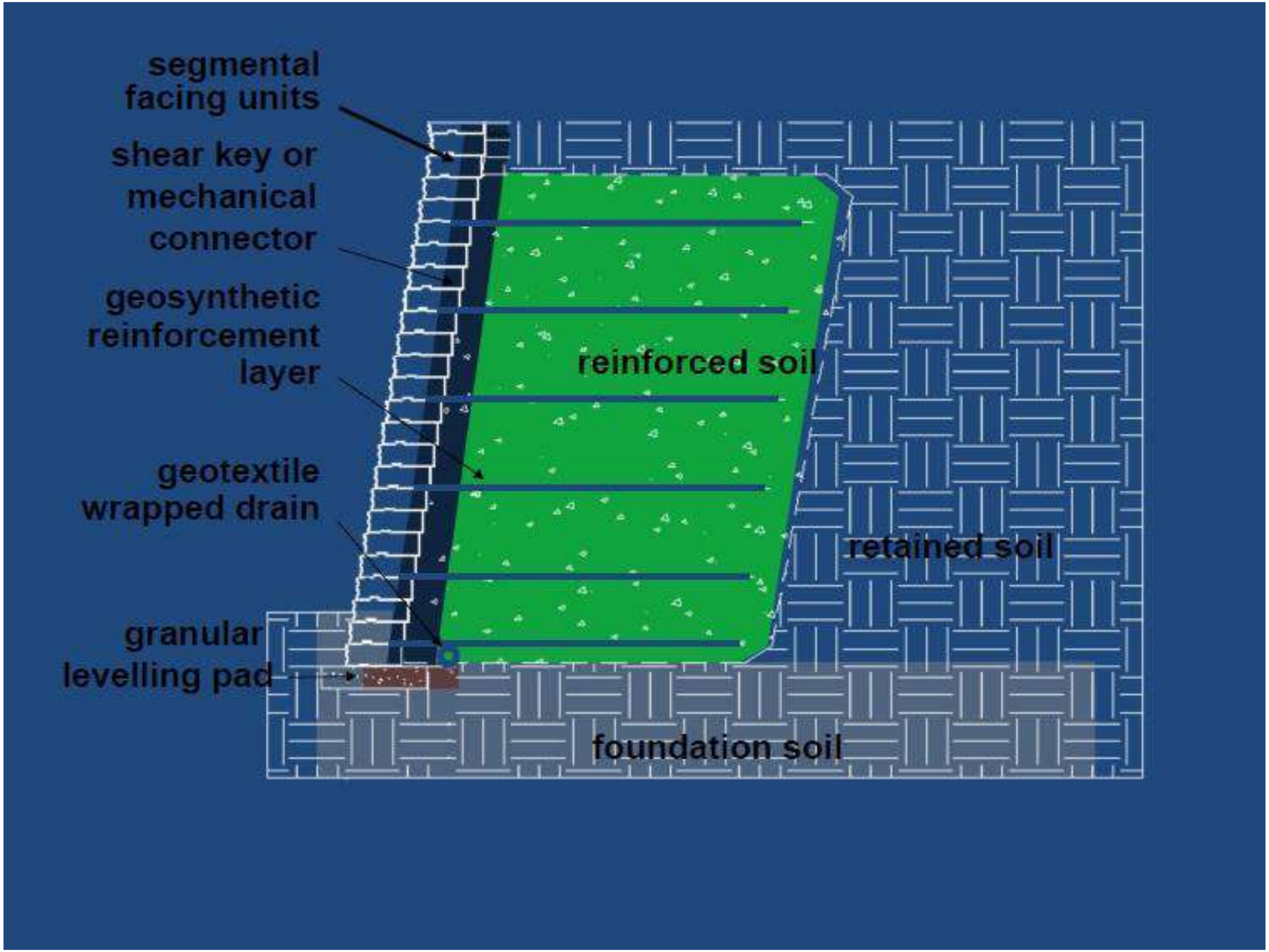

Surface Drainage
Facade Elements
Engineered Fill
Reinforcement
Sub-surface Drainage
Foundation

Temporary Earth Walls





- Nowadays, the main components of these types of walls are
  - *Backfill*—which is granular soil
  - *Reinforcement* in the backfill
  - A *cover* (or *skin*) on the front face
- The reinforcement can be thin galvanized steel strips, geogrid, or geotextile for descriptions of geogrid and geotextile).
- In most cases, precast concrete slabs are used as skin. The slabs are grooved to fit into each other so that soil cannot flow between the joints.
- Thin galvanized steel also can be used as skin when the reinforcements are metallic strips.
- When metal skins are used, they are bolted together, and reinforcing strips are placed between the skins.
- These walls are relatively flexible and can sustain large horizontal and vertical displacement without much damage.


segmental facing units
shear key or mechanical connector
geosynthetic reinforcement layer
geotextile wrapped drain
granular levelling pad
reinforced soil
retained soil
foundation soil

Reinforced Soil Walls

- It is a composite construction material in which the strength of fill is enhanced through addition of inextensible tensile reinforcement in the form of strips, sheets, grids or geotextiles.
- The technique of construction is quite suitable for hilly areas mainly due to the following reasons:

i) The fill materials which consists of mainly granular material is easily available in all parts of the hilly areas from cutting of hill side during construction of roads.

ii) These involve minimum alteration in natural slopes since the emphasis is on avoiding the cutting of natural slope.

iii) The land width or actual embankment width required is less.

iv) This is cost effective and environment friendly.


Boulanger


Boulanger


Boulanger


2. River Training Structures

River Training

- 'River training' refers to the structural measures which are taken to improve a river and its banks.
- River training is an important component in the prevention and mitigation of flash floods and general flood control, as well as in other activities such as ensuring safe passage of a flood under a bridge or protecting a road or railway embankement.

Objective of River Training

- To deflect the river from a bank and stop its erosion.
- To provide protection work along the banks of river, so that it may not damage and submerge cultivated and inhabited lands.
- To provide the minimum width of river required at the site of the bridge, so that the bridge can be constructed economically.
- If the navigation is to be done in river, river training works provide greater depth of water for this purpose.

- **BUT FOR ROADS**
- **To prevent out-flanking of bridges or other such types of construction works across the river and to train the river to flow in straight reach both u/s and d/s at the site of the bridge.**
    - *In Alluvial Rivers, the water flows in large width and has the tendency to erode side banks and submerge side areas.**(By changing Course)***
    - While designing bridges across such rivers, it is very difficult to decide the position of river due to uncertainty about the direction of their flow.
    - *There is always a danger that it may erode its one bank and change its course and may start flowing outside the constructed work.*
    - Under these conditions , it is take immediate measure to protect the banks.
    - At such places some special types of works are needed and known as "River Training Works".
- **To prevent the river from damaging highway and railway formation, bridges and other structures near the river**

Types of River Training Works/River Bank Protection Structures

1. Guide Bunds or Levees or Marginal Embankments
2. Spurs (Groynes)
3. Marginal Bunds
4. Closure Bunds
5. Assisted Cut-offs
6. Pitching of Banks and Subsiding Aprons
7. Pitched Islands
8. Silts and Closing Dykes

Guide Bunds/Banks

Necessity:

- Guide bunds are meant to confine and guide the river flow through the structure without causing damage to it and its approaches.
- They also prevent the out flanking of the structure.

Types of Guide Bunds

- Can either be divergent upstream or parallel.
- According to geometrical shape, the guide bunds may be straight or elliptical.

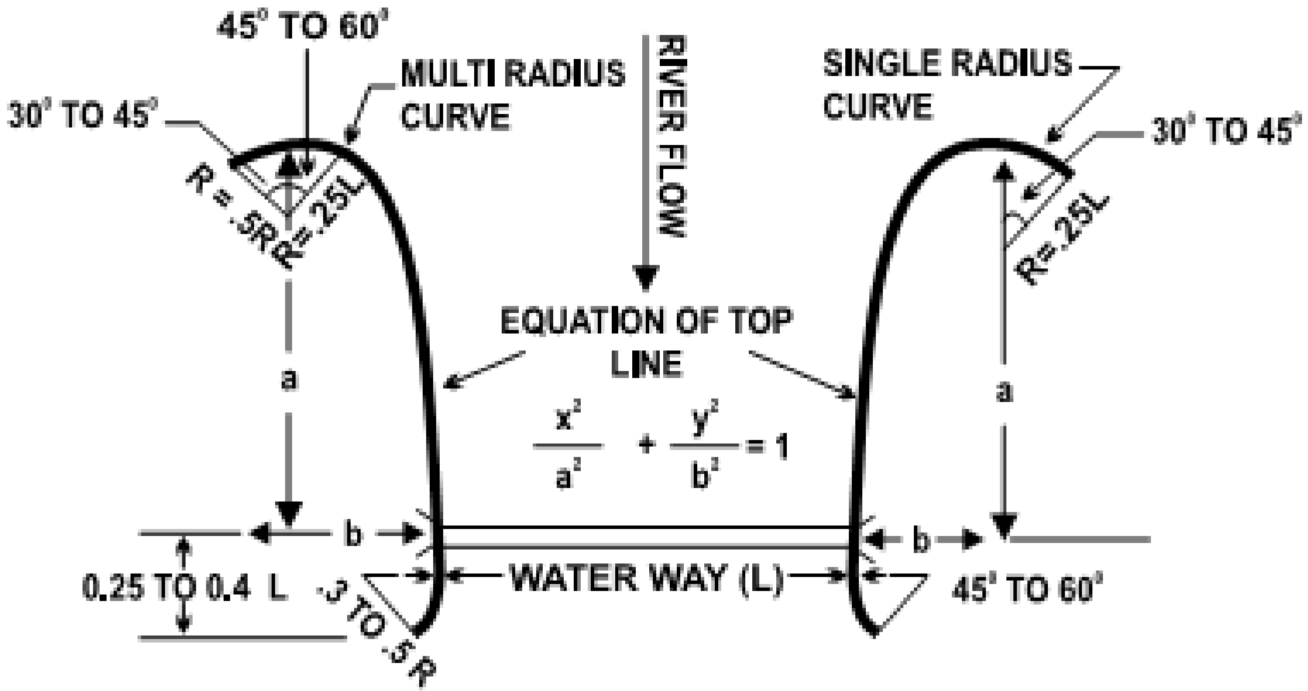


FIG. : ELLIPTICAL SHAPE OF GUIDE BUNDS

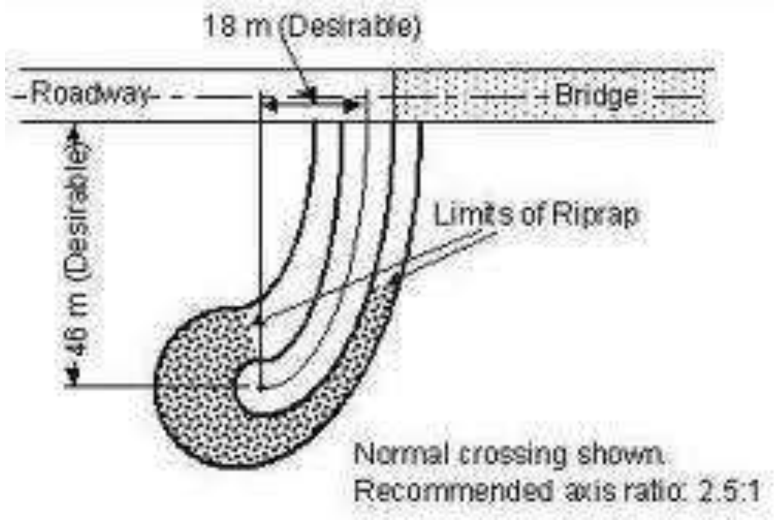
Spurs

- *When the river starts erosion of bank and changing of its course, the spurs or spurs are constructed to deflect the current away from the bank.*

- Spurs are the structures built transverse to the river flow extending from the river bank.

- If spurs are built in series, the bank can be completely protected.

- *A spur is a structure constructed transverse to the river flow and is projected form the bank into the river.*

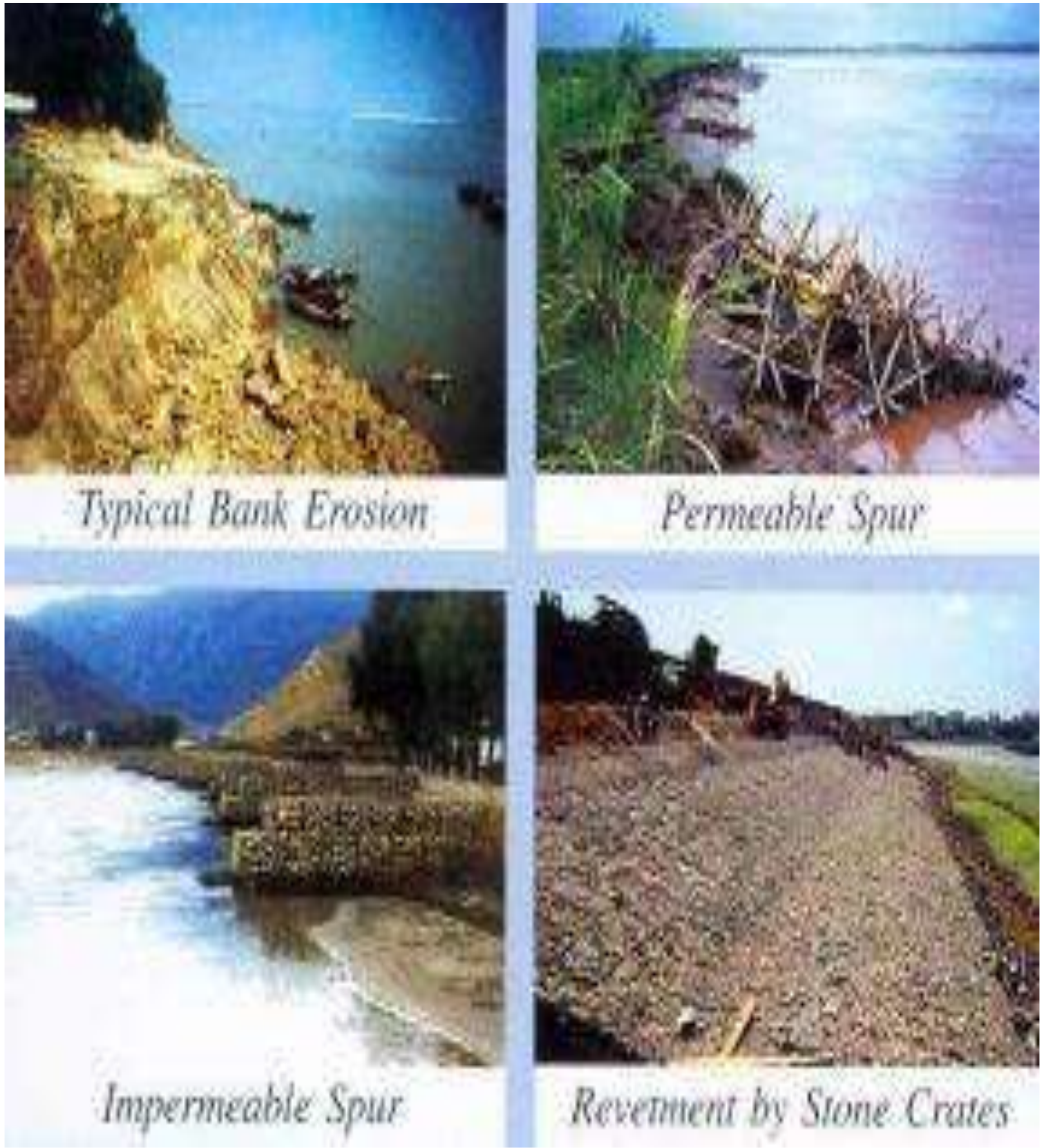


Types of Spurs /Groynes

i) Permeable Spurs

ii) Impermeable Spurs

- Permeable Spurs - **useful when concentration of suspended sediment** load is heavy; they allow water to pass through.
- Impermeable Spurs ***are made of solid core, constructed of stones or earth and stones with exposed faces protected by pitching. These spurs can with stand severe attack better than permeable spurs.***



Typical Bank Erosion

Permeable Spur

Impermeable Spur

Revetment by Stone Crates

ii) Spurs may be classified as

(a) Repelling (Deflecting)

(b) Attracting and

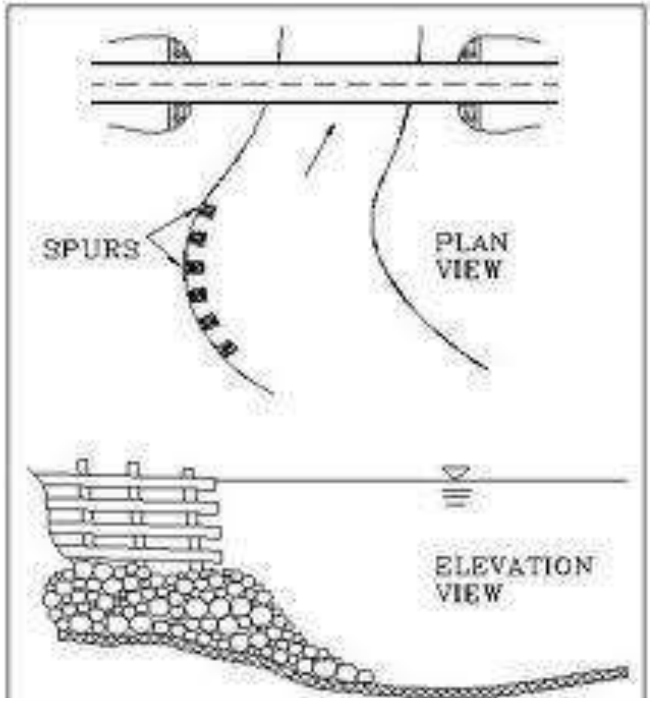
(c) Neutral (Sedimenting).

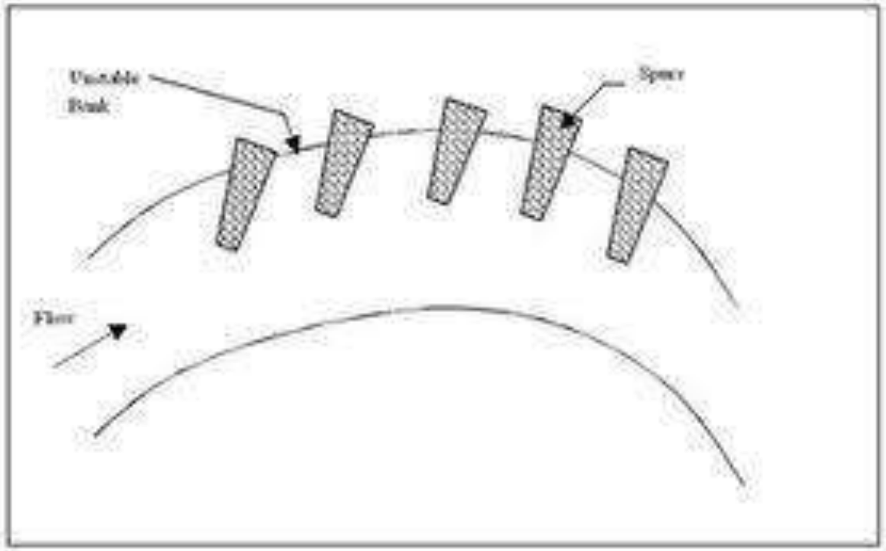
- Repelling (Deflecting) Spurs *are those which incline upstream at an angle of 60 degree to 70 degree to the river course and deflect the current towards the opposite bank. They cause silting in still water on the upstream pocket*.
- Attracting Spurs *incline downstream and make the deep channel flow continuously along their noses. They cause scour just on the downstream side of the head due to turbulence. The river flow is attracted towards the spur*.
- Normal (Holding or Sedimenting) Spurs *are those which are built at right angles to the bank to keep the stream in a particular position and promote silting between the spurs. They have practically no effect on the diversion of the current and are mostly used for training of rivers for navigational purposes.*


5 27'0

iii) Spurs are also classified as

- Full Height Spurs and
    - *Where top level is higher than HFL, it is called a full height spur.*
- Part Height Spurs.
    - *Where top level is below than HFL, it is called a part height spur.*


SPURS
PLAN VIEW
ELEVATION VIEW



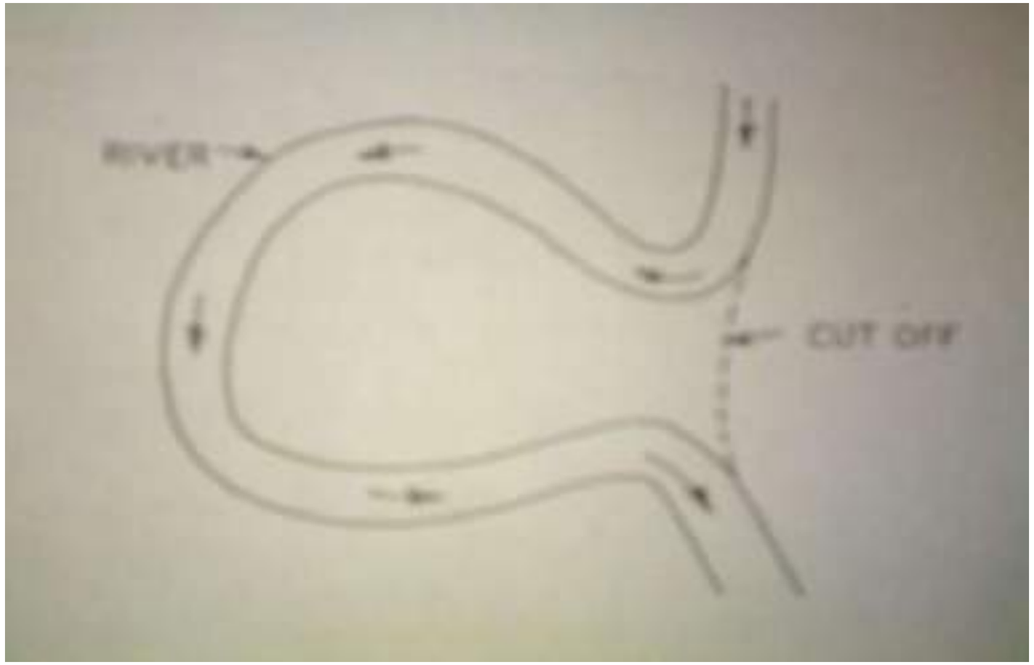

Narayani river

Marginal Bunds

- Marginal bunds are provided to contain the spread of the river when the river in flood spills over its banks upstream of the bridge site over wide area and likely to spill in the neighbouring water courses or cause other damages.
- *The marginal bund should normally be built well away from the active area of the river.*
- The slope should be well protected by turfing.
- *Where a marginal bund has to be built in the active area of the river, it should be protected with pitching and apron.*
- The earth for the construction of marginal bund should preferably be obtained form the river side.
- *The upper end of the marginal bund should be anchored into high ground well above HFL.*
- Marginal bunds should be inspected every year along with the annual bridge inspection and necessary repairs should be carried out before the onset of monsoon.
- *Cattle crossing and rodent holes across the marginal bund should be specially watched and deficiencies made good.*

Assisted Cut- Offs

- Sometimes when very heavy meandering develops near bridges and there is a danger of its encroaching too heavily into the still water area or otherwise dangerously approaching the railway embankment, it becomes necessary to dig a cut-off channel which will ultimately develop and help in the diversion of water through it.
- To effect economy, a pilot channel cut is usually made when there is low flow in the river and full development of the channel takes place during the flood.



- This cut off channel should preferably have

(i) at least three times the river's straight regime slope and

(ii) the upstream end should take off from where the bed load of main channel has less than the average amount of coarse material i. e. from the active part of the channel where the velocity is more.

- The entrance to the pilot cut should be bell shaped to facilitate entry of water.
- Cut off should be planned with care taking all relevant factors into account

Protection of Approach Banks

1. *Approach banks of bridges may be subjected to severe attack under the following conditions:*

i) When the HFL at the bridge is very high and there is spill beyond the normal flow channel.

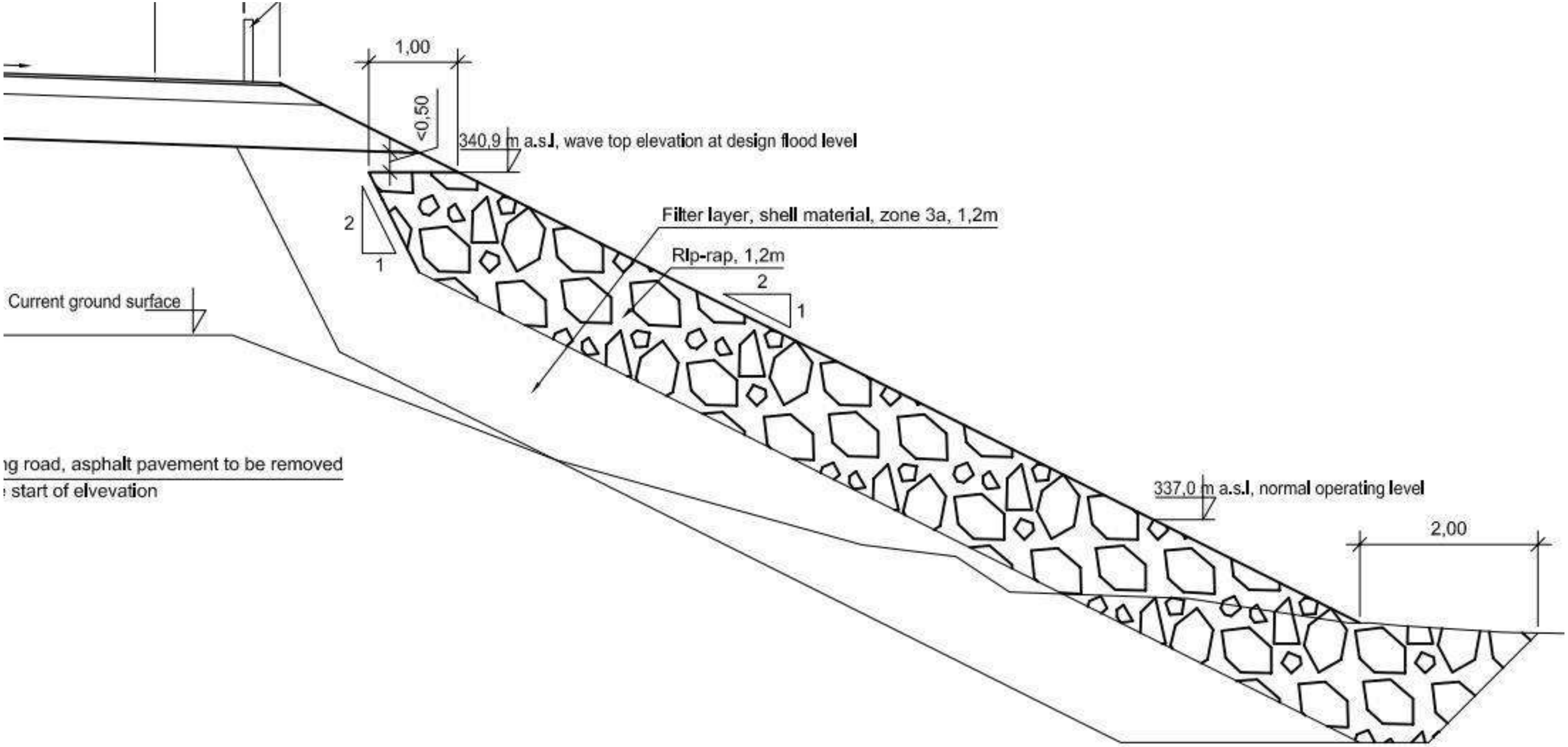
ii) When the stream meets a main river just downstream of the bridge.

iii) In the case of bridges with insufficient water way.

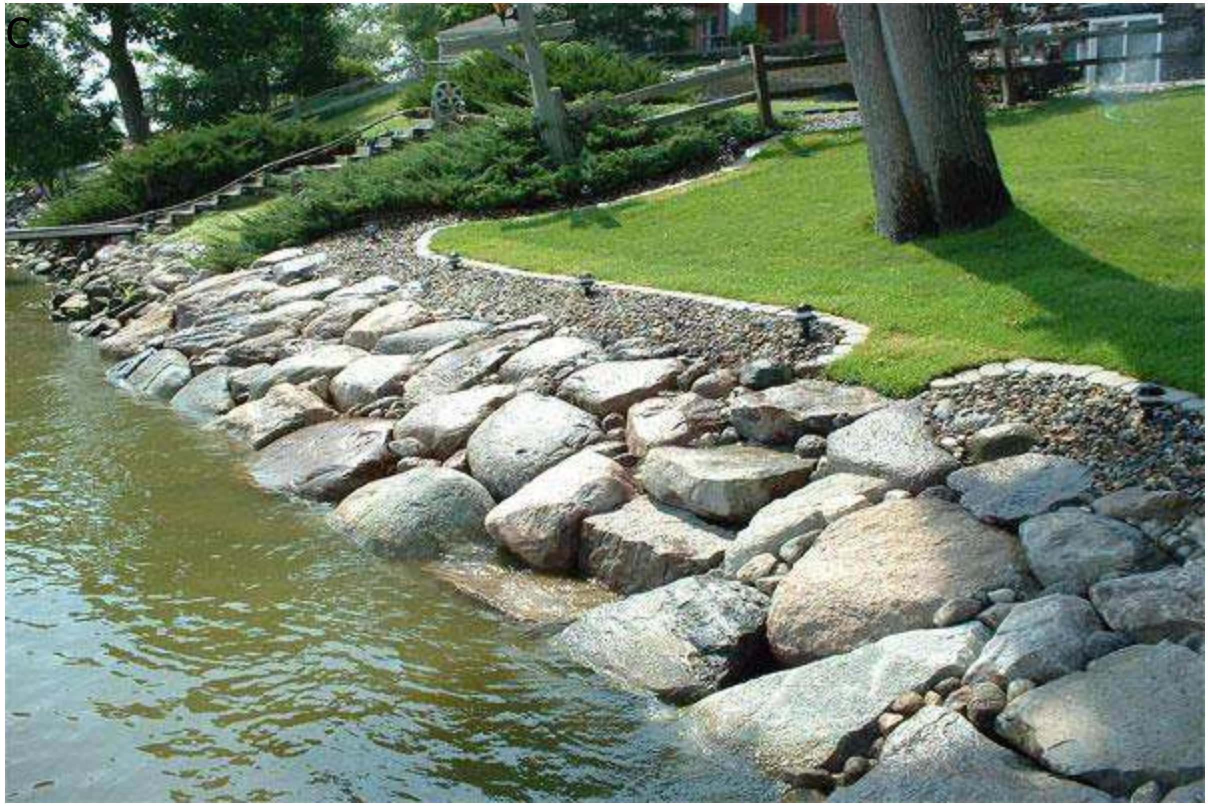
iv) The wave action on the approach bank of bridges situated in a lake/large tank bed may have a detrimental effect.

- *In all the above cases the pitching of the approach bank upto HFL with sufficient free board is an effective solution. Provision* of toe wall and *narrow apron in some cases will also be useful.*

RRM Riprap


1,00
<0,50
340,9 m a.s.l, wave top elevation at design flood level
Filter layer, shell material, zone 3a, 1,2m
Rip-rap, 1,2m
2
1
2
1
Current ground surface
ng road, asphalt pavement to be removed
e start of elvevation
337,0 m a.s.l, normal operating level
2,00

C



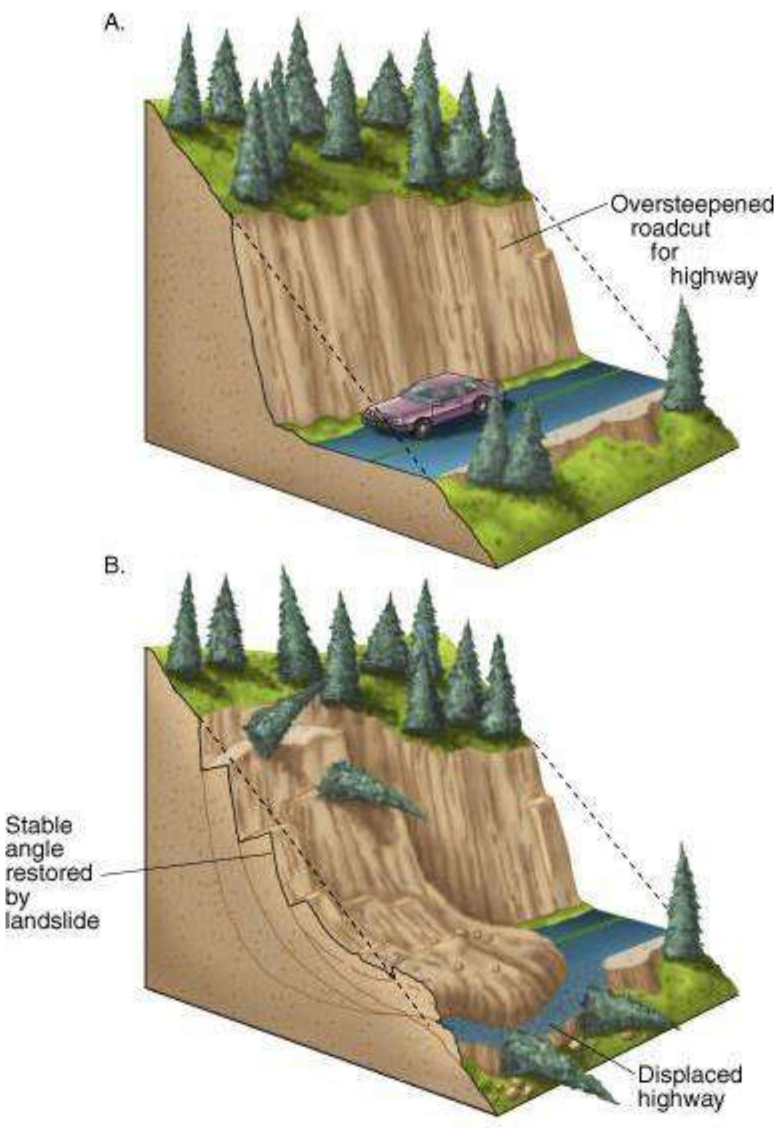
2. If deep borrow pits are dug near the toe of approach banks, the water flows through these pits and forms a gradually deepening water course which may eventually threaten the safety of the approach bank. In this case it will be useful to put rubble "T" spurs across the flow to reduce the velocity and expedite silting of the course.

3. Landslide Stabilization Structures/Slope Protection Structures/Slope Stabilization Structures

Landslides

- If a mass of earth moves along a definite plane or surface the failure is termed as Landslide.
- Large block known as a slump block moves during the landslide.
- The scar above a landslide is easilyvisible.
- They can occur along a slope where the internal resistance of the rocks are reduced or they loose their holdingcapacity.
- Common after earthquakes or after removal of part of the slope due to construction, particularly for construction of roads.

- During the movement landslide can result into the:
- **<u>Debris Slides or Slump</u>** - are failure of unconsolidated material on a surface; **<u>Rock Slides or Rock Falls</u>** – where movement of large rock block rolls



- They are also common along the steep banks of rivers, lakes etc.
- Pore Water Pressure is the key to monitoring landslides. Shear strength (a resisting force) decreases and the weight (a driving force increases).

Causes of Landslides

1) Landslide Triggers

(i) Cloud burst (200-1000mm/day)

(ii) Uncontrolled flow of water on slope surface from over flooded steep gullies.

(iii) Toe cutting may activate failure by overtopping of rock blocks or slides in colluvium.

(iv) Earthquake

(v) Blasting

(vi) Flash flood due toglacial lake outbursts

2) Causes

A) Man Made Causes

- (i) Deforestation
- (ii) Blasting quarrying
- (iii) Hill cutting
- (iv) Irrigation of paddy fields, water storage ponds
- (v) Undermining, tunnelling
- (vi) Vehicle vibration in hill roads

B) Erosion Process

- (i) Blocking of natural drainage
- (ii) High flow velocities in steep gullies

C) Pore water pressure

D) Geological conditions

- (i) Minéral composition, rock type, structure etc.

(Shrestha B.D, 2000)

Preventive Measures

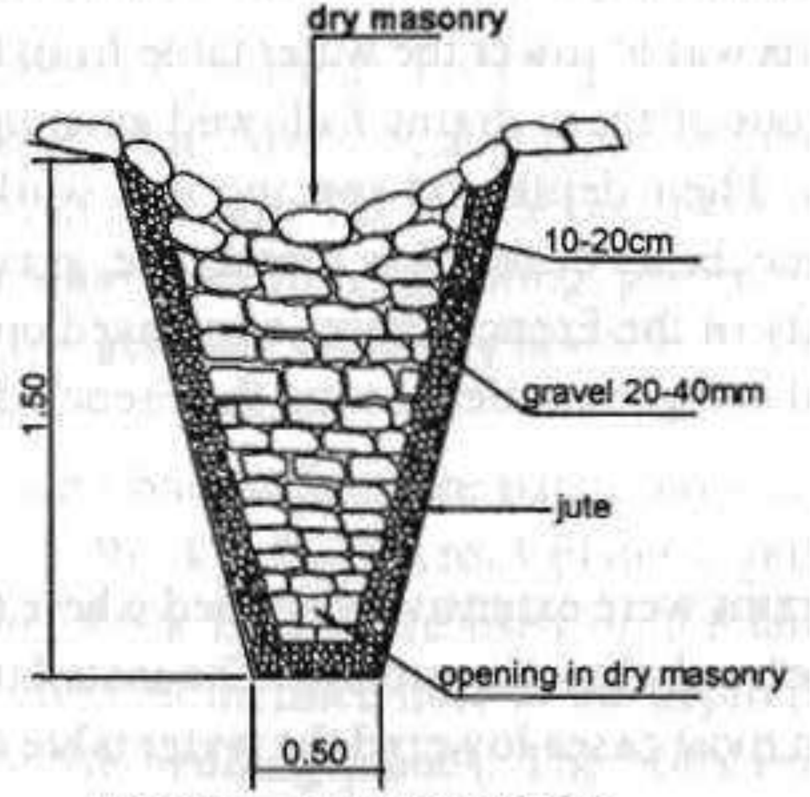
- The main factors which contribute to landslides are ***Slope, water content, geological structure, unconsolidated or loose sediments, lithology and human interference.***
- ***Effect of Water:*** Make proper drainage network for quick removal of percolating moisture or rain water by constructing ditches and water ways along the slope
- ***Slope:*** Retaining wall may be constructed against the slopes, which can prevents rolling down of material. Terracing of the slope is an effective measure.
- ***Geological structures:*** Weak planes or zones may covered or grouted to prevent percolation of water, this increases the compaction of loose material.

Landslide Stabilization Structures

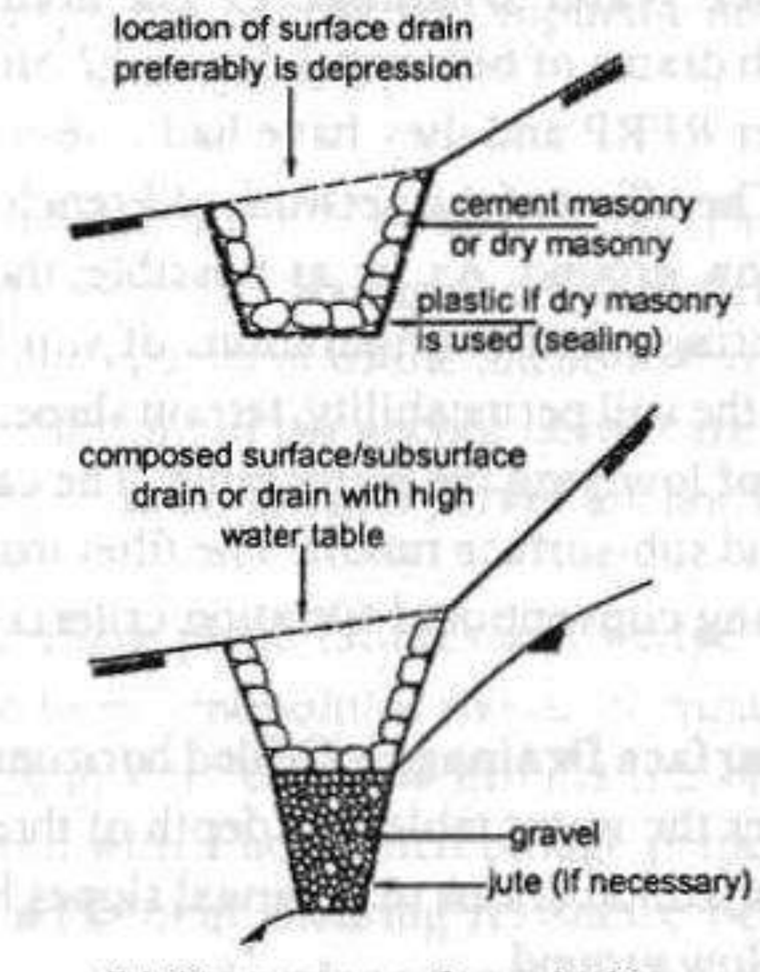
1) Water Management and Stabilization Measures/ Structures

a) French Drain – Stone Tributary Drain
b) Masonry Surface Drain
c) Stone Pitching
d) Gabion Tributary Drain

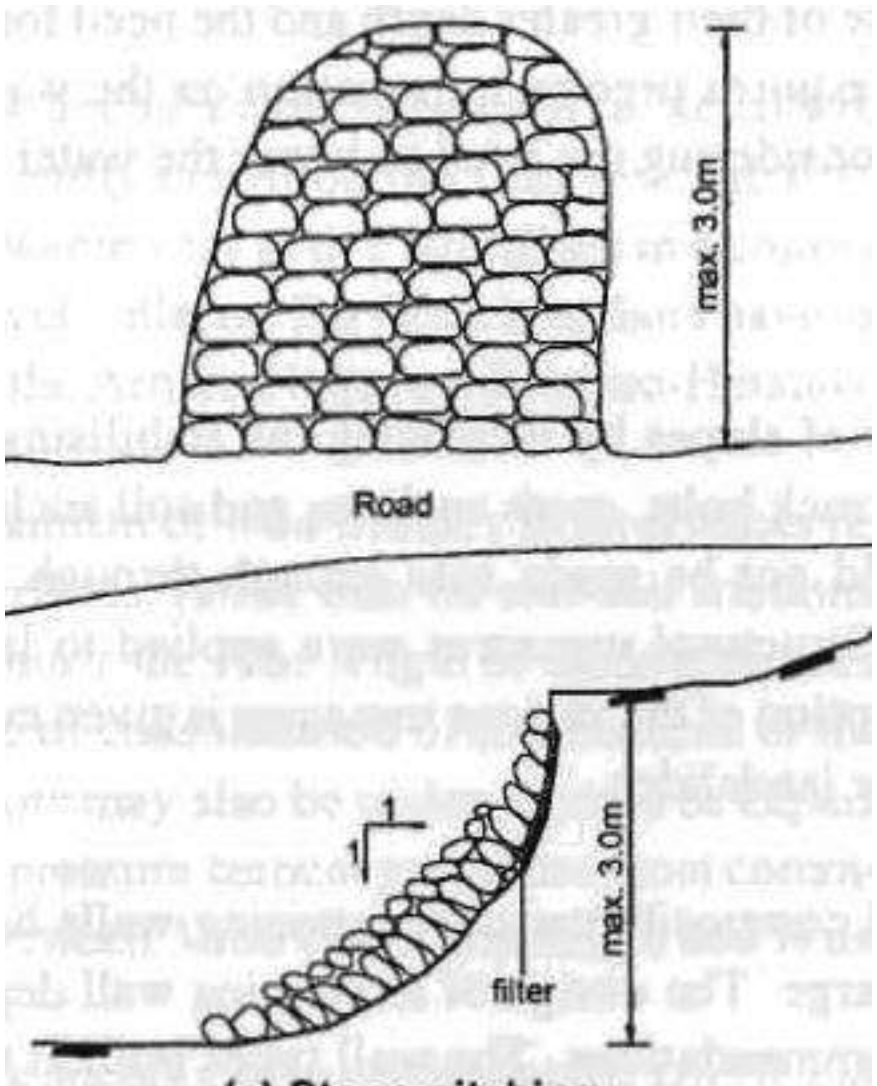
- Management of drainage is important for the control of landslides.
- Drainage management alone has significantly improved the stability of Medium and Large Landslide-prone Slopes.



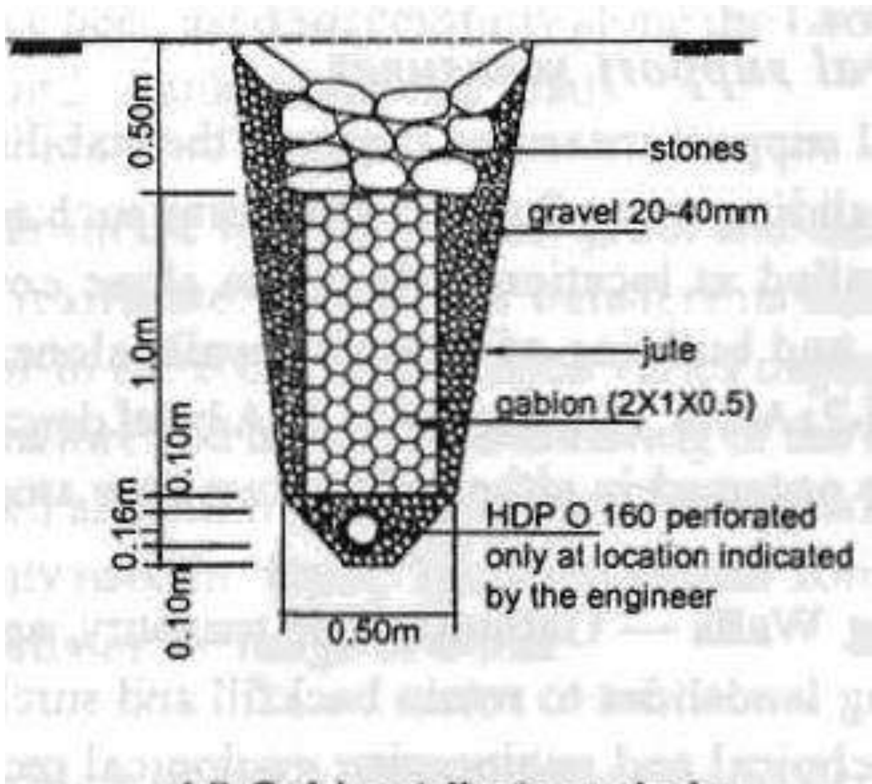
(a) Stone tributary drain
(French drain)



(b) Masonry surface drain



(c) Stone pitching



(d) Gabion tributary drain

Landslide Stabilization Structures

2) Slope stabilizing techniques

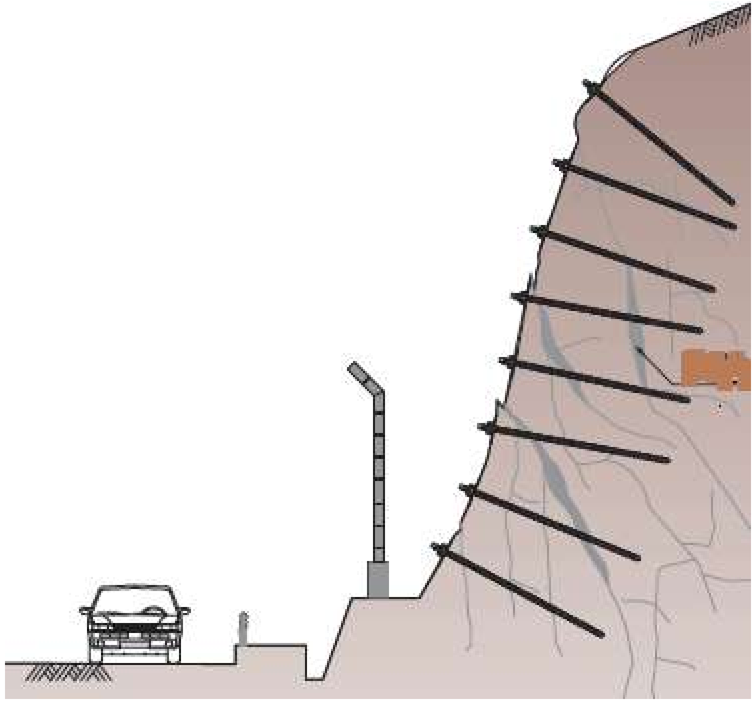
a. Scaling : Loose and unstable parts of the slope are removed

b. Concrete spraying (Shortcreting) :

- Slope is stabilized by spraying of concrete over the surface
- The sprayed concrete penetrates to the depths of the rock mass and forms ones solid block , thus prevents landslides

Rock bolting / Nailing :

- Loose surficial matters are tied to the lower lying rocks by use of rock bolt or nails

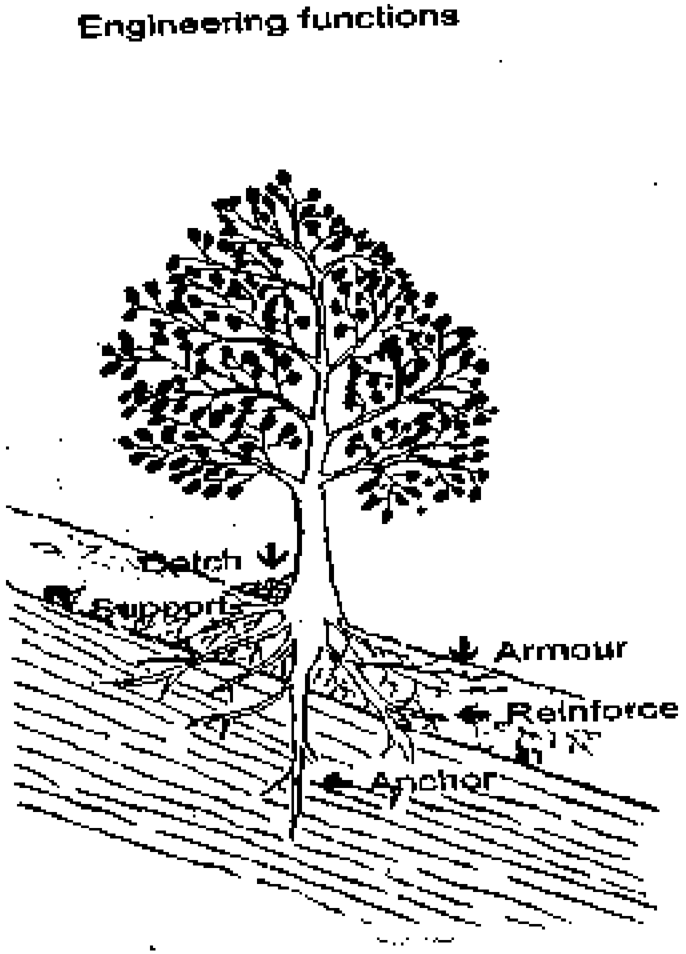


3) Bioengineering Structures for Slope Stabilization

- Soil Bioengineering is a useful and effective technology for slope stabilization and soil conservation.
- Soil bioengineering is defined as *"the use of living plant materials to construct structures that perform an engineering function".*
- The technology is now widely used for slope stabilization and soil conservation in many countries that experience slope instability.
- In addition to slope stabilization, soil bioengineering structures are also used to control gully and river bank erosion.
- Gullies commonly occur on landslides and fill slopes if treatment is not given in time and landslides are also triggered by undercutting from river and channel erosion.

Functions of vegetation (Bioengineering)

Catch
Support
Armor
Reinforce
Anchor
Drain



Types of Bio Engineering Structures
(a)Vegetative Retaining Walls

- Soil bioengineering retaining walls are effective in stabilizing slips and small landslides.
- Different types of soil bioengineering retaining walls have been used for stabilizing landslides in different parts of the world.
- Among these, the **most common soil bioengineering retaining walls are vegetated soft gabions, live brushwood, Vegetated Geotextile Retaining Wall and timber cribwalls.**
- The vegetated soft gabion and live brushwood retaining walls are also combined with gabion, stone masonry and concrete walls to reduced cost of engineering structures for slope stabilization.
- The selection of the type of bioengineering retaining wall for a particular site depends on the availability of the material required at the particular site and for the favored construction method.

Vegetated Soft Gabion Retaining Wall

- This retaining structure utilizes empty used bags of synthetic fiber or jute, generally available in the market at cheap rates.
- The ruble cleared from the toe of the landslide is used for filling the bags for the construction of vegetated soft gabion walls.
- The filled bags are used as building blocks like bricks to construct the retaining wall (Figure 1).
- The foundation is excavated at the toe of the landslide by removing the debris.
- The first layer of bags is placed length wise across the length of the retaining wall.

- A 15cm thick soil layer is placed on the bags and branches of the living woody plants and rooted seedlings are placed above the soil layer in such a way that their basal (butt) ends reaches the mother soil of the slope.
- The soil is placed on the brush-hedge layers and compacted well.
- Above the brush layer another layer of bags is placed width wise by giving a step of 20-35cm.
- The soil from the upslope is scrapped for filling the space behind the bags and compacted properly.
- A second layer of brush layer treatment is given above the bags as explained above.
- The process is repeated till the required height of the retaining wall is reached.
- After rooting and sprouting, thick vegetation is established at the toe of the landslide (Photo 1a, 1b and 1c). By the time the synthetic bags rot the vegetation is established and the slope is stabilized permanently.

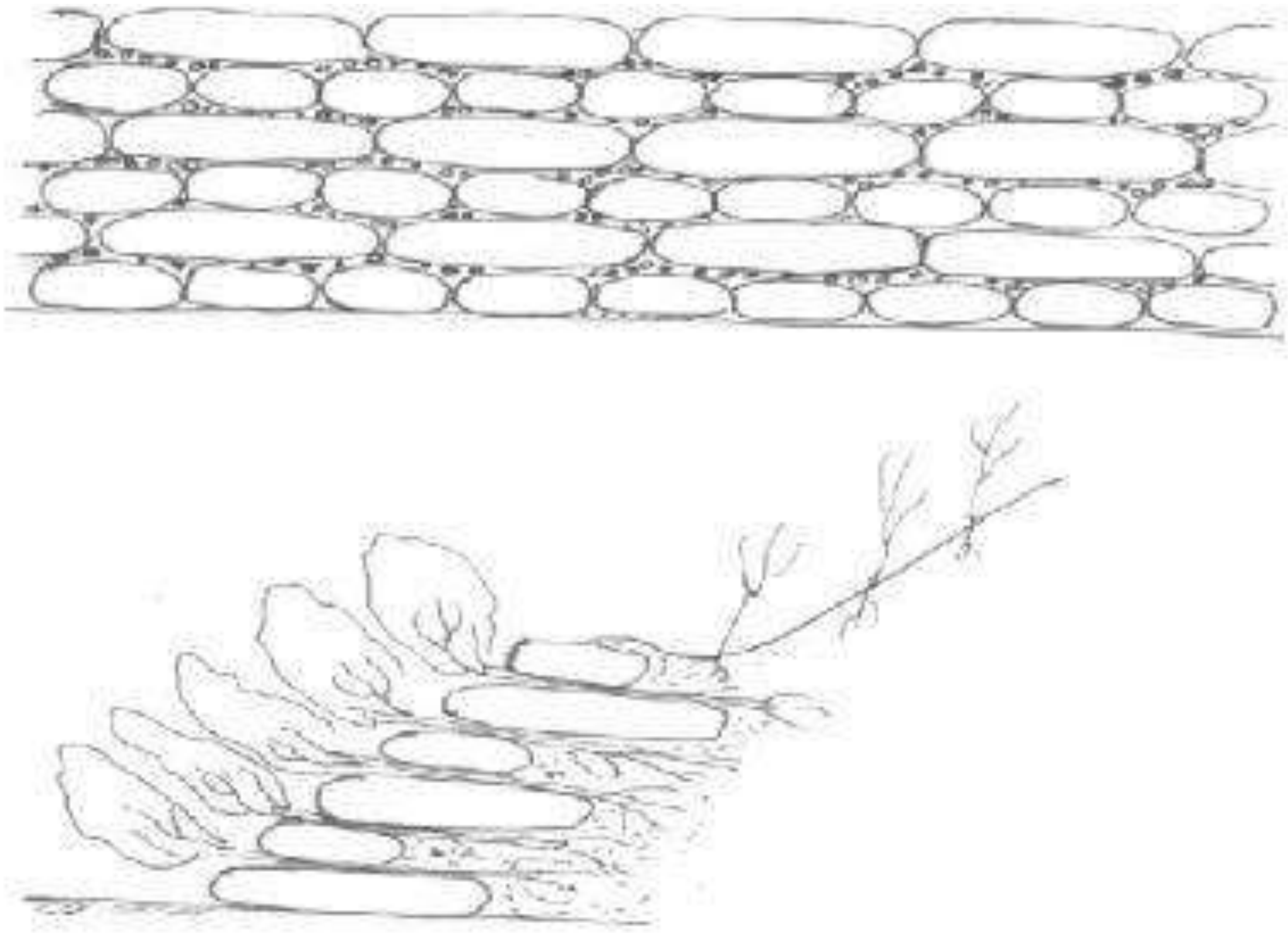


Figure 1. Schematic diagram of vegetated soft gabion

Photo 1a - Vegetated soft gabion wall at time of construction

Photo 1b - Vegetated soft gabion retaining wall, four months after construction

Photo 1c - Vegetated soft gabion Wall, two years after establishment

Live Brushwood Retaining Wall

- For establishing live brushwood retaining walls, poles of tree species such as *Marmele sp. (Amare fuik), Jatropha sp., Cordia spp. and Ficus spp.* are driven at the toe of a small landslide at 1m spacing across the toe of the slope.
- The length of the poles should be 1.5m (minimum). Brushwood bundles having 15cm diameter from any tree, bush or grass species available near the site are prepared and placed along the uphill side of the poles.
- Coconut or palm leaves along with their stalks are the best suited material for this purpose.
- The soil is pushed from the upslope and firmly packed behind the brushwood bundles or coconut leave stalks.
- After attaining 30cm height, brush layering treatment is carried out by using the brushwood of trees species with high growth. The placed brushwood is covered with soil which is then compacted.
- Only 10cm length of the tail ends of the brushwood is projected out of the brushwood wall. Brushwood bundles or palm leaves are again placed above brush layer treatment and the soil is filled as described above.
- The second layer of brushwood is placed and the process is repeated till the top of the poles is reached (Photos 2, 3 and 4). If the pole is less than the required height of the retaining wall, another live brush retaining wall is established after giving a step of 1m.
- The poles and the fresh brushwood used in brush layers quickly sprout, creating a live vegetation retaining wall. By the

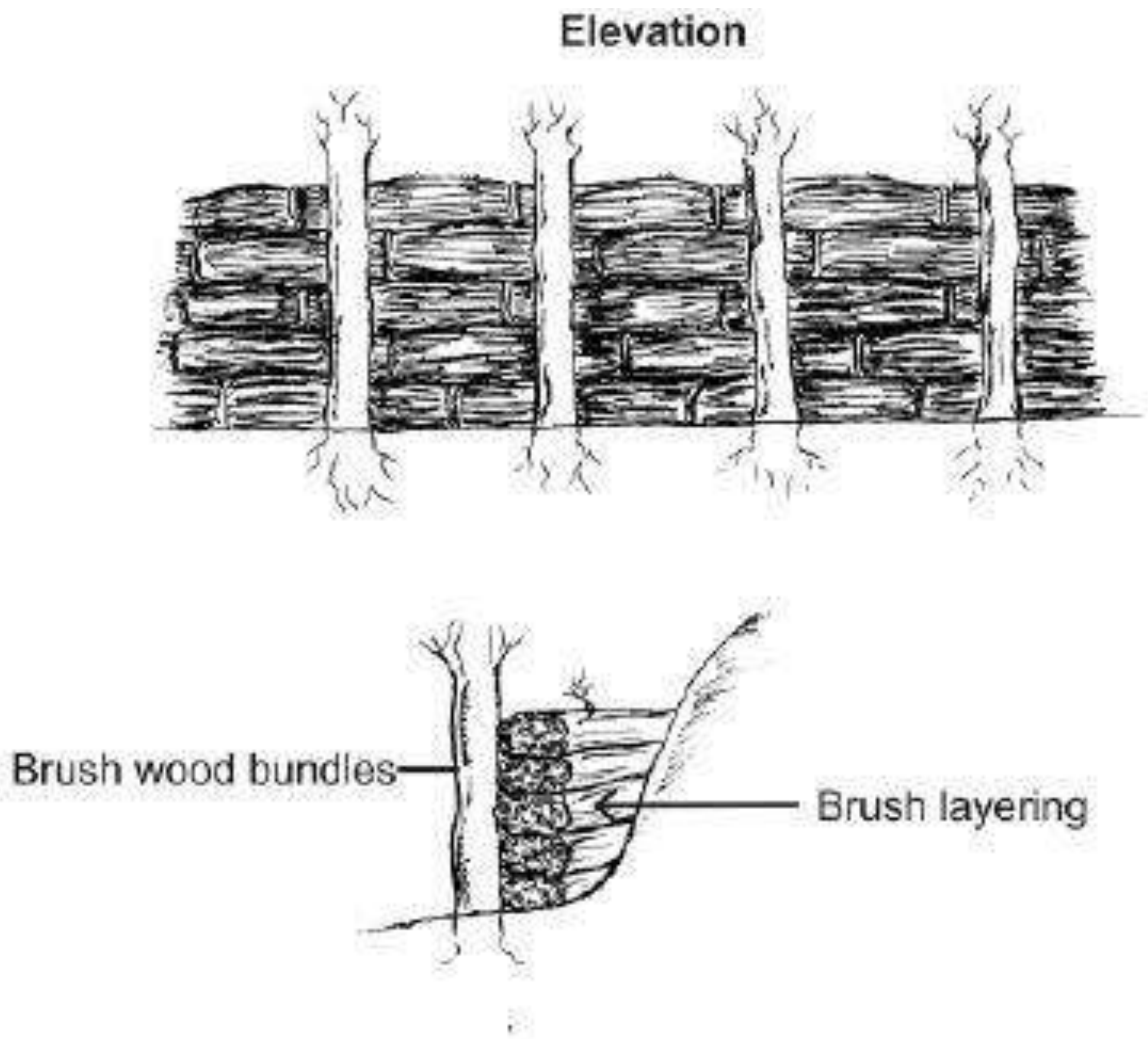


Figure 2 - Schematic Diagram of a Live Brushwood Retaining wall

Photo 2 - Live brushwood retaining wall

Photo 3 - Newly constructed live brushwood retaining wall.

Vegetated Geotextile Retaining Wall

- Geo-textile rolls are used for constructing vegetated geo-textile retaining walls. Coconut fiber and jute is also used for weaving the biodegradable geo-textile sheets. After removing the debris from the toe of landslide the geo-textile sheet is spread across a width of 1.5m. The remaining portion of the sheet is rolled and kept at the outer edge. The soil is pushed down from the cut slope and placed over the sheet and compacted well. The depth of the soil over the sheet is kept at 1m and its outer face is given a batter of 1 (horizontal):8 (vertical). The remaining roll of the sheet is overlapped on the compacted soil towards the cut slope. It is better to sow seeds of native grasses on outer face of the soil before covering it with the sheet. A 20cm thick layer of soil is placed on the sheet and covered with a 1.6m long brushwood layer extending it beyond the overlapped sheet to ensure adequate rooting takes place. A thin soil layer is placed over the brush layer and compacted before placing another geo-grid sheet with the same procedure as described above. At each layer a step of 35cm is given (Figure 3). The brushwood sprouts in the wet season. The roots reinforce the soil and make it strong to resist the shearing forces working on it. In Timor-Leste vegetated geo-textile walls could be constructed with sheets made from coconut fiber.

