Transportation Engineering -I

Course Content:

1. Introduction to Transportation Planning and Engineering(4 hr)
2. Highway Alignment and Engineering Survey (4 hrs)
3. Geometric Design of Highway (18 hrs)
4. Highway Drainage (4 hrs)
5. Hill Road (5 hrs)
6. Highway Materials (10 hrs)

Course content…..

Tutorials: Tutorial covering the entire course works.

Practical :

1. Penetration value and ductility value of bitumen
2. Viscosity and softening point of bitumen
3. Abrasion value of aggregate
4. Marshall stability test and asphalt mixed design.

References

- S.K.Khanna , C.G.E.Justo
  "Highway Engineering"
- Dr. L.R Kadiyali, Dr. N.B. Lal
  "Highway Engineering"
- Course Manual
- Nepal Road Standard (2070 Revised)
- Nepal Rural Road Standard (2071 Second Revised)
- Relevant Publication by DOR and DOLIDAR

Transportation Engineering

- **Definition:** The application of technological and scientific principles to the planning, design, operation and management of facilities for any mode of transportation in order to provide for the safe, rapid, comfortable, convenient, economical and environmentally compatible movement of people and goods.

Transportation System

Transportation System:

- Passenger Transportation

  and

- Goods Transportation

Passenger Transport

Passenger Transport

Passenger Transport

Passenger Transport

Goods Transport

Goods Transport

Goods Transport

Goods Transport

I. Primary modes of transportation

- Land Ways
- Air Ways
- Water Ways
- Space Ways

II. Secondary modes of transportation

- Ropeways (Cable based cabin)
- Pipe lines (Water, gas, sewer)
- Canal (Irrigation, water drainage)
- Belt Conveyors

Secondary modes of transportation

Secondary modes of transportation

Advantages of Road Transport

- Wide geographical coverage.
- Large influence area
- Low capital investment
- Door to door service
- Flexibility
- Quick and assured deliveries
- Highest employment potential
- Low cost packaging
- Personalized travel and service
- Economy
- Overall development of the country

Disadvantages of Road transportation

- Land coverage
- Environmental pollution
- Rate of accident is high
- Energy consumption
- Uneconomical (due to accident and environmental effect)
- Delay and congestion (Problem of motorization)

Constraints on the development of Road Transportation in Nepal

- Unfavorable geographical condition (Hilly and mountainous)
- Poor geological condition (unstable soil, landslide etc)
- Hydrological (River system)
  - number of river crossings
  - run-off is very high in monsoon and velocity is high
- Lack of financial resources
- Technological development.

Constraints on the development of other modes of transportation in Nepal

- **Railways:**
- Initial investment is high
- Geographical condition
- Technological development (lack of experience)

- **Waterways:**
- (Nepal is land-lock country so only inland transportation is possible)
- High velocity of water in monsoon period
- Water level in rivers

- **Airways:**
- Transportation cost is very high and not affordable for each people.
- Only for small aircraft/ helicopters.

Road Transportation Engineering

- It is a branch of civil engineering, most popular modes of transportation, which deals with art, science and techniques of planning, design, construction and maintenance of roads and highways. It also includes traffic engineering.

Scope of Highway Engineering

1. **Development planning and location**

   Historical background: Basis for planning; Master plan; Engineering surveys and highway alignment.

2. **Highway Design, geometric and structures**

   Road geometrics and their design,: rigid and flexible pavements; design factors and thickness design: design of drainage system.

3. **Traffic performance and its control**

   Traffic studies and analysis; traffic regulation and control; intersection design and their controls with signs; signals, islands, and markings.

Cont…..

4. **Materials, construction and maintenance**

   Highway materials and mix design; highway construction; earth work; construction of different type of pavements; pavement failures; maintenance of pavements and drainage system.

5. **Economics, Finance and Administration**

   Road user cost and economic analysis of highway projects; highway finance and phasing of expenditures.

Historical Development of Road Construction

Roman Roads (312 B.C.)

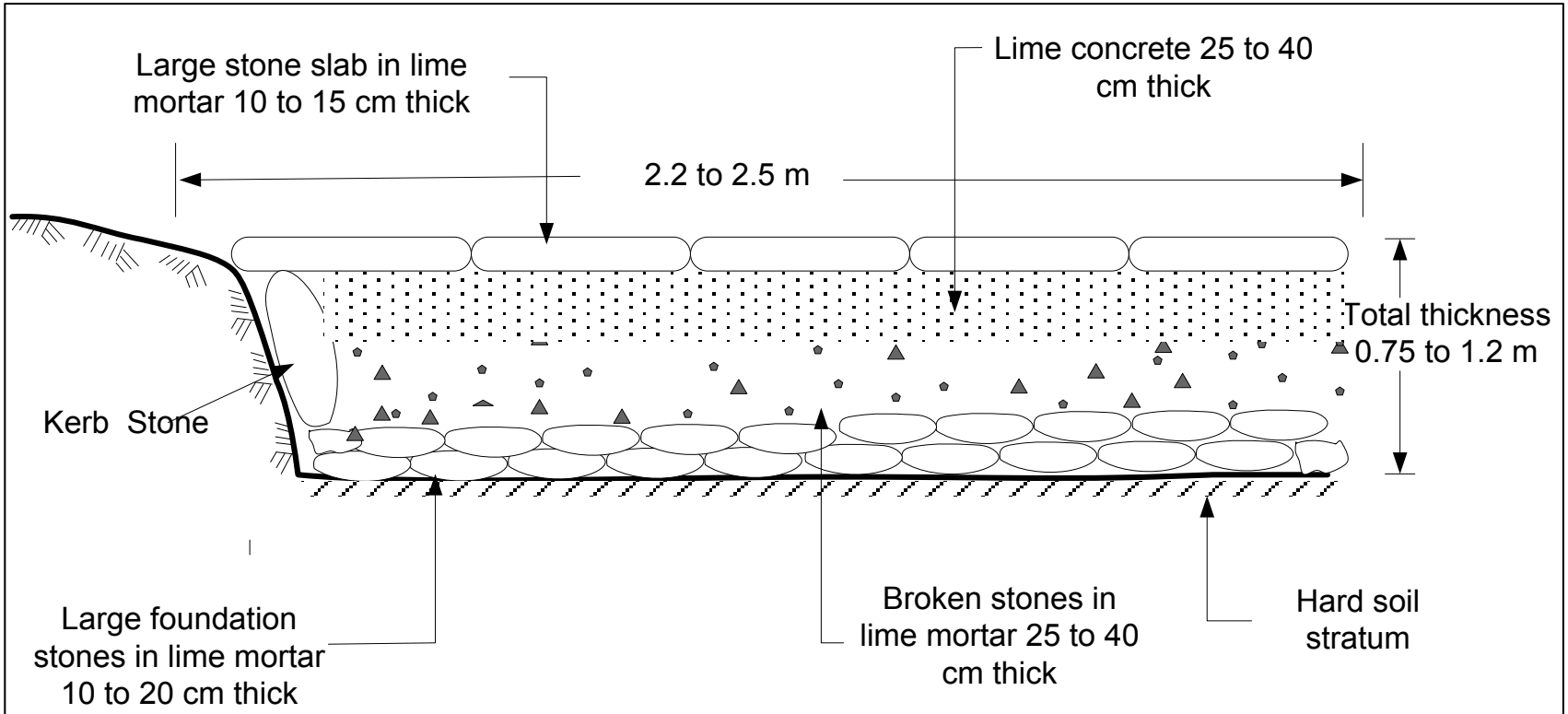


Fig.1.1 Typical cross section of Roman Road

Tresaguet construction (1775 A.D.)

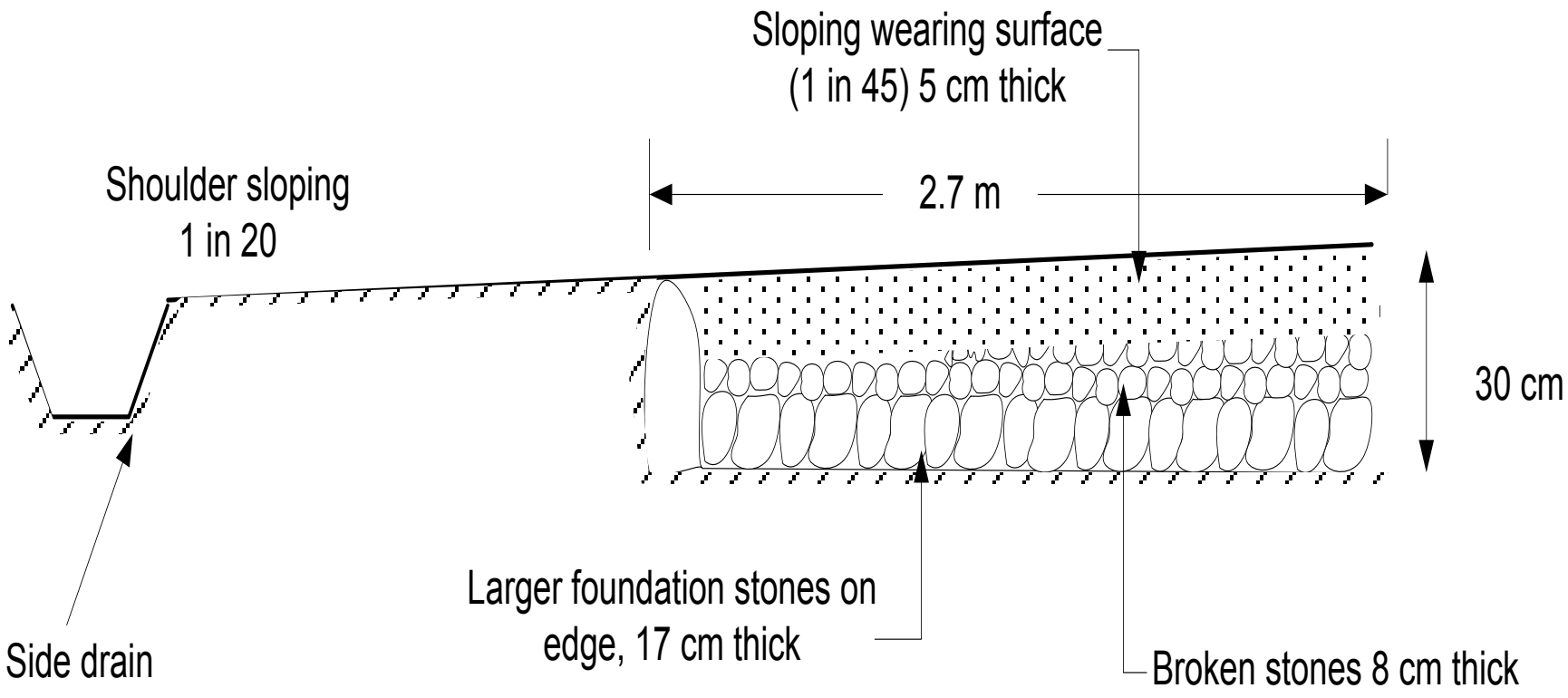


Fig. 1.2 Typical cross section of Tresaguet's Construction

Telford construction (1803)

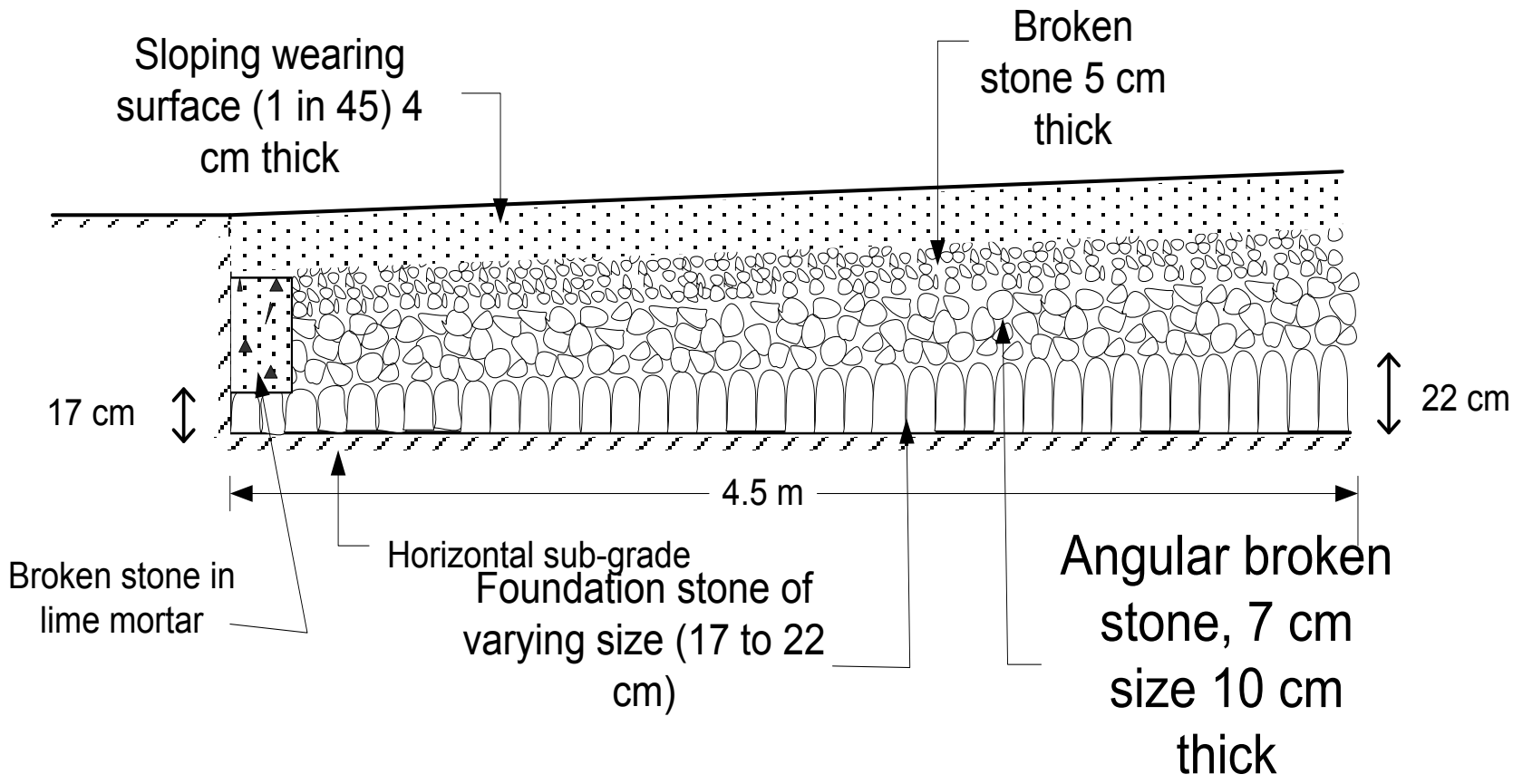


Fig. 1.3 Typical cross section of Telford's construction

Macadam Construction (1827)

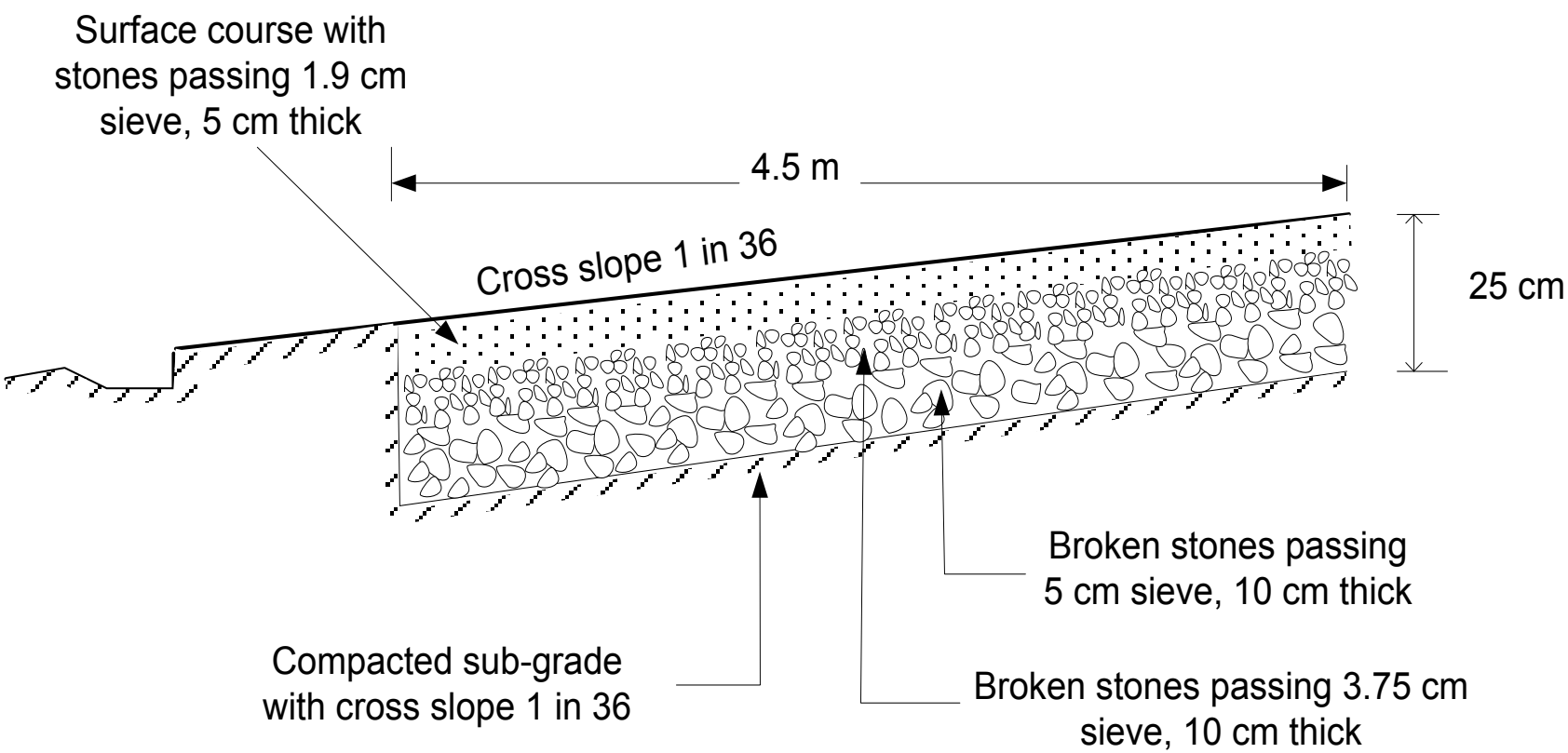


Fig. 1.4 Typical cross section of Macadam's construction

Modern Roads

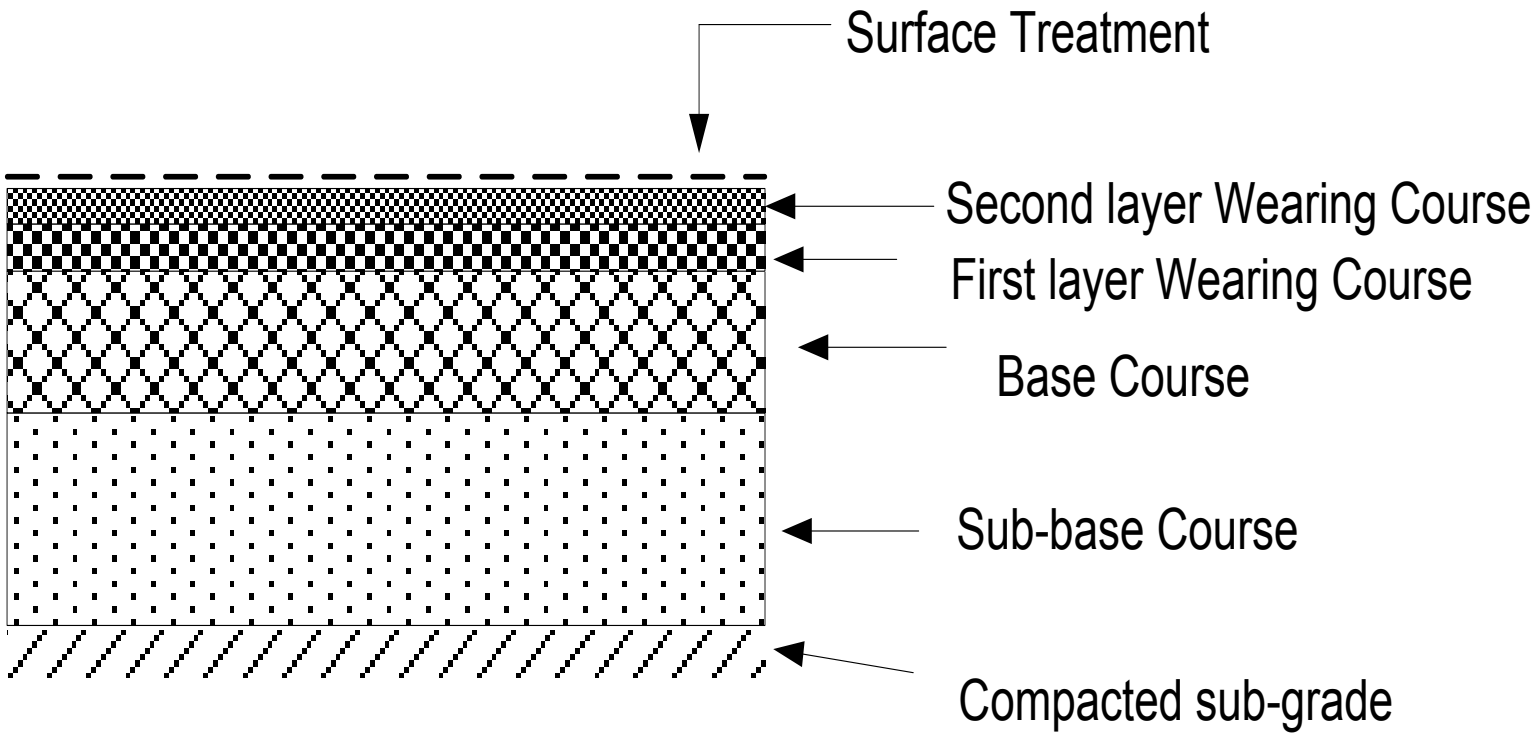


Fig. 1.5 Cross section of modern Roads

Modern Roads

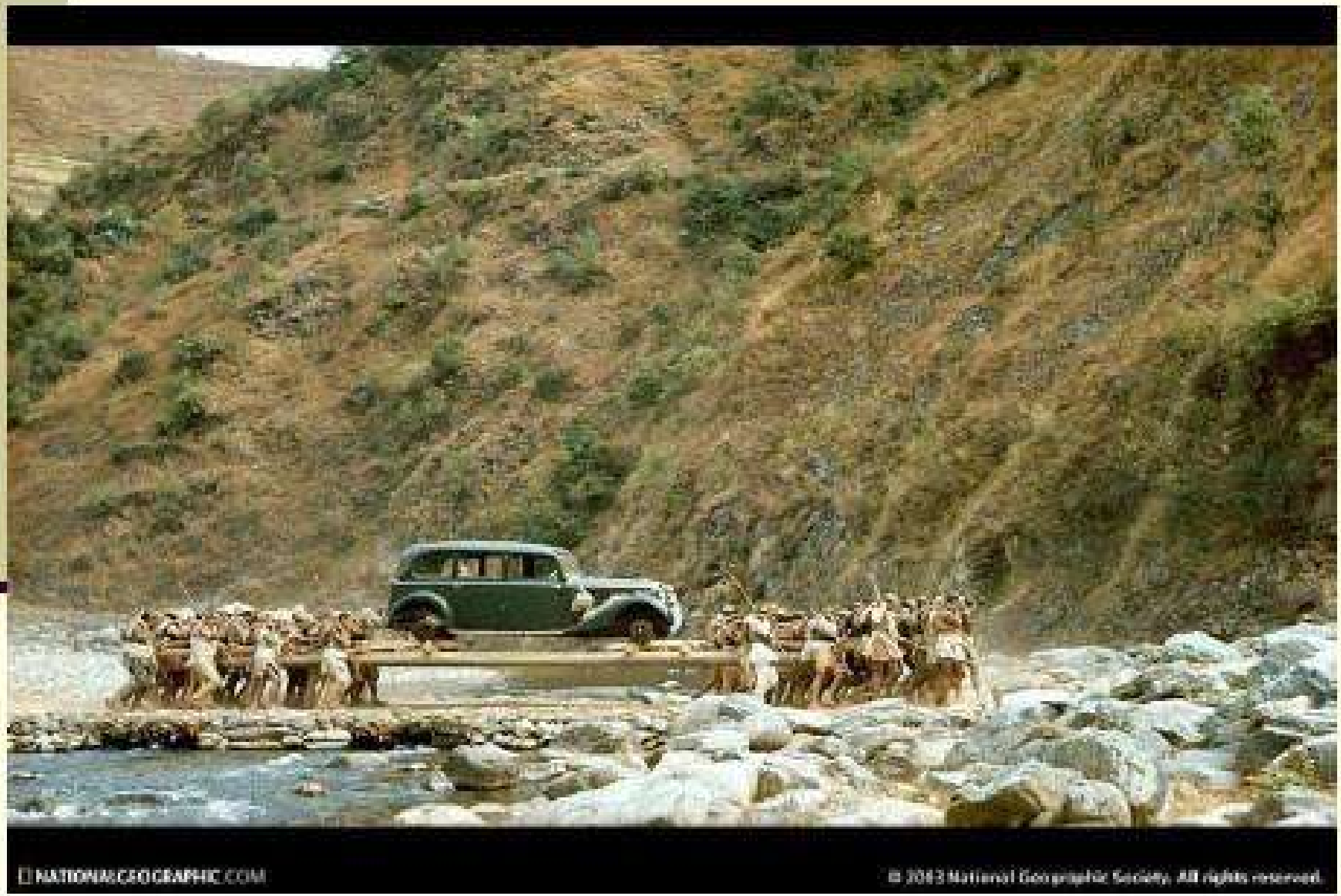
- Development of heavy vehicle and need of high speed resulted to the more stable and durable pavement structures.
- Crushed stone of different gradation are suitable for compaction and interlocking between them.
- Top layer of the pavement is constructed by stone aggregates bound by bitumen, tar or other binding materials.

Cont…

- For good friction to the wheel and to resist the forces during movement, surface treatment (thin layer) is constructed.
- Pavement is designed by considering wheel loads, natural soil and other construction materials.
- Modern roads are constructed according to Standards, Norms and Procedures, developed by government authority.

Road construction In Nepal

Once upon a time … in 1958



Road construction In Nepal

- **Ministry of Physical infrastructure and transport:**

  Department of Roads (DoR)

  Strategic Road Network (SRN)

- **Ministry of Federal Affairs & Local Development:**

  DoLIDAR (Department of Local Infrastructure Development and Agricultural Roads

  Local Road Network (LRN)

Classification of roads

- According to **Nepal Road Standard** (2070 Revised)

I. Administrative Classification:

- National Highways (NH)
- Feeder Roads (FR)
- District Roads (DR)
- Urban Roads (UR)

Classification of roads

- According to **Nepal Road Standard** (2070 Revised)

II. Technical/Fuctional Classification:

- Class I (ADT 20000 or more, Speed 120km/hr)
- Class II (ADT 5000-20000, Speed 100km/hr)
- Class III (ADT 2000-5000, Speed 80km/hr)
- Class IV (ADT less than 2000, Speed 60km/hr)

Classification of roads

- According to **Nepal Rural Road Standard** (2071 Second Revised)
  - District Road (Core Network)
  - Village Road

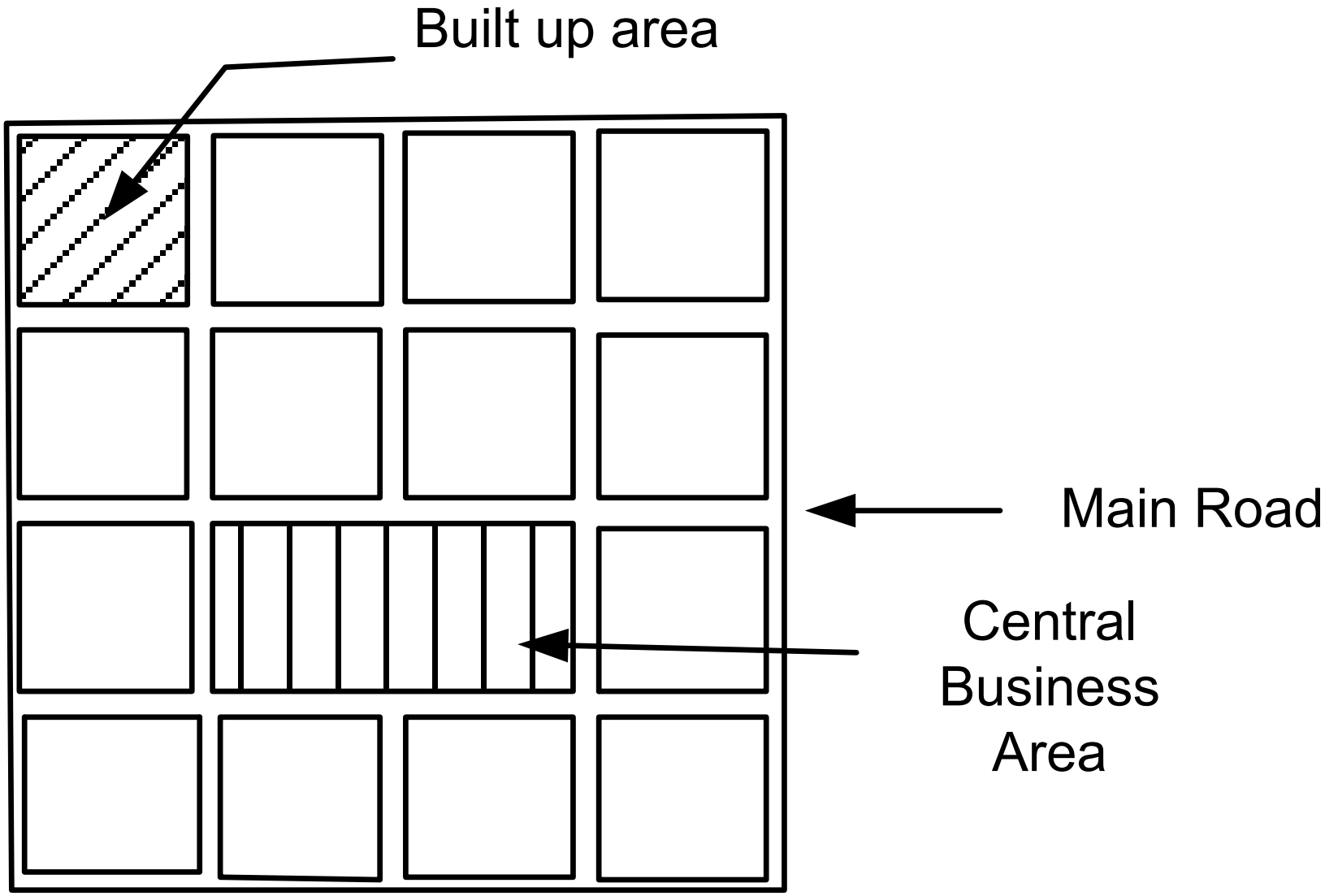
Urban Road Network

- Urban road network is the road system within the urban areas.