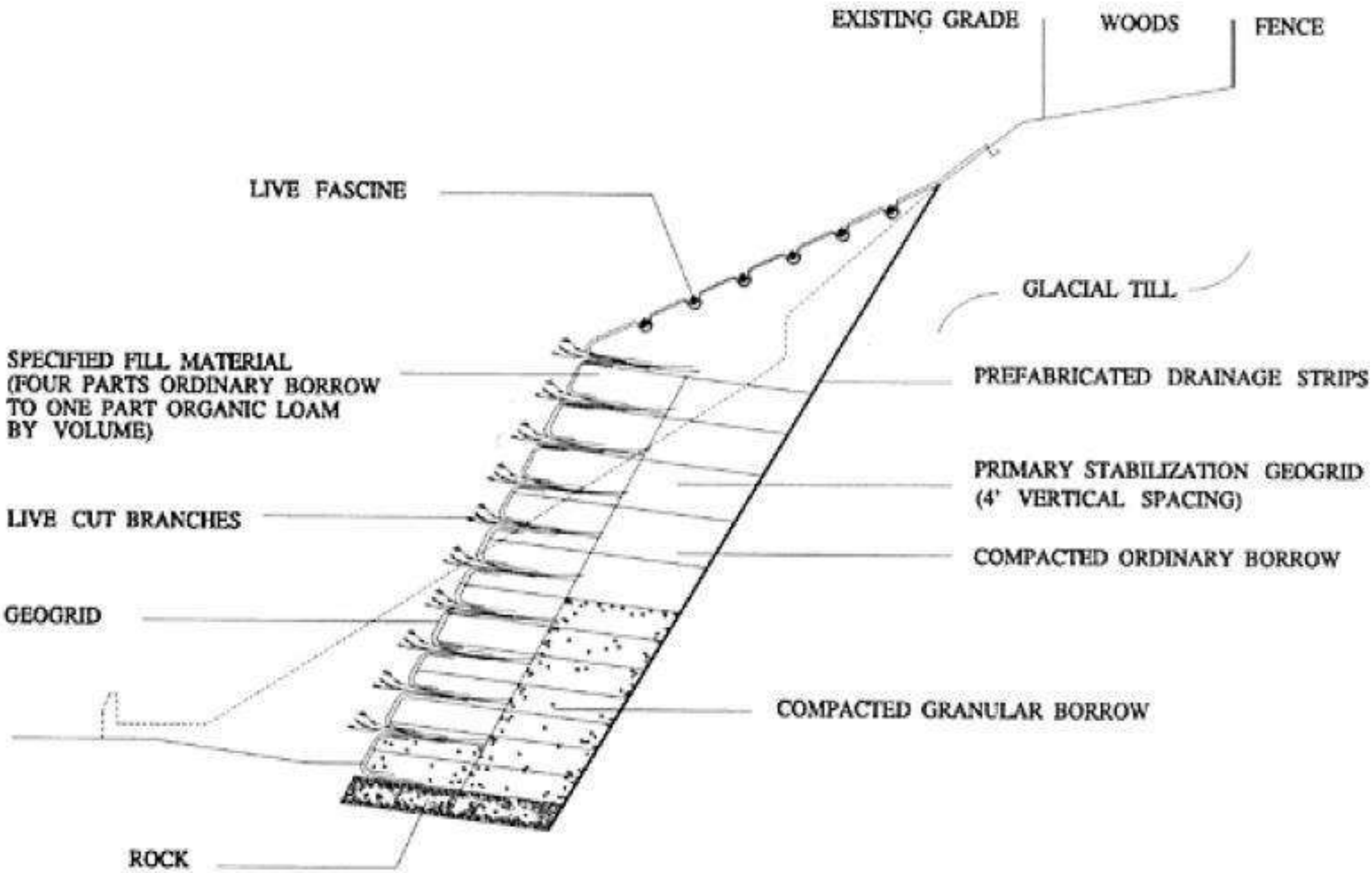


Figure 3 - Schematic diagram of a geo-textile retaining wall

Vegetated Timber Crib Wall

- Crib walls should be built from round poles or square timber held together by nails or bolts.
- Crib walls are placed at an angle of no more than 1:8 (horizontal: vertical) inclining toward the upslope.
- Wooden crib walls should not be higher than 3m. For construction of the wall, the first row of footers is placed in touch with the cut slope and parallel to it.
- The second row is placed at 1.5m distance parallel to the first row.
- The length of the footers depends on the available length of the poles.
- The headers are 1.5-2m long and are placed across the footers at 2m distance.
- During the crib wall construction, branches of living plants should be placed in the open spaces between the poles in such a way that less than 10cm length protrude from the wall.
- When the fill material is damped into openings between the poles, large hollow spaces should be avoided to ensure that the branches are in touch with the soil and will root properly.



(b) Bally Revetments

- In weak /wet sliding area, revetments of ballies/bamboos driven vertically and ties horizontally in rows parallel to the road along the hill slopes above and below the formation level to provide the temporary stability to the slope.
- Sometimes the temporary revetment is enough to stabilize the slopes permanently, these are provided.
- In case they are not sufficient these can be replaced by breast walls of masonry
- The revetment is made with selected varieties of fresh cut ballies, which take roots quickly under wet conditions, it provides vegetation cover and adds to stability to the slope.

(C) Live check dams

Check dams are formed by using plants

(d) Brush layering

Road Side Bio-engineering for landslide stabilization

Jute netting for grass plantation

Landslide stabilisation

Treatment for non-cohesive fill slope

Treatments for wet slumps

PHOTOGRAPHS

Dharan-Dhankuta-Hile Road

Dharan-Dhankuta

Dhankuta-Hile Road

Road Construction Technology

Introduction

- Requirements of Sustainable Highway Construction
  - Proper Design
  - Suitability of materials
    - Desired strength(Sufficient strength to stand the repetition of loads also sufficient thickness to limit the strains below the critical values)
    - Gradation and type & proportion of Binders.
  - Adaptation of locally and nearby available material for construction
  - **Proper Construction Methodology**

3 Main phases:

- Earthwork and preparation of subgrade
- Construction / Laying of Pavement
- Protection work and Drainages

- Road Construction Technology:
- Activities and technology or operation for changing existing ground to desired shape, slope and provide necessary facilities for smooth, safe and efficient traffic movement including reconstruction of roads.

Various activities of Road Construction:

1)Earthwork and Site Clearances:

- Site Clearance
- E/W in filling for embankment
- Excavation for Borrow Pit
- Excavation for cutting
- Excavation for Structural Foundation
- Disposal of Surplus Earth.

2) Drainage Works:

- Side Drains
- Surface and Subsurface Drainage
- Culverts
- Causeways
- Minor Bridges

3) Protection Works:

- Earth Retaining Structures
- River Training Works
- Gully Control Works
- Land Slide Stabilization
- Bridge Protection works

4) Pavement Works

- Subgrade Works
- Sub Base Works
- Base Works
- Surface Works

5) Miscellaneous:

- Road Ancillaries
- Traffic signs/Signals/Markings etc.
- Bio Engineering

3.2 Tools, Equipment & Plants used in Road Construction

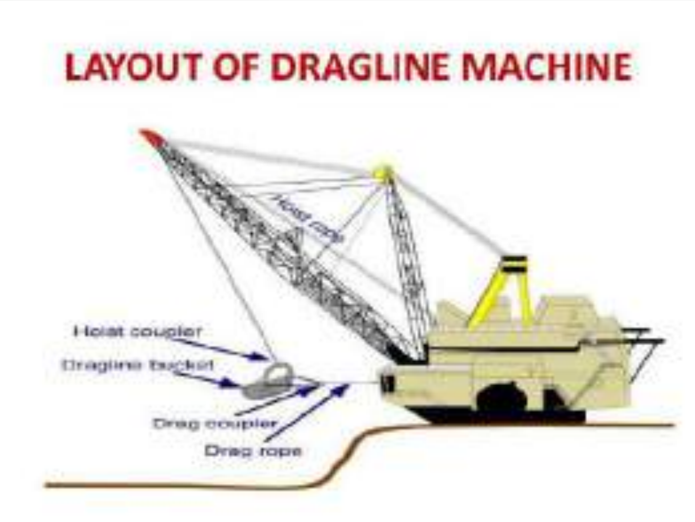
1) Tools

- Hand Shovel, Chisel, Peak, Spade, Hand Rammers, Brushes, Trowel, Wheel Barrows etc.

2) Equipments

a. Excavating Equipments:

- Dozer
- Scrapper
- Excavator
- Dragline
- Backhoe



b. Compacting Equipments:

- Increases Density By Rolling, Ramming orVibration
- Consist Of
    - Smooth Wheeled Roller
    - Pneumatic Roller
    - Sheep Foot Roller
    - Vibratory Roller
    - Rammer

I. Smooth WheelRollers:

- Three wheel or Macadam Rollers (Gross Wt. 4~18t)
- Two wheel or Tandem Rollers (Gross Wt. 1~14t)
- Granular base course of highways
- Gravel, sand, crushed rock
- Efficiency:
    - Diameter, Width and Weight of roller

Seal the surface and allow quick drain of water

II. Pneumatic TireRollers

- 9~11 Pneumatic (Rubber) tires Spaced to get complete coverage
- Kneading Action leading to compaction of Soil
- Both Cohesive and Cohesion-less soil
- 2-4 passes are adequate
- 20t-15 to 30cm compaction(Small Rollers)
- Max. wt. of 50t HeavyRoller for -30cm to 60 cm compaction

III. Sheep Foot Rollers:

- Hollow steel cylinder with projecting feet
- Wt. can be increased by adding water/soil in drums
- Tamping and kneading action during compaction
- Thickness of compaction 5cm greater than length of each foot
- ≥ 24 number of passes
- Suitable for Clayey soils.
- Smooth wheel roller are used afterwards

IV. Vibrators:

- Uses static and dynamic forces for the compaction of soil
- Suitable for dry cohesion-less and granular material

- Walk Behind Roller

- Vibrating roller

V.Rammers

- Hand operated or Mechanical
- Used for light compaction and in narrow places where large rollers cannot reach eg corners

Factors affecting compaction:

- Contact Pressure
- Number of Passes
- Layer Thickness
- Speed

c. Levelling Equipment :

- Mechanical Grader

e. Transporting Equipment

- Trucks
- Conveyors
- Trolleys
- Loader
- Clamshell

d. Lifting Equipment

- Backhoe
- Excavator
- Krane

f. Paving Equipment

- Bitumen Boiler
- Bitumen Spreador
- Aggregate Spreader
- Mechanical Paver

3. Plants

- Cement Conrete Plant
- Hot Mix Plant
- Cold Mix Plant
- Stone Crushing Plant
- Washing Plant

Construction of Roads : a. Preparation Road Bed

1 Site Clearance

- Clearing Hedges
- Trees, Stumps and roots
- Structures along alignment

2. Preparation of Subgrade

- All operations before the pavement structures could be laid over. Consists of
- **Earthwork**
  - shall be performed to take the road to desired height , earthwork may be embankment, excavation or existing ground surface
  - May be excavation or filling
  - Manually or using machine
  - Planning of cuts to nearest fill site to economize as far as possible
  - Economic haul and lift shall be calculated using Mass Haul Diagram
- **Grading** i.e. the process of bringing **vertical profile** of subgrade to designed grade and camber

- **Compaction**
- Packing of soil particles more closely done by removing air voids
- Improve properties and increase strength and bearing capacity
- Reduce compressibility and water absorption capacity
- Factors: moisture content, amount and type of compaction, soil type & stone content
- Compaction at OMC after deciding equipment.

- Road bed preparation may be of following type

Roads with earthwork in Excavation

- Natural G.L. is higher than design level
- Cutting, loosening & removing the earth/rock
- Also required in side drain construction
- Machines selected as per stiffness of materials
- **Design elements include: Depth, Stability of foundation and/or slopes, road side drains**

Stages of roadway excavation and construction process:

1.Cutting to Desired Height

2.Soil Compaction

Field control of compaction:

- Measurement of moisture content
- Measurement of dry density
- Dry density is controlled by increasing the number of passes for the selected equipment and thickness of each laye
  (Sand Replacement method is widely used)
- No 100% results
- More than 95% of standard density should be aimed

Roads with earthwork in embankment

- Filling of earth to achieve desired grade line
  - Natural G.L. below grade line so as to Maintain design standards
  - To keep subgrade above high GWT
  - Prevent surface water and capillary water effects

- Design Elements include:
  - Height of fill
  - Fill materials(Granular Soil is preferred)
    - No organic or silty clay

Settlement of embankment:

- Arises due to compressible soil, high moisture, consolidation due to increased load , insufficient compaction
- Material of sufficient strength and adequate compaction shall be ensured

Stability of foundation:

- FOS should be determined.
- Method of wedges or Sweding circular arc analysis.
- Shear stress and strengthis estimated
- Theoritical analysis (ElasticTheory)

Stability of slope:

- Flat slope as far as possible
- Elimination of failure
- FOS ≥ 1.5

- **Stages of embankment construction process:**

  1.Filling to Desired Height

  2.Soil Compaction
- Packing of soil particles more closely
- Removing air voids
- Improve properties and increase strength and bearing capacity
- Reduce compressibility and water absorption capacity
- Factors: moisture content, amount and type of compaction, soil type & stone content
- Compaction at OMC after deciding equipment.

Field control of compaction:

- Measurement of moisture content
- Measurement of dry density
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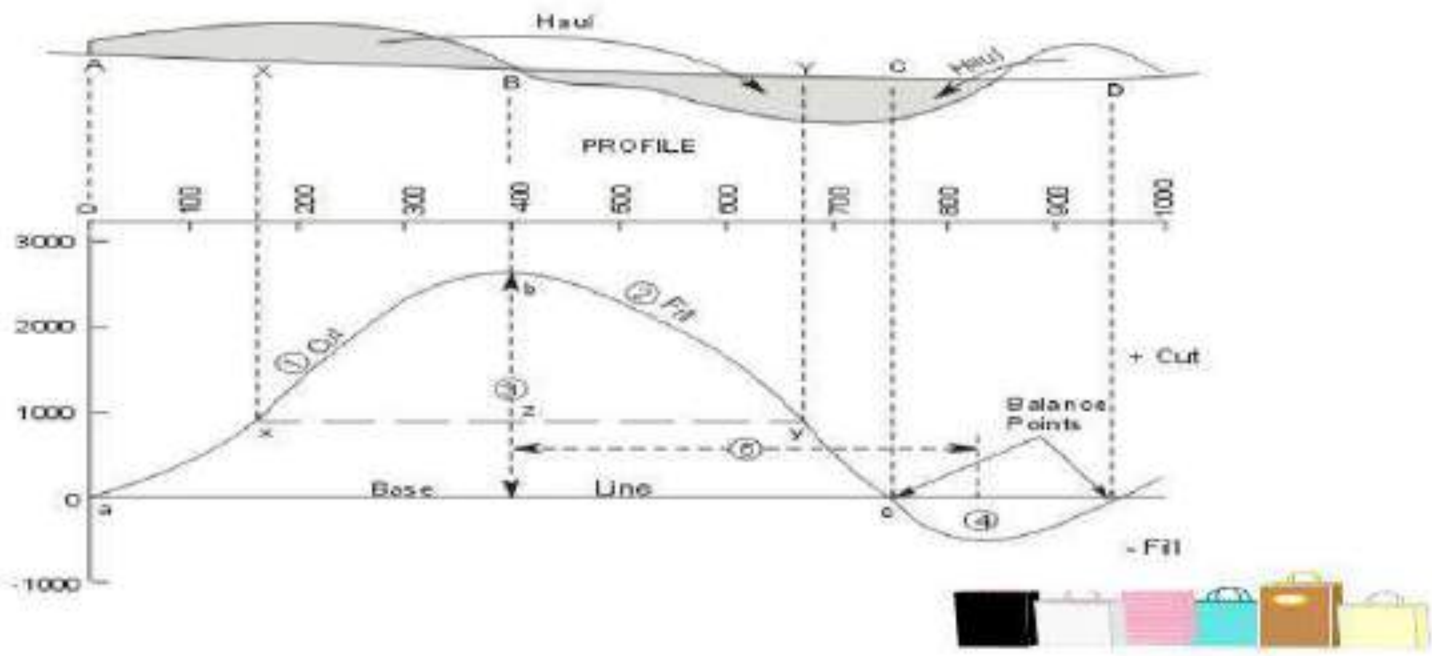
- No 100% results
- More than 95% of standard density should be aimed

Mass Haul Diagram

- It is the graphical representation of the amount of earthwork involved in road construction and the manner in which the earth to be hauled economically.
- Diagrammatic representation of earthwork volumes in linear profile.
- With the combined use of the MHD plotted directly below longitudinal section of the survey line, one can determine:
    - The distance at which the cut and fill will balance
    - Quantities of materials to be moved and the direction of movement
    - Areas where earth mass have to be borrowed or wasted and the amounts involved
    - The best policy to obtain the most economic use of plan

Mass Haul Diagram



Characteristics of MHD

- Plotted below the longitudinal profile of the road
- Horizontal distances are the chainages along the center line
- The ordinate at any station along the curve indicates the earthwork quantity accumulated up to that point and is the summation of the differences between cut and fill
  - The maximum ordinate (+) indicates a change from cut to fill
  - The minimum ordinate (-) indicates a change from fill to cut
- A rising curve at any point indicates an excess of excavation over fill at that point. A falling curve indicates the reverse.
- If the curve has steep slopes it indicates heavy cuts or high fills. Flat slopes indicate small E/W
- A convex loop of the MHD indicates that the haul from cut to fill is from left to right and concave loop indicates the reverse.
- Balance point is a point where the volume in excavation balances the volume in embankment
- Any line drawn parallel to the base line and intersecting two points within the same curve indicates a balance of cut and fill between these two points

- The area between a balancing line and the mass diagram is a measure of the haul between balance points. This area divided by the maximum ordinate between the balance line and the curve gives the average distance of haulage of the cut material to make the fill.
- When the earth of cut and fill balance at the end of the section, MHD would end at the base line at the zero point.
- Free haul is the distance to which the contractor is supposed to move the earth without any charge. Generally 50m.
- Overhaul is the distance in excess of free haul and extra payment has to be done.

- Economic haul
  - When the haul distances are large it may be economical to waste excavated material and borrow from more convenient source
  - Economic haul distance is the distance to which material from excavation to embankment can be moved more economically than to get from borrow opening.
  - The economic haul distance can be determined by equating the cost of roadway excavation plus overhaul and tipping in the embankment with the cost of borrow pit material plus excavation, haul and wasting of roadway material within free haul distance. So, if
    - a- cost of roadway excavation per cum
    - b- cost of overhaul and tipping per cum per station
    - c- cost of borrow materials per cum
    - L- economic overhaul distance in stations
    - a+b*L= c+a
    - L= c/b stations

- If the free haul distance is F, then the economic haul distance is given by,

$$F+L= F+c/b$$

Shrinkage and Swelling

- Shrinkage is, when earth excavated from borrow area and deposited on the embankment and compaction is done the final volume of the compacted bank becomes less than the borrow area volume. The shrinkage factor depends upon the soil deposit and vary 10~20%
- Swell is, if rock is excavated and deposited, the volume of material may occupy a larger volume. It may too vary 10~20%

Soil Stabilized Roads

- Soil stabilization is process of improving the bearing capacity of the soil by proportioning an controlled compaction with suitable admixtures or binders.
- Degree of stabilization required is a function of availability and cost of required materials of a stabilized soil mixture
- Use of local materials shall be prefered for minimizing cost to maximum extent
- Soil stabilization used for stage construction as well as high grade pavement construction in comparatively weak soils
- Field and laboratory investigations needed for soil stabilized roads are:
  - Investigation of route and alignment
  - Soil survey and field identification of soils
  - Survey for availability of materials and transportation
  - Lab tests on soils and materials

Steps Ascociated

Design of Suitable Stabilization preferably with local material if not with foreign materials shall be done associated steps are

- Evaluating the properties of soil and materials
- Deciding the admixtures to provide the lacking requirement
- Admixture may result in:
  - Change in physical property of soil: density, stability, shrinkage, expansion etc
  - Change in chemical properties
  - Retention of some minimum strength properties by water proofing
- Evaluating the properties of soil admixture wrt design criteria and fixing the optimum amount

- **TECHNIQUES OF SOIL STABALIZATION:**
- **Proper proportioning:**
- Locally available soil and aggregate are mixed in suitable proportion and compacted to get desired objective
- Stability of fine grained soil can be improved by the addition of gravel and sand components
- Stability of cohesionless sand may be improved by addition of cohesive soil.

CEMENTING :

- Strength can be increased in all soils using cementing agents like Portland cement, lime, lime
fly ash
- Bituminous material imparts binding property to non-cohesive sols like pure sand.

MODIFYING :

- Modifier brings a lot of improvement in performance of soil
- Lime is the commonly used modifier

WATER PROOFING AND REPELLING :

- Prevent loss of strength properties of soil.
- Bituminous materials are commonly used
- Vinyl resins or other resinous materials are used water proofing agents

WATER RETAINING :

- Some non-cohesive soils maintain strength with certain minimum amount of moisture
- Adding calcium chloride to stabilized soil continues moisture absorption to retain its stability.

HEAT TREATMENT:

- Useful for clayey soils
- Desirable for reduction in swelling properties
- Heat treated soils can be use as soft aggregate in stabilization techniques.

CHEMICAL STABILIZATION:

- Use of less than 0.5% by wt. of soil may impart useful changes in some soils
- Huge investigation and care is needed before adopting any of costly chemicals

- **METHODS OF SOIL STABALIZATION:**
- Mechanical stabilization.
- Soil-cement stabilization.
- Soil lime stabilization.
- Soil bitumen stabilization.

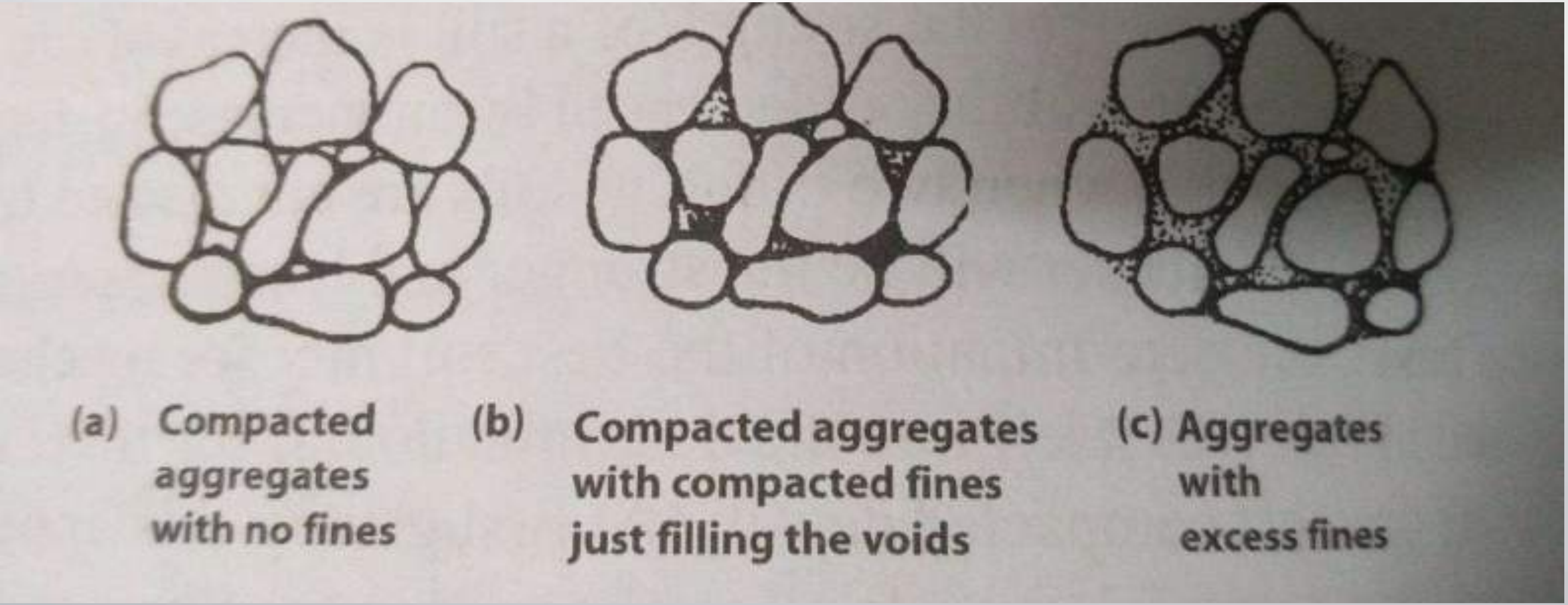
- **Except mechanical stabilization, other methods are generally used for immediate high cost roads construction**

MECHANICAL STABILIZATION:

- Granular stabilization or soil aggregate stabilization.
- Gradation is so chosen that construction depends on soil aggregate mixture alone for stability
- Two basic principles are proportioning and compacting
- Granular soil mixed with clay and clayey soil is mixed with granular soils to obtain desirable gradation and stability

- The degree of stabilization depends on what soil property is considered to be important
  - Subgrade: strength first and incompressibility second
  - Large fills: incompressibility first and strength second

- Three typical states in which compacted soil aggregate mixes can be formed:
  - Aggregate without fines
  - Voids in compacted aggregate are just filled with compacted binder
  - Aggregate mixed with excess fines and compacted



PROPERTIES OF SOIL AGGREGATE MIX

- Should be hard, durable and bear wheel loads
- Incompressibility
- Less change in volume and stability with variation in moisture content
- Good drainage, less frost suspectibility
- Ease in compaction.

DESIGN OF MIX:

Factors to be considered:

- Particle size distribution giving maximum density
- Fuller's formula can be used to obtain the theoretical gradation for maximum density.

$$P=100(d/D)^n$$

- P- % finer than diameter d (mm) in the material
- D- diameter of largest particle, mm
- n- gradation index which have values ranging from 0.5-0.3 depending on shape

- **CONSTRUCTION PROCEDURE:**
- **MATERIALS:**
- Collected from selected borrow pits and are stacked along road sides
- Shall have the following properties
- Liquid Limit (LL) < 25
- Plasticity Index (PI) <6
- **EQUIPMENT:**
- Equipment for excavation, haulage and compaction
- Machinery or manual labour
- Roller

- **CONSTRUCTION STEPS:**
- Subgrade prepared as before
- Materials mixed to desired proportions as per design

- Moisture content of the mix is checked and necessary correction is done
- Mix is spread to suitable grade and compacted and rolled until desired compaction is achieved
- Process is repeated with appropriate proportions for base course and surface course

Field control test:

- Moisture content and density during and after construction
- Modification is done if necessary
- Opened to traffic after the compacted layers harden by drying

- **FACTORS AFFECTING MECHANICAL STABILITY**
- Mechanical strength of aggregates
- Proportioning of the mix
- Properties of the soil
- Presence of harmful ingredients
- Amount of compaction

- **SOIL CEMENT STABILIZATION**

Principle and application

- Small Proportion of cement is applied to the soil for stabilization
- In Granular soil stabilization is due to the development of bond between cement and the compacted soil particles
- In fine grained soils the stabilization is due to reduction in plasticity

Design of soil cement mix

- Specimens are prepared with different cement contents in molds at OMC
- The cement content corresponding to 17.5kg/cm2 is taken as design cement content for low and medium traffic
- for heavy traffic 28-35 kg/cm^2 strength may be adopted for mix design.

Construction of Soil Cement stabilized road

A) Materials

- The borrow pit materials are collected and pulverized to bring the following properties. Passing 4.75 mm > 50 %; passing 0.075 mm < 50 % :Liquid limit **(LL) < 40 %** and Plasticity Index (PI) < 18.

- Ordinary Portland cement

B) Equipment

- Equipment for pulverizing, plant mixing for big projects, manual mix for small projects, Grader, Tippers, Water tanker and Roller or manually.

C) Construction Steps

- Preparation of sub-grade or sub - base.
- Pulverization of soil to the required degree.
- Application of cement and dry mixing.
- Addition or spraying of water and remixing.
- Spreading of mixed materials and grading
- Compaction by smooth wheeled roller.
- Soil — cement layer is allowed moist curing by preventing the moisture to escape.
- Open to traffic after set.

Quality control

- Conducting Atterber's limit, CBR and proctor density.
- Checking of degree of pulverization (sieve through 4.75 mm)
- Testing of mixing efficiency by compressive strength
- Checking of field moisture and dry density (> 95 %)
- Checking of camber and grade.

Factors affecting properties of soil-cement

i) Soil type
ii) Cement content
iii) Pulverization and mixing
iv) Compaction
v) Curing
vi) Additives like lime for clayey soil and also calcium chloride, sodium hydroxide, sodium carbonate might be used.

- **SOIL LIME STABALIZATION**

Principle

i) Cementing Action(Granular) ii)Modifying action (Non granular)

Generally used for clayey soils , when clay is treated with lime it reduces the thickness of water film around clay particles, due to which cementing action occurred and reduces the plasticity of soil

Construction of Soil Lime Stabilized Roads

A) Materials :

i) The borrow pit materials or scarified materials having the following properties.
Passing 4.75 mm > 50 %; passing 0.075 mm < 50 %.
Liquid limit (LL) < 40 % and Plasticity Index (PI) < 18.
ii) Lime powder

`B)Equipment:-

Equipment for scarification, pulverizing, mixing, Grader, Tippers, Water tanker and roller or manually.

C) Construction steps

- Preparation of sub-grade.
- Pulverization of soil to be stabilized.
- Addition of part of lime as dry powder or as slurry with water and mixing.
- Allowing mixture to age for about a day and remixing when pulverization becomes easy.
- Addition of rest of lime and water if necessary and remixing.
- Spreading of mixed materials to desired grade, shape.
- Compaction by smooth wheeled roller.
- Curing of the soil — lime layer is allowed moist curing by preventing the moisture to escape.
- Open to traffic after set.

Quality control

Conducting Atterber's limit, CBR and proctor density.
Checking of degree of pulverization (sieve through 4.75 mm)
Checking of field moisture and dry density (> 95 %)
Checking of camber and grade.

Factors affecting properties of soil - lime

i) Soil type
ii) Lime type and content
iii) Pulverization and mixing
iv) Compaction
v) Curing
vi) Additives.

- **SOIL BITUMEN STABILIZATION**

Principle and Application :

i) Water proofing ii)Binding

- For cohesion less soil binding is important and for clayey particles water proofing is important.
- Bituminous stabilized layer may be used as a sub — base or base course of the ordinary roads and surface course for very low traffic and low rainfall regions.

Construction procedure :

A) Materials

I) soil

The materials for stabilization are pulverized to have the following properties.

Passing 4.75 mm sieve -

Passing 0.425 mm sieve Passing 0.075 mm sieve -

Liquid limit (LL) <40 Plasticity index (PI) <18

ii) Bitumen Cutback or Bitumen Emulsion

B) Equipment:-

Equipment for scarification, pulverizing, mixing, Grader, Tippers, Water tanker and roller or manually.

C) Construction steps

- Preparation of sub-grade or sub - base.
- Soil to be stabilized is pulverized to the required degree.
- Addition of water to soil and mixed.
- Addition of cut back or emulsion and remixed.
- Spreading of mix to the desired grade and shape.
- Compaction by smooth wheeled roller.
- The compacted layer is allowed for curing until moisture and volatile elements evaporates.
- Open to traffic after set.

Quality control

Conducting Atterber's limit, CBR and proctor density.

Checking of degree of pulverization (sieve through 4.75 mm)

Checking of field moisture and dry density (> 95 %)

Checking of camber and grade.

C. Construction of Bituminous Pavements

- Bitumen used as binder
- Stage development can be adopted depending on traffic demands
- Bitumen content over optimum value is harmful reducing strength and stability
- The Different Components of Bituminous Pavements are
  Lower layers Sub Base and Base
  1. Interface Treatement
  - Prime Coat
  - Tack Coat
  2. Surfacing
  - Surface Dressing
  - Grouted/Penetration Macadam
  - Premix Construction like : Bituminous Bound macadam(BBM) , Asphalt Concrete
  3. Seal Coat : Tar Based or Asphalt Based :
     Used only in case of porous surfacings as top layer

3.5.2 Interface Treatment

- When a new bituminous wearing surface is to be placed upon a previously untreated compacted foundation layer such as earth, WBM, gravel etc. or over an existing treated surface for e.g. old road surface then ,it is necessary to bond the new surface with existing surface with the help of a bituminous material. This is known as interface treatment.
- <u>TYPES:</u>

Prime coat : If interface treatment is done over permeable surface for e.g. untreated soil then it is called prime scoat

Tack coat : If interface treatment is done over impermeable surface for e.g. Existing road surface then it is called tack coat

Prime Coat

- First application of low viscosity liquid bituminous material (RC-0, MC- 1, SC-1)
- Functions:
  - *Bond between base and the wearing surface*
  - *Sealing of pore and capillary voids, water proofing*
  - *Binding loose aggregates on existing surface*
- Bituminous primer of suitable grade or viscosity is chosen and sprayed uniformly at the rate of 7.3~14.6 kg/10 sq.m area depending on porosity
- Curing for at least 24 hrs is done
- No traffic is allowed during the curing period

Prime Coat

Prime Coat

<u>Tack Coat</u>

- Single initial application of bituminous material on existing pavement surface relatively impervious.
- Applied with higher viscosity bituminous material
- Generally hot bitumen at the rate of 4.9~9.8 kg/ 10 sq. m.
- Ensures adhesion between existing surface and new bituminous surface.

Tack Coat

Construction Of Prime Coat/Tack Coat

Material:-

for Prime coat either SC 30 or SC 70 cutback or bitumen emulsion.
For tack coat 80/100 Penetration grade bitumeb

Equipment:-

Mechanical broom or hand brushes; Air compressor, Bitumen storage tank with heating devices; Bitumen distributor; sample trays or manually for small projects.

Construction steps

- Preparation and intensive broom /cleaning of underlying layer (on crushed stone base or existing bituminous surface) to bring mosaic surface for better penetration of spread cutback.
- Spreading of cutback/Tack on the approved underlying layer as per the specified rate of application.
- Curing until the surface is dried.(In case of prime coat)

Quality control

- Testing of the cutback material for its suitability.
- Checking of cutback temperature before application.
- Checking the rate of the application of the cut back by tray and deep test.

Bituminous Surface Dressing/ Treatement

- Thin surface coverings of bituminous layer and mineral aggregate.

Dressing

- To prevent removal of binding materials from WBM
- To provide a water proof layer to prevent infiltration of surface water and

Treatement

- To protect the base course

Two Types

i) Single coat Surface Dressing/ Treatement : Single application of thin layer of bitumen followed by cover materials of specified size stone aggregate, compacted by rollers

ii) Double Coat Surface Dressing/ Treatement : Two coats of thin layer of bitumen one after another each followed by cover materials of specified size stone aggregate, compacted by rollers

Construction of Surface Dressing

Material **:-**

Bitumen :- Normally 80/100 grade Straight run bitumen

Aggregate :- Clean, strong, hard and durable with following properties:

Los Angeles Abrasion value (LAA)	-	35% (Max)
Aggregate Crushing Value (ACV)	-	30% (Max)
Flakiness Index (FI)	-	25% (Max)
Water Absorption	-	1 % (Max)
Stripping Value	-	25% (Max)

Equipment Requirement

- A Storage Tank with Bitumen Heating Device
- Mechanical Broom or Hand Brushes
- A Air Compressor
- A Bitumen Distributor
- A Aggregate or Stone Chip Spreader
- Pneumatic Roller

Construction Steps

1. Preparation of Existing Surface

Base course shall be done as per the design thickness and camber, after completion of base course ruts and depressions shall be identified and are filled to bring to desired profile. All loose materials shall be thoroughly sweeped and removes after which prime coat is applied to the base surface

2. Application of Binder

Uniform spraying of binder is done at specified rate on the prepared surface using mechanical surface and pouring can

3. Application of Stone

Stone chippings of required size are sprayed to cover surface immediately

4. Rolling of first coat

Rolling is dine by using tandem rollers starting from edges towards the center with overlaps not less than 1/3rd of wheel base

5. Application of Binder and Aggregate for second coat
Binder and aggregate is applied over the first coat in a similar manner as discussed previously

6. Rolling of Second Coat
Rolling is done in a similar way as in the first coat

7. Finishing and Opening to traffic
Finished surface is checked for variations with a straight edge



HANTA


Quality Control

- Checking of the conditions of the equipment
- Checking of temperature of binder
- Checking of dust content in stone chipping
- Tests conduction on binder at least penetration, viscosity and ductility or availability of laboratory facility at site
- Conduction of tests on stone chipping at least Gradation, LAA, ACV or AIV, FI, WA, Stripping Value or availability of laboratory facilities
- Checking of rate of application of binder and stone chipping by placing rectangular tray during spreading.

Precaution

- A Equipment condition should be in perfect running condition before starting
- A Excellent coordination between the labors, equipment and supervisor should be maintained perfectly
- Never attempt to start the work when the ambient temperature is below 16 ° C A Back up filling of chips at missing space manually.
- Back up rolling by pneumatic roller. It is better to roll when road surface attain high temperature.

Grouted/Penetration Macadam

- It is bituminous pavement based on macadam's principle of road construction
- The stability of the mix is achieved by means of interlocking between the aggregates which is assured by selecting proper gradation of aggregate , while the friction is reduced by using fine aggregates and binder (Soil bitumen etc)
- In penetration macadam pavement is constructed by spraying bitumen over previously laid aggregate followed by laying of key aggregate and then by sufficient rolling
- The bitumen applied thus partially fills the voids and partially combines the aggregate
- Depending upon the quantity of bitumen spread penetration macadam is classified as **full grout** when the bitumen penetrates to the full depth and **semi grout** when bitumen penetrates up to about half the depth.
- Full grout is adopted in regions of heavy rain fall where as semi grout on average rain fall and traffic. Usual thickness of the layer is 7.5 cm for full grout and 5 cm for semi grout.

<u>Construction of Penetration/Grouted Macadam</u>

<u>Material</u> **:-**

Bitumen :- Normally 80/100 grade Straight run bitumen

Aggregate :- Clean, strong, hard and durable with following properties

Los Angeles Abrasion value (LAA)	-	40% (Max)
Aggregate Impact Value (AIV)	-	30% (Max)
Flakiness Index (FI)	-	25% (Max)
Stripping Value	-	25% (Max)

Gradation of aggregates is chosen depending upon thickness of layer. Maximum size of coarse aggregate and key aggregate for 7.5 cm thick is 63 mm down and 25 mm down respectively and for 5 cm thick 50 mm down and 20 mm down respectively.

<u>Equipment Requirement</u>

- Storage Tank with Bitumen Heating Device
- Mechanical Broom or Hand Brushes
- Air Compressor
- Bitumen Distributor
- Aggregate spreader.
- Pneumatic Roller/smooth wheel roller

Construction Steps

1. Preparation of Existing Surface

Base course shall be done as per the design thickness and camber, after completion of base course ruts and depressions shall be identified and are filled to bring to desired profile. All loose materials shall be thoroughly sweeped and removes after which prime coat is applied to the base surface

2. Spreading of Coarse Aggregate

Coarse aggregate are sprayed by mechanical sprayer or by hand. Spreading shall only be done for a distance which can be rolled and penetrated in a day.
Properly graded aggregate shall be used

3. Rolling (Dry Rolling)

Rolling shall begin from the sides towards the center , maintaining a minimum overlap of 30cm. It shall be made sure that the desired camber is achieved at the end of the rolling of aggregates

4. Bitumen Application

Bitumen is applied at standard rate of 50 to 67kg per $10m^2$ through a pressure distributor or mechanical sprayer

Construction Steps

5. Spreading of key aggregate

Filler/ Key aggregate are sprayed and rolled after the application of bitumen and rolled by using smooth wheeled roller. Rolling action shall begin from edges and end at the center, there must be overlap equal to 1/3rd of wheel base at

6. Application of Seal coat

Seal coat contains premix sand bitumen which is provided over the top layer. It should be finely rolled but excessive rolling shall be avoided

7. Finishing

Finished surface is checked for variations with a straight edge

8. Opening to traffic

The finished surface shall be opened to traffic 24hour after the completion of seal coat



Quality Control

- Checking of the conditions of the equipments
- Checking of temperature of binder
- Tests conduction on binder at least penetration, viscosity and ductility or availability of laboratory facility at site
- Conduction of tests on stone chipping at least Gradation, LAA, AIV, FI, Stripping Value or availability of laboratory facilities
- Checking of rate of application of binder and stone chipping by placing rectangular tray during spreading of binder and stone chipping.

Precaution

- Equipment condition should be in perfect running condition before starting
- Excellent coordination between the labors, equipment and supervisor should be maintained perfectly.

Bituminous Bound Macadam

- The bituminous bound macadam is the premix which is laid in the finished thickness of 5 or 7.5 cm
- It contains coarse aggregate and fine aggregates mixed together with suitable bituminous binder, the size of aggregate depends on thickness of layer and the
- The layer of this type of the pavement is open graded premix and used as base course. If laid as surface course at least seal coat is necessary.

Construction of Bituminous Bound Macadam

Material **:-**

Bitumen :-

Normally 80/100 grade Straight run bitumen

Aggregate :-

Clean, strong, hard and durable with following properties

Los Angeles Abrasion value (LAA)	40% (Max)
Aggregate Impact Value (AIV)	30% (Max)
Flakiness Index (FI)	25% (Max)
Stripping Value	25% (Max)

Gradation and quantities of aggregates should be as per the specification depending upon thickness of layer and traffic volume.

Equipment Requirement

- Mechanical Broom or Hand Brushes
- Air Compressor
- Bitumen Distributor
- Hot mix plant or manual mixing (for small area coverage)
- Mechanical paver or manual
- Pneumatic Roller/smooth wheel roller

Construction Steps

1. Preparation of Existing Surface

Base course shall be done as per the design thickness and camber, after completion of base course ruts and depressions shall be identified and are filled to bring to desired profile. All loose materials shall be thoroughly sweeped and removed

2. Application of Prime/Tack Coat

Prime shall be applies at the rate of 7.5 – 10 kg/m^2 and tack shall be applied at the rate of 4 – 7.5 kg/m^2. The interface treatment shall be done just ahead of spreading of premix

3. Premix Preparation

The aggregates and bituminous binder to be used are heated to certain temperature and mixed together. The mixture us now transported to constructin site through trucks

4. Placement

Mixture is placed on the ground at specified thickness. The camber shall be maintained in the base itself any ratifications necessary shall be done through the BBM mixture

5. Rolling and Finishing
Rolling is commenced from the edge to the center of the pavement providing sufficient overlap.The finished surface shall not show lines of rolling, the roller wheels shall be kept wet so that materials do not stick to it.

6. Construction of Seal Coat :
If BBM is to be used as surfacing then a layer of premix sand bitumen seal coat shall be applied over it and rolled slowly till smooth surface is obtained

7. Finishing
Finished surface is checked for variations with a straight edge

8. Opening to traffic
The finished surface shall be opened to traffic 24hour after the completion of seal coat

Quality Control

- Checking of the conditions of the equipments
- Checking of temperature of binder
- Tests conduction on binder at least penetration, viscosity and ductility or availability of laboratory facility at site

Asphalt Concrete

- ***It*** is the dense graded premixed bituminous mixture consisting of carefully proportioned mixture of dry coarse aggregate, fine aggregate, mineral filler and bitumen.
- It is the highest quality of construction among the group of black top pavements.
- When properly designed with appropriate proportion of ingredients, it will provide a surfacing of exceptional durable and capable in carrying the heaviest traffic.

Construction Of Asphalt Concrete

A) Materials

Bitumen: - Normally 80/100 grade Straight run bitumen

Coarse aggregate: - The coarse aggregate should be entirely crushed and should be clean, strong, hard and durable with following properties

Los Angeles Abrasion value (LAA)	30% (for wearing) 35 % (for binder) (Max)
Aggregate Impact Value (AIV)	30% (Max)
Flakiness Index (FI)	25% (Max)
Stripping Value	25% (Max)

Fine aggregate:-

- Fine aggregate should be free from clay, silt, organic and other deleterious matter and shall be non plastic.
- It shall consist of entirely crushed rock produced from stone having a Los Angeles Abrasion of not more than 30.
- The sodium sulphate soundness not more than 12.
- The grading requirements of combined mixture of coarse and fine aggregates should be as per the specification.

Mineral Filler:-

- Mineral filler shall consist of finely ground particles of lime stone, hydrated lime, ordinary Portland cement or other non plastic mineral material.
- It shall be thoroughly dry and free from lumps.
- At least 75 % (by weight) shall pass a 0.075 mm sieve and 100 % shall pass a 0.425 mm sieve.
- The grading requirements of mineral filler should be as per the specification.

<u>Equipment Requirement</u>

- Storage Tank with Bitumen Heating Device
- Mechanical Broom or Hand Brushes
- Hand tools like shovel, wheel barrow, rakes etc.
- Air Compressor
- Bitumen Distributor
- Tippers
- Hot mix plant
- Mechanical paver
- Pneumatic Roller/smooth wheel roller
- Edge cutter and core cutter machines

<u>Construction Steps</u>

- Intensive cleaning of underlying layer by labors with the help mechanical broom or by hand brushes before asphalt concrete laying activities.
- Cleaning of underlying layer by air compressor before the commencement of asphalt concrete laying activities.
- Preparation of necessary equipment at laying site such as bitumen distributor, mechanical paver, smooth wheel roller, pneumatic roller and laying team in the ready position to receive the asphalt concrete mix and start spreading.
- Transportation of the AC mix by tipper. Mix is covered for the preservation of temperature and contamination.
- Application of tack coat before laying asphalt concrete mix.
- Delivery of AC mix on the hopper of the mechanical paver to start asphalt concrete laying.
- Checking of temperature of mix before delivering, during laying and before compaction. The temperature difference should not be greater than 10 ˚C in each activity.
- During the laying of the asphalt concrete mix, a good coordination between the equipment and labors is very important and shall be maintained.
- Checking the loose thickness manually.
- Follow up level corrections by skilled labors.
- Finishing the asphalt concrete layer before compaction by skilled and unskilled labor team for the level corrections at joints while laying on next lane.
- Initial compaction of the asphalt concrete layer by smooth wheel roller.
- Follow up compaction by pneumatic roller. The rolling shall be continued until the voids measured in the completed layer are within the appropriate range.
- Cutting the edge of previously laid mix with edge cutter for laying mix on next lane. The edge cut should be perfectly vertical.
- Core sample of the previously laid mix is taken out with the help of core cutter for further necessary laboratory tests

Quality Control

- Checking of the conditions of the equipments
- Checking of temperature of binder and AC mix
- Conduction of tests on binder at least penetration, viscosity and ductility or availability of lab.facility at site
- Conduction of tests on aggregates at least Gradation, LAA, ACV, FI, and Stripping Value.
- Conduction of tests on AC mix such as binder extraction, gradation of the aggregate after extraction, density, Marshall stability, Marshall flow, core analysis and voids.

Precaution

- Arrangement of materials, tools and equipment properly.
- Proper arrangement of skilled labor, unskilled labor and operators during laying.
- Proper joint cutting, tack coating on both longitudinal and transverse joints.
- Proper preparation of site and intensive cleaning of the under lying layer before laying of AC courses.
- Choose short routes and cover the mix for temperature preservation during transportation.
- Controlling and monitoring the production temperature, laying temperature and compaction temperature.
- Proper coordination and communication between laying site and asphalt concrete plant location.
- Surface finishing with trained skilled labour.


BOMAG

Seal Coat

- Very thin surface treatment or single coat surface dressing, either applied as a final step in new surface or existing surfaces which are worn out.
- Premixed sand bitumen (Hot Mix) is commonly used over premixed carpet.
- Purpose:
  - *Seal against ingress of water*
  - *Increase resistance to skid*
  - *Increase strength and bearing capacity of existing surface*

Types of seal coat

1. Coal Tar Sealer

Coal tar sealants are made from coal tar, sand, clay, polymers and other additives that give it pliability, ease of application and resistance to the elements. They are the most durable and long lasting option and last for many years. These sealers are impervious to gasoline and other fluids from vehicles. They are also resistant to fading and discoloration from intense sunlight. They are also quite affordable. The drawbacks of coal tar sealers include low environment friendliness,

2. Bituminous Sealer / Asphalt Sealer

Asphalt sealers are composed primarily of asphalt. They are slightly higher priced than coal tar sealers. However, they are much safer options considering the environment but high level of volatile organic compounds, risk to health and possibility of skin irritation.

3.6 Construction of Cement Concrete Pavement

- Construction of pavement slab
- Design and placement of joints

3.6 Construction of Cement Concrete Pavement

Types of Concrete Pavement

- **Ordinary Concrete**
- **Cement grouted concrete**
  - Open graded aggregate mix of minimum size 18~25mm is laid on prepared subgrade
  - Dry rolled to provide 80% of rolled thickness.
  - Grout: mix of cement, coarse sand and water
  - Applied on the surface and allowed to seep through aggregate matrix

3.6 Construction of Cement Concrete Pavement

- **ROLLED CONCRETE LAYER:**
  - Lean mix of aggregate, sand, cement and water is laid on prepared subgrade or sub base course.
  - Rolling similar to WBM
  - Loose thickness is 20% more than finished thickness.
  - Tandem rollers are proffered and rolled before final setting time.
  - **Both cement grouted and rolled concrete are suitable for base course only.**

3.6 Construction of Cement Concrete Pavement

- Basically 2 methods:

- **ALTERNATE BAY METHOD**

- **CONTINUOUS BAY METHOD**

- **ALTERNATE BAY METHOD:**
  - Construction of one slab in alternate succession
  - Next or intermediate bays are followed after a week or so
  - Provides additional working convenience for laying slab
  - Construction joints are easier to provide
  - Numerous transverse joints are to be provided resulting in high cost for construction and smoothness in riding is reduced.
  - Surface water is collected in the subgrade between the bays
  - Traffic has to be completely halted or diverted

- **CONTINUOUS BAY METHOD:**
  - All slabs laid in sequence
  - Construction joints provided at the end of day's work
  - Construction of half of the pavement width can be done at a time and traffic can be diverted on the other half
  - Generally in practice

- **PROPORTIONING OF CONCRETE:**
- Mix should produce a minimum rupture of 40 kg/cm2 on field specimen at 28 days or
- Develop minimum compressive strength 280 kg/cm3 at 28 days or higher values

3.6 Construction of Cement Concrete Pavement

- **MATERIALS:**

1. Cement: OPC in general but RHPC may also be used

2. Coarse Aggregate: Max size < ¼ of slab thickness

- Gradation of coarse aggregate range from 50mm to 4.75 or 40mm to 4.75 mm
- Shall have the following Properties
  - Crushing value< = 30%
  - Impact Value <= 30%
  - LAA <= 30%
  - Soundness <= 12 % Na2SO4, <= 18% MgSO4

3. Fine Aggregates: Natural sand or crushed stone

3.6 Construction of Cement Concrete Pavement

PLANTS AND EQUIPMENTS:

- Concrete mixer, batching equipment, wheel barrows, internal vibrators, float, straight edge, belt, brush, edging tool and other small tools

CONSTRUCTION STEPS:

1.Preparation of Subgrade and Sub base:

- No soft spots, extend 30cm on both sides of width to be concreted, properly drained, plate bearing test result 5.54 kg/cm2 (Modulus of subgrade reaction)
- Checked 2 days in advance and should be kept moist at the time of placing concrete

- **PLACING OF FORMS:**
  - Steel or wooden forms
  - Depth = thickness of pavement
  - Wooden forms: base width 10 cm for 20cm slab, and 15 cm for > 20 cm slab
  - Maximum deviation during entire work < 3mm from straight edge 3m in length

- **BATCHING OF MATERIAL AND MIXING:**
  - Proportion of coarse and fine aggregates are proportioned WRT no. of bags of cement and put in the mixture
  - Batch mixer mixes the materials in uniform manner with uniformity in color and is homogeneous
  - Water introduced within first 15 seconds of mixing
  - Mixing completes approximately in 1 and half minutes

- **TRANSPORTING AND PLACING OF CONCRETE:**
  - Mixed concrete should be used immediately, within the prepared form to a required thickness
  - No segregation should take place
  - Redistribution can be done by shovels
- **COMPACTING AND FINISHING:**
  - Compaction by power driven finishing machine or vibrating hand screed
  - For smaller width of slab, corner of junction, hand consolidation is considered
  - Further compacted by longitudinal float
  - Tested for grade and level

- **CURING:**
- For initial curing Covered with jute mats and water is poured
- Final curing done by placing wet soil thoroughly saturated by water for 14 days
- **OPENING TO TRAFFIC:**
- After concrete acquires adequate strength or after 28 days of curing



3.6.2 Construction of Joints

- Joints provided for expansion, contraction and warping of the slabs
- **Expansion joints**
  - Provided to allow for expansion
  - Provided at interval of 50~60 m for smooth interface laid in winter and 90~120m for summer
  - 140m spacing for rough interface
  - Gap width of expansion joint: 20~25mm

- **Contraction joints**
  - Provided to permit the contraction
  - Spaced closer than expansion joints
  - Physical interlocking by the aggregates projecting out at the joint faces
  - Maximum spacing in unreinforced cement concrete 4.5 m and for RCC of thickness 20cm is 14m
- **Longituditional Joints**
  - Provided for width more than 4.5 m
  - Allows differential shrinkage and swelling caused by moisture variation in subgrade
  - Prevents longitudinal cracks
  - Acts as hinge and helps maintaining the level of slabs

- **Transvers Joints(Construction Joints)**
  - Staggered arrangement, uniform arrangement and skew arrangement
  - Allows interaction of water and ingress of stone grits
  - If subgrade is clayey soil, mud pumping occurs
  - Joint spaces should be filled with compressible joint filler first and sealed with sealer.

Highway maintenance, Repair and Rehabilitation

4.1 Introduction

- Maintenance , Repair and Rehabilitation together form the set of tasks of preservation, repairing and restoring of elements serviceable conditions of highway
- Variety of operation from planning, programming, and scheduling to actual activities which can be outlines as follows:
  - Identification of defects
  - Possible causes
  - Appropriate Remedial measures
  - Implementation
  - Monitoring results





4.1 Introduction

- Maintenance is the set of activities that is performed so that performance of the road is maintained
- Repair is the activities that shall be performed when the serviceability of the road is decreased
- Rehabilitation is performed when whole roadways and all its layers are damaged

Out of the given activities maintenance is the most important . Proper maintenance

- Maintenance provides better facilities, longer life and better appearance
- Increases comfort of travel
- Decreases the cost of travel
- Eliminates the chances of costly rehabilitation process

4.1 Introduction

- The monetary requirement for the maintenance activity is called maintenance cost
- The maintenance cost depends upon the degree of damage to roads
- The degree of deteriorations depends on :
  - Weather
  - Organic growth
  - Traffic wear
  - Damage
  - **Design**
  - Maintenance cost will be high for poorly constructed roads at the time of alignment studies.

  - Proper considerations in maintenance to overcome the problems such as:
  - Drainage problem
  - Soil conditions
  - Directness of route
  - Landslides problems

- Similarly maintenance cost will be high if there is sufficient gap between maintenance activities and lack of proper routine maintenance

Types of Maintenence

- Based on the surface where the repair activities are conducted Highway maintenance can further be divided to :
  - Road maintenance
    - Concerns with works on carriageway and shoulder and on all structures within and immediately adjacent to roadway
    - Road surface , Side ditches, culverts, causeways etc.
  - Roadside Maintenance
    - Structures and surface above and below the road having direct active and or passive influence on road
    - Culvert protection works, retaining walls, area drain, cut slopes, fill slopes, unstable natural slopes, river protection

4.2 Classification of maintenance activities

Based on the nature of maintenance activities it can be classified as

1. Routine maintenance
2. Recurrent Maintenance
3. Preventive/Specific Maintenence
4. Periodic maintenance
5. Emergency Maintenence

Routine maintenance

- Carried as frequently as required
- Done on all elements of highway
- Localized nature required continually whatever may be its engineering characteristics or traffic volume
- Generally done by labor

Routine maintenance

- Includes Activities Like
  - Grass and bush cutting, grading shaping of unpaved surface
  - Cleansing of carriageways, ditches, drains, signs and signals etc
  - Minor damage to carriageways, slopes, culverts, signals and sign post barriers, lighting facilities
  - Replacement of ancillary furniture and equipment e.g. Signing, barriers, road markings, drainage tubes etc.
  - Clearance of snow and ice in winter seasons

सडक को सतह लाइ सफा राखने

सडक को खाल्डखुल्डी टाली दिनेकाम

सडक संगैको नाली सफा गर्ने

सडक वर पर को वाल/कलबर्टहरु सफा गर्ने

सडकको सोल्डर मर्मत गर्ने

सडक वरपर को चिन्हहरु देखिने गरि राखने

- <u>Recurrent maintenance</u>
- Localized nature and of limited extent
- Re-occurance duration 6 months to 2 years depending on traffic volume
- Use of minor equipment
- Paved roads: sealing cracks, local surface treatment, holes and ruts, pothole patching, edge repair etc


colors

PHOTO


Silver

Preventive Maintenance

- Prevent premature deterioration retarding the progression of deficiencies and effectively increasing the useful life of pavement
- Involves
- Large Potholes Patching
- Small Scale Rigid pavement works
- Drain and wall repair

Periodic maintenance

- Covers all long term programmable operations required within service life
- At certain interval of several years
- Renewal of wearing course and preventive maintenance of various items.
- Frequency and type of renewal depend on type of original surfacing, traffic, rainfall and other climatic conditions.
- Resealing, resurfacing, renovation of wearing surface

Emergency Maintenance

- Need for special problems which may cause pavement failure if not dealt timely.
- Damages caused by floods
- Works to be done immediately after landslides
- Can be classified into two types
- Urgent Works : Removal of debris, placement of warning signs and diversion etc.
- Reinstatement of the road after critical period due to reconstruction or repair

Inspection, Prioritization and planning of Maintenance Operations

1 Assessment of maintenance Needs

- Type and extent of maintenance depends on serviceability standard, funds and priorities.
- A road inventory including information regarding the soils, terrain and climate of the district serviced
- Knowledge of the nature and amount of the traffic using the road

2 Determining priorities

- We must be able to allocate the limited resources available for maintenance organization in such a way that it nearly satisfies the objectives and policies wrt maintenance of highway system
- Priorities can be as:
  - Emergency repairs
  - Routine Drainage Works
  - Routine Pavement works
  - Other Routine Works
  - Periodic Works
  - Special Works

3. Funding Management
4. Implemantaion and Monitoring

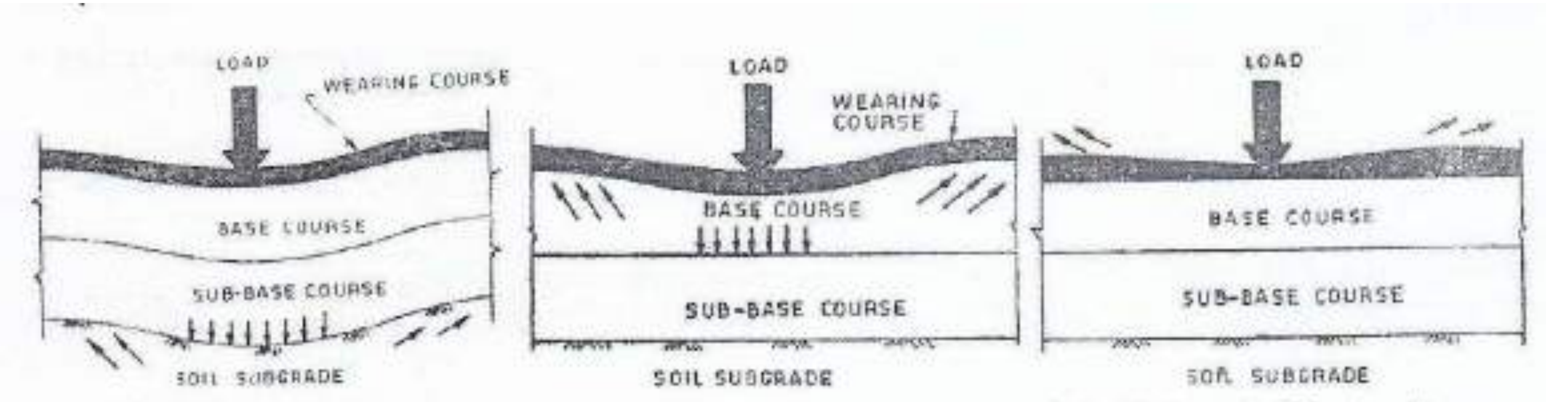
Maintenance Management System

- System approach is appropriate for maintenance
- Factors to be included in maintenance are:
  - Minimum serviceability standards
  - Field surveys for evaluation
  - Factors like: soil, drainage, climate, traffic etc
  - Estimation of rate of deterioration
  - Type and extent of maintenance requirements
  - Alternatives and their economic evaluation
  - Funds available
  - Maintenance cost, materials availability, manpower and equipment
  - Allocation for optimum utilization of inputs and fixing maintenance priorities

Types of Failures and Causes

1. Failure in Flexible Pavement

- Usually flexible pavement fails due to localized depression or settlements. Localized depression normally is followed with heaving in the vicinity.
- The failure in any of the layers of flexible pavement causes failure of the pavement
- The failure in different layers and their causes are as follows



(a) Failure in Subgrade (b) Failure in Base Course (c) Failure in Wearing Course

Failure of sub-grade:-

- Flexible pavement failure due to excessive deformation in sub-grade soil can be noticed in the form of excessive undulation or waves and corrugation in the pavement surface

Major causes of failure of sub-grade may be due to

i) Inadequate stability, this may arise due inherent weakness of the soil itself or due to excessive moisture or due to improper compaction.

ii) Excessive stress application, this may arise due to the inadequate pavement thickness or loads in excess of design value. Deformation increases with increase in number of load repetitions

Failure of sub-base/base course:- Causes of failure of sub-base or base course may be due to

i) Inadequate stability or strength, this may happen due to poor mix proportions, inadequate thickness, soft varieties of aggregates, improper compaction or improper quality control during construction.

ii) Loss of binding action, this may happen due to internal aggregate disturbance, loosening of materials.

iii) Loss of sub-base/base materials, this may occurred due to the pot holes development or surface course not provided.

iv) Inadequate wearing course, this may be due to inadequate thickness, damage by rain, frost action or heavier traffic.

v) Use of inferior materials and crushing of sub-base/base course materials, this may occur due to expose to the atmosphere and weather cycle.

vi) Lack of lateral confinement for the granular sub-base/base course.

Failure of wearing course:- Main causes of wearing course failure are **may** be due to

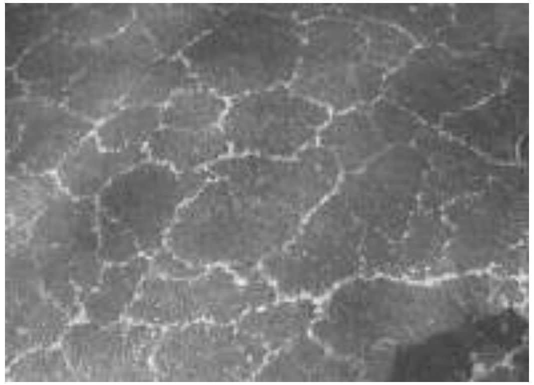
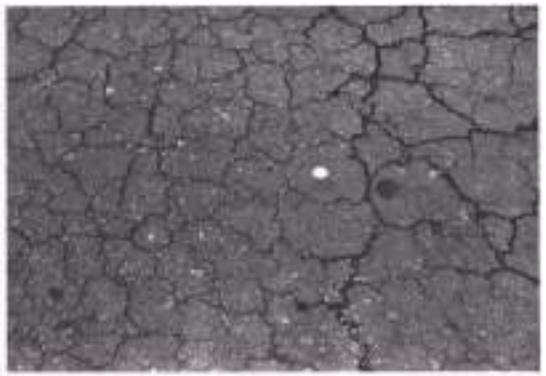
- Improper mix design, this may be due to wrong binder content and use of aggregate not conformed gradation and etc.
- Volatilization and oxidation, this make the layer brittle which develop cracks causing infiltration of rain water weakening the underlying layer.

❖ Typical Flexible Pavement failures

Following are some of the typical flexible pavement failure

Description of failure	Causes
i) Alligator (map) cracking	- due to fatigue, localized weakness in base course would cause such cracking
ii) Consolidation of pavement layers	- formation ruts due to consolidation, repeated load cause cumulative deformation as consolidation, deformation or may be due to sub-grade or other failure.
iii) Shear failure	- due to inherent weakness of the paving mixes, shear resistance being low, inadequate stability or excessive heavy loading, upheaval of pavement followed with depression.
iv) Longitudinal cracking	- causes of longitudinal cracks are due to frost action, differential volume changes in sub-grade, settlements of fill or sliding of side slope.
v) Frost heaving	- Frost of underlying layer.
vi) Lack of binding with lower course	- Slipping occurs when the surface is not bound with underlying layers. This cause opening and loss of pavement materials forming pot holes.
vii) Reflection cracking	- Mostly this case occurs in case of overlay of bituminous layer over existing cement concrete pavement.
viii) Formation of waves and corrugation	- Defective rolling, poor sub-grade condition, poor soil or inadequate stability, poor gradation of mix, compaction temperature, unstable underlying layers.
ix) Edge failure	- Edge failure occurs due to crossing of the vehicles on single lane road. While crossing vehicles pass pavement edge with high strength materials to shoulder with less strength materials
x) Rise or depression of shoulders	- Raise of shoulder due to uncontrolled over growing grass and deposit of debris along shoulder. Depression of shoulder normally occurs due to erosion during rainy season and when vehicles pass on single lane road using part of the shoulder.


STOP

Alligator Crack

As interconnected cracks forming a series of small blocks.

Causes

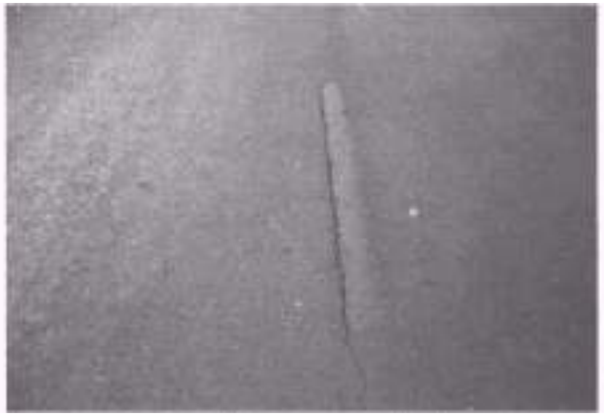
- Excessive Deflection of surface over unstable subgrade , subbase , base
    - Unstable condition may arise from saturation of underneath layer
- Excessive overload by heavy vehicle
- Inadequate pavement thickness
- Brittleness of the binder due to ageing/overheating binder or aggregate (crazing)

Treatment of Defects

Determine main cause

- Crack sealing by bitumen emulstions
- Crack sealing by rubbereised and modified bitumen
- Milling and surface recycling

In case of a pavement being structurally inadequate or weak , aproperly designed overlay based on evaluation shall be provided.




Longitudinal Crack

- **Appears more or less on a straight line , along road at joints**

Causes

o Alternate wetting and drying beneath the shoulder owing to poor drainage
oTrucks passing over the joints (shoulder and pavement)
oA Weak joints between adjoining layers

Treatment of Defect

Treatment for longitudinal cracks depend upon the severeity and extent of the cracking

- Low and medium severity (1-3 mm , 3-6 mm) : crack sealing , preferably using rubberized bitumen
- High severity cracks : remove and replace the cracked pavement layer with fresh overlay

Transverse crack – occure due to reflection of crack or joint in an underlyaing pavement layer . Thelow temperature brittleness or oxidation of bitumen and also structural failure at concrete base course are causes for it

- Treated using slurry seal or rubberized bitumen.

2. Cracks

Shrinkage Crack

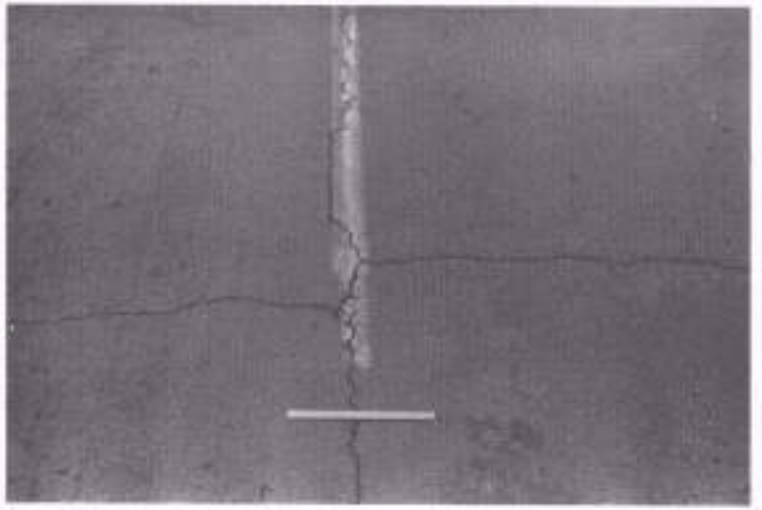
Appear in transverse direction or as interconnected to form large blocks

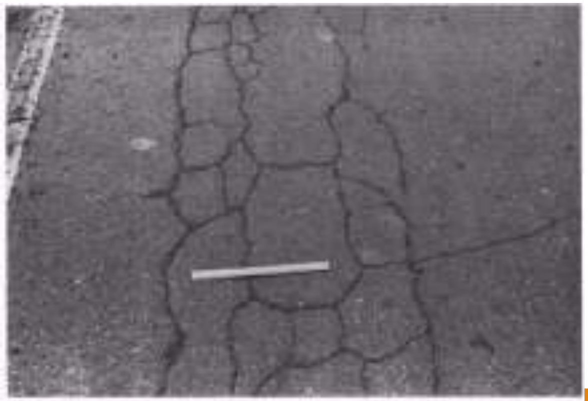
Causes

o Shrinkage of bituminous layer itself with age (the loss of ductility becomes brittle)

Treatment

By crack sealing





Reflection Crack

Appear in bituminous surface over joints and cracks in pavement ur

Causes

- Due to joints and cracks in pavement layer underneath
- Due to not treating the cause of deterioration

Treatment

If pavement is structurally sound – crack filled with bitumen binder having low viscosity. Cut back bitumen , emulsion

In wider crack – slurry seal or sand bituminous premix patching

If finer crack – fog seal'

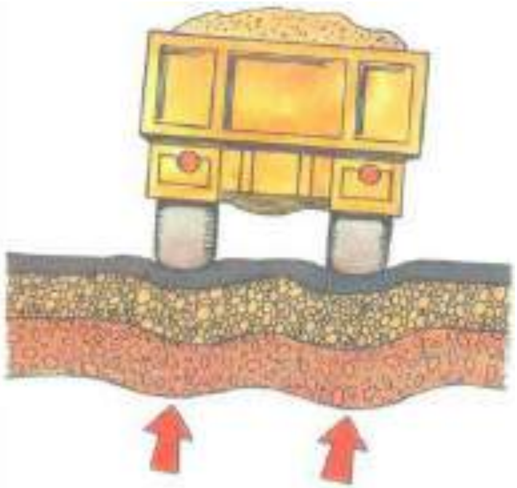
Stress Absorbing Membrane (SAM) or Stress Absorbing Membrane interlayer (SAMI) may be used to seal reflection cracking and preventions of occurrence.

Rutting

A longitudinal depression or groove in the wheel track

<u>Causes</u>

o Heavy channelized traffic
oInadequate compaction of mix at the surface or in the underlying course
oImproper mix design (lacking in stability of the mix to support the traffic and leading to plastic movement laterally under traffic)
oWeak pavement
o<u>Intrusion of sub grade clay into the base</u>



<u>Treatment</u>

- Filling of ruts with premix (open graded or dense graded) patching materials and compacting to the desired levels after applying a tack coat.

1. Failure of Rigid pavement:-

Failures of cement concrete pavements (Rigid Pavement) are recognized mainly by the formation of structural cracking. The failures are mainly due to two factors.

- Deficiency of pavement materials or material handling

a)	Soft aggregate	-	disintegration of cement concrete
b)	Poor workmanship in joints	-	Formation of cracks
c)	Poor joint filler and sealer material	-	Spalling of joints, poor riding surface
d)	Pure surface finish.	-	Slippery surface.
e)	Improper and insufficient curing	-	Formation of shrinkage cracks.

- Structural inadequacy of the pavement system.
    - Inadequate pavement thickness.
    - Inadequate sub-grade support and poor sub-grade soil.
    - Incorrect spacing of joints

Corrugation

Formation of fairly regular undulations (ripples) across the surface (about 25 mm and spacing waves at 3 m)

Causes

- Lack of stability in the mix (excessive binder , high proportion of fines , too roun too smooth textured course or fine aggregate, too soft a binder)
- Faulty laying of surface course
- Oscillation set up by vehicle spring (frequent stop and start)

Treatment

- Surface is scarified and re-surfacing

Settlement and Upheals

Large deformation of pavement (extremely uncomfortable to traffic) followed by extensive crack.

Causes

- Frost effect
- Inadequate compaction of the fill (bridge abutment , utility cuts)
- Excessive moisture in sub-grade (capillary action or poor drainage)
- Inadequate pavement thickness

Treatment of Defects

-if pavements and upheavals indicate any inherent weakness in the fill , it may be necessary to excavate the defectinve fill and do the embankment afresh under properly controlled conditions.

Material having good drainage qualities should be preferred .
Under drains may become necessary in locations where lack of drainage has been identified as the cause of failure.
Where the cause of deformation is inadequate pavement thickness , then properly designed pavement shall be provided.

Stripping

The separation of bitumen adhering to the surfaces of aggregate particles, in the presence of moisture.

Causes

- o Use of hydrophilic aggregate
- oInadequate mix composition
- oInitial overheating of binder or the aggregate or both
- oPresence of dust or moisture on aggregate when it come in contact with bitumen
- oSSD : delay in spreading the cover agg over sprayed bitumen or insufficient compaction
- oOccurrence of rain or dust storm immediately after the construction
- oOpening of the road to fast traffic before the binder has set

- Treatment of Defects
- In case of ssd – hot course sand heated to at least 150 degree C and spread over the affected areas, to replaced the lost aggregates , rolled immediately
- If aggreagates are only partially whipped off , a liquid seal may be used.
- In other case , existing bituminous mix should be removed and a fresh one laid
- Rejuvenating sealants, slurry seal or microsurfacing can be used to treat stripped surface.

Pot-Holes

Bowl shaped holes varying size in a surface layer or extending into the base course caused by localized disintegration of material

Causes

- Common cause is the ingress of water into the pavement through the surface course
  - Happen if the surface is open-textured and lacks proper camber
  - Water soften the surface , under action of traffic depression form
  - Also the rate increase due to use of plastic filler in WBM
- Lack of proper bond between surface and underlying layer (tack coat or any localized inadequacy can cause)
- Insufficient bitumen content.
- In dense graded mixture , pot-hole forms by too much fines or inadequate camber
- Too thin bituminous surface (unable to withstand the heavy traffic , when associated with improper or inadequate camber)

Treatment of Defects

- Hot/cold Mixes for immediate use
- Storable cold mixes (Cutback /emulsion)
- Readymade mixes
- Cold mixes by patching machines

Edge-Breaking

Edge of the bituminous surface get broken in an irregular way.

Causes

- Infiltration of water which soften the foundation layer causing the pavement edges to break
- Worn out shoulders resulting in insufficient side support to the pavement
- Inadequate strength at the edge of the pavement due to inadequate compaction
- Lower layer of pavement not being wider than the upper layer

Treatment

A bituminous surface similar to that in the adjacent reach should be laid

<u>Failures of Rigid Pavement</u>

- **Scaling of cement concrete** —Excessive vibration makes mortar on top of the layer which get abraded exposing aggregates of the mix. This makes surface rough and shabby in appearance.
- **Shrinkage cracks.**
- **Spalling of joints** — Develops extensive cracks due to removal of material at angle.
- **Warping crack** — Cracks appears normally due to improper joint design and if proper reinforcement is not provided at the longitudinal and transverse joints.
- **Mud pumping** — It occurred when soil slurry ejects out through the joints and cracks of cement concrete pavement caused during the downward movement of slab under the wheel load.


photo courtesy of FHWA

Types and Methods of Pavement Repair

4.5.1 Maintenance of Earthen Roads

Damages:

- Formation of dust in dry weather
- Formation of longitudinal ruts along wheel path
- Formation of cross ruts due to surface water

Types and Methods of Pavement Repair

- Dust can be reduced by
  - Sprinkling of water
  - Treatment with calcium chloride and other palliatives
  - Application of oiled earth

- Ruts can be repaired by
  - Spreading moist soil along ruts and reshaping of camber
  - Cross ruts should be repaired time to time
  - Oiled earth and calcium chloride application retains some water due to hygroscopic nature of the mix
- **The other activities include cutting of grass , repair of potholes etc**

Types and Methods of Pavement Repair

Maintenance of Earthen Roads

Damages:

- Formation of dust in dry weather
- Formation of longitudinal ruts along wheel path
- Formation of cross ruts due to surface water

Maintenance Activities

Dust can be reduced by

- Sprinkling of water
- Treatment with calcium chloride and other palliatives
- Application of oiled earth

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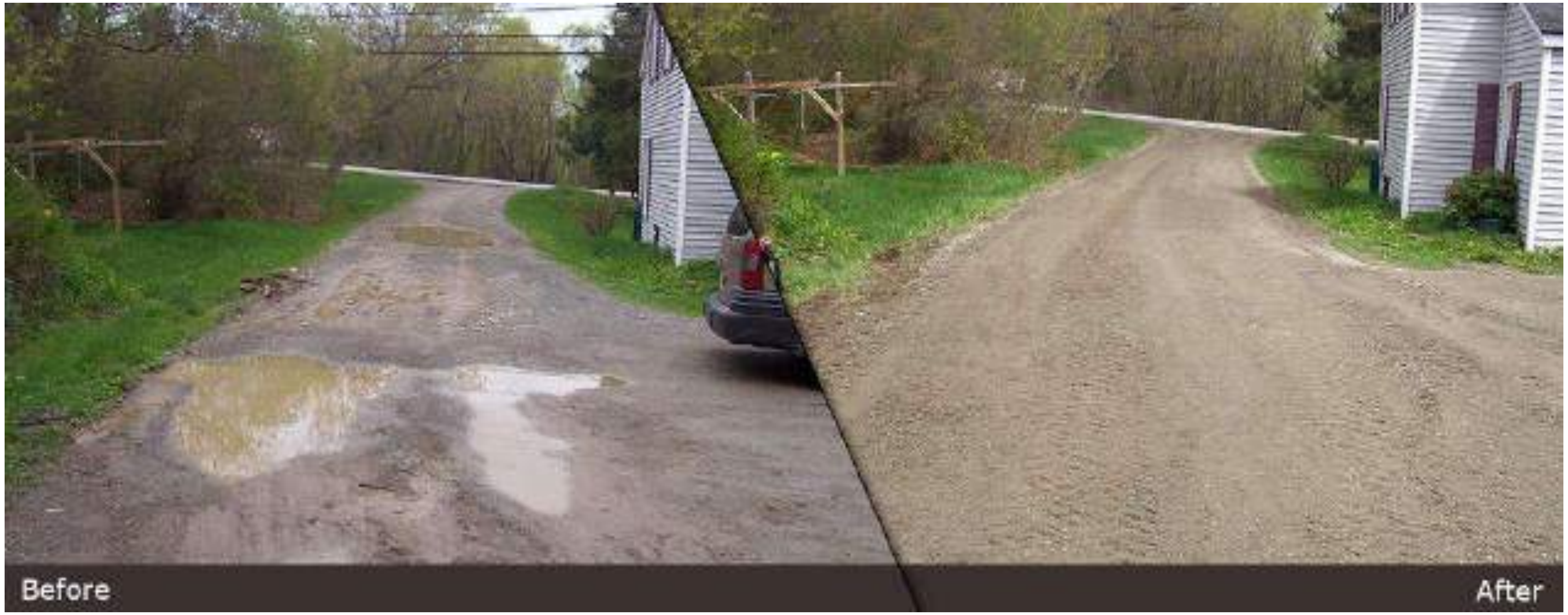

Before
After

Types and Methods of Pavement Repair

Maintenance of Gravel Roads

Damages:

- Formation of dust in dry weather
- Formation of longitudinal ruts along wheel path
- Formation of cross ruts due to surface water

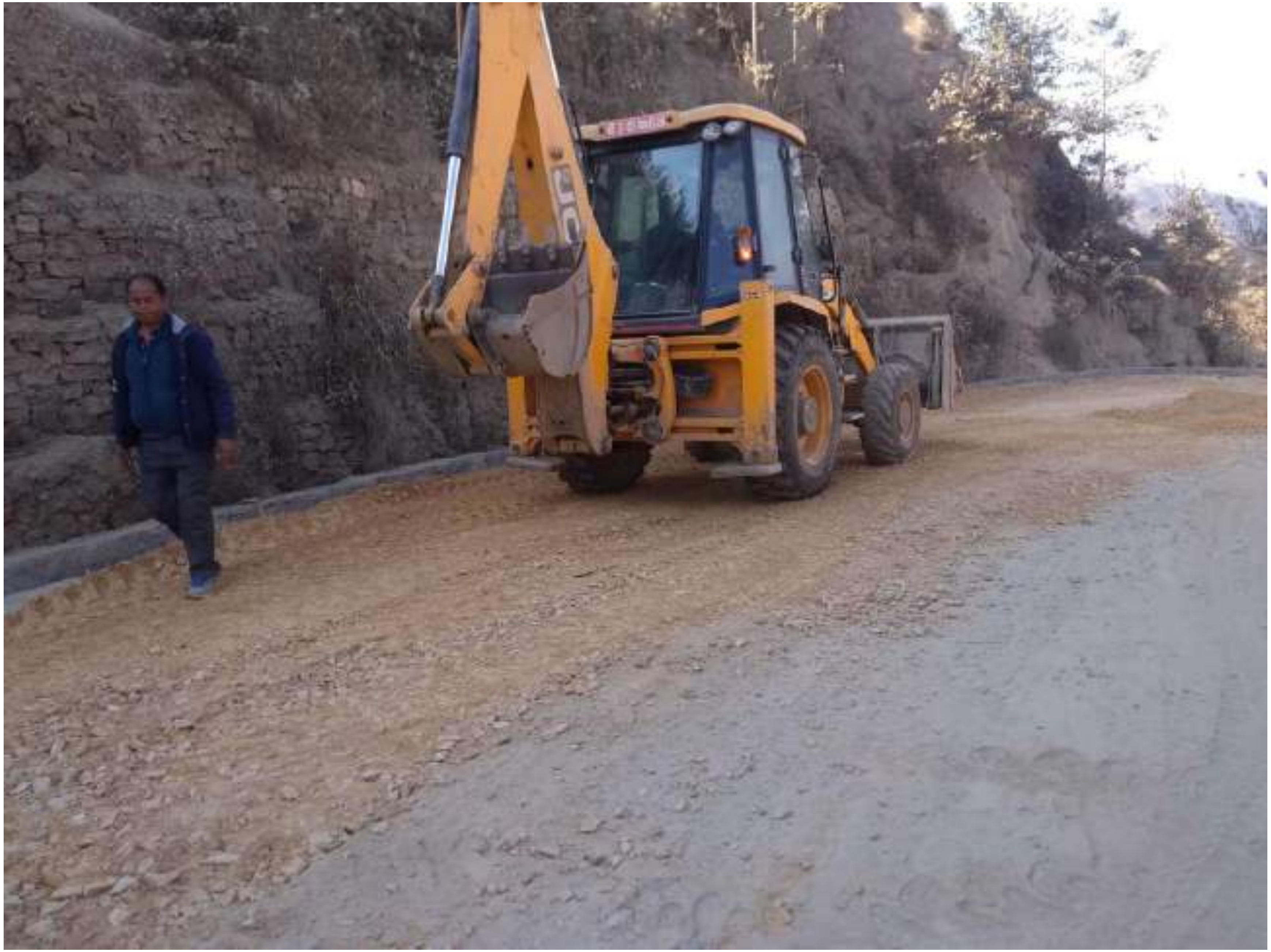
Maintenance Activities

For Dust

- Sprinkling of water
- Treatment with calcium chloride and other palliatives
- Application of oiled earth

For ruts and potholes

- A uniform layer of gravel has to be spread at the damaged locations
- Spread Thickness of 50 cm should be maintained

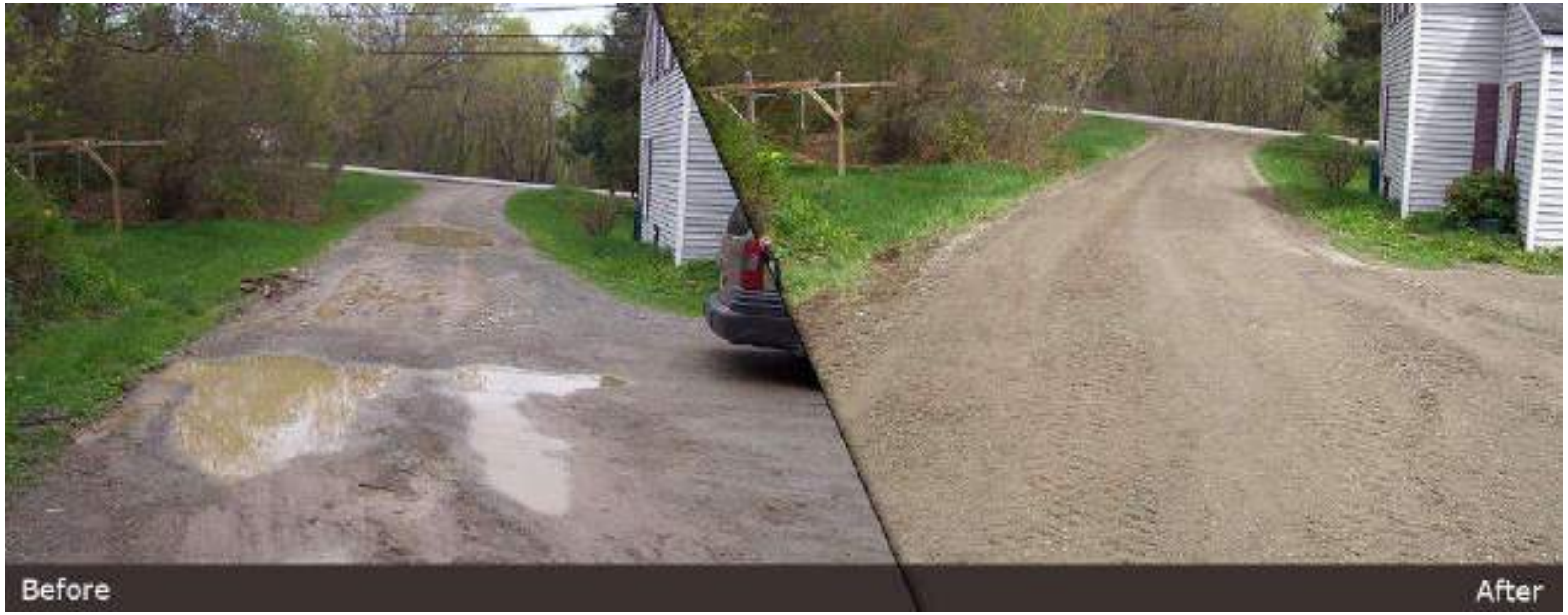



Maintenance of WBM Roads

- Damaged rapidly due to heavy mixed traffic, fast moving vehicles and adverse climatic conditions.
- **Remedies**
  - Spread thin layer of moist soil binder after monsoons prevents loosening of gravels
  - Potholes and ruts are repaired by patch repair works
  - Dust can be prevented by dust palliatives, moist soil or bituminous surface dressing
  - Resurfacing after useful life


GRT


Before
After


Before
After

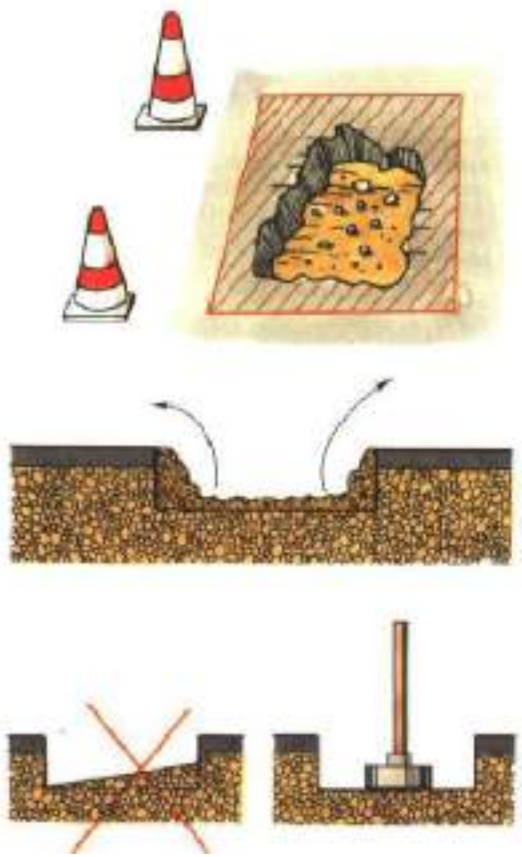
Types and Methods of Pavement Repair

4.5.4 Maintenance of Bituminous Surfaces

- Regular inspections for repairing failures in early stages, rainy season inspections are helpful
- **Patch Repair:**
  - For damaged, improper sections and pot holes formed
  - Corrugation occurs due to incorrect gradation, excessive bitumen, traffic overloads or excessive moisture
  - Done on localised areas using cold mix
  - No bump should be felt

Seven Steps

1. Mark patch boundaries
2. Cut boundaries
3. Clean and repair foundation
4. Apply tack coat
5. Fill the hole with patching material
6. Compact the patch
7. Clean up



PATCHING PROCEDURE

1.Mark patch boundaries

- Mark the boundary to include all deteriorated area (15- 30 cm outside crack)
  - Should be free of cracks and apear as solid
  - Area can be changed if exposes more detereoration
- Mark should be straight not necessary to be rectangular

2.Cut boundaries

- Remove the deteriorated material leaving sound vertical sides
  - Removal should begin from center of patch and worked towards boundary
  - Smooth cut surface for good riding and sealing

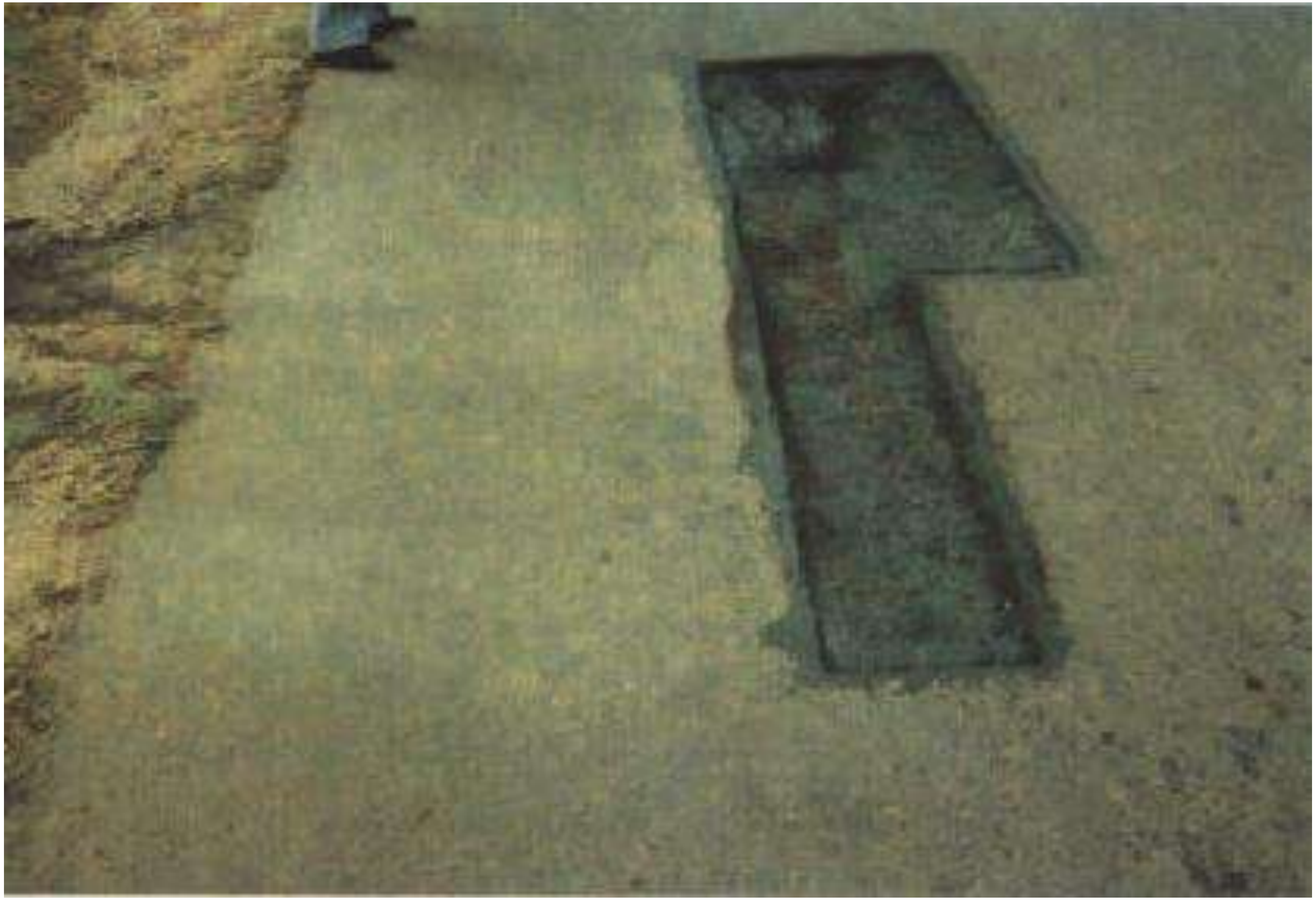
3.Clean and repair foundation

- Perform a thorough cleaning to provide a surface good bond of old and new with tack
- Compressed air should be used to remove all loose particles , especially in the corners
- Rework ,If the bottom of foundation is wet , loose , soft or disturbed
  - Rework to dry the surface , recompacted , or otherwise removed
- Reconstruct , if high deflection are present and not corrected . Patch will deteriorates rapidly.
  - Density level and moisture content should be monitored closely to ensure that an adequate structure is obtained

4.Apply Tack coat(emulsion/cutback)

- Wet the existing surface to promote bonding with the patch mix.
  - Tack coat should be low-pressure sprayed or brushed onto the patch area to obtain a uniform thin coating along the edges of the prepared hole
  - Excessive tack coat not to be used which reduces the effectiveness of the patch
  - Don’t use tack on bottom of pacth when cold mix is used which soften the cold mix , increase shoving and promote stripping

PATCHING PROCEDURE



5.Placing Material

Place AC with a shovel working from one side to other side of patch.

- Never throw or rake the patch material into the hole , as this could result in seggregation
- Enough material , so that after compation , center of the pach remains 6 mm higher thatn the surrounding pavement.

6.Compact the patch

Assume it as most critical procedure to obtain good patch

- Hot mix AC must be compacted before they cool
- Under-compacted mix will ravel , shove out of the patch or excessibly-compacted lead a depression

The material should first be pinched into the hole by rolling from the edge.

Center of the patch should be rolled , moving outward toward the edges in every pass

The roller must rest completely on the patch mix and not on the old pavement.

Roll transversely across the pavement if rutting is present

Hand tanping is not allowed , does not provide adequate commpactive effort.

7.Clean Up

- The pavement should be swept clean and then sealed the edges by pouring and brushing with non sticky ashphalt product like tack coat
- Clean sand or screening should be placed over the asphalt product
  - Road dust or large stone should not be used

Pothole patching

Bitumen Heating

Mixing heatened sand and aggregates with a determined amount of hot bitumen

Spreading of hot ashphalt concrete mix to backfill the hole

Compacting the mix thoroughly by means of a vibratory roller

PATCHING Equipment

An effective pothole repair requires the use of proper equipment

- Cleaning , tacking and sealing equipment
  - Brooms , brushes , spray cans (for tack and seal) , rags and torches (for drying) , air compressor (with a sprayer useful in blowing debris from the hole and also for drying.
- Hole preparation equipment
  - Jackhammer with a chisel point is the best tool for squaring a hole and establishing vertical faces
- Compaction equipment
  - Vibrating plate or vibrating roller compacts effectively (work while it is hot)
  - Other are static or nonvibrating steel rollers (for large potholes)





Types and Methods of Pavement Repair

Base Repair:

- Failure results from inadequate thickness, inadequate subgrade support, excess moisture, consolidation, shear in subgrade, sub base, base or surface
- Replace the base material with new material


JCB

Types and Methods of Pavement Repair

Surface Treatment:

- Too much bitumen results in bleeding of bitumen forming corrugation, ruts, shoving and slippery surface
- Corrected by use of blotting materials; aggregate chips or coarse sand free from dust and rolled
- More than one layer of surface treatment is necessary if surface is seriously damaged due to oxidization or volatilization.

Types and Methods of Pavement Repair

Resurfacing:

- If paving surface is totally worn out, it may be economical to provide additional surface.
- Inadequate thickness also can be repaired by overlay


CAT

Types and Methods of Pavement Repair

Maintenance of Waves and Corrugations

- Generally Done by pavement chipping
- followed by overlay

Maintenance of Skidding of pavement Surfaces:

- Keep the highway clean and dry
- Providing renewal of surface course when wheels do the polishing of aggregates and spreading of stone chips when bitumen bleeding occurs can develop skid resisting surface.

Types and Methods of Pavement Repair

Maintenance of Cement Concrete Roads:

- Major issue is the development of cracks and failure in the joints
- **Treatment of Cracks:**
  - Temperature cracks formed across the slab (Not Harmful)
  - Structural Cracks near edge and corner regions due to combined wheel load and warping stresses
  - Also be due to localized embankment settlement or underground drainage are prime causes
  - Structural cracks needs immediate attention as these indicate possible beginning of failure therefore before cracks get widened and further deterioration, should be sealed
  - Crack treatment/sealing for minor cracks
  - Reconstruction for badly cracked surface

Types and Methods of Pavement Repair

Sealing Of Cracks

- Cracks are thoroughly cleaned
- Kerosene oil is applied on cleaned cracks for proper bonding
- Cracks are filled by suitable gradse bituminous sealing compound heated to liquid consistency
- Sealer is placed upto about 3mm above the slab level along the crack
- Sand layer is spread over it to protect the sealer temporarily

Types and Methods of Pavement Repair

Maintenance of Joints:

- Removal of sealer and deteriorated filler from the expansion joints
- Cleaning
- Replacement with new filler
- Sealing the top of joints with suitable sealer

Types and Methods of Pavement Repair

Mud Jacking or Lifting of slabs:

- Patching for localized subsidence
- Drill number of holes 4 to 5 cm dia and 1.5 to 3 m apart
- Grouting is done under pressure through these holes using 1:3.5 Cement sand mix or bitumen by using compressor

Maintenance of Drainage Structures

- Good surface drainage maintained by having surface water proofed as far as possible and providing crown
- Shoulders are maintained flush with the pavement and smooth enough to provide free flow of water away from edge to side ditch
- Side ditch should be maintained below the grade of subgrade in order that so water from subgrade can be drained to side ditch
- Side ditch should be below 30-45 cm minimum below the top of subgrade
- Other elements of drainage system such as catch basins, manholes, culverts etc should be inspected frequently

Types and Methods of Pavement Repair

Maintenance of Shoulder

- Common defects: depression along edge, deep ruts, holes etc
- Balding and dragging at frequent intervals to eliminate ruts
- Grass offers increased stability and reduces erosion
- Grass should be cut often to an attractive height
- Holes should be immediately repaired
- Periodic reshaping and re-tamping

Maintenance of Retaining Walls

- Regular inspections to detect defects
- Drain holes must be kept open
- Erosion at the base should be prevented

Maintenance of Miscellaneous Items

- Maintenance of cut & fill slopes are best done by stabilising with vegetation.
- Erosion should be closely watched
- Construction of intercepting ditches on top of the slopes
- Loose rocks should be scaled for loose rocks in rock slopes

Evaluation of Pavement Distress and Pavement Condition

- Thorough study of various factors to assess the existing conditions and make decisions for maintenance and strengthening job.

- **Structural Evaluation:**
  - Checked by amount deflection on specified load or load carried at specified deflection
  - Benkelman Beam is the most commonly used equipment

Evaluation of Pavement Surface Condition:

- Flexible Pavement: surface unevenness, ruts, cracks etc.
- Rigid Pavement: cracks and faulty Joints
- Indicators : IRI , SDI

International Roughness Index (**IRI**)

The IRI summarizes the longitudinal surface profile in the wheel-path and is computed from surface elevation data collected by either a topographic survey or a mechanical profilometer. It is defined by the average rectified slope (ARS), which is a ratio of the accumulated suspension motion to the distance traveled obtained from a mathematical model of a standard quarter car transversing a measured profile at a speed of 50mph (80km/h)

Surface Distress Index :
Surface distress is “Any indication of poor or unfavorable pavement performance or signs of impending failure; any unsatisfactory performance of a pavement short of failure” It can be in the form of

- *Fracture*.
- *Distortion*.
- *Disintegration*.

SDI measurement can be either subjective or objective.
Subjective measurement can be done through rating of high, medium, or low based on a brief visual inspection.
Objective measurements, which are generally more expensive to obtain, use different types of automated distress detection equipment.

Strengthening of Existing Pavements:

- If pavements have to support increased wheel load and load repetitions, number of amount of periodic and routine maintenance should be increased
- Alternative can be either diverting traffic or strengthening the existing pavement by providing additional thickness of the pavement

Types of overlay:

1. Flexible over Flexible
2. Cement Concrete over Flexible
3. Flexible over Rigid
4. Rigid over Rigid

- **Choice depends on different factors like thickness of overlay, local materials, wheel load, costs etc.**

Flexible overlay over flexible Pavement:

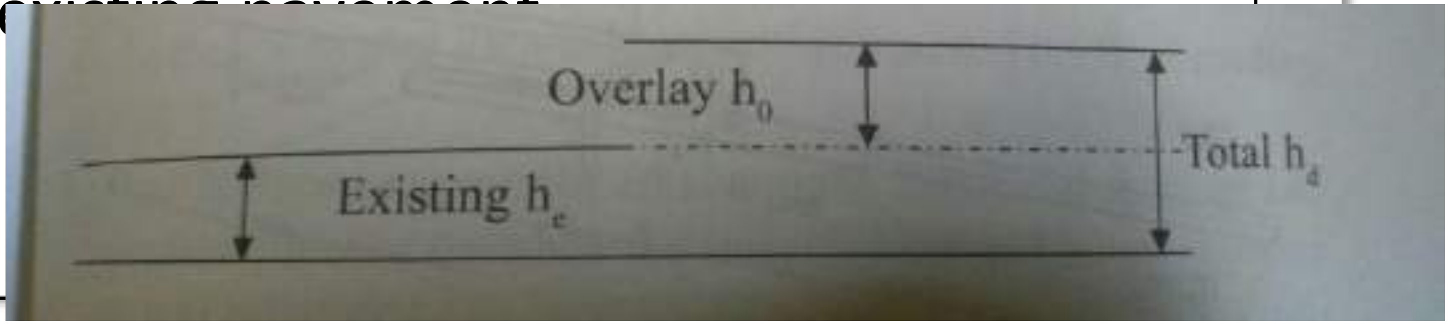
Design of Overlay

<u>Conventional Method</u>

- Evaluation of existing thickness and overlay thickness

- Total pavement thickness required is designed for design traffic and existing conditions of subgrade.
- CBR value of Subgrade is determined at field density and CBR method of pavement design is adopted.
- Existing thickness is found by digging pits on wheel path.`

- The overlay thickness required is given by
- $h_0 = \ h_d - h_e$
- Where, h_0 = overlay thickness required
- h_d = Total Design thickness required, presently determined
- h_e= Total Thickness of the existing pavement
- *all dimensions are in cm.



Benkelman Beam Deflection Studies

- AC Benkelman used it for first time in 1953
- Permissible maximum deflection for satisfactory performance of a road depends on traffic, material and environmental factors
- Benkelman Deflection more than allowable deflection suggests overlay.
- Tests are suggested to be carried out after the monsoon

Benkelman Beam Deflection Studies

Conceptual Principle

- Measures the rebound deflection of pavement due to dual wheel load assembly or design wheel load.
- Beam of length 3.66. pivoted to a datum frame at a distance of 2.44m from the probe end
- Datum frame rests on a pair of front levelling legs and rear leg with adjustable height.
- Probe end of the beam is inserted between the dual rear wheels of truck and rests on pavement surface at the center if the loaded area

Benkelman Beam Deflection Studies

- Dial gauge is fixed on the datum frame with its spindle in contact with the other end of the beam such that the distance between the probe end and the fulcrum of the beam is twice the distance between fulcrum and dial gauge
- Rebound deflection measured by dial gauge is half of the actual movement of the probe end.

Benkelman Beam Deflection Studies

Deflection Measurement Procedure:

- The pavement Stretches (>500m) are classified and grouped as good, fair and poor.
- Loading points are located along a wheel path on a line 0.9m from edge for road width more than 3.5m and 0.6m for narrow roads
- Minimum 10 deflection observations are to be done

Benkelman Beam Deflection Studies

- Standard loaded truck with rear axle weighing 8170 Kg and fitted with dual tire each having a tyre pressure of 5.6 kg/sq. cm. is used
- Dual wheel is centred above the selected point
- Probe of the beam is placed between the two wheels
- Lock is removed and checked for free movement
- If stationary, initial dial gauge reading is taken Do.
- Truck is moved slowly and stopped at 2.7m
- Corresponding deflection is noted if recovery of pavement is <= .025mm/minute, recorded as intermediate reading

Benkelman Beam Deflection Studies

- Truck is moved forward for another 9m and final reading is taken
- Difference between final and initial reading intermediate and initial readings are calculated
- If difference lies within 0.025mm then actual pavement deflection is twice the final differential reading
- Else apparent pavement deflection is calculated as twice the final differential reading.
    - **True pavement deflection = apparent pavement deflection + 2.91 * twice the difference between the intermediate and final readings.**
- Pavement temperature is recorded at one hour intervals and subgrade moisture content is recorded in suitable interval.

Benkelman Beam Deflection Studies

Deflection value D with Leg Correction

$D = \quad 2 \ \left(D_0 - D_f\right)$ + 2K $\qquad \left(D_i - D_f\right) dvisions$

$K = \frac{3d-2e}{f}(2.91\ Generally)$

Where, Do = Initial Dial gauge Reading

Di= Intermediate Dial Gauge Reading

Df= Final Dial Gauge Reading

d= distance between the bearing of beam and rear adjusting leg

e= distance between dial gauge and rear adjusting leg

f= distance between front and rear legs

Benkelman Beam Deflection Studies

Correction for pavement Temperature and Subgrade Moisture Variations:

- According to IRC Standard pavement temperature is 35 Degree Celsius and a correction factor of 0.0065 mm per Degree Celsius to be applied for other temperature.
- Negative if temperature above 35 and positive if below.
- Studies should be carried when pavement temperature is above 30 degrees
- Moisture correction facors are of 2 for clayey soil, 1.2¬1.3 for sandy subgrade, if the observations are taken during dry seasons.

Benkelman Beam Deflection Studies

Data Analysis:

- Rebound deflections are calculated in mm after applying the leg corrections if necessary by using observed values of the initial, intermediate and final deflection
- Mean Deflection $= D = \frac{D}{n}$ mm
- Standard Deviation = $\sigma = \sqrt{(} \frac{(\overline{D} - D)^2}{n-1}$
- Characteristics Deflection $D_c = D + t\sigma$
- When t=1, it covers 84% of the cases and when t=2 it covers 97.7% of cases of deflection values
- Necessary corrections for temperature and subgrade moisture should be applied to characteristics deflections.

Benkelman Beam Deflection Studies

Overlay Thickness Design:

The overlay Thickness required can be calculated using Ruiz's Equation:

$$h_0 = \frac{R}{0.434} \log_{10} \frac{D_c}{D_a}$$

h_0= thickness of bituminous overlay in cm

R = Deflection reduction factor depending upon the overlay material (Usually 10¬15, Average 12)

D_a= allowable deflection which depends upon the pavement type and the desired design life, values ranging from 0.75¬1.25 mm.

Benkelman Beam Deflection Studies

***IRC* Formula for equivalent granular material of WBM layer**

$$h_0 = 550 \log_{10} \frac{D_c}{D_a} \ mm$$

h_0= thickness of Granular or WBM overlay in mm

D_c= $(\overline{D} + t\sigma)$ *after applying the corrections for pavement temperatures and subgrade moisture.*

D_a= 1,1.25 and 1.5mm if the projected traffic is 1500-4500, 450-1500 and 150-450 respectively

Benkelman Beam Deflection Studies

A = $\boldsymbol{P[1+r]^{n+10}}$

If bituminous concrete or bituminous macadam with bituminous surface course is provided as the overlay, an equivalency factor of 2 is used as suggested by *IRC* to decide actual thickness required.

General Causes of Pavement Failure

- Defects in quality of materials
- Construction methods
- Improper quality control
- Inadequate surface or subsurface drainage
- Increase in magnitude of wheel load
- Settlement of foundation of embankment and fill materials
- Heavy rainfall, soil erosion, high water table, snowfall, frost action

Traffic Engineering (For PSC Highway Engineer)

Glimpses of Syllabus

- Traffic engineering and scope
- Interrelationships between human/machinery/ environmental elements
- Impact of human and vehicular characteristics on traffic planning
- Traffic management (Traffic control and regulations , Traffic control devices)
- Traffic flow studies (Volume studies , Speed studies , Origin and destination (OD) study , parking studies, accident studies , capacity , traffic flow theory & level of service analysis)
- Intersection characters and design
- Traffic signal characters and design
- Traffic Lighting characters and design
- Traffic projection and forecasting

Traffic engineering and scope

- “ Traffic engineering is the branch of engineering which deals with the planning and design of streets and abutting land with respect to traffic operation so as to provide a safe convenient and economic flow of traffic (people and goods)”
- **Scope of traffic engineering**

1. Traffic(road user) characteristics
2. Traffic flow study and analysis
   - Volume study
   - Speed study . **Speed and delay study**
   - Origin and destination study
   - Capacity and level of service study
   - Accident study
   - Congestion , delay , queing , shockwaves etc. (Not a part of our syllabis)
3. Traffic operation and regulation
   - Traffic control
   - Traffic regulation

4. Design
    - Intersection
    - Street lightning
    - Parking (Not a part of our syllabis)
    - Terminal (Not a part of our syllabis)
5. **Traffic planning (Not a part of our syllabis)**
6. **Traffic administration and management (Not a part of our syllabis)**
7. **Traffic research**

Traffic(road user) characteristics

<u>Human Vehicle and Environment system</u>

- A highway (or transportation) system comprises of three different elements

1. The Road users (The driver and pedestrians)
2. The Vehicle
3. The road environment

- The road user takes information form the environment and acts so as to successfully complete the travel objective using the vehicle
- The vehicle executes the command of the user against all the resistance and in turn is depleting the environment
- The environment provides the information to user and air resistance etc. to the vehicle while itself is subjected to the action of the user and the vehicle

Traffic(road user) characteristics

- For a highway system to successfully operate there must is a very reasonable balance in between all these elements. For a proper balance
  - The user shall be well aware of the environment , the vehicle and the effect of their actions on the environment and the vehicle
  - The vehicle shall be in good conditions whereby it can execute the commands efficiently and also cause lesser damage to the environment
  - The environment shall be less punishing and confusing in nature also less demanding for the vehicle
- To ensure this proper engineering judgement and consideration shall be given during
  - Alignment selection
  - Facility design
  - Vehicle manufacture
  - Transportation Planning

Traffic(road user) characteristics

Road User Characteristics

Driving Task model (Components and Processes)

- In order to understand what characters of the user influence the operation of the transportation system the process of the driving taks and their interrelationships shall be understood
- In order to execute the travel demand successfully the driver performs the following taks

1. Control : It is the process of keeping the vehicle in the desired track
2. Guidance : It is the process of interacting with other vehicles like merging diverging , following , passing etc. maintaining safe distances
3. Navigation : It is the process of following the best suited path by use of maps signals signs etc.

Traffic(road user) characteristics

Road User Characteristics

Driving Task model (Components and Processes)

- Among these three navigation is the most important and most demanding task , followed by guidance and control. Since each task requires full attention so the driver switches actively between theses to accomplish the travel demand. The efficiency of this switching is limited by the characteristics of the users and thus system shall be designed considering these characters as far as possible and the characters which are not embedded into the system shall be limited through regulation

Traffic(road user) characteristics

Road User Characteristics

- The different road user characters are
- Physical Characteristics

1. Sensitivity/ Perception reaction
   - (PIEV Theory)
2. Age
3. Vision
   - Visual activity : What sized object can the user see
   - Contrast sensitivity : What is effect of this size due to lack of sufficient light
   - Peripheral Vision :
   - Visual search
4. Alcoholic and drug effect

Traffic(road user) characteristics

Road User Characteristics

- Mental Characteristics : Related to mental computations during the driving task

1. Information processing capacity / Intelligence
2. Speed choice
    1. Perpetual cues
    2. Road environment cues
3. Driver experience and expectation

- Psychological Characteristics : Related to state of mind of the user

1. Anxiety / Impatience
2. Overconfidence
3. Anger and frustration
4. Attentiveness

Vehicle Characteristics

Static Characteristics :

- The size of the design vehicle for a highway is an important factor in the determination of design standards for several physical components of the highway.
- These include lane width, shoulder width, length and width of parking bays, and lengths of vertical curves. The axle weights of the vehicles expected on the highway

Kinematic Characteristics :

Related to the motion characters of the vehicle

Speed

Acceleration

Breaking

Traffic Management

- Traffic management is the process of ensuring safe comfortable , economical and efficient traffic flow through use of set of accepted methodologies and elements. It can be achieved by

1. **Traffic Regulation/Control :** These are set of rules which are made to guide the vehicular traffic into proper flow . The different methods of traffic regulation/controls are

- Road user control :
  - Driver test before licensing
  - Regular test before renewal licesing
  - Financial liability
  - Road user training
- Vehicle control :
  - Regular maintenance check
  - Maximum weight check
  - Environment compatibility check
  - Age check

Traffic Management

- Flow control :
  - One way street
  - Dedicated lane
  - Speed limit
- General control :
  - Obstruction clearance
  - Tidal flow lane
  - Speed limit

2. **Traffic control devices :**

These are physical elements that are used to implement the traffic regulations and controls and also to guide the vehicle into the desired streams and channels

A traffic control device shall satisfy the following requirements

- **The control device should fulfill a need**: Each device must have a specific purpose for the safe and efficient operation of traffic flow. The superfluous devices should not be used.
- **It should command attention from the road users**: This affects the design of signs. For commanding attention, proper visibility should be there. Also the sign should be distinctive and clear. The sign should be placed in such a way that the driver requires no extra effort to see the sign.
- **It should convey a clear, simple meaning**: Clarity and simplicity of message is essential for the driver to properly understand the meaning in short time. The use of color, shape and legend as codes becomes important in this regard. The legend should be kept short and simple so that even a less educated driver could understand the message in less time.
- **Road users must respect the signs**: Respect is commanded only when the drivers are conditioned to expect that all devices carry meaningful and important messages. Overuse, misuse and confusing messages of devices tends the drivers to ignore them.
- **The control device should provide adequate time for proper response from the road users**: This is again related to the design aspect of traffic control devices. The sign boards should be placed at a distance such that the driver could see it and gets sufficient time to respond to the situation. For example, the STOP sign which is always placed at the stop line of the intersection should be visible for at least one safe stopping sight distance away from the stop line.

The different traffic control devices are

A. **Traffic sign**

- They are graphical symbols placed on road or near the road bearing information , requirement , restriction , prohibition etc.
- They shall be such that they are easily understood and shall be placed such that they are seen easily
- They are of following types

1. Regulatory sign

- These signs are also called mandatory signs because it is mandatory that the drivers must obey these signs
- These signs are primarily meant for the safety of other road users. These signs have generally black legend on a white background. They are circular in shape with red borders
  - Stop/ Yield sign (Right of way series)
  - Speed limit sign
  - Turn , do not turn (Movement series)
  - No parking sign
  - Pedestrian sign etc

2. Warning sign

- Warning signs or cautionary signs give information to the driver about the impending road condition.
- These signs are meant for the own safety of drivers. They call for extra vigilance from the part of drivers.
- color convention used for this type of signs is that the legend will be black in color with a white background. The shape used is upward triangular or diamond shape with red borders.
- Example : Landslide prone zone , High grade , Shaprp curve etc

3. Informatory sign

- Informative signs also called guide signs, are provided to assist the drivers to reach their desired destinations.
- These are predominantly meant for the drivers who are unfamiliar to the place.
- For e.g. route markers, destination signs, mile posts, service information, recreational and cultural interest area signing etc.
- They are written black letters on yellow background.

The different traffic control devices are

B. **<u>Traffic marking</u>**

- They are markings or symbols made on the pavement or objects near it in order to give clue about the nature of the road alignment and surrounding
- The different types of road marking are

1. Longitudinal markings

- Longitudinal markings are placed along the direction of traffic on the roadway surface, for the purpose of indicating to the driver, his proper position on the roadway.
- Longitudinal markings are provided for separating traffic flow in the same or different direction and the predominant color used is white.

Type of marking	Site	Length (mm)	Gap (mm)	Width (mm)	Spacing of studs if used (mm)	Use
Centre lines (white) Lanes (white)						Division of carriageway into traffic lanes
Permissive line	Urban	1500	4500	100	12000	
	Rural	2000	7000	100	18000	
Warning line	Urban	4000	2000	100	6000	Hazard ahead
	Rural	6000	3000	100	9000	Hazard ahead
Centre line(white)						
Prohibitory line	Urban	unbroken		100	4000	Overtaking prohibited
	Rural	unbroken		150	6000	Overtaking prohibited
Edge lines(yellow)						Delineation of edge of carriageway
Permissive line	Rural	1000	2000	150		
Prohibitory line	Both	unbroken		150		Parking prohibited

Table 1: Summary of centre, lane and edge lines

2. Transverse markings

- Transverse markings are marked across the direction of traffic. They are marked at intersections etc.
- For e.g. Stop sign , Zebra crossing sign

3. Object marking

- Used to adequately mark physical obstructions in a carriageway like traffic island or obstructions near carriageway like signal posts, pier etc. which can cause serious hazard to the flow of traffic
- For e.g. Kerb marking , island marking etc.

c. Traffic signal

- In busy intersections the conflict points are reduced using phase operation of traffic so as to ensure smooth flow
- A traffic signal is an electronic device used to replace the manual switching of the phases at a busy intersection
- It contains 3 lights namely the Green Amber and Red which have timings and run in a cycle the timing of the individual colors may be

1. Fixed time
2. Variable time / Traffic actuated

Traffic Studies

Traffic studies are carried out to analyze the traffic characteristics. It has the following objectives

- Managing for physical system including inventories of control devices (signs, signals, markings), lighting fixtures, repair and maintenance activities, decisions and authorizations, permits, street maps, condition assessments
- Investigating trends over time including volume, speeds, accidents and needs assessments so that actions can be anticipated, identified and taken.
- Understanding the needs and choices of the public and industry for mobility including mode choice, routings, parking, trip making by time of day, goods delivery, space utilization and motivation for ride sharing.
- Calibrating basic parameters or relations such as the perception reaction time, friction coefficients, discharge headways, lane utilization
- Assessing potential impacts including traffic and environmental impact assessments, site developments and access requests.
- Evaluating performance of systems or sub systems specially focused on how well mobility is being delivered.

Traffic Studies

The different types of traffic studies are as follows

- Traffic volume study
- Speed studies (spot speed study, speed and delay study)
- Origin and destination study
- Traffic flow characteristics
- Traffic capacity study
- Parking study
- Accident study

Traffic Studies

Traffic Volume Studies

- Traffic volume is defined as the number of vehicles per unit time traversing the given highway section for a specified unit of time
- A complete traffic volume study includes the classified volume study by recording the volume of various types and classes of traffic, directional distribution and turning movements and the distribution on different lanes per unit time. The objectives and uses of traffic volume studies are:
  - Traffic volume study is generally accepted as true measure of the relative importance of roads and in deciding the priority for improvement and expansion.
  - Traffic volume study is used in planning, traffic operation and control of existing facilities and also for planning and designing the new facilities.
  - Traffic volume study is used in the analysis of traffic patterns and trends.

- Classified traffic volume study is useful in structural design of pavements, in geometric design and in computing roadway capacity.
- Volume distribution study is used in planning one way streets and other regulatory measures.
- Turning movement study is used in the design of intersections, in planning signal timings, channelization and other control devices.
- Pedestrian traffic volume study is used for planning sidewalks, cross walks, subways and pedestrian signals.

Terminology

- Demand : It is the number of vehicles (or persons) that desire to travel past a point during a specified period (also usually one hour).
- Capacity : It is the maximum rate at which vehicles can traverse a point or short segment during a specified time period. It is a characteristic of the roadway. Actual volume can never be observed at levels higher than the true capacity of the section.
- Volume : It is the number of vehicles (or persons) passing a point per unit time during a specified time period, which is usually one hour, but need not be.
- Rate of flow : It is the rate at which vehicles (or persons) pass a point during a specified time period less than one hour, expressed as an equivalent hourly rate.

Types of Volume counts

Based on purpose

1. **Cordon Count:**

- These are made at the perimeter of an enclosed area (CBD, shopping center etc.). Vehicles or persons entering and leaving the area during a specified time period are counted.

2. **Screen Line Count:**

- these are classified counts taken at all streets intersecting an imaginary line (screen line) bisecting the area. These counts are used to determine trends, expand urban travel data, traffic assignment etc.

3. **Pedestrian Count:**

- These are used in evaluating sidewalk and crosswalk needs, justifying pedestrian signals, traffic signal timings etc.

4. **Intersection Count:**

- These are measured at the intersections and are used in planning turn prohibitions, designing channelization, computing capacity, analyzing high accident intersections etc.

Types of Volume counts

Based on period of study

1. Daily volume counts

- It is the study of the volume of vehicles per day. It is of the following types

- **Annual Average Daily Traffic (AADT):** expressed in vehicles per day. It is (1/365)th of the total annual traffic flow. Total number of vehicles passing in a year is divided by 365 days. All vehicles are converted into passenger car unit.
- **Average Daily traffic (ADT)**: If the flow is not measured for all the 365 days, but only for few days (less than one year) the average flow is known as Average Daily Traffic (ADT).
- **Average Annual Weekday Traffic (AAWT)**: is the average 24 hour traffic volume occurring on weekdays over a full year.
- **Average weekday traffic**: is an average 24 hour traffic volume occurring on weekdays for some period less than one year, such as one month or one season.
- This kind of survey is used for design of pavements , for palnning traffic etc.

Short term counts variations in Daily count

- If ADT is used due to lack of time and fund etc. then it shall be understood that the average for a short period varies considerably than the average all over the year
- Thus a number of variations have to be considered. These are
  - Daily variation
  - Weekly variation
  - Monthly Variation/ Seasonal Variation

2. HOURLY volume counts

- It is the study of the volume of vehicles per hour . The actual hourly volume varies widely from that calculated by using AADT the hourly flow of vehicles is required for many engineering purposes for e.g. rotary design
- The maximum value of the hourly flow is most important this is called DDHV flow and can be calculated from AADT using following formula

$$DDHV = AADT * K * D$$

3. Sub hourly count and rate of flow

- In some cases like signal design the hourly volume might be insufficient as the sub hourly volumes are different than averages obtained from the hourly volumes , in these cases a system based on the average values might lead to congestion and queuing that might not be clear for even the whole hour itself therefore a sub hourly count usually that of peak 15 min is required
- This 15 minute count expanded to 1 hour is known as the rate of flow
- In order to relate the actual flow in the hour to the anticipated flow using the sub hourly volume a term called the peak hour factor is used which is given by

$$PHF = \frac{Hourly\ volume}{Maximum\ rate\ of\ flow}$$

Methods of traffic flow measurement

1. **Manual counting:**

- In its simplest form an observer counts the numbers of vehicles along with its type, passing through the section for a definite time interval.
- Surveyors with adequate knowledge of the methods are equipped with all necessary tools and counts are taken
- For light volumes, tally marks on a form are adequate. Mechanical or electrical counters are used for heavy traffic.

Advantages

- This method provides with data that other methods are not able to give for example
  1. Turning and through movement studies
  2. Classification and occupancy studies
  3. Pedestrian activity and interaction

Advantages

- No sophisticated equipments are required at max a mechanical counter will be required
- Low chances of data damage

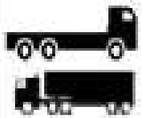
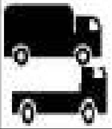
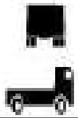
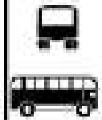
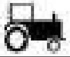
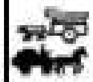
Disadvantages

- Method is costly
- Not suitable for very high traffic flow
- Suitable for long periods as manpower availability for short time is difficult to manage

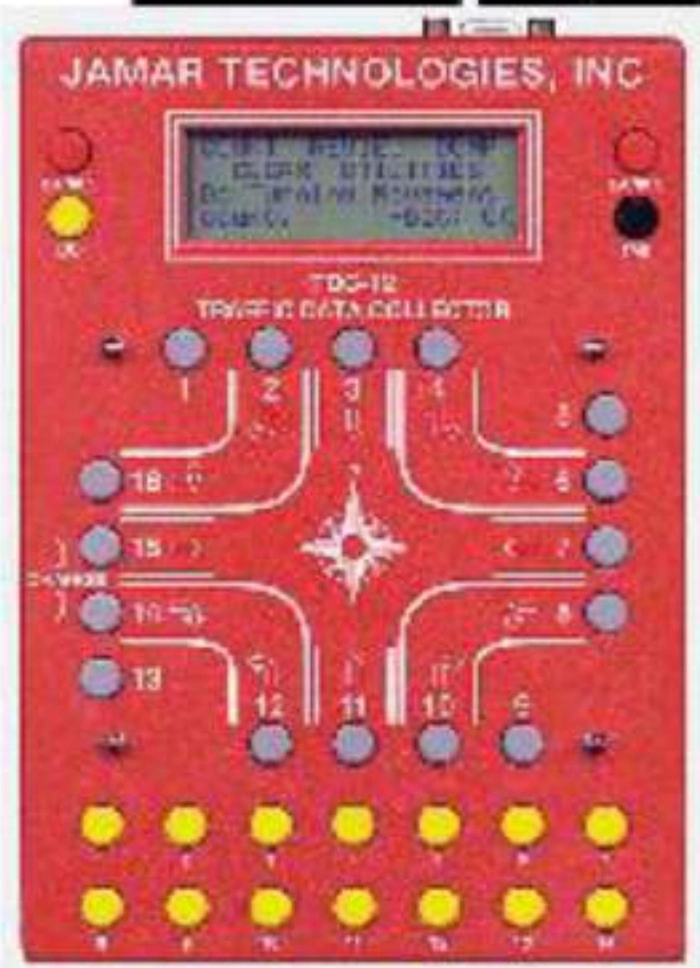
Subregional Transport Enhancement Project

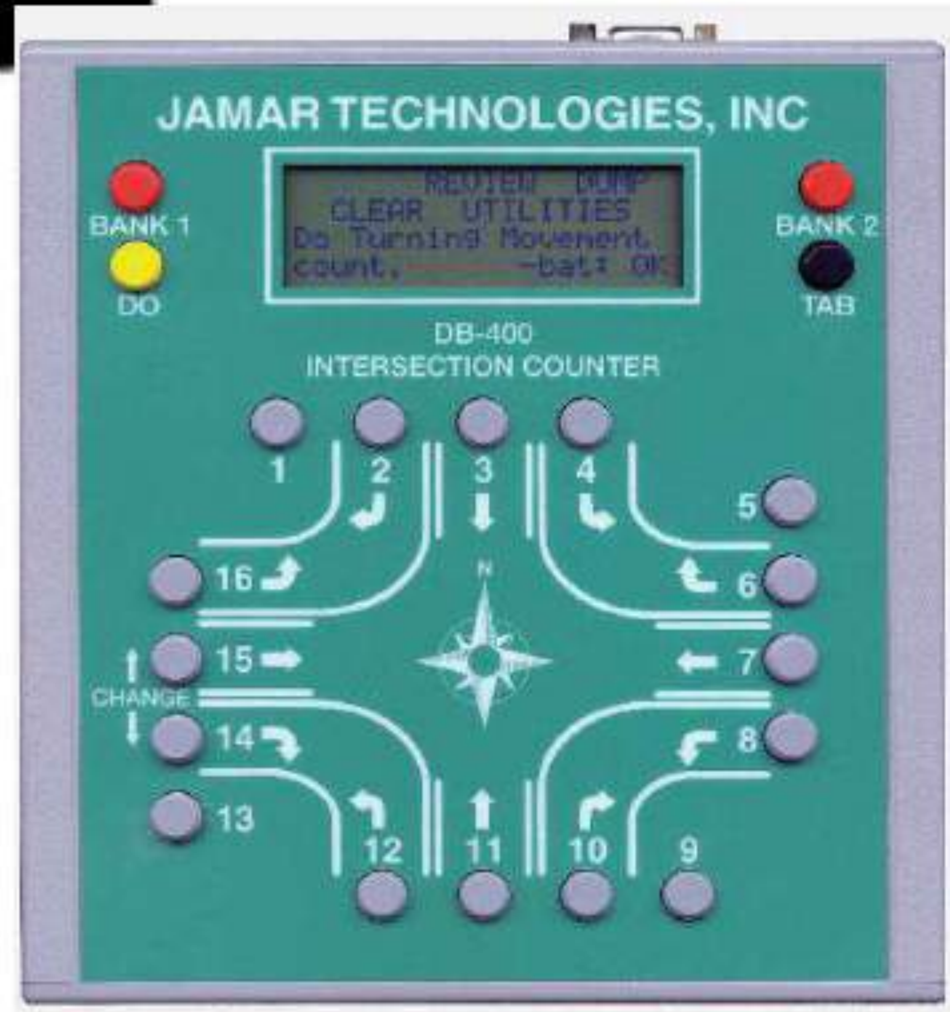
Traffic Count Form

Road Number or Name:			
Location:	Place Name:	km from	Day:
Surveyor Name:		Direction of Traffic:	Date:

Type	Motorised											Non-Motorised		
	Heavy Truck	**Heavy Truck**	**Mini Truck**	**Large Bus**	**Mini Bus**	**Micro Bus**	**Car Jeep Taxi**	**Utility / Pickup**	**Auto rickshaw**	**Tractor**	**Power Tiller**	**Motor cycle**	**Animal Cart**	**Rick shaw**	**Bicycle**
	3 or more axles	2 axles			Max 35 Seats	Max 14 Seats			all 3-wheelers	With or WO Trailer					
															
Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

* All Trucks have double wheels on the rear axle. Mini Trucks have two axles. Heavy Trucks should be divided into two groups: with 2 axles and with 3 or more axles.