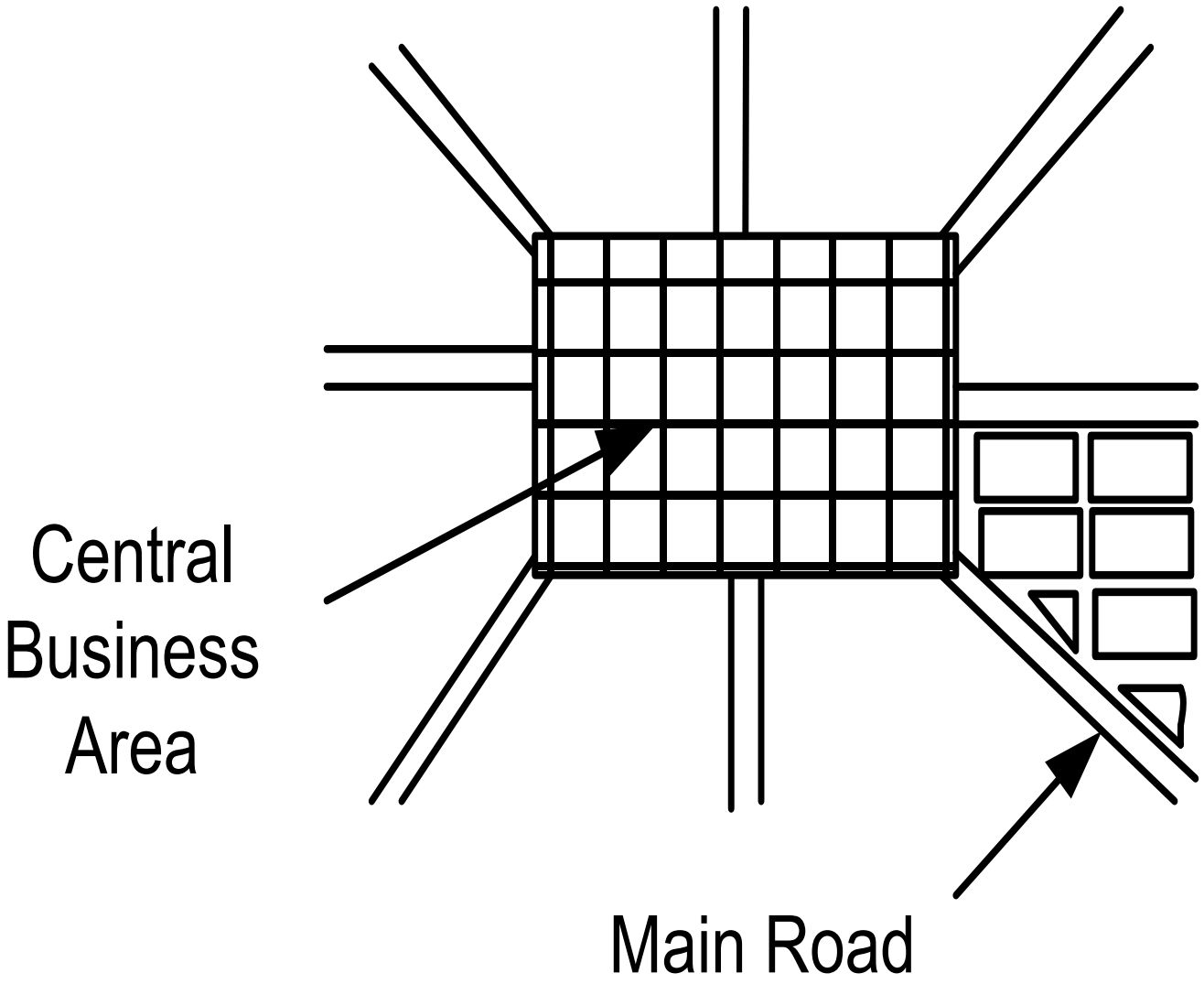
Road patterns in urban area

- Rectangular pattern
- Radial/Star and block pattern
- Radial/Star and circular pattern
- Radial/Star and grid pattern
- Hexagonal patterns

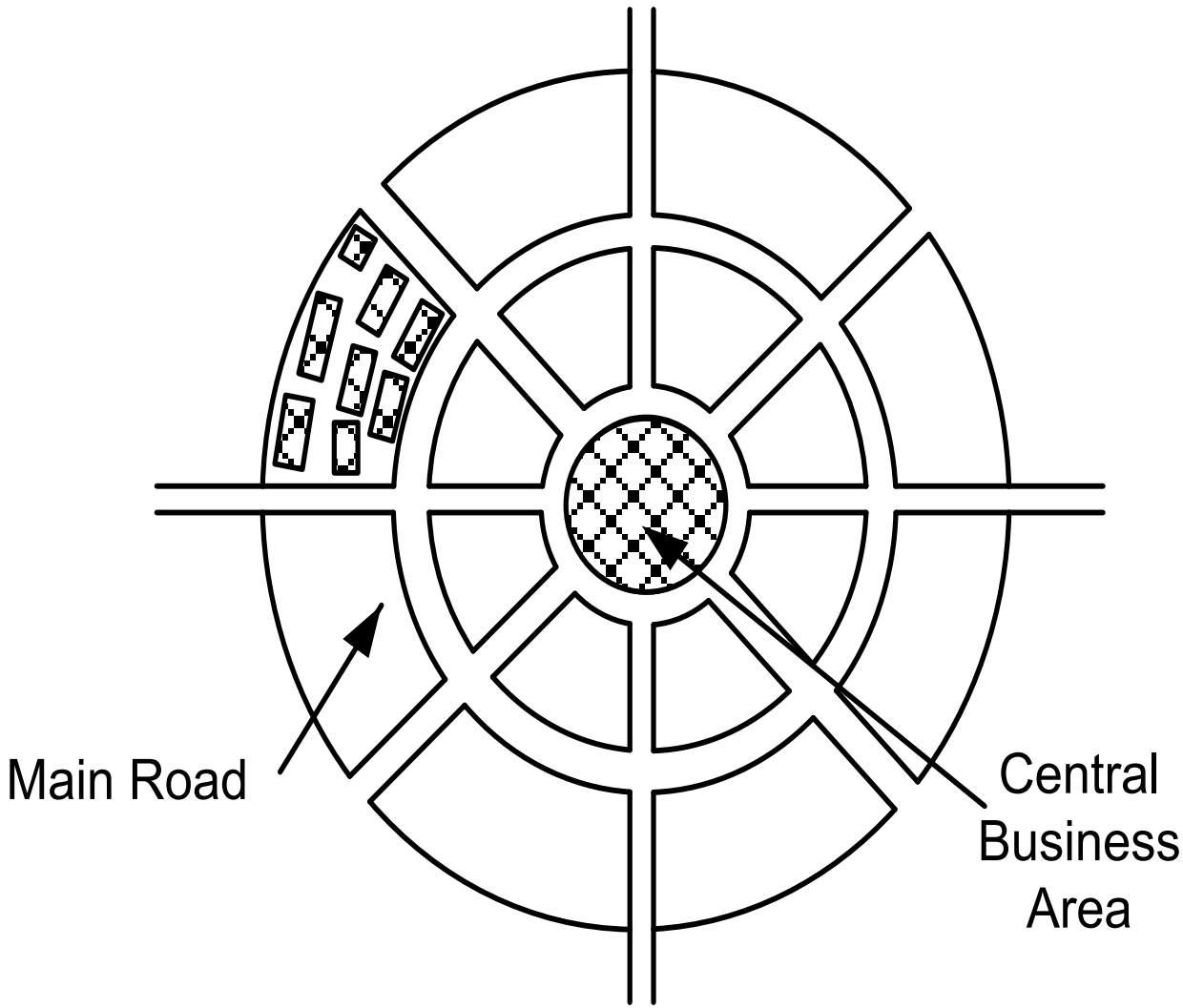
Rectangular or block pattern



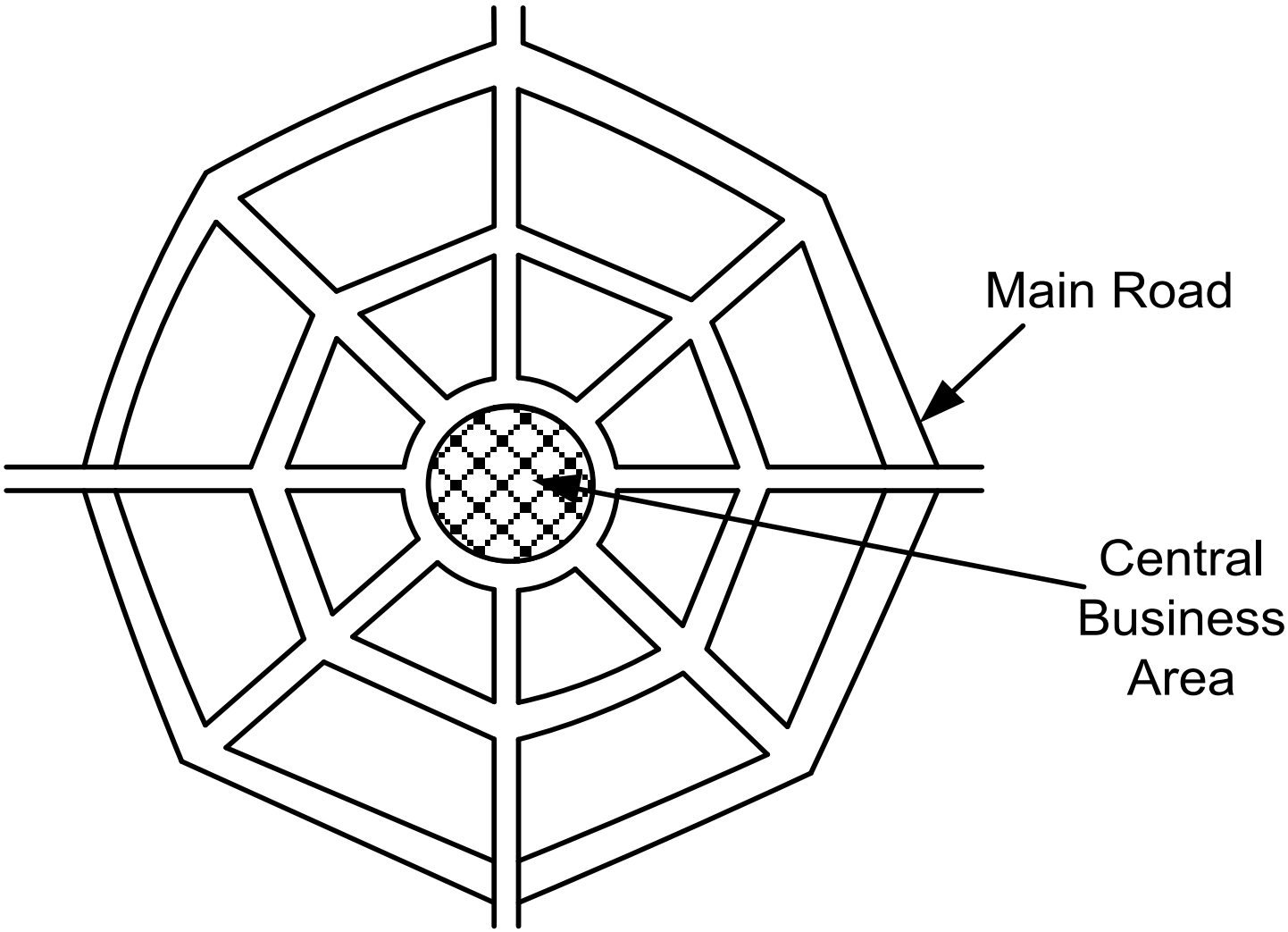
Radial or star and block pattern



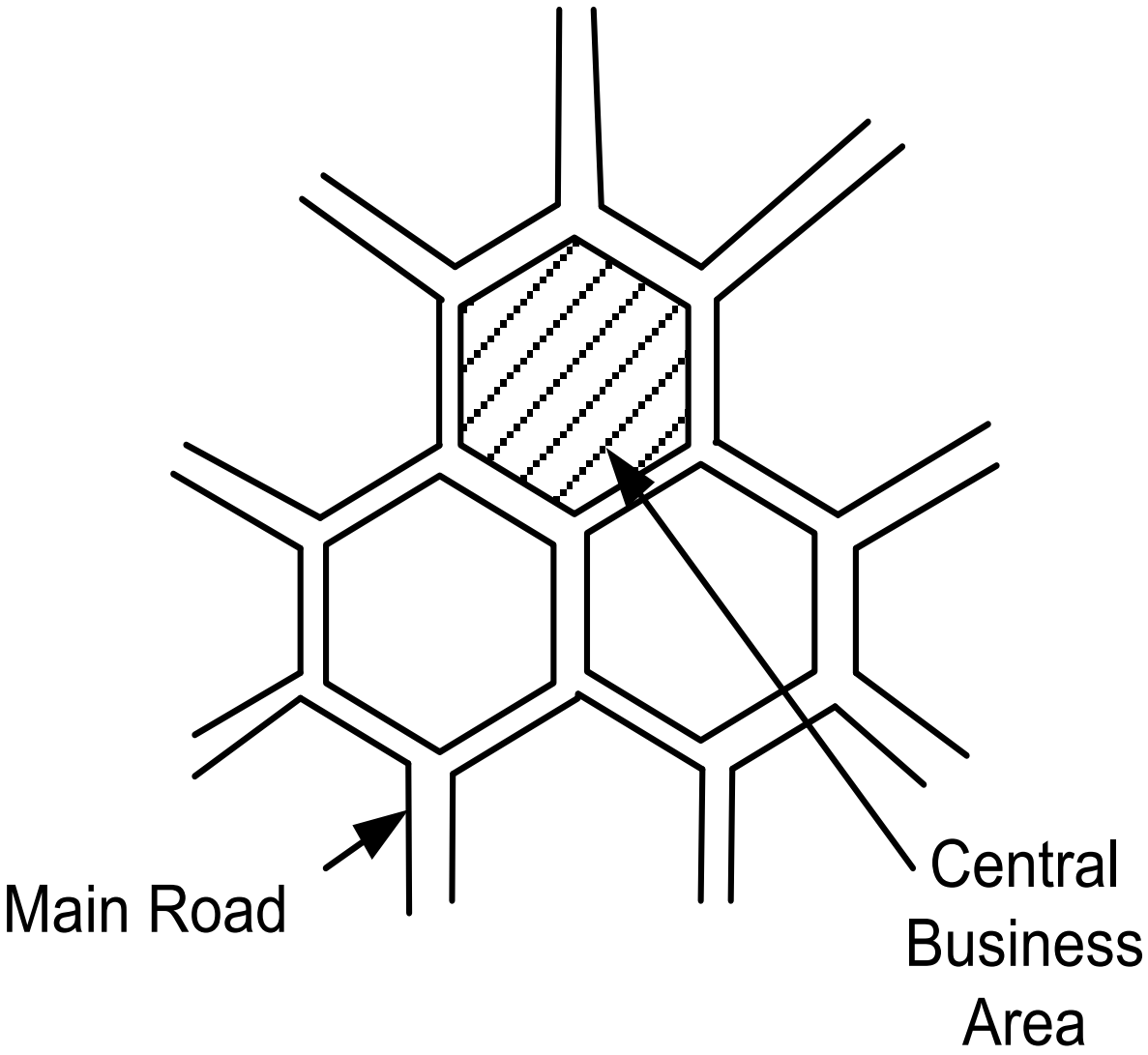
Radial or star and circular pattern



Radial or star and grid pattern



Hexagonal pattern



Ring Road

- Ring road is a link roughly circumferential about the centre for an urban area and which permits traffic to avoid the centre.
- The main traffic generator is located within the central area. Lacks of suitable by-pass for through traffic, central area becomes congested. Solution for this problem is to build a ring road around the central business area.
- Depending upon the population first, second and third ring road may be developed.

Highway Planning

What is planning?

Planning is the process of thinking about and organizing the activities required to achieve a desired goal.

Conceptual Framework

Highway Surveys

Highway survey and selection of best alignment.

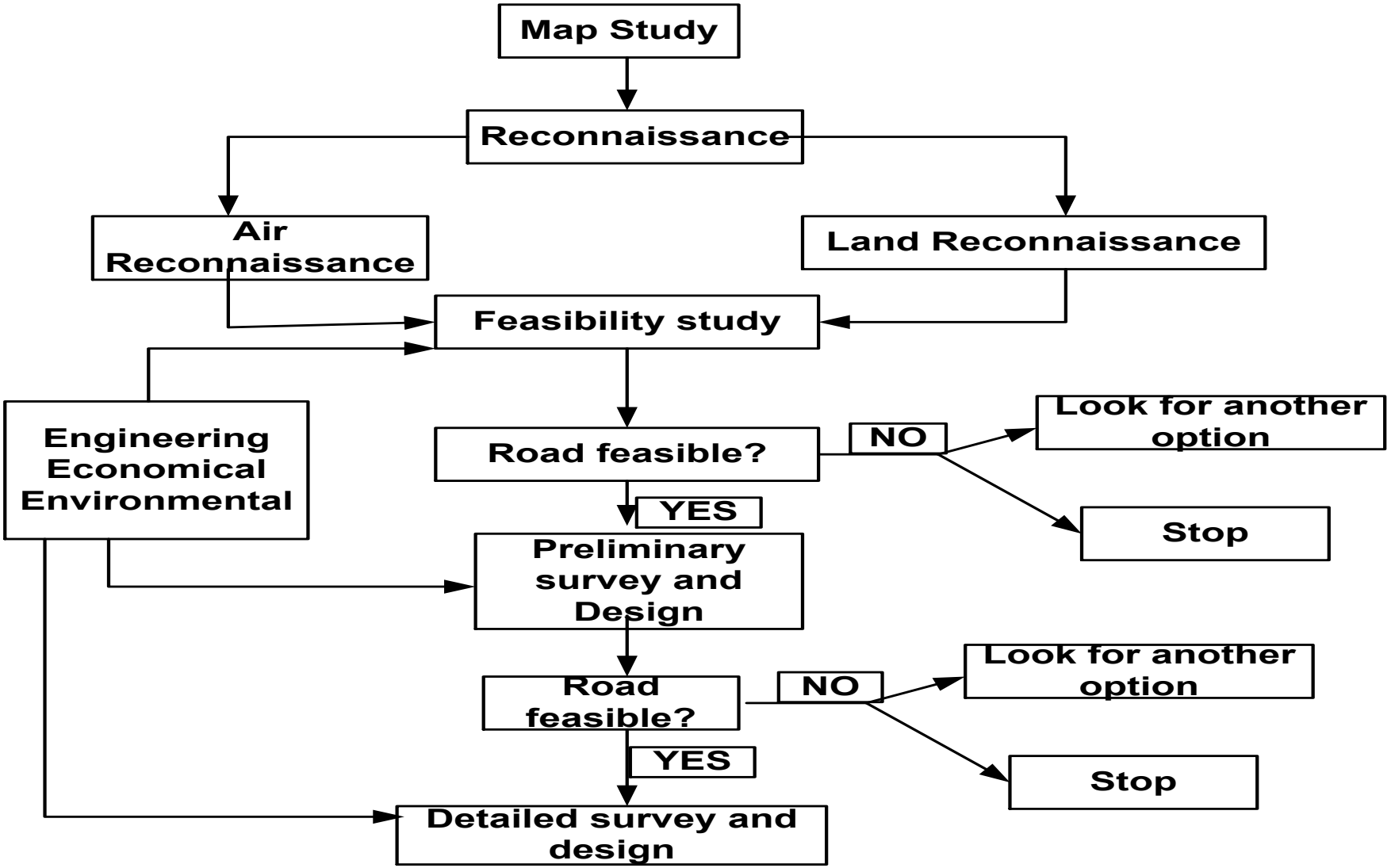
- Process of identifying best route location
- Physical surveys: map study and Reconnaissance, preliminary and detailed surveys
- Highway alignment and controlling factors

What is Highway Planning?

- Objectives of highway Planning:
  - To establish integrated highway network capable of accommodating all highway travel in an orderly, safe, efficient and economic manner
  - To forecast the future requirement of road kilometrage needed in different parts of the country
  - To fix the priorities and schedule for the construction of roads and bridges
  - To plan for our financial system

Example: Nepal Twenty Year Road Plan

Flow Chart of Route Location Process



Flow Chart of Route Location process

Map study:

By careful study of topographical maps, it is possible to have an idea of several alternate routes so that further details of these may be studied later at the site.

The probable alignment can be located on the map from the following details available on the map.

- Alignment avoiding valleys, ponds or lakes.
- Possibility of crossing through a mountain pass.
- Avoiding bend of the river for crossing rivers.
- Keeping the permissible gradient.

Reconnaissance:

- The second stage of surveys for highway location is the reconnaissance to examine the general character of the area for deciding the most feasible routes for detailed studies. Some of the details to be collected during reconnaissance are given below.
- Valley, ponds, lakes, ridge, hills, permanent structures and other obstructions along the route which are not available in the map.
- Approximate values of gradient, length of gradient and radius of curves of alternate alignment.

Cont…….

- Number and types of cross drainage structure, maximum flood level and natural water level.
- Soil type and observation of geological features.
- Sources of construction materials, water and location of stone quarries.
- Type of rocks, seepage flow, the road passes through hilly or mountainous terrain.

Preliminary surveys

The main objectives of the preliminary survey are;

- To survey the various alternate alignments proposed after the reconnaissance.
- To collect all the necessary physical information and details of topography, drainage, and soil.
- To compare the different proposals in view of the requirements of a good alignment.
- To estimate quantity of earth work.
- To finalize the best alignment.

It is done by using the instruments such as chain, compass, tape, level & theodolite.

Detailed survey:

- **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

Detailed survey;

- The alignment finalized at the office design is to be located on the field by establishing center line.
- The center line stakes are driven at suitable intervals (50m intervals in plain and rolling terrain and 20 m intervals hilly terrain.)
- Bench marks are fixed at interval of about 250m and all drainage structures.
- Levels along the final center line should be taken at all staked points.

Cont……..

- The cross section levels are taken up to the desired width.
- All river crossing, valley etc. should be surveyed in detail
- Detailed soil survey is carried out
- The data during the detailed survey should be complete for preparing detailed plans, design and estimate of the project

Highway Alignment:

The position or the layout of the centre line of the highway on the ground is called alignment.

- Horizontal alignment – (straight path, curves, horizontal deviations)
- Vertical alignment – (Changes in gradient and vertical curves)

Disadvantages of improper alignment

- Increase in construction cost
- Increase in maintenance cost
- Increase in vehicle operation cost
- Increase in accident rate

Basic requirements of an ideal alignment

- ***Short*** –It is desirable to have a shortest alignment between two terminal stations.

- ***Easy*** – The alignment should be such that it is easy to construct and maintain with minimum problems.

Cont…

- ***Safe*** – The alignment should be safe enough for construction and maintenance from the view point of stability of natural hill slopes, embankment and cut slopes and foundation of embankments. It should be safe for the traffic operation with safe geometric features.

- ***Economical*** – If the total cost including initial cost, maintenance cost and vehicle operation cost is low the road alignment could be considered economical.

Factors controlling the highway alignment

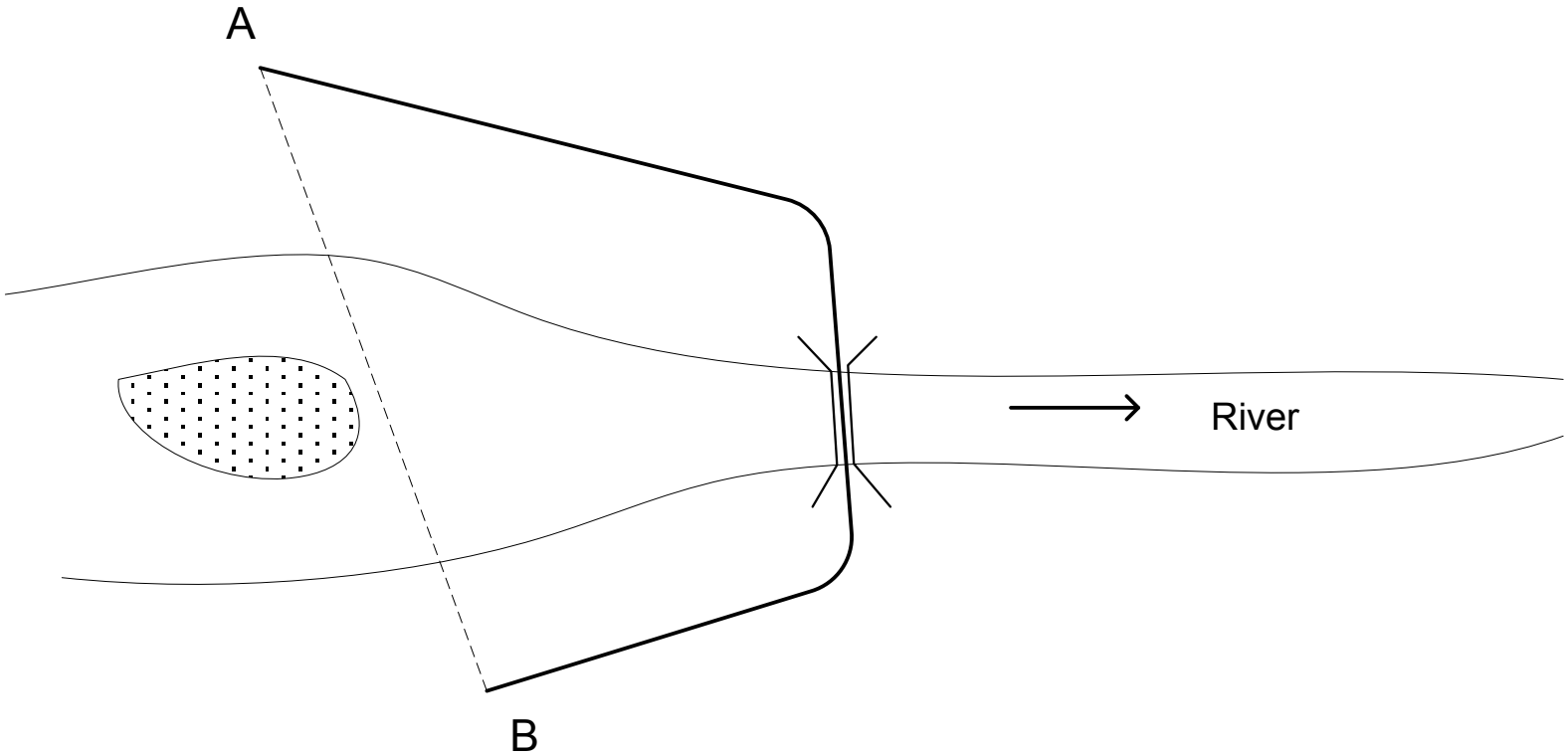
- Obligatory points
- Traffic
- Geometric design
- Economy
- Others

Obligatory points:

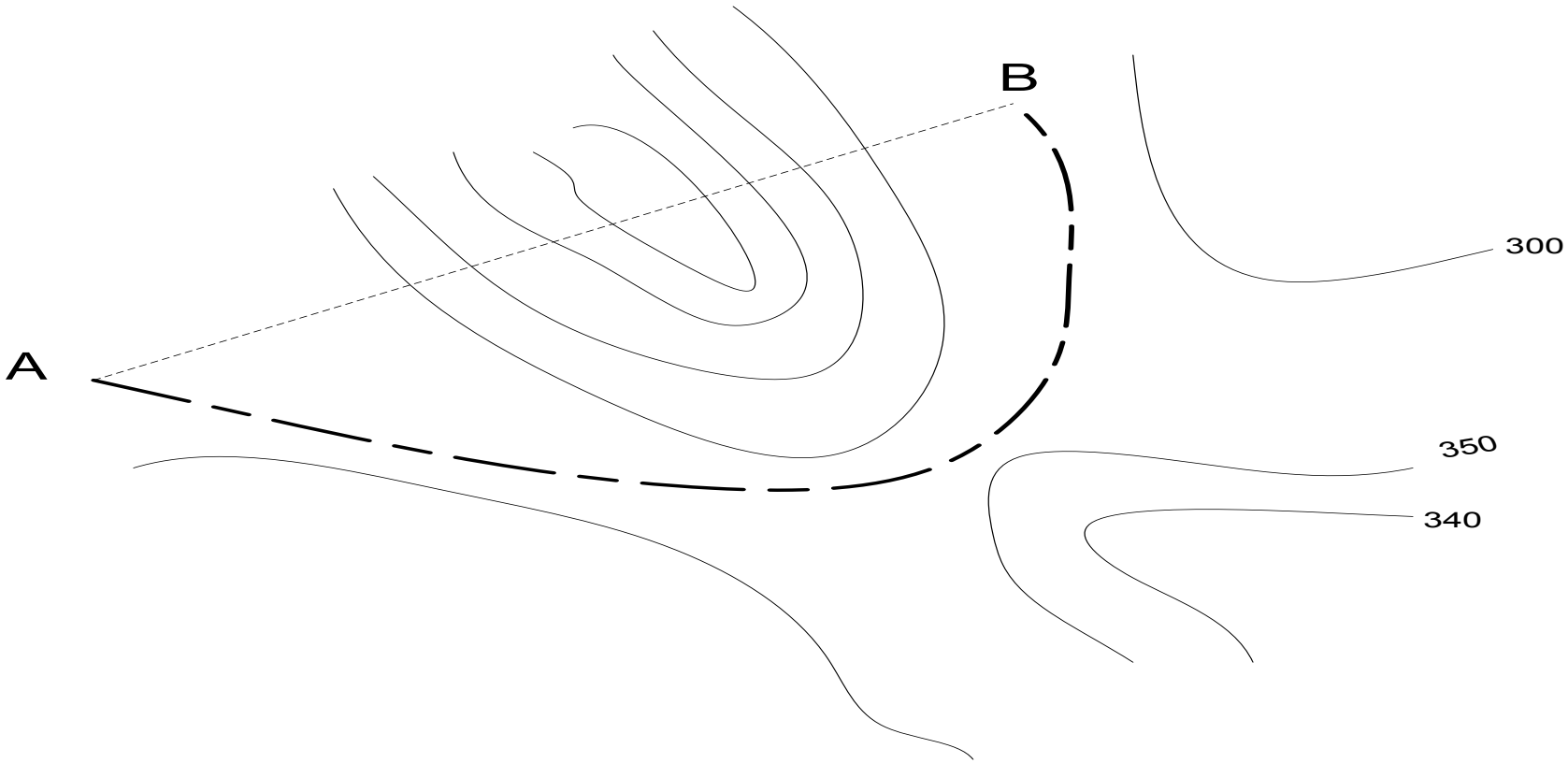
Points through which the **alignment is to pass**

- Bridge site
- Industrial area
- Hill pass
- Intermediate town

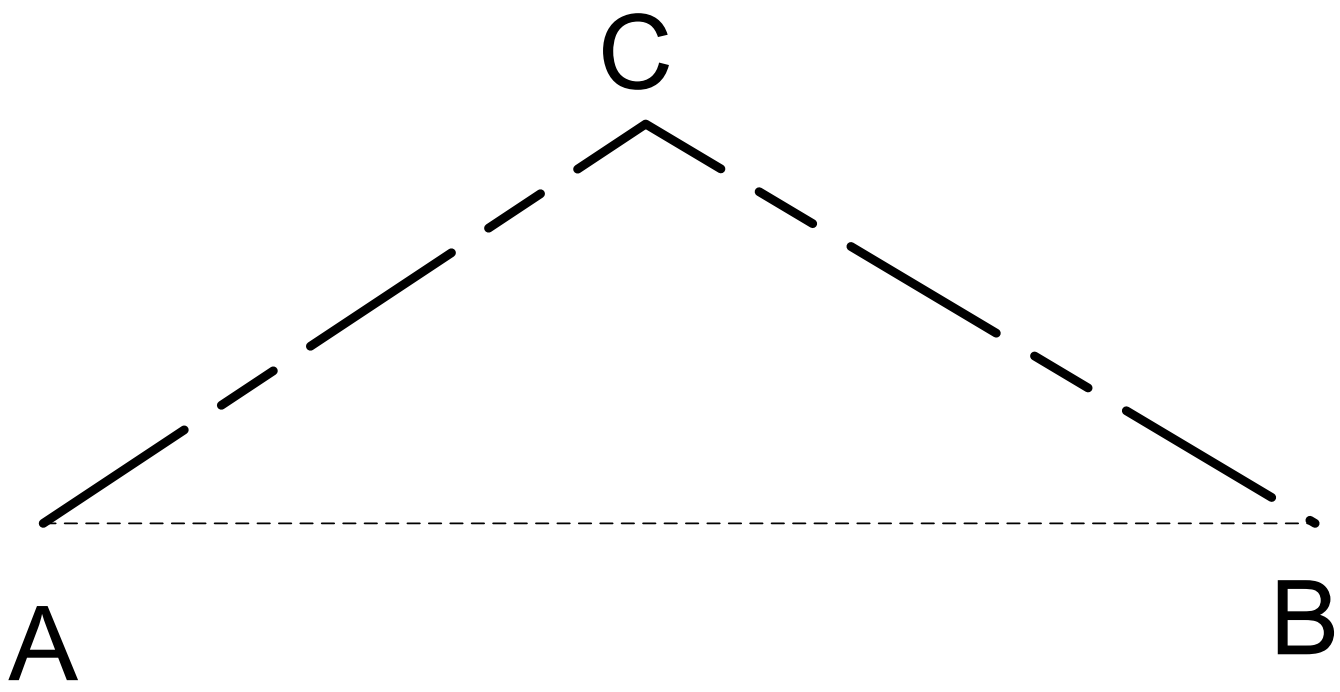
Bridge Site



Alignment along the hill pass



Connecting intermediate town



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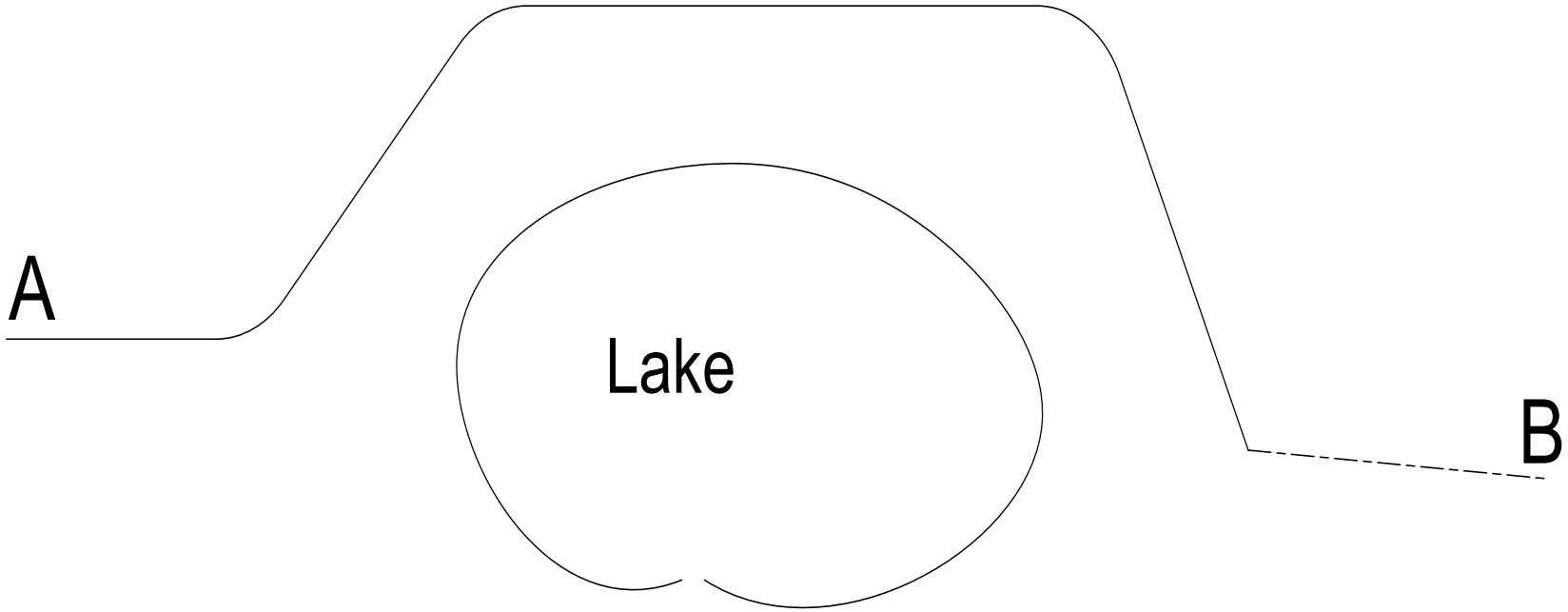
Points through which the **alignment should not pass:**

- Waterlogged area
- Historical or archeological site
- Restricted zone for defense/national security
- Densely populated area
- Very costly structures


A
Lake
B

Traffic

- The alignment should suit traffic requirements. Origin and destination study should be carried out in the area.

Geometric design

- The geometric design of a highway deals with the dimensions and layout of visible features of the highway such as gradients, radius of curve, sight distance, and super elevation etc.

Economy

- The alignment should also be economical

Others Factors

- Various other factors such as drainage, hydrological factors, political considerations, monotony, Sub-surface water level, seepage flow and high flood level

Transportation Engineering I

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Chapter 2: Geometric Design

Definition: Highway geometric design refers to the calculations and analysis made by designers to fit the highway to the topography of the site while meeting the safety, service and performance standards. Elements of the highways that are visible to the drivers and road-users. However, the engineer must also take into consideration the social and environmental impacts of the highway geometry on the surrounding facilities.

Objectives:

- Determine, within the allowance permitted by the design standard and right-of-way, the routing of proposed highway.
- Incorporate, within the design standard, various physical features of the road alignment to ensure that drivers have sufficient view of the road (and obstacles) ahead for them to adjust their speed of travel to maintain safety and ride quality.
- Provide a basis for the highway engineers to evaluate and plan for the construction of a section of the proposed highway.

Elements:

Geometric Design of Highways deals with the following elements:

- Cross section elements
- Sight distance considerations
- Horizontal alignment details
- Vertical alignment details
- Intersection elements

Design control and criteria:

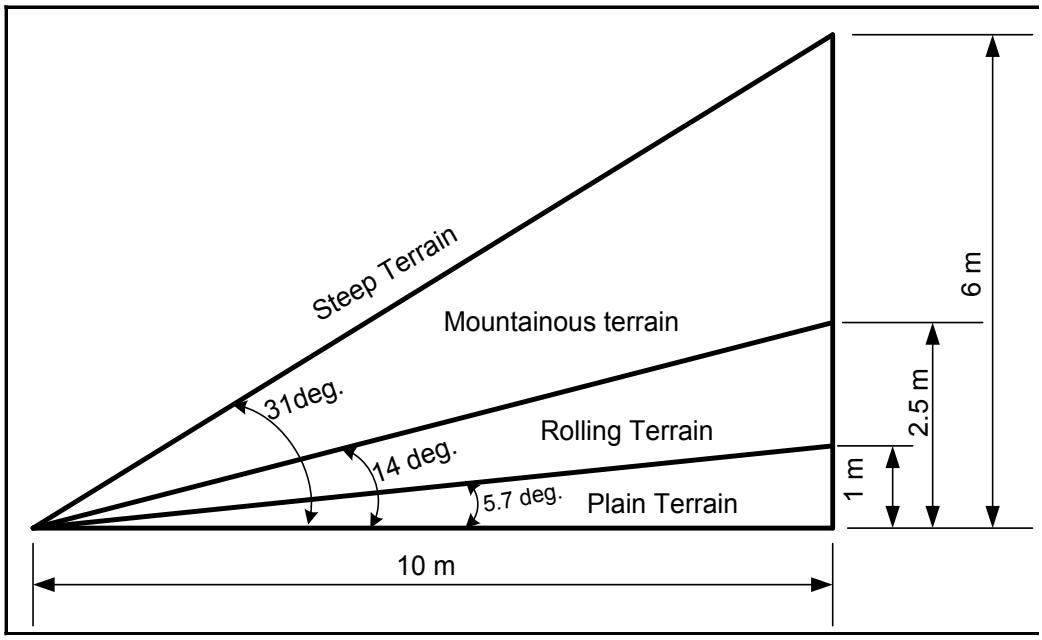
Major factors which control the Geometric elements are :

- Topography
- Design vehicle
- Design speed
- Traffic factors
- Driver & road user behavior
- Environmental factors
- Economical factors

Terrain Classification:

Class	Terrain type	Percent Cross-slope
1	Plain	0 to 10
2	Rolling	>10 to 25
3	Hilly/Mountainous	>25 to 60
4	Steep	>60

Terrain Classification:



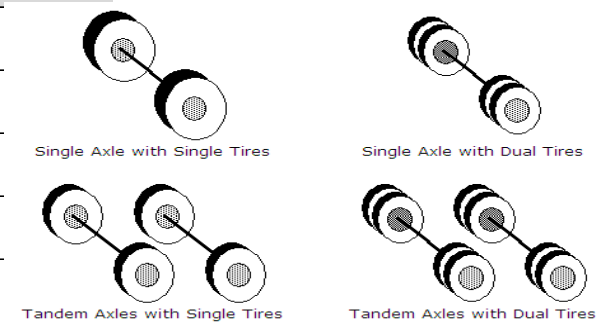
Design Vehicles:

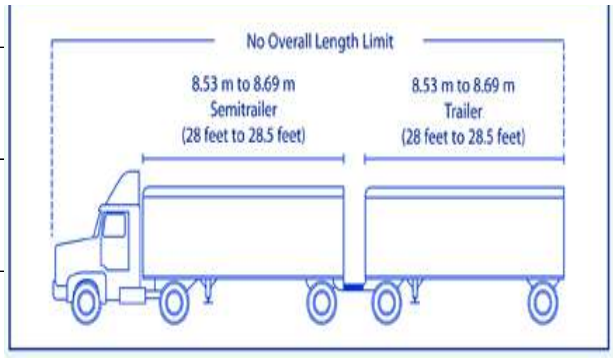
The vehicle characteristics affecting the road design are as:

- **Width of the vehicle:** width of traffic lane, width of shoulder, width of parking space;
- **The height of vehicle:** clearance to be provided to overhead structures ;
- **Overall length of vehicle:** design of horizontal curves, valley curves, safety regulations;
- **Vehicle loads:** bridge design, pavement thickness, design of ruling gradients
- **Vehicle speed:** superelevation, limiting radius, sight distances, width of pavement on straights and curves, width of shoulder, intersection design, traffic capacity of a lane.