JAMAR TECHNOLOGIES, INC


JAMAR TECHNOLOGIES, INC
REVIEW DUMP
CLEAR UTILITIES
Do Turning Movement
count. -bat: OK
BANK 1
DO
BANK 2
TAB
DB-400
INTERSECTION COUNTER
CHANGE

Methods of traffic flow measurement

2. **Mechanical counting:**

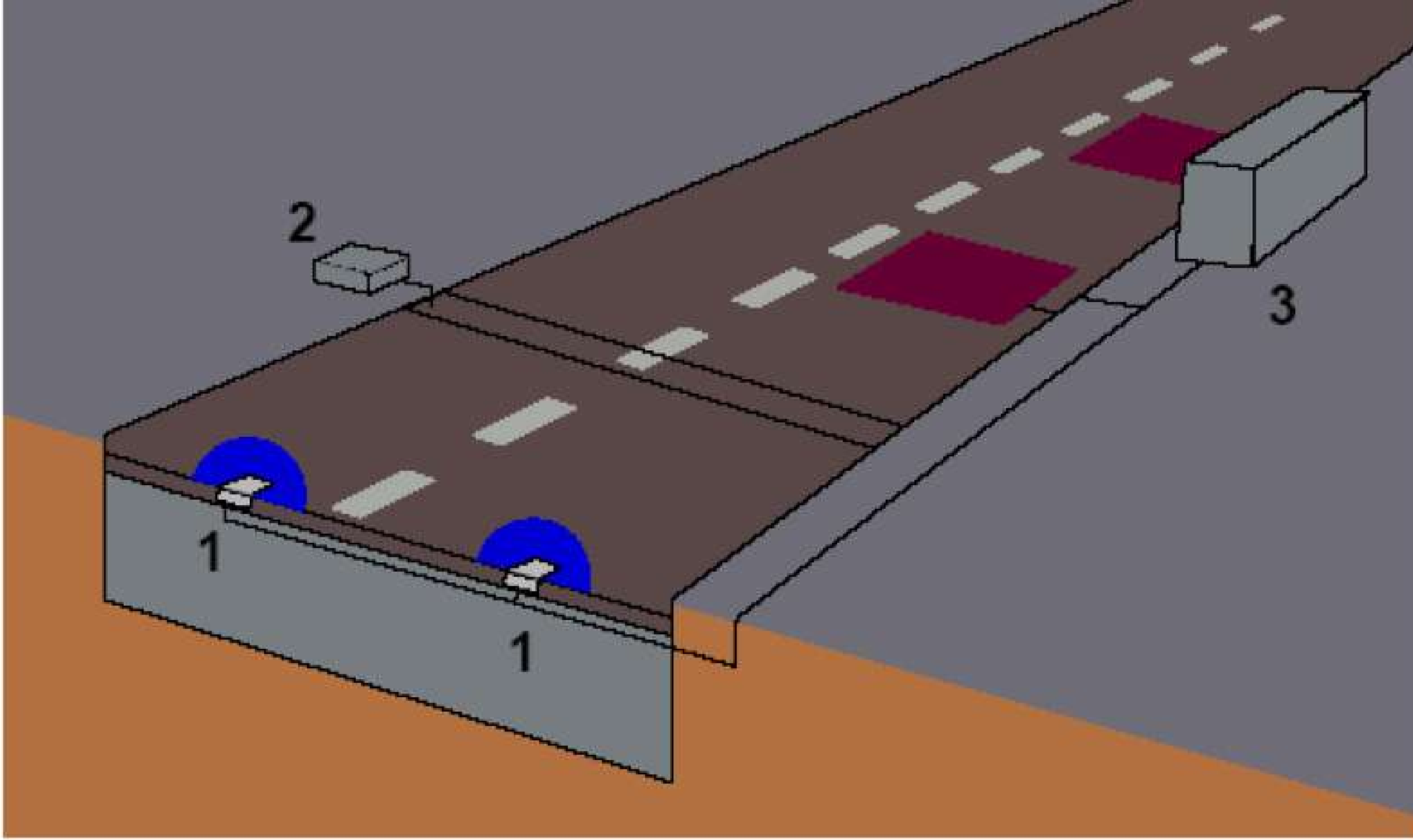
- This method utilized sensors for counting vehicles.It is of two types

A. **Intrusive methods :**

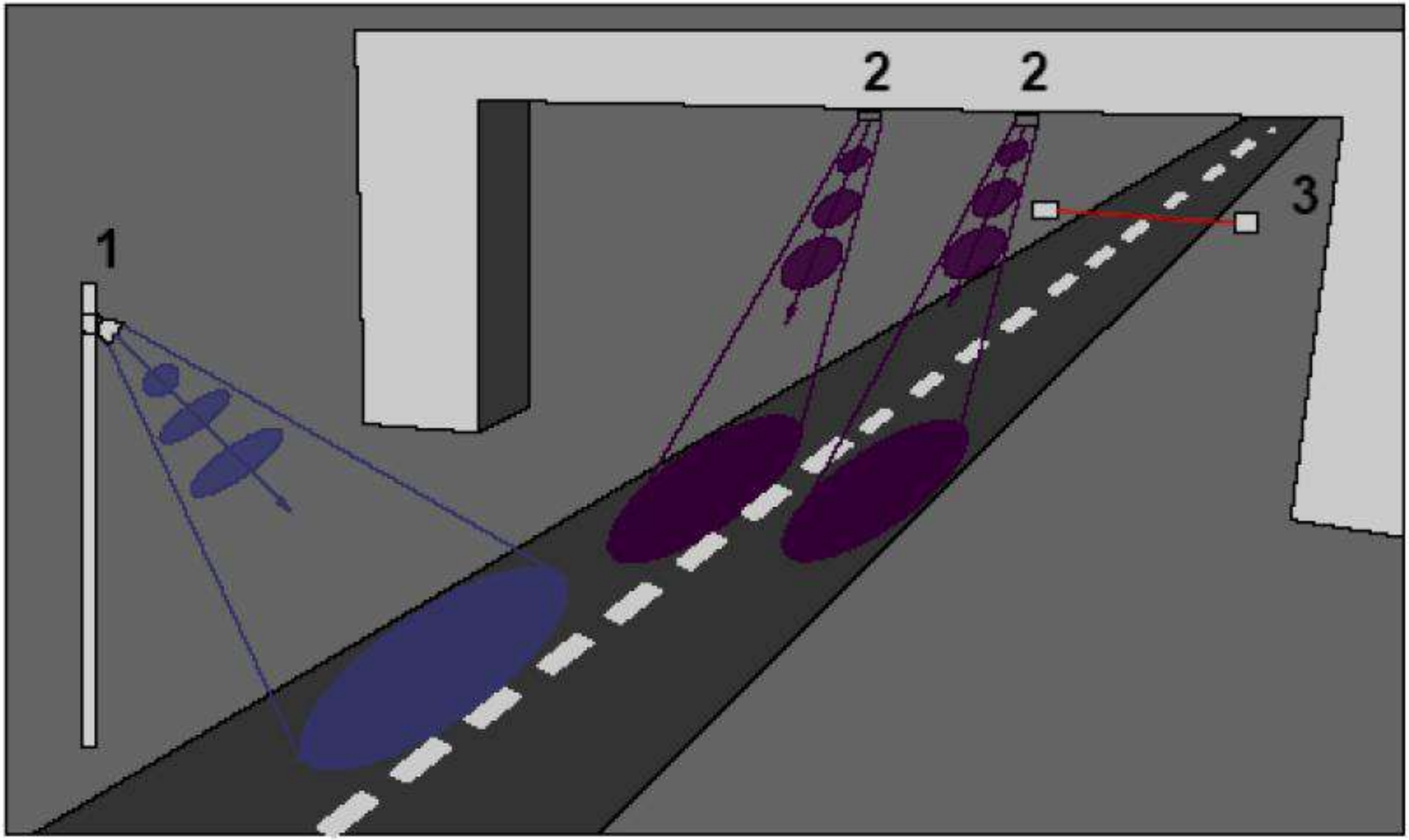
- These methods use intrusive sensors i.e. sensors placed on the surface of the road itself
- The most common type of sensor is the pneumatic sensor , it consists of a tube embedded in the road which is activated and counts the axles when they pass over them.
- It is to be noted that this sensor counts axles not vehicles so a sample count shall be taken and these axles have to be converted into the vehicles

B. **Non Intrusive methods :**

- These methods use advanced sensors like microwave , radar wave , ultrasonic wave , videography technique etc. to detect the vehicle
- These methods can detect the vehicle as well as their speeds

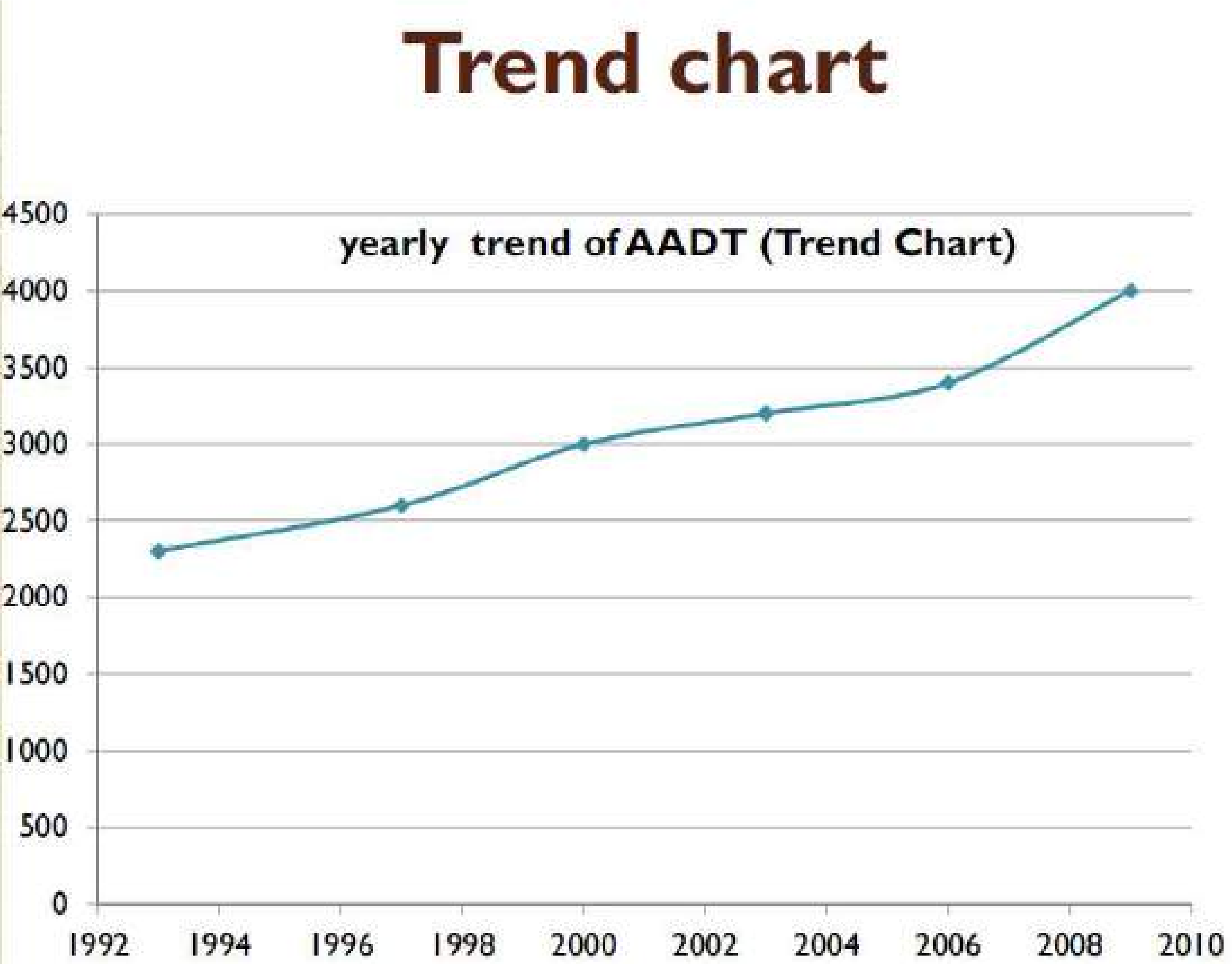


Type:1. Embedded magnetometers
2. Pneumatic tube detectors
3. Inductive detector loops

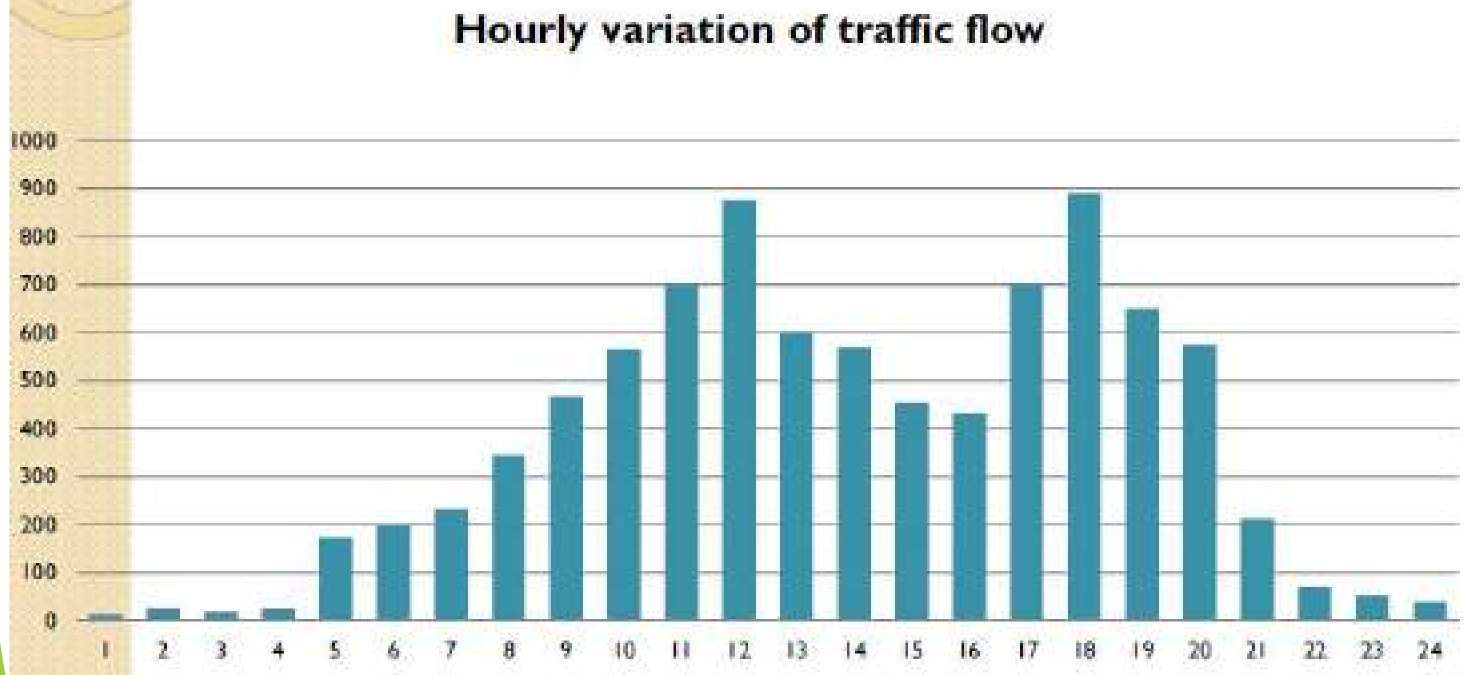


Type 1. Roadside, Mast-mounted type
2. Gantry or bridge underside
3. Cross-fire

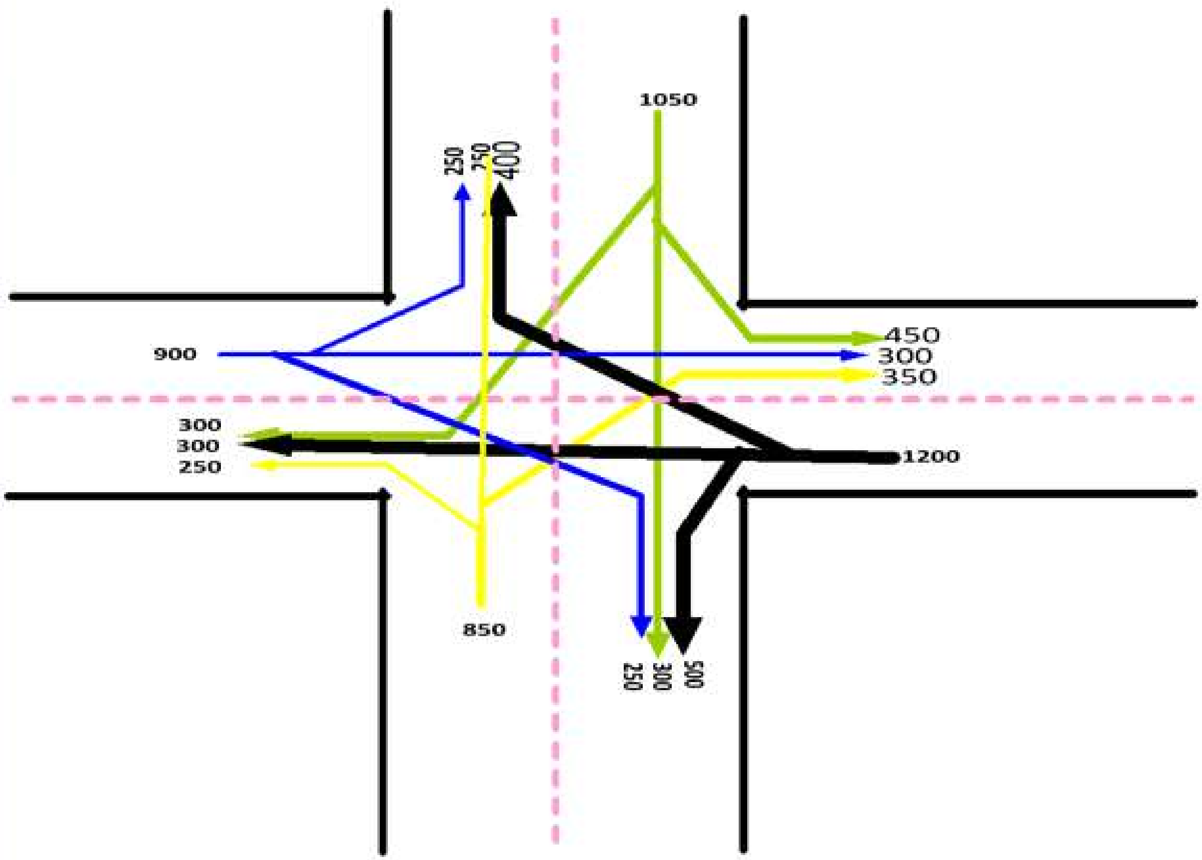
Presentation and analysis of traffic volume data



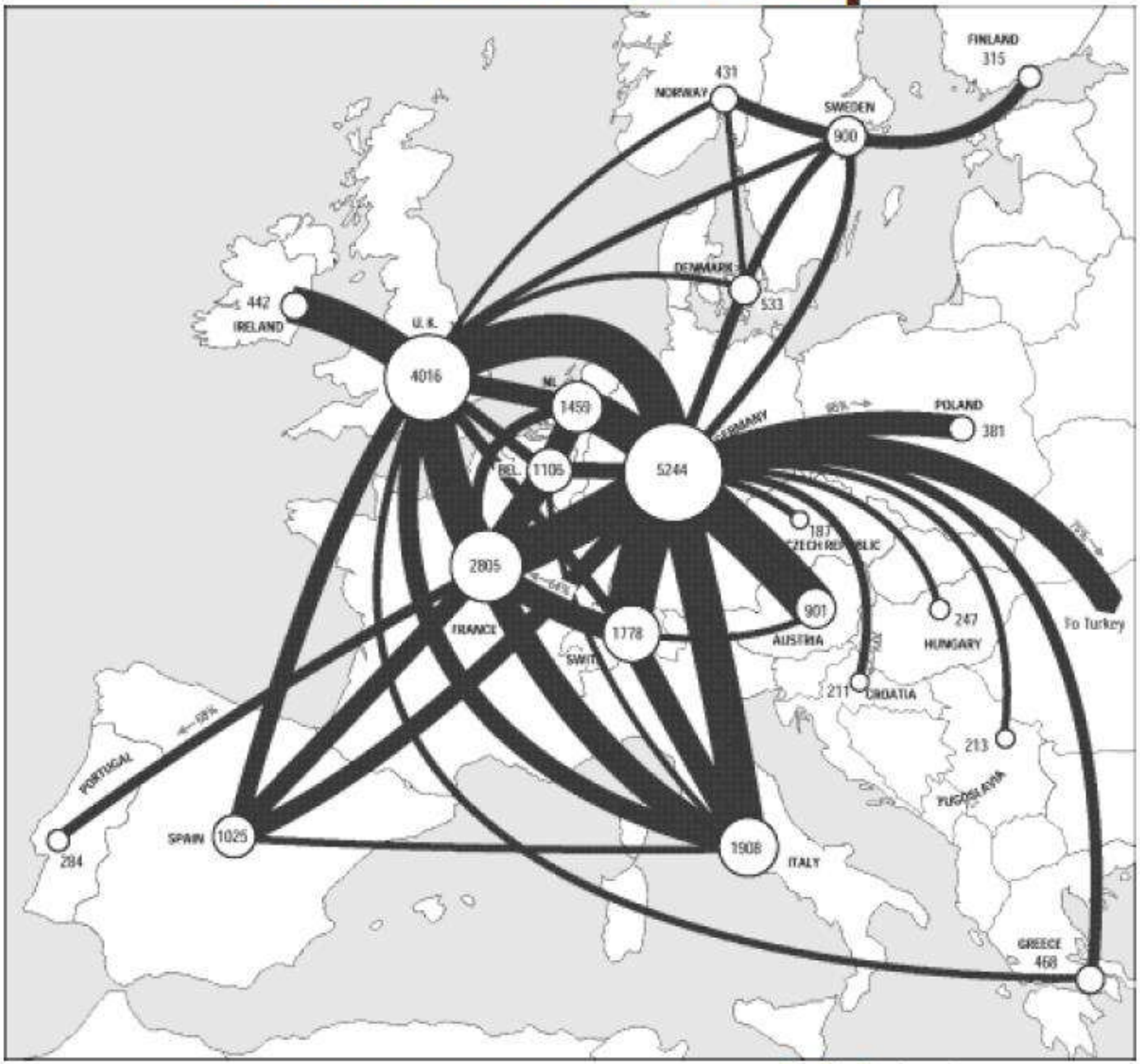
Hourly Variation



Count at Intersection



Traffic flow map



Traffic Engineering

Traffic Studies

Speed Study

- Evaluation of different types of speed related parameters in a highway section are termed as the speed study
- Requirements
  - Traffic operation like sign location and timings, establishing speed zones etc.
  - Geometric design of elements like curvatures, super elevation, stopping sight distance etc.

Terminology

1. Spot speed

- It is the speed of the vehicle calculated at a point
- Spot speed is affected by physical of road like pavement width, curve, sight distance and grade.

2. Running speed

- It is the speed calculated based on the actual running time. It is useful for assessing traffic capacity of roads.

$$\textbf{Running Speed} = \frac{\textbf{Length of Route}}{\textbf{Running Time}} = \frac{\textbf{Length of Route}}{\textbf{Journey time} - \textbf{delay time}}$$

3. Journey speed : It is the speed calculated based on the actual journey time i.e.

$$\textbf{Running Speed} = \frac{\textbf{Length of Route}}{\textbf{Joutney time}}$$

4. Average speed:

- It is the average speed of several vehicles passing a specific section . There are two types of average speed
- Space mean speed : Average speed of vehicles over a certain road length at any time. It is the harmonic mean of speeds observed at a point. It is calculated using the average travel time and length of the roadway.

$$v_s = \frac{L}{\frac{\sum_{i=1}^{n} t_i}{n}} = \frac{1}{\sum_{i=1}^{n} \frac{1}{v_i}}$$

- n - Number of individual vehicle observation;
- L- Length of the road section;
- t_i - observed travel time in sec for the i th vehicle to travel L m.

Time mean speed(spot speed): Average speed at a point over a period of time. It is the arithmetic mean of the speeds observed at a point. It represents speed distribution of vehicles at a point.

$$v_t = \frac{\sum_{i=1}^{n} v_n}{n}$$

The space mean speed and time mean speeds can be related using

$$v_t = v_s + \frac{\sigma_s^2}{v_s}$$

NUMERICAL EXAMPLE

26 spot speed observations were taken as

50 , 45 ,47 , 60 , 55 , 58 , 61 , 42 , 40 , 52 , 54 , 42 , 40 , 52 , 53 , 43 , 57 , 60 , 62 , 40 , 42 , 43 , 50 , 49 , 60 , 59

Calculate :

(i) Time mean speed

(ii) Space mean speed

(iii) Verify their relation

Traffic Studies

Types Speed Study

1. Spot speed study

It is the analysis of the speed of the vehicle at a point. It is used in

- Geometric design of roads
- Regulation and control of traffic operation;
- Analyzing the causes of accidents;
- Before and after study of improvement projects;
- Determining the problems of congestion in the road section;
- Capacity study

Spot Speed Measurement

General consideration for the site selection for spot speed measurement:

- Location selection should be according to the specific purpose;
- Minimum influence to the traffic flow and their speed by the survey team and equipments;

Generally straight, level and open section should be selected.

Traffic Studies

<u>Spot Speed Measurement</u>

<u>Methods of spot speed measurement</u>

1. **<u>Direct timing procedure</u>**

- Simple method
- Two reference points are marked on the pavement at a suitable distance apart and an observer starts and stops an accurate stopwatch as a vehicle crosses these two marks.
- One observer stands at the first reference point and gives signal to the observer standing at last reference point (with stopwatch).
- From the known distance and measured time intervals spot speed is calculated;
- Large effects may occur due to the parallax effect;
- Reaction of individual observer may affect the result.

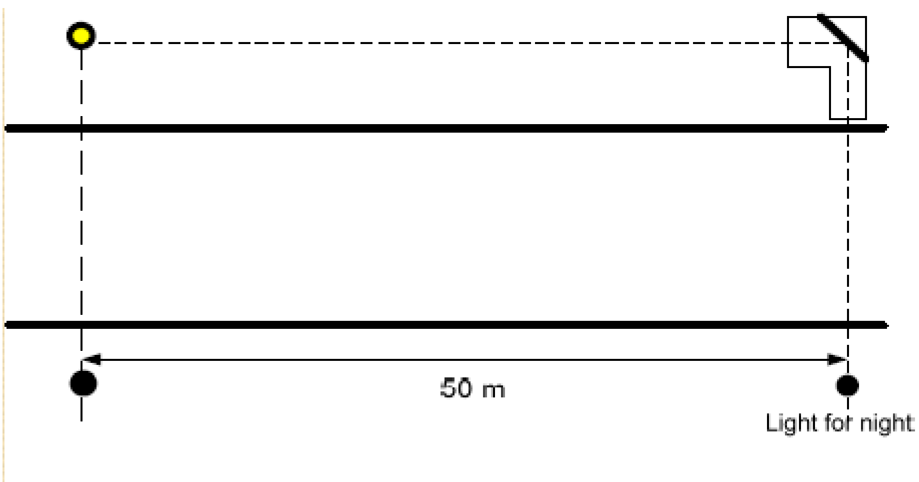
Traffic Studies

Spot Speed Measurement

Methods of spot speed measurement

2. **Enoscope method**

- It is a simple device consisting of L-shaped mirror box, open at both ends. It has a mirror set fixed at 45 degree to the arms of the instrument as in figure
- Vehicle can be observed from the same point as it passes through both the start and end location



Traffic Studies

Spot Speed Measurement

Methods of spot speed measurement

3. **Pressure contact tubes**

- In this method detectors are used to indicate the time of entering and leaving the base length by the vehicle.

4. **Radar speed meter**

- This automatic device works on theDoppler principle that the speed of a moving body is proportional to the change in frequency between the radio wave transmitted to the moving body and the radio wave received back.
- It directly measures speed.

5. **Photographic and video camera method**

- Time-lapse camera photography has been used to determine the speed of the vehicles.
- In this method, photographs are taken By projecting the film on the screen, the passage of any vehicle can be traced with reference to time.
- Video camera also can be used to measure the speed of the vehicle

Presentation and analysis of spot speed data

1. **Tabular presentation:** Grouping of spot speeds into speed ranges to facilitate easy computation.
2. **Graphical presentation:** (Histogram and cumulative frequency curves)

I. **Histogram :** It is the plot of the speed value vs the frequency. It is used to find

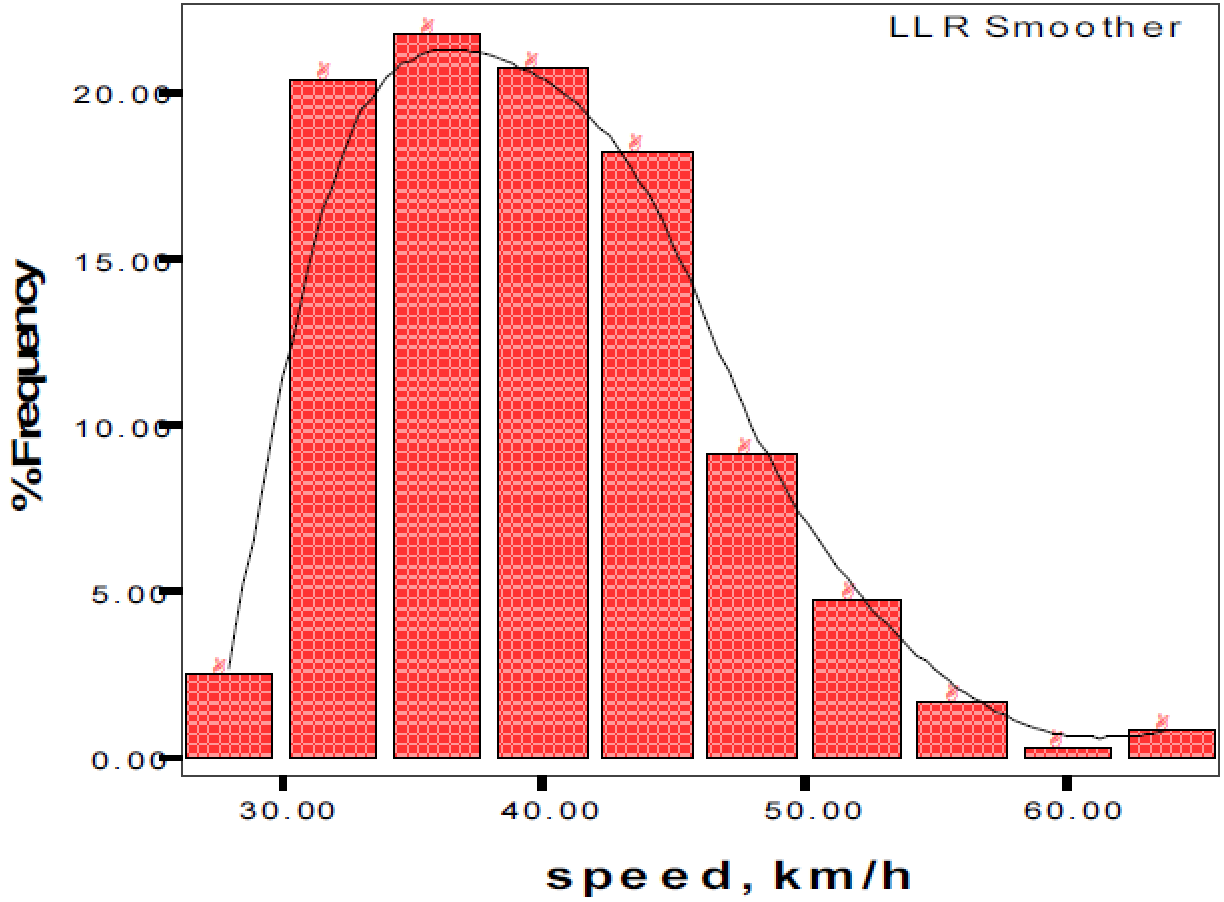
- **Modal speed:** peak of the frequency curve. (Mode of the distribution)

II. **Cumulative frequency curves :** They provide with

- **Median Speed:** 50th percentile speed
- **98th percentile speed:** below this speed 98% of vehicles move, and it is taken as design speed for the geometric design.
- **85th percentile speed:** 85% of the vehicles move below this speed. It is used to establish upper speed limit for traffic management. It is taken as limit of safe speed in the road.
- **15th percentile speed:** 15% of vehicles move below this speed. It is used for determining minimum speed limit for major highways.

3. **Arithmetic mean or average spot speed:** Summation of all variable speed divided by the number of observations.

Histogram:


LLR Smoother
20.00
15.00
10.00
5.00
0.00
%Frequency
30.00
40.00
50.00
60.00
speed, km/h

Numerical Example

- Spot speed studies were carried out at a certain stretch of a highway and the data collected are given below.

Class Limit km/hr	26-29.9	30-33.9	34-37.9	38-41.9	42-45.9	46-49.9	50-53.9	54-57.9	58-61.9	62-65.9
Freq.	9	74	79	75	66	33	17	6	1	3

- Determine:

(i) Upper speed limit,

(ii) Lower speed limit,

(iii) Speed to check design elements,

(iv) Modal speed

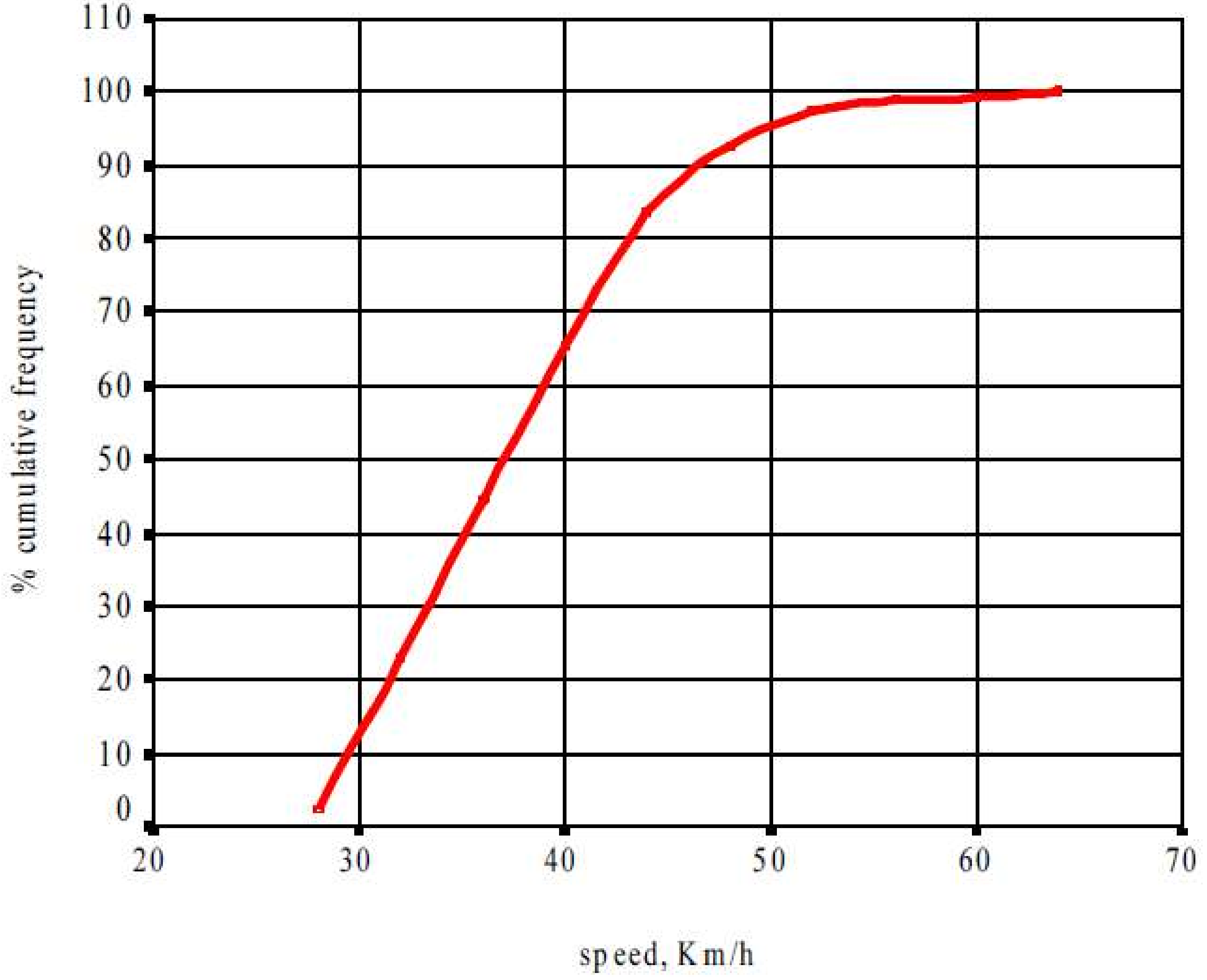
(V) Average speed,

(VI) Std. Deviation of speed

Solution

Class		Mid Value (Fi)	Frequency (Xi)	Percentage Frequency	Cumulative Percentage Frequency	Fi * Xi
Lower	Upper					
26	29.9	27.95	9	2.479338843	2.479338843	251.55
30	33.3	31.65	74	20.38567493	22.86501377	2342.1
34	37.7	35.85	79	21.7630854	44.62809917	2832.15
38	41.9	39.95	75	20.66115702	65.2892562	2996.25
42	45.9	43.95	66	18.18181818	83.47107438	2900.7
46	49.9	47.95	33	9.090909091	92.56198347	1582.35
50	53.9	51.95	17	4.683195592	97.24517906	883.15
54	57.9	55.95	6	1.652892562	98.89807163	335.7
58	61.9	59.95	1	0.275482094	99.17355372	59.95
62	65.9	63.95	3	0.826446281	100	191.85
		n	363		Σfi * Xi	14375.8
					Mean = Σfi * Xi/n	39.6026

The cumulative percentage frequency diagram



Traffic Studies

Types of Speed Study

2. Travel time study (Speed and Delay Study)

- It is the study of the Travel time and is conducted for significant lengths of a facility or group of facilities forming a route.
- The information on the travel time between key points within a study area is found and is used to identify those segments in need of improvements.
- Travel time studies are often coordinated with delay observations at points of congestion along the study route.

Use of speed and delay study

- To identify problem locations on facilities
- To measure arterial level of service
- To provide necessary input to travel assignment models, which focus on link travel time
- To provide travel time data for economic evaluation
- To develop time contour maps and other depictions of traffic congestion in an area

Traffic Studies

Use of speed and delay study

- Running speed is useful for highway planner, where as a passenger is more concerned to journey time.
- Journey time that considers both speed and delays, gives measure of traffic congestion and adequacy of road system including basis for transportation economic studies.
- It gives running speed, overall speed, and delays between two terminals.

Traffic Studies

<u>Methods of speed and delay studies</u>

1. Registration number plate method

- In this method the whole area cordoned and entry and exits are defines
- License plate number of all vehicles entering and leaving and then matched to know the total travel time
- This method gives only the travel time and is applicable when the entering vehicles leave

2. Elevated observer method

- In this method an observer is placed on a high building or a camera is placed
- From the analysis of the motion of vehicles the travel time , the running time and the delay time/ delay points can be eveluated

Traffic Studies

Methods of speed and delay studies

3. Moving car observer method

- Three observers on a test vehicle:
  - First observer: counts opposite traffic using hand tallies.
  - Second observer: with two stopwatches records time for each individual delays (at intersections or on bridges) and total time duration for the trip of predefined route.
  - Third observer: records the number of overtaking and overtaken vehicles.

Calculations

$$q = \frac{X + Y}{t_a + t_w}$$

- q- flow of vehicles in one direction of the stream
- X - average number of vehicles met in the section when the test vehicle travelling against the stream
- Y - average number of vehicles overtaking the test vehicle minus the number of vehicles overtaken when the test vehicle travelling with the stream
- t_a - average journey time in minute when the test vehicle is travelling against the stream q
- t_w - average journey time in minute when the test vehicle is travelling with the stream

$$\text{mean travel time } (t) = t_w - \frac{Y}{q}$$

$$\text{mean journey speed } (t) = \frac{\text{Travel distance (d)}}{\text{Average time (t)}}$$

$$\text{mean travel time } (t) = \frac{\text{Travel distance (d)}}{\text{Average time (t)} - Delay\ time}$$

Numerical example

- The following tables give the particulars collected for a section of road 0.7km long during the course of a moving observer study:
  - Calculate the flow in PCU per hour in both directions of traffic assuming an equivalency factor of one per car, 3 for bus and 2 for trucks.
  - Calculate the journey speed and running speed.

Journey: North bound

Run no	Journey time(min)	Stopped time(min)	Vehicles met with in the opposing direction			Vehicles in the same direction	
			Car	Bus	Truck	Overtaking vehicles	Overtaken Vehicles
1	1.01	0.04	11	0	5	1	0
2	0.92	0.1	13	0	0	2	1
3	0.77	0.08	19	2	11	1	1
4	1.03	0.14	14	2	4	1	0
5	0.84	0.08	2	0	11	0	1
6	1.06	0.13	19	1	7	2	1

South Bound Journey

Run no	Journey time(min)	Stopped time(min)	Vehicles met with in the opposing direction			Vehicles in the same direction	
			Car	Bus	Truck	Overtaking vehicles	Overtaken Vehicles
1	1	0.05	10	0	2	1	1
2	0.87	0.07	2	0	3	1	0
3	1.2	0.11	23	1	6	2	1
4	1.18	0.12	7	0	1	2	0
5	1.06	0.09	8	0	1	1	1
6	1.02	0.1	11	0	8	2	0

Traffic Studies

Delay and its types

Any acess time than that due to normal travel is called delay

Delay studies along routes are best done by the moving observer method described earlier.

Types of Delay

1. **Fixed delays (stopped delay):** delays at the intersections, traffic signals, stop signs, railway crossings, etc. that exists due to fixed roadway conditions and does not depend on the traffic density.
2. **Operational delay (congestion delay):** they are caused by the interference of traffic movements, such as crossing and turning vehicles, parking and pedestrians, accidents etc. Uncontrolled intersections adjacent to each other and carrying heavy turning movements can be the cause of a considerable amount of weaving within the stream as vehicle attempt to enter and leave the main road.

Traffic Studies

Origin and Destination (OD) Study

- Study on the attributes of trip
- In a transportation study, it is often necessary to know the exact origin and destination of the trips.
- Origin and Destination (O-D) surveys provide a detailed picture of the trip patterns and travel choices of a city's or region's residents.

Objectives

- To determine the amount of bypassable traffic that enters a town and thus justify the need for a bypass
- To develop trip generation and trip distribution models in transport planning process
- To determine the extent to which the present highway system is adequate and to plan for new facilities
- To assess the adequacy of parking facilities and to plan for future
- To judge adequacy of existing route
- To locate express way or major route along desire.
- To locate the terminal facilities
- To locate new bridge as per traffic demand
- To locate intermediate stops for public transport

Information collected by O-D study

- An OD Survey provides with the following data
  - Travel mode
  - Travel time of day & duration
  - Point of origin
  - Point of destination
  - Route of journey
  - Purpose of journey

Methods of O-D study

- An OD Survey provides with the following data
  1. Road side interview method
  2. License plate method
  3. Return post card method
  4. Tag-on-car method
  5. Home interview method

Road side interview method

- The site for the interview is located , and vehicles are stopped taking help of Traffic Police
- While selecting the site it shall be noted that the selected site has space enough to stop the vehicle and also there is no significant effect of the parking of the vehicle on the traffic flow
- After vehicles are stopped the prescribed forms and questionnaire are filled by interviewing the road users
- The information collected include : place & time of O-D; route location, stoppages, purpose, vehicle and number of passengers.
- This is quick method, but it may cause the delay for traffic flow and it needs sufficient space to stop vehicles & take interviews.

License plate method

- Entire study area is cordoned and observers are stationed at all points of entry and exit on all routes.
- Each party at the station notes the registration number of the vehicles entering and leaving the cordoned area and the time.
- Separate sheets are maintained for each direction. After collecting field data office computation is done by tracking the vehicle number and its time of entering and leaving the cordoned area.
- This method is quite easy and quick in field, but it involves a lot of office work.

Return Post card method

- Prepaid business reply post cards with return address are distributed to the road users.
- Questionnaire to be filled is printed on the card along with the request for the cooperation.
- The received cards are analyzed and conclusions are drawn
- It is not effective in developing countries due to poor postal system.

Tag on vehicle method

- Pre-coded card/tag is stuck on the vehicle as it enters the study area.
- When the car leaves the cordon area tags are removed and recorded.
- Time of entering and leaving are recorded on the tag.
- Tags may be of different colour and shape for different routes.
- The vehicle movement could be tracked at the office

Home Interview Method

- 0.5 to 10 % of the household is randomly selected for the home interview survey.
- Specific questionnaire is designed for the interview.
- Travel related data of household and socioeconomic data is collected.

Presentation of O-D data

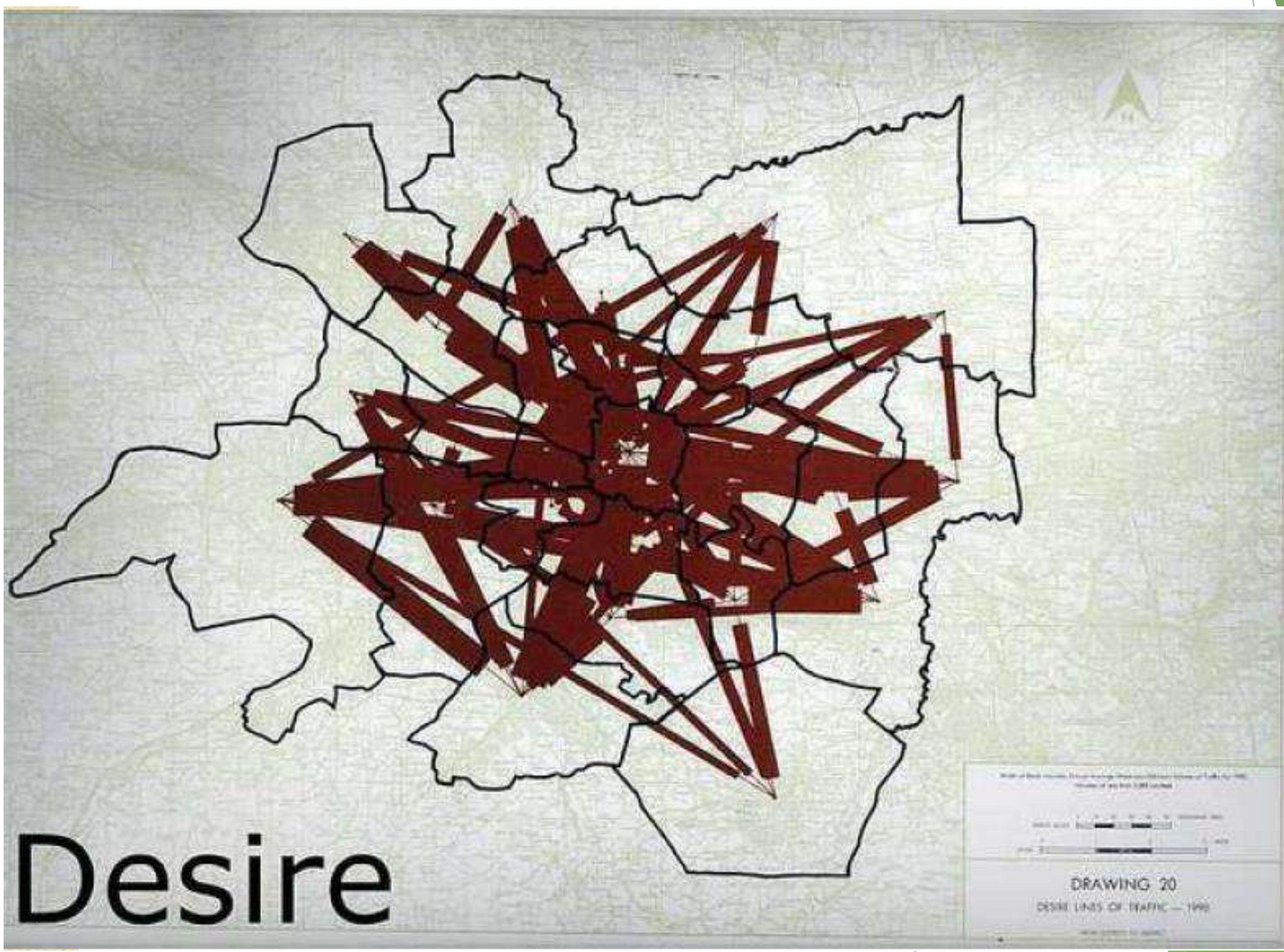
- O-D matrix: tables/matrix is prepared showing the number of trips between different zones.

		Destination zones						
		1	2	3	4	5	6	7
Origin zones	1							
	2							
	3							
	4							
	5							
	6							
	7							

- Desired lines are plotted which is graphical representation of O-D survey. Density of the desire lines shows actual desire of the road user.

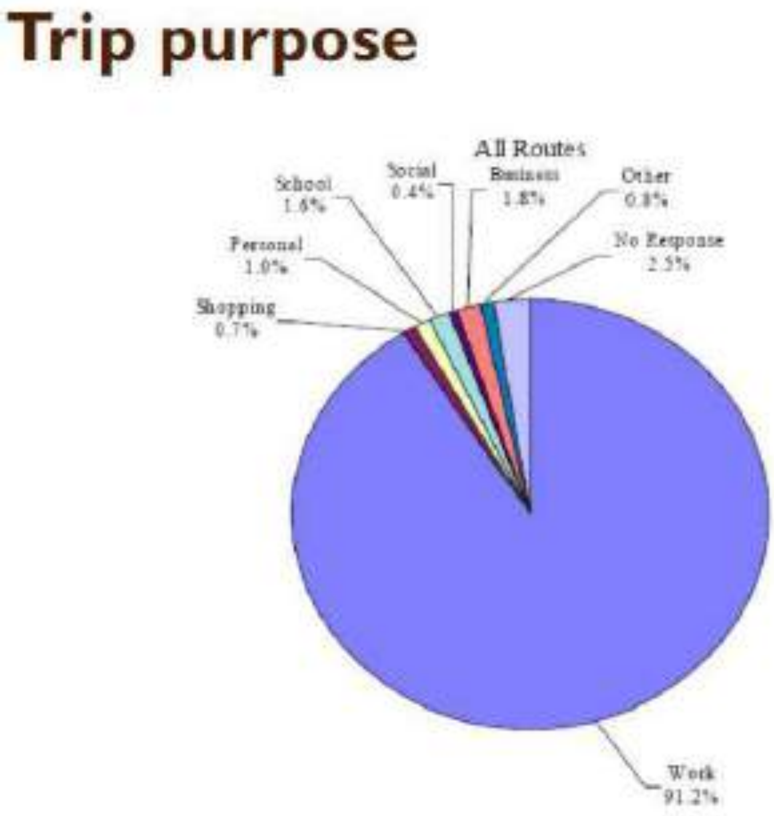
Presentation of O-D data

Desire Line

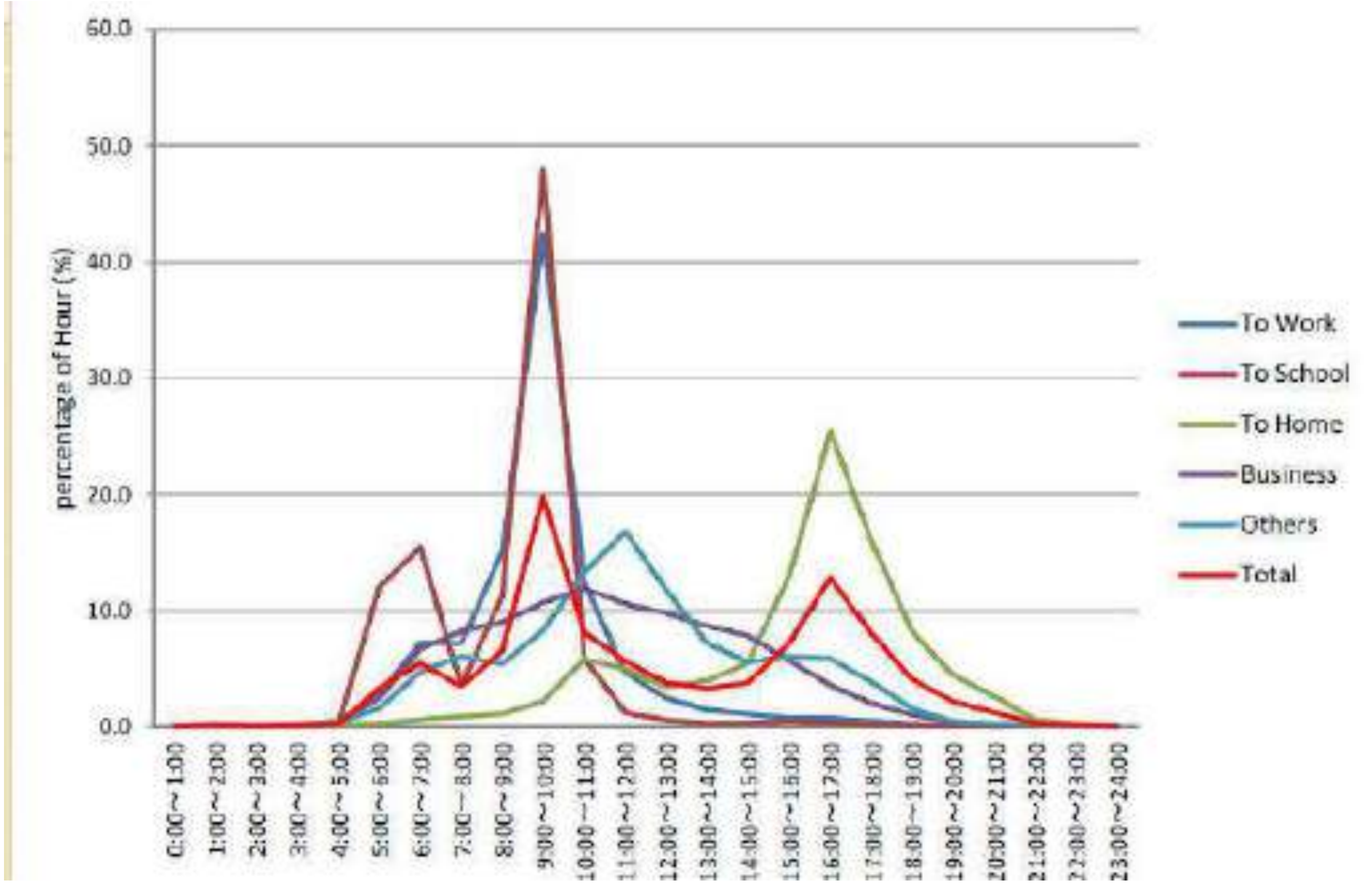


Presentation of O-D data

- Pie chart the relative magnitude of the generated traffic and geometrical relationship of the zones involved represented by pie chart.



Hourly Trip Generation by Purpose



Traffic Studies

Parking Studies

- It is the study of the traffic demand its supply and the balance making between these two

Parking policy

- It is the plan which guides how the parking needs will be fostered i.e. what part will be addressed and what part will be managed alternatively
- Forming a parking policy is a difficult task as it requires co-ordination with different organization , deals with lack of resources , deals with error in estimation of demand and supply
- The main considerations that shall be done during the formation of parking policy are
  1. Proper compromise between space for parking vehicle and movement of vehicles
  2. Separate treatment of short and long term parkers
  3. To manage off street parking and their approaches
  4. To ensure compliance with the overall transport policy
  5. To ensure the interests of all concerned sectors like business industry etc.
  6. To protect the locality beauty/ aesthetics and environment

Traffic Studies

Negative Effects of Parking

- Congestion:

Parking takes considerable street space leading to the lowering of the road capacity. Hence, speed will be reduced; journey time and delay will also subsequently increase. The operational cost of the vehicle increases leading to great economical loss to the community.

- Accidents:

Careless maneuvering of parking and unparking leads to accidents which are referred to as parking accidents. Common type of parking accidents occur while driving out a car from the parking area, careless opening of the doors of parked cars, and while bringing in the vehicle to the parking lot for parking.

Traffic Studies

Negative Effects of Parking

- Environmental pollution:

They also cause pollution to the environment because stopping and starting of vehicles while parking and unparking results in noise and fumes. They also affect the aesthetic beauty of the buildings because cars parked at every available space create a feeling that building rises from a plinth of cars.

- Obstruction to fire fighting operations:

Parked vehicles may obstruct the movement of firefighting vehicles. Sometimes they block access to buildings.

Prohibited Parking

It is desirable to prohibit parking at certain locations to ensure safety and convenience. Such locations are:

1. Near intersection

It is the general practice to prohibit parking for a distance of about 50m on the approaches to a major intersection.

2. Narrow streets

It is generally desirable to prohibit parking on two-way streets less than 5.75 m wide and one way-streets less than 4.0m wide.

3. Pedestrian crossings

It is desirable to prohibit parking within about 8m from the pedestrian crossing.

4. Structures

Structures such as bridges, tunnels and underpasses generally have a roadway width less than the highway and for this reason it is desirable to prohibit parking on them.

5. Entrance driveways

Vehicles should be prohibited from parking in front of entrance driveways leading to house and buildings.

Parking analysis/studies

It is the process of analysis of the supply and demand of the traffic.

Purpose of parking studies

- To determine the congestion in the city or town areas
- To assess the suppressed parking demand
- To estimate the desires and demands of the public for parking facility
- To decide the capacity, location and type of future parking facilities

It contains two parts

1. **Parking Supply Analysis**

This part aims to evaluate the total number of parking facilities that are available under the current scenario. It aims to provide assessment of on-street and off-street parking facilities available.

2. **Parking Demand Analysis**

This part aims to provide the existing demand of parking facilities so that the existing facilities might be analyzed, compared and corrected if necessary

Demand shall be determined based on the following

i. Growth of population

ii. Trends of growth

iii. Policies

Parking Survey

They are studies carried out for the parking supply and demand analysis

- **For Parking supply analysis**

1. **Parking space inventory**

In parking space inventory we observe the number of bays , prevailing parking practices , their interaction with existing traffic flow and problems associated with parking. Some of the main things observed are

- Total length of kerb, and lengths governed by no waiting and limited waiting restrictions.
- Number of parking space provided in the street
- Street width
- Location of bus stops, Bus bays, pedestrian crossings, loading
- zones, taxi stands and other features that are likely to affect the use of the street for parking.
- Traffic management measures in force, such as prohibited turns, one way streets etc.
- Number and type of traffic signs for regulation of parking
- Private streets
- Vacant or unused land suitable for temporary or permanent parking space

For Parking Demand Analysis

1. **Parking usage survey by patrol**

- This method consists of making periodic observations of parked vehicle on each patrol (covering both the morning and evening peak period) , the parking accumulation and turn over.
- The survey can be for on-street and off-street parking.
- the purpose of parking usage survey is to obtain data on the extent of usage of parking spaces.

STEPS

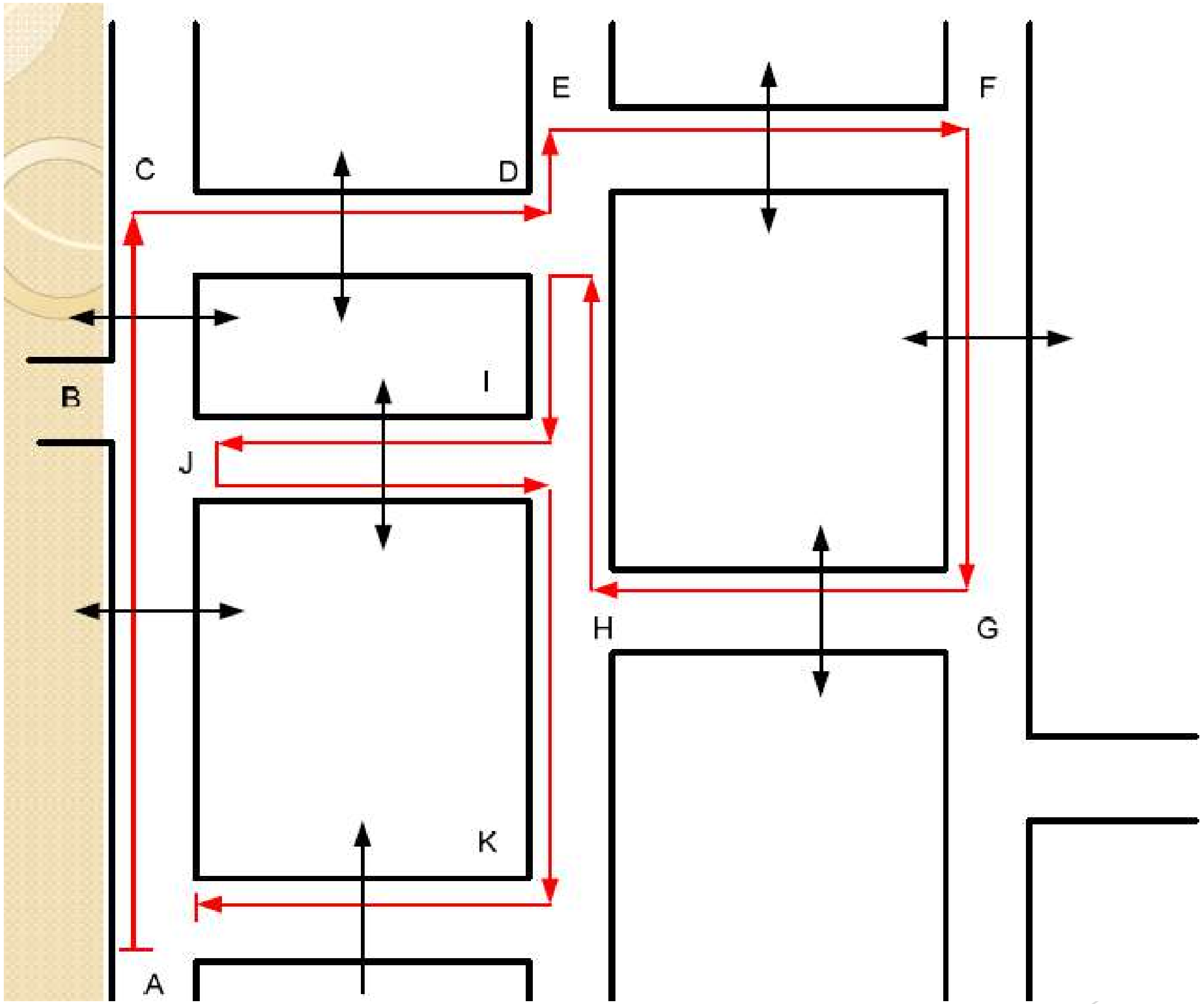
i. **Mapping the street system:**

The first step is to prepare a map of the street system that will be covered by the patrol, showing therein its sub-division into sections. Street junctions make convenient points for determining the sections.

The map and the forms should clearly show the direction of travel by the patrol man and the side or sides where observations are to be recorded (by arrows).

1. **Parking usage survey by patrol**

i. **Mapping the street system:**



1. **Parking usage survey by patrol**

ii. **Frequency of patrol:**

A frequency of half an hour is considered to be satisfactory for on-street parking, while a frequency of one hour could be used for offstreet parking.

A frequency of half an hour is likely to miss short term parkers (up to 29 minutes duration) and this makes it necessary to have more frequent patrols in selected areas where short term parking may be significant e.g. near banks, post offices etc.

iii. **Method of observation:**

Usually patrols are by foot, but too close to one another a moving car may also be used. As an aid a tape recorder may be used to record the registration numbers of vehicles.

iv. **Timing of survey:**

The survey should be done on a typical week day, free from factors likely to result in non representative characteristics. The period of the survey is usually 10 to 12 hours, so as to cover the arrival and departure of commuters and shoppers.

1. **Parking usage survey by patrol**

v. Equipment and form of recording

Each observer will be equipped with a watch, a pencil, a supply of forms, a map of the street and a board.