Design Vehicles:

Dimensions	Vehicle type	Maximum dimensions, m
Width	All	2.5
Height	Single decked vehicle	3.8 – 4.2
	Double decked vehicle	4.75
Length	Single unit with two axle	11.00
	Single unit with more than two axle	12.00
	Tractor semi-trailer combination	16.00
	Tractor Trailer combination	18.00





Weight of the vehicles:

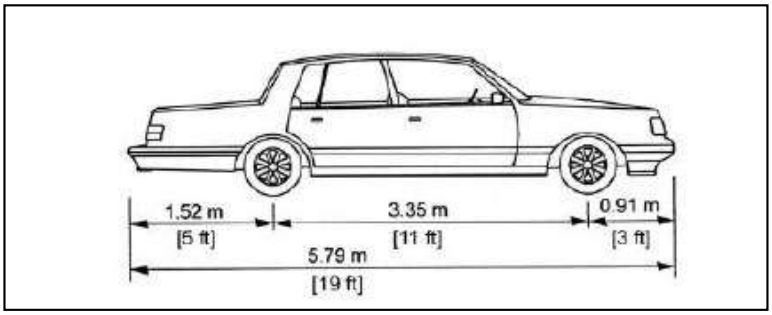
IRC suggests that **single axle load should not exceed 10.2 tonnes (102 kN) and for tandem axle 18 tonnes (180 kN).** The gross load of any vehicle or combination of vehicles should not exceed the weight worked out by the following formula:

$$W = 1525(L + 7.3) - 14.7L^2$$

Where, W is the gross weight of the vehicle in kg, L is the distance between the extreme axles in m.

Minimum turning Paths (at 15 Kmph):

The principal dimensions affecting design are the minimum centerline turning radius (CTR), the out-to-out track width, the wheelbase, and the path of the inner rear tire. Turning template of a typical passenger car is shown in the figure below.



Design speed:

Highway type	Terrain	Design speed, Km/h
National highway	Level	120
	Rolling	80
	Mountainous	50
	Steep	40
Feeder Road	Level	100
	Rolling	60
	Mountainous	40
	Steep	30

Design Volume

S/N	Highway Category	Design Capacity in both direction		
		Veh./hr	Veh/day	(PCU/day)
1	**Single lane black-topped**			
	Plain terrain	100	1000	2000
	Rolling terrain	90	900	1800
	Mountainous terrain	90	900	1800
	Steep terrain	70	700	1400
2	**Single lane water bound**			
	Plain terrain	90	900	1800
	Rolling terrain	80	800	1600
	Mountainous terrain	75	750	1500
	Steep terrain	40	400	800
3	**Intermediate lane black-topped** (carriageway 5 to 6 m)			
	Plain terrain	300	3000	6000
	Rolling terrain	285	2850	5700
	Mountainous terrain	260	2600	5200
	Steep terrain	225	2250	4500
4	**Two lane black topped**			
	Plain terrain	750	7500	15000
	Rolling terrain	500	5000	10000
	Mountainous terrain	350	3500	7000
	Steep terrain	250	2500	5000
5	**Four lane divided carriageway**			
	Plain terrain	5000	50000	100,000
	Rolling terrain	4000	40000	80,000

Environmental considerations :

It is essential that the highway be considered as an element of the **total environment**. The term *"environment*," as used here refers to the totality of humankind's surroundings: social, physical, natural, and aesthetic. It includes the human, animal, and plant communities and the forces that act on all three.

Traffic Factors: Pedestrian considerations

- Walking speed
- Walkway capacities
- Level of Service of pedestrian walkways
- Pedestrian at intersections
- Consideration of disabled persons

Traffic Factors: Bicycle Facility

- Safety for bicycle users,
- Types of carriageway for bicycle-way,
- Bicycle-safe drainage grades
- Adjusting manhole covers to the grade
- Maintaining a smooth, clean riding surface

Economic considerations:

Highway economics is concerned with the cost of a proposed improvement and the benefits resulting from it. Final design decisions on the proposed projects are supported by the economic analysis.

Elements of Geometric Design :

1. Elements of cross section

- Pavement surface & characteristics
- Traffic lane, carriageway, shoulder
- Camber
- Extra widening of pavement
- Super elevation
- Sight distance across the road

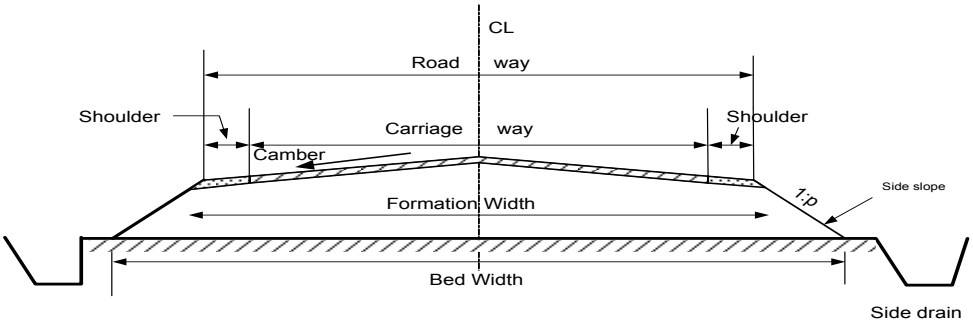
2.Elements of horizontal alignment

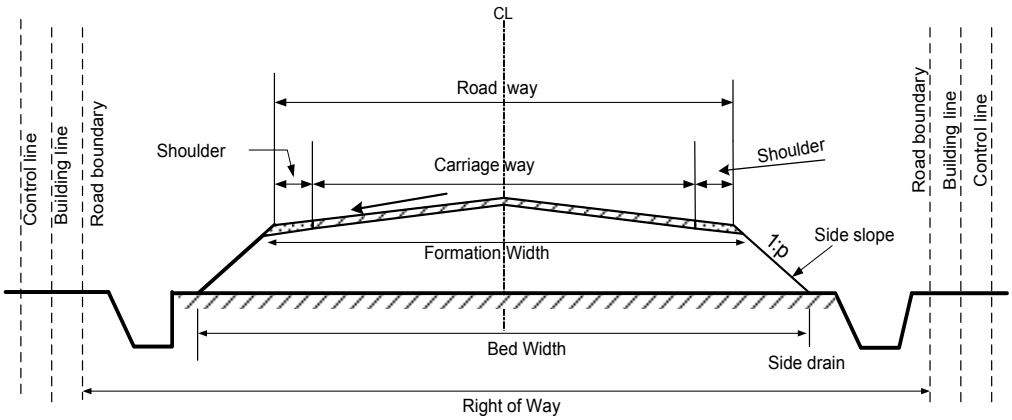
- Review of turning angle
- Horizontal curvature
- Transition curve
- Sight distance along the road plan

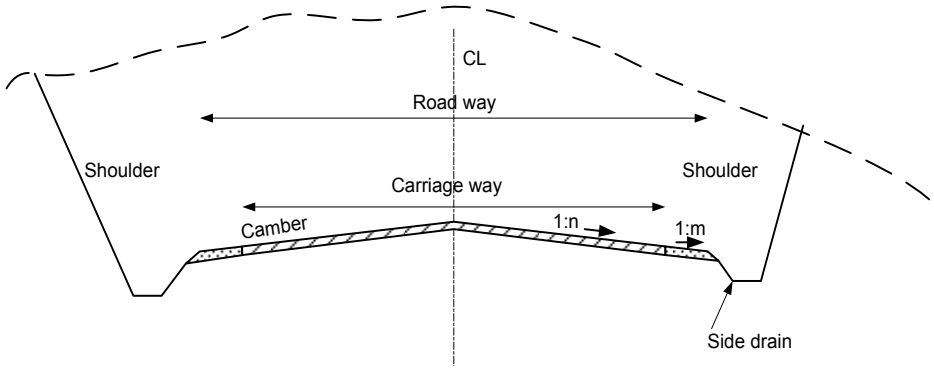
3. Element of vertical alignment

- Gradient
- Vertical curves
- Sight distance along the road profile

Elements of cross section



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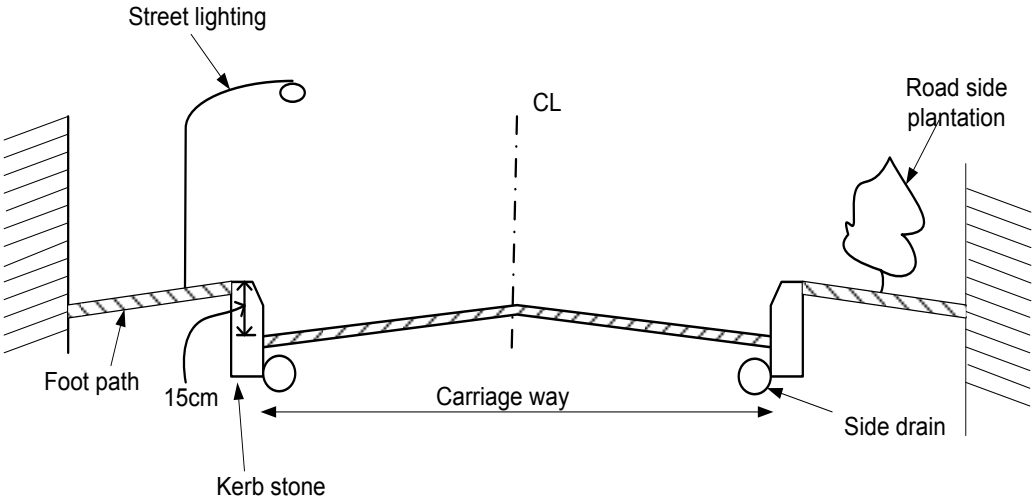
Road way
Shoulder
Shoulder
Carriage way
Camber
1:n
1:m
Side drain


Street lighting
CL
Road side plantation
Foot path
15cm
Carriage way
Side drain
Kerb stone

Cross Section Elements:

Pavement Surface & Characteristics: Important surface characteristics of pavements are friction, unevenness, light reflecting characteristics and drainage of surface.

Friction: Friction between vehicle tyre and pavement surface affect of the operating speed and distance required in stopping and accelerating the vehicle. When a vehicle negotiates the horizontal curve, the lateral friction developed counteracts the centrifugal force and thus governs the safe operating speed.

For the calculation of stopping sight distances, NRS recommends coefficient of friction as: **0.42 at the speed of 20 km/h and 0.28 at the speed of 120 km/h**. Coefficient of side friction for the superelevation is taken as **0.17 and 0.12 for the speed of 30 km/h and 120 km/h** respectively. The ranges of coefficients are distributed uniformly for other values of speed.

Pavement unevenness:

Pavement unevenness affects vehicle operation cost, comfort, safety and wear and tear of tyres and other moving parts.

Pavement unevenness is measured in terms of unevenness index, which is cumulative measure of vertical undulations of the pavement surface recorded per unit horizontal length (mm/km). An unevenness index value less than **1500 mm/km is considered as good, a value less than 2500 mm/km is satisfactory up to speed of 100 kmph and values greater than 3200 mm/km is considered as uncomfortable even for 55 Kmph**23

Light reflecting characteristics:

Light reflecting characteristics of the pavement surface increase the night visibility. The glare caused by the **reflection of head light considerably high on wet pavement surface than dry surface**.

- White roads have good visibility at night, but caused glare during day time
- Black roads has no glare during day, but has poor visibility at night
- Concrete roads has better visibility and less glare

Carriage way width and number of lane:

Width of the carriage way or the width of the pavement depends on the width of the traffic lane and number of lanes. Width of a traffic lane depends on the width of the vehicle and the clearance. Side clearance improves operating speed and safety. The maximum permissible width of a vehicle is **2.44m** and the desirable side clearance for single lane traffic is **0.68 m**. This requires minimum of lane width of **3.75** m for a single lane road. However, the side clearance required is about **0.53 m**, on both side and **1.06** m in the center. Therefore, a two lane road requires minimum of **3.5 meter** for each lane.

According to NRS:

Width of carriage way ,m			
Single lane	**Intermediate lane**	**Two lanes**	**Multilane carriage way (width per lane)**
3.8/3.5	5.5 (5.0-6.0)	7.0	3.5

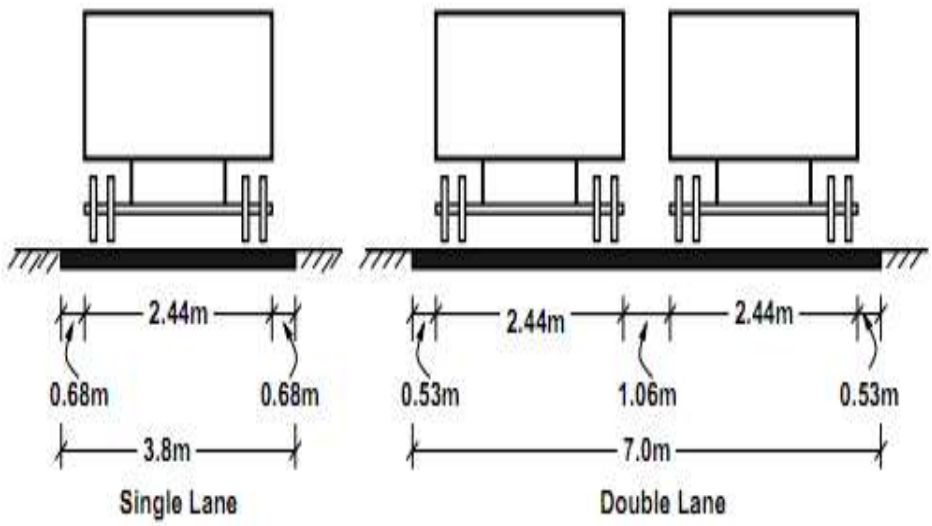


Figure 12:2: Lane width for single and two lane roads

Number of Lane:

Number of traffic lane is the function of Design hourly volume and the capacity of the traffic lane. Number of traffic lane can be found by using the formula below:

$$n = \frac{N}{C} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (I)$$

$$C = \frac{1000V}{S} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (II$$

Where, N is the design hourly traffic volume, veh/hr; C is the traffic capacity of a single lane; V is design speed Kmph; S is the average spacing of vehicles in m (s=V*tr+6.1)m.

Similarly, carriage way width can be calculated by using the following relationship. It is that strip of road which is considered for the movement of vehicular traffic.

$$C_w = T_w n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (III)$$

Where, T_W is width of traffic lane; n is the number of traffic lane.

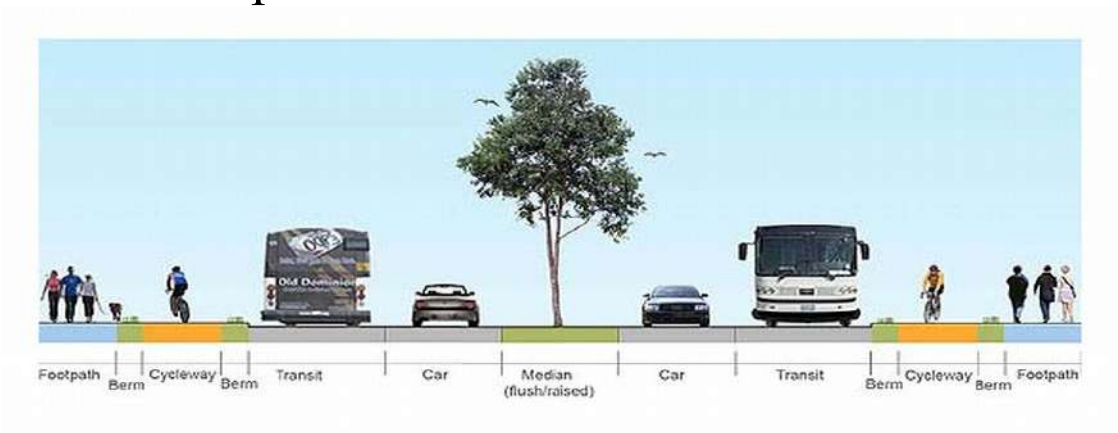
Road Margin:

Shoulder: Shoulder is the portion of road way on either side of the carriage way which is **periodically used for overtaking, parking or repairing vehicles, fixing traffic sign and signal, stacking construction material**. Well maintained shoulder increases the life time of pavement.

Type of carriage way	Total shoulder width; m (both side included)
Two and four lanes (black topped)	4.0 to 6.0
Single lane (surface dressed)	4.0 to 5.0
Single lane (gravelled surface)	3.0 to 5.0

Note: Lateral slops on shoulder 5% for gravel and 8% for turf.

Median Strip: It is the grassy or paved area that divides a highway so that traffic going in one direction is kept separate from traffic going in the opposite direction. The glare from the opposing vehicle can also be prevented from the median strip. Width=0.5m-2.5m



Cycle tracks: Cycle tracks are provided in urban areas when the volume of cycle traffic on the road is very high. Minimum width for cycle track should be **kept 2 m and it may be increased by 1 m for each additional cycle lane**.

Footpaths or sidewalks: These are exclusive "Right of Way" to pedestrians, especially in urban areas. They are provided for the safety of the pedestrians when both the pedestrian traffic and vehicular traffic is high. Minimum width is **1.5 meter and may be increased based on the traffic**. The footpath should be either as smooth as the pavement or smoother than that to induce the pedestrian to use the footpath.

NRS recommendation for sidewalk: In urban areas, the sidewalk should be provided as per the number of pedestrians estimated for future. **Usually a 60 cm width should be provided for a pedestrian density of 30 pedestrian /min, subject to a minimum sidewalk of 2.5 m on each side of carriageway.**

Guard rails: Provided at the edge of the shoulder when the road is constructed on a fill so that the vehicles are prevented from running off the embankment, especially when the **height of the fill exceeds 3 m**.

Embankment slopes: It should be as flat as possible for the purpose of safe traffic movement and also for aesthetic reasons. However, from the slope stability point of view a steeper slope may be possible, it may be kept as flat as permitted by economic considerations.

Drainage: The pavement surface should be absolutely impermeable to prevent seepage of water into the pavement layers. **Minimum 0.5%** slope should be adopted.

Right of way: Right of way (ROW) or land width is the width of land acquired for the road, along its alignment. It should be adequate to accommodate all the cross-sectional elements of the highway and may reasonably provide for future development. The right of way width is governed by:

Width of formation: It depends on the category of the highway and width of roadway and road margins.

Height of embankment or depth of cutting: It is governed by the topography and the vertical alignment.

Side slopes of embankment or cutting: It depends on the height of the slope, soil type etc.

Drainage system and their size which depends on rainfall, topography etc.

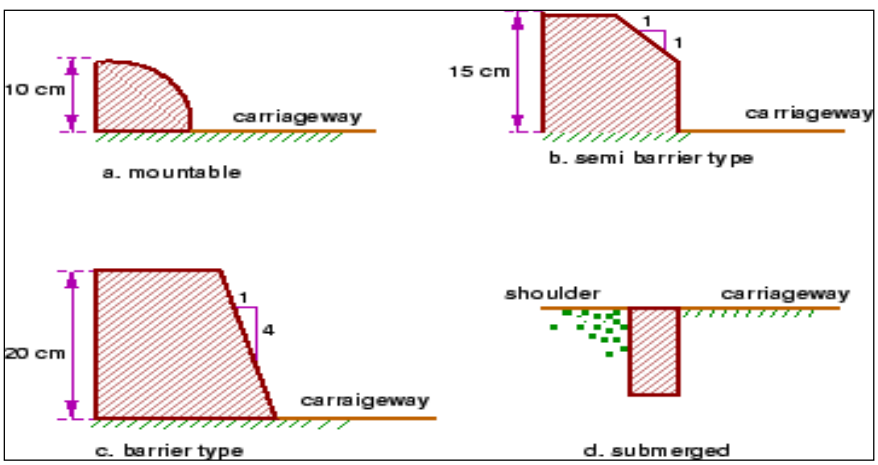
Sight distance considerations: On curves there is restriction to the visibility on the inner side of the curve due to the presence of some obstructions like building structures etc.

NRS recommends the minimum width of Right of way as in the table below.

Type of Road	Minimum Right of way, m	Building line, m
National Highway	50 (25m on either side of the road center line)	62
Feeder Road	30 (15m on either side of the road center line)	42
District Road	20 (10m on either side of the road center line)	32

Kerbs:

Kerbs indicate the boundary between the carriage way and the shoulder or islands or footpaths. Different types of kerbs are shown in the figure below (IRC recommendation).



Camber: Camber or cant is the cross slope provided to raise middle of the road surface in the transverse direction to drain off rain water from road surface. The objectives of providing camber are:

- Surface protection especially for gravel and bituminous roads
- Sub-grade protection by proper drainage
- Quick drying of pavement which in turn increases safety

Too steep slope is undesirable for road will erode the surface. Camber is measured in *1 in n or n%* (eg. 1 in 50 or 2%). Amount of camber mainly depend upon amount of rainfall in the area and type of road surface.

Disadvantages of steep camber

- Transverse tilt of vehicles
- Uncomfortable
- Unequal wear of tyres
- Discomfort when crossing the crown during overtaking operation
- Formation of cross ruts due to rapid flow of water
- Tendency of most of the vehicles to travel along the center line.

Type of road surface	Camber, percent
Earthen	5
Gravel	4
Bitumen	2.5
Cement Concrete	1.5-2

NRS recommendation for the values of camber

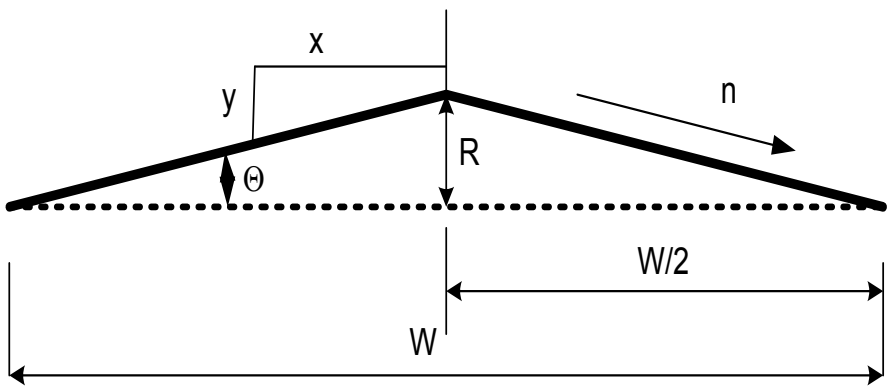


Figure : Straight line camber

$$n = \tan\theta = \frac{R}{W/2} = \frac{2R}{W}$$

$$\frac{2R}{W} = \frac{y}{x}$$

$$y = nx \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (IV)$$

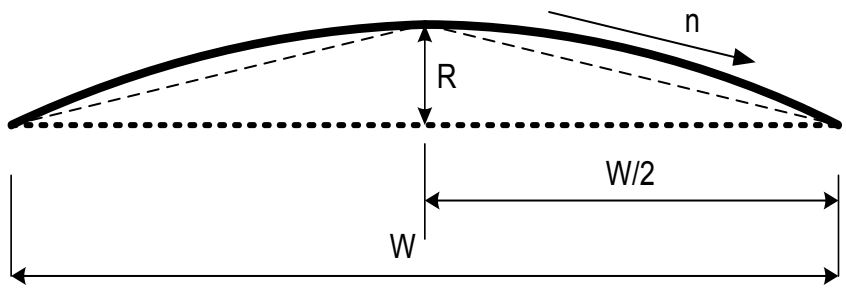


Figure : Parabolic type of camber

$$y = x^2$$

$$\frac{y}{x^2} = \frac{R}{(W/2)^2} = \frac{2R}{W} * \frac{2}{W}$$

$$n = \frac{2R}{W}$$

$$y = n\frac{2x^2}{W} = \frac{2nx^2}{W} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(V)$$

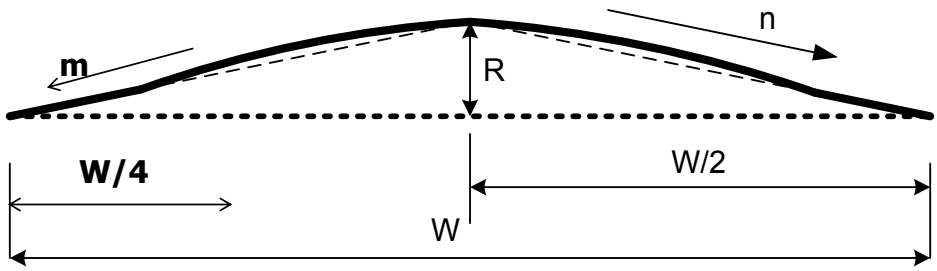


Figure :Composite type of camber

Tutorials:

1. In a region of heavy rainfall, a major district road of WBM pavement is to be constructed. If the width of road is 3.75m, find the height of the crown with respect to the edges. What would be the height of crown with respect to the edges if 7.5m wide bituminous concrete pavement is to be constructed.

2.The width of the pavement is 7.0m. If the centre line of the road has an elevation 0f 412.23m., find the elevation of the road at the edges of the pavement and at the centre of the lane for

a) Straight line camber is provided

b) Parabolic camber is provided

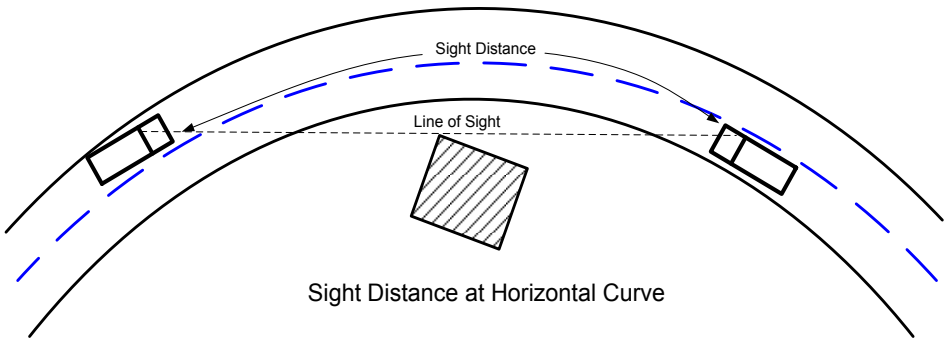
Assignment No:1

3. The centre line of double lane road has an elevation of 320m as recorded from longitudinal profile. The camber is 2.5% and cross-fall of shoulder is 5%. Calculate the elevation of road surface at centre of line edges of the pavement and road edge if shoulder is 1.5m wide if a) Straight line camber is provided. Take lane width equal to 3.5m

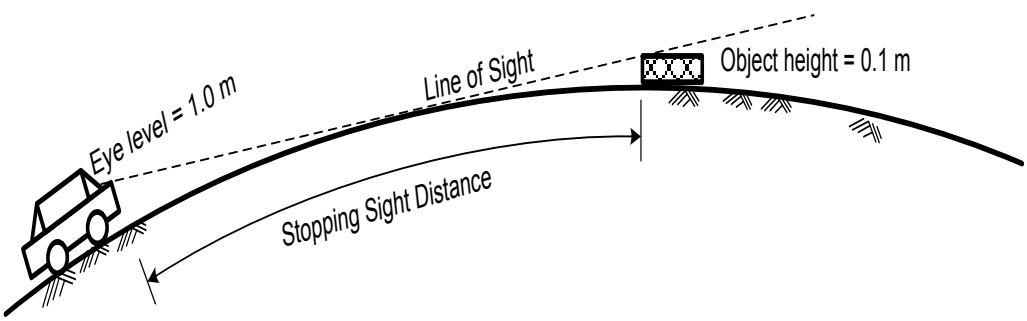
Sight Distance:

For operating a motor vehicle safely and efficiently, it is of utmost importance that drivers have the capability of seeing clearly ahead. Therefore, sight distance of sufficient length must be provided so that the drivers can operate and control their vehicles safely.

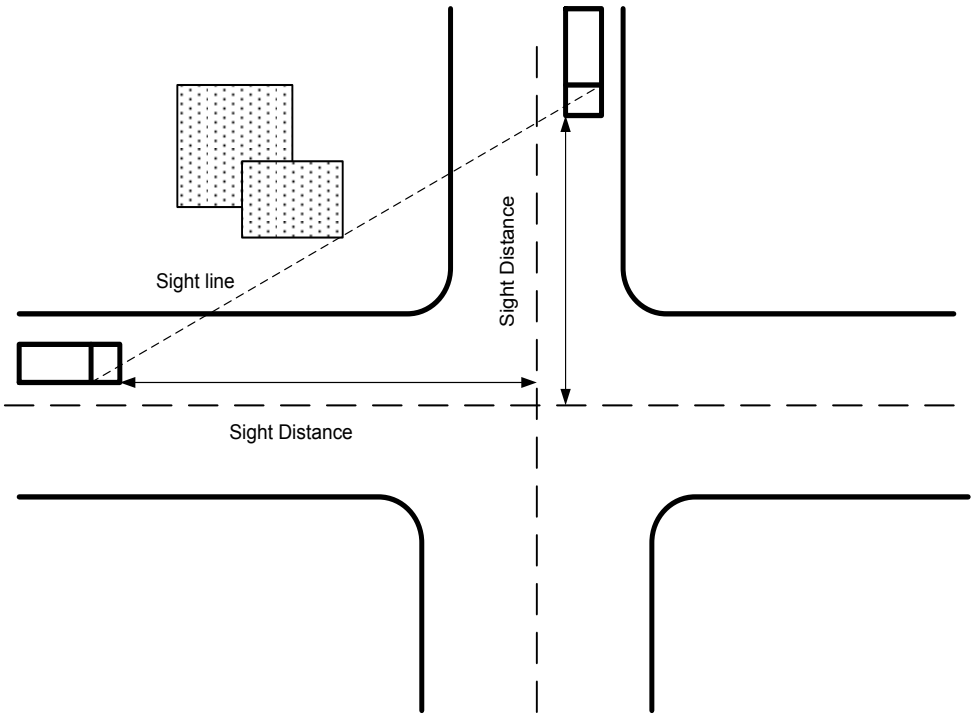
Sight distance available from a point is the actual distance along the road surface, which a driver from a specified height above the carriageway has visibility of stationary or moving objects. Restriction to sight distance may be caused at horizontal curves, by objects obstructing vision at the inner side of the road or at vertical summit curves or at intersections.



Sight Distance at Horizontal Curve



Sight Distance at vertical summmit curve



Sight Distance at Intersection

The standards for sight distance should satisfy the following three conditions:

- Driver traveling at the design speed has sufficient sight distance or length of road visible ahead to stop the vehicle, in case of any obstruction on the road ahead, without collision.
- Driver traveling at the design speed should be able to safely overtake, at reasonable intervals, the slower vehicle without causing obstruction or hazard to traffic of opposite direction.
- Driver entering an uncontrolled intersection (particularly unsignalized Intersection) has sufficient visibility to enable to take control the vehicle and to avoid collision with another vehicle.

Apart from the three situations mentioned above, the following sight distances are considered by the IRC in highway design:

- **Intermediate sight distance:** This is defined as twice the stopping sight distance. When overtaking sight distance cannot be provided, intermediate sight distance is provided to give limited overtaking opportunities to fast vehicles.
- **Head light sight distance:** This is the distance visible to a driver during night driving under the illumination of the vehicle head lights. This sight distance is critical at up-gradients and at the ascending stretch of the valley curves.

Stopping Sight Distance (SSD): The minimum sight distance available on a highway at any spot should be of sufficient length to stop a vehicle traveling at design speed, safely without collision with any other obstruction. The **absolute minimum sight** distance is therefore equal to the stopping sight distance, which is also sometimes called **non-passing sight distance**.

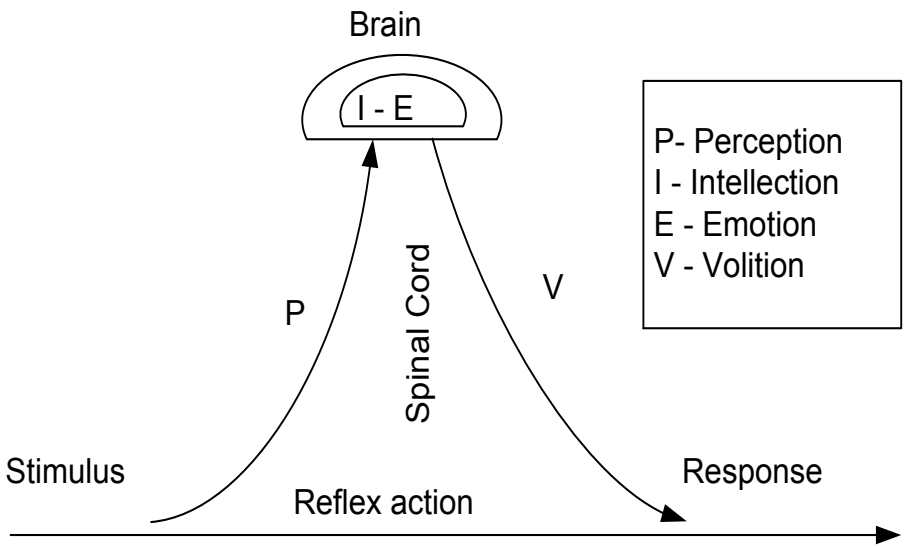
The sight distance available on a road to a driver at any instance depends on

- Features of the road ahead,
- Height of the drivers eye above the road surface.
- Height of the object above the road surface.

- NRS has suggested the height of eye level of drivers as 1.0 (1.2m) m and the height of the object as 0.10 m above the road surface.
- IRC recommendation: stopping distance available at a summit curve is that distance measured along the road surface at which an object of height 0.15 m can be seen by a driver where eye is at a height of 1.2 m above the road surface.

The distance within which a motor vehicle can be stopped depends upon the factors listed below :

- Total reaction time of the driver
- Speed of vehicle
- Efficiency of brakes
- Frictional resistance between the road and the tyres
- Gradient of the road



Reaction time & PIEV Process

For the calculation of stopping sight distances, NRS recommends coefficient of friction as: 0.42 at the speed of 20 km/h and 0.28 at the speed of 120 km/h.

Analysis of stopping distance:

The stopping distance of a vehicle is the sum of:

- The distance traveled by the vehicle during the total reaction time know as **lag distance**
- The distance traveled by the vehicle after the application of the brakes, to a dead stop position which is known as the **braking distance**.

Lag distance: During the total reaction time or PIEV time the vehicle may be assumed to proceed forward with a uniform speed at which the vehicle has been moving and this speed may be taken as the design speed. If ***'v'*** is the design speed in m/sec and ***'t'*** is the total reaction time of the driver in seconds, then the lag distance will be ***'v.t'*** metres. The NRS has recommended the total reaction time 2.5 secs.

Braking distance: Assuming a level road, the braking distance may be obtained by equating the work done in stopping the vehicle and the kinetic energy developed.

If F is the maximum frictional force developed and the braking distance is l, then **work done** against friction force in stopping the vehicle is $F \times l = f\ W\ l$, where W is the total weight of the vehicle.