Data recording form by patrol

Parking Survey

On street

Patrol : 2

Street : King Street

Section : AB

Side : Right

Date : Friday, 02/02/2011

AM PM

8:00		8:30		9:00		9:30		10:00		10:30		11:00		11:30		12:00	
L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
	1256		1256		1256		3454		3454		3454						
	3454		6545		3454		8765		9873		6548						
	5645		3456		8761		9873		7659								
			6784		9873		6784		3543								
					5314		7655		1234								
					6542		3543		6548								
					6784		1234		5417								
							3224		9878								
							5460		9807								
							7899		2548								
							6548		3544								
									3475								

Parking Survey

- For parking demand analysis

2. Questionnaire type parking usage survey

- The questionnaire type parking usage survey involves interviews with the drivers who use the parking facilities.
- The survey can either be made by making enquiries among the car owners living in the vicinity of the survey area, or by making enquiries among the drivers of cars seen to park in the area at the time of survey.
- In this interview of actual parkers, the information collected should include:
  - Address of origin of the trip
  - Address of destination of the trip
  - Trip purpose
  - Time of arrival at the parked place
  - Time of departure from the parked place
  - Type of parking space used
  - Type of vehicle

- Normally one interviewer is required to cover about fifteen spaces. All the parkers in 8 or 10 hours period are interviewed. The duration of the survey may be a single day or may be spread over a number of days

3. Cordon count

- In this method, the area to be surveyed is demarcated by a cordon line which is crossed by the roads originate from the area.
- Counting stations are established at these crossing points and a count is made of all the vehicles entering and leaving the area.
- The difference between the top traffic gives the number of vehicles parked or in motion in the area.

4. License plate method

- In license plate method , the license plate of vehicles occupying different bays are noted at regular interval and based on these the different parameters are evaluated

Types of Parking Facilities

1. On Street Parking :

Under this type of parking , the space near to the kerb Is used for parking , while that in the center is used for vehicular movement. This type of parking has an advantage that the people can park nearby to the places that they are going to. Despite this if the road is not made considering the parking then it is bound to cause congestion and jam.

Based on orientation it is of following type

i. Parallel parking

This type of parking is used in streets with limited space , but the process of parking is little bit long.

ii. Angle parking

It may be

30^o Parking , 45^o Parkin , 60^o Parkin ,90^o Parking (Perpendicular parking)

Generally 45 ^{o} Parking is more preffered

Traffic Studies

Accident Studies and analysis

- These are systematic studies to investigate the causes of accidents and preventive measures in terms of designs and control which may decrease the rate of accidents.
- Consequence of traffic accident may include property damages, personal injuries, fatal cases as well as social and moral effect of a community.
- The most effected group are the youths who have great potential for the country thus proper accident study and analysis is of great importance for the country economy as well as the society

Objective of Accident Study

- To study the causes of accidents and to suggest corrective treatment at potential locations.
- To evaluate performance of existing facilities in terms of safety
- To support proposed design. (Road Safety Audit)
- To carry out before and after studies of improvement schemes.
- To make computations of financial loss during accidents.
- To give economic justification for improvement schemes.
- To define and identify high-accident locations.

Causes of Accidents

1. **Road User**

I. Driver

- Perceptuel error : Failure to understand the underlying traffic condition and giving the wrong decision
- Lack of skill : Unskilled and unexperienced drivers require more visibility and perception reaction time which is not always available/
- Temporary alcholic effect
- Behaviour : Agression , frustration , excessive speeding etc.
- Violating traffic rules : Lane Bycotting , Unauthorized overtaking etc.

II. Prdestrians :

- Improper crossing , walking on carriageway etc.

Traffic Studies

2. **Vehicle related**

- Defective steering , tires , brakes etc.
- Lack of regular maintenance

3. **Roadway and Environment related**

I. Road way related

- Adverse design : Unsuitable layout causing lack of visibility , too many bends ,
- Surface Defects : slippery surface, potholes ruts , unwarned holes etc.
- Inadequate road marking
- Unexpected road obstruction

II. Road environment related

- Weather conditions like fog , heavy rainfall , landslide etc.
- Animals on the roadway

Accidental study :

- It is the method of collecting storing managing and dissipating detailed date regarding the accidents.
- The various steps of accidental study are

1. **Collection of accident data**

- As soon as the accident occurs a number of data about it are recorded this can be done by the police or by the witness as well
- In Nepal it is done by police
- The date to be collected are as follows

• General: Date, time, persons involved in the accident, classification of accident (fatal, serious, minor etc.)

• Location: Description and details of the location site of accident.

- Details of vehicles involved: Registration number, description of vehicle, loading details, vehicles details, vehicular defects etc.
- Nature of accident: Condition of vehicles, details of collisions, pedestrians or objects involved damages etc.
- Road and traffic conditions: Details of road geometry, surface characteristics, traffic condition (density etc.)
- Primary causes of accident: Various possible cause and primary causes.
- Accident costs: Property damages, personal injuries and casualties.

2. **Accidental Reporting**

- The recorded data is now routed to the traffic police offices which then make hard copies of the data and then transfers it to the directorate and then to headquarter through Summary sheets
- Nowadays with the improvement of IT the Road Accident Information Management System(RAIMS) is implemented from 2075 Mangsir 25th which allows the police stations to record the data digitally and transfer it directly to central system
- It is under test and is applied to Kathmandu valley and Kathmandu Burgunj corridor

3. **Accidental Record**

- These are detailed records which gives all the data about the accidents. They may be in one or more of these formats
  - Location Files : Location based records
  - Spot Maps : Shows accidents spot wise
  - Collision Diagram : Shows different collisions in a black spot
  - Condition Diagram : Shows the physical condition of the black spot

4. **Accidental Statistics**

- These are different statistical parameters that are used to describe the accidents and their effects
- They give details about :
- Occurrence(in terms of type of accident i.e. fatal serious injury , non serious and no injury) , Involvement (Number of vehicles and involvement) and severity (No of fatality and serious accidents)

There are many types of accidental statistics some of the most common ones are

I. **Accidental Rates**

- Simple statistics citing total numbers of accidents, involvements, injuries, and/or deaths per unit of a particular base. They are

1. Population-based accident rates

Some common bases for population-based rates include:

• Area population (Accidents per 100000 area population)

• Number of registered vehicle (Accidents per 10000 registered vehicle)

• Number of licensed drivers (Accidents per 10000 licensed drivers)

• Highway mileage (Accidents per 1000 km highway)

2. Exposure-based accident rates

Exposure based accident rates attempt to measure the amount of travel as a replacement for the individual’s exposure to potential accident situations.

The two most common bases for exposure-based rates are:

- Vehicle miles traveled (Accidents per 100000000 vehicle miles travelled)
- Vehicle hours traveled (Accidents per 10000000 vehicle hours travelled)

II. **Severity Index:**

A widely used statistic for the description of relative accident severity is the severity index (SI), defined as the number of fatalities per accident .

Application of Crash Data

Out of all the applications the most important is the calculation of velocity from the skid distances and the site investigation and treatment

A. Calculation of velocity from the skid distances

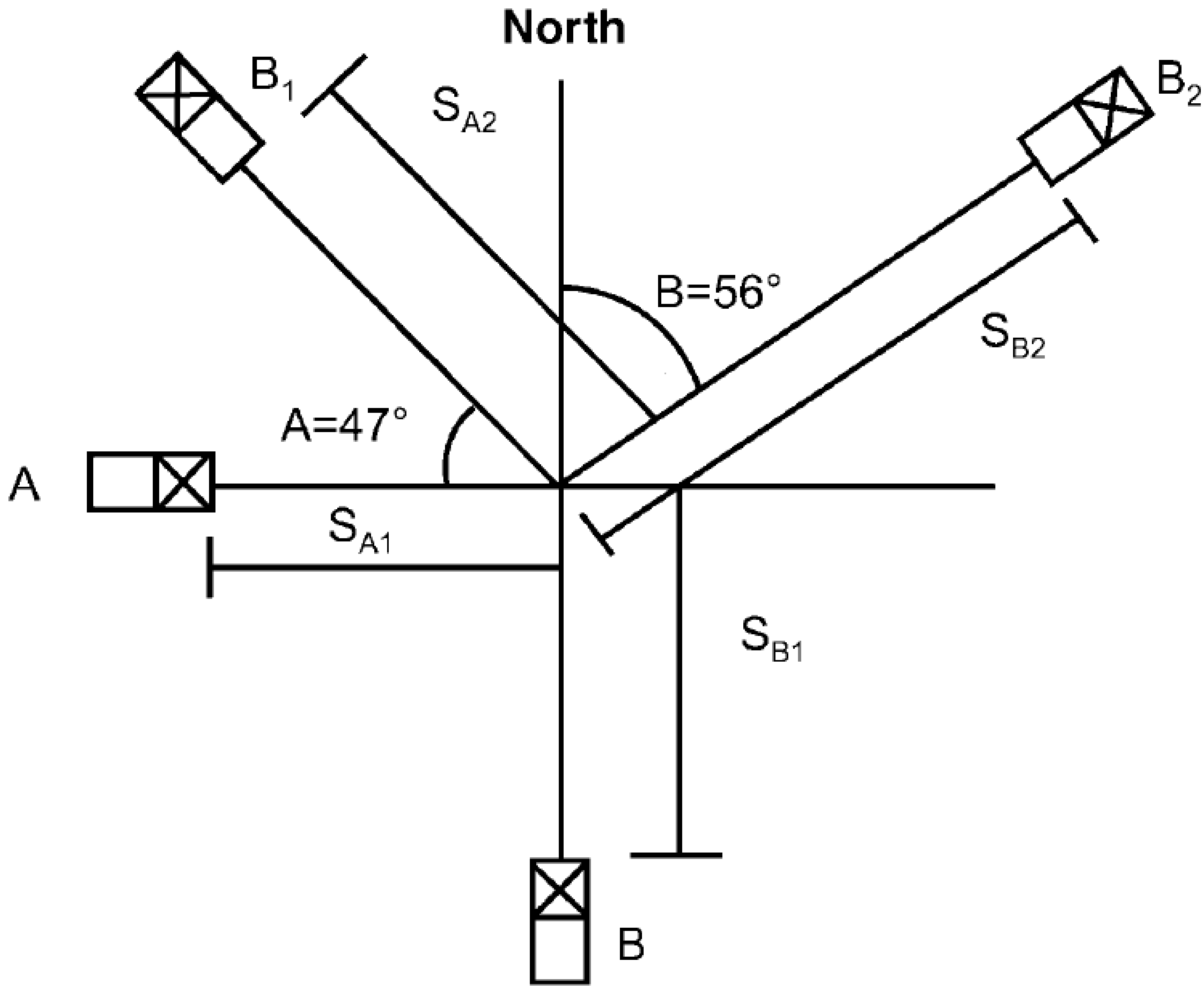
There are two cases

1. **Moving vehicle Colliding with Stationary vehicle**

A vehicle of weight 2.5 tonnes skids through a distance equal to 38 m before colliding with another parked vehicle 1.5 tonne. After collision both the vehicles skid through a distance of 15m before stopping. Compute the initial speed of the moving vehicle. Assume coefficient of friction as 0.48.

1. **Moving vehicle colliding with another moving vehicle**

Two vehicles A and B approaching at right angles, A from West and B from South, collide with each other. After the collision, vehicle A skids in a direction 47o North of West and vehicle B, 56o East of North. The initial skid distances of the vehicles A and B are 32 and 18 m respectively before collision. The skid distances after collision are 14m and 33 m respectively. If the weights of vehicles A and B are 4 and 6 tonnes respectively, calculate the original speeds of vehicles. The average skid resistance of the pavement is found to be 0.52.


North
B1
SA2
B2
B=56°
SB2
A=47°
A
SA1
SB1
B

B. Site investigation and treatment

It is the process of analyzing nature and cause of accidents in the accident prone zone a determining the solution to them. The steps of site investigation are as follows

- Obtain adequate vehicle accident records
- Select site with high accident frequency of that of severe accidents
- Prepare collision diagram and collision diagram for these
- Summarize facts and determine causes of accidents
- Supplement the conclusion with field observation
- Analyze the causes and select suitable countermeasure

Measures for the reduction in accident rates

- The various measures to decrease the accident rates may be divided into three groups:
  - Engineering
  - Enforcement
  - Education

"3-Es"

1. Engineering Measures

- Road design:

– The geometric design features: sight distances, width of pavement, horizontal and vertical alignment and intersection design elements are checked and corrected if necessary.

– The pavement surface characteristics are checked and suitable maintenance steps taken to bring them up to the design standards.

- Maintenance of vehicle:

– The braking system, steering and lighting arrangements on vehicle may be checked.

1. Engineering Measures

- Before and after studies:

– After making the necessary improvement in design and enforcing regulation, it is again collect and maintain the record of accidents “before and after” the introduction of preventive measures to study their efficiency.

- Road lighting:

– Lighting is particularly desirable at intersections, bridge sites and at places where there are restrictions to traffic movements.

2. Enforcement measures

- Speed control:

– Checking of spot speed of all fast moving vehicles should be done at selected locations and timings and legal actions on those who violate the speed limits should be taken

- Traffic control devices:

– Signals may be re-designed or signal system be introduce if necessary. Proper traffic control device like signs, markings or channelizing island may be installed if necessary.

- Training and supervision:

– the transport authorities should be strict in testing and issuing license to driver.

- Medical check:

– The drivers should be tested for vision and reaction time at prescribed intervals.

- Special precautions for commercial vehicles:

– having attendant to help and give proper direction to drivers of heavy vehicles.

- Observance of law and regulations:

– Traffic authorities should send study groups of trained personal, to different locations to check whether the traffic regulations are being followed by the road users and also to enforce the essential regulations.

3. Educational measures

- Education of road users:

– The passengers and pedestrians should be taught the rules of the road, correct manner of crossing etc.

- Safety drive:

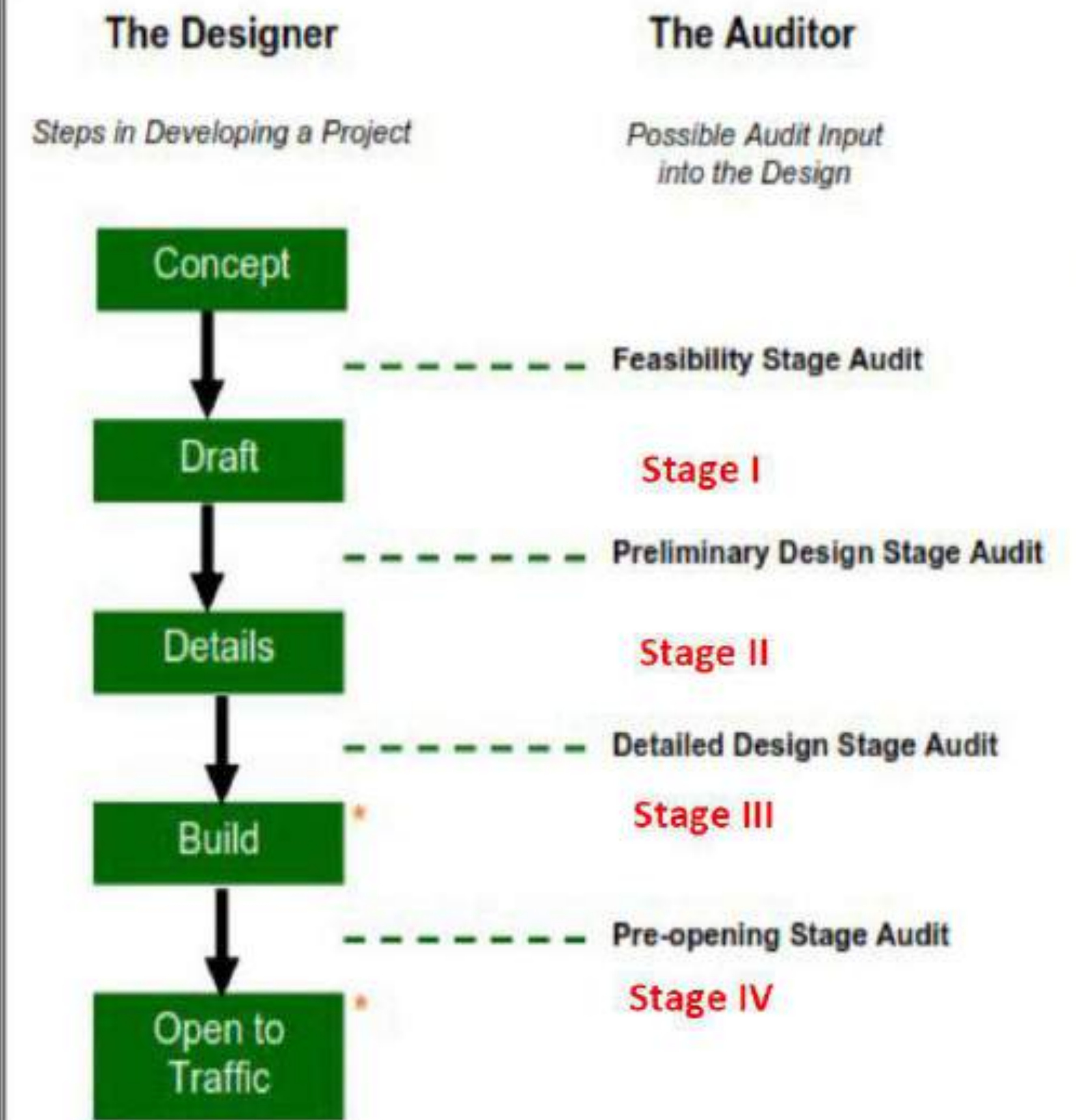
– Imposing traffic safety week when the road users are properly directed by the help of traffic police and transport staff is a common means of training the public these days.

Road Safety Audit

- **Formal, systematic check** to identify road safety
- hazards
- Desk-top study and/or site inspection
- Commissioned by the project sponsor/client
- Audit team independent from design

Road Safety Inspection

- Similar to road safety audit but done on operational roads to inspect safety and suggest remedial measures



RSA Stages

Post opening RSA (Stage 4 audit): New road within 6 month of opening
Existing road RSA (Stage 5): also Road Safety Inspection/ Checks

RSA PROCEDOR

Traffic Studies

Capacity Studies

Determination of the capacity of transportation systems and facilities is a major issue in the analysis of transportation flow.

The *Highway Capacity Manual* defines the capacity of a facility as "the maximum hourly rate at which persons or vehicles can be reasonably expected to traverse a point or uniform segment of a lane or roadway during a given time period under prevailing roadway, traffic, nd roadway conditions. "

Factors affecting Capacity and LOS

Roadway Factors

- **Lane width:** According to HCM a lane width of 3.6 is considered as ideal. As lane width decreases capacity also decreases.
- **Lateral clearance:** Such as retaining walls, abutments, sign posts, light posts, parked cars etc. located closer than 1.8m from the edge of traffic lane reduce the capacity.
- **Width of shoulder:** Narrow shoulders reduce the effective width of traffic lanes as the vehicle travel towards the center of the pavement.

Traffic Studies

Factors affecting Capacity and LOS

Roadway Factors (Continued…..)

• **Grades:** Grade adversely affects the speed of the vehicles, especially trucks and thus influence the capacity.

• **Presence of intersections:** intersections restrict free flow of traffic and thus adversely affect the capacity.

• **Alignment**: Alignment and geometric (particularly sight distance) are not of design standards, the capacity will decreases.

• **Surface condition:** A deteriorated and poorly maintained pavement adversely affects the capacity

Traffic factors

• Percentage of commercial vehicles: Large commercial vehicles like truck and buses influence the traffic stream in two ways;

-They occupy more space than passenger cars

-They have poor operating capabilities than passenger cars, particularly with respect to acceleration, deceleration and ability to maintain speed in upgrades

• Directional distribution :This is an important factor in case of two lane highway facility.

Traffic Studies

- **Types of capacities:**
- **Basic capacity-** the maximum volume of vehicles per hour that can pass a certain point or section of a road in a given time under the ideal condition (most ideal road way, traffic and control conditions that can possibly be attained)
- Theoretically ,

$$C = \frac{1000v}{S}$$

- **C = Theoritical capacity , v = design capacity S = Spacing between vehicles**
- **Possible capacity** -The maximum number of vehicles that can pass a given section during a given period of time under prevailing (most frequent roadway, traffic and control condition)
- **Practical capacity -** Capacity without the traffic density being so great as to cause unreasonable delays, hazard or restrictions to the driver's freedom under the prevailing condition of roadway, traffic and control.

NUMERICAL EXAMPLE

- **Determine the capacity of lane in terms of vehicle per hour when f= 0.5 T = 1 Sec and speed 30 km/hr**

Traffic Studies

- **Traffic flow studies**
- **Traffic flow studies deals with the studies of models which describe the nature of the traffic movement. The different types of models are as follows**

Terminology

- ***Flow*** **(*q*)** is the equivalent hourly rate at which vehicles pass a point on a highway during a time period less than 1 hour.
- ***Density*** **(*k*)** [also referred to as *concentration]* is the number of vehicles traveling over a unit length of highway at an instant in time. The unit length is usually 1 mile (mi) thereby making vehicles per mile (veh/mi) the unit of density.
- *Speed* (*u*) is the distance traveled by a vehicle during a unit of time. It can be expressed in miles per hour (mi/h), kilometers per hour (km/h), or feet per second (ft /sec).
- *Time headway* (*h*) is the difference between the time the front of a vehicle arrives at a point on the highway and the time the front of the next vehicle arrives at that same point. Time headway is usually expressed in seconds.

Traffic Studies

Terminology

- ***Space headway*** **(*d*)** is the distance between the front of a vehicle and the front of the following vehicle and is usually expressed in feet.
- **Clearance (c) and gap (g)** are related to the spacing parameter and headway. These four measurements are shown in figure below. The difference between spacing and clearance is obviously the average length of a vehicle in ***m***. Similarly the difference between headway and gap is the time equivalence of average length of a vehicle (L/*v*)

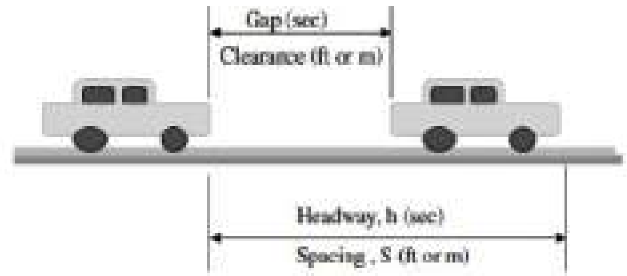


Figure gap and headway

- Mathematically

$$g = h - \frac{L}{v}$$

- Where, ***g*** is the gap, sec; ***L*** is the mean length of vehicle, m; ***c*** is the mean clearance, m; ***h*** is the mean headway, sec; ***v*** is the mean speed, m/sec.

Traffic Studies

Microscopic model

- Microscopic models describe the motion of individual vehicles and their interactions with one another
- Microscopic models capture the movement of every vehicle.
- Microscopic behavior includes acceleration, deceleration, lane changes, passing maneuvers, turning movement execution, and gap acceptance.
- Microscopic models are:
  - Car-following Models
  - Lane Changing Models
  - Gap-acceptance Models

Traffic Studies

Macroscopic Simulation Model

- Macroscopic models tend to employ flow rate variables speed, flow and density to describe traffic flow
- Different flow models are
  - Greenshields's Model
  - **Greenberg’s logarithmic model**
  - **Underwood’s exponential model**
  - **Stoke’s Shock wave model**

Greenshields's Equation (Refer Notes)

NUMERICAL

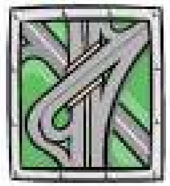
Level of Service studies

Level of service is a qualitative measure of the highway's operating conditions under a given demand within a traffic stream and their perception by motorists and/or passengers.

LOS intends to relate the quality of traffic service to given volumes (or flow rates) of traffic.

The parameters selected to define LOS for each facility type are called measures of effectiveness (MOE).

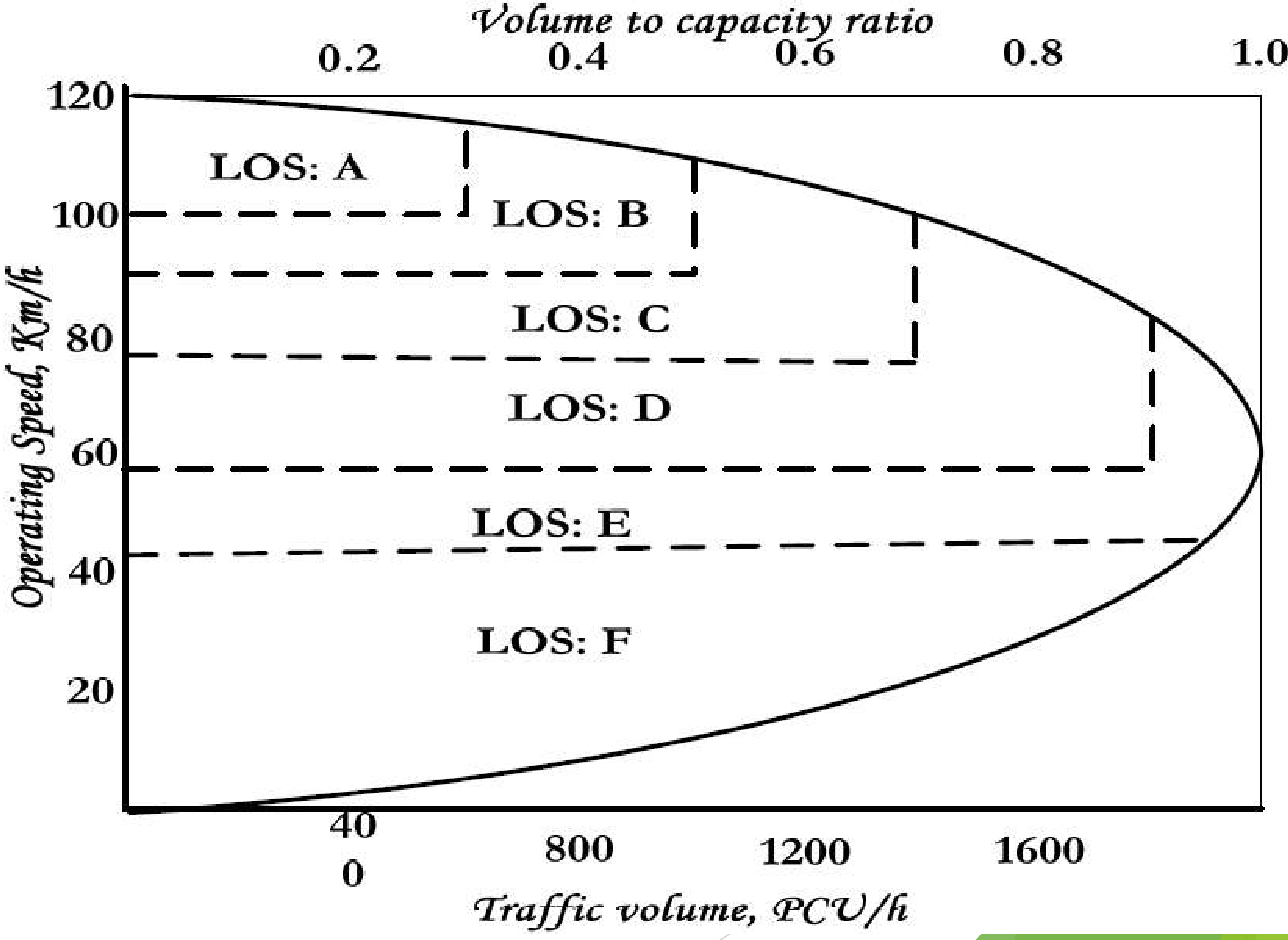
These parameters can be based on various criteria, such as travel times, speeds, total delay, probability of delay, comfort, and safety.

Uninterrupted 	Freeways	Density (pc/km/ln)
	Multilane highways	Density (pc/km/ln)
	Two lane highway	Average travel speed (km/h) Percent-time spent following (%)
Interrupted 	Signalized intersections	Control delay (sec/veh)
	Unsignalized intersections	total delay (sec/veh)
	Arterials (urban street)	Average travel speed
	Pedestrians (on footpath)	Space (sq ft/ped)

- Freeway/Highways

LOS	K (veh/km/lane)	FFS (Km/hr)	v/c
A	0-7	120	0.35
B	7-11	120	0.55
C	11-16	114	0.77
D	16-22	99	0.92
E	22-28	85	1.0
F	> 28	< 85	> 1.0

LOS can be distinguished as in the figure below



Level of Service A

- free-flow conditions (traffic operates at free flow speeds). Individual users are virtually unaffected by the presence of others in the traffic stream. Freedom to select desired speeds and to maneuver within the traffic stream is extremely high. The general level of comfort and convenience provided to drivers is excellent.

Level of Service B

- Allows speeds at or near free-flow speeds, but the presence of other users in the traffic stream begins to be noticeable. Freedom to select desired speeds is relatively unaffected, but there is a slight decline in the freedom to maneuver within the traffic stream relative to LOS A.

Level of Service C

- speeds at or near free-flow speeds, but the freedom to maneuver is noticeably restricted (lane changes require careful attention on the part of drivers). The general level of comfort and convenience declines significantly at this level. Disruptions in the traffic stream, such as an incident (for example, vehicular accident or disablement), can result in significant queue formation and vehicular delay. In contrast, the effect of incidents at LOS A or LOS B are minimal, and cause only minor delay in the immediate vicinity of the event.

Level of Service D

- conditions where speeds begin to decline slightly with increasing flow. The freedom to maneuver becomes more restricted and drivers experience reductions in physical and psychological comfort. Incidents can generate lengthy queues because the higher density associated with this LOS provides little space to absorb disruption in the traffic flow.

Level of Service E

- represents operating conditions at or near the roadway's capacity. Even minor disruptions to the traffic stream, such as vehicles entering from a ramp or vehicles changing lanes, can cause delays as other vehicles give way to allow such maneuvers. In general, maneuverability is extremely limited and drivers experience considerable physical and psychological discomfort.

Level of Service F

- describes a breakdown in vehicular flow. Queues form quickly behind points in the roadway where the arrival flow rate temporarily exceeds the departure rate, as determined by the roadway's capacity. Vehicles typically operate at low speeds in these conditions and are often required to come to a complete stop, usually in a cyclic fashion. The cyclic formation and dissipation of queues is a key characterization of LOS F.

Traffic Signal

- It is an electronic device that is used to control various phases in a busy intersection and is a replacement to the manual control by traffic police

- Advantages
  - The installation of traffic signals is justified by the need to:
  - Reduce delay to motorists and pedestrians moving through the junction
  - Reduce accidents at the junction
  - Improve the control of traffic flow into and through the junction in particular and the area in general, thereby minimizing journey times
  - Impose certain choosen traffic management policies.

- ***Disadvantages:***
  - They must undergo frequent maintenance along with frequent monitoring to ensure their maximum effectiveness
  - There can be inefficiencies during off-peak times leading to increases in delay and disruption during these periods
  - Increases in rear-end collisions can result
  - Signal breakdown due to mechanical/electrical failure can cause serious interruption in traffic flow.

Traffic Signal

Types of Traffic Signal

- Based on Control

1. **Signals for the control of vehicles:**

- Conflict at a junction is manifest as an increase in delay and an increase in the accident rate. Thereby demanding for proper management
- The primary purpose of a traffic signal installation at a road junction is to reduce conflict between traffic streams.
- Traffic control is by means of red, amber and green light signals

i. **Red light** - Denotes that traffic is prohibited from proceeding beyond the stop line.

ii. **Green light** - Indicates that vehicular traffic may proceed beyond the stop line, and may turn in any direction, subject to the normal priority rules being observed and provided that the turn is not prohibited by a supplementary light signal (red arrow) or a regulatory traffic sign.

Traffic Signal

iii. **Amber light** – Conveys same prohibition as red signal except where vehicles are so close to the stop line that they cannot safely stop before stop line, they should proceed. This phase is usually displayed for three seconds.

2. **Signals to control pedestrian movements:**

- Signal-controlled pedestrian crossings are appropriate at sites where traffic speeds are high or where pedestrian flow is very heavy. Crossings with pedestrian signals can also be incorporated in junctions controlled by traffic lights.

i. **Red Standing Man -** Denotes that pedestrian are prohibited from crossing the road.

ii. **Green Walking Man -** Denotes that pedestrians may cross the road with care.

iii. **Flashing Green Man** – Denotes that pedestrian are prohibited from crossing the road except where they have started to cross the road, in which case they should continue to cross the road.

Terminology

- **Cycle**: A signal cycle is one complete rotation through all of the indications provided.
- **Cycle length**: Cycle length is the time in seconds that it takes a signal to complete one full cycle of indications. It indicates the time interval between the starting of of green for one approach till the next time the green starts. It is denoted by C .
- **Interval**: Thus it indicates the change from one stage to another. There are two types of intervals –
  - *Change interval* is also called the yellow time indicates the interval between the green and red signal indications for an approach.
  - *Clearance interval* is also called *all red* is included after each yellow interval indicating a period during which all signal faces show red and is used for clearing off the vehicles in the intersection.
- **Green interval**: It is the green indication for a particular movement or set of movements and is denoted by G. This is the actual duration the green light of a traffic signal is turned on.
- **Red interval**: It is the red indication for a particular movement or set of movements and is denoted by R. This is the actual duration the red light of a traffic signal is turned on.

Terminology

- **Phase**: A phase is the green interval plus the change and clearance intervals that follow it. Thus, during green interval, non conflicting movements are assigned into each phase. It allows a set of movements to flow and safely halt the flow before the phase of another set of movements start.
- **Lost time**: It indicates the time during which the intersection is not effectively utilized for any movement. For example, when the signal for an approach turns from red to green, the driver of the vehicle which is in the front of the queue, will take some time to perceive the signal (usually called as reaction time) and some time will be lost here before he moves.
- ***Lane group***. A lane group consists of one or more lanes on an intersection approach and having the same green phase.
- ***Critical lane group***. The lane group that requires the longest green time in a phase. This lane group, therefore, determines the green time that is allocated to that phase.

Signal Design

<u>Three Methods of Design (Refer Notes)</u>

- *Trial cycle method.*
- *Webster's Method*
- *Approximate method*

Roadway Intersection

- Intersection is an area shared by two or more roads.
- This area is designated for the vehicles to turn to different directions to reach their desired destinations.
- Its main function is to guide vehicles to their respective directions.
- Objectives and Considerations of Intersection Design

Objectives

- *The main objective of intersection design is to "reduce the severity of potential conflicts between vehicles". The other objectives are*
  - *There should be adequate visibility on all the approaching roads*
  - *The width of pavement shall be provided properly so that turning movement is eased*
  - *Area of conflict shall be decreased as far as possible through channelization*
  - *The relative speed of vehicles shall be ensured to be small*
  - *Good Lightning , proper signs and signalization is necessary*
  - *Special provision for pedestrians and cyclist shall be taken in urban areas*

Roadway Intersection

Considerations

- Four basic elements are generally considered in the design of at grade intersection.

◦ Human factors: driving habits and decision and reaction times

◦ Traffic considerations: capacities and turning movements, vehicle speeds and size and distribution of vehicles

◦ Physical elements: Characteristics and use of abutting property, sight distance and geometric features

◦ Economic factors: cost and benefits and energy consumption

Roadway Intersection

Types of Intersection

1. **Intersection at grade**

The roads in these types of interchange intersect at the same RL. The different types of intersection at grade are as follows

I. Unchannelized intersection :

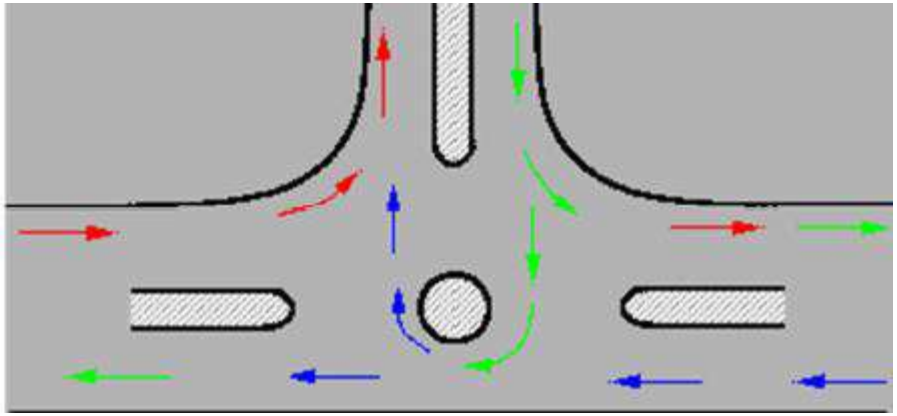
These kind of intersections do not have any kind of island for directing traffic in definitive path. In some cases the width of the intersection is increased this is called flared intersection

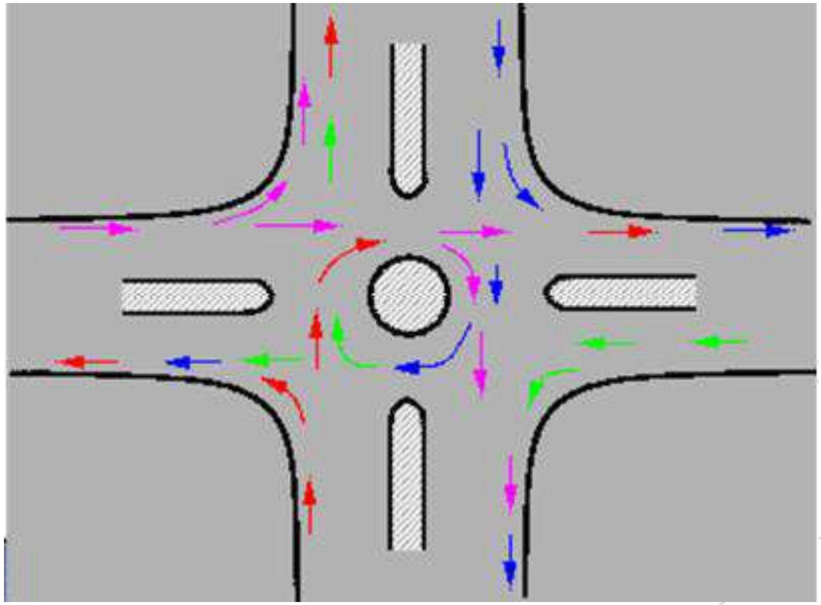
II. Channelized intersection :

This kind of intersection are provided with raised areas called islands which provide channelization of traffic

These islands ensure safe and smooth flow of capacity and thus increase the traffic flow

Roadway Intersection





Roadway Intersection

Types of Intersection

III. Rotary Intersection :

Rotary intersections or roundabouts are special form of at grade intersections laid out for the movement of traffic in one direction around a central traffic island.

Essentially all the major conflicts at an intersection namely the collision between through and right-turn movements are converted into milder conflicts namely merging and diverging.

The vehicles entering the rotary are gently forced to move in a clockwise direction in orderly fashion. They then weave out of the rotary to the desired direction.

- **Advantages and disadvantages of rotary**

The key advantages of a rotary intersection are listed below:

1. Traffic flow is regulated to only one direction of movement, thus eliminating severe conflicts between crossing movements.

Roadway Intersection

2. All the vehicles entering the rotary are gently forced to reduce the speed and continue to move at slower speed. Thus, none of the vehicles need to be stopped, unlike in a signalized intersection.

3. Because of lower speed of negotiation and elimination of severe conflicts, accidents and their severity are much less in rotaries.

4. Rotaries are self governing and do not need practically any control by police or traffic signals.

5. They are ideally suited for moderate traffic, especially with irregular geometry, or intersections with more than three or four approaches.

Limitations of rotary:

1. All the vehicles are forced to slow down and negotiate the intersection. Therefore, the cumulative delay will be much higher than channelized intersection.

2. Even when there is relatively low traffic, the vehicles are forced to reduce their speed.

3. Rotaries require large area of relatively flat land making them costly at urban areas.

4. The vehicles do not usually stop at a rotary. They accelerate and exit the rotary at relatively high speed. Therefore, they are not suitable when there is high pedestrian movements.

Roadway Intersection

Types of Intersection

2. **Grade separated intersections**

Methods of grade separations

i. Flyover

If the road having major traffic is elevated to a higher grade for further movement of traffic, then such structures are called overpass

Advantages

- No drainage problem
- Cost is less
- No problem for future expansion

Disadvantage

- Increased grades thereby difficult for heavy vehicles

Roadway Intersection

i. Underpass

If the major road is depressed to a lower level to cross another by means of an under bridge or tunnel, it is called under-pass.

Advantages

- Higher capacity and safety
- Comparatively easy to travel

Disadvantage

- Drainage problem

Roadway Intersection

Types of Grade separated intersections

1. Grade separated intersection without interchange

It includes simple bridge or underpass structure so as to allow intersecting traffic to cross each other without any sort of interchange.

These are generally used where major expressway intersects a minor road

2. Grade separated intersection with interchange

These kind of intersections have two roads separated vertically along with provisions for interchange of vehicles among the roads

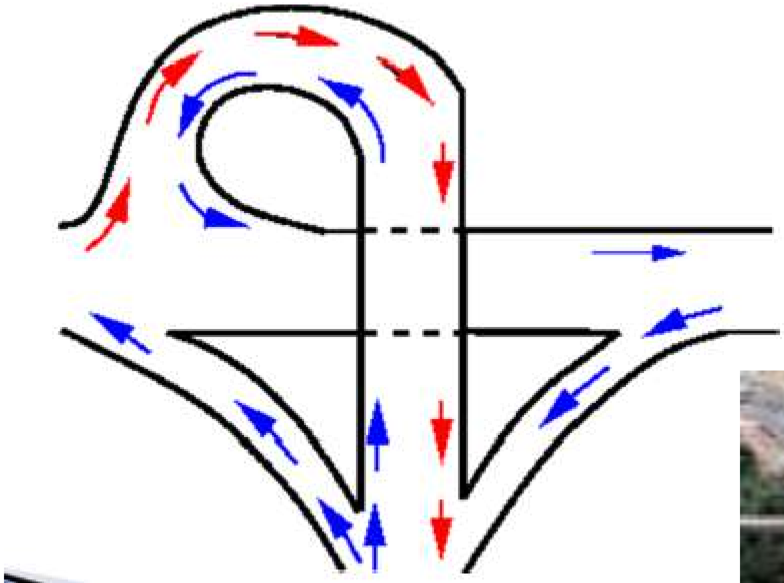
It is of two types

Three legged interchange

Four legged intercahge

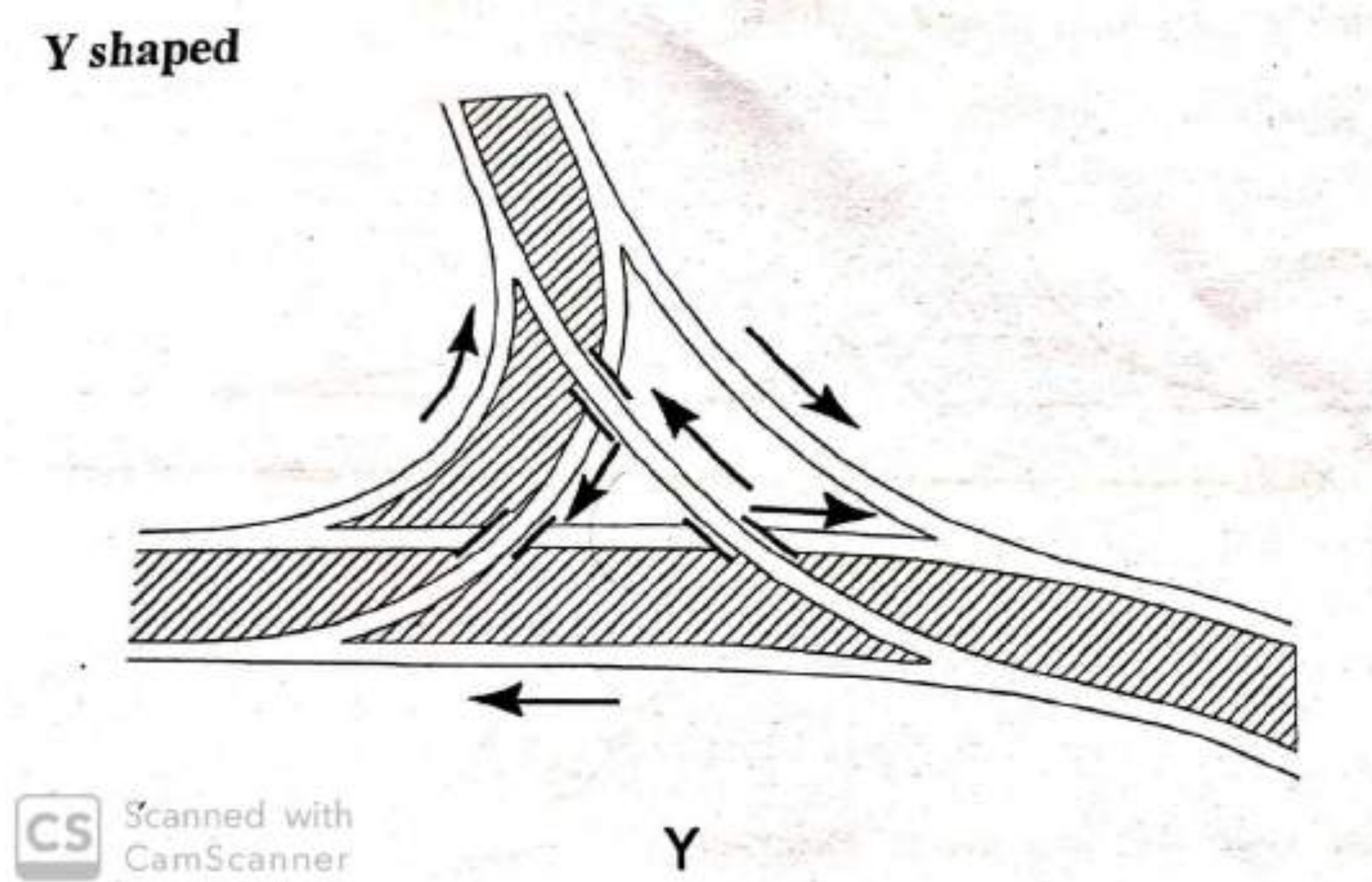
1. Three legged Interchange

i. Trumpet interchange



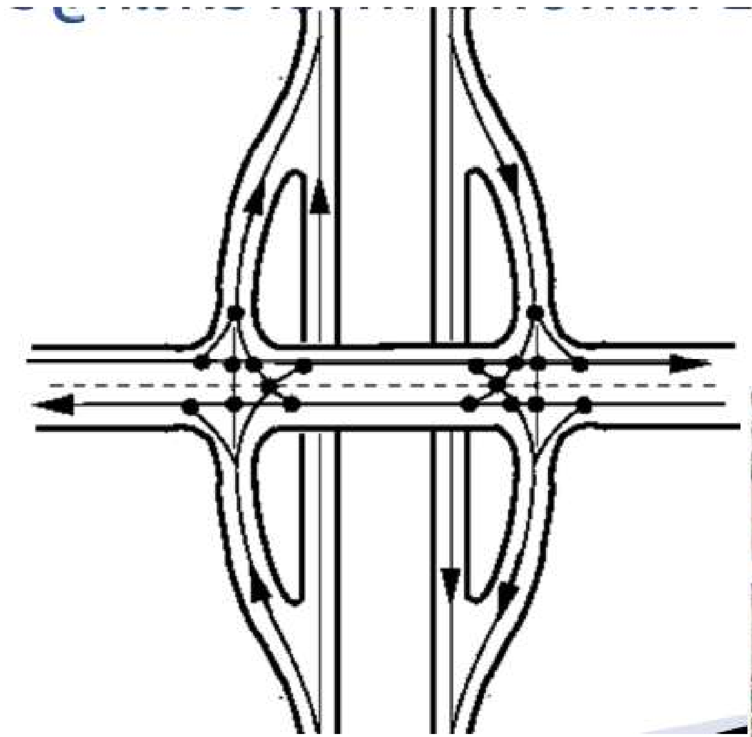
1. Three legged Interchange

ii. Y Shaped interchange

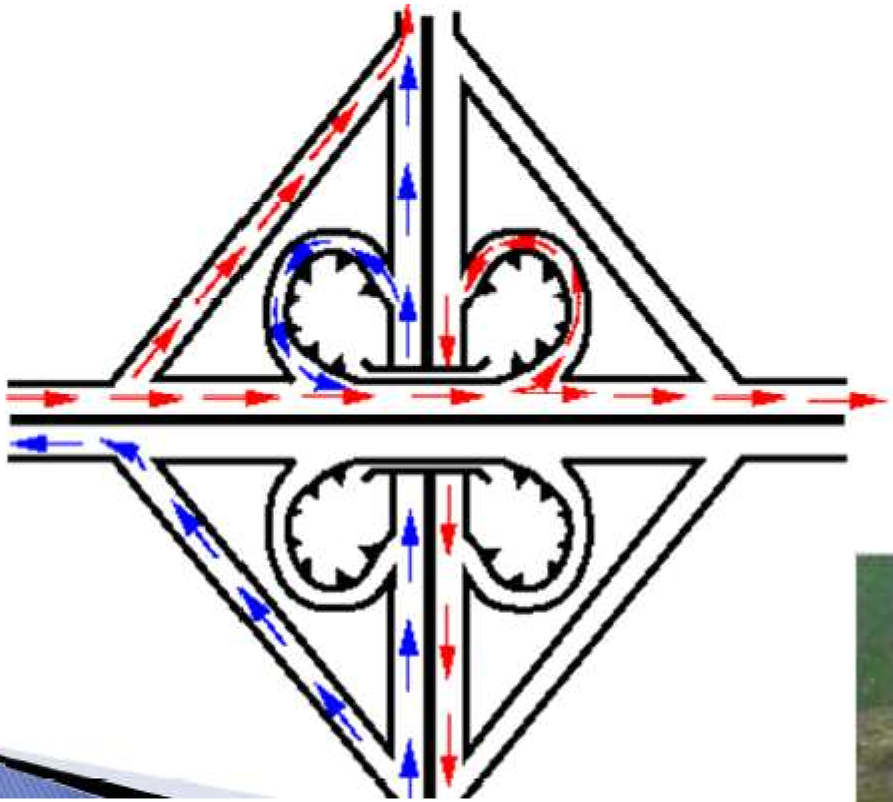


2. Three legged Interchange

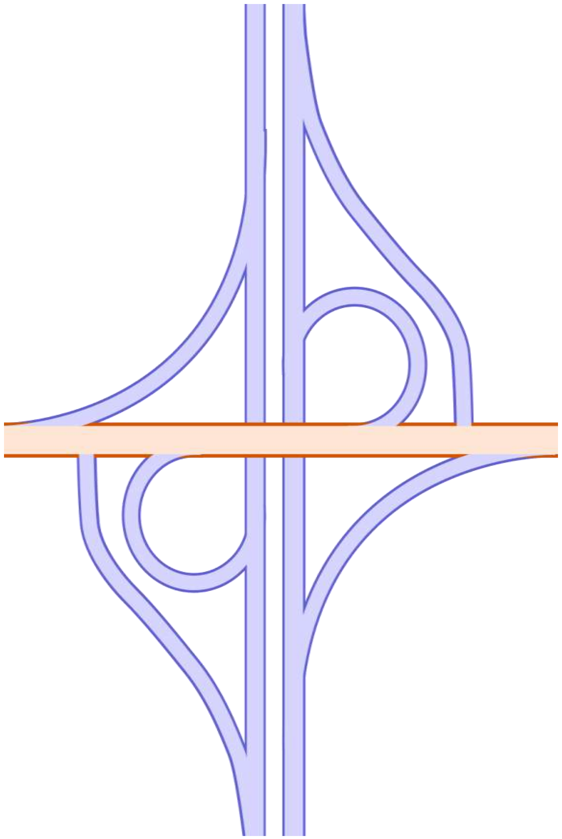
i. Diamond Interchange



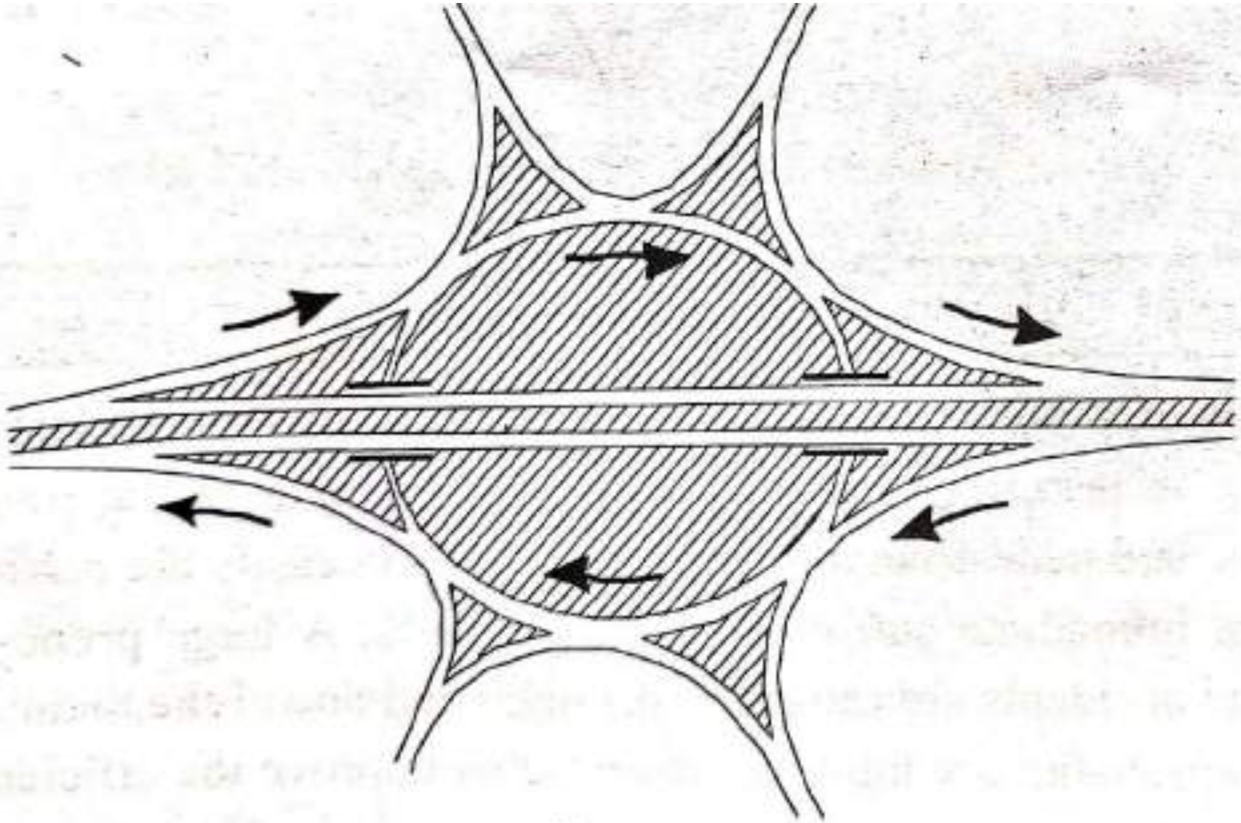
ii. Cloverleaf Interchange



iii. Half Cloverleaf Interchange



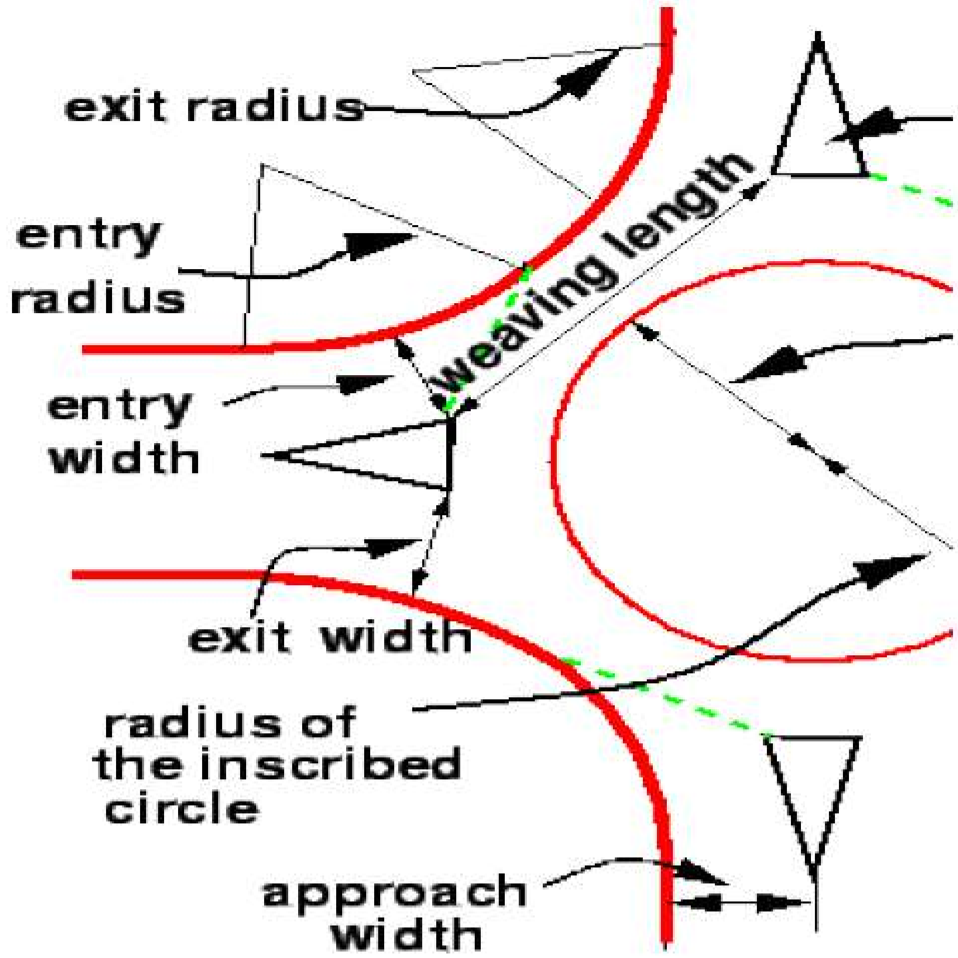
iv. Rotary Interchange



Rotary

Design of Roatary Intersections

Design Criteria



Design Criteria

Flow Requirement

- For a rotary to be introduced the minimum flow from each leg shall be 500 veh/hr , similarly the total flow shall not exceed 3000 veh/hr .

Design speed

- All the vehicles are required to reduce their speed at a rotary. Therefore, the design speed of a rotary will be much lower than the roads leading to it. Although it is possible to design roundabout without much speed reduction, the geometry may lead to very large size incurring huge cost of construction. The normal practice is to keep the design speed as 30 and 40 kmph for urban and rural areas respectively.

Entry, exit and island radius

- The radius at the entry depends on various factors like design speed, super-elevation, and coefficient of friction. The entry to the rotary is not straight, but a small curvature is introduced. This will force the driver to reduce the speed. The entry radius of about 20 and 25 metres is ideal for an urban and rural design respectively.

Design Criteria

Entry, exit and island radius

- The exit radius should be higher than the entry radius and the radius of the rotary island so that the vehicles will discharge from the rotary at a higher rate. A general practice is to keep the exit radius as 1.5 to 2 times the entry radius. However, if pedestrian movement is higher at the exit approach, then the exit radius could be set as same as that of the entry radius.

- For central island superelevation is not provided in the rotary it has to nulled and the the radius of the central island depends on the velocity and the coefficient of friction

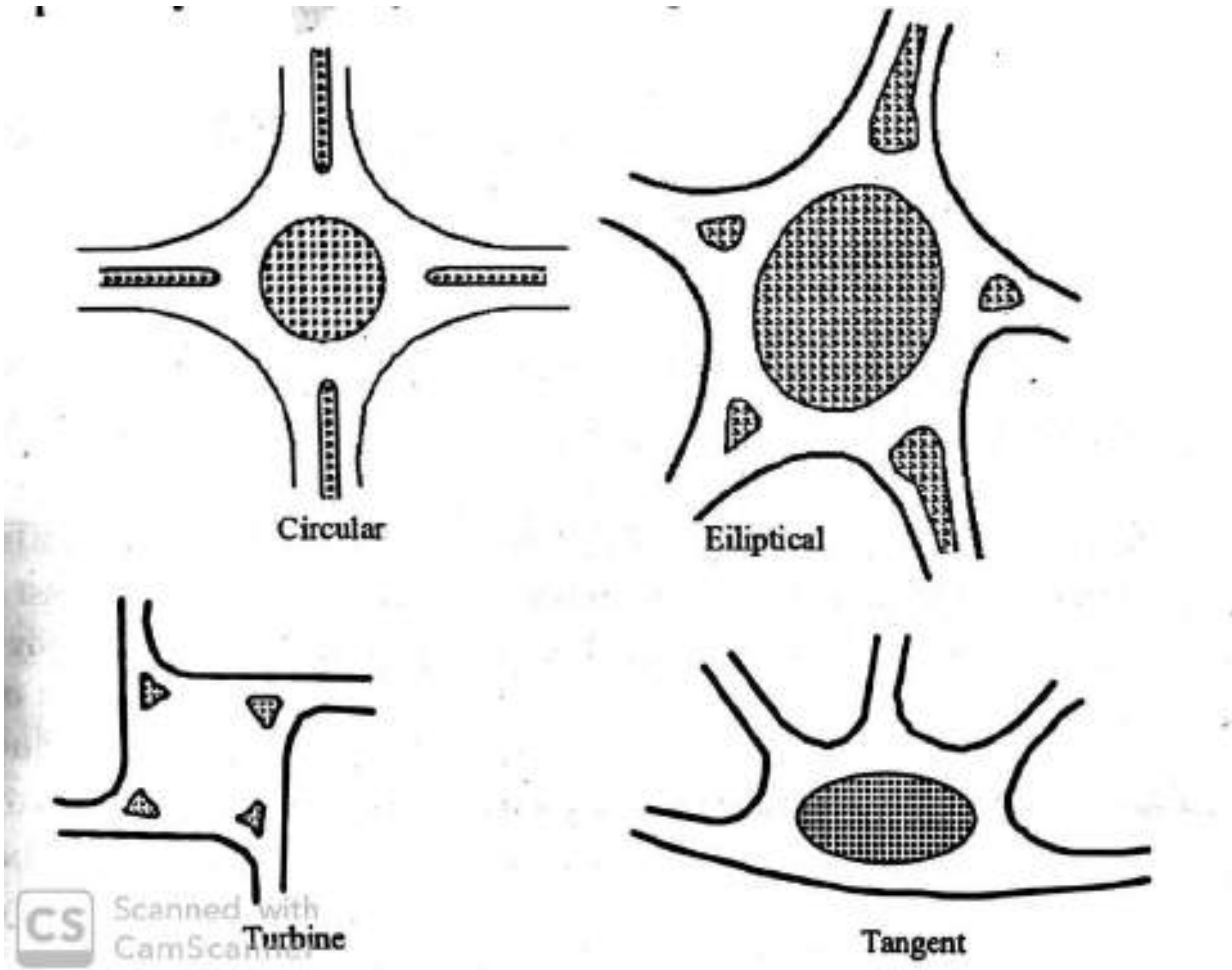
$$R = \frac{v^2}{127f}$$

  - The value of f is taken as 0.43 for rural and 0.47 for urban roads
  - in practice, is given a slightly higher radius so that the movement of the traffic already in the rotary will have priority.
  - The radius of the central island which is about 1.3 times that of the entry curve is adequate for all practical purposes.

Design Criteria

Shape of central island

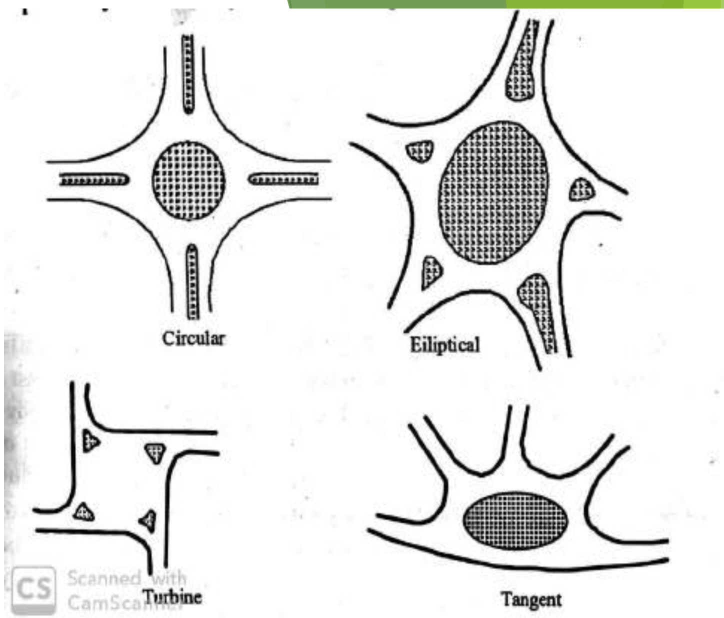
- The different shapes of central island are as follows



Design Criteria

Suitability

- For equal volumes on all roads the circular type is preferred
- For roads with varying volumes the elliptical type is preferred
- For Rotaries with high speed the turbine and tangential type is preferred.