The kinetic energy at the design speed of ***v m/sec*** will be

$$\frac{1}{2} m v^2 = \frac{W v^2}{2g}$$

$$fWl = \frac{W v^2}{2g}$$

$$or, l = \frac{v^2}{2gf}$$

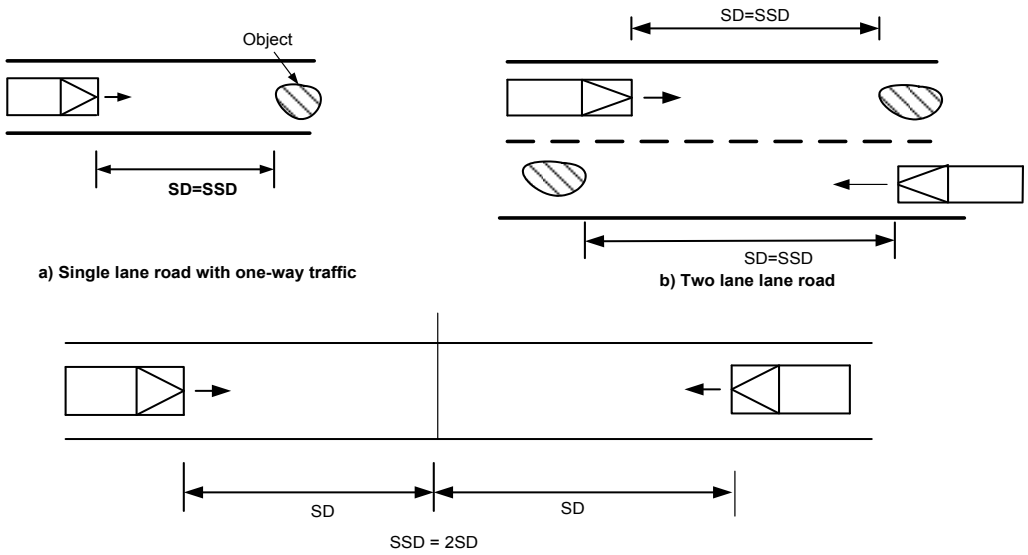
$$Stopping \text{ Distance} = \text{lag distance} + \text{braking distance}$$

$$\text{SD}, m = vt + \frac{v^2}{2gf} \text{.....} (VI)$$

Here, l = Braking distance; *v* = speed of vehicle, m/sec; *f* = Design coefficient of friction; *g* = acceleration due to gravity, 9.8 m/sec^2.

Stopping distance at slopes:

$$SD, m = vt + \frac{v^2}{2g(f \pm \frac{n}{100})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (VII)$$



a) Single lane road with one-way traffic

b) Two lane lane road

c) Single lane road with two-way traffic

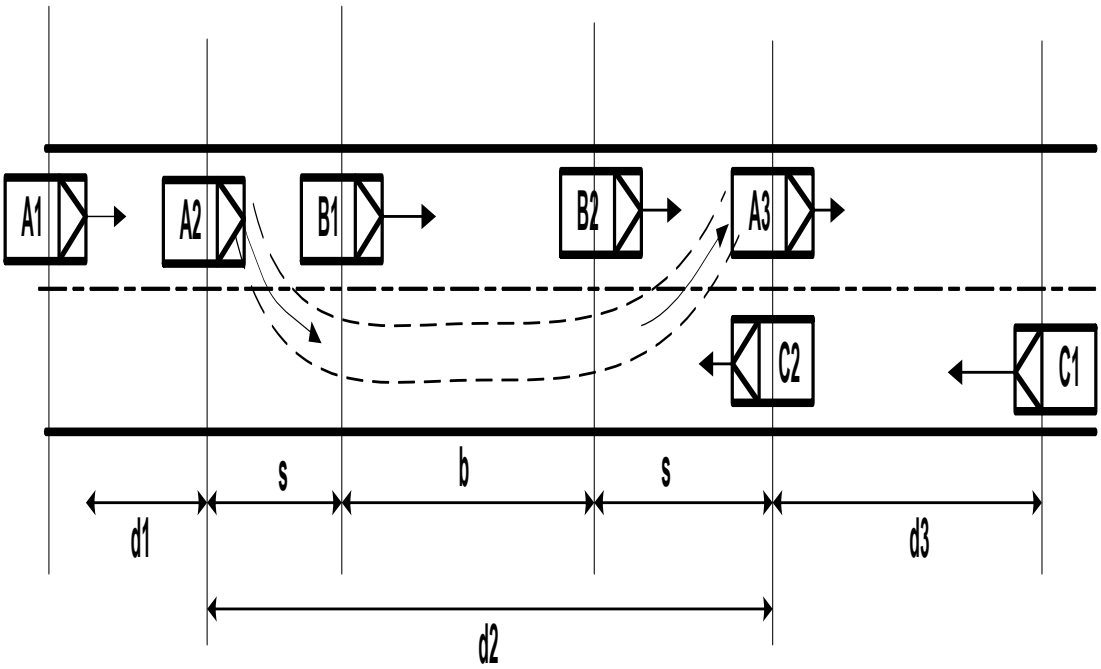
The safe stopping distance values calculated in the similar manner for various design speeds and recommended by NRS are given in Table below.

Design speed, km/h	Minimum stopping sight distance, m
120	200
100	145
80	110
60	85
50	65
40	45
30	30
20	20

Q. Calculate the safe stopping sight distance on a national highway in rolling terrain at an ascending gradient of 3% and brake efficiency of 80%. Assume relevant data as per NRS recommendation.

Overtaking Sight Distance (OSD):

The minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the traffic of opposite direction is known as the minimum overtaking sight distance (OSD) or the safe passing sight distance available. The overtaking sight distance (OSD) is the distance measured along the centre of the road which a driver with eye level 1.2 m above the road surface can see the top of an object 1.2 m above the road surface.



Overtaking Manoeuvre

Analysis of Overtaking Sight Distance : Figure shows the overtaking manoeuvre of vehicle **A** traveling at design speed, and another slow vehicle **B** on a two-lane road with two-way traffic. Third vehicle **C** comes from the opposite direction. The overtaking manoeuvre may be split up into three operations, thus dividing the overtaking sight distance into three parts, **d1, d2 and d3**.

- ***d1*** is the distance travelled by overtaking vehicle ***A*** during the reaction time ***t*** sec of the driver from position ***A1*** to ***A2***.
- ***d2*** is the distance travelled by the vehicle ***A*** from ***A2*** to ***A3*** during the actual overtaking operation, in time ***T*** sec.
- ***d3*** is the distance travelled by on-coming vehicle ***C*** from ***C1*** to ***C2*** during the overtaking operation of ***A***, i.e. ***T*** secs.

Certain assumptions are made in order to calculate the values of **d1, d2 and d3**.

In Figure **A** is the overtaking vehicle originally traveling at design speed **v**m/sec; ***B*** is the overtaken or slow moving vehicle moving with uniform speed $v_{\mathbf{b}}$ m/sec; **C** is a vehicle coming from opposite direction at the design speed **v**m/sec.

1. It may be assumed that the vehicle ***A*** is forced to reduce its speed to the speed $\boldsymbol{v_b}$ of the slow vehicle ***B*** and moves behind it allowing a space **s**, till there is an opportunity for safe overtaking operation. The distance traveled by the vehicle ***A*** during this reaction time is ***d1*** and is between the positions ***A1*** and ***A2***. This distance will be equal to $v_b \times t$ meter, where ***t*** is the reaction time of the driver in second.

$$d1 = v_b\ t \ \text{ m}$$

2. From position ***A2*** , the vehicle **A** starts accelerating, shifts to the adjoining lane, overtakes the vehicle ***B*** and shifts back to its original lane ahead of ***B*** in position ***A3*** in time **T** sec. The straight distance between the position ***A2*** and ***A3*** is taken as ***d2***. The minimum distance between position ***A2*** and ***B1*** may be taken as the minimum spacing ***s*** of the two vehicles while moving with the speed $\boldsymbol{v_b}$ m/sec. The minimum spacing between vehicles depends on their speed and is given by empirical formula.

$$s = (0.7v_b + 6.1) \text{ m}$$ vb in m/sec

The minimum distance between ***B2*** and ***A3*** may also be assumed equal to ***s*** as mentioned above. If the taken by vehicle ***A*** for the overtaking operation from position ***A2*** to ***A3*** is *T* second, the distance covered by the slow vehicle *B* from position **B1 to B2** traveling at a speed of $\boldsymbol{v_b}$ m/sec.

$$b = v_b T \text{ m} \qquad d2 = (b + 2s), \text{m}$$

$$d2 = (b + 2s) = v_b \mathrm{T} + \frac{1}{2} \mathrm{aT}^2$$

$$b = v_b T,\ \ 2s = \frac{1}{2} a T^2$$

$$T = \sqrt{\frac{4s}{a}}$$

$$d2 = (v_b T + 2s)\ \mathrm{m}$$

3. The distance traveled by vehicle ***C*** moving at design speed ***v*** m/sec during the overtaking operation of vehicle ***A*** i.e. during time ***T*** is the distance ***d2*** between positions C_1 to C_2.

$$d3 = vT, \text{m}$$

Thus,

$$OSD = d1 + d2 + d3 = v_b t + v_b T + 2s + vT, \text{m} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (VIII)$$

Note: In case the speed of overtaken vehicle v_b is not given, the same may be assumed as $v_b = (v - 4.5)$ m/sec and *v* is the design speed in m/sec.

Speed; km/hr	Speed; m/sec	Max. overtaken acceleration (a); m/sec^2
25	6.93	1.41
30	8.34	1.30
40	11.10	1.24
50	13.86	1.11
65	18.00	0.92
80	22.20	0.72
100	27.80	0.53

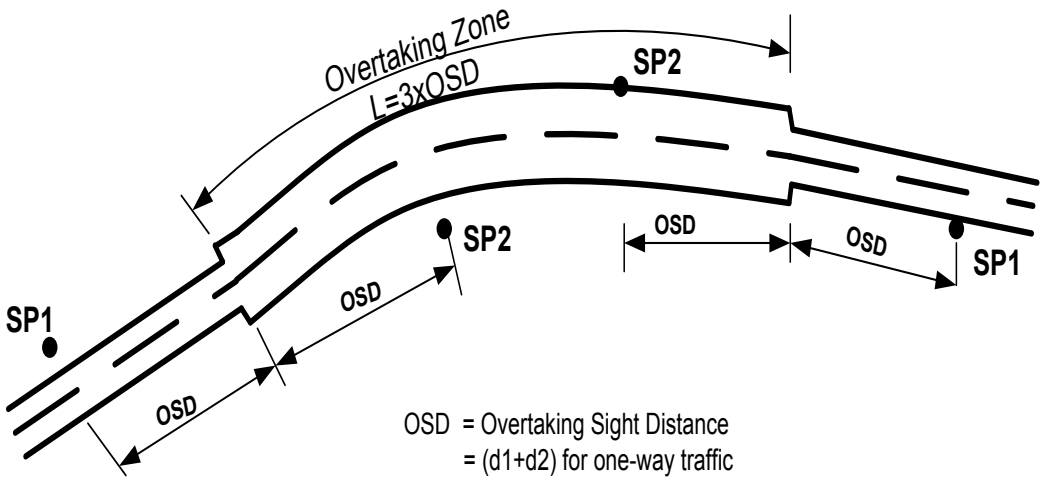
Note:

1. At overtaking sections, the minimum overtaking distance should be $(d_1 + d_2 + d_3)$ when two-way traffic exists.

2. On divided highways and on roads with one way traffic regulation, the overtaking distance should be $(d_1 + d_2)$ as no vehicle is expected from the opposite direction.

Overtaking Zone:

1. Minimum Length of Overtaking Zone= 3* OSD
2 . Desirable Length of Overtaking Zone= 5* OSD



OSD = Overtaking Sight Distance
= (d1+d2) for one-way traffic
= (d1+d2+d3) for two-way traffic
SP1 = Sign Post 'Overtaking Zone Ahead'
SP2 = Sign Post 'End of Overtaking Zone'

Tutorials:

1. A vehicle is moving at a speed of 90 Kmph decided to overtake another slow moving vehicle. Calculate the safe overtaking sight distance. Considering the following:

a. Two Lane road with two way traffic.

b. One lane road with one way traffic. Assume all necessary data. Take a=3.6 Kmph/sec.

2. The speed of the overtaking and overtaken vehicles are 60Kmph and 30 Kmph respectively on a two way traffic road. If the acceleration of overtaking vehicle is 1m/sec^2. Calculate the following:

a. Safe overtaking sight distance

b. Minimum and desirable length of overtaking zone

Horizontal Curves:

A horizontal curve in a highway is the curve in plan to provide change in direction to the central line of a road. When a vehicle traverses a horizontal curve, the centrifugal force acts horizontally outwards through the centre of gravity of the vehicle.

The centrifugal force developed depends on the radius of the horizontal curves and the speed of the vehicle negotiating the curve. This centrifugal force is counteracted by the transverse frictional resistance developed between the tire and the pavement surface. Centrifugal force P is given by the equation:

$$P = \frac{Wv^2}{gR}$$

The ratio of the centrifugal force to the weight of the vehicle, ***P/W*** is known as the ***centrifugal ratio*** or the ***impact factor***. The centrifuge ratio is thus equal to v^2/gR.

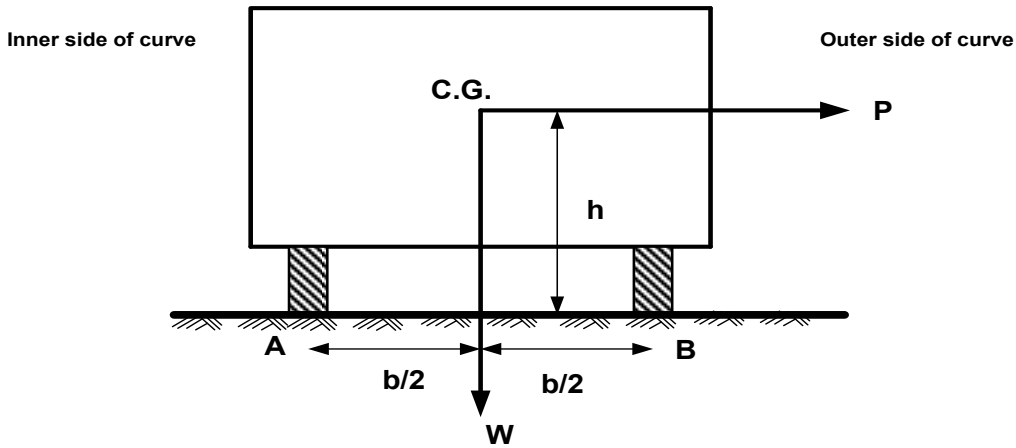
The centrifugal force acting on a vehicle negotiating a horizontal curve has two effects;

- **Tendency to overturn the vehicle outwards about the outer wheels**
- **Tendency to skid the vehicle laterally, outwards**

The analysis of stability of those two conditions against overturning and transverse skidding of the vehicles negotiating horizontal curves without Super-elevation are given below:

1. Overturning effect:

The centrifugal force that tends the vehicle to overturn about the outer wheels ***B*** on horizontal curve without super-elevation is illustrated in figure below.

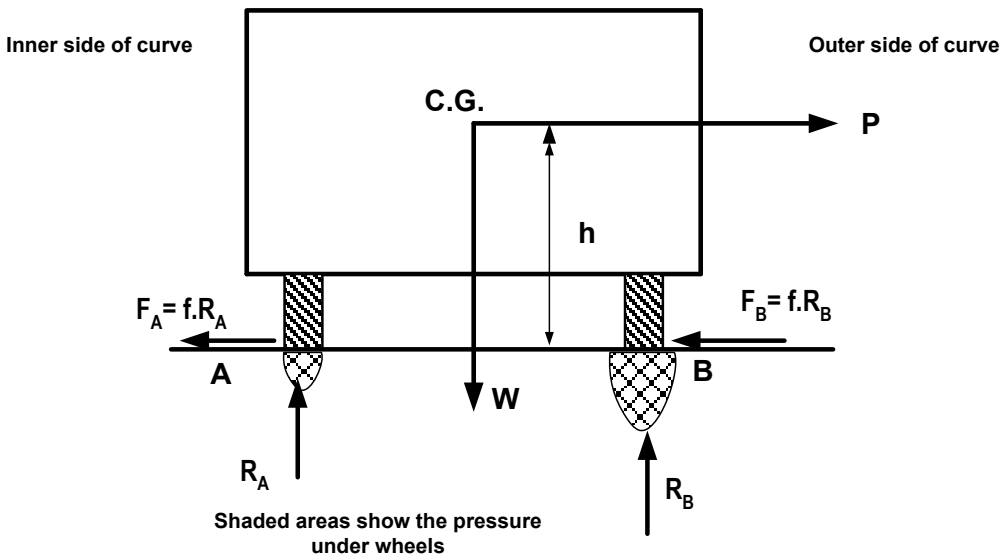


The **overturning moment** due to centrifugal force **P** is **P. h**; this is resisted by the **restoring moment** due to weight of the vehicle **W** and is equal to ***W.b/2***, where **h** is the height of the centre of the gravity of the vehicle above the road surface and **b** is the width of the wheel base or the wheel track of the vehicle.

The equilibrium condition for overturning will occur when ***P.h*** = ***W.b/2***, or when ***P/W*** = ***b/2h.*** **This means that there is danger of overturning when the centrifugal ratio *P/W* or v^2/gR attains a values of *b/2h*.**

2. *Transverse skidding effect:*

The centrifugal force developed has also the tendency to push the vehicle outwards in the transverse direction. If the centrifugal force **P** developed exceeds the maximum possible transverse skid resistance due to the friction, the vehicle will start skidding in the transverse direction.



The equilibrium condition for the transverse skid resistance developed is given by:

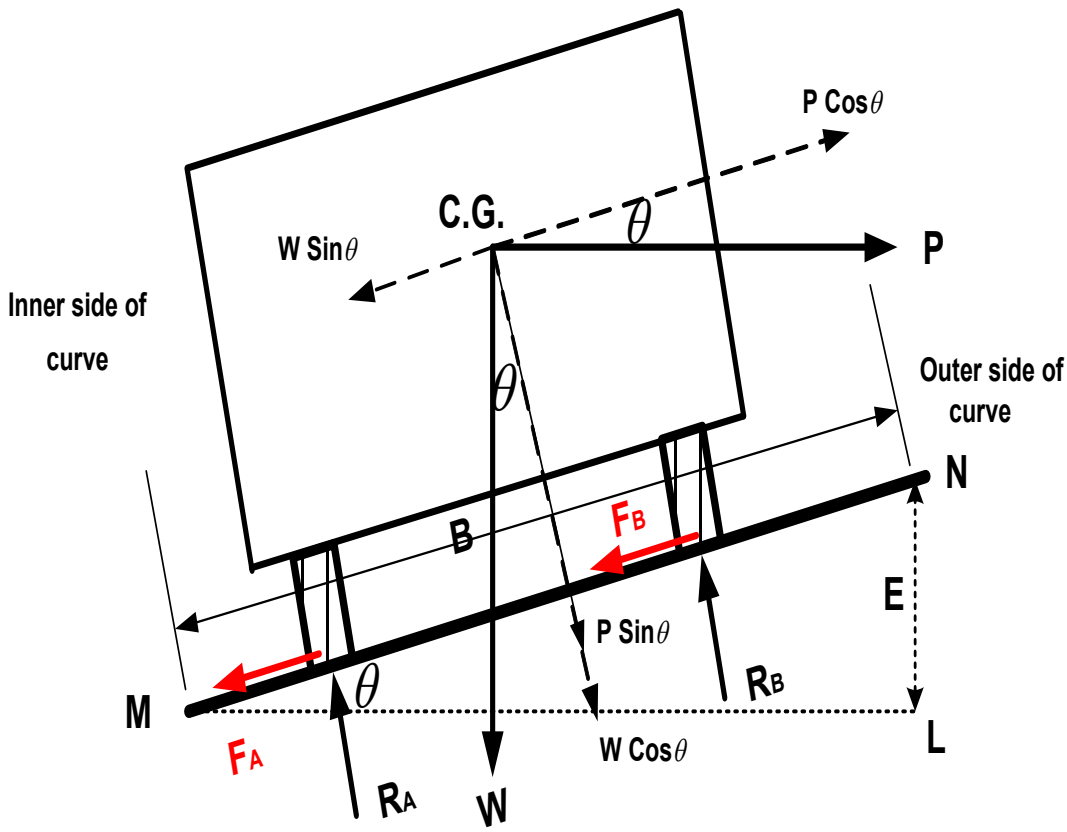
$$P = F_A + F_B = f(R_A + R_B) = fW$$

Since $P = f\ W$, the centrifugal ratio P/W is equal to 'f '. **In other words when the centrifugal ratio attains a value equal to the coefficient of lateral friction *(f)* there is a danger of lateral skidding.**

Thus to avoid overturning and lateral skidding on a horizontal curve, the centrifugal ratio should always be less than $b/2h$ and also 'f'.

If the pavement is kept horizontal across the alignment, the pressure on the outer wheels will be higher due to the centrifugal force acting outwards and hence the reaction $\boldsymbol{R_B}$ at the outer wheel would be higher. When the limiting equilibrium condition for overturning occurs the pressure at the inner wheels becomes equal to zero. At that condition the vehicle will overturn and skid.

Super-elevation: In order to counteract the effect of centrifugal force and to reduce the tendency of the vehicle to overturn or skid, the outer edge of the pavement is raised with respect to the inner edge, thus providing a transverse slope throughout the length of the horizontal curve, this transverse inclination to the pavement surface is known as Super-elevation or cant or banking. The Super-elevation ***'e'*** is expressed as the ratio of the height of outer edge with respect to the horizontal width. 85


P Cosθ
C.G.
θ
W Sinθ
P
Inner side of curve
θ
Outer side of curve
N
B
F_B
E
P Sinθ
R_B
M
θ
L
F_A
W Cosθ
R_A
W

$$e = \frac{NL}{ML} = \tan\theta$$

In practice the inclination $\boldsymbol{\theta}$ with the horizontal is very small and the value of $\boldsymbol{\tan\theta}$ seldom exceeds 0.07. Therefore the value of than $\boldsymbol{\theta}$ is practically equal to $\boldsymbol{\sin\theta}$. Hence, $\boldsymbol{e = \tan\theta = \sin\theta = E/B}$ which is measured as the ratio of the relative elevation of the outer edge, $\boldsymbol{E}$ to width of pavement, $\boldsymbol{B}$.

If e is the Super-elevation rate and $\boldsymbol{E}$ is the total super elevated height of outer edge, the total rise in outer edge of the pavement with respect to the inner edge = $\boldsymbol{NL = E = eB}$.

Analysis of Super-elevation:

The force acting on the vehicle while moving on a circular curve of radius ***R*** meters, and at speed of ***v*** m/sec are:

- The centrifugal force $P = Wv^2/gR$ acting horizontal outwards through the centre of gravity
- The weight ***W*** of the vehicle acting vertically downloads through the CG
- The frictional force developed between the wheels and the pavement surface counteracts transversely along the pavement surface

The centrifugal force is thus opposed by corresponding value of the friction developed and by a component of the force of gravity due to the Super-elevation provided.

For equilibrium condition,

$$PCos\,\theta = WSin\,\theta + F_A + F_B$$

$$PCos\,\theta = WSin\,\theta + f\,(R_{A+}R_B) = WSin\,\theta + f\,(WCos\,\theta + PSin\,\theta)$$

$$P(Cos\,\theta - fSin\,\theta) = WSin\,\theta + fWCos\,\theta$$

Dividing by W cosΘ,

$$\frac{P}{W}(1 - f\tan\theta) = \tan\theta + f$$

$$\frac{P}{W} = \frac{\tan\theta + f}{1 - f\tan\theta}$$

The value of coefficient of lateral friction, ***'f'*** is taken as ***0.15*** for design purposes. The value of **tan Θ** or transverse slope due to Super-elevation seldom exceeds **0.07 or about 1/15**. Hence the value of **f tan Θ** is about **0.01**. Thus the value of **(1- f tan Θ)** in the above equation is equal to **0.99** and may be approximate to **1.0**.

$$\frac{P}{W} \approx \tan\theta + f = e + f$$

$$\frac{P}{W} = \frac{v^2}{gR}$$

$$e + f = \frac{v^2}{gR} \text{.....} (IX)$$

Where,

e = rate of Super-elevation = tan Θ

f = design value of lateral friction coefficient = 0.15

v = speed of the vehicle, m/sec

R = radius of the horizontal curve, m

g = acceleration due to gravity = 9.8 m/sec^2

1. If **f=0**, **e=v²/gR**, the pressures on the outer and inner wheels will be equal; but this will result in a very high value of Super-elevation. (equilibrium Super-elevation)

2. If **e=0**, **f=v²/gR,** the frictional force has to fully counteract the centrifugal ratio.

Numerical Example :

1. The radius of a horizontal circular curve is **100 m**. The design speed is **50 Kmph** and the design coefficient of lateral friction is **0.15**.

a. Calculate the super-elevation required if full lateral friction is assumed to develop

b. Calculate the coefficient of friction needed if no super-elevation is provided

c. Calculate the equilibrium super-elevation

Maximum super-elevation:

Super-elevation. IRC recommends the maximum values of super-elevation as:

1. e_{max} = 7% in plain and rolling terrain and in snowbound areas

2. e_{max} = 10% on hill roads not bound by snow

3. e_{max} =4% on urban roads

Minimum super-elevation:

Design speed (Kmph)	Radius (meter) of horizontal curve for camber of :				
	4%	3%.	2.5%	2%	1.7%
20	50	60	70	90	100
25	70	90	110	140	150
30	100	130	160	200	240
35	140	180	220	270	320
40	180	240	280	350	420
50	280	370	450	550	650
60	470	620	750	950	1100
80	700	950	1100	1400	1700
100	1100	1500	1800	2200	2600

Super-elevation design:

Steps for super-elevation design:

Step 1: The super-elevation for 75% of design speed is calculated neglecting friction

$$e = \frac{(0.75v)^2}{gR}$$

Step 2. If the calculated value of ***"e"*** is less than 7% or 0.07 the value so obtained is o.k. If the value of ***"e"*** exceeds 0.07 then provide the maximum super-elevation = 0.07 and proceed with steps 3 or 4.

Step 3: Check the ***"f"*** for the maximum value of e= 0.07. $f = \frac{v^2}{gR} - e$

If the value of ***"f"*** thus calculated is less than 0.15 the super-elevation is (e=0.07) safe for the design speed. If not follow the step 4.

Step 4: The allowable speed (v_a m/sec) at the curve is calculated by considering the design coefficient of lateral friction and the maximum super-elevation,

$$v_a = \sqrt{0.22\, gR} = \sqrt{2.156R}\ m/sec$$

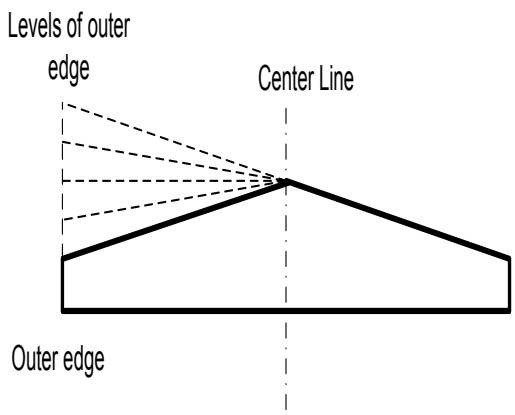
Numerical Example:

1. A two lane road with design speed **80 Kmph** has horizontal curve of radius **480m**. Design the rate of super-elevation for mixed traffic. By how much should the outer edge of the pavement be raises with respect to the centerline. Assume the width of the pavement at the horizontal curve is **7.5m**.

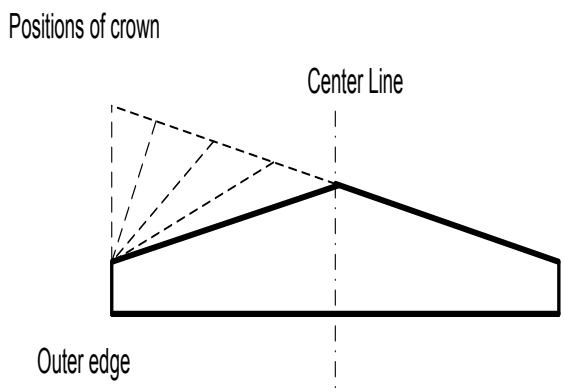
2. The design speed of a highway is **80Kmph**. There is a horizontal curve of radius **200m**. Calculate the super-elevation needed to maintain this speed. If the maximum super-elevation of **0.07** is not to be exceeded, calculate the maximum allowable speed on this horizontal curve. Safe limit of coefficient of friction is **0.15**.

Methods of introducing (building) super-elevation:

1.Elimination of crown of the camber: This may be done by two methods. In the first method, the outer half of the cross slope is rotated about the crown at a desired rate such that the surface falls on the same plane as the inner half and the elevation of the centre line is not altered.



Method I: Rotating outer edge about the crown

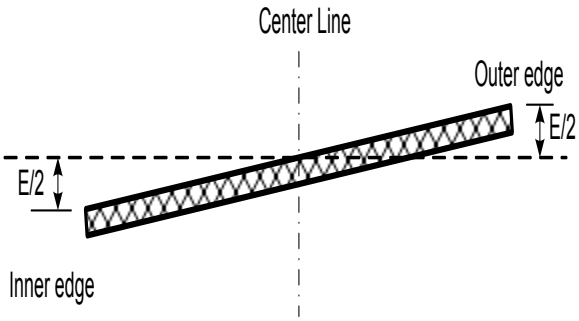


Method II: Shifting crown outwards (diagonal crown method)

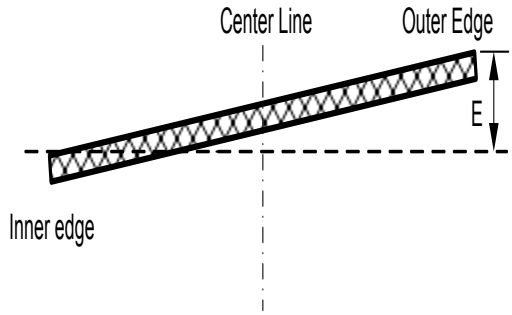
2. Super-elevation is gradually attained to its full value at the start of the circular curve: When the crown of the camber is eliminated, the Super-elevation available at this section is equal to the camber. But the Super-elevation to be provided at the beginning of circular curve may be greater than the camber (in many cases when the design Super-elevation is more than the minimum). Hence the pavement section will have to be rotated further till the desired super-elevation is obtained.

a. Center line rotation: By rotating the pavement cross section about the centre line, depressing the inner edge and raising the outer edge each by half the total amount of Super-elevation, i.e. by **E/2 with respect to the centre**.

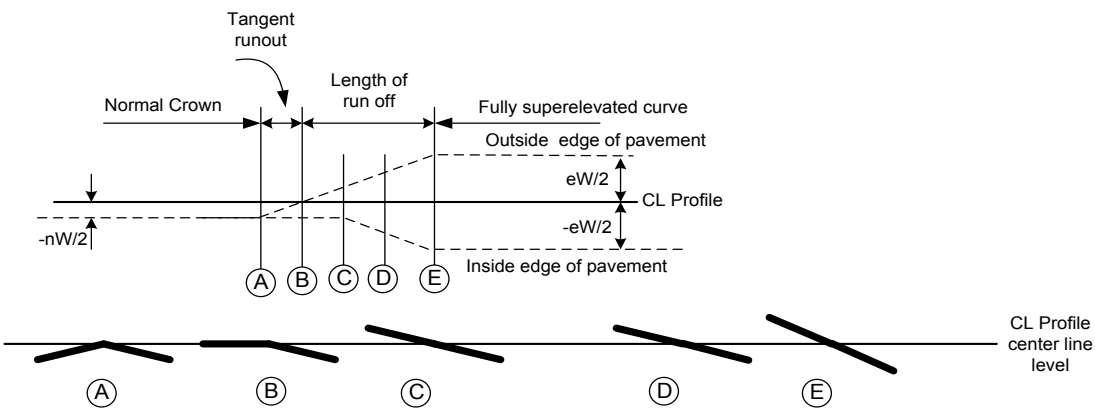
b. Inner edge rotation: By rotating the pavement cross section about the inner edge of the pavement section raising both the centre as well as the outer edge of the pavement such that the outer edge is raised by the full amount of super-elevation, **E with respect to the inner edge.**



Rotating about center line



Rotating about inner egde

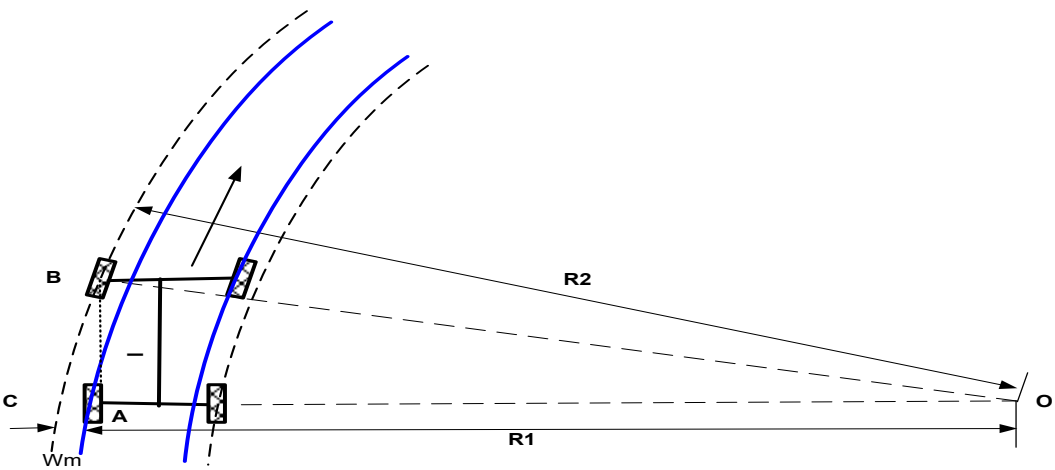


Crowned Pavement revolved about Centerline

c. Outer edge rotation: It consists of progressively revolving the straight line slope about the outer edge thereby depressing the center line and inner edge gradually.

Widening of Pavement on Horizontal Curves: Extra widening refers to the additional width of carriageway that is required on a curved section of a road than required width on a straight alignment. This widening is done due to the following reasons:

1. An automobile has a rigid wheelbase and only front wheels can be turned; when this vehicle takes a turn to negotiate a curve, the rear wheel do not follow the same path as that of front wheels. This phenomenon is called as **off tracking**. Normally, the rear wheels follow the inner path of the curve as compared with those of corresponding front wheels. The off tracking depends upon the length of wheelbase and turning angle or the radius of the curve negotiated.



2. In the case of higher speeds when super elevation and lateral friction developed are fully able to counteract the outward thrust due to the centrifugal force, some transverse skid may occur and the rear wheel may take paths on the outside of those traced by the front wheels on the horizontal curves.

3. The paths traced by the wheels of trailers is also likely to be either side of the central path, depending on the speed, rigidity of the universal joints and pavement roughness.

4. Psychological tendency of the driver is such that in curves (especially in cutting or in the areas with obstruction inside) they prefer to take the outer lane for greater visibility.

5.While two vehicles cross or overtake at horizontal curve there is a psychological tendency to maintain greater clearance between the vehicles, than on straights to increase speed.

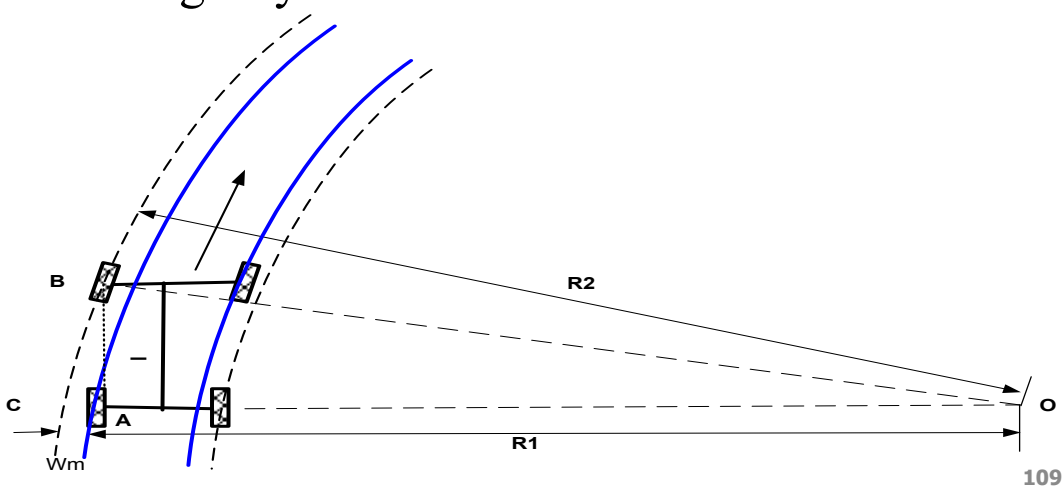
The Extra widening on the horizontal curve (We) depends on the following factors:

- Length of wheel base
- Radius of the curve
- Psychological factor which is the function of speed and radius of the curve.

Generally, extra widening on the horizontal is provided on the horizontal curves when the radius is less than about 300 m.

Analysis of extra widening: Extra widening on horizontal curve is divided into two parts: mechanical and psychological widening.

1. Mechanical Widening: Mechanical widening (Wm) is provided to account the off tracking due to the rigidity of wheels.



Where,

- R1 – Radius of the path traversed by the outer rear wheel, m
- R2 - Radius of the path traversed by the outer front wheel, m
- Wm – Mechanical widening, m
- l – Length of the wheelbase, m

$$W_m = OC - OA = OB - OA = R_2 - R_1$$

$$\Delta OAB,\ OA^2 = OB^2 - BA^2$$

$$R_1^2 = R_2^2 - l^2$$

$$R_1 = R_2 - W_m$$

$$(R_2 - W_m)^2 = R_2^2 - l^2$$

$$l^2 = W_m(2R_2 - W_m)$$

$$W_m = l^2/(2R_2 - W_m)$$

$$W_m = l^2/2R$$

Here, **R** is the mean radius of the curve. Mechanical widening calculated above is required for one vehicle negotiating a horizontal curve having ***n*** traffic lanes. The total mechanical widening required is given by:

$$W_m = \frac{nl^2}{2R} \quad \text{.....} (xiii)$$

2. Psychological widening: Extra width of pavement is also provided for psychological reasons such as to provide greater maneuverability of steering at high speeds, to allow for the extra space requirements for the overhangs of vehicles and to provide greater clearance for crossing and overtaking vehicles on the curve. An empirical formula has been recommended by the IRC for finding the additional psychological widening W_{ps} which is dependent on the design speed and the radius of the curve.

$$W_{ps} = \frac{V}{9.5\sqrt{R}} \quad \text{.....} (xiv)$$

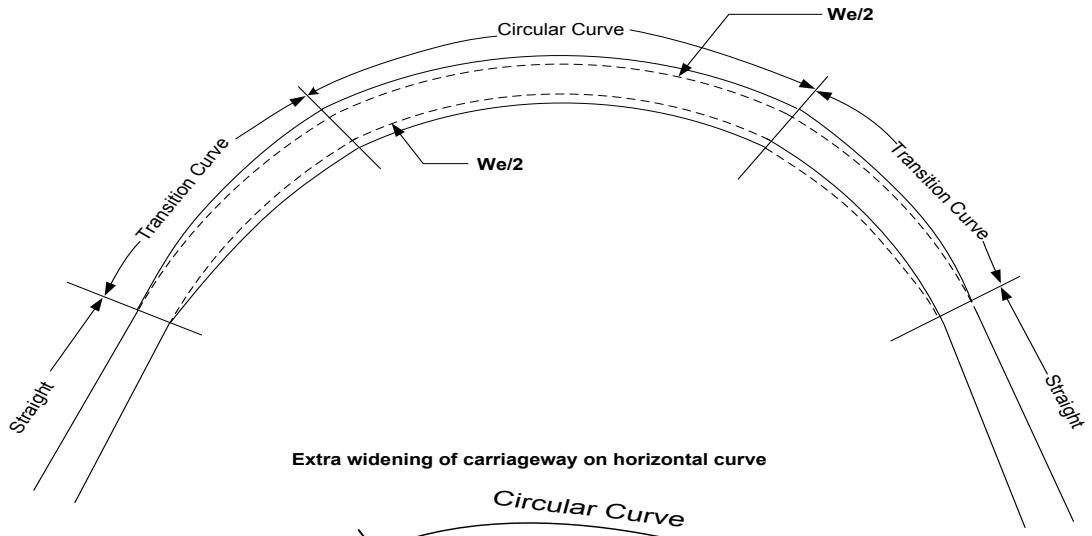
where, ***V*** is the design speed in Kmph and ***R*** is the radius of the curve in m.

Hence the total widening $\boldsymbol{W_e}$ required on horizontal curve is given by:

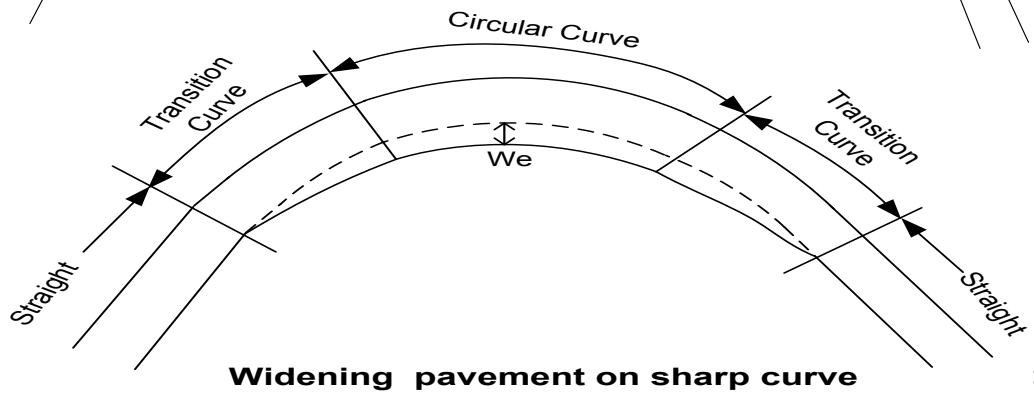
$$W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}} \quad \text{.....} (xv)$$

Methods on introducing extra widening:

The widening is gradually introduced staring from the beginning of the transition curve or the tangent point and progressively increased at uniform rate, till the full value of designed widening '***We'*** is reached at the end of transition curve where full values of super elevation is also provided. The full value of extra width (We) is continued throughout the length of the circular curve and then decreased gradually along the length of the transition curve. Usually ***We*** is equally distributed i.e $W_e/2$ on inner and outer sides of the curve. **But the sharp curves on the hill roads** the extra widening W_e may be provided in full on inside of the curve.



Extra widening of carriageway on horizontal curve



Widening pavement on sharp curve

Numerical Examples:

1. Calculate the amount of extra width required on a horizontal curve of radius **300m** on a two lane highway. The design speed is **80 Kmph**. Assume the length of wheel base is **6.2m.**

2. Find the total width of the pavement on a horizontal curve for a new national highway along a rolling terrain with a ruling minimum radius. Assume suitable data.

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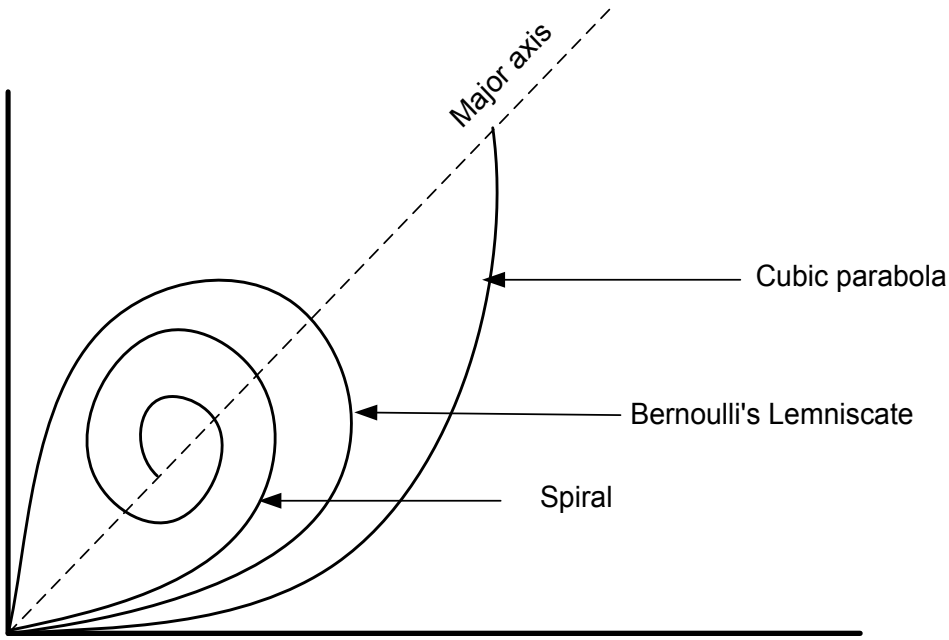
Design of Horizontal transition curve:

Transition curve is provided to change the horizontal alignment from straight to circular curve gradually and has a radius which decreases from infinity at the straight end (*tangent point*) to the desired radius of the circular curve at the other end (*curve point*).It is provided if R<1000m.

Objectives:

- To introduce gradually the centrifugal force between the tangent point and the beginning of the circular curve, avoiding sudden jerk on the vehicle to provide the comfort to the passengers.
- To enable the driver turn the steering gradually for his own comfort and security.
- To provide gradual introduction of super elevation
- To provide gradual introduction of extra widening.
- To enhance the aesthetic appearance of the road.



Types of Transition Curves

Length of transition curve:

The length of the transition curve should be determined as the maximum of the following three criteria:

- Rate of change of centrifugal acceleration
- Rate of introduction of designed super-elevation
- Minimum length by IRC empirical formula

1. Rate of change of centrifugal acceleration:

At the tangent point, radius is infinity and hence centrifugal acceleration (v^2/R) is zero as the radius is infinity. At the end of the transition, the radius has minimum value $\mathbf{R_{min}}$. Hence the centrifugal acceleration is distributed over the length of transition curve (Ls). The centrifugal acceleration should be developed such that it will not cause discomfort to the passengers of a vehicle travelling at the design speed. It is obvious that larger the length of transition, lower will be the rate at which the centrifugal acceleration is introduced.

Let the length of transition curve be ***Ls***. If **t =Ls/v** is the time taken in second to traverse this transition length at uniform design speed of ***v*** m/sec. The maximum centrifugal acceleration of ***v²/R*** is introduce in time t through the transition length ***Ls*** and hence the rate of change of centrifugal acceleration ***C*** is given by:

$$C = \frac{v^2}{Rt} = \frac{v^2}{R\frac{Ls}{V}} = \frac{v^3}{RL_s}$$

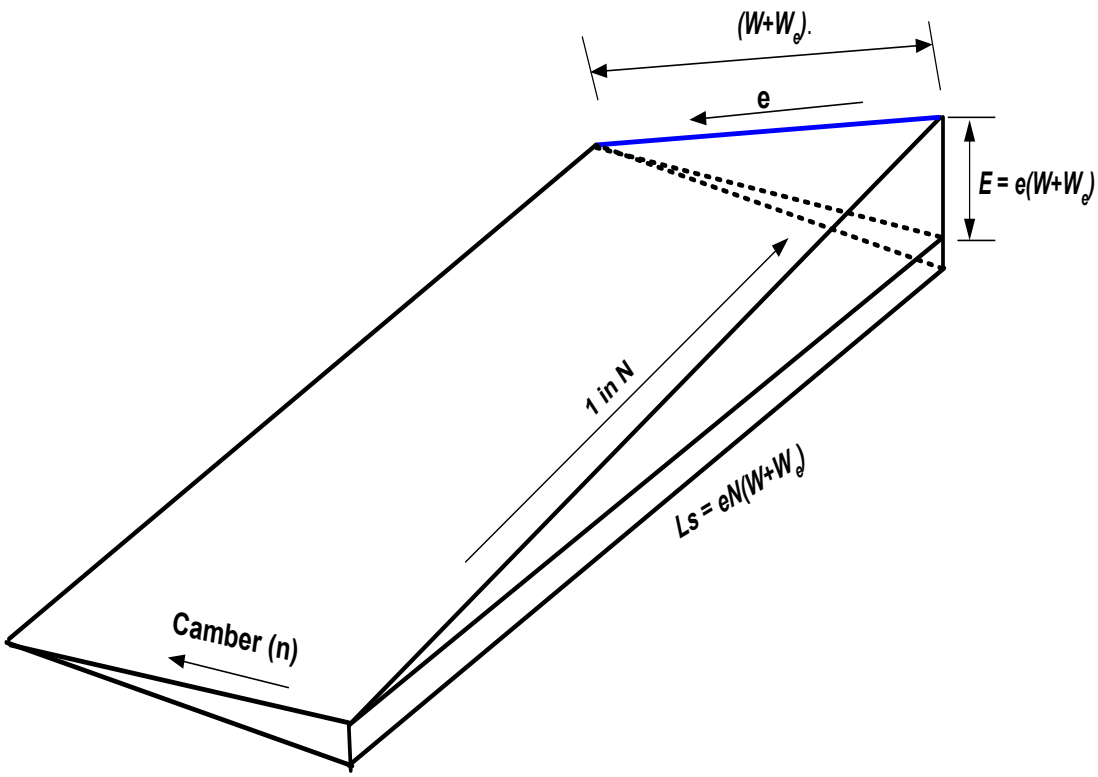
$$L_s = \frac{v^3}{RC} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (xvi)$$

The maximum allowable value of the rate of change of centrifugal acceleration without causing discomfort is depend on the speed and varies inversely with the radius. IRC recommendation for the value of ***C*** for the design speed ***V*** kmph.

$$C = \frac{80}{(75+V)}\ m/sec^3$$ **[0.5<C<0.8]-NRS**

2. **Rate of introduction of super-elevation:** In the open areas with sufficient space for roadway clearance is not desirable to raise the outer edge of road at a larger rate than **1 in 150**. In case of built up and hilly areas, rate of rise of outer edge may be taken as **1 in 100 and 1 in 60** respectively.

Let W be the normal width of the carriageway and W_e extra widening at the circular curve. Hence, the total width of carriageway at the circular curve is $(W+W_e)$. If the e is the rate of super-elevation based on 75 % of design speed, then the total rise of outer edge with respect to inner edge is equal to $E = e(W+W_e)$. If the pavement is rotated about the center line after neutralizing the camber then the maximum amount by which the outer edge is raised at a circular curve with respect to center is $E/2$.



Rotation with respect to inner edge

If the rate of introducing the super-elevation is **1 in N** then the length of transition curve is given by at centre line rotation:

$$L_s = \frac{EN}{2} = \frac{eN}{2}(W + W_e) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (xvii)$$

Similarly, if the pavement is rotated about the inner edge, the length of the transition curve is given by:

$$L_s = EN = eN(W + W_e) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (xviii)$$

3. Using empirical formula: According to the IRC recommendation the length of transition curve ***Ls*** should be not less than the value given by the following equation for the terrain classification.

a. For plain and rolling terrain:

$$L_s = \frac{2.7V^2}{R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (xix)$$

V in Kmph

b. For hilly and steep terrain:

$$L_s = \frac{V^2}{R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (xx)$$

The length of transition curve should be higher of the three above values mentioned above.

Numerical example:

1. A highway with 2 lanes, each **3.5m** wide has **0.6m** of extra-widening at a horizontal curve of radius **150 m**. Design the length of transition curve if design speed is **65 Kmph**. Desired rate of introducing super-elevation is **1 in 80**. Assume pavement is rotated about the inner edge.

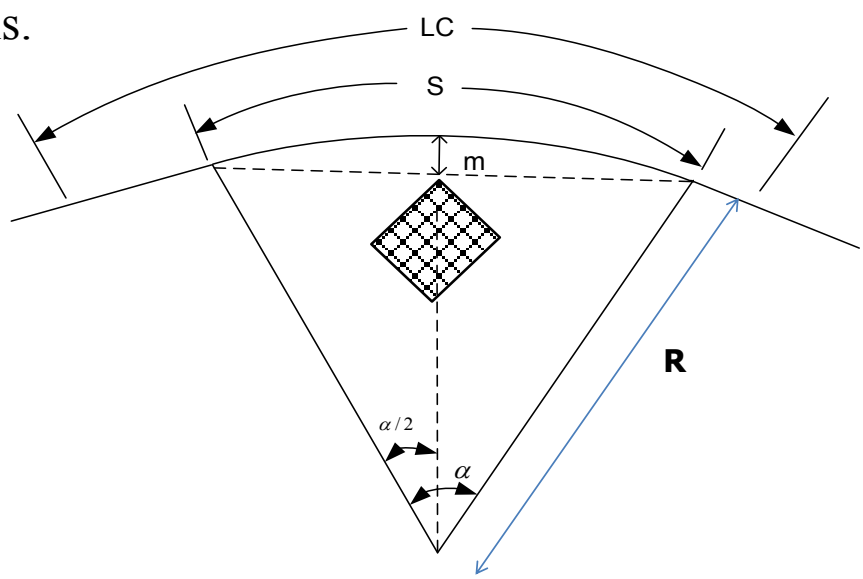
2. Design the transition curve for national highway constructed in plain terrain of the country. The radius of curve is **220m**. Assume suitable data if necessary.

Setback distance on horizontal curve:

In the design of horizontal alignment, the sight distance along the inner side of the curve should be considered. There may be **sight obstruction like buildings, cut slopes, or trees** on the inner side of the curve should be removed to provide adequate sight distance.

As mentioned above the absolute minimum sight distance, i. e. safe stopping sight distance should be available at every section of the highway.

1. Case L_c > S: L_c is the length of curve which is greater than the sight distance ***S***. The angle subtended by the arc of length S at the center is α. The sight distance is measured along the center line of the road and the angle subtended at the center is equal to S/R radians.



Therefore half central angle is given by:

$$\frac{\alpha}{2} = \frac{S}{2R} radians = \frac{180S}{2\pi R} \deg rees$$

The distance from the obstruction to the centre is: $RCos\frac{\alpha}{2}$

Therefore the set-back distance in the case of narrow (**single lane roads**) roads the required ***m*** is given by:

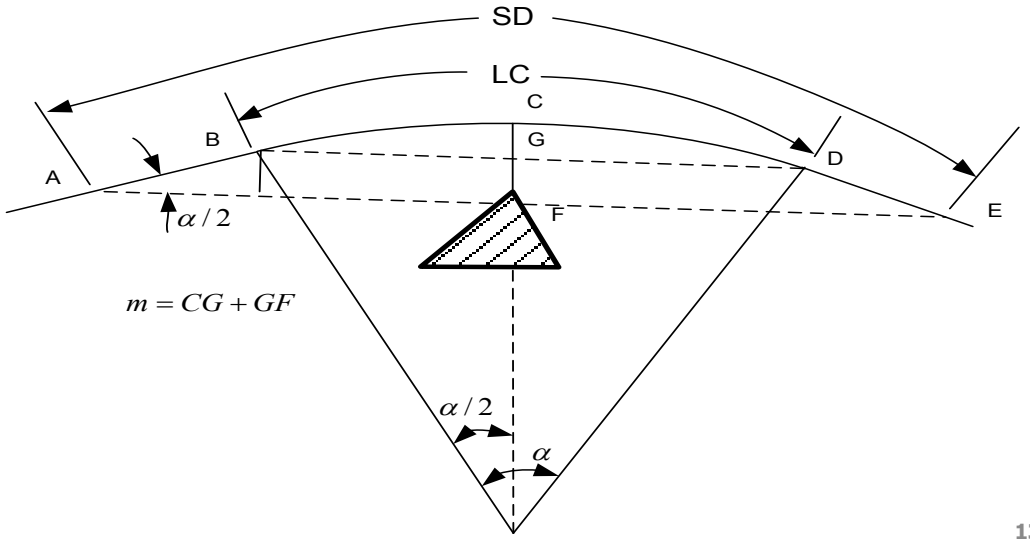
$$m = R - RCos\frac{\alpha}{2} .....(xxii)$$

In the case of wide roads (**two or more lanes**), **if the distance d is the distance between the center line of the road and the center line of the inside lane** in meter, the sight distance is measured along the middle of the inner side lane and the set-back distance, m is given by:

$$m' = R - (R - d)Cos\frac{\alpha'}{2} \text{.....} (xxiii)$$

$$\frac{\alpha'}{2} = \frac{180S}{2\pi(R-d)} \deg rees$$

2. Case L_c < S: If the sight distance (S) required is greater than the length of the curve ($\mathbf{L_c}$), then the angle subtended at the center is determined with reference to the length of circular curve $\mathbf{L_c}$ and the set-back distance is worked out in two parts as given below:



From the geometry of the figure, set-back distance is: $m = CG + GF$

$$CG = R - RCos\frac{\alpha'}{2} \qquad CG = R - (R-d)Cos\frac{\alpha'}{2}$$

$$GF = \frac{S - L_c}{2} Sin\frac{\alpha'}{2}$$

$$\frac{\alpha}{2} = \frac{180L_c}{2\pi(R-d)} \deg rees$$

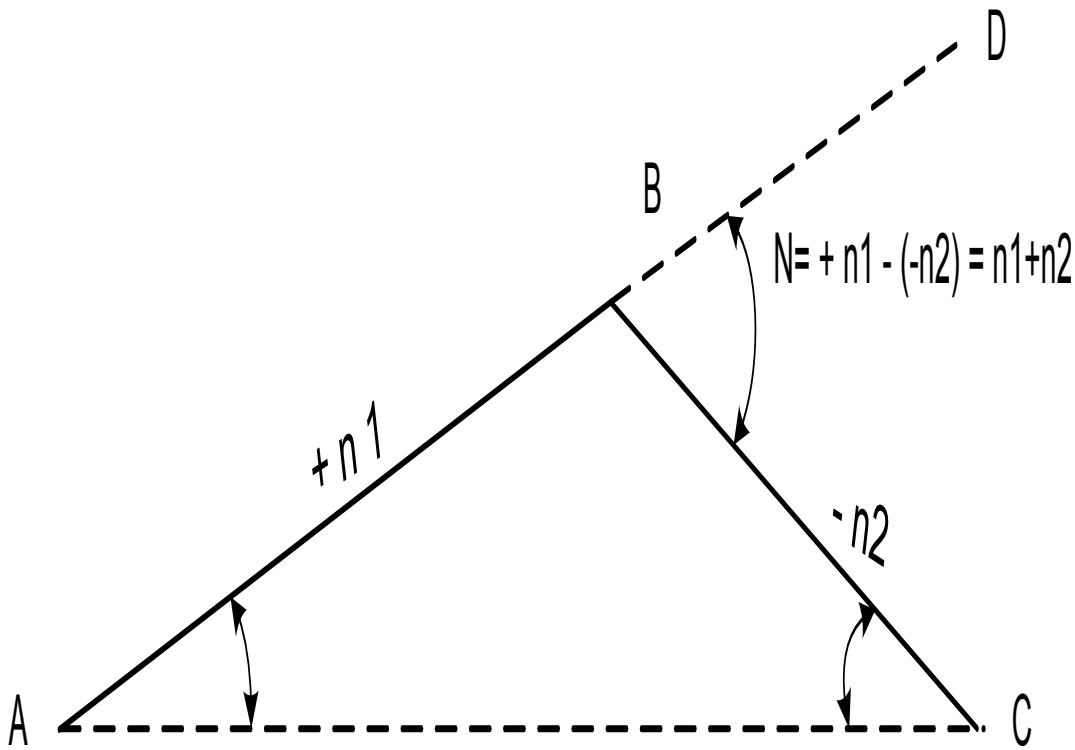
$$m' = R - (R-d)Cos\frac{\alpha'}{2} + \frac{(S-L_c)}{2} Sin\frac{\alpha'}{2} \text{.....} (xxiv)$$

The clearance of obstruction up to the set-back distance is important when there is cut slope on the inner side of the horizontal curve.

Numerical example:

1. A national highway with design speed **80 Kmph** has a horizontal curve of radius equal to the minimum ruling radius. Design all the geometric features of this curve, with suitable data. Specify the minimum set-back distance from the center line of the two lane highway on the inner side of the curve up to which the building should not be constructed for considering intermediate sight distance. Assume the length of the circular curve is greater than the sight distance. (R, e,W,Ls,SSD,ISD,m)

Gradient: Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. It is expressed as the ratio of **1 in x** (1 vertical unit to x horizontal units). Some time it is also expressed as a percentage. The ascending gradients are given positive sign and are denoted as **+n** and descending gradient are given negative sign and are denoted as **–n**. The angle which measures the change of direction at the intersection of two grades is called **deviation angle N**, which is equal to the algebraic difference between the two grades.


D
B
N= + n1 - (-n2) = n1+n2
+ n 1
- n2
A
C

Types of gradients:

Gradients are divided into following categories:

- Momentum gradient
- Ruling gradients
- Limiting gradient
- Exceptional gradient
- Minimum gradient

Momentum grade: Momentum grades are those grades on which the momentum gained by the vehicles at the beginning of a steep climbing section is used to overcome the road resistance due to grade. In fact any minor ascending grade may be referred as momentum grade if the same is overcome by vehicle with its initial momentum.

Ruling gradient: It is the maximum gradients within which the designer attempts to design the vertical profile of road. Gradients up to the ruling are adopted as normal in design of vertical alignment and accordingly the quantities of cut and fill are balanced. Hence, ruling gradient is also called as "Design gradients".

Limiting gradient: In some cases of unfavorable topography, it is necessary to adopt steeper gradients than ruling gradients, which are known as limiting gradients. Length of such gradients should be limited.

Exceptional gradient: In some extra ordinary situations, it is necessary to provide exceptional gradients to provide still steeper gradients at least for short stretches and in such cases the steeper gradient upto exceptional gradient may be provided. However, exceptional gradient is strictly limited only for short distance not more than 100m.

Design Speed (Kmph)	20	30	40	60	80	100	120
Maximum Gradient %	12	10	9	7	6	5	4

NH	Terrain type		
	Mountain	Rolling	Level
Max. average gradient Max. grade Max. length of grade in excess of av. grade	5% 8% 150m	4% 6% 210m	3% 5% 250m
FR			
Max. average gradient Max. grade Max. length of grade in excess of av. grade	7% 10% 120m	6% 8% 180m	5% 7% 210m
DR			
Max. average gradient Max. grade Max. length of grade in excess of av. grade	7% 12% 100m	6% 10% 120m	5% 7% 100m

Compensation of grades on Horizontal Curve: When there is a horizontal curve in addition to the gradient, there will be increased resistance to friction due to both gradient and curve. It is necessary that in such cases the total resistance due to grade and curve should not normally exceed the resistance due to the maximum value of the gradient specified. When sharp horizontal curve is to be introduced on a road which has already the maximum permissible gradient, then the gradient should be decreased to compensate for the loss of tractive effort due to the curve. This reduction in gradient at the horizontal curve is called grade compensation.

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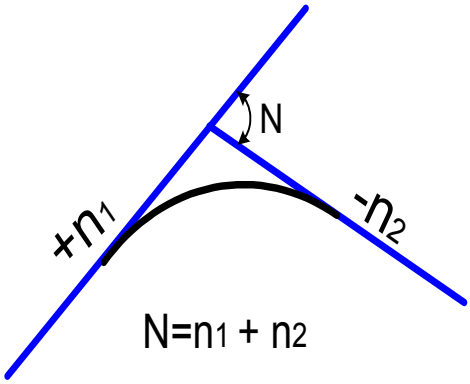
Grade compensation, percent $= \frac{30 + R}{R}$ subject to a maximum value of 75/R, Where R-radius of the circular curve; m

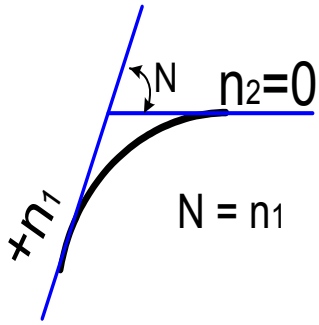
According to the IRC the grade compensation is not necessary for gradient flatter than 4%.

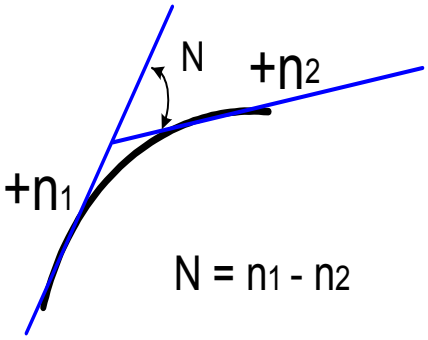
Example: 1. While aligning a hill road with a ruling gradient of 6%, a horizontal curve of radius 60 m is encountered. Find the compensated gradient at the curve.

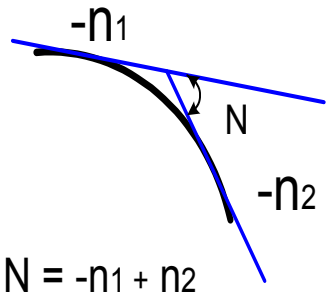
Vertical curves: Due to the change in grades in the vertical alignment of highway, it is necessary to introduce vertical curves at the intersection of different grades to smoothen out the vertical profile. Vertical curves should be simple in application and should result in a design that is safe and comfortable in operation, pleasing in appearance, and adequate for drainage.

Summit curves: Summit curves with convexity upwards are formed in any one of the case illustrated in the figure below. The deviation angle between the two interacting gradients is equal to the algebraic difference between them.


N
+n1
-n2
N=n1 + n2

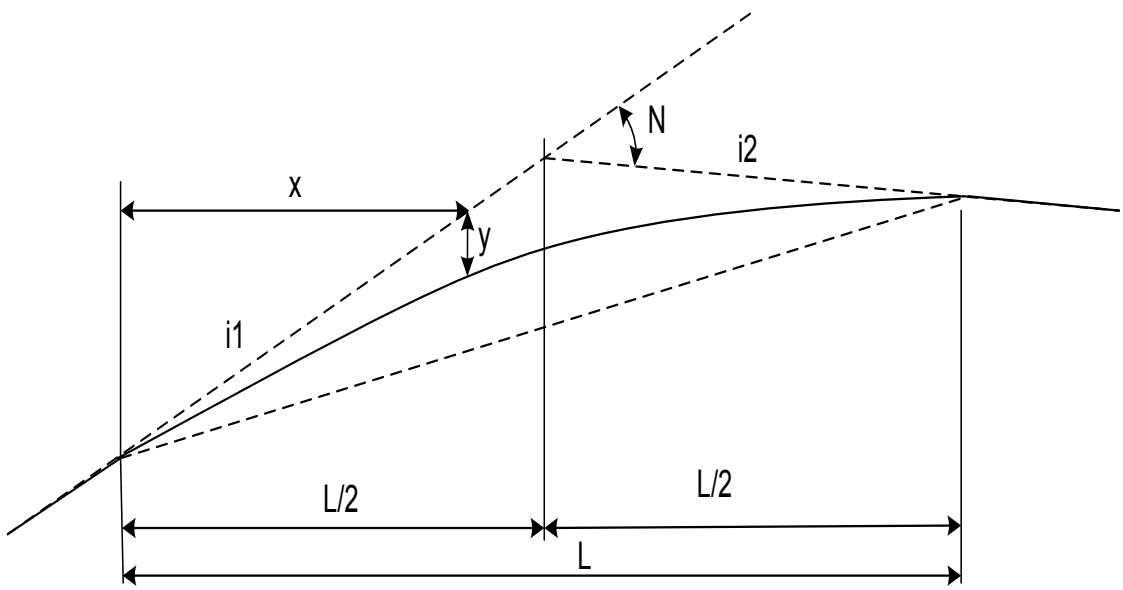

N
n2=0
+n1
N = n1


N
+n2
+n1
N = n1 - n2


-n1
N
-n2
N = -n1 + n2

The design of the summit curve is governed by the consideration of sight distance, transition curves are not necessary. The deviation angles in vertical curves are very small a simple parabola is nearly congruent with a circular arc, also a parabola is very easy for arithmetic calculation for computing ordinates. The use of simple parabola as summit curve is found to give good riding comfort too. Because of these reasons in actual practice a simple parabolic curve is used as summit curve instead of circular arc.

a. Length of summit curve for safe stopping sight distance (SSD)



H(1.2m) is height of driver's eye level and h(0.15m) height of the object above road surface, then length of summit curve is equal to When 1. L > SSD

$$L = \frac{NS^2}{(\sqrt{2H} + \sqrt{2h})^2} \quad \text{.....} (xxix)$$

2. L < SSD:

The general equation for the length of the parabolic summit curve, when it is less than the sight distance is given by: The general equation for the length of the parabolic summit curve, when it is less than the sight distance is given by:

$$L = 2S - \frac{\left(\sqrt{2H} + \sqrt{2h}\right)^2}{N} \quad \ldots\ldots\ldots\

Length of summit curve for safe overtaking sight distance (OSD) or intermediate sight distance. (ISD=2 OSD):

i. The length of curve is greater than the overtaking sight distance or intermediate sight distance (L > S): H=h=1.2m

$$L = \frac{NS^2}{\left(\sqrt{2H} + \sqrt{2h}\right)^2} = \frac{NS^2}{8H}$$

ii. When the length of the curve is less than sight distance (L< S)

$$L = 2S - \frac{(\sqrt{2H} + \sqrt{2h})^2}{N}$$

$$L = 2S - \frac{8H}{N}$$

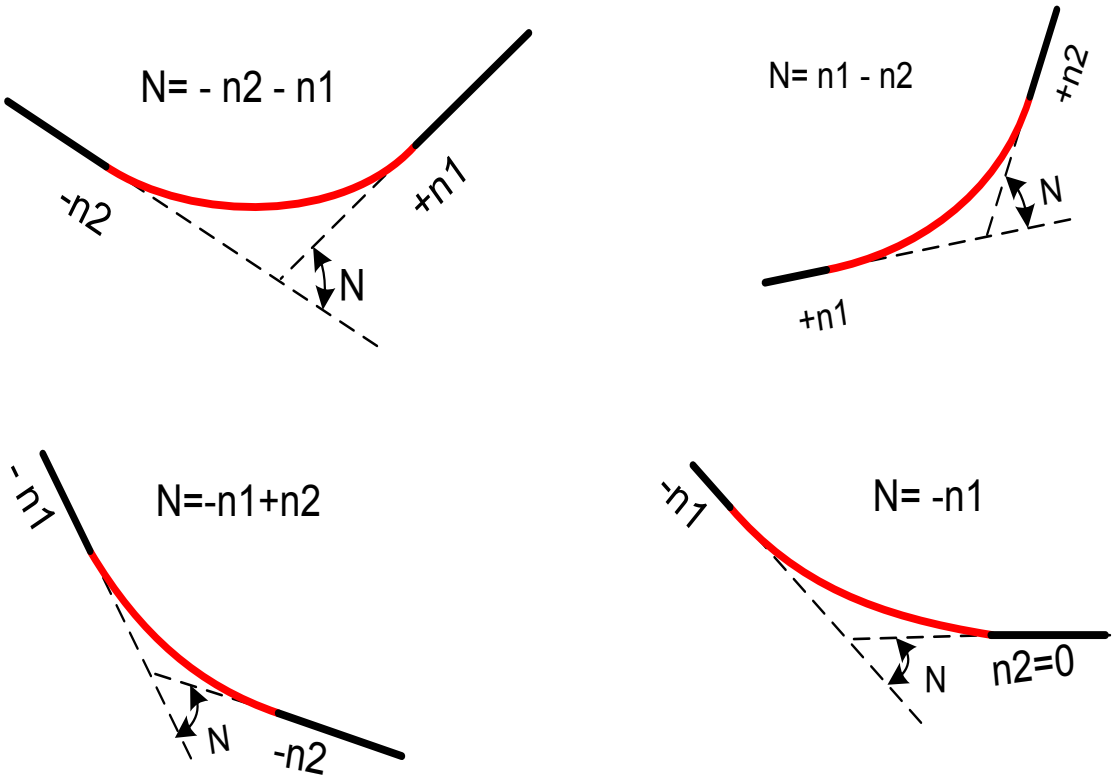
Design speed (Kmph)	Maxm grade change not requiring vertical Curve	Minimum length of curve (higher grade change value)
35	1.5	15
40	1.2	20
50	1.0	30
65	0.8	40
80	0.6	50
100	0.5	60

Numerical Example:

1. A vertical summit curve is formed at the intersection of two gradients, +3.0% and -5.0%. Design the length of summit curve to provide a stopping sight distance for a design speed of 80 Kmph. Assume suitable data if required.

b. Valley curve : Valley curve or sag curves are vertical curves with convexity downwards. They are formed when two gradients meet as illustrated in figure below:

- When a descending gradient meets another descending gradient,
- When a descending gradient meets a flat gradient,
- When a descending gradient meets an ascending gradient,
- When an ascending gradient meets another ascending gradient,


N= - n2 - n1
-n2
+n1
N
N= n1 - n2
+n2
N
+n1
N=-n1+n2
- n1
N
-n2
N= -n1
-n1
N
n2=0

Design consideration of Valley Curve: There is no restriction to sight distance at valley curves during day time. But visibility is reduced during night. In the absence or inadequacy of street light, the only source for visibility is with the help of headlights. Hence valley curves are designed taking into account of **headlight distance**. In valley curves, the centrifugal force will be acting downwards along with the weight of the vehicle, and hence impact to the vehicle will be more. This will result in jerking of the vehicle and cause discomfort to the passengers.