Width of the rotary

- The entry width and exit width of the rotary is governed by the traffic entering and leaving the intersection and the width of the approaching road. The width of the carriageway at entry and exit will be lower than the width of the carriageway at the approaches to enable reduction of speed. IRC suggests that a two lane road of 7 m width should be kept as 7 m for urban roads and 6.5 m for rural.

Design Criteria

Width of the rotary

- IRC suggests The following entry width (e_1) values

Width of Approach	Width at entry(e1) for Urban Roads	Width at entry(e1) for Rural Roads
7m	7m	6.5m
10.5m	7	7.5
14	8	8
21	13	13

- The exit width (e_2) shall be at least equal to the entry width if possible more than that
- The width of the weaving section should be higher than the width at entry and exit. Normally this will be one lane more than the average entry and exit width. Thus weaving width is given as,

Design Criteria

Weaving angle(α) and weaving length (L)

- The angle between the vehicle leaving the rotary and that entering the rotary at adjacent roads is called the weaving angle and it shall not be less than 15 degree.
- The weaving length is the length between two legs where the merging and diverging actions occurs. It shall be minimum of 4 times larger than the mean of the entry and exit widths. i.e. $L > 4W$

Sight distance

- The sight distance shall be as large as possible and in no case be smaller than the SSD

Channelizing island

- It shall be provided at the approach i.e. the entrance and exits it helps to force the vehicle systematically into the traffic and thereby reduce their speed and also provide space for traffic signs and symbols etc.

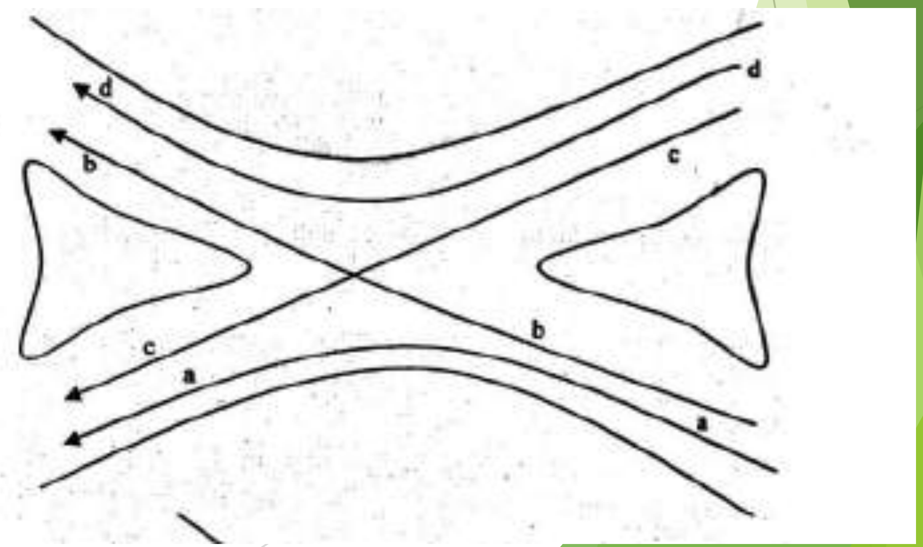
Design Criteria

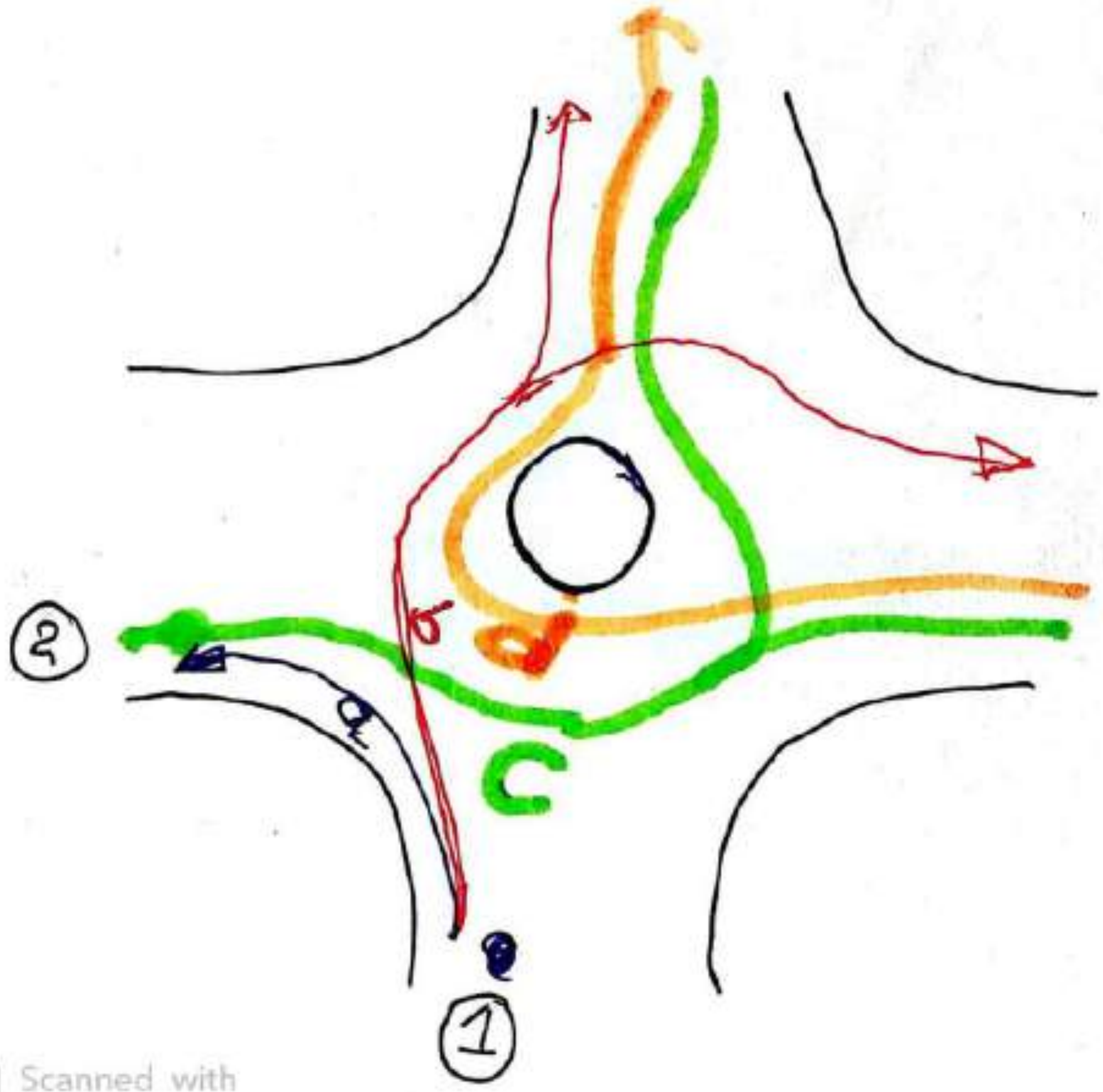
Capacity of rotary

- Transportation road research lab (TRL) proposed the following empirical formula to find the capacity of the weaving section.

$$Q_w = \frac{280W\,(1 + \frac{e}{w})(1 - \frac{P}{3})}{(1 + \frac{W}{L})}$$

- Where
- W = Width of the the weaving section
- e = average of the entry and exit width
- P = Ratio of weaving to non weaving traffic = $\frac{b+C}{a+b+c+d}$
- L = Length of weaving section

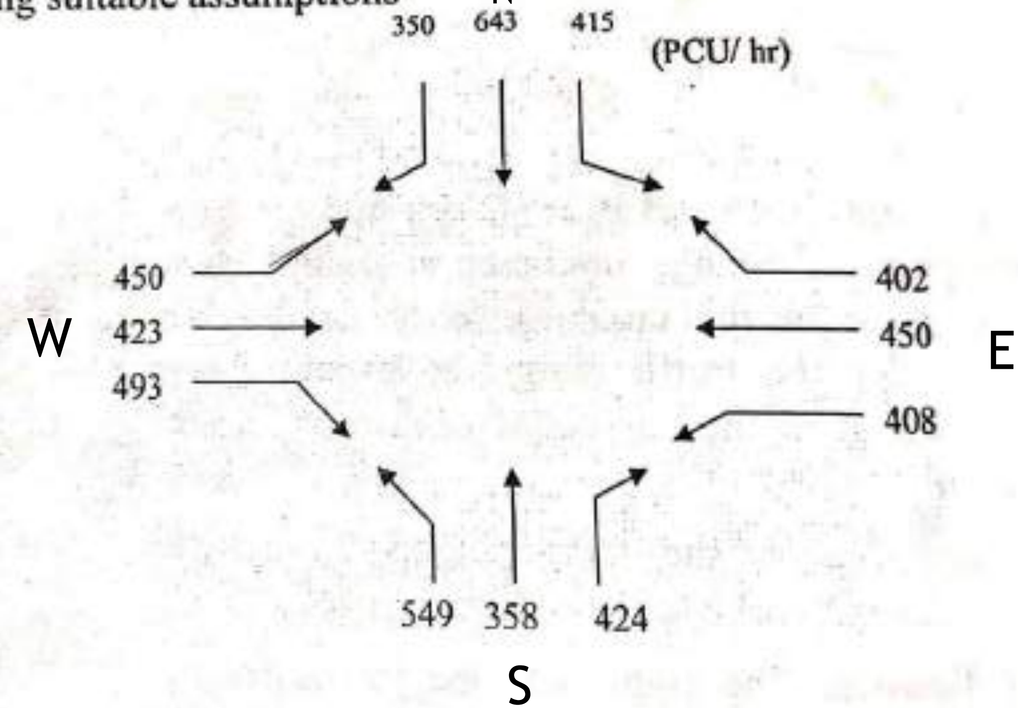




2
1
a
b
c
d

Numerical Example (Design)

Traffic flows in an urban section at the intersection of two highways in the design year are given below. Design a rotary intersection making suitable assumptions



Leg	a	b	c	d	b+c	a+b+c+d	P
ES	408	852	1136	350	1988	2746	0.723962127
SW	549	782	800	402	1582	2533	0.624555863
WN	450	916	760	424	1676	2550	0.657254902
NE	415	993	847	493	1840	2748	0.669577875

Try yourself (Use traffic growth factor of 5% and a design and construction period of 3 years and service period of 10 years)

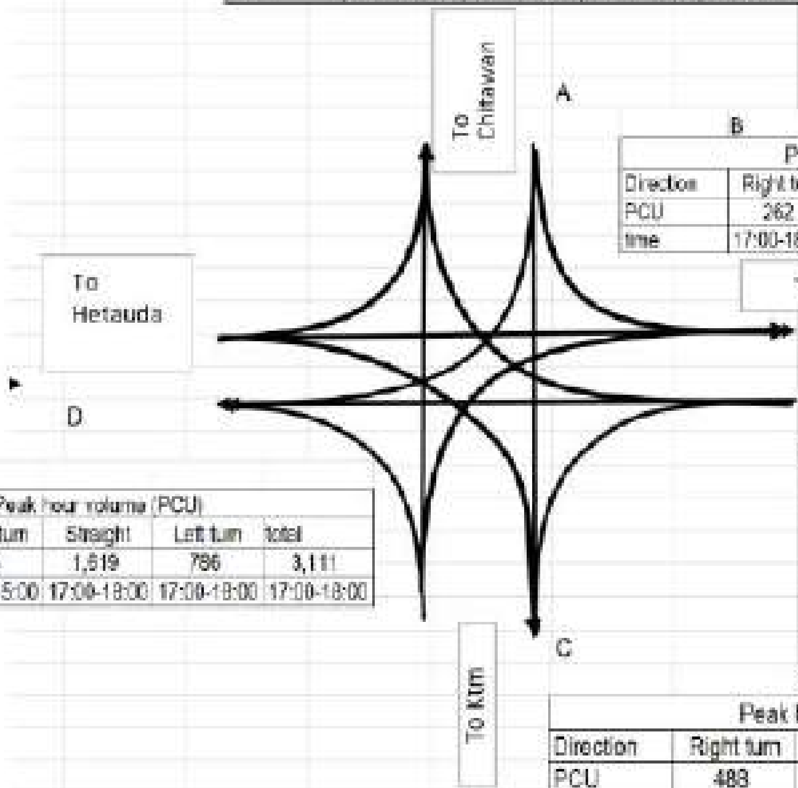
Design

A

Peak hour volume (PCU)				
Direction	Right turn	Straight	Left turn	total
PCU	268	420	183	773
time	7:00-8:00	16:00-17:00	4:00-5:00	7:00-8:00

B

Peak hour volume (PCU)				
Direction	Right turn	Straight	Left turn	total
PCU	262	922	596	1,780
time	17:00-18:00	17:00-18:00	17:00-18:00	17:00-18:00



D

Peak hour volume (PCU)				
Direction	Right turn	Straight	Left turn	total
PCU	764	1,619	796	3,111
time	14:00-15:00	17:00-18:00	17:00-18:00	17:00-18:00

C

Peak hour volume (PCU)				
Direction	Right turn	Straight	Left turn	total
PCU	488	466	1,187	2,141
time	17:00-18:00	17:00-18:00	17:00-18:00	17:00-18:00

Roadway Lighting

Good visibility under day or night conditions is one of the fundamental requirements enabling motorists to move along roadways in a safe and coordinated manner.

Street lighting design aims to produce uniform lighting levels conforming to industry standards and thus facilitate the visibility of motorists, pedestrians, and other objects at night or in situations in which light levels are diminished (i.e., a tunnel).

factors influencing visibility:

- The brightness of an object on or near the roadway.
- Ambient light.
- The size of objects and identifying details.
- The contrast between an object and its surroundings.
- The contrast between pavement and its surroundings as seen by the observer.
- The time available for seeing the object.
- Glare (both disability glare and discomfort glare).
- The quality of the driver’s vision.

- **Design factors**

1. Lamps

The different types of lamp are

- Filament
- Fluorescent- CFL tube light
- Sodium or mercury vapor- yellow color, halogen heater
- Led lamp [light emitting diode]- low power consumption

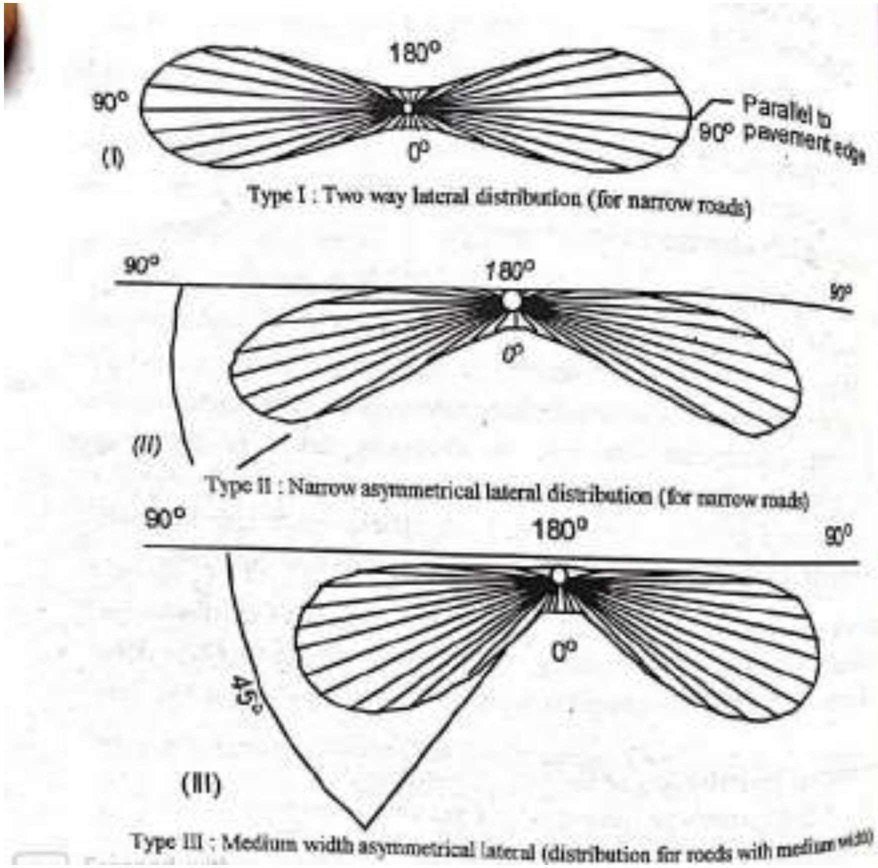
The choice of lamp type depends upon

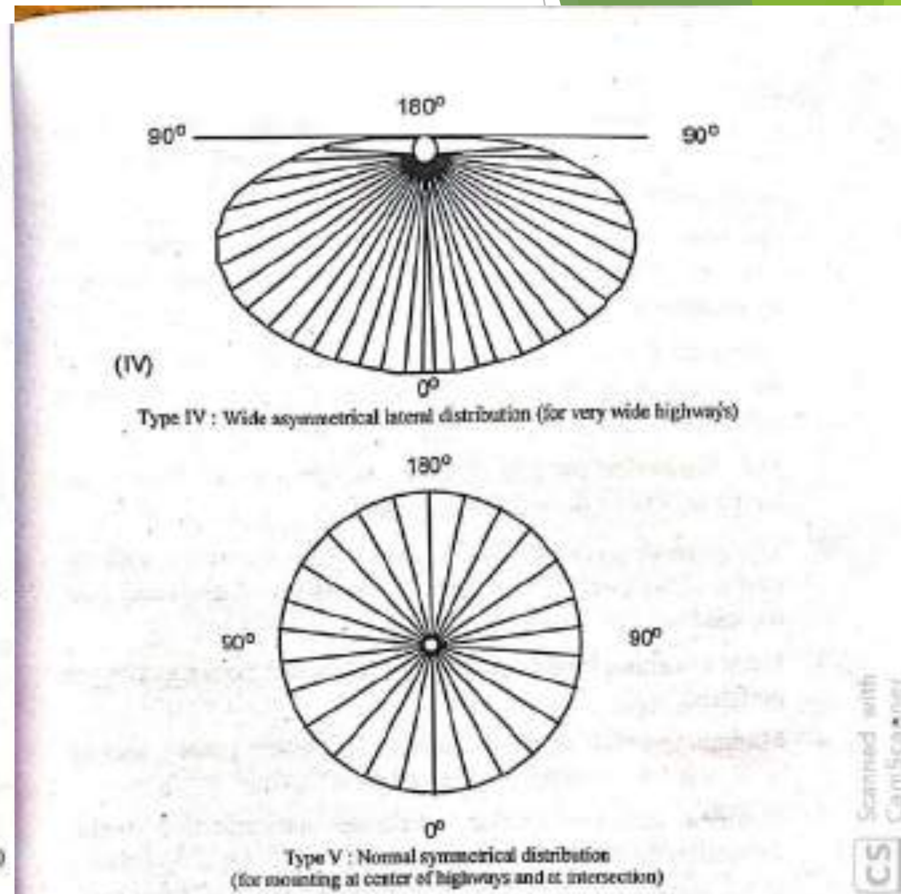
- Capital cost
- Operating cost
- Maintenance cost
- Appearance requirement
- Life of lamp etc.

2. Size of lamp

- Shall be choosen for illuminating the pavement area (Kerb + area 3 to 5 m beyond pavement edge) sufficiently
- 20 to 30 lux= average lux- in urban area
- 5 lux- other main road

3. Luminaire distribution



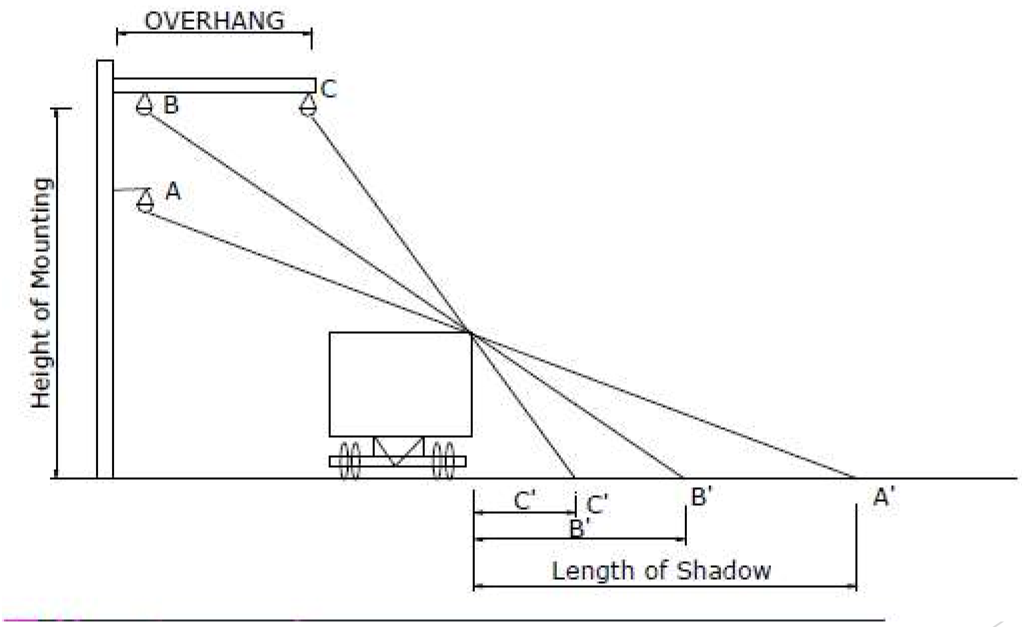


3. Height and Overhang

The height of mount is generally 8 – 10 m (It shall be 6 meter above the power lines)

The overhang is 0.6 – 1.8m

Lateral placement from the kerb is 0.6m



4. Layout

i. Single sided

- Economical but good for narrow roads only

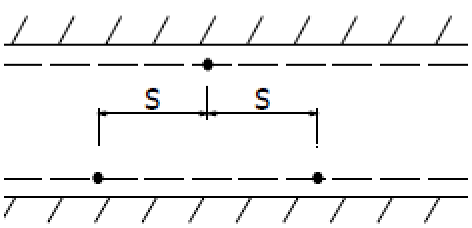
ii. Central mounting :

- Applicable for wider roads with medians
- Footpath is also illuminated

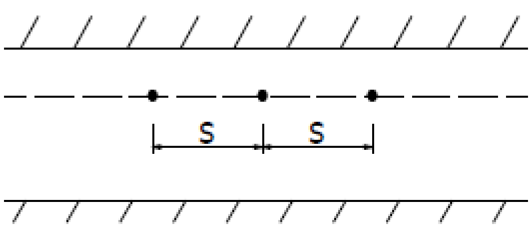
- Not possible if center is allocated for trees

iii. Staggered

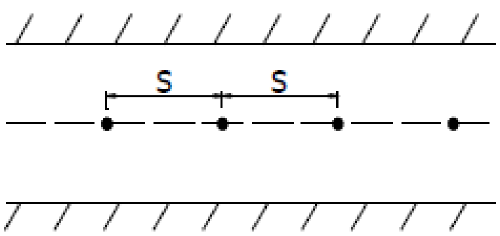
- most widely used
- Gives best brightness



Staggered



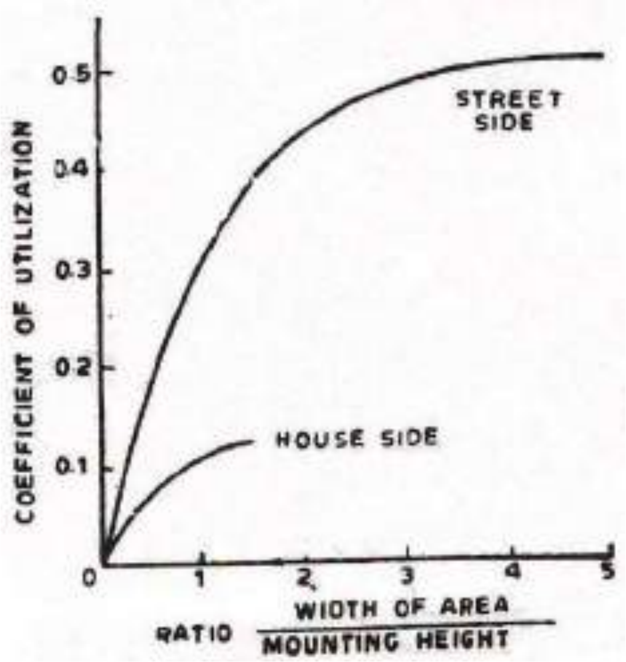
Single side



Central on single carriageway

4. Spacing

- The wider the spacing of lanterns, the lower the level of light and the more patchy it becomes.
- However, small spacing result in greater cost and are not always practical.
- a ratio of Spacing to Mounting Height is given in codes to ensure that minimum standards are achieved.



4. Spacing

$$Spacing = \frac{Lamp\ lumen\ * Coeff\ of\ utilization\ * Maintenance\ factor}{Average\ Lux\ * Width}$$

Design a street lighting from the data below

- Street width = 15m
- Mounting height = 7.5m
- Lamp size = 6000 lumen
- Luminaire type = II
- Average lux = 6

Solution :

Ratio of Width to height ratio = 2

CU from graph = 0.44

Assume MF = 0.8

Spacing = ?????

Traffic Forecasting and Prediction

"Anything can be forecasted but nothing can be predicted"

Prediction implies inferring something from rule of nature

Forecasting implies inferring something from a probabilistic stand point.

- Forecast is scientific and free from intuition and personal bias, whereas prediction is subjective and fatalistic in nature.
- Forecasting is an extrapolation of past into the future while prediction is judgmental and takes into account changes taking place in the future. Therefore, prediction is utilized more in business and economics while forecasting takes place in weather and earthquakes.
- Predicting is saying or telling something before the event while forecasting is done on the basis of analysis of the past.
- Forecasting is still not a complete science as there are chances of error.

Traffic forecasting

Importance

Why/when traffic forecasting is important:

- Design : Width of pavement is decided based on the traffic volume(no. of standard axles) it can efficiently accommodate and needs to be widened when flow exceeds capacity.
- Economic analysis : Correct forecasting of future traffic for a certain highway project points out whether it benefits the current traffic flow
- Toll rate analysis : Forecasting of the likely traffic flow to use the tolled road so as to estimate the economic benefit of the tolled road.

Traffic forecasting

STEPS

1. Measurement of existing traffic flow

- 7 day count two times every year(peak and lean season) and average the two gives rough ADT.

- For more accurate value, seasonal factors based on round the year census data are required for particular month and location.

- Measured in Passenger Car Units (PCU) per hour or PCU per day.

Modification of the measured value i.e. Forecasting.

Factors governing Forecasting

Economic factors

- Gross Domestic Product(GDP)
- Agricultural Output
- Industrial Output

Demographic factors

- Population
- Rural/Urban mix of population

These factors vary from place to place so traffic growth rates also vary.

Determination of Growth Rate

Determined from following indicators

- Traffic census
- Vehicle registration
- Fuel Sales

$P_n = P_0(1+r)^n$

$Log_e P_n$=$Log_e P_0$+nLog_e(1+r)

$Y = A_0 + A_1 n$

For establishing reliable traffic growth rates traffic flow data from a number of years is used and regression analysis is done to estimate the growth rate.

For smaller projects, data from 5-10 years is used for projection of traffic, while for large scale projects, 15-20 years data are used.

THANKS FOR ATTENTION

Pavement Engineering

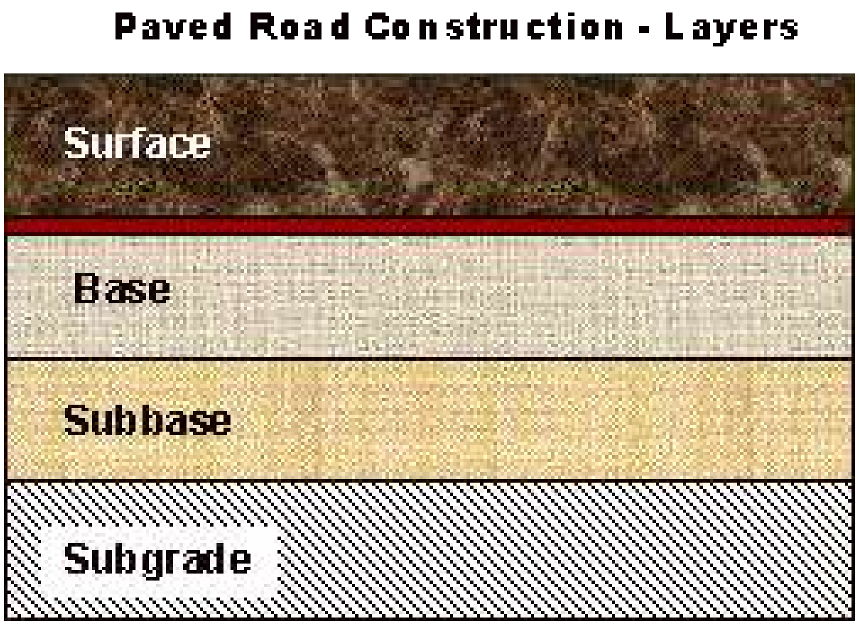
Introduction

- A pavement is a **relatively stable layer constructed over a natural soil**-

(i) for the purpose of **supporting and distributing the wheel loads** so that the bearing capacity of the underlying soil is not exceeded, and

(ii) for providing an adequate wearing surface.

- A pavement is a multi-layered structure.
- The layers are placed horizontal one over other.



Objectives of Pavement

- To **provide a stable and unyielding surface** due to loads caused by traffic.
- *To **support and distribute wheel load of vehicles** over a wide area of the underlying sub grade soil.*
- To **provide an even surface** so that passengers in fast moving vehicles will not be put to discomfort and unsafe.
- *To **prevent water from entering the soil** which may lead to yielding(soft/elastic) of the road.*
- *To **keep temporary deformation of the pavement within the permissible limits** so that the pavement can sustain a large number of repeated load applications during its design life.*

Types of Pavements

- *Based upon the Structural Behaviour of the Materials Used in the Construction, Pavements are Classified as:*

1. Flexible Pavement

2. Rigid Pavement

3. Semi-Rigid Pavement

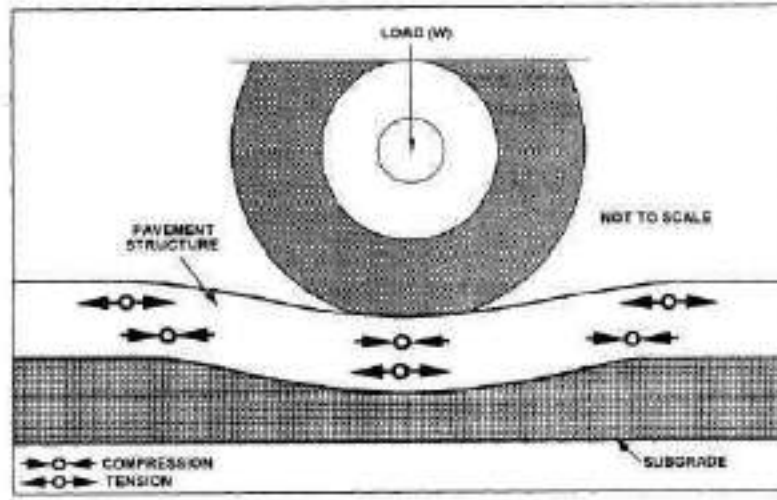
4. Composite Pavement

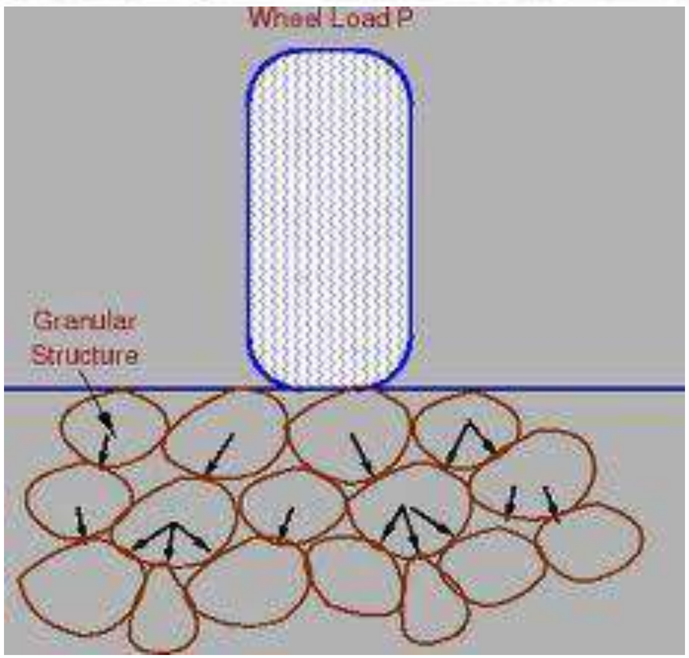
1. Flexible Pavement

- So named because the **pavement structure Deflects or Flexes under Loading.**

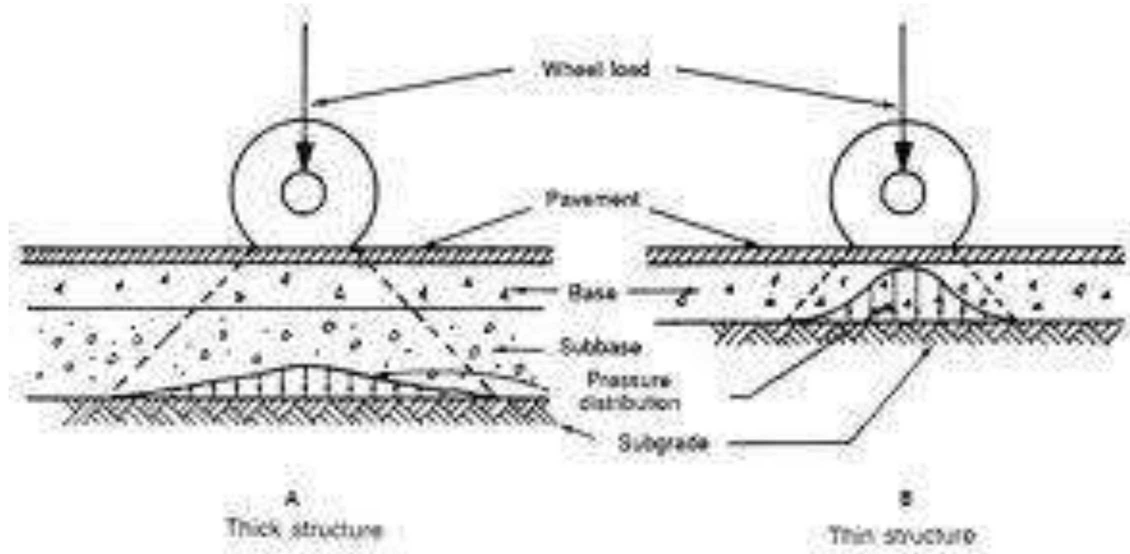
- Pavements having Very Little Resistance to Deformation under the Wheel Loads.

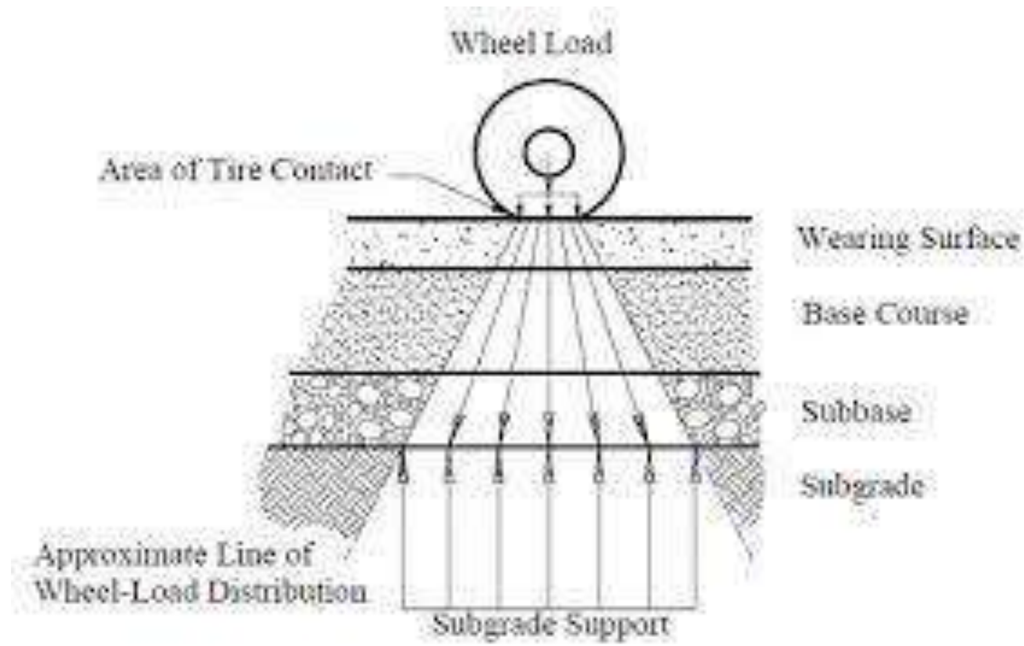
- Which have Very Low Flexural Strength and is Flexible in the Structural Behaviour under the Wheel Loads.





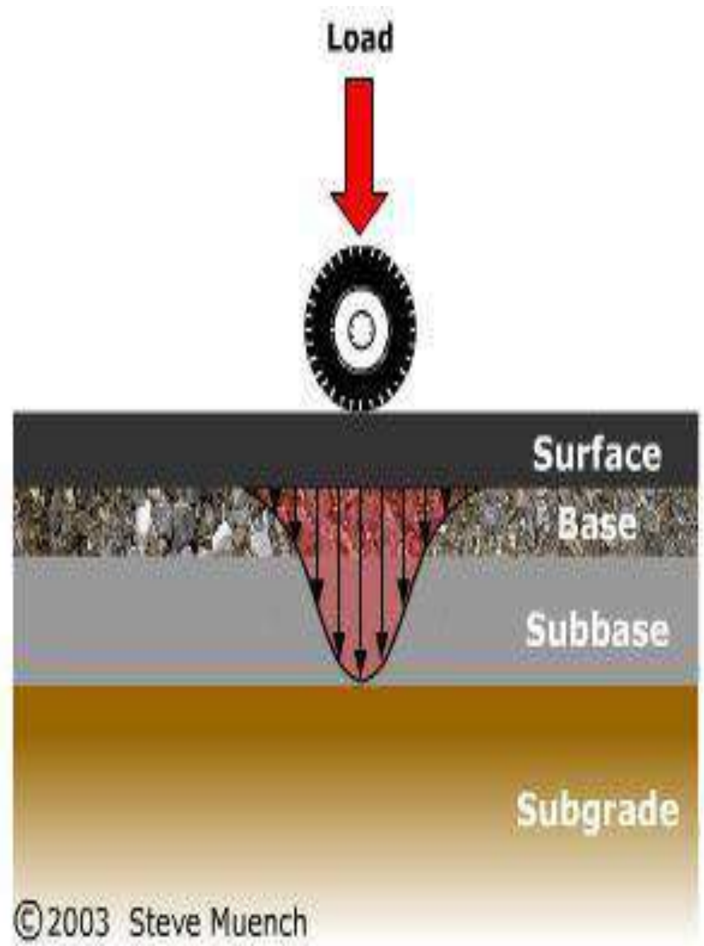
- Its layers reflect the deformation of the lower layers on to the surface of the layer.
- Thus if lower layer somehow gets deformed, the surface layer of the pavement also gets deformed





Stress Distribution in Flexible Pavement

- Each layer receives the loads from the above layer, spreads them out, then passes.
- Top layer experiences more stress than the descending layers.
- So materials of higher quality is used on the top layer than the lower layers i.e. gradually decrease in material quality with depth → Design Principle of Flexible Pavement



Types of Flexible Pavement

- Dense-graded HMA
- Open-graded HMA
- Bituminous surface treatments (BSTs)

Types of Flexible Pavements

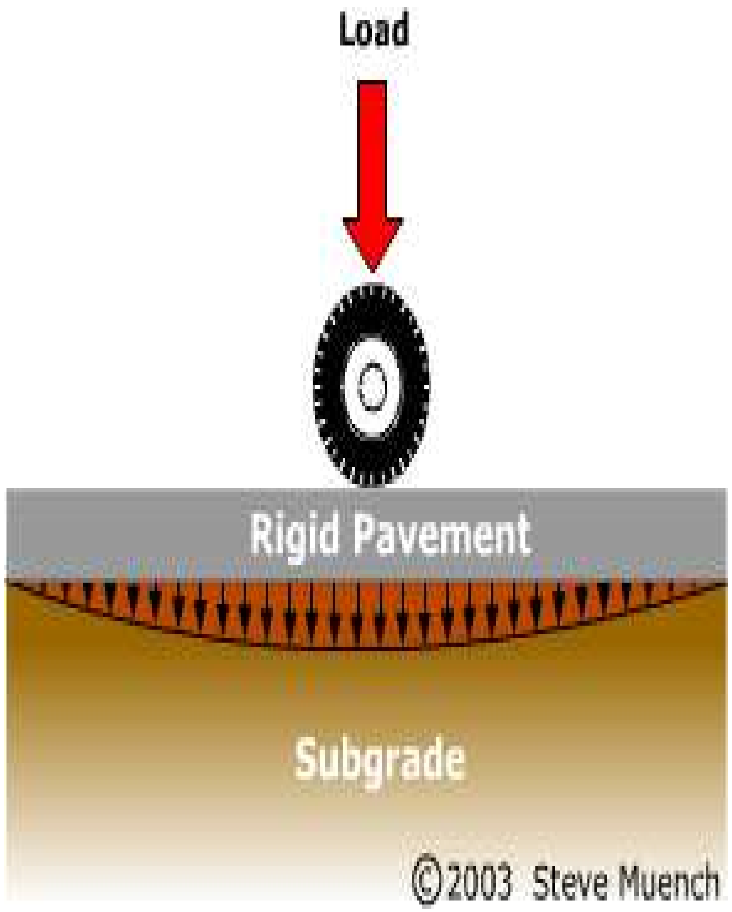
Rigid Pavement

- So named because the pavement structure deflects very little under loading due to the high modulus of elasticity of the surface course.

- Possesses considerable flexural strength.
- Has slab action and is capable of transmitting the wheel loads through a wider area below.

Rigid Pavement

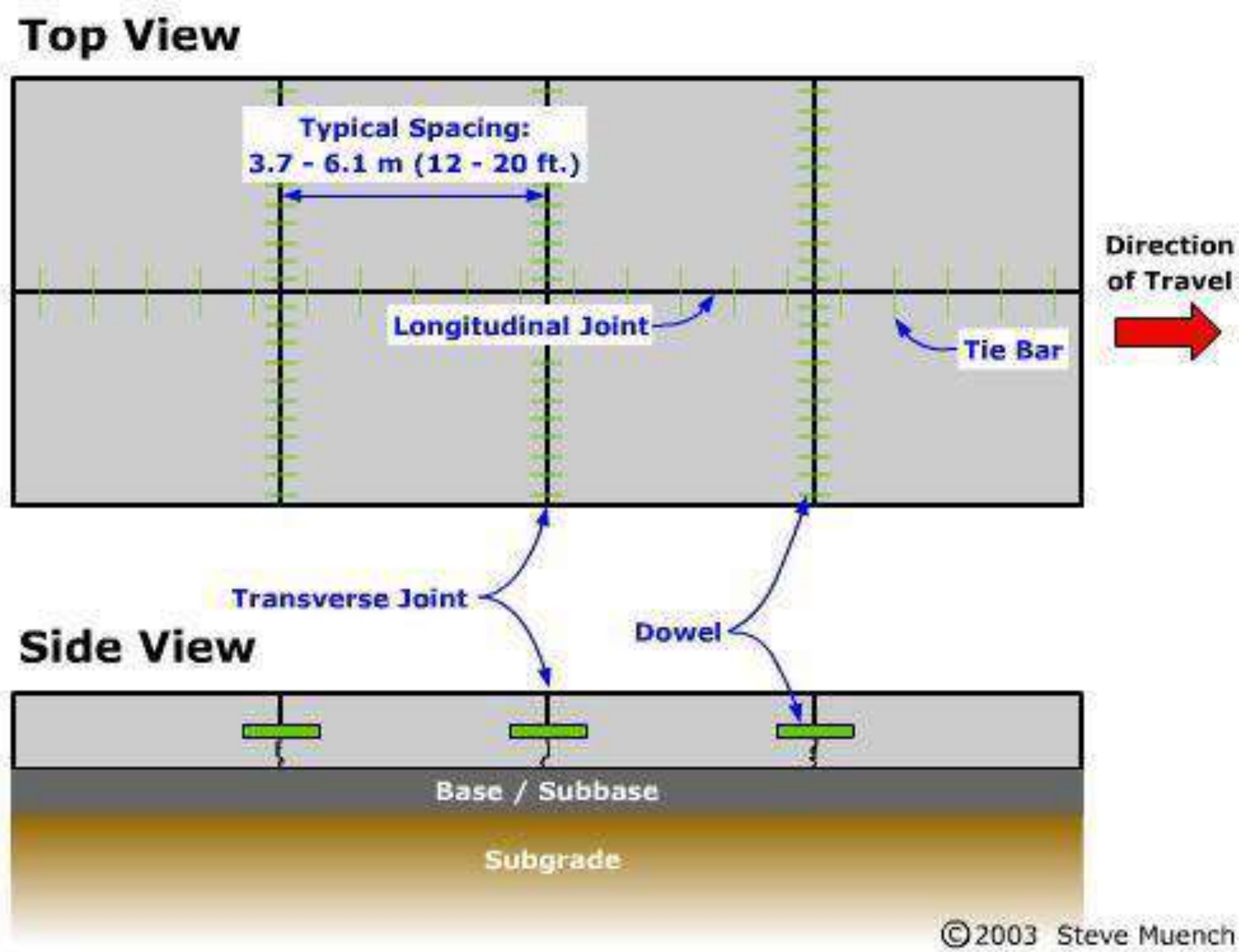
- Doesn't get deformed to the shape of the lower surface as it can bridge the minor variations of lower layers.
- Can take appreciable tensile stresses .
- Made of cement concrete which may be either plain, reinforced or pre-stressed.



Stress Distribution in Rigid Pavement

Types Of Rigid Pavements

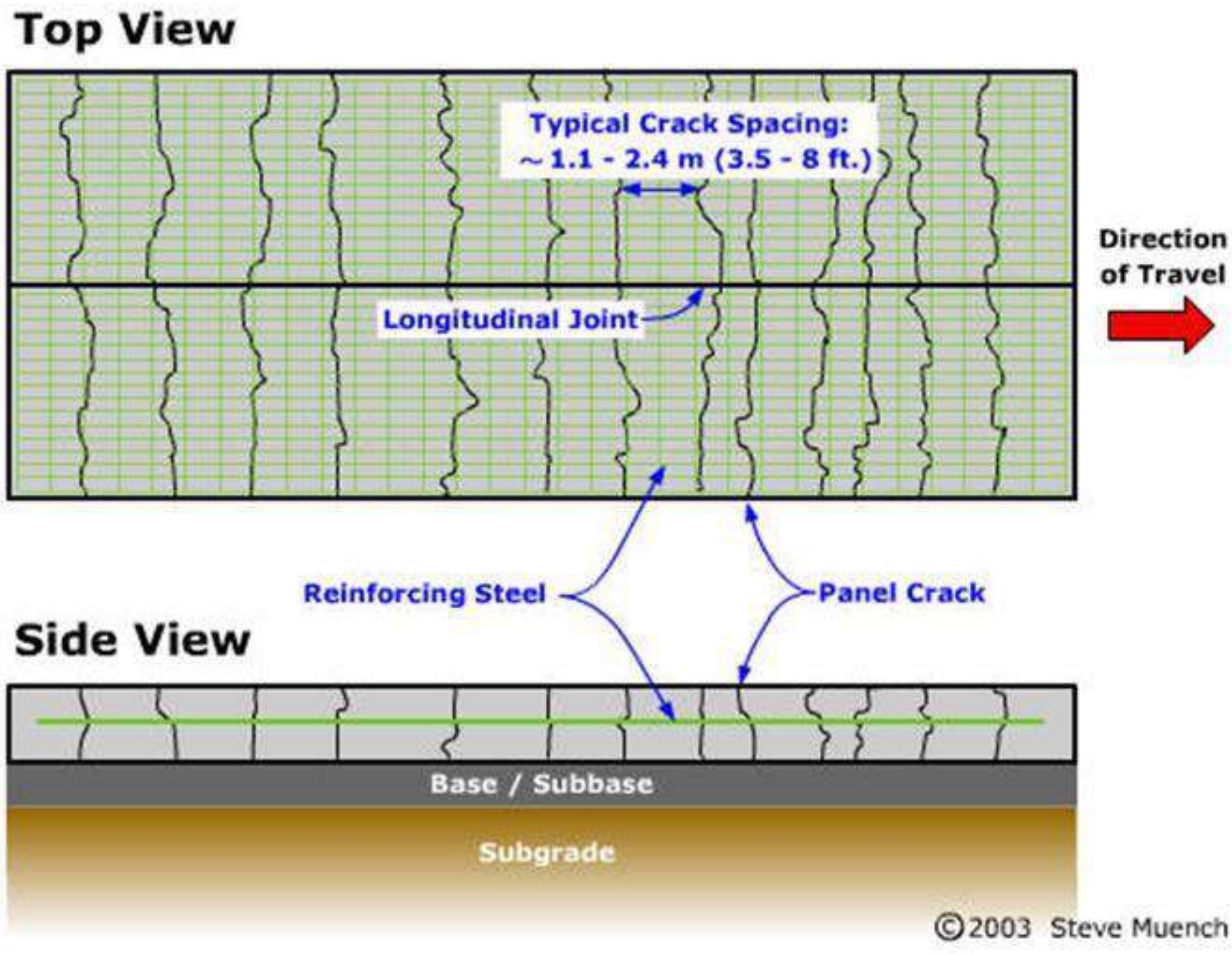
1. Jointed Plain Concrete Pavement (JPCP)



Jointed plain concrete pavement (JPCP)

- Constructed with closely spaced contraction joints
- Dowels or aggregates interlock may be used for load transfer across the joints
- Joints spacing 15-30 ft
- Tie bars are used for longitudinal joints

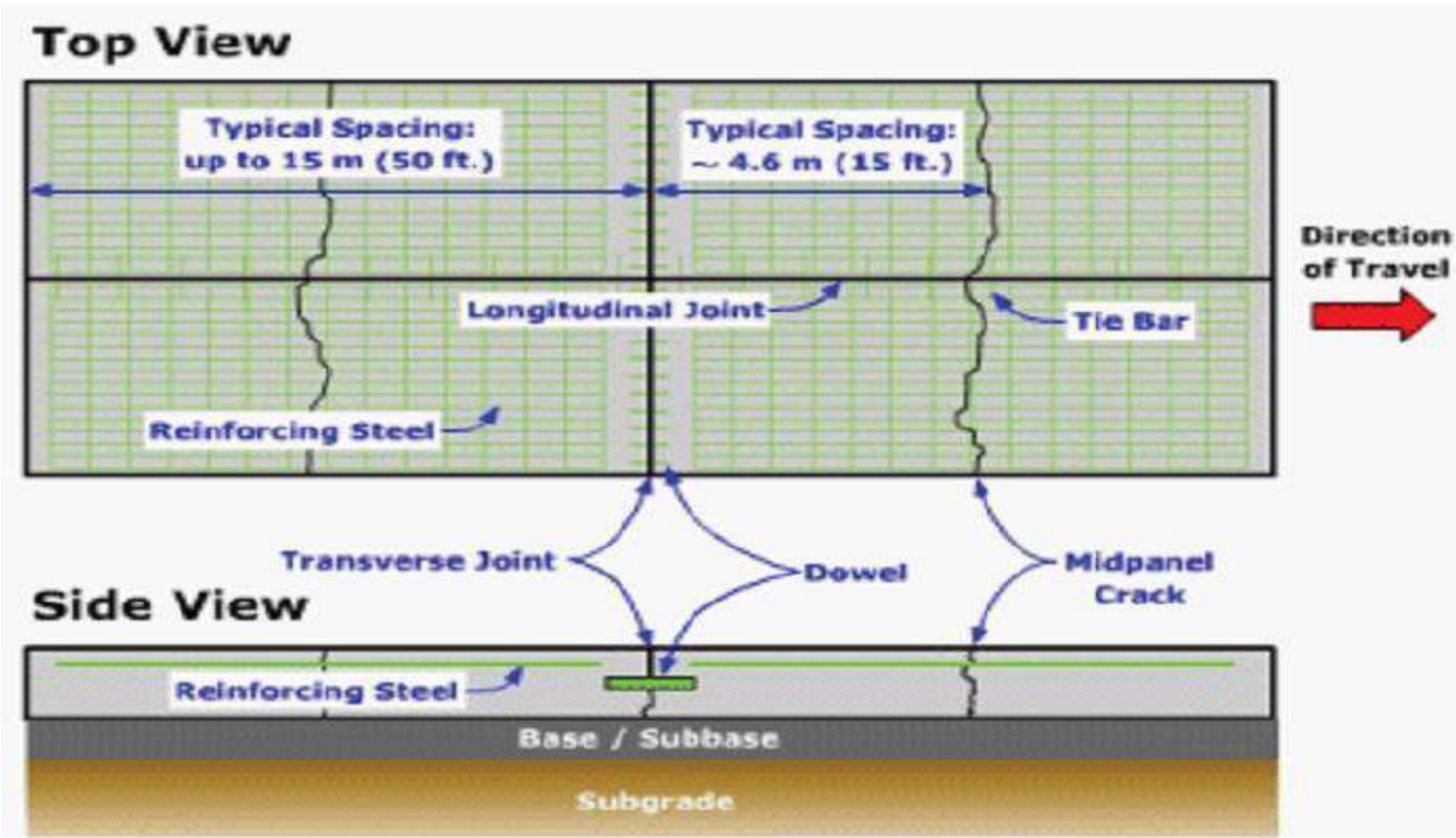
2.Continuously Reinforced Concrete Pavement (CRCP)



Continuous Reinforced Concrete Pavements (CRCP)

- It has no joints
- Joints are weak spots in rigid pavements
- Eliminating joints reduced thickness of pavement by 1 to 2”
- Most frequent distress is punch-out at the pavement edge

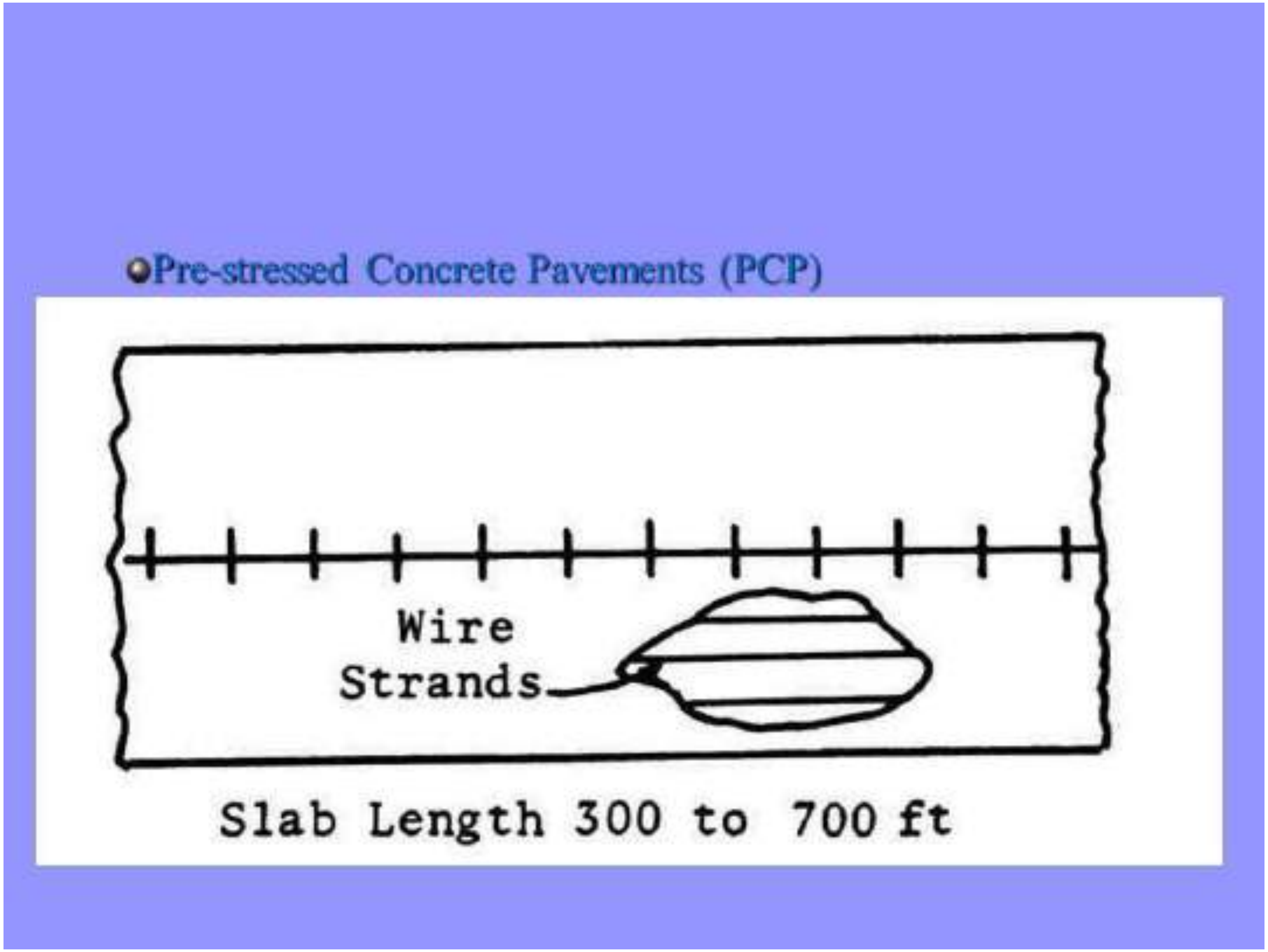
3.Jointed Reinforced Concrete Pavement (JRCP)



Jointed Reinforced Concrete Pavements(JRCP)

- Steel reinforcement in the form of wire mesh or deformed bars do not increase the structural capacity of pavements but allow the use of longer joint spacing.
- Joint spacing (30-100ft)
- Dowels are required for load transfer across the joints
- The amount of distributed steel increase with the increase in joint spacing and is designed to hold the slab together after cracking

4. Pre-stressed Concrete Pavement (PCP)



Pre-tensioned Concrete Pavement (PTCP)

Post-tensioned Concrete Pavement (PTCP)

Pre-stressed Concrete Pavement (PCP)

- The pre application of a compressive stress to the concrete greatly reduces the tensile stresses caused by traffic and thus decrease the thickness of concrete required
- Has less probability of cracking and fewer transverse joints and therefore results in less maintenance and longer pavement life
- Used more frequently for airport pavements than highway pavements because the saving of thickness for airport pavements is much greater than for highways.

Rigid Pavements

ADVANTAGES

1. **HIGH STRENGTH→** *compressive, abrasion, compression-tension*
2. **GOOD STABILITY→** *water, heat stability, strength increases with time*
3. **DURABILITY→** *20~40 years*
4. **LOW MAINTENENACE COST→** *large economic gain, big investment but long design period therefore maintenance cost per year is LOW*
5. **SUITABLE FOR NIGHT DRIVING**

DISADVANTAGES

1. **NECESSITY OF CEMENT AND WATER ID LARGE→** *for 20 cm depth, 7 m wide cement concrete pavement for every 1 km road needs 400~500 ton cement and 25 ton water*
2. **HAVE JOINTS→** *difficult to construct and maintain, cause vibration on vehicle*
3. **DIFFICULT TO REPAIR →** *repairing work influences the traffic movement largely*
4. **PAVEMENT IS QUITE LATELY AVAILABLE FOR TRAFFIC OPERATIONS→** *needs 15~20 days*

Semi –Rigid Pavement

- Has the intermediate properties between the flexible and the rigid pavement.
- Has much lower flexural strength compared to concrete slabs but derives the support by the lateral distribution of loads through the pavement depth as in a flexible pavement.
- Has low resistance to impact and abrasion and therefore is usually provided with the flexible pavement surface course.
- Bonded materials like pozzolanic concrete(lime-fly ash-aggregate mix), lean cement concrete or soil cement are used in the base or sub-base courses which has higher flexural strength than the common flexible pavement layers, But have low flexural strength than rigid pavements.
- Eg. Lean-concrete Base, Soil-cement, Lime–pozzolana Concrete Constructions, etc.

Composite Pavement

- Comprises of multiple, structurally significant layers of different composition.
- Consists of PCC as a bottom layer and bituminous layer as a top layer.
- Bottom layer (PCC) provides a strong base and bituminous layer(top) provides a smooth and non-reflective surface.
- Very expensive type of pavement so rarely used.

Eg. Brick -sandwitched Concrete Pavement (under research in India), Asphalt concrete overlay over a PCC slab

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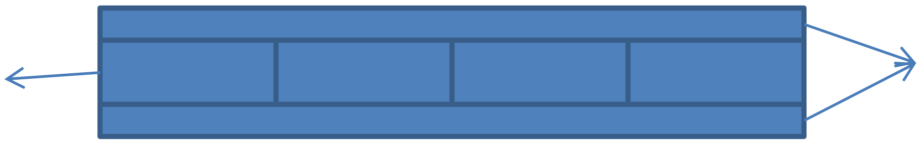
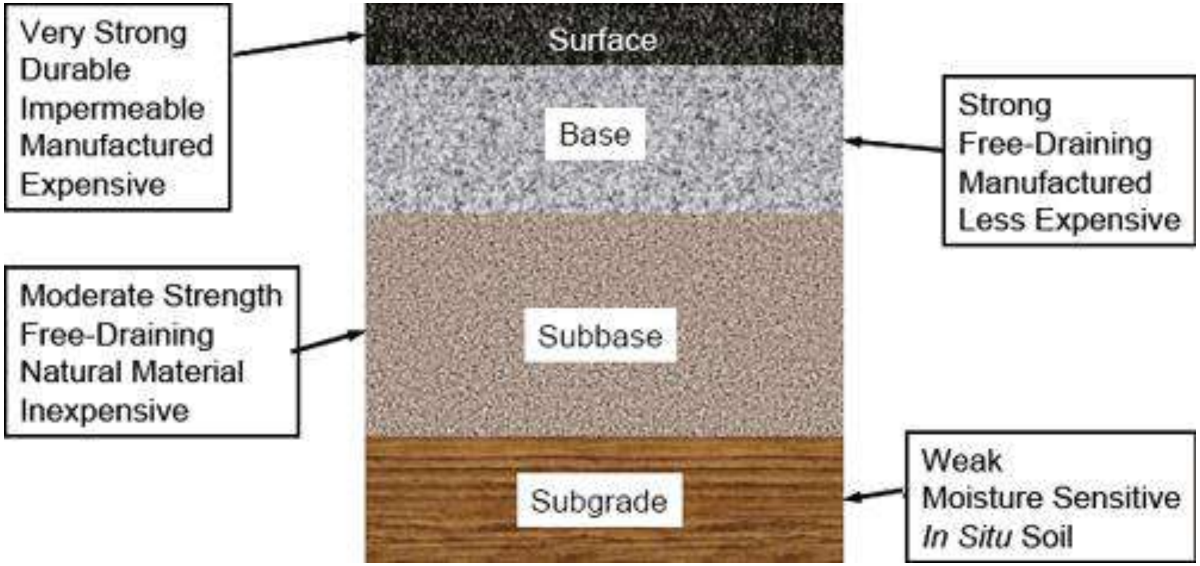


Structural Elements of a Pavement

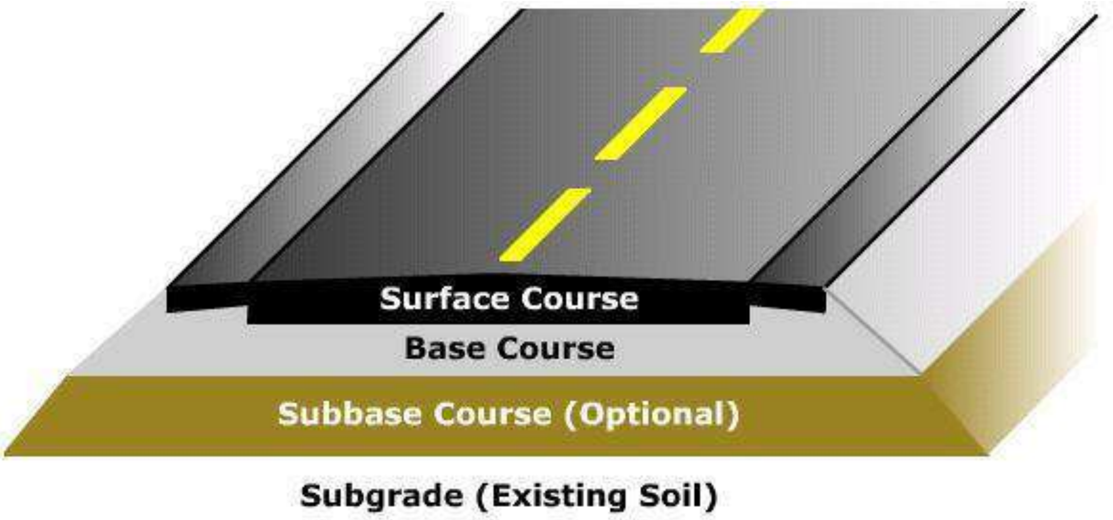
- *A typical pavement structure consists of -*

1. Subgrade
2. Sub-base Course
3. Base Course
4. Surface Course



For Flexible Pavements

1. Subgrade
2. Sub-base Course
3. Base Course
4. Wearing/Surface Course



Indian Practice

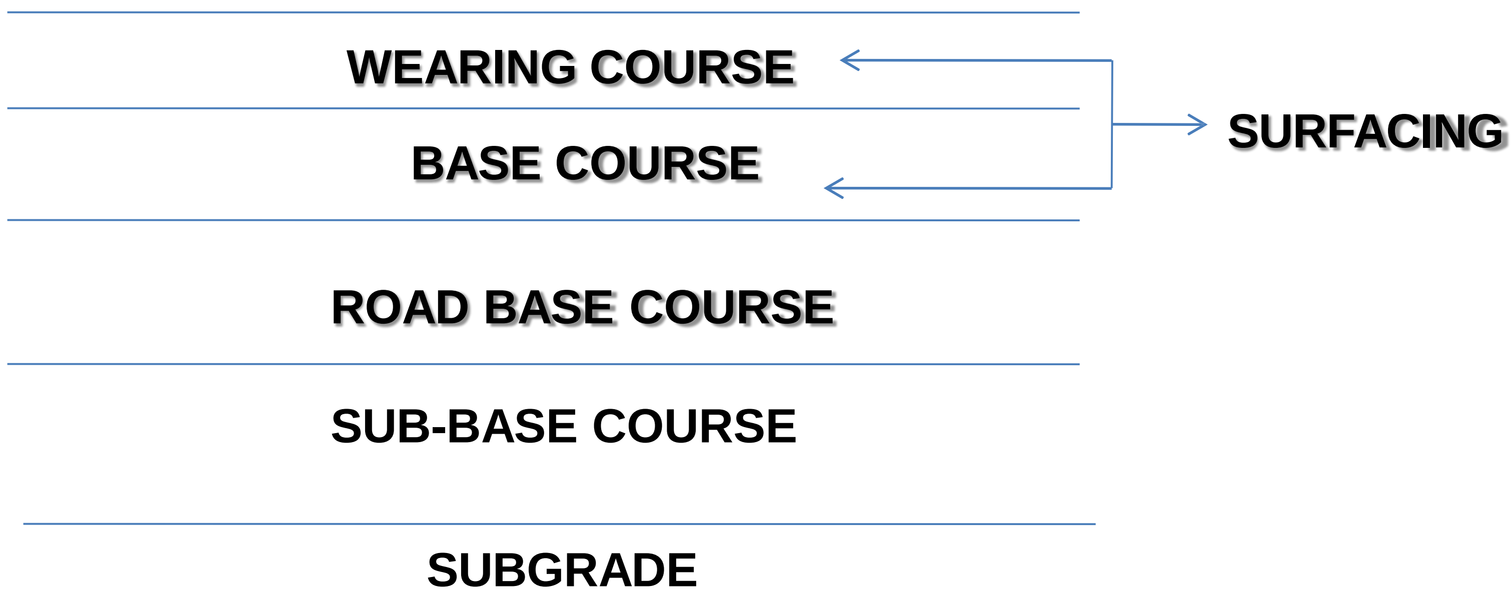
SURFACE/WEARING COURSE

BASE COURSE

SUB-BASE COURSE

SUBGRADE

British Practice



American Practice

SURFACE COURSE

BINDER COURSE

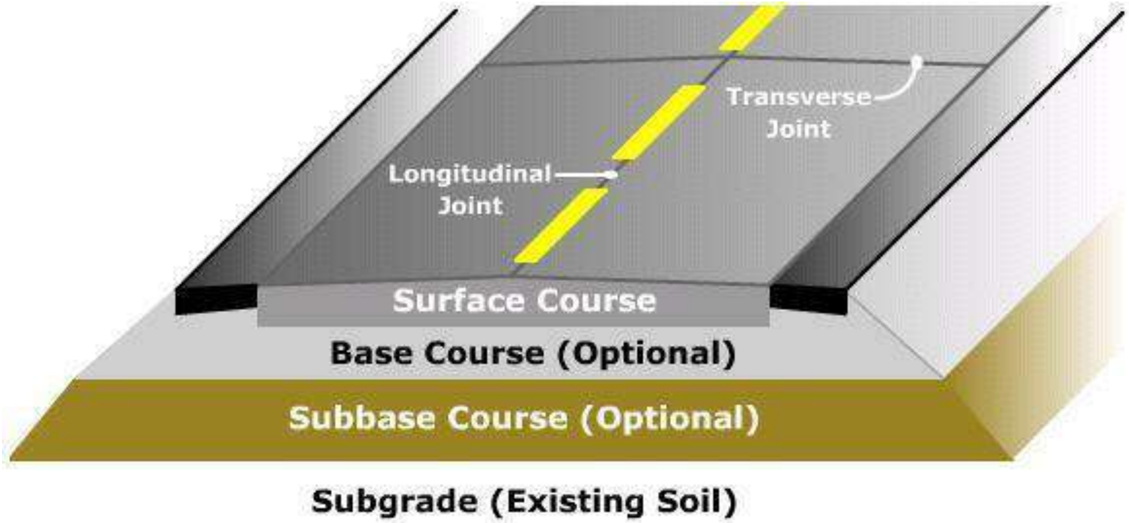
BASE COURSE
BASE COURSE

SUB-BASE COURSE
SUB-BASE COURSE

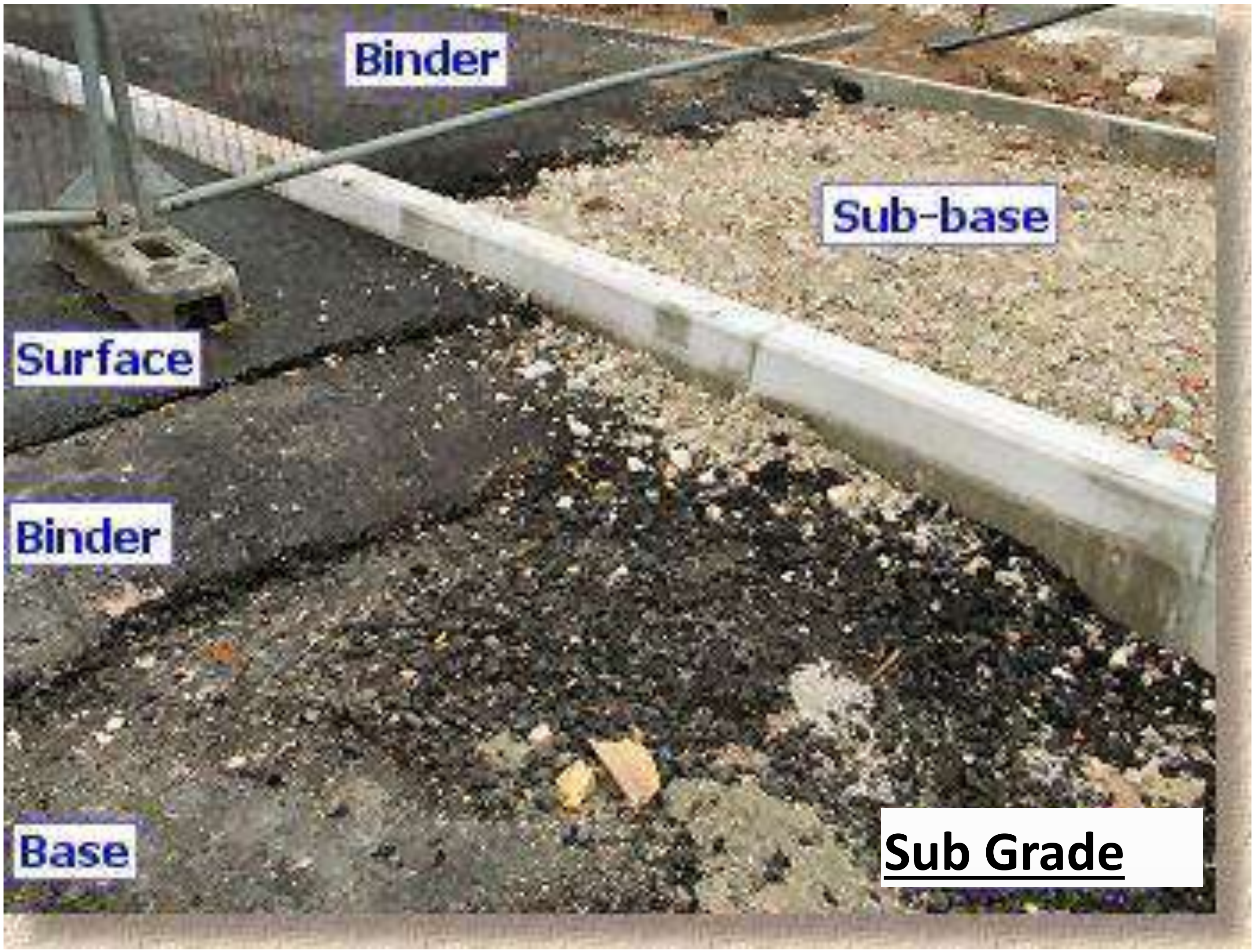
SUBGRADE

For Rigid Pavements

1. Subgrade
2. Sub-base Course
3. Base Course
4. Wearing/Surface Course



Functions and Characteristics of Pavement Layers



Subgrade

- Soil beneath the pavement is called the subgrade.

- Subgrade is a layer of natural soil prepared to receive the other layers of the pavement.

- The performance of the pavement is affected by the characteristics of the subgrade.
- Desirable properties which the subgrade should possess are: strength, drainage, ease of compaction, permanency of compaction, and permanency of strength.

- The strength of subgrade is increased by compaction or in some cases by stabilization.

Sub-base Course

- A sub-base is a layer of material between the base and subgrade.
- Base course and sub-bases are used under the pavement primarily to increase the load supporting capacity of the pavement distributing the load through a finite thickness of pavement.

- A sub-base material can be of a lower quality materials such as burnt clinkers, natural aggregates or slag than the base course.

- The sub-base should be laid as soon as possible after final stripping to formation level, to prevent damage from rain or sun baking which could cause surface cracks.

- **Primary function** to give structural support but it can also:

- Minimize the intrusion of fines from the subgrade into the pavement structure.

- Improve drainage.

- Minimize frost action damage.

- Provide a working platform for construction.

Base Course

- Layer of granular material which lies immediately below the wearing surface of the pavement which is the main spreading layer of the pavement.

- It may be composed of crushed stone, crushed slag, or other untreated or stabilized materials.

- The base course lies close to the pavement surface and hence it must possess high resistance to deformation in order to withstand the high pressures imposed upon it. So, it is of superior quality materials.

Functions:

- This course receives the impact of the traffic through the wearing course.

- The loads are transferred to the sub-base and subgrade through it.

Surface/Wearing Course

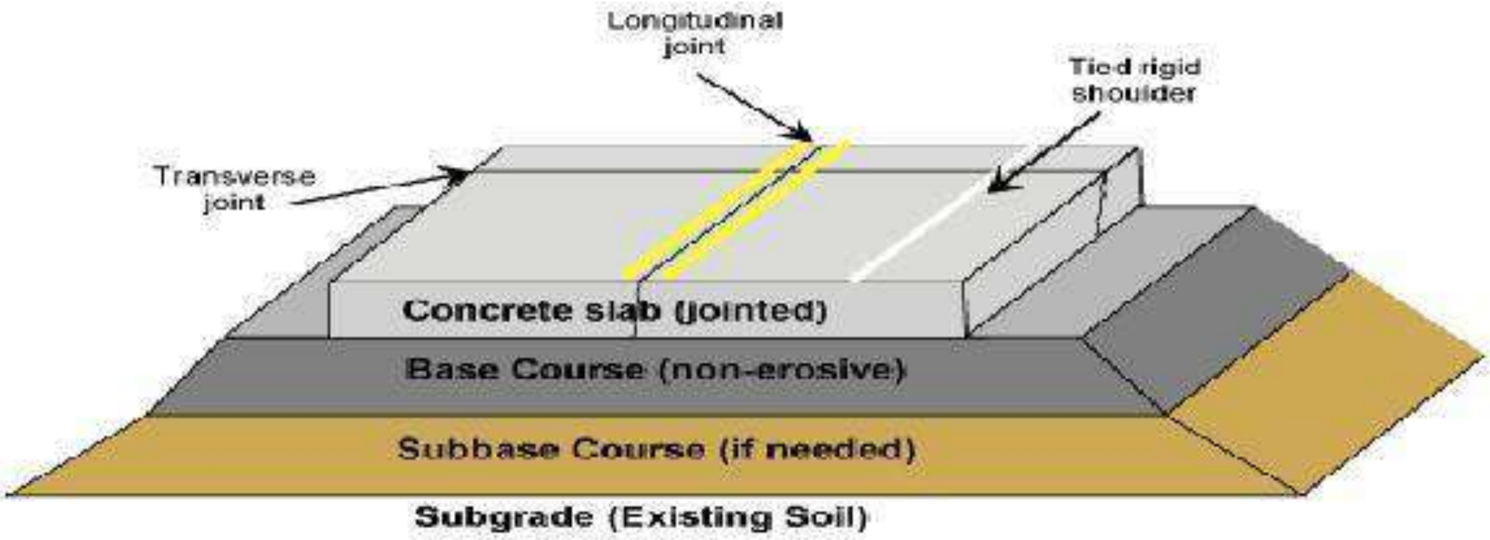
- The wearing or surface course is the top course of a pavement with which the wheels of vehicles are in actual contact.

- This is the layer in direct contact with traffic loads.

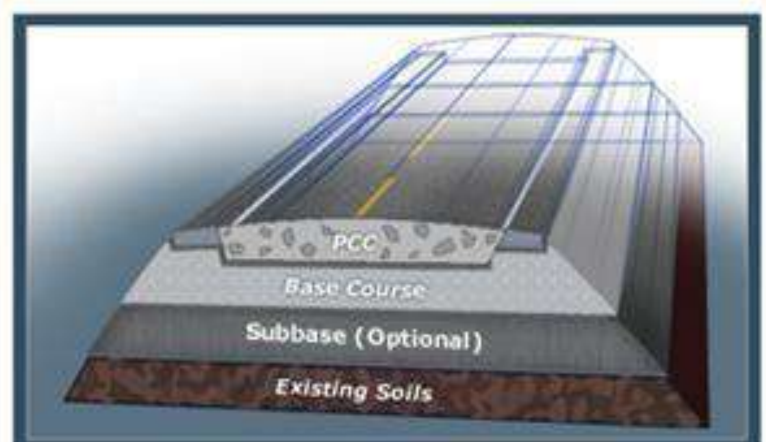
Functions:

- To distribute the load to the base.
- To water-proof the base against the surface water.
- To provide smooth riding surface, dust preventive surface.

Comparison Between Flexible and Rigid Pavement



Typical Flexible Pavement



Typical Rigid Pavement

Comparison Between

CRITERIA	FLEXIBLE PAVEMENT	RIGID PAVEMENT
1.Design Precision	LOW flexible pavements designs are mainly Empirical.	MORE rigid pavements are designed using precise structural analysis.
2.Design Life	10 ~ 20 years	About 40 years
3.Mainteneance	Needs frequent	Needs very little
4.Initial Cost	LOW	HIGH
5.Stage Construction	POSSIBLE intial minimum thickness can be provided and additional overlays are provided in keeping with the traffic growth	DO NOT FIT for such SCHEME

Comparison Between

CRITERIA	FLEXIBLE PAVEMENT	RIGID PAVEMENT
6. Availability of Material	Bitumen→ *scarce resource and imported*	Cement→ *can be produce in the country*
7. Surface Characteristics	Relatively LOW	GOOD→ *produces pavement surfaces free from rutting, potholes and corrugations with good riding quality*
8. Penetration of Water	NOT IMPERVIOUS SURFACE → *water enters through pores and cracks*	PRACTICALLY IMPERVIOUS *except at joints where mud pumping can takes place*
9.Utility Location	POSSIBLE→ *public utilities such as water supply pipes, telephone cables sewer lines, etc can be buried by digging*	IMPOSSIBLE
10. Glare and Night Visibility	Black in color so needs more street lights	Grey in colour so produces glare on sunlight

Comparison Between

CRITERIA	FLEXIBLE PAVEMENT	RIGID PAVEMENT
11. Traffic Dislocation	*Traffic can be opened* SHORTLY *after it is rolled*	LONGER → *Needs 28 days to cure and set the concrete to gain its strength*
12. Environmental Considerations During Construction	MORE HAZARDOUS → *by burning bitumen*	NO HAZARDOUS
13. Overall Economy on a Life Cycle Basis	NOT ECONOMICAL	FAR MORE ECONOMICAL

Flexible Pavement – Construction

Factors Controlling Pavement Design/*Pavement Design*

1. Traffic Factors and Loads Characterization
2. Material Characterization - Soil Factors
3. Environmental Factors
4. Failure Criteria

1. Traffic Factors and Loads Characterization

- Traffic is the most important factor in the pavement design.
- The key factors include:

a) Tire/Wheel/Axle Loads
b) Axle and Tire Configurations
c) No. of Load Repetitions
d) Traffic Distribution
e) Contact Area

A) Tire/Wheel/Axle Loads

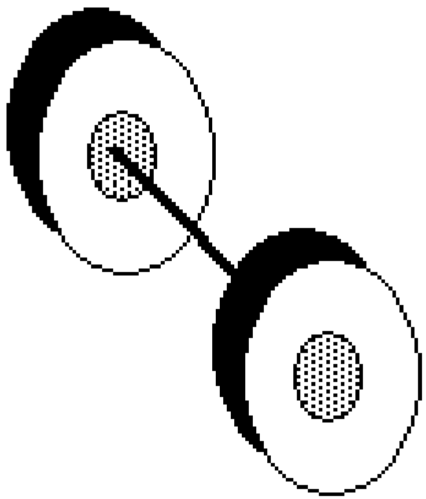
- Wheel load which determines the depth of the pavement required to ensure that the sub grade soil is not failed.

B) Axle and Tire Configurations

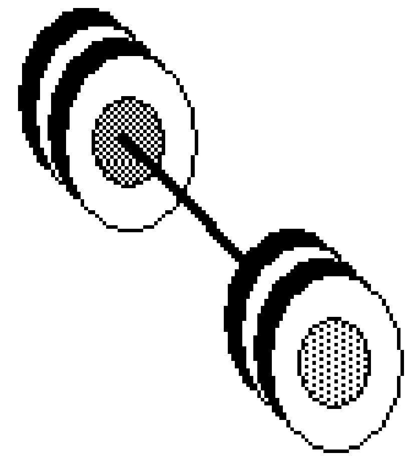
Axle -The common axis of rotation of one or more wheels whether power-driven or freely rotating.

Axle Load

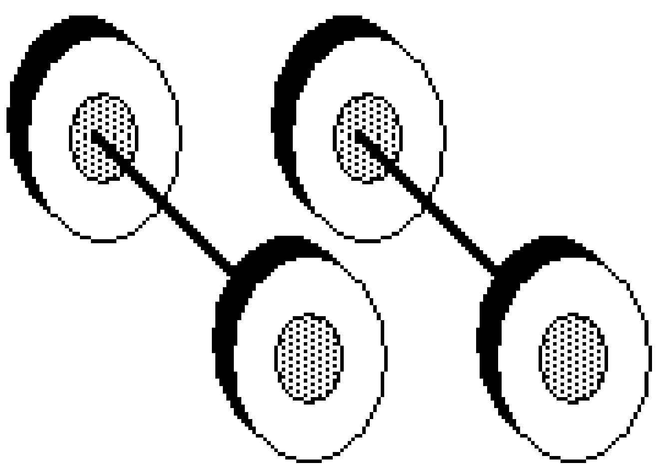
- The total weight felt by the roadway for all wheels connected to a given axle.
- In another way, it is the fraction of total vehicle weight resting on a given axle.



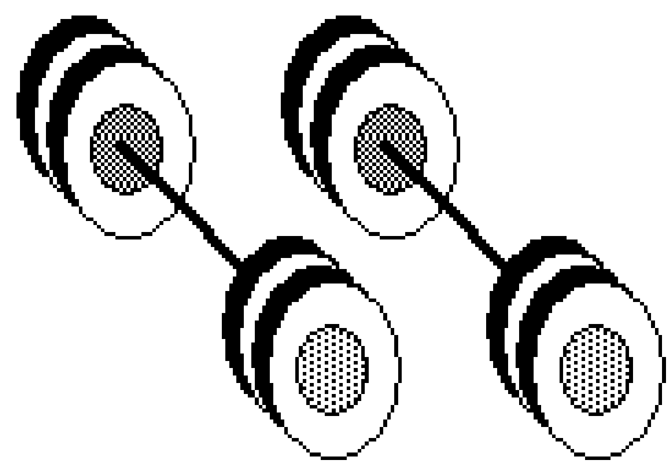
Single Axle with Single Tires



Single Axle with Dual Tires



Tandem Axles with Single Tires



Tandem Axles with Dual Tires

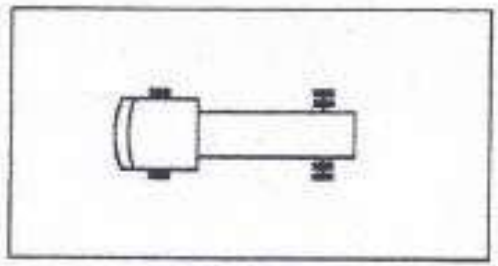
- **Single Axle Load** - The total load transmitted by all wheels of a single axle extending the full width of the vehicle.

Tandem Axles

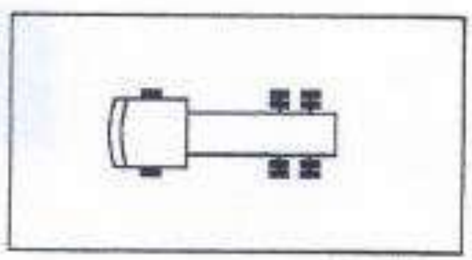
Tridem Axles

Quad Axles

Truck Configuration

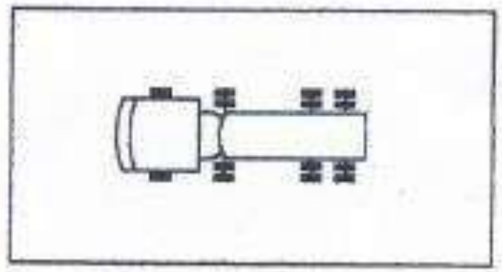


2 Axle Truck – 16t

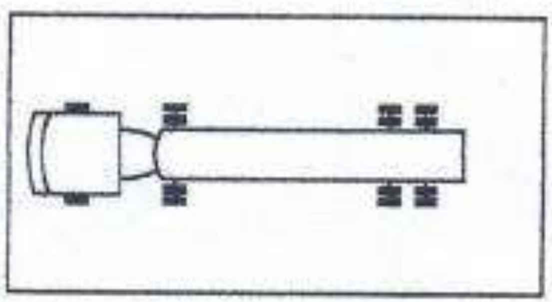


3 Axle Truck – 24t

Truck Configuration

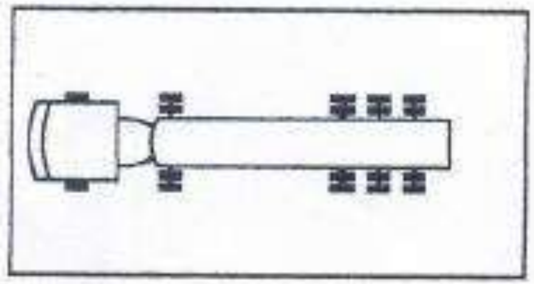


4 Axle Semi Articulated – 34t

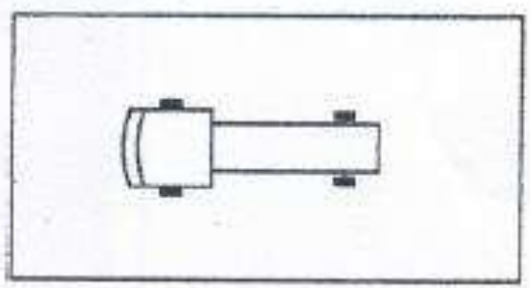


4 Axle Articulated

Truck Configuration



5 Axle Truck – 40t



LCV

Axle Loads Practice in Nepal

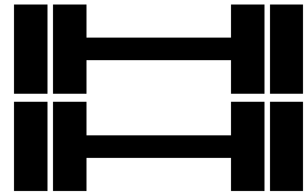
According to DOTM, Nepal -

- 6 wheel : 16.2 T
- 10 wheel : 25 T
- 12 wheel (lift axle) : 31 T
- 14 wheel : 35.2 T

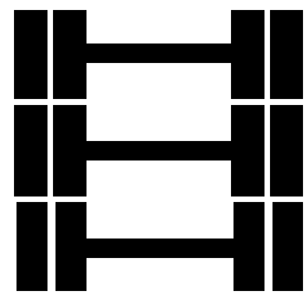
Axle Configurations and Loads

Single Axle With Single Wheel
(Legal Axle Load = 6t)

Single Axle With Dual Wheel
(Legal Axle Load = 10t)

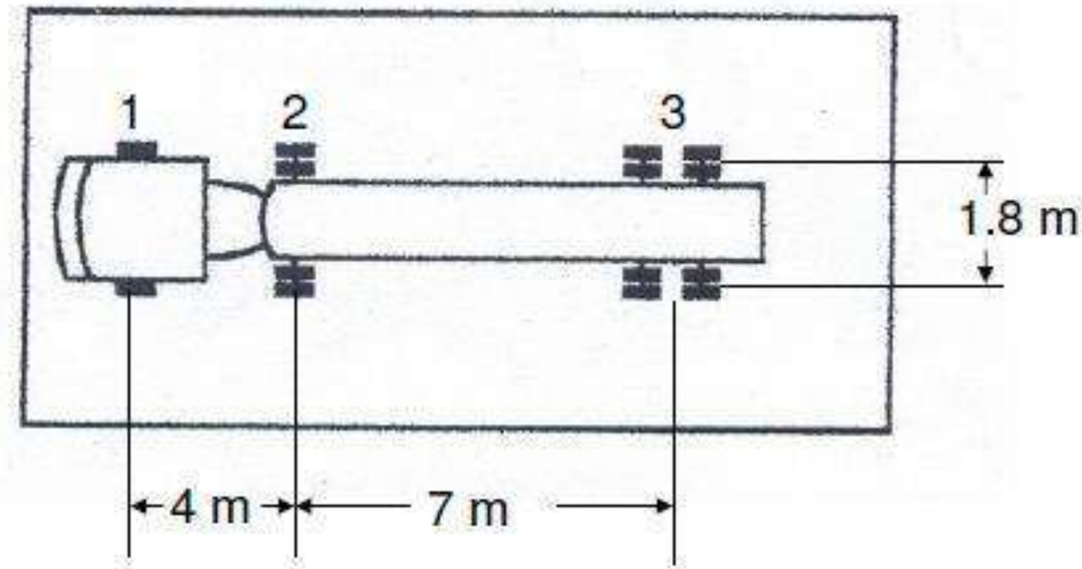


Tandem Axle
(Legal Axle Load = 18t)



Tridem Axle
(Legal Axle Load = 24t)

Effect of Wheel Configuration



•The effect of axles 1, 2 and 3 on stresses and strains within pavement layers should be considered independently.

•Within a group of axles, each axle can not be considered as independent.

•In the design of flexible pavements by layer theory, only the wheels on one side are considered.

•In the design of rigid pavements by plate theory, the wheels on both sides (even at a distance more than 1.8 m) are usually considered.

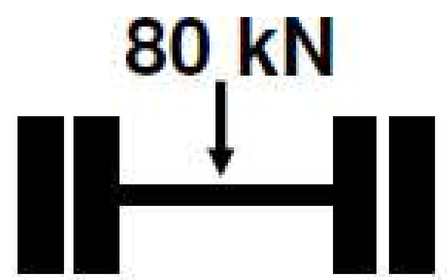
C) No. of Axle Load Repetitions

- The influence of traffic on pavement not only depends on the magnitude of the wheel load, but also on the frequency of the load applications.

- The number of repetition of loads cause plastic and elastic deformations.
- Each load application causes some deformation and the total deformation is the summation of all these.

- Although the pavement deformation due to single axle load is very small, the cumulative effect of number of load repetition is significant.
- When a load from a heavy vehicle is applied repetitively to the pavement it causes certain damage (cumulative strains in various layers of the pavement)

- The damage caused by each axle depends on its load, configuration and repetitions.
- It is possible to evaluate the damage caused by the repetitions of each axle load group.
- Instead of analyzing each axle load group separately, they can be converted into equivalent repetitions of a **standard axle** using **equivalent axle load factors.**
- **Standard Axle:** Single axle with dual wheels carrying a load of 80 kN (8.16 tonnes or 18,000 lb) is defined as standard axle.



Standard Axle

2000 Repetitions < 1 Repetition

Axle load survey must be carried out to determine the axle load distribution of a sample of the heavy vehicles using the road.
Data collected from these surveys are used to calculate the mean number of equivalent standard axles for a typical vehicle in each class.

Equivalence factor is calculated by using the following relationships:

Single axle dual wheel

$$EF = \left(\frac{Axle\,load, kgf}{8160\,kgf\,(80kN)} \right)^4$$

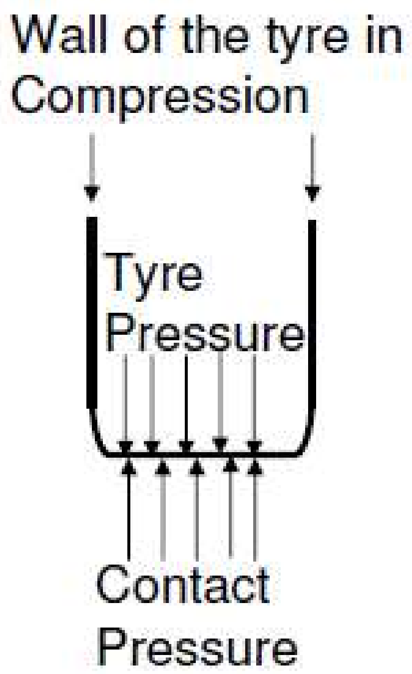
Tandem axle dual wheel

$$EF = \left(\frac{Axle\,load, kgf}{14968\,kgf\,(146.8kN)} \right)^4$$

Contact Area

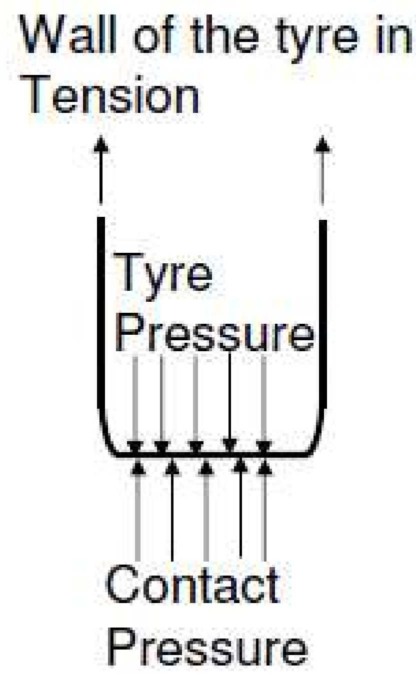
- If the effect of the tire wall is ignored, the contact pressure between the tire and pavement must be equal to the tire pressure.
- For low-pressure tires, contact pressures under the tire wall may be greater than at the center of the tire.
- For high-pressure tires the reverse is true.
- For most problem however, the assumption is made that contact pressures are uniform over the imprint area.

Relationship between Contact Pressure and Tyre Pressure



Low Pressure Tyre

Contact Pressure > Tyre Pressure



High Pressure Tyre

Contact Pressure < Tyre Pressure

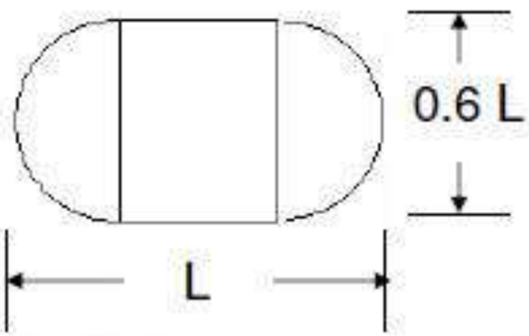
Shape of Contact Area

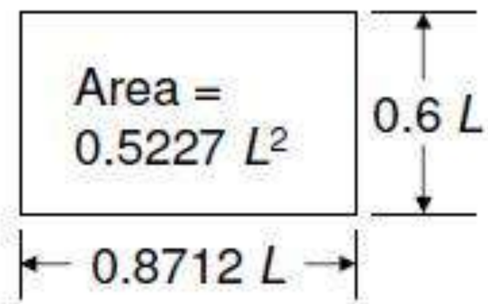
- The true shape of contact area is elliptical
- In the analysis of flexible pavements, however, it is approximated to circular shape for the ease of calculations
- Thus, the radius of the contact area (*a*) for a wheel load *P* and contact pressure *p* can be found out as

$$a = \sqrt{\frac{P}{p\pi}}$$

Shape of Contact Area

- The contact area can not be approximated to a circular shape in the case of rigid pavements, as the error committed by this assumption is significant
- For the convenience of calculations, the elliptical shape is approximated by a rectangle and two semicircles as





Equivalent Area

- Therefore, contact area A_c is given by

$$A_c = \pi\,(0.3L)^2 + (0.4L)(0.3L)$$
$$= 0.5227\,L^2$$

- In analysing the rigid pavement using FEM, rectangular area is assumed with length 0.8712 L and width 0.6L

Traffic Distribution

- Along with load type and repetitions, the load distributions across a particular pavement must be estimated.
- For instance, on a 6-lane highway (3 lanes in each direction) the total number of loads is probably not distributed exactly equally in both directions.
- Often one direction carries more loads than the other.
- Furthermore, within that one direction, not all lanes carry the same loading.
- Typically, the outer most lane carries the most trucks and therefore is subjected to the heaviest loading.
- Therefore, pavement structural design should account for these types of unequal load distribution.

Traffic Distribution Contd…

- Typically, this is accounted for by selecting a "design lane" for a particular pavement.
- The loads expected in the design lane are either

(1) directly counted or

(2) calculated from the cumulative two-direction loads by applying factors for directional distribution and lane distribution.

Vehicle Speed

- Speed is directly related to duration of loading.
- The greater the speed, larger the modulus of elasticity and smaller the strains on the pavement.
- So higher speed of the vehicles is DESIREABLE.
- In general, slower speeds and stop conditions allow a particular load to be applied to a given pavement area for a longer period of time resulting in greater damage.
- At bus stops (where heavy buses stop and sit while loading/unloading passengers) and intersection approaches (where traffic stops and waits to pass through the intersection)

2. Environmental Factors

The environmental factors that influence pavement design include temperature and precipitation, both affecting the elastic moduli of the various layers.

a) Temperature

On Flexible Pavements: Temperature affects the resilient modulus of asphalt layers. During the winter when temperature is low, the HMA becomes rigid and reduces the strains in the pavement. Low temperature can cause asphalt pavement to crack.

- The effect of temperature on asphalt pavement is different from that on concrete pavements.

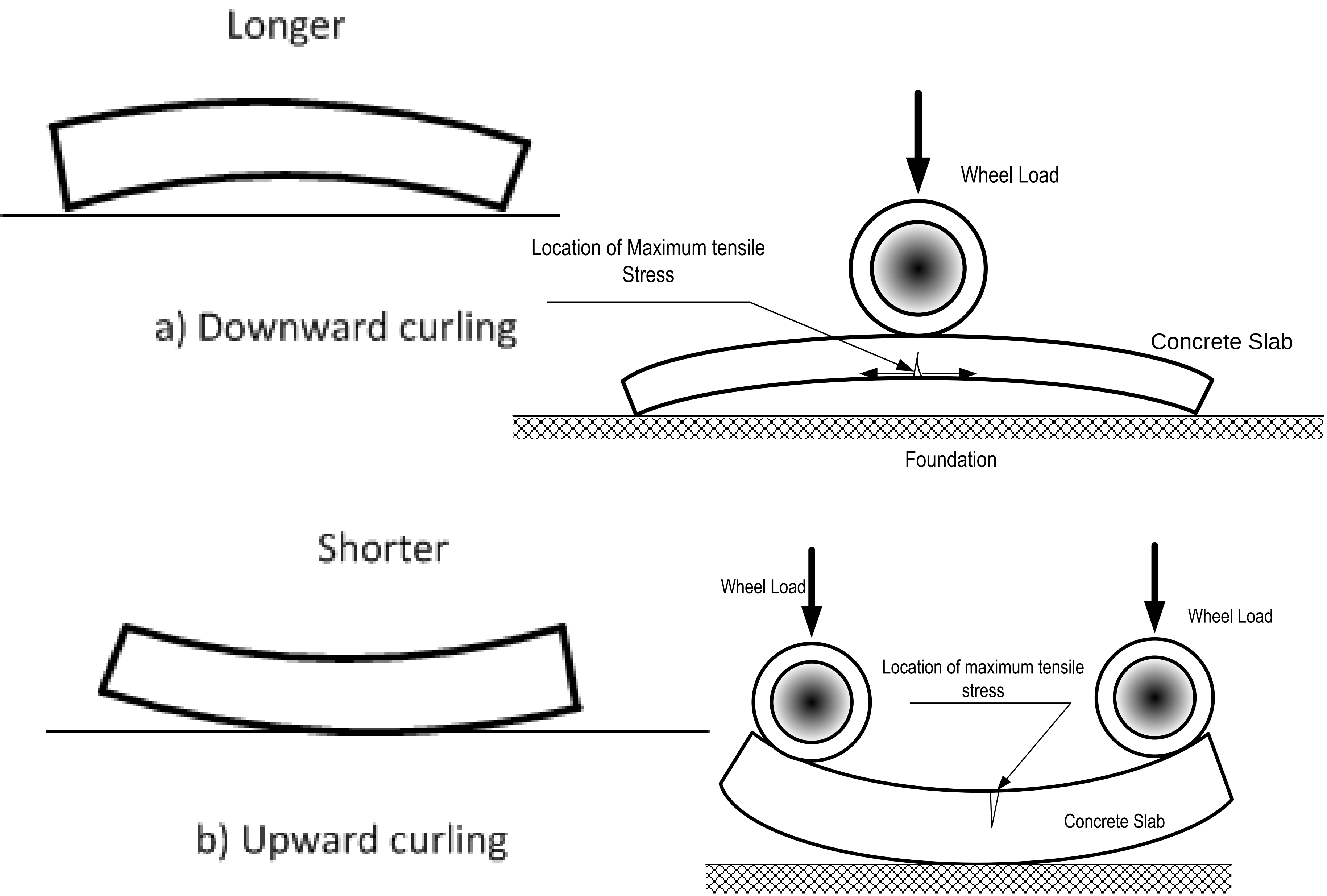
Environmental factor…

<u>On Rigid Pavements:</u> The temperature gradient in concrete pavements creates the curling stress at the same time it affects the slab subgrade contact.

During the day when the temperature at top is higher than that at bottom, the slab curls down so that its interior may not be in contact with the subgrade.

At night time the temperature at top is lower than that at bottom, the slab curls upward so that its edge and corner may be out of contact with sub-grade. The loss of subgrade contact will affect the stresses in concrete due to wheel loads.

The change between maximum and minimum temperatures also determines the joint and crack openings and affects the efficiency of load transfer.


Longer
a) Downward curling
Wheel Load
Location of Maximum tensile Stress
Concrete Slab
Foundation
Shorter
b) Upward curling
Wheel Load
Wheel Load
Location of maximum tensile stress
Concrete Slab

Environmental factor…

b). Precipitation

The precipitation from rain and snow affects the quantity of surface water infiltrating into the subgrade and the location of the ground water table.

If rain water can be drained out within a short time, its affect can be minimized, even in regions of high precipitation.

The location of the ground water table is also important.

The water table should be kept at least 3 ft. below the pavement surface.

3. Materials

In mechanistic-empirical methods of design, the properties of materials must be specified, so that the response of pavement, such as stresses, strain and displacements in the critical components can be determined.
The following general material properties should be specified for both flexible and rigid pavements:

- When pavements are considered as linear elastic, the elastic moduli and Poisson's ratios of the subgrade and each component layer must be specified.
- If the elastic modulus of material varies with the time of loading, the resilient modulus, which is the elastic modulus under repeated loads, must be selected in accordance with a load duration corresponding to the vehicle speed.
- When a material is considered nonlinear elastic, the constitutive equation relating the resilient modulus to the state of stress must be provided.

4. Failure Criteria

1. Fatigue Cracking

- Is due to the build up of tensile strain at the bottom of Asphaltic Concrete Layer
- Pavement is considered failed if 20% of the surface has cracked

2. Rutting Failure

- Is due to the build up of excessive compressive strain at the top of subgrade layer
- Pavement is considered failed if it exhibits a rut depth of 20 mm

Design Methods of Flexible Pavements

1. Mechanistic(Theoretical/Analytical) Design Approach

- Based on Boussinesq's Theory
- Based on Burmister's Theory

2. Mechanistic-Empirical Design Approach – Semi-empirical Design Approach

- Triaxial Method

3. Empirical Design Approach

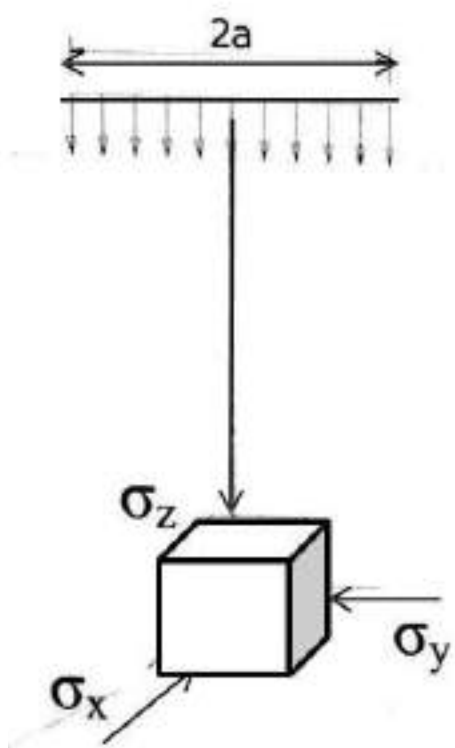
- Asphalt Institute Method
- Group Index Method
- CBR(California Bearing Ratio) Method
- IRC Method
- Road Note 29 Method
- Road Note 31/ Catalogue Method
- AASHTO Method

1. Mechanistic(Theoretical/Analytical) Design Approach

- Based on Boussinesq's Theory
- Using this layer theory as a structural model, one can find the solution for stresses, strains and deflections at any point in a layered system.
- It assumes the constant elastic parameters (E and μ) for all the pavement layers and the subgrade soil. i.e. it assumes that the soil mass is
  - Homogeneous
  - Isotropic
  - Ideally elastic and
  - Semi-infinite
- At any distance Z below the center of the loaded area of radius 2a the stress is given by.

$$\sigma_z = p\left[1 - \frac{z^3}{(a^2+z^2)^{\frac{3}{2}}}\right]$$

Where,
p = applied pressure per unit area
a = radius of circular loaded area
z = depth



Stresses below a circular loaded plate

- Based on Boussinesq's Theory
- The Vertical deflection is given by
- For flexible loaded area

$$\Delta = \frac{2pa}{E}(1 - \nu^2)$$

For Soil ν = 0.5 Therefore

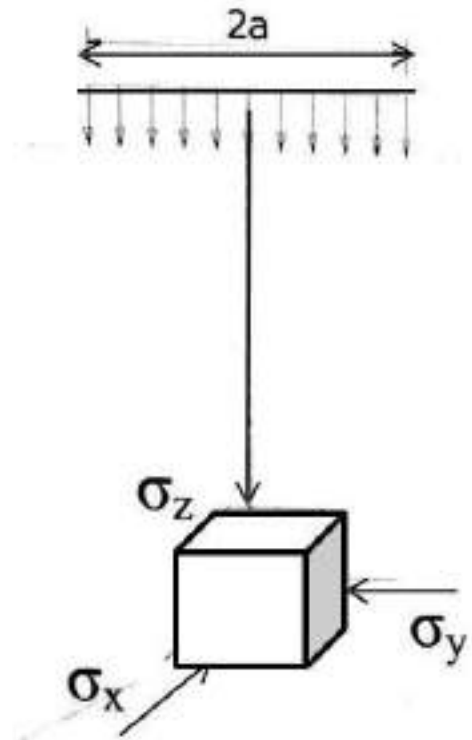
$$\Delta = \frac{1.5pa}{E}$$

- For rigidly loaded area

$$\Delta = \frac{\pi pa}{E}(1 - \nu^2)$$

For Soil ν = 0.5 Therefore

$$\Delta = \frac{1.18pa}{E}$$



Stresses below a circular loaded plate

Calculate the vertical deflection at the surface of a flexible pavement due to a wheel load of 30 kN and a tire pressure of 0.75 MN/m². Take $E_{pavement} = E_{subgrade} = 15$ MN/m².

Solution:

Here, Wheel Load (P) = 30 KN

Tire Pressure (p) = 0.75 MN/m^2

E = 15 MN/m^2

Tire pressure (p) = $\dfrac{Wheel\ Load}{Area} = \dfrac{P}{A} = \dfrac{P}{\pi a^2}$

1. Radius of contact area (a) = $\sqrt{\dfrac{P}{\pi\ x\ p}} = \sqrt{\dfrac{30\ x\ 1000}{\pi\ x\ 0.75\ x\ 10^6}}$

$= 0.1128$ m $= 11.28$ cm

2. Vertical Deflection at the surface of the flexible pavement,

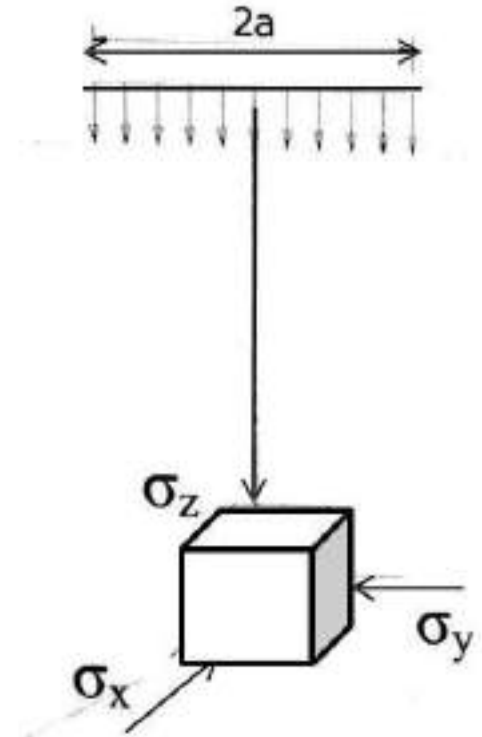
$$\Delta = \frac{1.5pa}{E} = \frac{1.5\ x\ 0.75x10^6\ x\ 0.1128}{15x10^6} = 0.846 \text{ cm} \approx \mathbf{0.85\ cm}$$

Application to pavement Design

For the following conditions determine the required thickness of pavement if the soil below It canot take a stress of beyond 3.5 Kg/cm^2

Gross load of tire = 20000 Kg

Pressure = 7 Kg/cm^2



Stresses below a circular loaded plate

Solution

$$Area = \frac{20000}{7} = 2857.14cm^2$$

$$\pi a^2 = 2857.14\ cm^2$$

$$a = 30.2\ cm$$

$$\sigma_z = p\left(1 - \frac{z^3}{(a^2 + z^2)^{3/2}}\right)$$

$$3.5 = 7\left(1 - \frac{z^3}{(0.302^2 + z^2)^{3/2}}\right)$$

Solving we get

Z = 38.5cm

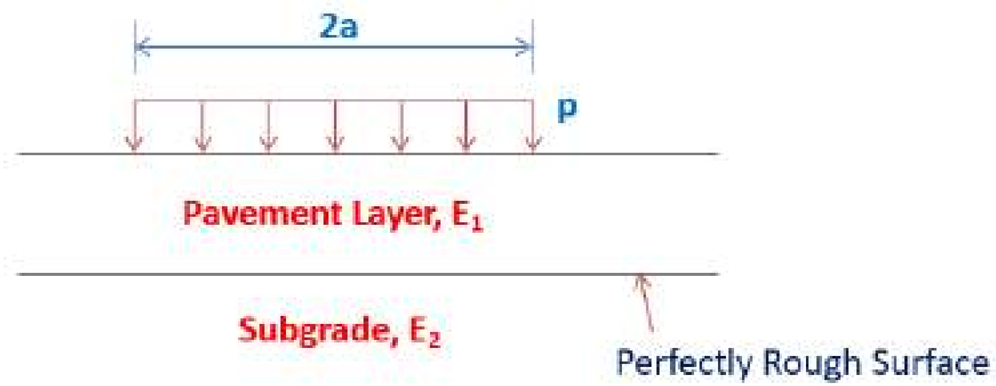
Drawbacks/Limitations in Boussinesq's Method

- Soils are not perfectly elastic and homogeneous. They may be elastic only upto a certain limit.
- Modulus of Elasticity, *E* of all pavement layers are not constant.
- Load is may not be uniformly distributed.

1. Mechanistic(Theoretical/Analytical) Design Approach

➢ Based on Burmister's Theory

- System consists of two layer: a pavement and a subgrade.
- Stress and deflection values depend upon E_1 and E_2 values.



Assumptions

The materials in the layers are assumed to be homogeneous, isotropic and elastic.

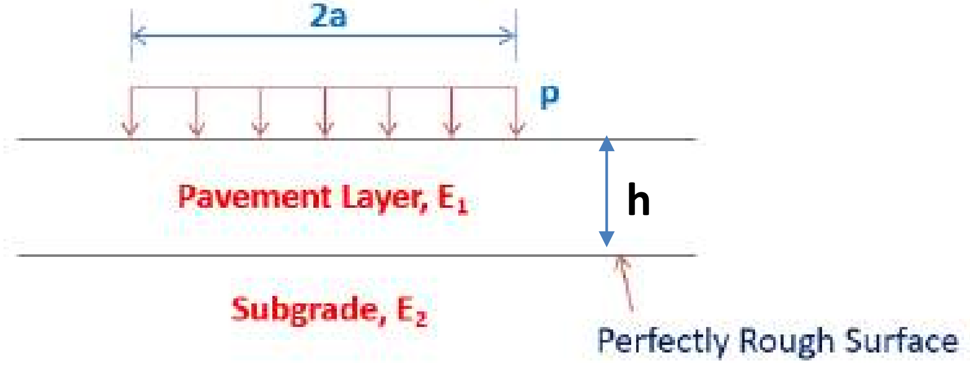
Surface layer is assumed to be infinite in extent in the lateral direction but of finite depth, whereas the underlying (lowest) layer is infinite in both the horizontal and vertical direction.

Layers are in continuous contact and full friction is developed between the interface.

Stress solutions are characterized by two material properties E and μ

Surface layer is free of shearing and normal stresses outside the loaded area.

1. Mechanistic(Theoretical/Analytical) Design Approach



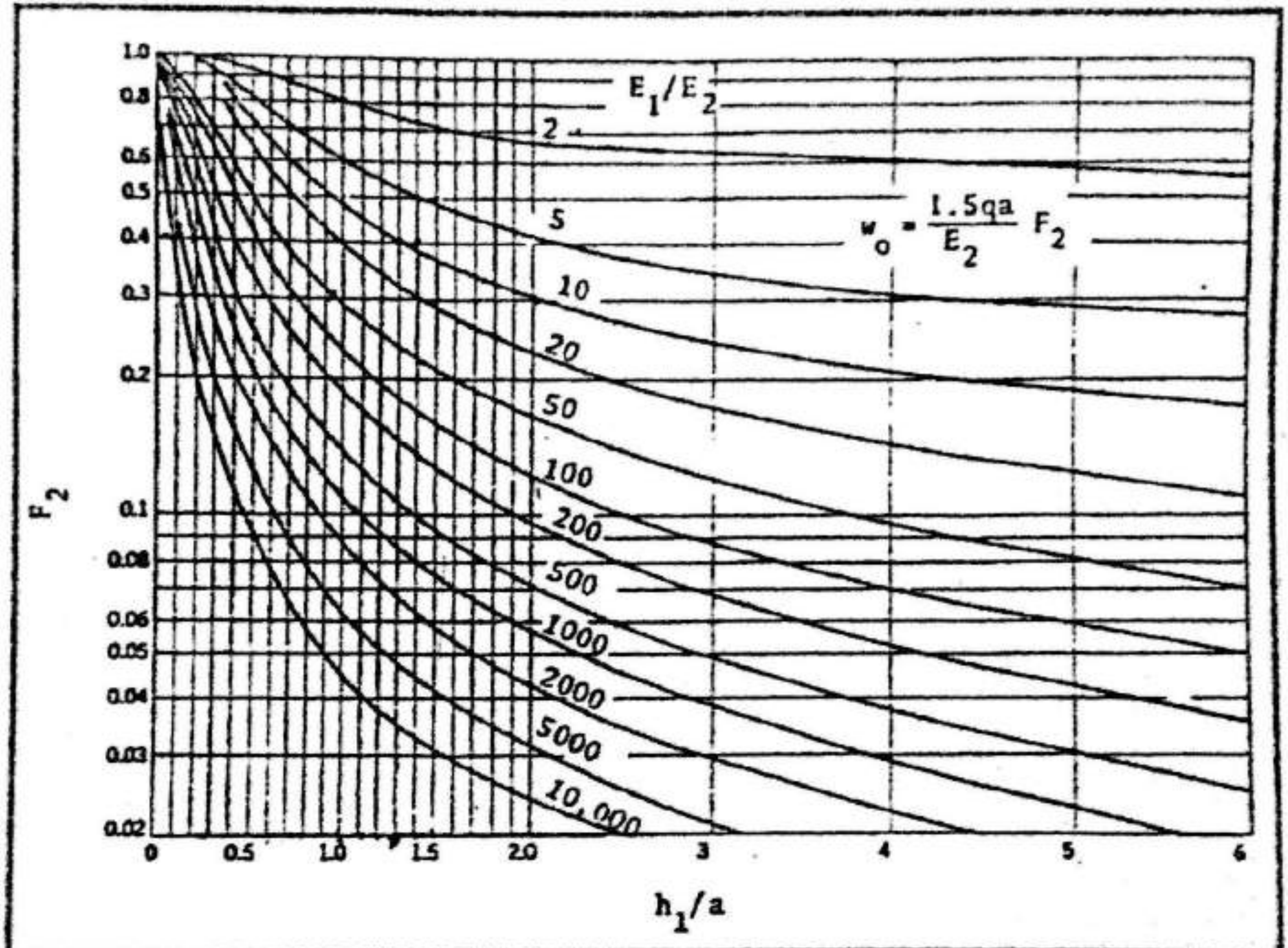
- For flexible loaded area

$$\Delta = \frac{1.5pa}{E} F_2$$

- For rigidly loaded area

$$\Delta = \frac{1.18pa}{E} F_2$$

The Displacement Factor $\boldsymbol{F_2}$ can be obtained from the graphs proposed by Burmister.



E_1/E_2
2
5
10
20
50
100
200
500
1000
2000
5000
10,000
$w_o = \frac{1.5qa}{E_2} F_2$
F_2
1.0
0.8
0.6
0.5
0.4
0.3
0.2
0.1
0.08
0.06
0.05
0.04
0.03
0.02
0
0.5
1.0
1.5
2.0
3
4
5
6
h_1/a

Design the thickness of a flexible pavement by Burmister's 2- layered analysis for a wheel load of 30 kN and a tire pressure of 0.75 MN/m². The modulus of elasticity of the pavement materials is 200 MN/m² and that of the subgrade soil is 40 MN/m². Take maximum allowable deflection = 1.5mm

$$Tire\ area(\pi a^2) = \frac{Tire\ load(P)}{Pressure(p)} = \frac{30}{0.75}$$

$$a = \sqrt{\frac{P}{\pi * p}} = 0.1128m$$

$$\Delta = \frac{1.5pa}{E} F_2$$

$$0.0015 = \frac{1.5 * 0.75 * 0.1128}{40} F_2$$

$$F_2 = 0.476$$

For F_2= 0.476 and E1/E2 = 5 from chart h/a = 2

i.e. h = 2a = 0.1128*2 = 0.2256 m = 23 cm

Adopt thickness of 25cm

2. Mechanistic-Empirical Design Approach – Semi-empirical Design Approach

- Triaxial Method

$$\Delta = \frac{3}{2}\frac{pa}{E}\frac{a}{(a^2+z^2)^{1/2}}$$

Using $p = \frac{P}{\pi a^2}$

$$\Delta = \frac{3}{2}\frac{P}{\pi E\,(a^2+z^2)^{1/2}}$$

$$Z = \sqrt{\frac{3P}{2\pi E_2 \Delta} - a^2}$$

In Triaxial method Kankas State Highway Department employs the equation along with the Empirical Modification for –

(a) Traffic coefficient (X) and

(b) Saturation coefficient (Y)

(c) Ratio of E2/E1

$$Z = \sqrt{\frac{3P\,XY}{2\pi E_2 \Delta} - a^2} \quad * \frac{E_2}{E_1}$$

Design the pavement section using the following data by Triaxial Method:

Wheel load = 4100 Kg

Radius of contact area = 15 cm

ADT of Design Traffic = 4001 – 6000

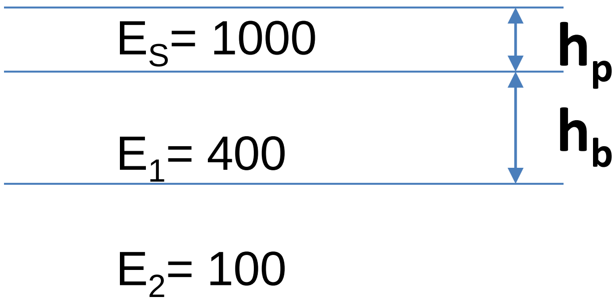
Average Annual Rainfall, cm = 91 –

100 Design deflection = 0.25 cm

E of subgrade soil = 100 Kg/cm²

E for base course material = 400 Kg/cm²

E for 7.5 cm thick bituminous concrete surface course = 1000 Kg/cm²



$$T_p = \sqrt{\frac{3P\ XY}{2\pi E_2 \Delta} - a^2 * \frac{E_2}{E_1}}$$

$$T_p = \sqrt{\frac{3\ * 4100 * 0.9\ * 1.5}{2\pi\ * 100\ * 0.25} - 15^2 * \frac{100}{400}} = 65.92cm$$

Relation between pavement layers thickness t_1 and t_2 and the elastic moduli E_1 and E_2 is given by

$$\frac{t_1}{t_S} = \left(\frac{E_s}{E_1}\right)^{1/3}$$

ts = actual thickness of surface

t1 = Equivalent thickness of surface of E = 1000 kg/cm^2 in terms of base of E = 400 kg/cm^2

$$\frac{t_1}{7.5} = \left(\frac{1000}{400}\right)^{1/3}$$

$$t_1 = 10.18\ cm$$

- Remaining thickness of base = 65.92-10.18 cm = 55.74 cm
- Provide surface of 7.5cm thickness over a base course of 60cm thickness

3. Empirical Design Approach
Asphalt Institute Method

Design steps

1. Cumulative ESALs is calculated

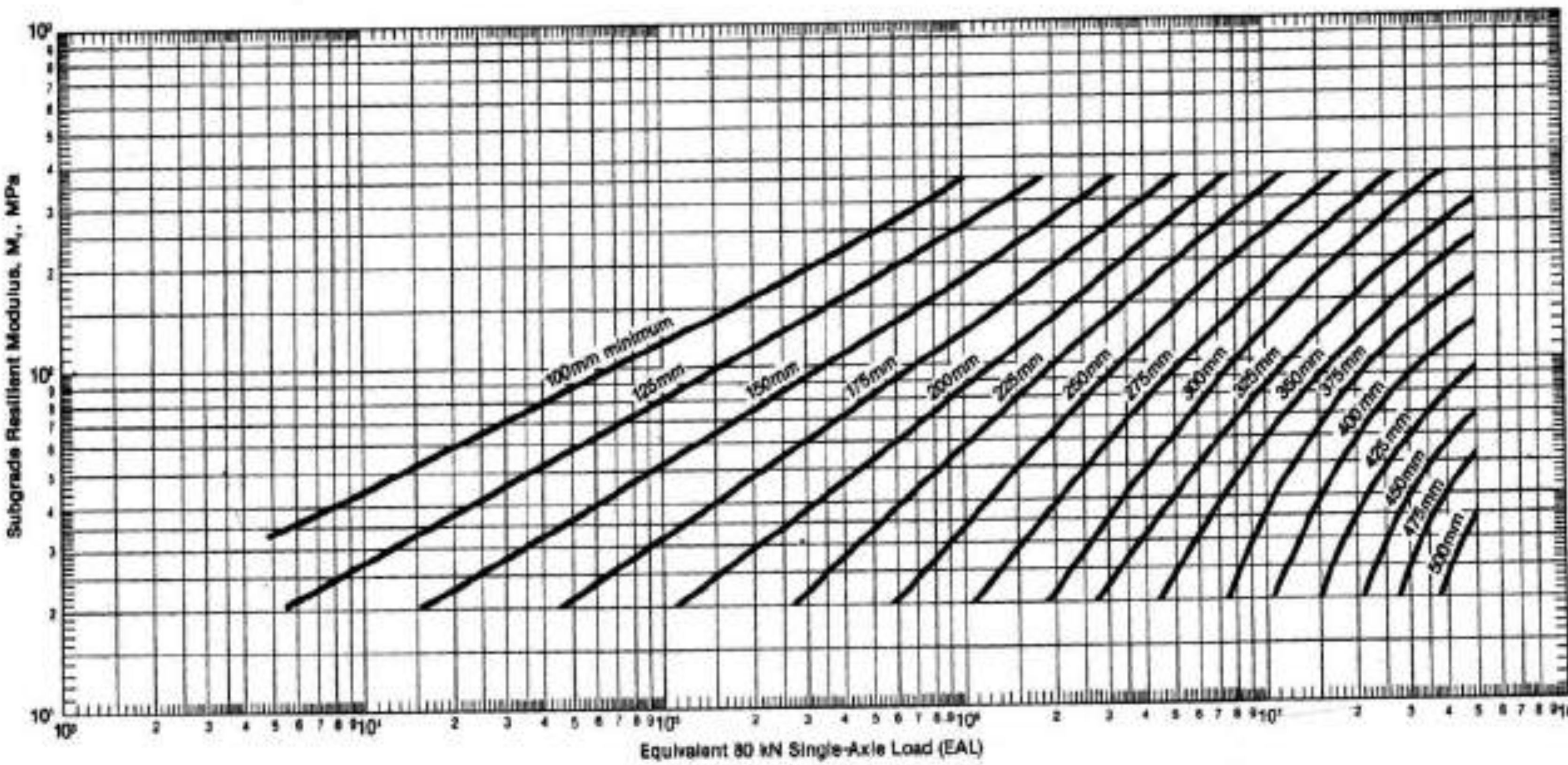
$N = \Sigma$ No of vehicle x Truck factor

1. Design CBR is converted to sub-grade resilient modulus
   M_R (MPa) =10.3 x CBR
   M_R (Psi) = 1500 x CBR
3. From chart “full depth asphalt concrete” defines the total thickness of A/C corresponding to the ESAL and M_R.
4. Obtained full thickness of A/C is converted into the different layers (subbase and base) of other materials with given modulus of elasticity, using the ratio;

$$\frac{t_1}{t_2} = \left(\frac{E_2}{E_1}\right)^{1/3}$$

t_1, t_2 = Thickness of layer 1 and 2 respectively
E_1, E_2 =Modulus of elasticity of layer 1 and 2 respectively

Full-Depth Asphalt Concrete



3. Empirical Design Approach

Group Index Method

- **Group Index (GI)** is a parameter used in the classification of soils by AASTHO system. It An arbitrary number which characterizes the nature of soil.
- GI = f(*material passing 75-micron IS or No. 200 ASTM sieve in %. F, LL and* I_p) *i.e.* ***GI = ƒ (F, LL , I_p)***
  - *The higher the value of the group index, the lower the quality of the soil to carry traffic.*
  - *The higher the group index requires the thicker pavement to carry the design traffic.*

Group Index (GI) = $0.2a + 0.005ac + 0.01bd$

Where,

a = that portion of percentage of subgrade soil passing 75 micron IS or No. 200 ASTM sieve greater than 35 and not exceeding 75, expressed as a positive whole number (0 to 40)

b = that portion of percentage of subgrade soil passing 75 micron IS or No. 200 ASTM sieve greater than 15 and not exceeding 55, expressed as a positive whole number (0 to 40)

c = that portion of the numerical liquid limit greater than 40 and not exceeding 60, expressed as a positive whole number (0 to 20)

d = that portion of the numerical plasticity index greater than 10 and not

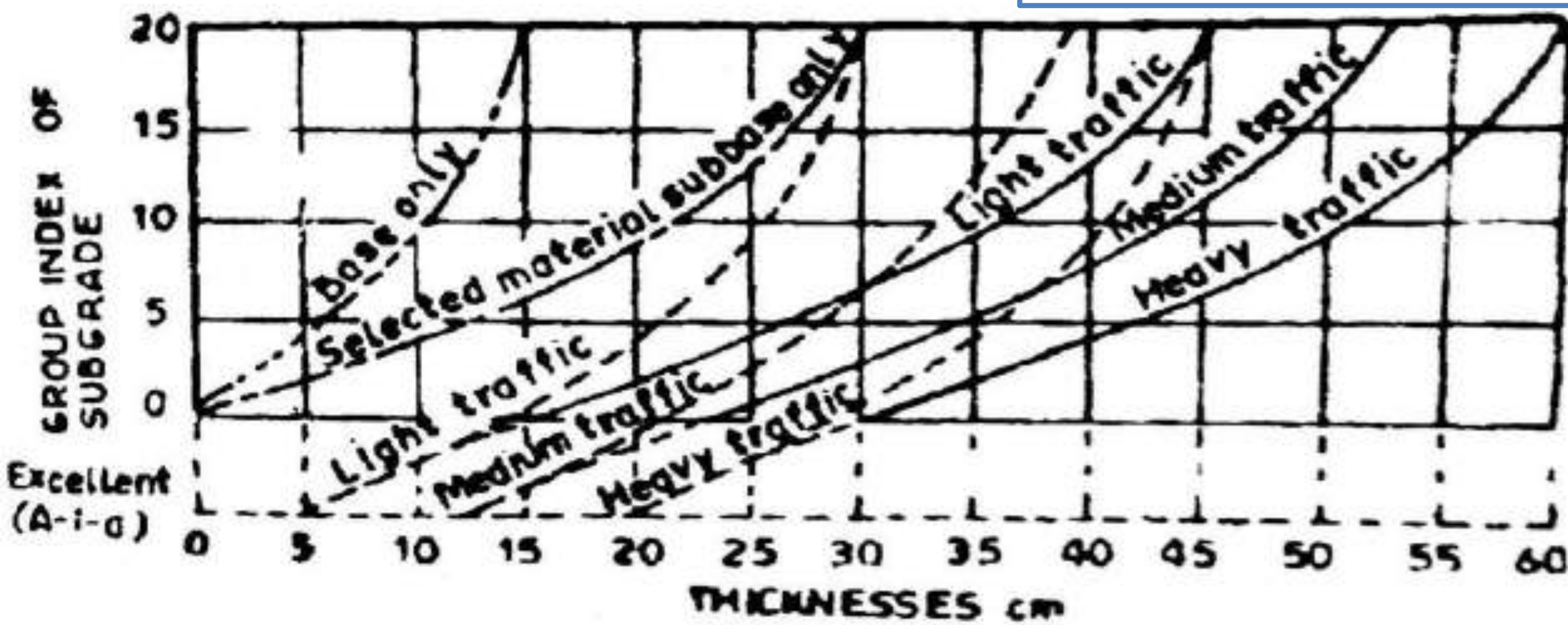
exceeding 30, expressed as a positive whole number (0 to 20)

Step 1: Determine the group index.