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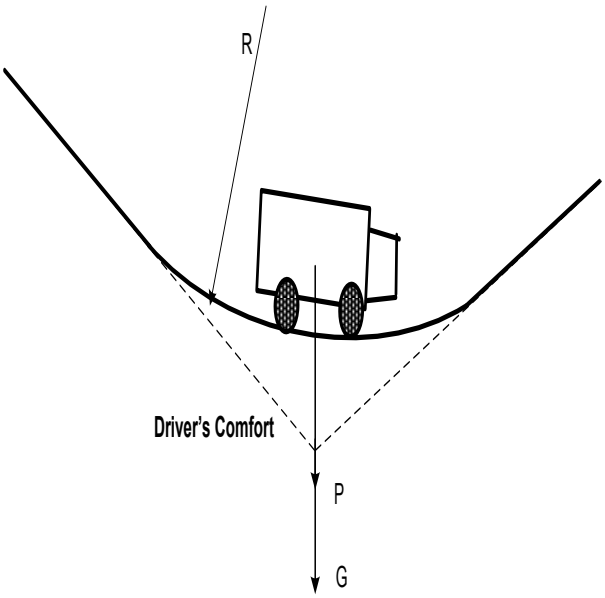
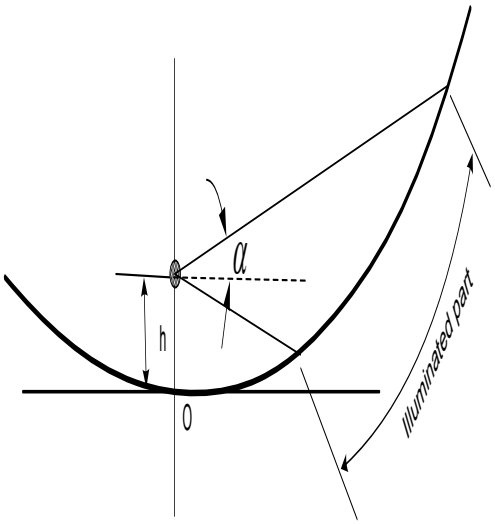
Thus the most important design factors considered in valley curves are:

- Impact-free movement of vehicles at design speed and
- Availability of stopping sight distance under headlight of vehicles for night driving.

For gradually introducing and increasing the centrifugal force acting downwards, the best shape that could be given for a valley curve is a transition curve. Cubic parabola is generally preferred in vertical valley curves. During night, under headlight driving condition, sight distance reduces and availability of stopping sight distance under head light is very important. The head light sight distance should be at least equal to the stopping sight distance. There is no problem of overtaking sight distance at night since the other vehicles with headlights could be seen from a considerable distance.

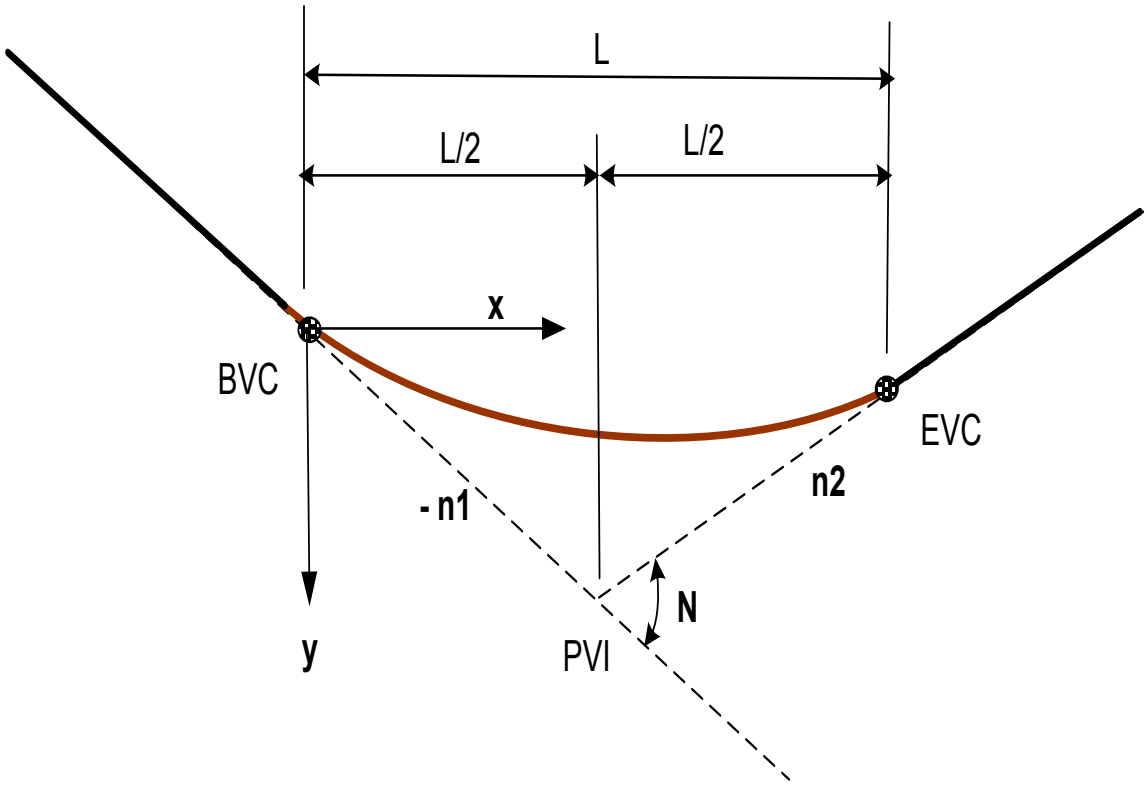




Safety for night driving

Length of Valley Curve: The valley curve is made fully transitional by providing two similar transition curves of equal length. The transition curve is set out by a cubic parabola $y = bx^3$ where $b = 2N/3L^2$. The length of the valley transition curve is designed based on two criteria:

- **Comfort criteria:** The allowable rate of change of centrifugal acceleration is limited to a comfortable level of about 0.6 m/sec^3.
- **Safety criteria:** The driver should have adequate headlight sight distance at any part of the curve.


L
L/2
L/2
x
BVC
EVC
- n1
n2
N
y
PVI

Comfort criteria :The length of the valley curve is based on the rate of change of centrifugal acceleration that will ensure comfort. Let ***c*** is the rate of change of acceleration, ***R*** the minimum radius of the curve, ***v*** is the design speed and ***t*** is the time, then ***c*** is given as:

We know the length of transition curve: $L_s = \frac{v^3}{CR}$

Minimum radius (R) at any point on the curve is:

$$R = \frac{L_s}{N} = \frac{L}{2N}; \left(\because L_s = \frac{L}{2} \right) \quad L_s = \frac{v^3}{CR} = \frac{v^3 N}{CL_s}$$

$$L_s^2 = \frac{Nv^3}{C}$$ **Total length of the Valley curve is** $L = 2L_s = 2\sqrt{\frac{Nv^3}{C}}$

Safety criteria (head light sight distance): Length of the valley curve for headlight distance may be determined for following conditions:

Case 1: Length of valley curve greater than stopping sight distance (L > S) :The total length of valley curve L is greater than the stopping sight distance SSD. The sight distance available will be minimum when the vehicle is in the lowest point in the valley. This is because the beginning of the curve will have infinite radius and the bottom of the curve will have minimum radius which is a property of the transition curve.

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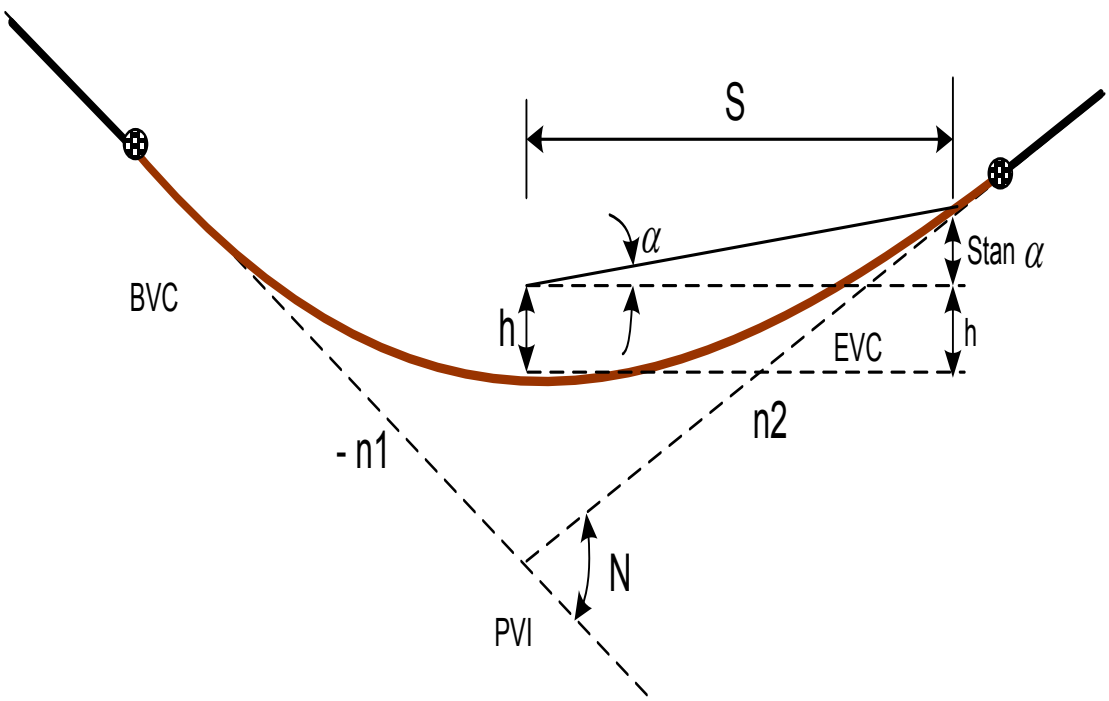


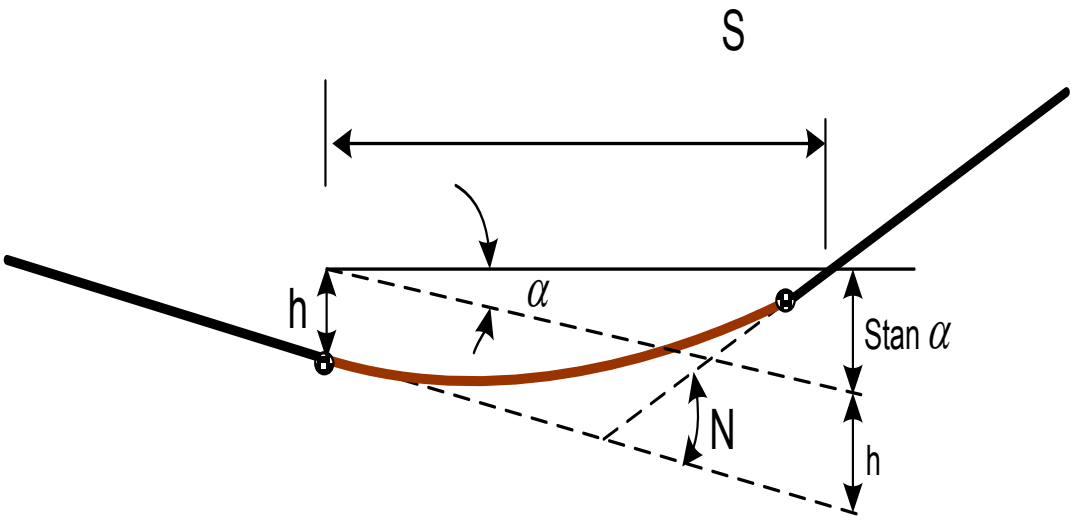
Case I: L > S

Where **N** is the deviation angle in radians, ***h*** is the height of headlight beam, is the head light beam inclination in degrees and S is the sight distance. The inclination is approximately 1 degree.

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

If the average height of the headlight is taken as h = 0.75 m and the beam angle is one degree then the length of Valley curve is given by: $L = \frac{NS^2}{1.5 + 0.035S}$

Case 2: Length of valley curve smaller than stopping sight distance (L < S) : In this case the minimum sight distance is from the beginning of the curve. The important points are the beginning of the curve and the bottom most part of the curve. If the vehicle is at the bottom of the curve, then its headlight beam will reach far beyond the endpoint of the curve whereas, if the vehicle is at the beginning of the curve, then the headlight beam will hit just outside the curve. Therefore, the length of the curve is derived by assuming the vehicle at the beginning of the curve.



Case I: L < S

Where **N** is the deviation angle in radians, ***h*** is the height of headlight beam, is the head light beam inclination in degrees and S is the sight distance. The inclination is approximately 1 degree.

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

If the average height of the headlight is taken as h = 0.75 m and the beam angle is one degree then the length of Valley curve is given by: $L = 2S - \frac{1.5 + 0.035S}{N}$

Numerical Example:

1. A valley curve is formed by a descending grade of 1 in 25 meeting an ascending grade of 1 in 30. Design the length of valley curve to fulfill both comfort condition and head light sight distance requirements for a design speed of 80 Kmph. Assume allowable rate of change of centrifugal acceleration is 0.6m/s3

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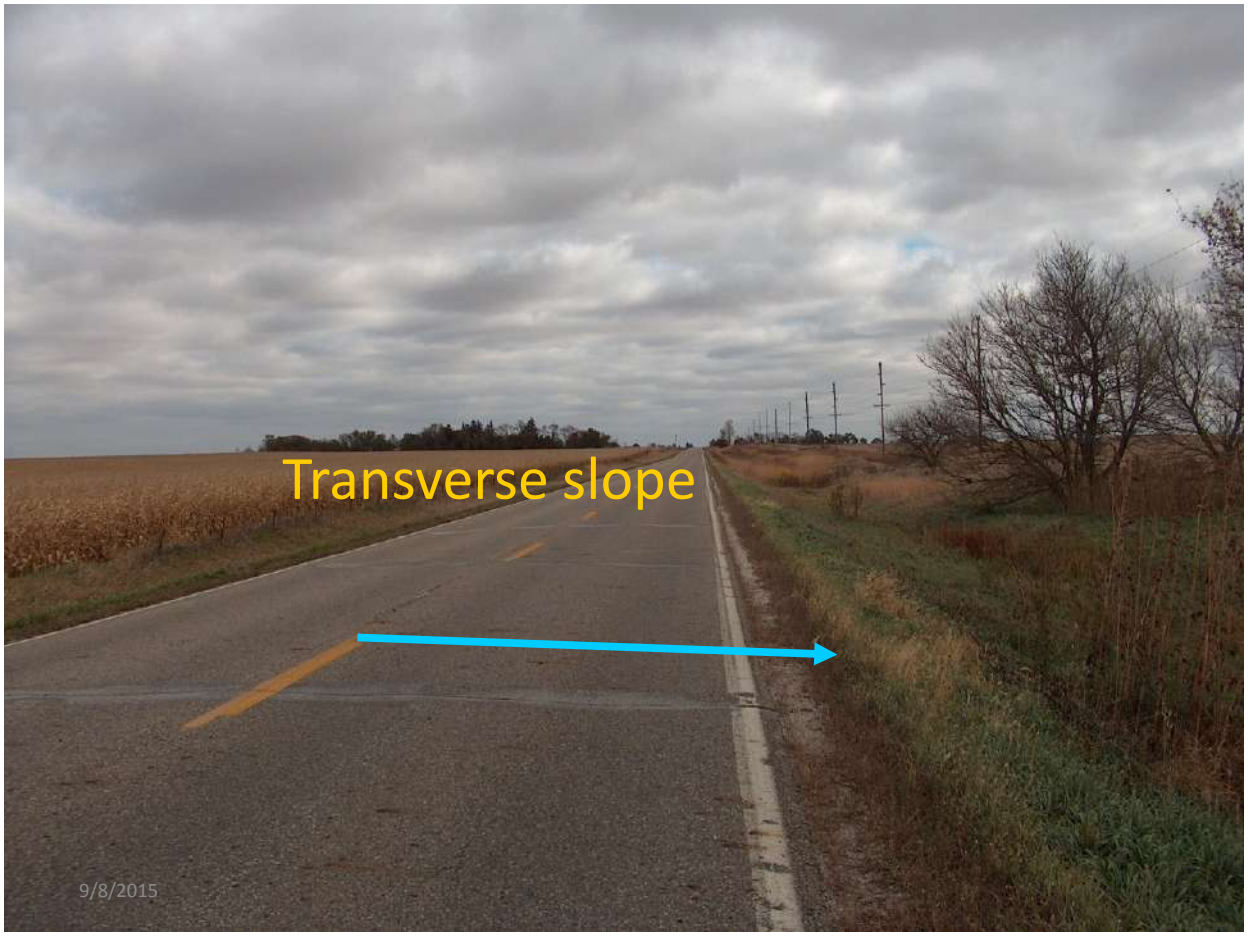
END OF CHAPTER

THANK YOU

Highway Drainage

Er. Narayan Timilsena
Paschimanchal Campus, Pokhara

Longitudinal channel
9/8/2015


Transverse slope
9/8/2015

Longitudinal slope
9/8/2015

Highway Drainage

Hill Road side drain

Highway Drainage

Course Content:

- Introduction, importance of drainage and classification of highway drainage structures
- Causes of moisture variation in sub-grade soil
- Surface drainage system
- Sub-surface drainage system

Highway Drainage

It is process of removing and controlling excess surface and sub-surface water within the right of way.

-*Surface drainage*: Removal and diversion of surface water from the roadway and adjoining land.

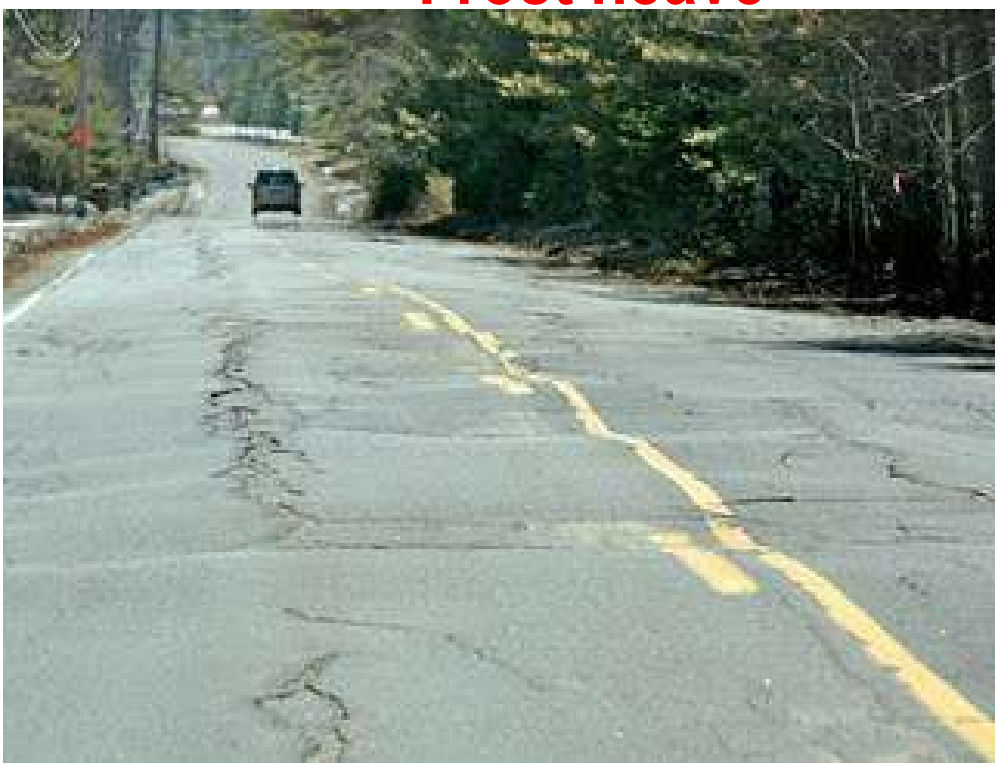
-*Sub surface drainage*: Removal and diversion of excess soil water from the subgrade.

Importance of highway drainage

1. Excess moisture content reduces stability of subgrade
2. Excess moisture content reduces strength of pavement
3. Variation of moisture content may cause in the change in volume of sub grade soil
4. Bituminous pavement becomes failure due to continuous contact with water (corrugations)
5. Excess water damages shoulder & pavement edge
6. In cold climate (below freezing temperature) pavement is damaged by frost action of ground water (frost heave)
7. Failure of rigid pavement due to mud pumping

Corrugation

Frost heave



Frost heave

Mud Pumping

Damaged pavement edge

Requirements of good highway drainage system

1. Surface water from carriageway should be drained off effectively without percolating to the subgrade
2. Surface water from adjoining area should not be allowed to enter the roadway
3. Side drain should have sufficient capacity and longitudinal slope for all surface water collection
4. Flow of surface water from carriageway and shoulder should not cause erosion
5. Seepage & other sources of groundwater should be drained off by sub-surface drainage
6. Highest level of groundwater table should be kept below the subgrade at least 1.2m
7. Special precautions should be taken in water logged areas

Causes of moisture variation in subgrade soil

1. Seepage from the higher adjoining ground
2. Percolation of moisture from pavement
3. Percolation of water from shoulder & edge of the pavement
4. Rise and fall of ground water
5. Capillary rise of moisture by the soil below the subgrade level
6. Transfer of moisture vapour due to difference in temperature of soil layers

Water balance in soil subgrade

$$W = (A+B+C)-(D+E+F)$$

W = water content in subgrade soil at any time of the year.

A = water infiltrated into subgrade soil during rainfall

B = water seeping towards subgrade from adjoining higher ground.

C = water coming to subgrade due to

- Capillary rise
- Upward movement of water table
- Transfer of vapour from lower soil layers.

D = Loss of water from subgrade due to flow away towards lower adjacent ground.

E = Loss of water due to evaporation, transpiration

F = Loss of water due to percolation down ward

Sources of Moisture Variation in Subgrade

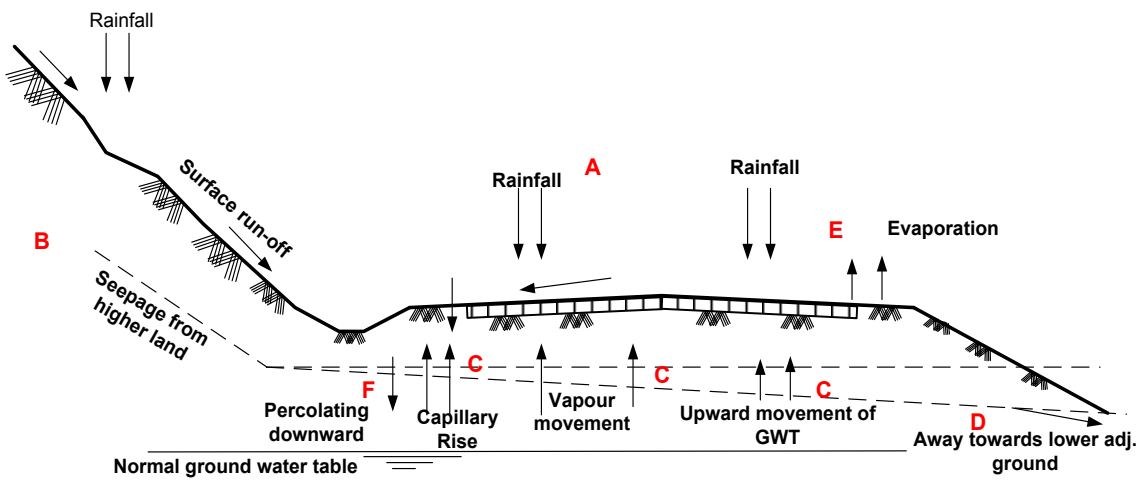


Fig. Sources of moisture variation in sub-grade

Components of Highway drainage System:

- Surface Drainage system
- Sub-surface Drainage system

Highway Drainage System

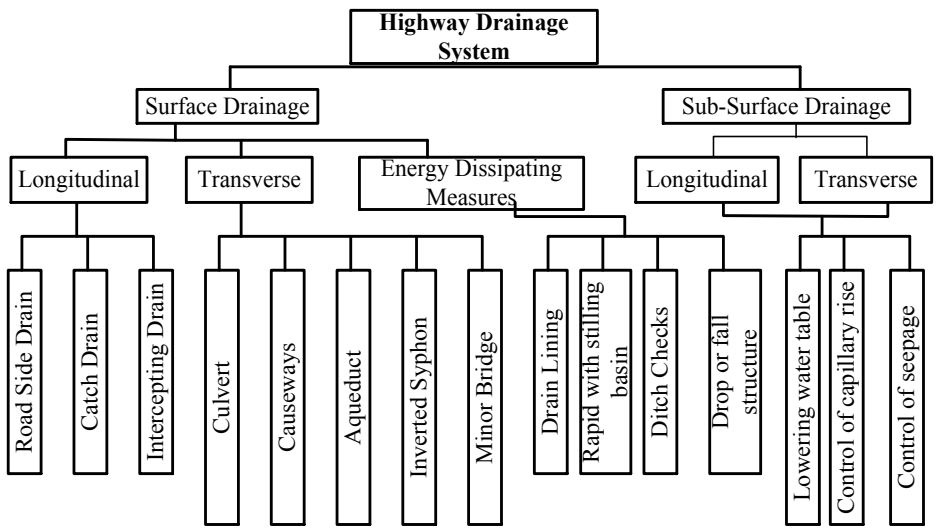


Fig. Highway Drainage System

Surface Drainage

Highway drainage system consists of:

- Removal of water laterally during rainfall towards road side by providing camber, cross falls on shoulder
- Trapped runoff is allowed to flow along roadway by providing side drain.
- Cross drainage are provided for the final removal of water from side drains by means of culverts, bridges, causeways etc.

Drains

- Drains are generally provided along the roadside in order to intercept surface water running off the carriageway, shoulders and side slopes bordering the roadway.
- If the cut slopes and hill side slopes are long enough and accumulates more water than the capacity of usual sized side drain and if the run off may erode the slope then the run off is intercepted on its way to roadway by providing drains at these slope itself.
- These drains are known as **intercepting** drains and are common drainage components in hill roads.

Typical side Drains

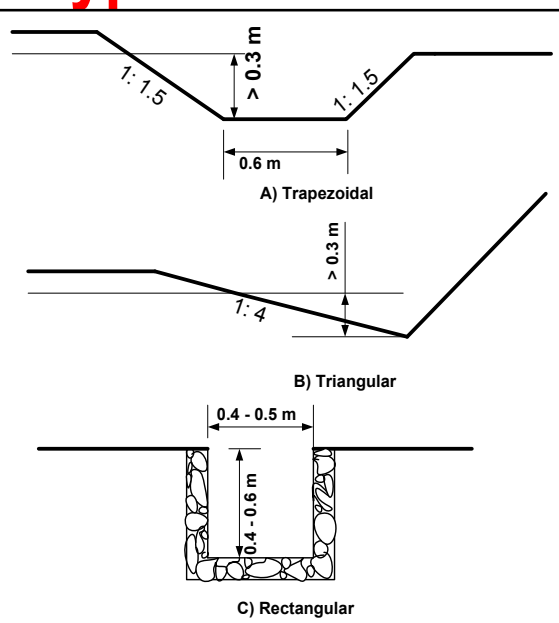


Fig. Typical Side drains

Cross Drainage Structures

Importance:

- Adequate functioning of a road depends to a large extent on the effectiveness of cross drainages.
- A road has to be aligned to cut across natural drainage channels and major rivers.
- At the same time the road cuts across man made channels (irrigation).
- The function of the cross drainage structures is to ensure that the run-off water is discharged across the road from one side to the other, as quickly as possible, without causing undue pounding, overtopping of the road embankment or erosion of the portion of the road.
- Quick drainage, prevents water from penetrating the soil in the embankment. A dry subgrade has greater bearing strength than wet subgrade.

Types of cross drainage structures

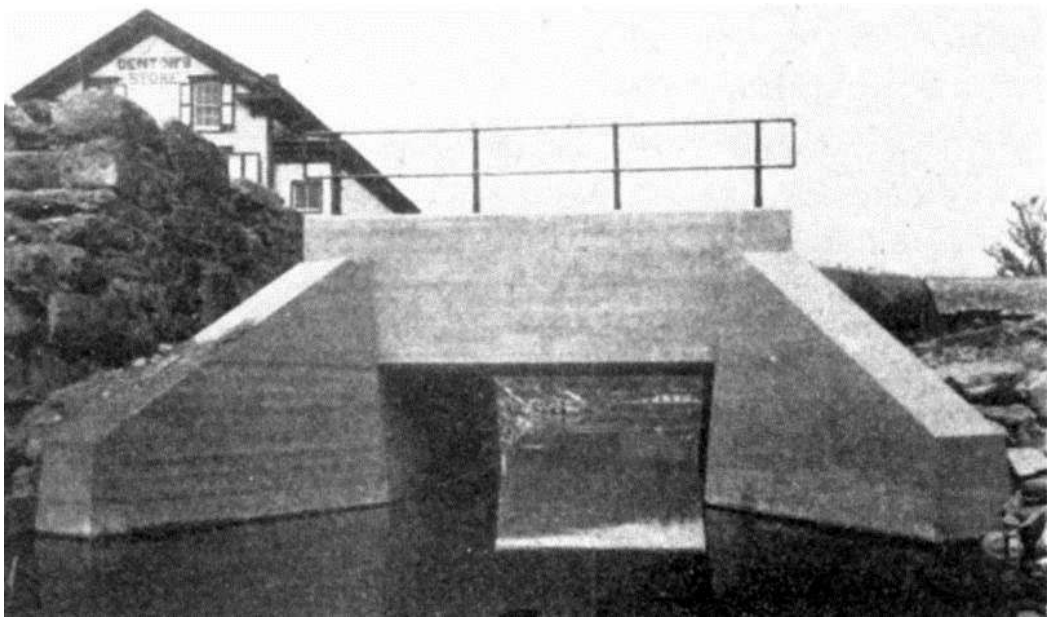
- **Culverts**: upto 6 m length
- **Minor bridge**: more than 6 m and upto 20 m length
- **Medium bridge**: Above 20 m length, span length less than 20 m.
- **Major bridge**: bridge with span length greater than 20 m.
- **Causeway:** which allow the water to flow over the road way.

Types of Culvert:

- Pipe culvert
- Slab Culvert
- Box Culvert
- Arch Culvert

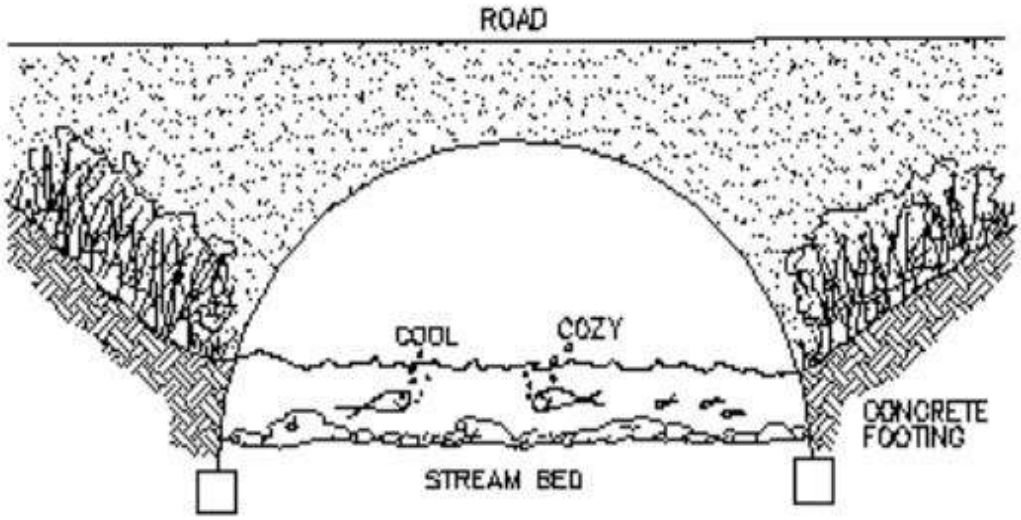
Pipe culvert

Slab culvert



Box culvert

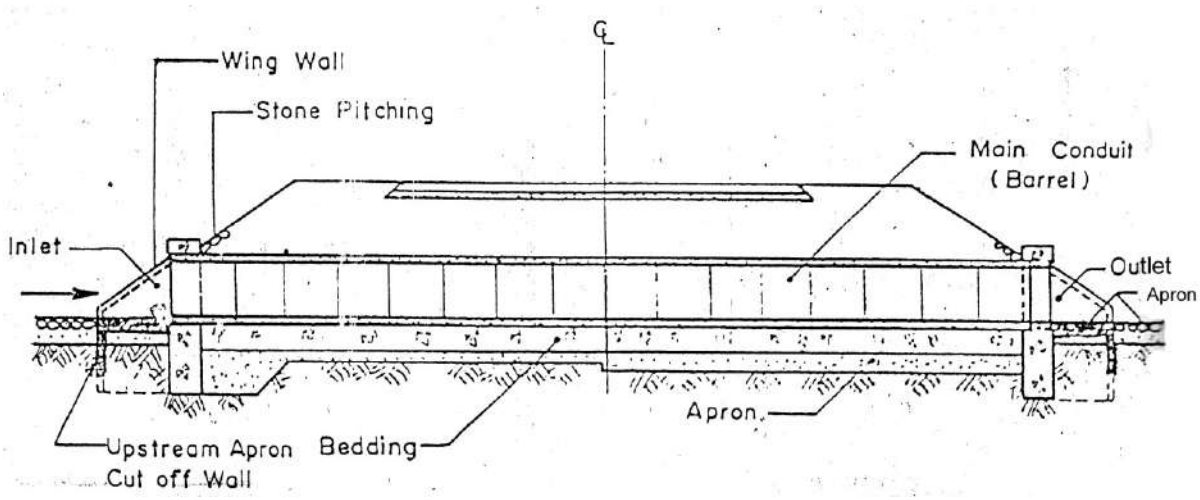
Arch culvert

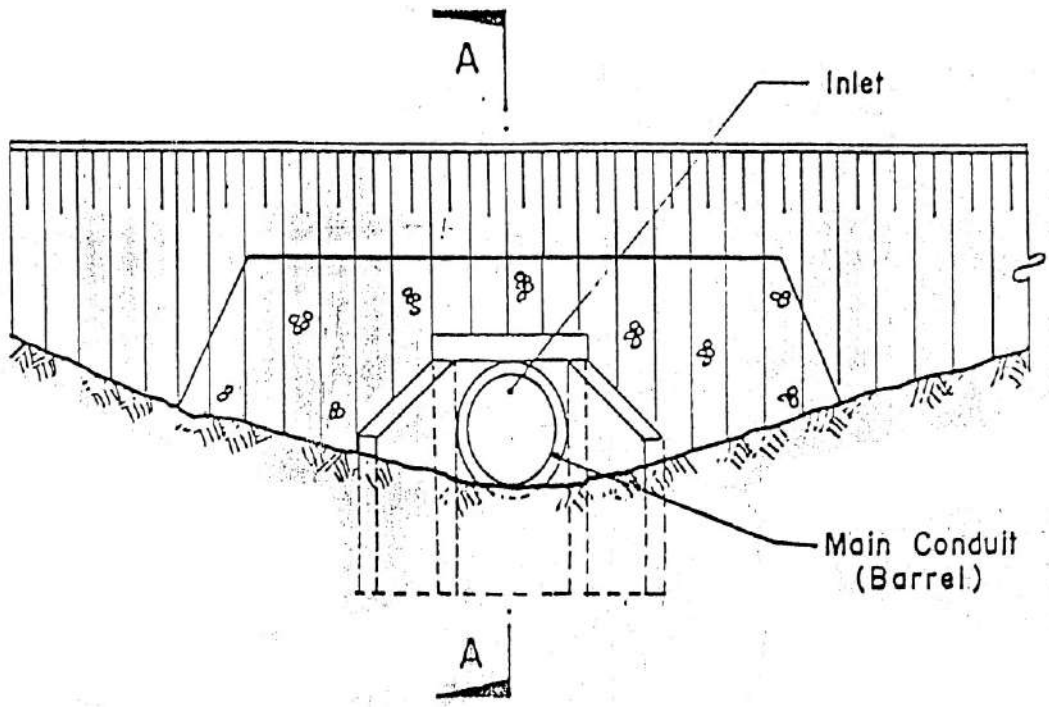


Suitability of types of culverts:

- **Slab Culvert:_** Perennial(continuous flow) or non perennial stream with boulder movement & debris flow.
- **Pipe Culvert:** In non perennial or at very small stream, frequently provided to carry surface run-off from side drain.
- **Arch Culvert:** In high hills, deep cuts.
- **Box culvert:** to serve large flow, where the boulder movement occurs, they are RCC structures thus resists high impact loads.