Step 2: Determine the anticipated traffic volumes. $A = P(1+r)^{n+y}$

Step 3: Use the appropriate design according to the traffic volumes.

- Light volume traffic vehicles/day : Less than 50
- Medium volume traffic vehicles/day : 50 to 300
- Heavy volume traffic vehicles/day : over 300



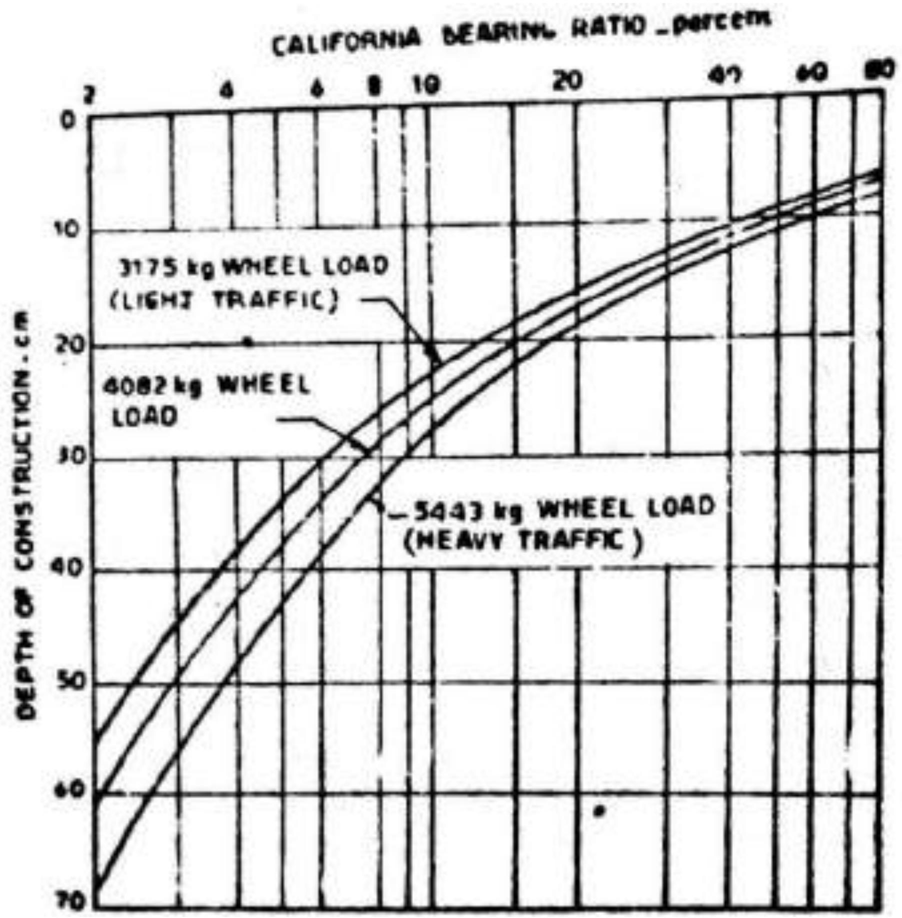
— Combined thickness of surface, base and sub-base

- - - Thickness of surface and base.

3. Empirical Design Approach

CBR(California Bearing Ratio) Method

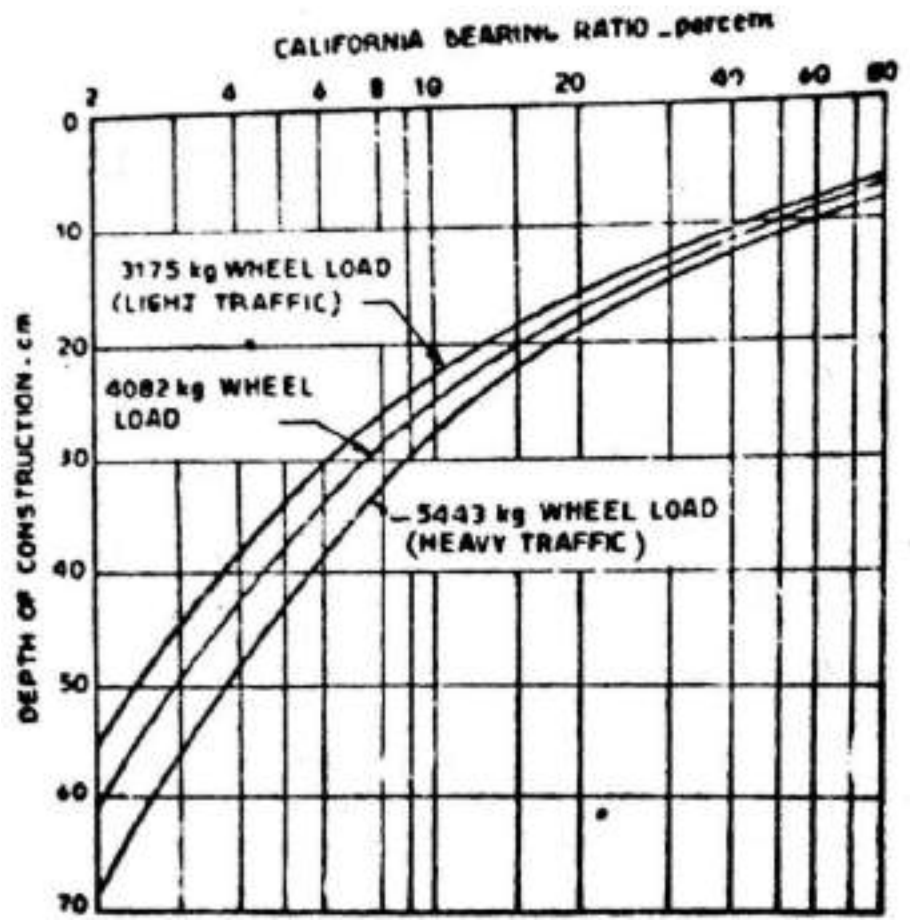
- Original Design Chart of California State Highway Department
- CBR Tests were Carried Out by the California State Highway Department on Existing layers Including Sub-grade, Sub-base and Base Course.
- From the Data Collected on the Existing Pavements which Behaved satisfactorily and as well as which Failed, Empirical Design Curves were Developed Correlating CBR Values and Pavement Thickness.
- For a Given CBR and Wheel Load, the ***Total Thickness of Pavement Required on Top of that Material*** can be Directly Obtained from These Curves.



Step 1: Determine the Traffic type.

Step 2: Determine CBR of Subgrade , Subbase and Base courses.

Step 3: Use the appropriate design according to the traffic volumes.



IRC Methods

1) IRC Recommended CBR Methods (IRC : 37-1970)
2) IRC : 37-1984 (First Revision)
3) IRC : 37-2001 (Second Revision)
4) **IRC : 37-2012 (Third Revision)**

IRC : 37-1970

Estimated Traffic

$$A = P(1 + r)^{n+y}$$

Where

A = Flow of vehicles having load greater than 3KN in loaded axle at the end of the anticipated life

P = Present flow of vehicle

r = Growth rate of traffic

n = Design life (About 10 years)

y = Anticipated period between the count and the completion of survey

Step 1: Determine the estimated traffic.

Step 2: Determine CBR of Subgrade , Subbase and Base courses.

Step 3: Use the appropriate design according to the traffic volumes.

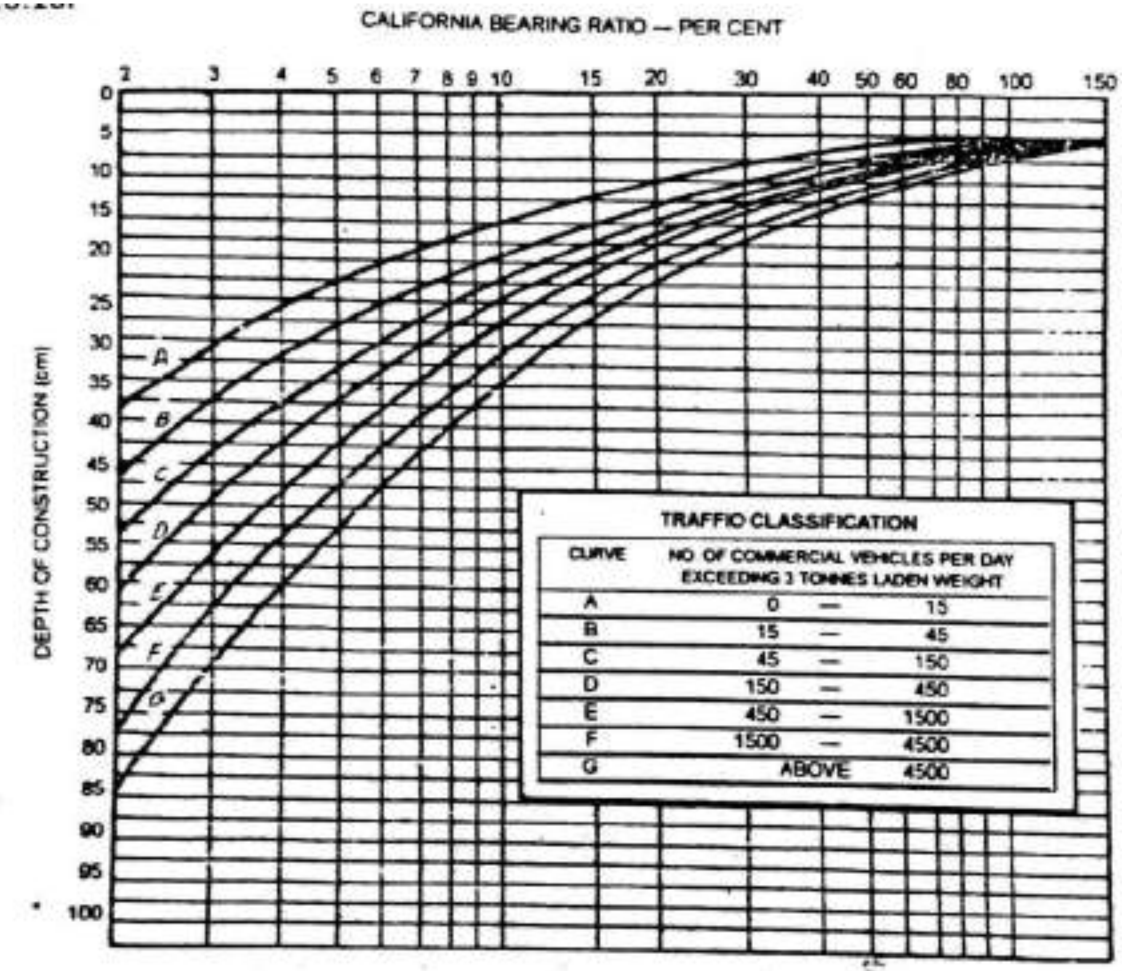


Fig. 16.12. CBR design curves as per IRC-37 (1970).

IRC: 37-1984 Guidelines

- To handle large spectrum of axle load, these guidelines were revised in 1984 following **the Equivalent Axle Load Concept**.
- In this approach, the pavement thickness was related to the **cumulativelb)** to be carried out for different subgrade strengths during the design life of the **number of standard axles (8160 kg or 8.16 ton or 18,000** road.
- The subgrade strength is assessed in terms of the CBR value of the subgrade soil.
- These guidelines were based on **semi-empirical approach** based on a large extent on past experience and judgment of highway agencies.
- Design curves were developed to cater upto **30 million standard axles (msa**), later extrapolated to 200 msa.

Anticipated ESAL Repetition

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

Where,

N_s = Cumulative Number of Standard Axles to be Catered in the Design (msa)

A = Initial Traffic, in the year of completion of construction, in terms of the no. of cvpd properly modified to account for lane distribution = $P(1 + r)^y \times D$

P = Number of commercial vehicles per day at last count

r = Annual growth rate of commercial traffic

n = Design Life in years

y = Number of years between the last count and the year of completion of construction

D = Lane distribution factor

F = Vehicle Damage Factor (VDF); No. of Standard Axles per Commercial Vehicles

D (**Distribution of Commercial Traffic over the Carriageway**)

Single Lane Roads (3.75 m) → LDF, D = 2 of CV in Both Directions

Intermediate Width Roads (5.5 m) → LDF, D = 1.5 of CV in Both Directions

2- Lane Single Carriageway Roads → LDF, D = 0.75 (= 75%) of CV in Both Directions

4- Lane Single Carriageway Roads → LDF, D = 0.4 (= 40%) of CV in Both Directions

Dual or Divided Carriageway Roads

Dual 2 – Lane Carriageways → D = 0.75 (= 75%) of CV in Each Direction

Dual 3 – Lane Carriageways → D = 0.60 (=60%) of CV in Each Direction

Dual 4 – Lane Carriageways → D = 0.40 (=40%) of CV in Each Direction

Vehicle Damage Factor (VDF), *F*

- VDF is a multiplier for **converting the number of commercial vehicles of different axle loads and axle configurations to the number of standard axle-load repetitions.**
- It is defined as equivalent number of standard axles per commercial vehicle.
- The VDF varies with traffic mix, type of transportation, type of commodities carried, time of year, terrain, road condition, and degree of enforcement.
- The AASHTO axle-load equivalence factors may be used to convert the axle load spectrum to an equivalent number of standard axles.

Single Axle Load:

$$\text{Equivalency Factor, } E = \left(\frac{W}{W_s}\right)^4 = \left(\frac{L}{L_s}\right)^4 = \left(\frac{\text{Axle Load in kg}}{8160}\right)^4$$

Tandem Axle Load:

$$\text{Equivalency Factor, } E = \left(\frac{\text{Axle Load in kg}}{14968}\right)^4$$

The Exact VDF Values are got after Extensive Field Surveys.

Table: Indicative VDF Values

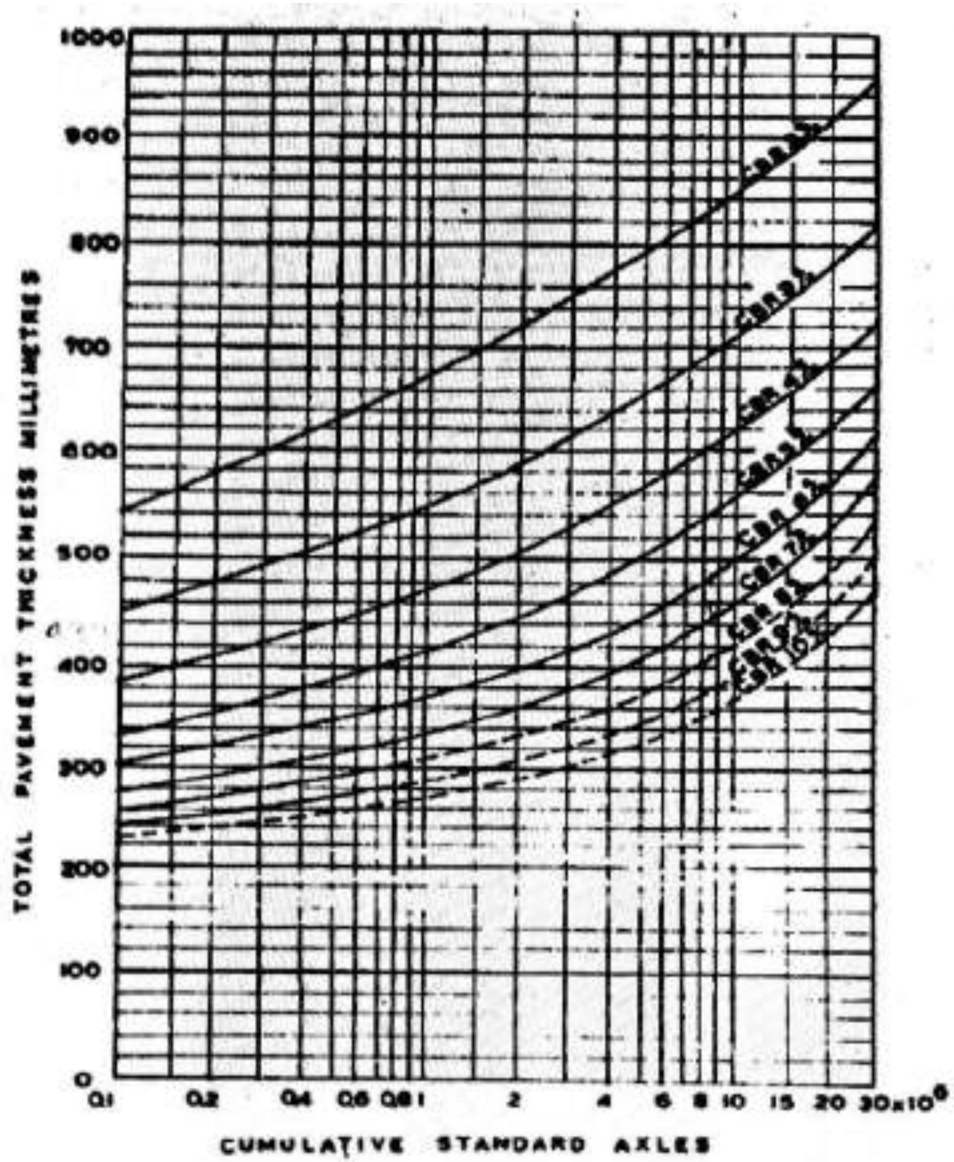
Initial Traffic Intensity in terms of no. of cvpd	Terrain	VDF Values (Standard Axle 8.16 tones per Commercial Vehicles)		
		Unsurfaced	Thin Bituminous Surfacing	Thick Bituminous Surfacing
< 150	Hilly	**0.5**	0.75	
	Rolling	1.5	1.75	
	Plain	2.0	2.25	
150 - 1500	Hilly		1.0	1.25
	Rolling		2.0	2.25
	Plain		2.5	2.75
> 1500	Hilly		1.25	1.5
	Rolling		2.25	2.5
	Plain		2.75	**3.0**

Step 1: Determine the estimated traffic.

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

Step 2: Determine CBR of Subgrade , Subbase and Base courses.

Step 3: Use the appropriate design according to the traffic volumes.



IRC: 37-2001 Guidelines

- These guidelines follow **analytical designs** and developed new set of designs up to **150 msa**.
- These guidelines will apply to design of flexible pavements for Expressway, National Highways, State Highways, Major District Roads, and other categories of roads.
- Flexible pavements are considered to include the pavements which have bituminous surfacing and granular base and sub-base.

Design Traffic

- The design traffic is considered in terms of the cumulative number of standard axles in the lane carrying maximum traffic during the design life of the road.
- This can be computed using the following equation:

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

N = Cumulative number of standard axles to be catered for the design in terms of million standards axle (msa)

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

D = Lane distribution factors **F** = Vehicle damage factor **n** = Design life in years, and

r = Annual growth rate of commercial vehicles (r=0.075 if growth rate is 7.5 percent per annum).

The traffic in the year of completion is estimated using the following formula:

$$A = P(1+r)^x$$

Where,

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

x = Number of years between the last count and the year of completion between the last count and the year of completion of the project

D(Distribution of Commercial Traffic over the Carriageway)

Single Lane Roads (3.75 m) → **LDF, D = 1 of CV in Both Directions**

Intermediate Width Roads (5.5 m) → **LDF, D = 1.5 of CV in Both Directions**

2- Lane Single Carriageway Roads → **LDF, D = 0.75 (= 75%) of CV in Both Directions**

4- Lane Single Carriageway Roads → **LDF, D = 0.4 (= 40%) of CV in Both Directions**

Dual Carriageway Roads

a) **Dual 2 – Lane Carriageways** → **D = 0.75 (= 75%) of CV in Each Direction**

b) **Dual 3 – Lane Carriageways** → **D = 0.60 (= 60%) of CV in Each Direction**

c) **Dual 4 – Lane Carriageways** → **D = 0.45 (= 45%) of CV in Each Direction**

Vehicle Damage Factor (VDF), *F*

- VDF is a multiplier for **converting the number of commercial vehicles of different axle loads and axle configurations to the number of standard axle-load repetitions.**
- It is defined as equivalent number of standard axles per commercial vehicle.
- The VDF varies with traffic mix, type of transportation, type of commodities carried, time of year, terrain, road condition, and degree of enforcement.
- The AASHTO axle-load equivalence factors may be used to convert the axle load spectrum to an equivalent number of standard axles.

Single Axle Load:

$$\text{Equivalency Factor, } E = \left(\frac{W}{W_s}\right)^4 = \left(\frac{L}{L_s}\right)^4 = \left(\frac{\text{Axle Load in kg}}{8160}\right)^4$$

Tandem Axle Load:

$$\text{Equivalency Factor, } E = \left(\frac{\text{Axle Load in kg}}{14968}\right)^4$$

Vehicle Damage Factor (VDF), *F*

- Determining the exact VDF value requires extensiveaxle load survey and research work in case of absence of the VDF values a indiacative VDF values can be Taken as follows

TABLE 1. INDICATIVE VDF VALUES

Initial traffic volume in terms of number of commercial vehicles per day	Terrain	
	Rolling/Plain	Hilly
0-150	1.5	0.5
150-1500	3.5	1.5
More than 1500	4.5	2.5

Step 1: Determine the estimated traffic.

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

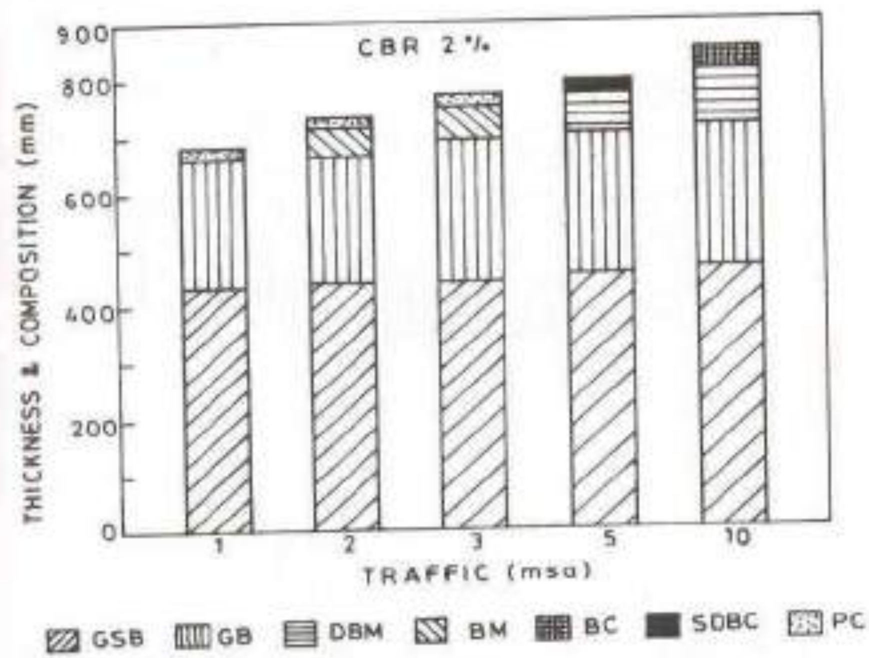
Step 2: Determine CBR of Subgrade , Subbase and Base courses.

Step 3: Use the appropriate design according to the traffic volumes.

PAVEMENT DESIGN CATALOGUE

PLATE 1 – RECOMMENDED DESIGNS FOR TRAFFIC RANGE 1-10 msa

CBR 2%					
Cumulative Traffic (msa)	Total Pavement Thickness (mm)	PAVEMENT COMPOSITION			
		Bituminous Surfacing		Granular Base (mm)	Granular Sub-base (mm)
		Wearing Course (mm)	Binder Course (mm)		
1	660	20 PC		225	435
2	715	20 PC	50 BM	225	440
3	750	20 PC	60 BM	250	440
5	795	25 SDBC	70 DBM	250	450
10	850	40 BC	100 DBM	250	460



GoN, DOR's Flexible Pavement Design Guidelines, 2014

- Made in accordance to Nepali Materials
- Based on CBR principle

Estimated ESAL repetition

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

Vehicle Type	VDF	Remarks
Heavy Truck (3-axle or more)	6.50	
Heavy Truck (2-axle)	4.75	Hilly Terrain 3.5
Mini Truck/Tractor	1.00	
Large Bus	0.50	
Bus	0.35	

GoN, DOR's Flexible Pavement Design Guidelines, 2014

STEPS

Step 1: Determine the estimated traffic.

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

Step 2: Determine CBR of Subgrade , Subbase and Base courses.

Step 3: Use the appropriate design according to the traffic volumes.

Pavement Design Catalogue

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

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

Road Note 31/ Catalogue Method

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

Traffic classes

Traffic classes	Range (10^6 esa)
T1	< 0.3
T2	0.3 - 0.7
T3	0.7 - 1.5
T4	1.5 - 3.0
T5	3.0 - 6.0
T6	6.0 - 10
T7	10 - 17
T8	17 - 30

Subgrade strength classes

Class	Range (CBR %)
S1	2
S2	3 - 4
S3	5 - 7
S4	8 - 14
S5	15 - 29
S6	30

Road Note 31/ Catalogue Method

STEPS

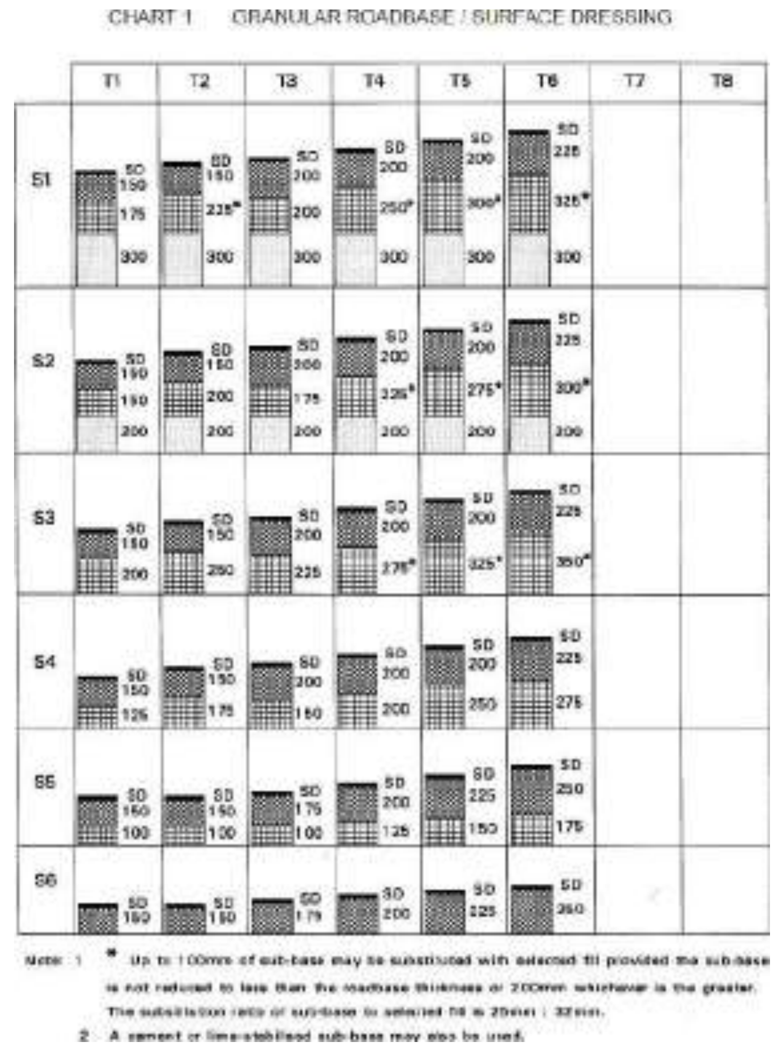
Step 1: Determine the estimated traffic.

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

And finalize traffic type

Step 2: Determine CBR of Subgrade and finalize soil type

Step 3: Use the appropriate design according to the traffic volumes.



Road Note 29

STEPS

Step ***1:*** Determine the estimated traffic.

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

Step ***2:*** Determine CBR of Subgrade and Sub base thickness

Step ***3:*** Use the appropriate design chart to finalize the thickness of surface and bas

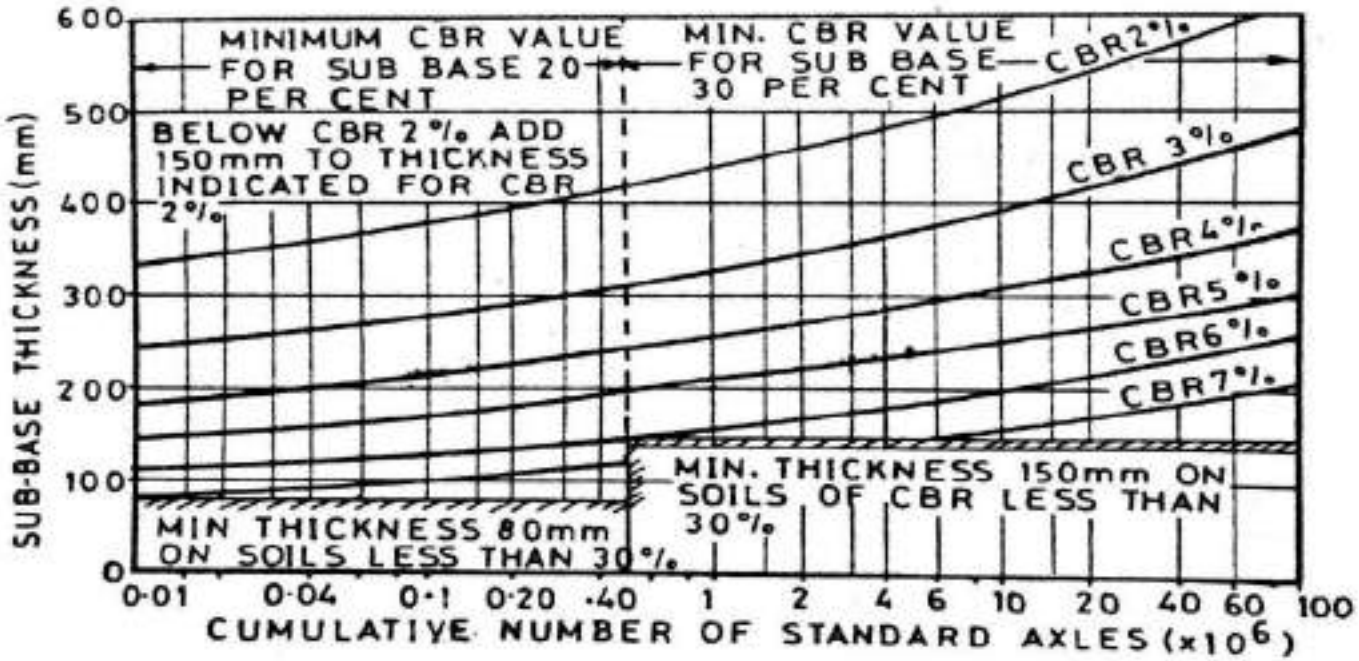


Fig. 16.8. Sub-base thickness as per Road Note 29.

(*ii*) Rolled asphalt and dense macadam road-base and surfacing (Fig. 16.9).

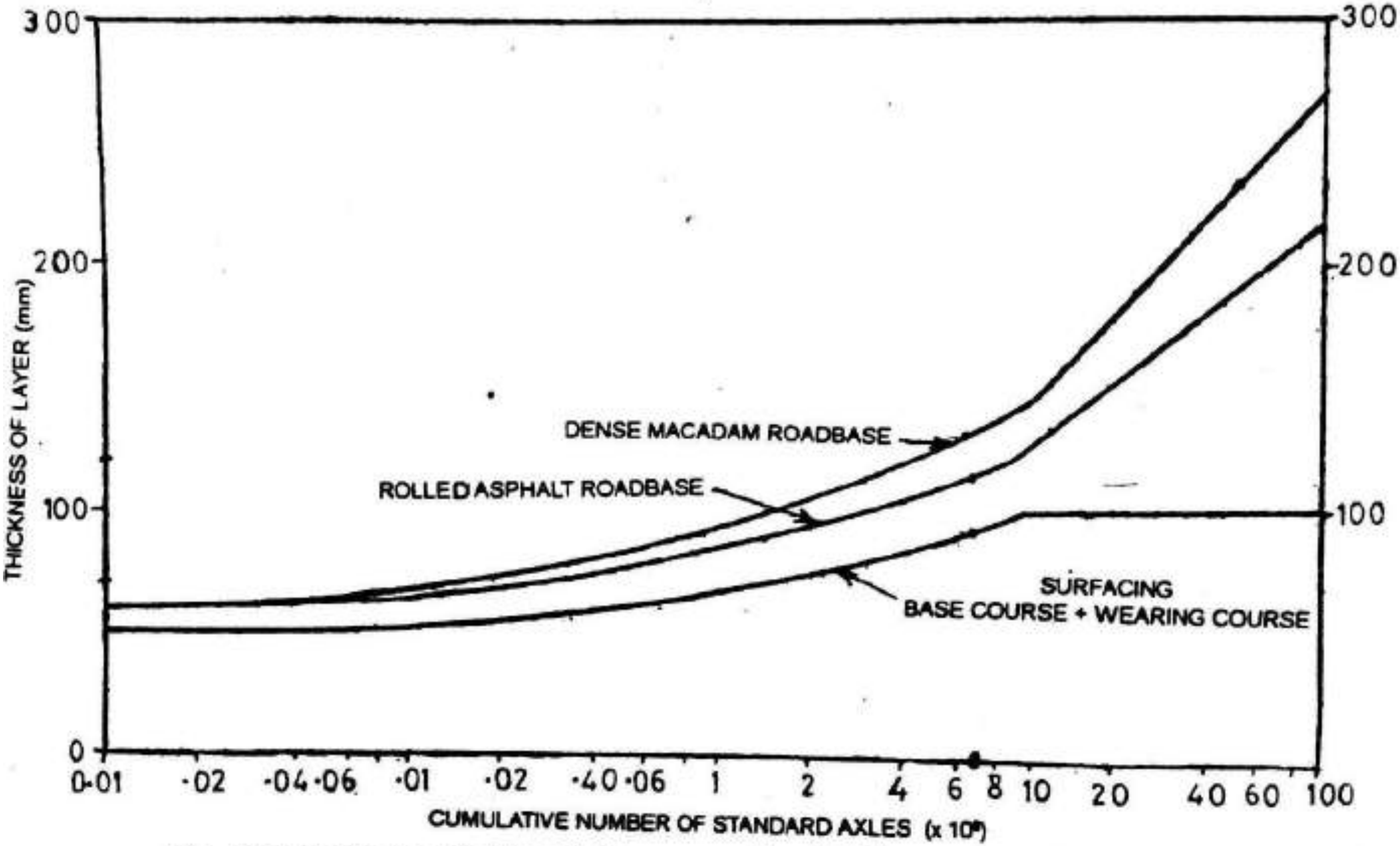


Fig. 16.9. Rolled asphalt and dense macadam thickness as per Road Note 29.

AASHTO Method

Terminology

- ***Equivalent Single Axel Load (ESAL)*** – The conversion of mixed vehicular traffic into its equivalent single-axle, 18- Kip Load. The equivalence is based on the relative amount of pavement damage.
- ***Daily ESAL (T_{18})*** – The average number of equivalent 18- Kip loads which will be applied to the pavement structure in one day.
- Normally, a 20-year design period is used to determine the daily load.

- ***Pavement Serviceability Index (PSI).*** A measure of a pavement's ability to serve traffic on a scale of 0 to 5. It reflects the extent of pavement condition.

AASHTO Method

Terminology

- **Initial Serviceability (p_i).** The Initial Serviceability (PI) is the condition of a newly constructed roadway. A value of 4.2 is assumed
- ***Terminal Serviceability Index (p_t).*** A pavement design factor which indicates the acceptable pavement serviceability index at the end of the selected design period (usually 20 years).
- ***Change In Serviceability (ΔPSI)*** The Change In Serviceability (ΔPSI) is the difference between the Initial Serviceability (pi) and Terminal Serviceability (pt). The Department uses a value of 1.7.

$$(\Delta PSI) = (p_i) - (p_t)$$

- **Standard Normal Deviate (Z_R).** The Standard Normal Deviate (Z_R) is the corresponding Reliability (%R) value that has been converted into logarithmic form for calculations purposes.
- **Standard Deviation (S_O).** The Standard Deviation (S_O) of 0.45 is used in the design calculations to account for variability in traffic load predictions and construction.
- **Design Periods.** The design periods that will be used for flexible pavement design vary from 8 years to 20 years based on the type of construction proposed.

AASHTO Method

Terminology

- ***Structural Number (SN).*** A measure of the structural strength of the pavement section based on the type and thickness of each layer within the pavement structure.
- ***Layer Coefficient.*** The relative structural value of each pavement layer per inch of thickness. It is multiplied by the layer thickness to provide the contributing SN for each pavement layer.
- **Reliability.** Traffic disruption and congestion associated with construction operations result in significant user costs. Increased design reliability helps reduce these user costs. Thus, reliability levels approaching 99.9 percent are used to design structural resurfacings on the Interstate Highway System. Reliability levels approaching 99.5 percent should be used to design structural resurfacings on other limited access highway.
- **Resilient Modulus (M_R).** The Resilient Modulus (MR) is a measurement of the stiffness of the roadbed soil.

Design Steps

Step 1 : Determine Reliability

TABLE 8.5 Suggested Levels of Reliability for Various Functional Classifications (AASHTO, 1993)

Functional Classification	Recommended Level of Reliability	
	Urban	Rural
Interstate and other freeways	85–99.9	80–99.9
Principal arterials	80–99	75–95
Collectors	80–95	75–95
Local	50–80	50–80

Step 1 : Determine Standard Deviation

- The overall standard deviation (S_o) takes into consideration the **variability of all input data**.
- The 1993 design guide recommends an approximate range of 0.4 to 0.5 for flexile pavements. i.e. **S_o = 0.4 to 0.5 ; S_o = 0.45 (Usually Taken)**

Step 3 — Cumulative Equivalent Single Axle Load

TABLE 8.6 Lane Distribution Factor (AASHTO, 1993)

No. of Lanes in Each Direction	% of 18-kip ESAL in the Design Lane
1	100
2	80–100
3	60–80
4	50–70

Design Steps

Step 4 — Effective Roadbed Soil Resilient Modulus

$$M_R\,(\text{psi}) = 1500 * \text{CBR}\,(\%)$$

$$M_R\,(\text{MPa}) = 10.3 * \text{CBR}\,(\%)$$

Step 6 — Serviceability Loss

Step 7 — Structural Numbers (SN)

$$SN_1 \le a_1 D_1$$

$$SN_2 \le a_1 D_1 + a_2 D_2 m_2$$

$$SN_3 \le a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3$$

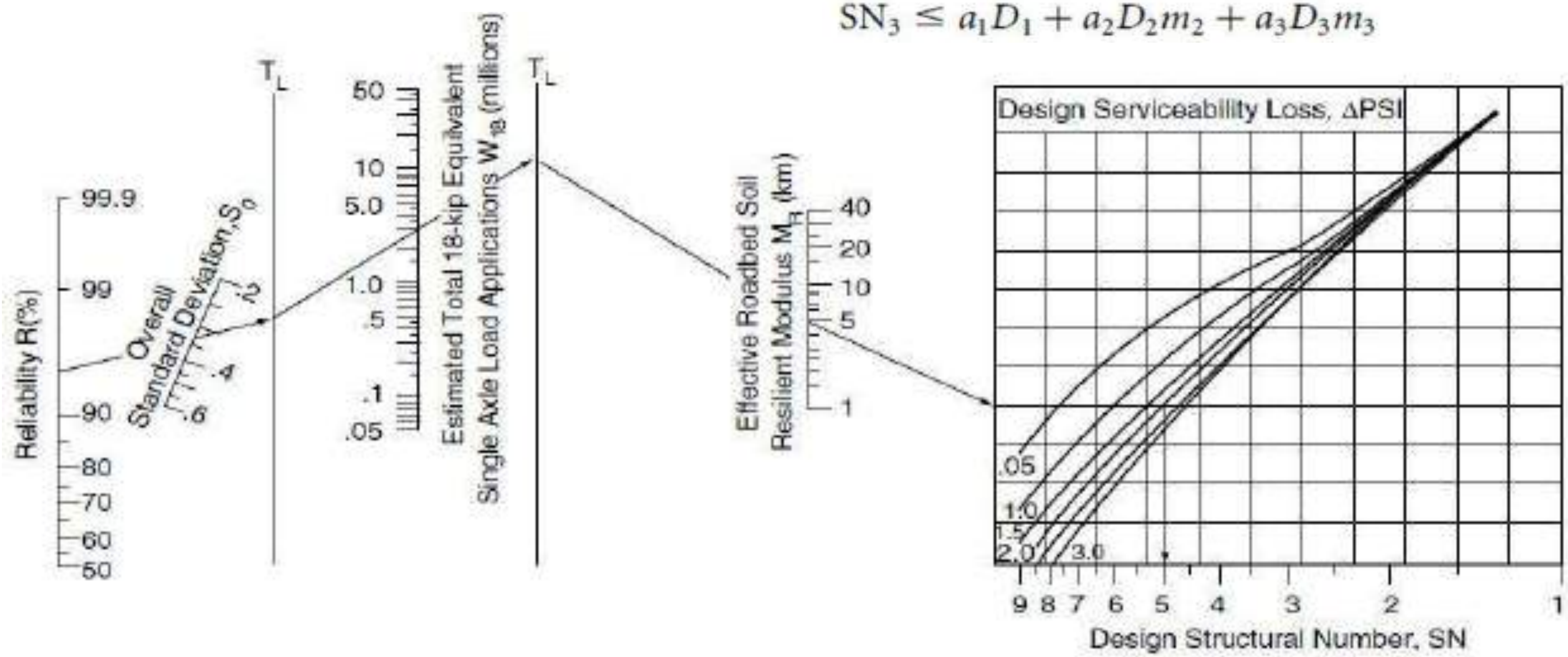
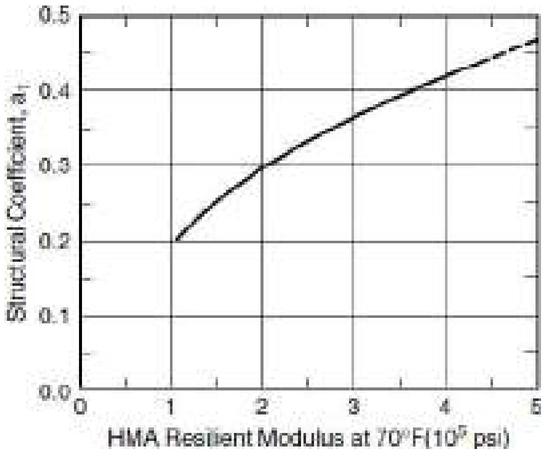


FIGURE 8.22 Design chart for flexible pavements based on using mean values for each input (AASHTO, 1993).

Step 8 — Structural Layer Coefficients



CBR (%)	a_2
100	0.14
55	0.12
45	0.11
30	0.09
20	0.07

CBR (%)	a_3
100	0.14
40	0.12
30	0.11
25	0.10
15	0.09
10	0.08

$$\alpha_2 = 0.249 \log_{10}(M_r\,\text{base}) - 0.977$$
$$\alpha_3 = 0.227 \log_{10}(M_r\,\text{base}) - 0.839$$

Step 9 — Drainage Coefficients

TABLE 8.4 Recommended Drainage Coefficients for Untreated Bases and Subbases in Flexible Pavements (AASHTO, 1993)

Quality of Drainage		% of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation			
Rating	Water Removed Within	<1%	1–5%	5–25%	>25%
Excellent	2 h	1.40–1.35	1.35–1.30	1.30–1.20	1.20
Good	1 day	1.35–1.25	1.25–1.15	1.15–1.00	1.00
Fair	1 week	1.25–1.15	1.15–1.05	1.00–0.80	0.80
Poor	1 month	1.15–1.05	1.05–0.80	0.80–0.60	0.60
Very Poor	Never drain	1.05–0.95	0.95–0.75	0.75–0.40	0.40

Step 10 — Layer Thickness

$$\mathrm{SN}_1 \leq a_1 D_1$$

$$\mathrm{SN}_2 \leq a_1 D_1 + a_2 D_2 m_2$$

$$\mathrm{SN}_3 \leq a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3$$

Design Methods of Flexible Pavements (JPCP)

Stresses in rigid pavement

Stresses in rigid pavements result from a variety of causes including:

- wheel loads,
- cyclic changes in temperature (warping and shrinkage or expansion)
- changes in moisture and
- volumetric changes in the sub-grade or base course

These changes tend to deform the slab, causing stresses of widely varying intensity. In addition, the magnitude of stresses depend upon continuity of sub-grade support. Complete continuity can be destroyed by pumping of the sub-grade.

Stresses in rigid pavement

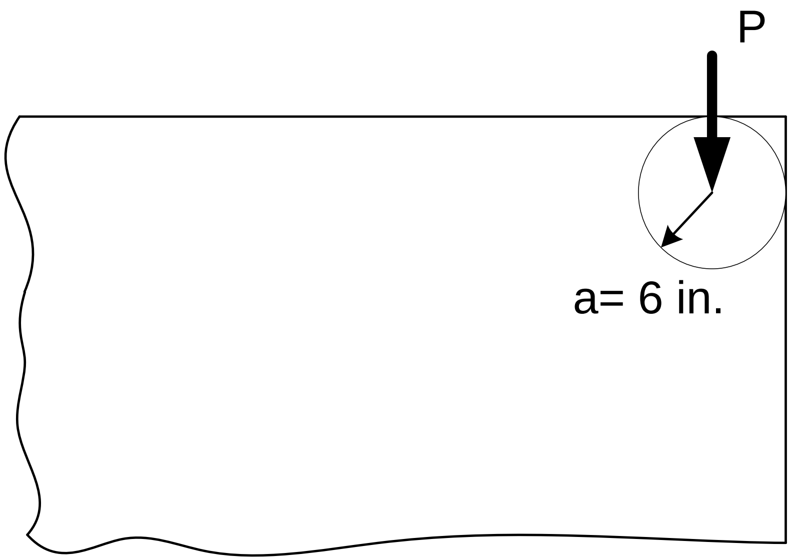
Stresses and deflections due to loading

Three methods can be used to determine the stress and deflection in concrete pavements: westerguards formulas, Influence charts and finite element computer programs.

The formula originally developed by Westergaard can be applied only to a single wheel load with a circular, semicircular, elliptical or semielliptical contact area.

a). Corner Loading

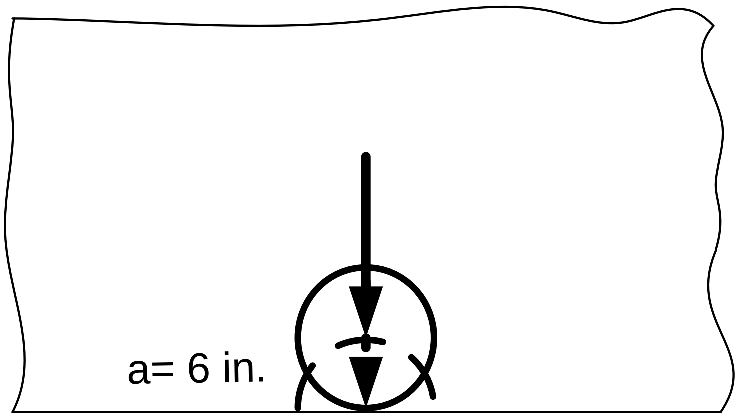
$$\sigma_c = \frac{3p}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$$



Stresses in rigid pavement

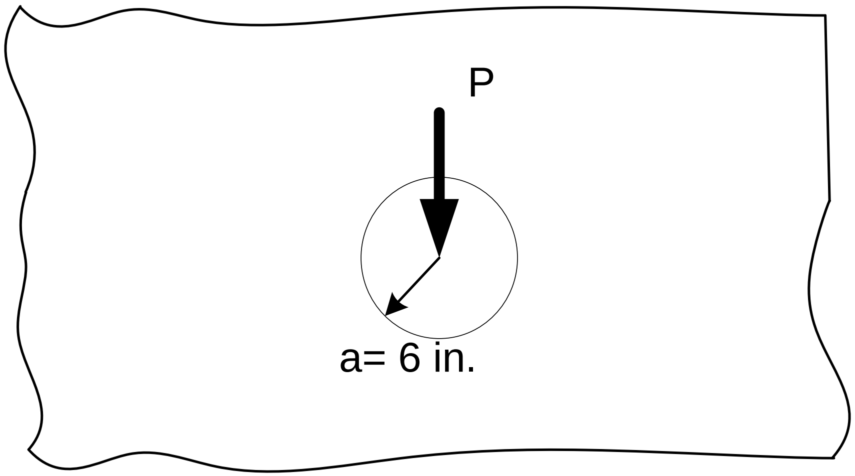
b) Edge Loading

$$\sigma_e = \frac{0.572P}{h^2}\left(4\,log_e\left(\frac{l}{b}\right) + 0.359\right)$$



c) Interior Loading

$$\sigma_i = \frac{0.316P}{h^2}\left(4\,log_e\left(\frac{l}{b}\right) + 1.069\right)$$



h = slab thickness
P = Wheel load in Kg
a = Radius of wheel load distribution (cm)
l = radius of relative stiffness
b = radius of resisting section

$$b = a \quad \text{when } a \geq 1.724h$$

$$b = \sqrt{1.6a^2 + h^2} - 0.675h \quad \text{when } a < 1.724h$$

Radius of relative stiffness

It is the ratio of the strength if the slab to the strength of the subgrade. Its unit is that of Length

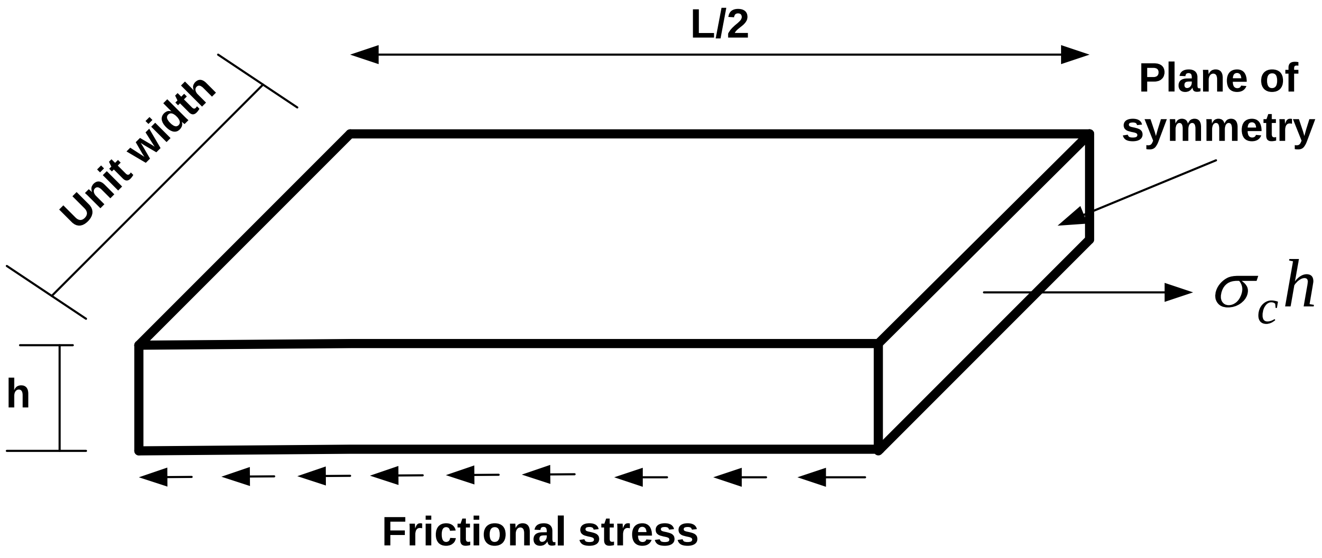
$$l = \left[\sqrt[4]{\frac{Eh^3}{12(1-\vartheta^2)k}} \right]$$

h = the thickness of the slab
k = the modulus of sub-grade reaction

Stresses due to friction

The friction between a concrete slab and its foundation causes tensile stresses in the concrete, in the steel reinforcements, if any and in the tie bars. For plain concrete pavements, the spacing between contraction joints must be so chosen that the stress due to friction will not cause the concrete to crack.

Figure shows a concrete pavement subject to a decrease in temperature. Due to symmetry, the slab tends to move from both ends towards the center, but the subgrade prevents it from moving; thus, frictional stresses are developed between the slab and the subgrade



The tensile stress in the concrete at the center and can be determined by equating the frictional force per unit width of slab, **$\gamma_c h L f_a / 2$** , to the tensile force **$\sigma_c h$**

Stress in concrete can be calculated from the equation:

$$\sigma_c = \frac{\gamma_c L f_a}{2}$$

$\sigma_c = Stress\ in\ the\ concrete$

$\gamma_c = unit\ weight\ of\ the\ concrete\ (= 150pcf)$

$L = length\ of\ slab$

$f_a = average\ coefficient\ of\ friction\ between\ slab\ and\ subgrade\ (= 1.5)$

Equation implies that the stress in the concrete due to friction is independent of the slab thickness.

Stresses due to curling (Temperature stress)

During the day when the temperature on the top of the slab is greater than that at the bottom, the top tends to expand with respect to the neutral axis while the bottom tends to contract.

However, the weight of the slab restrains it from expansion and contraction; thus compressive stresses are induced at the top while tensile stresses occur at the bottom.

At night when the temperature on the top of the slab is lower than that at the bottom, the top tends to contract with respect to the bottom; thus, tensile stresses are induced at the top and compressive stresses at the bottom.

Curling stresses in finite slab

1. Interior stress

The total stress in the x direction can be expressed as:

$$\sigma_x = \frac{C_X E \propto_t \Delta_t}{2(1-\vartheta^2)} + \frac{C_y \vartheta E \propto_t \Delta_t}{2(1-\vartheta^2)} = \frac{E \propto_t \Delta_t}{2(1-\vartheta^2)}\left(C_x + \vartheta C_y\right)$$

C_x *and* C_y *are correction factors for slab.*

E – *Elastic modulus of concrete*

Δ_t – *temperature differential between top and bottom of the slab*

$\propto_t$ – *coefficient of thermal expansion of concrete*

ϑ – *Poisson ratio of concrete*

Similarly the total stress in the y direction is:

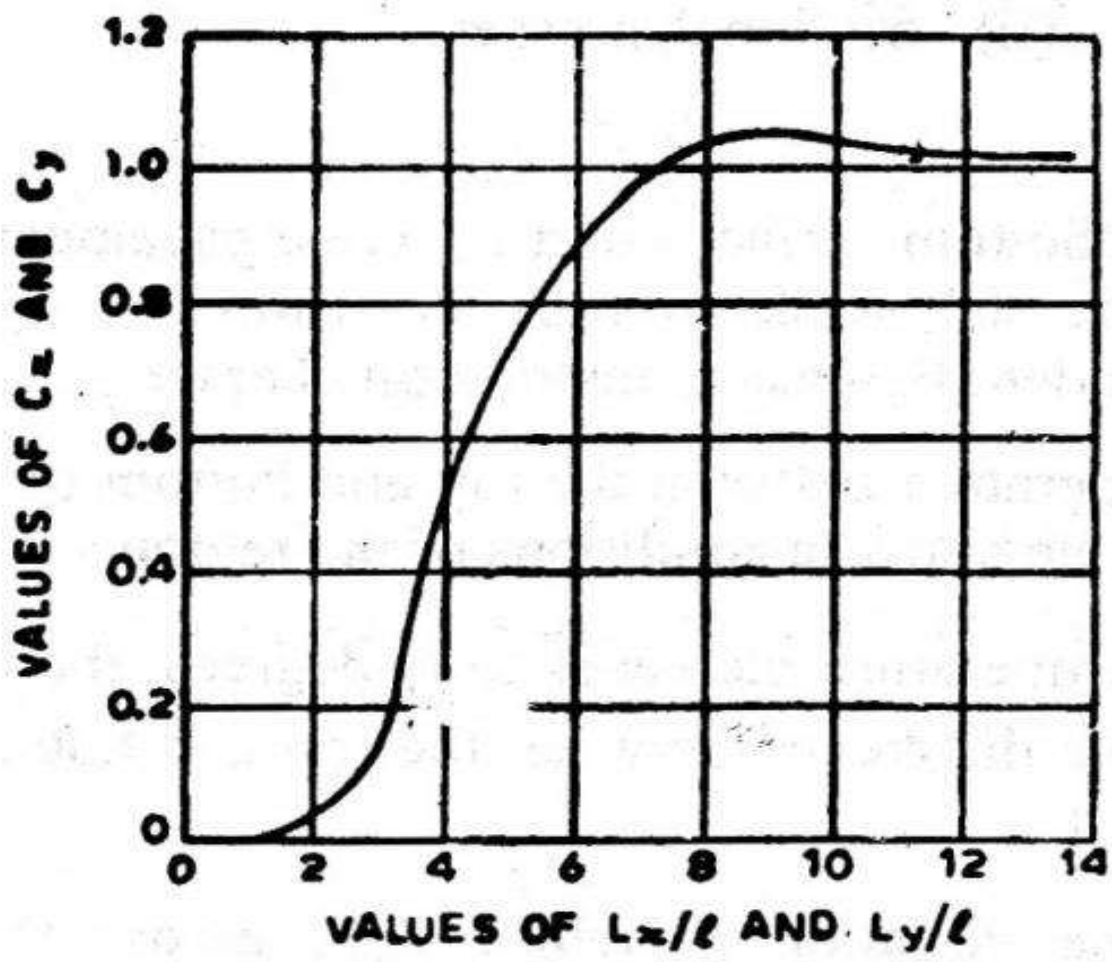
$$\sigma_y = \frac{E\,\alpha_t\,\Delta_t}{2(1-\vartheta^2)}\left(C_y + \vartheta C_x\right)$$

2. Edge stress :

$$\sigma = \frac{CE\alpha_t\Delta t}{2}$$

In which σ may be σ_x or σ_y depending on weather C is Cx or Cy.

Based on Westergaard's analysis, Bradbury (1938) developed a simple chart for determining C_x and C_y shown in fig. below. The correction factor C_x depends on l_x/l and the correction factor C_y depends on l_y/l , where l is the radius of relative stiffness.



Radius of relative stiffness

It is the ratio of the strength if the slab to the strength of the subgrade. Its unit is that of Length

$$l = \left[\sqrt[4]{\frac{Eh^3}{12(1-\vartheta^2)k}} \right]$$

h = the thickness of the slab

k = the modulus of sub-grade reaction

Steps for Rigid Pavement Design : Slab Thickness

1. Fix the width of the slab (Generally one lane wide)
2. Calculate the length of the slab using the permissible value of frictional stress
3. Assume trial thickness of the slab
4. Calculate load stress at the edge
5. Calculate the residual strength using the concrete flexural capacity(f_r) and the edge stress
6. Calculate the warping stress at the edge
7. Calculate the factor of safety

$$FOS = \frac{Residual\ Strength}{Warping\ stress}$$

- If FOS is very greater than 1 decrease thickness
- If FOS is very smaller than 1 increase thickness
- If FOS is equal to 1 then go to step 8

8. Repeat steps 4 to 7 for corner then for interior stress

Steps for Dowel Bar

1. Assume joint width (δ) cm
2. Determine the spacing between joints using

$$l_e = \frac{\delta}{100\ \alpha_c(T_2 - T_1)}$$

3. Determine the embedment length using

$$l_d = 5d\sqrt{\frac{F_f(l_d + 1.5\delta)}{F_b(l_d + 8.8\delta)}}$$

4. Assume load transferred to be 40% of the total load
5. Find the load transfer capacity P_s P_f and P_b

$$P_s = 0.785 d^2 f_s$$

$$P_f = \frac{2d^3 f_f}{l_d + 8.8\delta}$$

$$P_b = \frac{f_b l_d^2\ d}{12.5(l_d + 1.5\delta)}$$

Where F_s , F_f , F_b = Permissible stress in shear flexure (bending) and Bearing

6. Find the number of dowels required $0.4P/P_s$, $0.4P/P_f$ and $0.4P/P_b$

7. Find spacing

a. The effective distance upto which the load transfer takes place is given by 1.8l , where l is the radius of relative stiffness
b. Assume a linear variation of capacity factor under the load and 0 at 1.8l from it
c. Assume dowel spacing and determine the capacity factor
d. Adjust spacing till the required factor is obtained

Steps for Tie bar

1. Assume Dia (Generally 8 to 10 cm)
2. Determine the area of steel required per meter

$$A_s = \frac{b * h * w * f}{100S_s}$$

3. Determine the spacing using are
4. Determine the minimum length required by

$$l_t = \frac{dS_s}{2S_b}$$

Add 50mm for FOS and 50mm for cutting and finalize length

Here
b = Width of pavement(m)
h = slab thickness (mm)
W = unit weight of concrete (Kg/m^3)
f = friction coefficient
S_s = Allowable tensile strength in dowel bar (Kg/cm^2)
S_b = Allowable bond strength in dowel bar