Elements of culvert




A
Inlet
Main Conduit
(Barrel)
A

- Depending upon the type of soil foundation there may be either sand bedding or PCC or RCC.
- Inlet or outlet structure consists of apron.
- Cutoff wall on its base and wing wall on its side to protect earth slope and to streamline the flow. Slope embankment should be protected with stone pitching, gabion work etc.
- Additional elements like hand rail, parapet wall may be provided.

Culvert location, layout & selection

Proper location is necessary for the efficient & economic operation of the culvert.

- Near to the natural water course in respect of both plan and profile.
- Perpendicular or skew culverts are compared on the basis of cost.
- Slope of the culvert should be normally as the natural bed slope of water course. (min 0.5 % is allowable).
- Selection of the type of the culverts:
  - Availability of construction material & technology
  - Nature of the water course
  - Economic comparison
  - Importance of road

EROSION CONTROL AND ENERGY DISSIPATION MEASURES:

- Velocity of water will be higher than non scouring velocity at:
  - After the outlet of the culvert or cross drainage
  - High bed slope of side drain & intercepting drains
- High velocity of water may cause:
  - Erosion of hill slope bed
  - Removal of vegetation layer.
- Control of the erosion is directly concerned with the dissipation of energy which ultimately means the reduction of velocity

Erosion Control & Energy Dissipating Measures

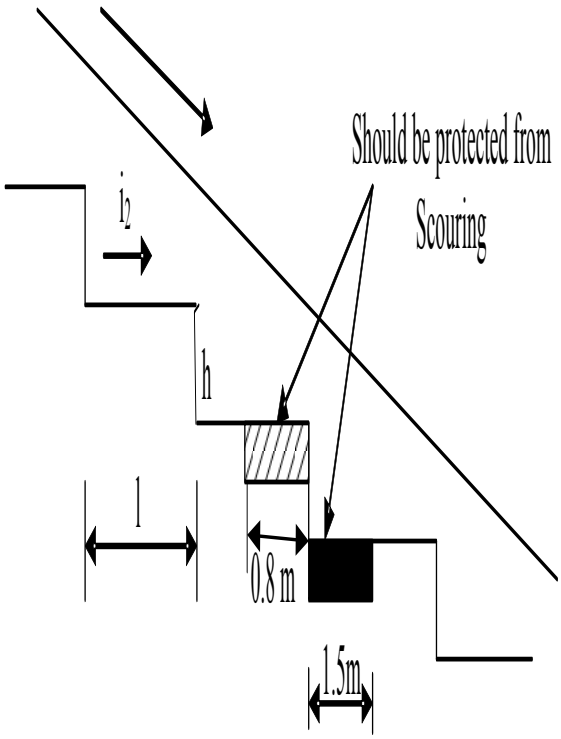
1. Drain lining

- For the particular type of soil; mean velocity may exceed than permissible & it should be protected against scouring.
- Slope of the drain is lined with turf and bottom is covered by cobbles & gravels of desired sizes.

Bed slope	Type of bed soil	Type of lining
Up to 1%	Sandy Soil	No lining
Up to 2%	Clay	No lining
(1-2)%	Sandy Soil	Turfing
(2-4)%	Clayey Soil	Turfing
Up to 5%	All types	Dry stone paving
More than 5%	All types	Ditch checks and stone masonry continuous lining

2. Ditch Checks (Drops):

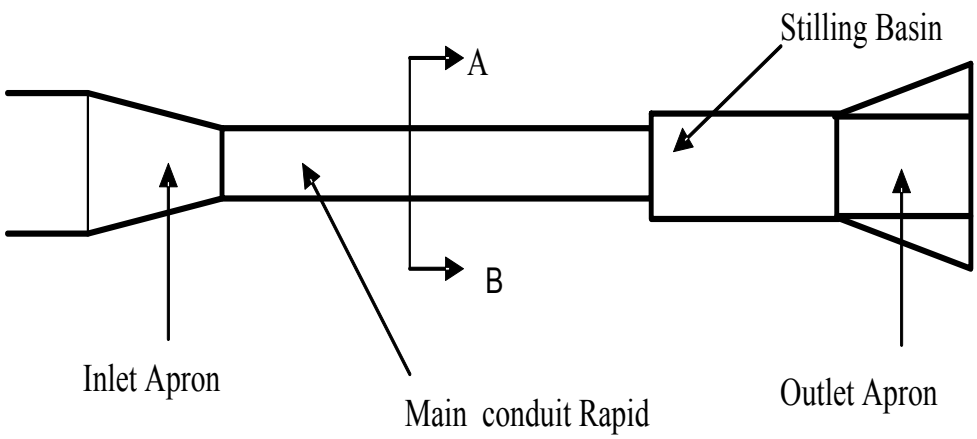
- Continuous lining with stone masonry in cement mortar is expensive and whenever possible bed slopes are made gentle by providing falls at certain interval, such type of structure is known as ditch checks.

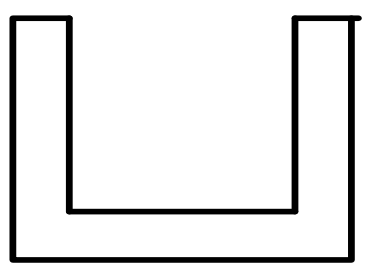


Ditch Checks

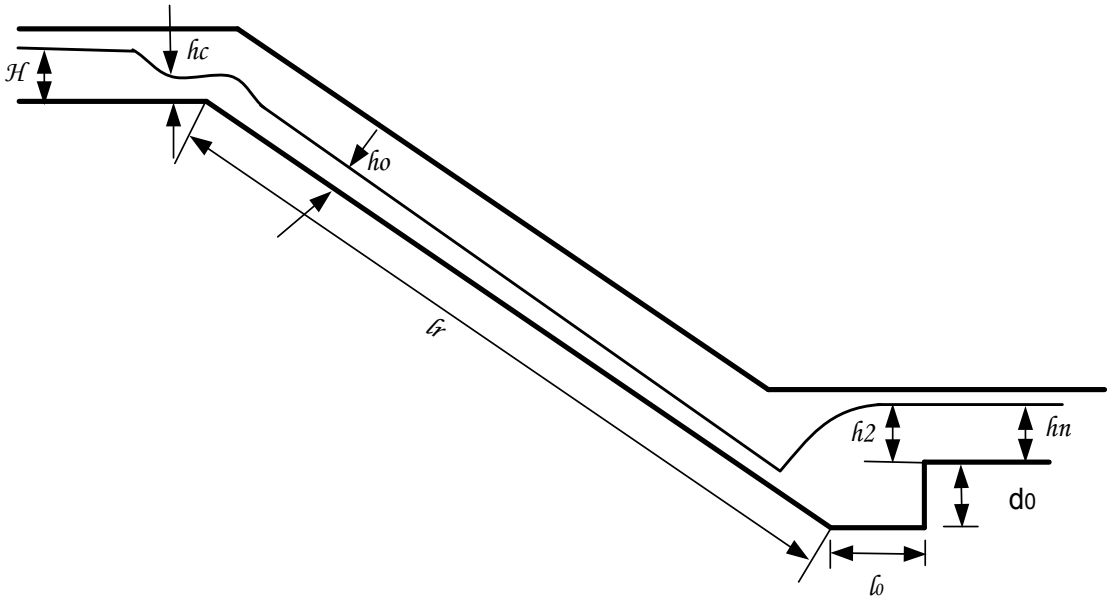
3. Road Rapids:

- Road channels having bed slope more than critical slope are referred as rapids.
- Rapids are provided on short length.
- It is provided at the end section of catch or intercepting drains.





Section at A-B


hc
H
ho
G
h2
hn
do
lo

4. Fall or Drop Structure:

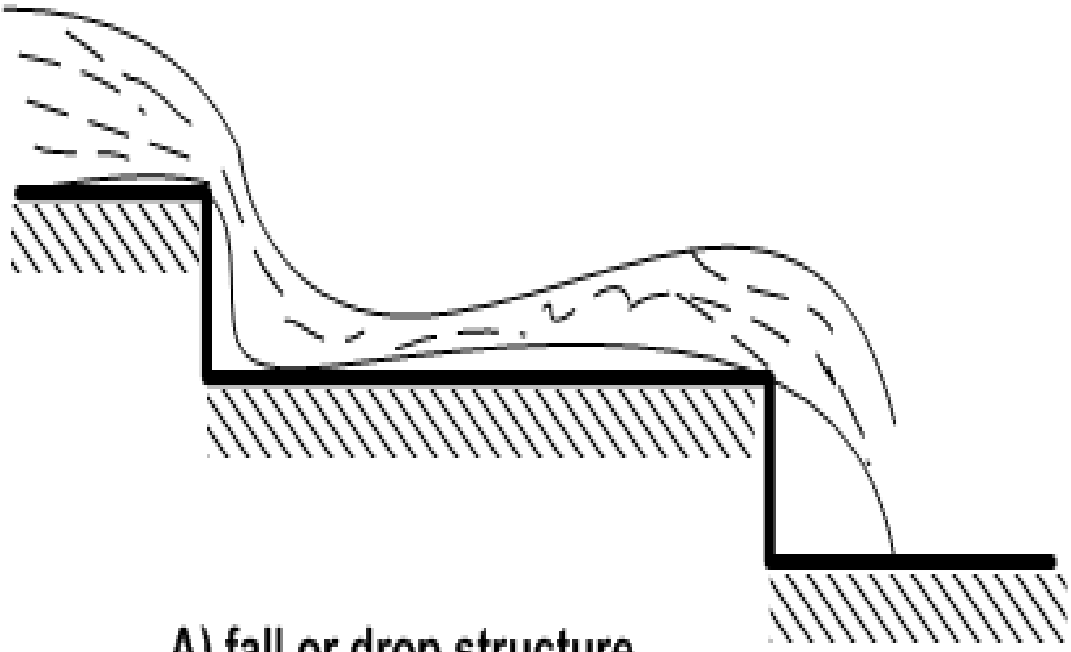
- They are provided both upstream & downstream of cross drainage.
- Different types of drop structures:

  a) Drop without stilling basin and friction wall

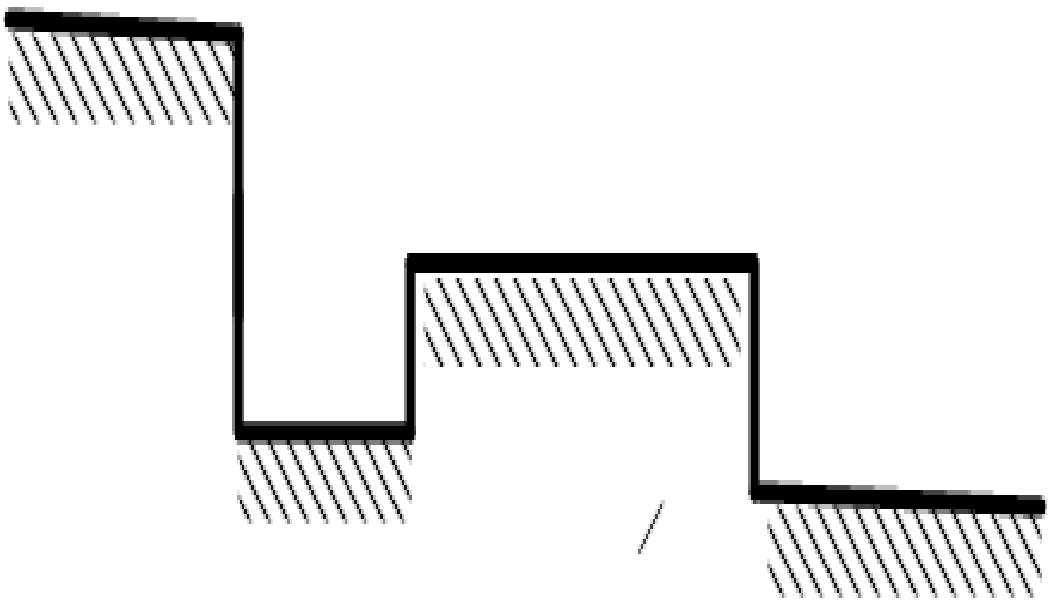
  b)Drop with stilling basin

  c) Drop with frictional wall

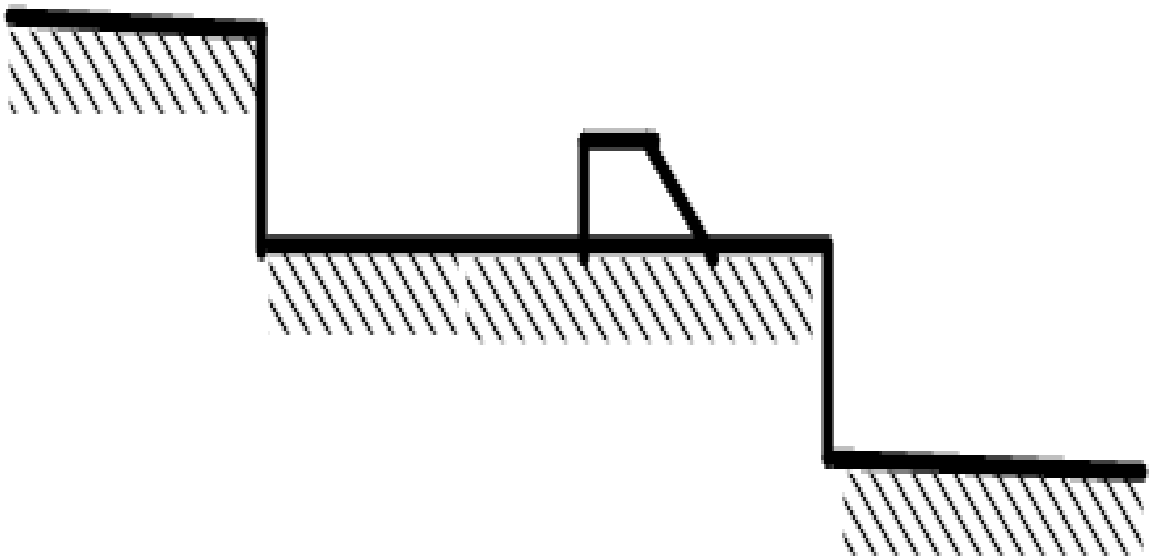
  d) Drop with frictional wall and stilling basin



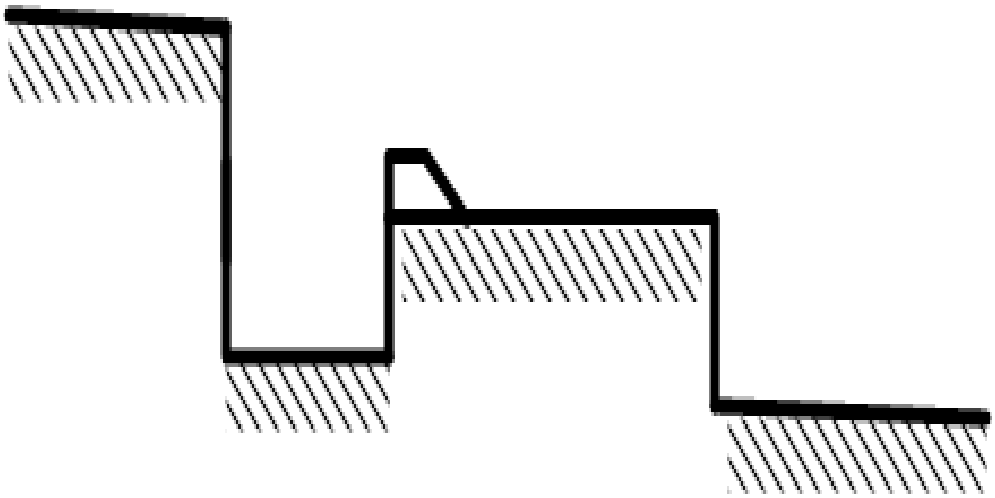
A) fall or drop structure



A) fall or drop structure with stilling basin



A) fall or drop structure with friction wall



A) fall or drop structure with stilling basin and friction wall

MISCELLANEOUS EROSION CONTROL MEASURES

Main reasons on soil erosion:

- Formation of new fills & cut slopes
- Excavation of drainage way
- Diversion of waterways along new channels
- Embankment construction
- Removal of top soil
- Increase in human activities on construction site
- Deforestation

MISCELLANEOUS EROSION CONTROL MEASURES

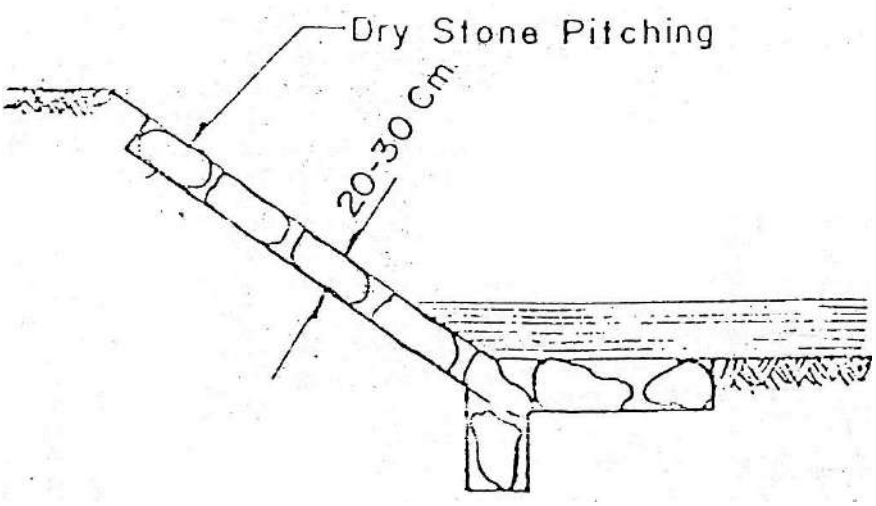
a) Vegetation:

- For slopes 1:1.5 and flatter, turf & other ground cover could be rapidly established.
- Ground covered with low growing herbaceous or woody plants are arranged.
- Trees & shrubs on steep hill slopes.
- Trees, shrubs and grass on road surrounding usually satisfy multiple function.
- Vegetation plays aesthetical role also.

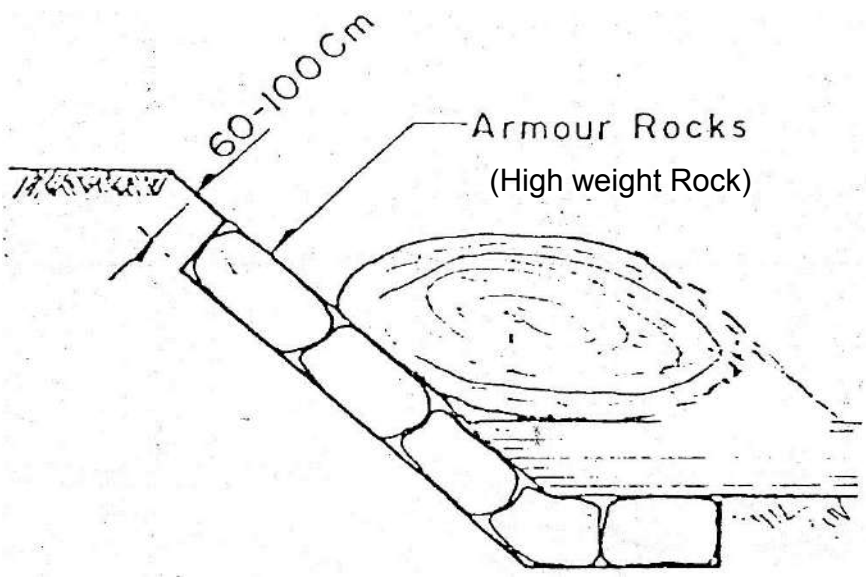
b) Slope pitching, lining & Protection walls:

- Dry stone pitching
- Armour rock protection
- Gabion crates filled pitching
- Stone masonry with cement mortar
- Concrete block lining
- Retaining wall

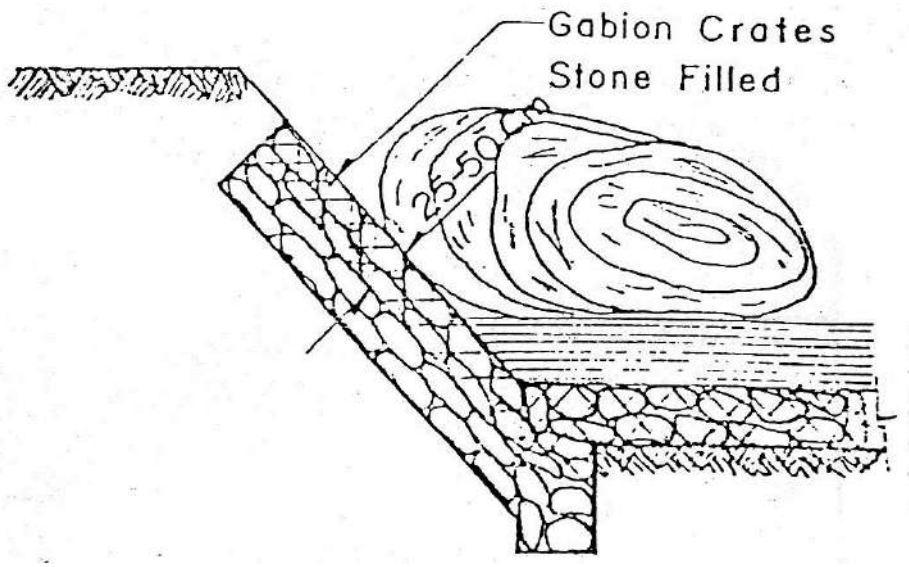
Dry stone pitching



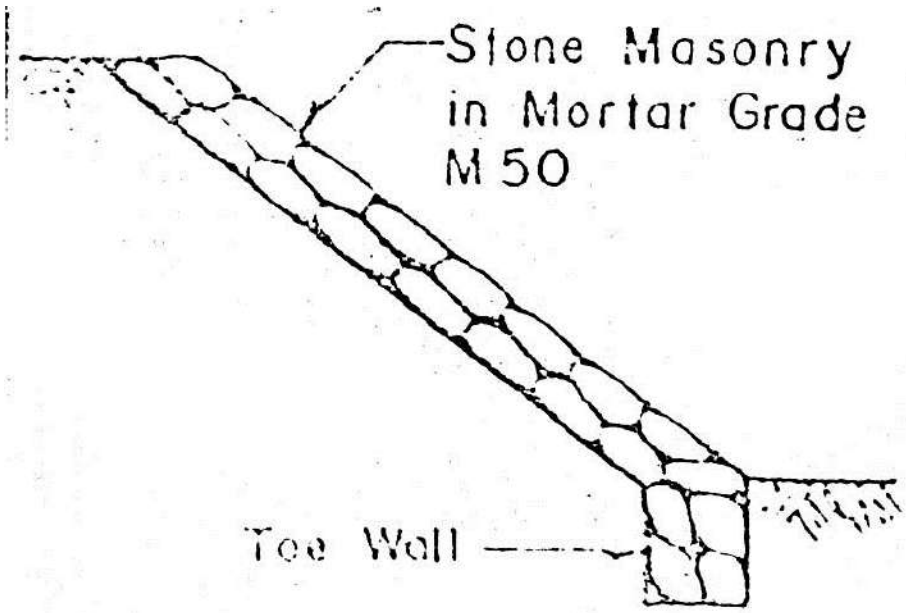
Armour rock protection



Gabion creates filled pitching

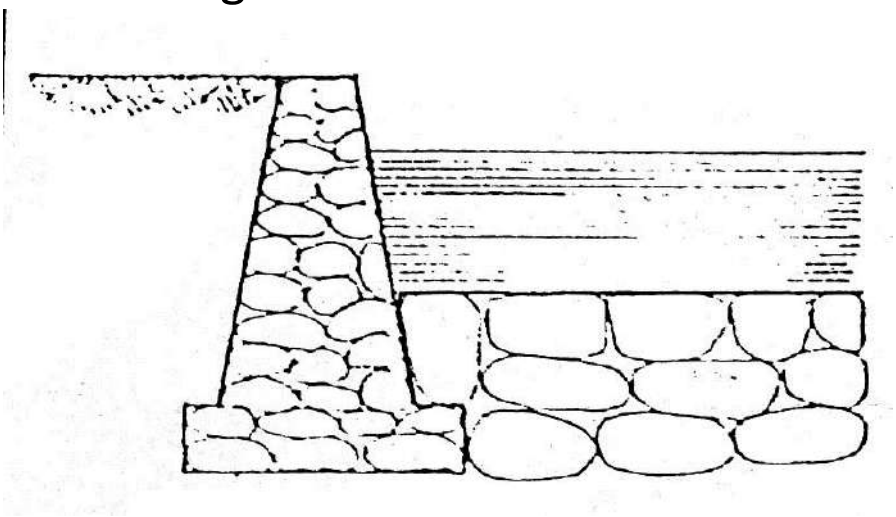


Stone masonry in C.M.

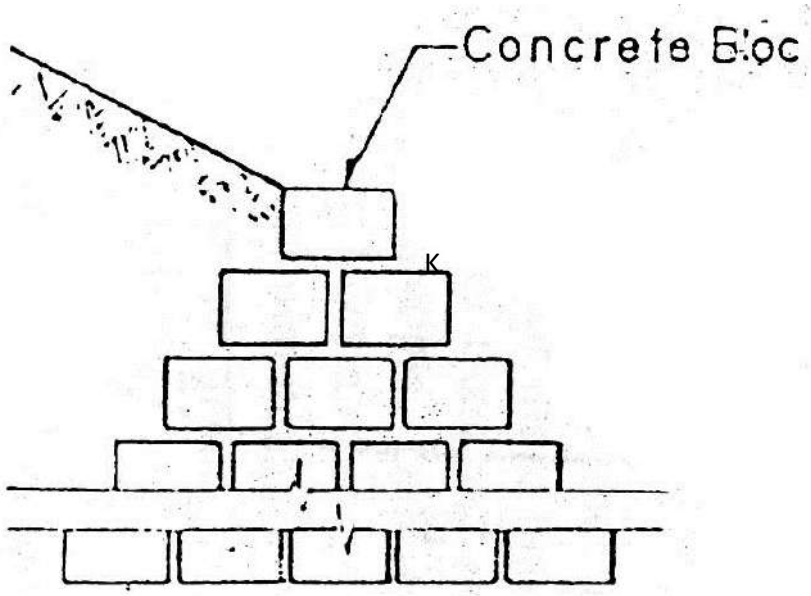


Retaining wall

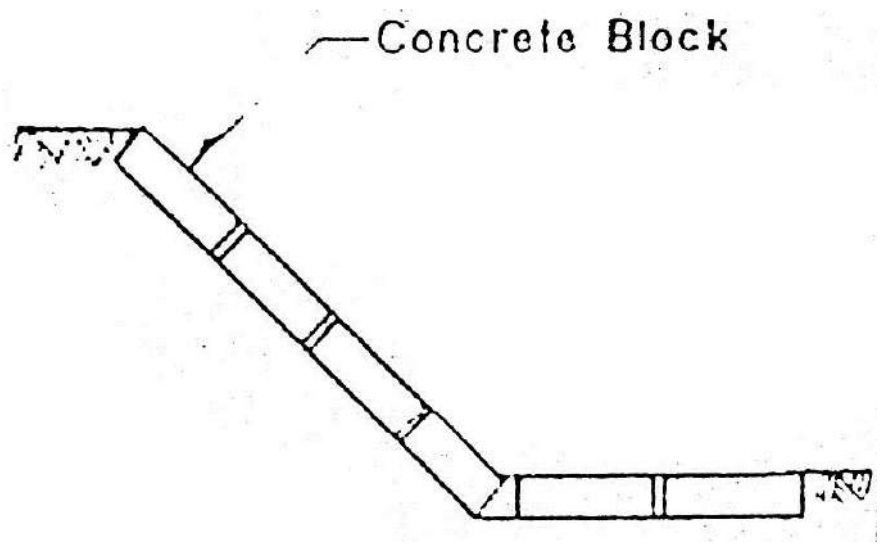
Retaining wall



Concrete block



Concrete block lining



c) Bank protection spur & check dams:

- **Spur:** perpendicular structure to the direction of flow to dissipate the water energy & protect the erosion.
- **Check Dams:** structures constructed across the stream having high bed slope in a particular section to retain boulder or bed material.

Spur

Check Dam

Other Miscellaneous Cross drainage structures

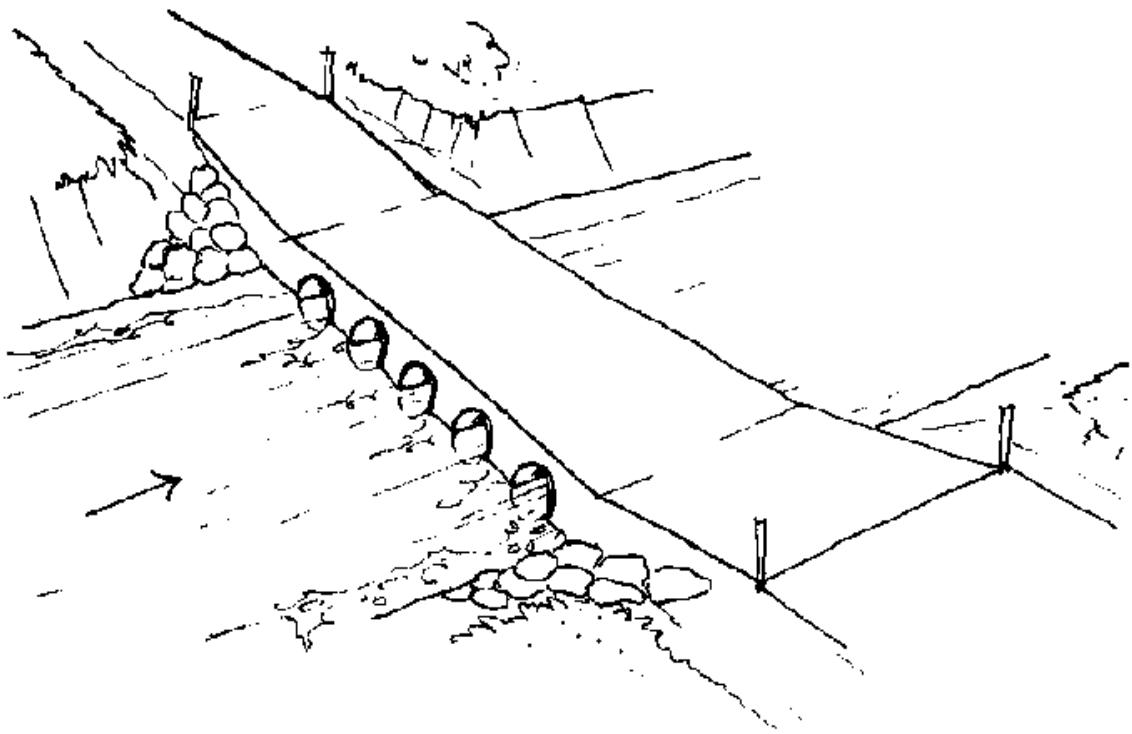
1. Causeways:

- A cross drainage structure with or without openings below road surface provided across a shallow drainage course at or about the bed level which allows floods/ runoff to pass over it is referred as **Causeway.**
  - A causeway with vents below to pass regular flow under the road and flash flood across the road surface is often known as high level causeway or submersible bridge.
  - A causeway constructed at bed level which allows flood to pass over the road surface at any time is referred as flush causeway. It is sometimes called as Ford.

Causeway

Causeway

Vented Causeway



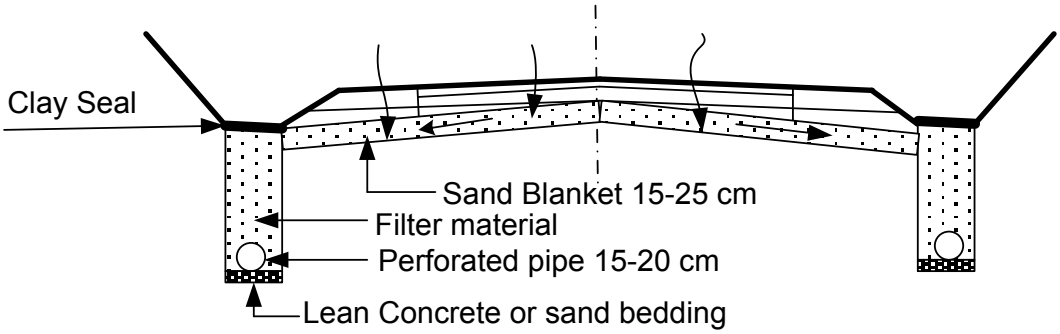
Sub-surface Drainage

- Surface drainage system is the preventive measure to control excessive moisture in sub-grade soil and various pavement layers. Unfortunately, whatever effective measures for the surface drainage may be considered, water finds its own way to get into the sub-grade and further below. The provision of drainage under the ground surface is referred as sub-surface.

Subsurface drainage system

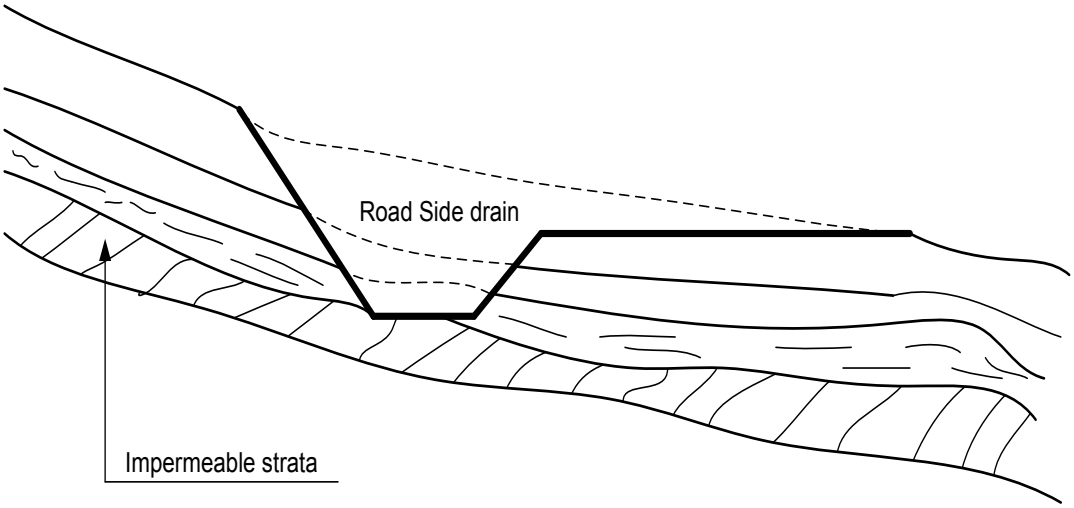
- Drainage of infiltrated water
- Control of seepage flow
- Lowering water level
- Measures for capillary vapour transfer cut off

Drainage of infiltrated water



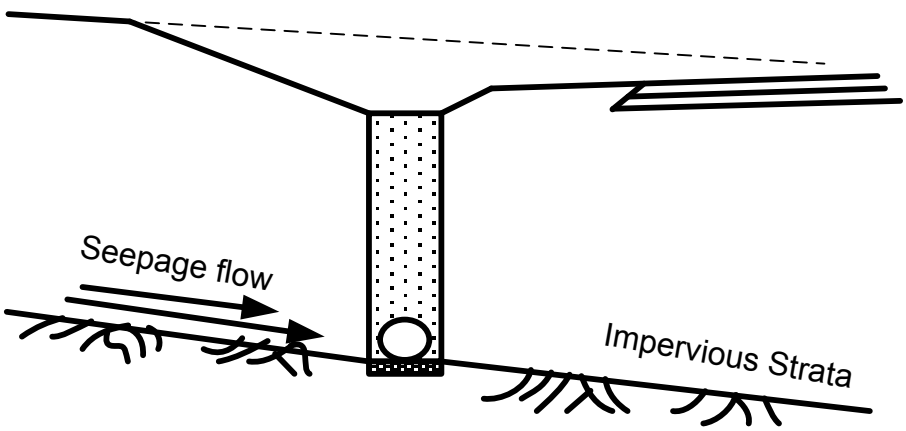
1. Drainage of infiltrated water

Control of seepage flow



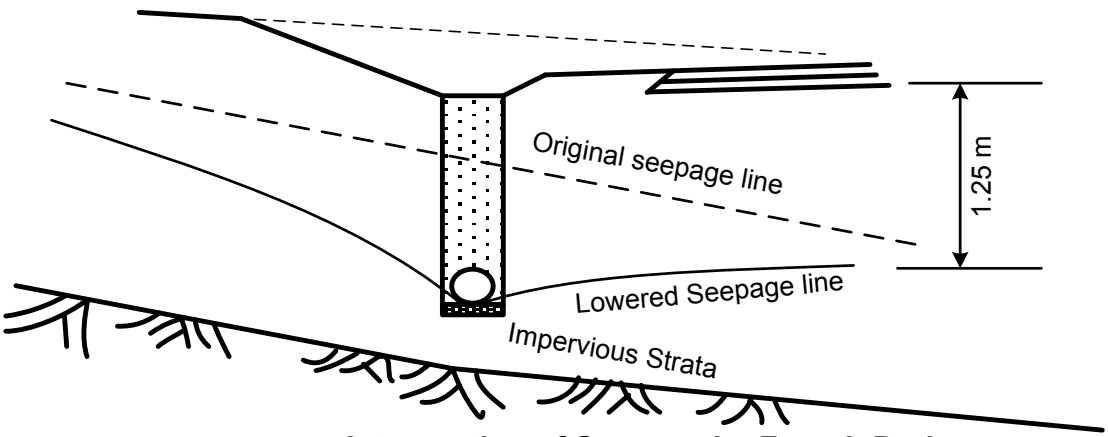
2. Interception of seepage flow by surface drainage

Control of seepage flow



B) impervious strata deep below

Lowering water level



Interception of Seepage by French Drain

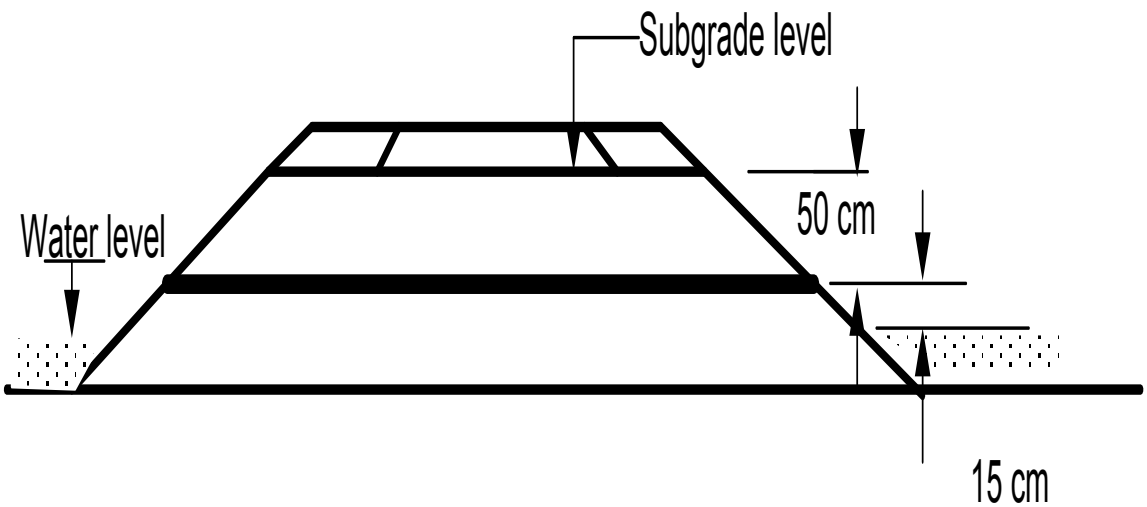
Measures for capillary vapor transfer cut off

- In water logged areas capillary action is more severe, if roads are constructed from fine grained soil. In such cases, capillary cutoff are provided, to make the subgrade soil free from excessive moisture.
- Moisture movement in the form of vapor is resulted where substantial fluctuation in daily temperature takes place

Some suitable Measures:

- Sand blanket for capillary cut off
- Tarfelt for both capillary cut off & vapor movement
- Polythene envelops for capillary cut off and vapour movement
- Use of impermeable membrane (bitumen)
- Bitumen stabilized soil for impermeable membrane

Tar Felt
dreamstime.com



Capillary / Vapour Cut off

THANK YOU

Transportation Engineering I

Er. Narayan Timilsena
Paschimanchal Campus, Pokhara

Chapter 5: Hill Road

Definition: A terrain can be classified into four groups based on the ground cross slope i. e. the slope approximately perpendicular to the C.L. of the highway alignment.

Terrain type	**Cross slope, %**
Level/Plain	0 – 10
Rolling	>10 – 25
Mountainous	>25 – 60
Steep	Above 60

- A hill road is defined as the one which passes through the terrain with a **cross slope of 25% or more.**
- Nepal has a total area of about 140,000 km^2 of which about 66% are covered with thinly populated hills, mountains and Himalayas.
- **The construction of hill roads is not practicable and direct investment on it is not profitable. But it is necessary due to:**
- National distribution of agro-product
- Supply of industrial goods
- Social justification and cultural development/linkage
- Good administration, security and national defense

Design and construction problems in hill roads:

- Hilly area has broken relief with widely differing elevation in a short distance. It requires considerable length of road
- Geological condition varies in a short distance. It makes difficult to design and construct embankment and for other structures.
- Cross slope may become unstable after road construction due to removal of vegetation and other activities.
- Difficult to investigate and forecast the hydro-geological condition of hill slopes which may cause land slide

- Requires more numbers of cross drainage structures and other special structures
- Steep slope needs careful arrangement of erosion control measures.
- Surface run-off become very high in a short period after heavy rain fall, it requires the big opening for cross drainage.
- Variation of climatic condition causes the road damage
  - Temperature
  - Atmospheric pressure
  - Precipitation
  - Wind
- Special safety measures should be taken during survey and construction

Special considerations are required during:

- Road location and alignment
- Geometric design
- Typical cross section
- Special structures (retaining walls, drainage, slope protection works etc)

Alignment of hill roads:

Special consideration should be made in respect to variation in:

- ❖Temperature
- ❖Precipitation/rainfall
- ❖Atmospheric pressure and wind
- ❖Geological condition

Temperature:

- Temperature decreases per 100m increase in elevation (0.5^0C)
- Hill slopes facing **south-west and south** receive **enough solar heat**; snow disappears quickly and rain water evaporates rapidly.
- North and north east; rain water and snow remains for long period.
- Sharp temperature variation of south and south-west slopes results the fast weathering process, which causes deposition of alluvial fan on that side, mud flow and avalanches occur frequently.

Rainfall:

- In general, the increase of rainfall for every 100m of elevation averages 40 – 60 mm. Hill/ mountain slopes which face winds, receive more rainfall.
- Heavy rainfall may occur in hills, which may cause serious damages to hill roads
- Openings of the cross drainage requires very large.

Atmospheric pressure and wind:

- Atm. pressure decreases with the elevation
- At low atmospheric pressure effort of engine become less
- At high altitude wind blows with high velocities cause erosion of pavement material
- Wind may damage the road pavement: by blowing away the binding particles (in dry season), and by the erosive action of surface run off (in wet season).

Geological condition:

- Sedimentary rocks often occur as folds which may concave and convex with inclinations
- Degree of stability of hill slopes depends upon the rock type, strata, inclination and presence of ground water.

11

Alignment of Hill Roads (Route location):

Selection of alignment in hilly region is a complex problem. The designer should attempt the shortest, most economical and safe route. Hill roads tend to follow routes with large number of curves.

Route location may be:

- ❖River route
- ❖Ridge route

River route: The location of a route along the river valley is the most frequent ease of hill road alignment owing to the distinct advantage of running the road at a comparatively **gentle gradient**. The route along the **river route serves rural settlements** situated next to the water course. It has the advantage of **low operating cost, availability of water and other construction materials** in the vicinity. However, a valley run may involve **numerous horizontal curves, construction of large bridges over tributaries and on stretches along steeply sloping hill sides**, which in some places may be insufficiently stable.

Advantages:

- Minimum gradient
- Availability of water and other construction materials
- Road can serve settlements, situated along river valley
- Low vehicle operation cost

Disadvantages:

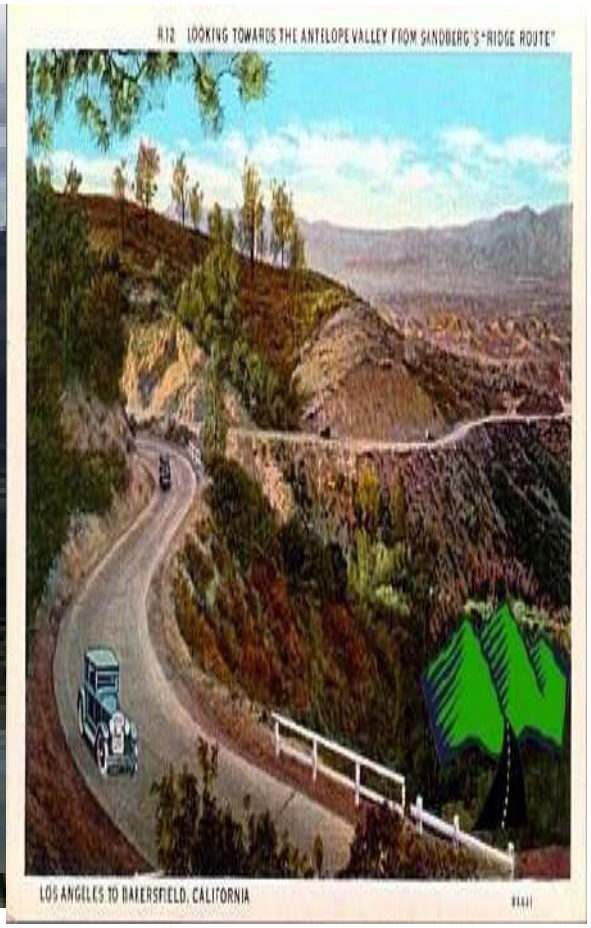
- River alignment has many horizontal curves
- Route cross large number of tributaries. It means large number of cross drainage works.
- Need of protection works against the washout, or toe cutting of foundation of road bed or other retaining structure.

Basic consideration in locating the river route:

- Road bed should be away and above from the maximum water level in the river so that the risk of erosion or seepage during high water level.
- Embankment slope facing the river should be protected and stabilized
- It needs good geological and hydro-geological surveys of local conditions
- When crossing water courses, several route alternatives have to be investigated.

Ridge route:

- Steep gradient
- Large number of curves (hair pin bends)
- Expensive rock work, many other structures
- It climbs continuously up from the valley till it reaches a mountain pass and descends down to follow another hill system
- Mountain pass should have the least elevation to the direction of destination
- If land slope is steeper than the permissible maximum gradient, the route can't be laid along the shortest direction. So length has to be increased to gain the height with permissible gradient.
- The route is traced out in the map by following more or less the line of equal gradient, slightly lower than the ruling gradient.


R12 LOOKING TOWARDS THE ANTELOPE VALLEY FROM SANDBERG'S "RIDGE ROUTE"
LOS ANGELES TO BAKERSFIELD, CALIFORNIA

Alignment survey of hill roads:

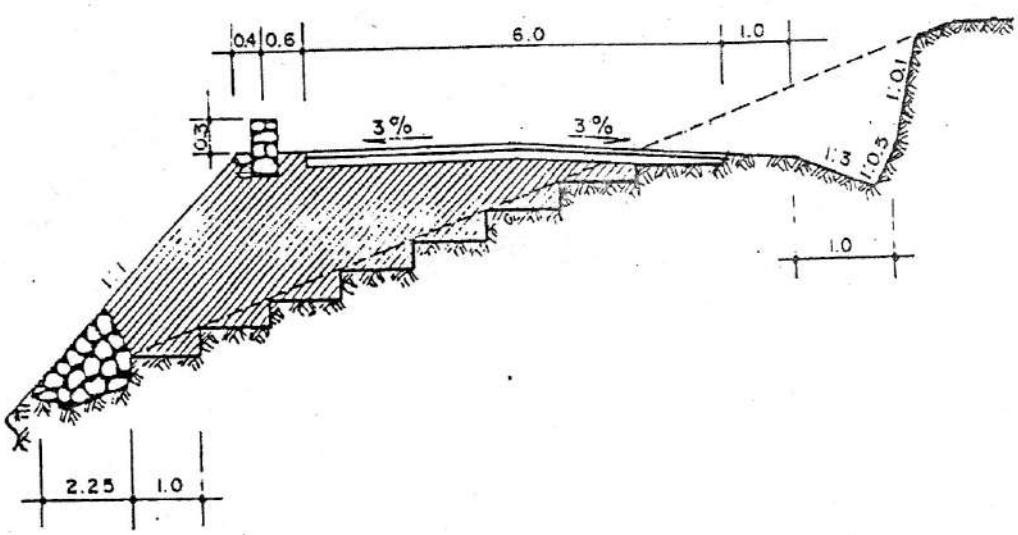
The alignment of hill roads is fixed in the three stages:

- Reconnaissance
- Preliminary Survey
- Trace cut-1 to 1.2 m wide track
- Detailed survey-B/M Fixation, L- section, X-section, Center line marking, Hydrological and soil investigations

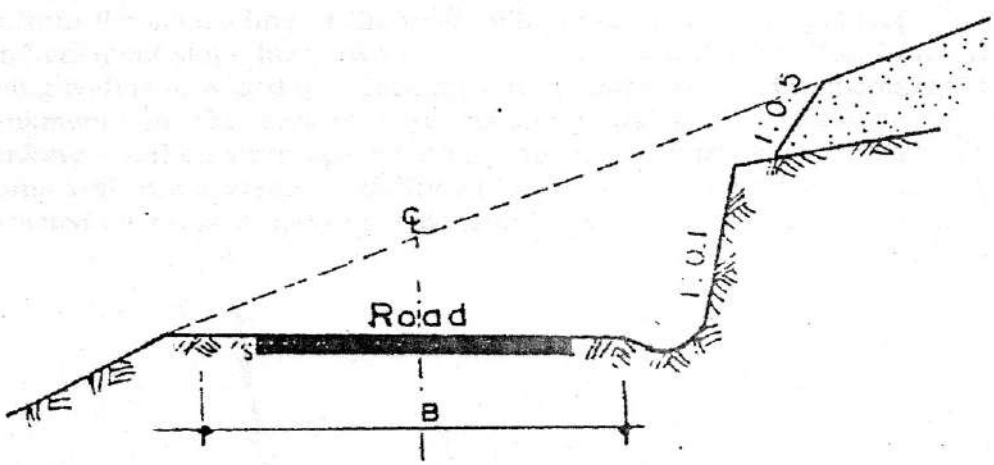
Geometric design of hill Roads: Main reasons for the difference in design are complexity of terrain, high altitude factors and other problems in the design and construction of hill roads. Special consideration should be given for the selection of gradient and the design of hair pin bends.

Typical cross section of hill roads:

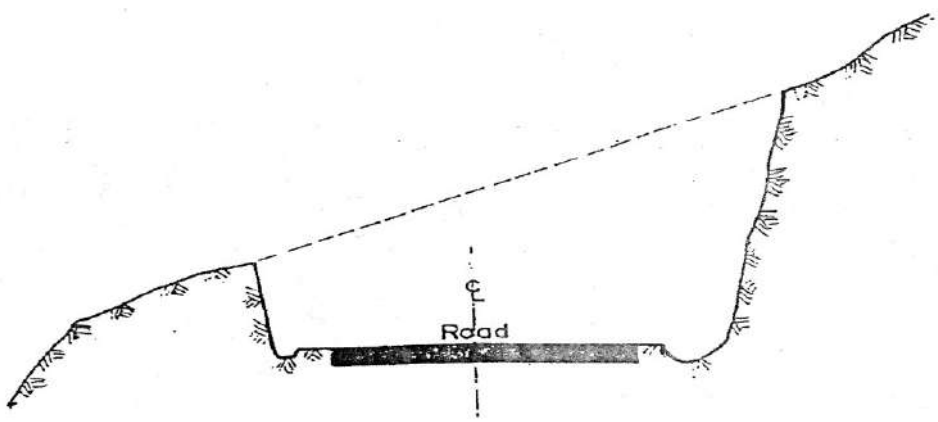
Cut and fill: (with hill side slope of 2%,), Cheaper and Environmental friendly



Bench type: If the side slope is greater, it is difficult to fill the embankment and compaction is also difficult. Bench type cross section is the most suitable

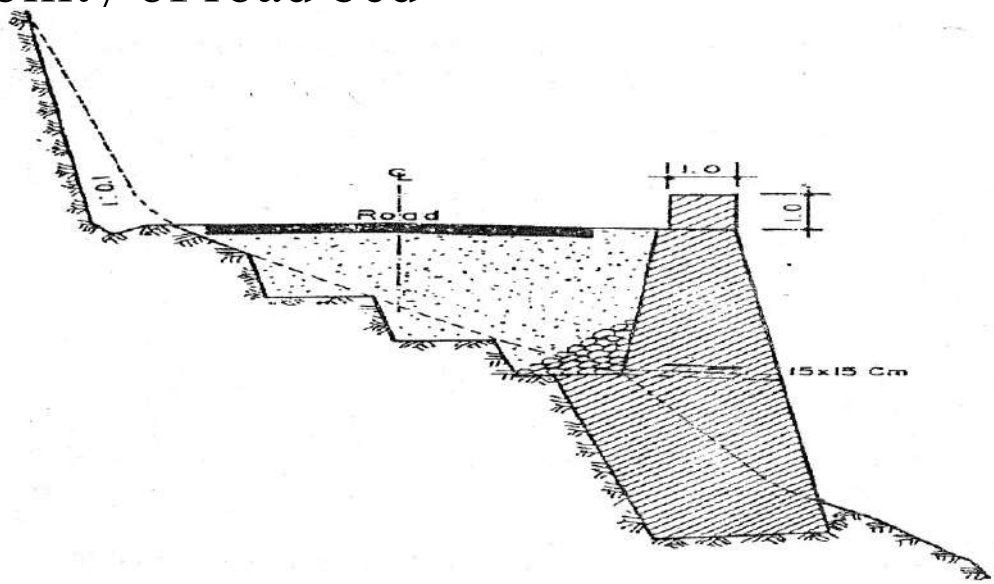


Box type: If the location of road bed in hill slope is unstable or unsuitable, then road bed is designed as trench type of cross section

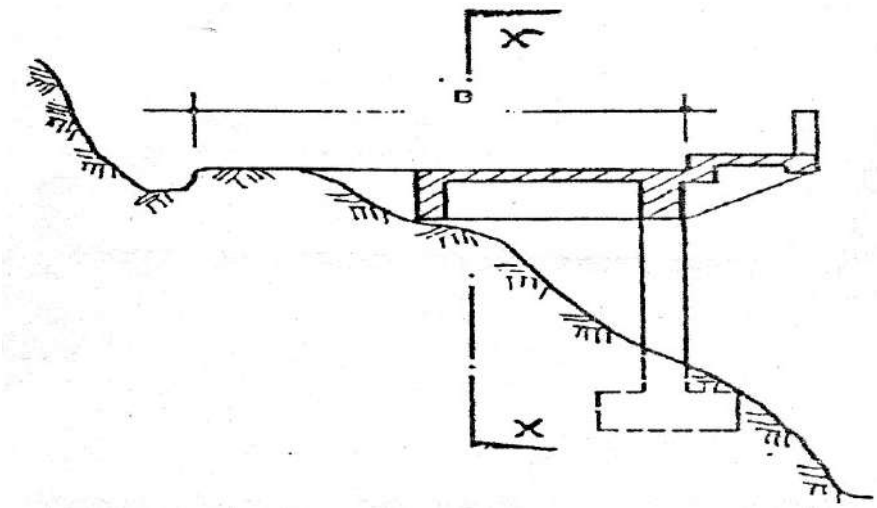


Embankment with retaining wall:

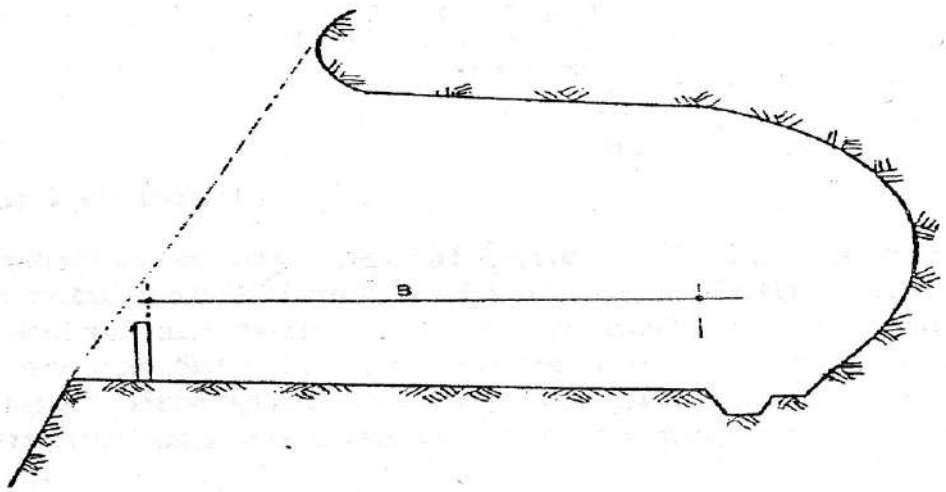
e/w increases, Cross slope 30-35^0, To reduce e/w Retaining wall is constructed, To ensure stability of road bed



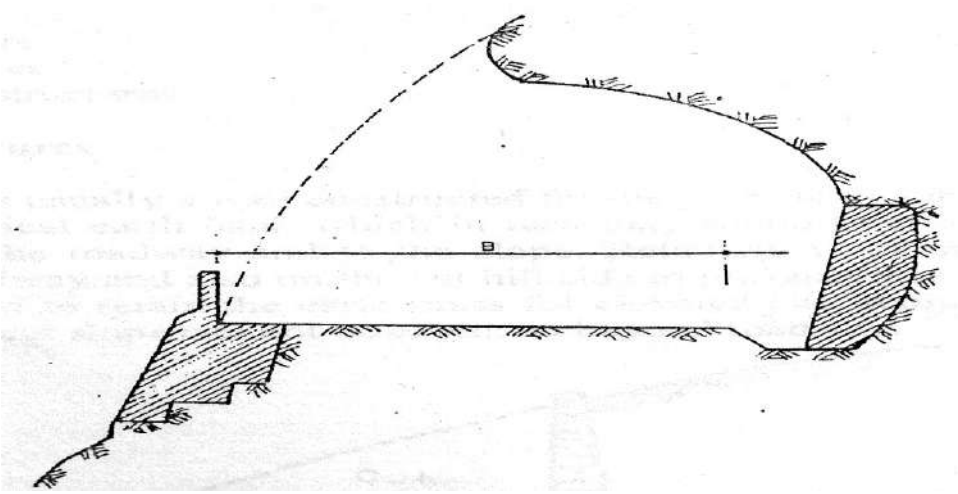
Semi bridge : If road is located across step slope, retaining wall may have to be very high. In such cases semi bridge may be constructed



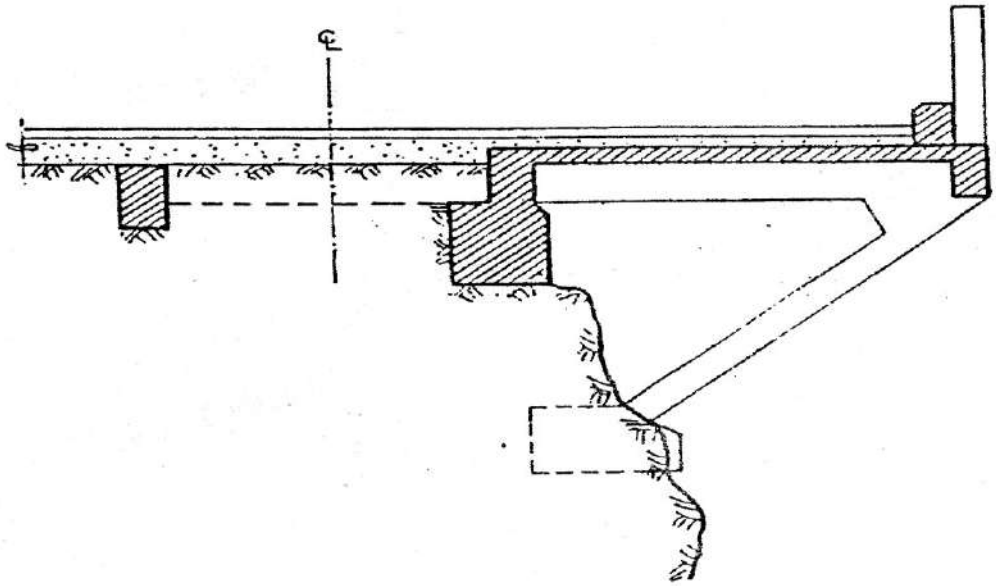
Semi tunnel : When cutting into steep hills in stable hard rock, the rock may be permitted to overhang



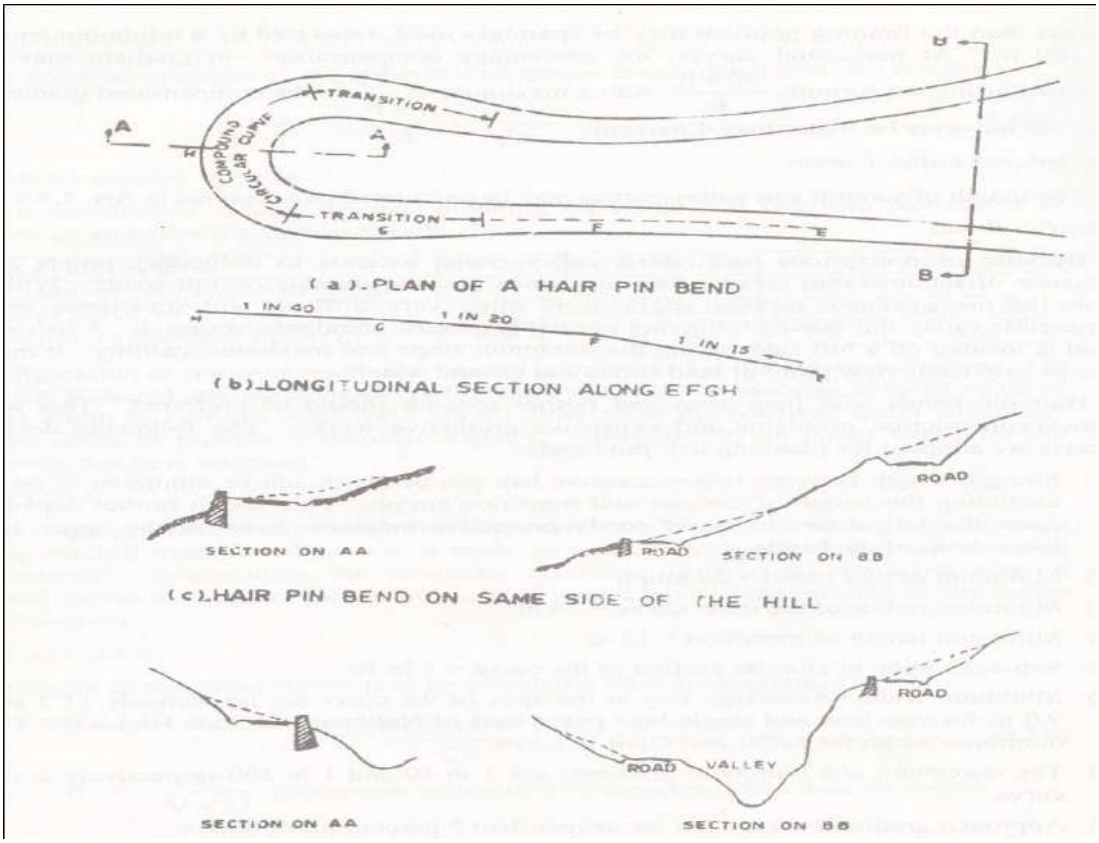
Semi tunnel with retaining wall and breast wall :

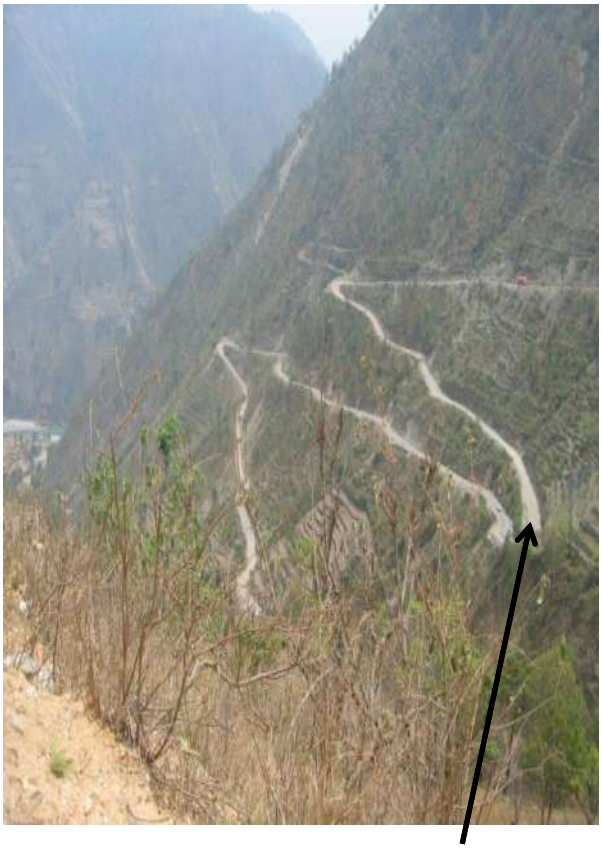


Platform :



Hair pin bends: When developing a route in hilly area, it is frequently necessary to insert sharp angles. But it is very difficult and sometimes impossible to layout curves following normal geometric standard of design. When inscribing a curve inside a turning angle the length of the route will be substantially reduced, which results in a steep gradients. In such cases it is preferable to round-off the route by circumscribing the curve around the turning point. Such compound curve is called “hair pin bends” or “reverse loops”.

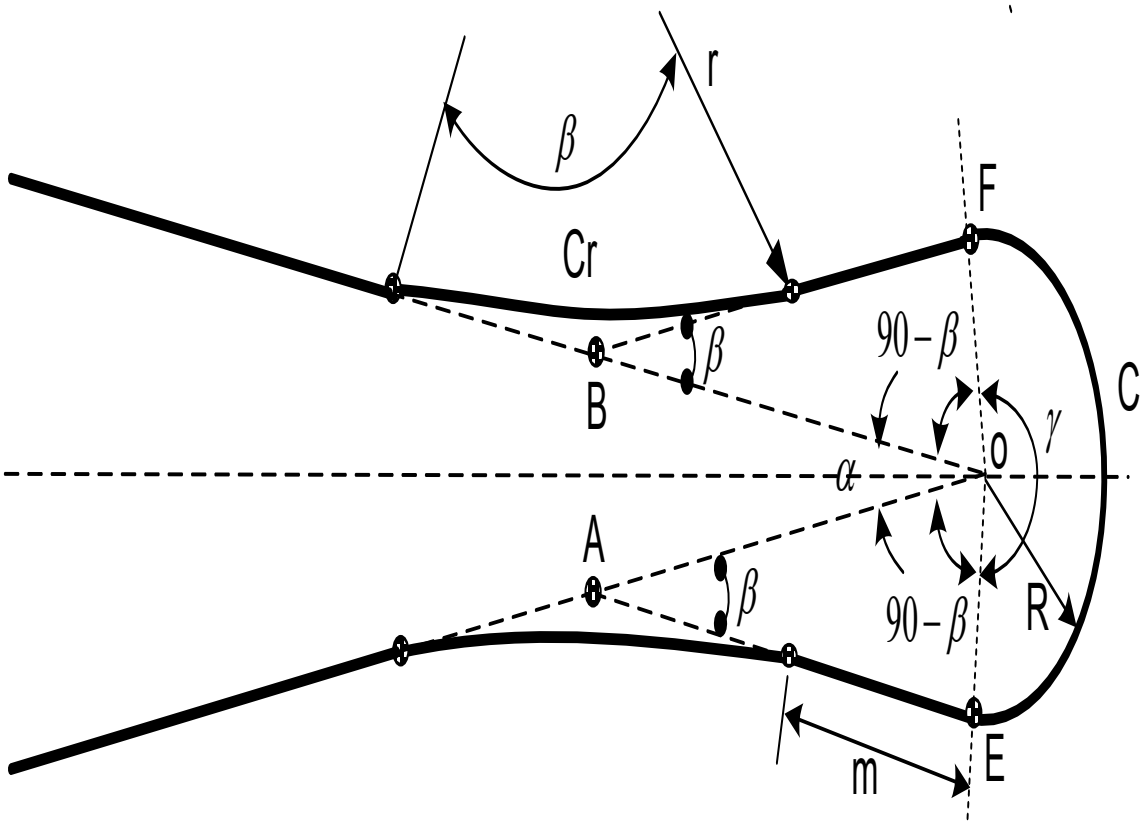

TRANSITION
A
A
COMPOUND
CIRCULAR CURVE
TRANSITION
G
F
E
B
B
(a).PLAN OF A HAIR PIN BEND
1 IN 40
1 IN 20
1 IN 15
H
G
F
E
(b).LONGITUDINAL SECTION ALONG EFGH
ROAD
SECTION ON AA
ROAD
SECTION ON BB
(c).HAIR PIN BEND ON SAME SIDE OF THE HILL
ROAD
ROAD
VALLEY
SECTION ON AA
SECTION ON BB



Hair Pin Bend

Design of hair pin bends: Radius of the main curve **R**, radius of the reverse curve (**r**) and length of the straight portion (**m**) are selected based on the site situation and conforming to the required geometric standards. Design parameters of hair pin bends

- Design speed =20kmph
- Min. radius of main curve = 14m
- Min. length of transition curve =15m
- Minimum gradient with bend =2.5%
- Super-elevation in curved portion =10%
- Approach gradient should not be steeper than 5% for 40 meters.


r
β
Cr
F
β
90 − β
C
B
γ
o
α
A
β
90 − β
R
m
E

For the designing and layout of the hair pin bends elements such as **radii of the main curve and reverse curves (R and r) and the length of tangent (m) are initially selected** based on the site situations in conformity with design standards. The design of hair pin bends then basically consists of establishing the value of the turning angle at point A and B which satisfies the preselected parameters of the bend.

Tangent length of the reverse curve,

$$T = r\tan\frac{\beta}{2}$$

The distance from the apex of the reverse curve to the commencement of the main curve is, $AE = BF = T + m$

From triangle AOE and BOF it is found that:

$$\tan\beta = \frac{OE}{AE} = \frac{R}{T+m} = \frac{R}{m + r\tan\frac{\beta}{2}}$$

From the trigonometry it is known that:

$$\tan\beta = \frac{2\tan\frac{\beta}{2}}{1-\tan^2\frac{\beta}{2}}$$

Substituting in proceeding expression:

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

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

$$2r\tan^2\frac{\beta}{2} + R\tan^2\frac{\beta}{2} + 2m\tan\frac{\beta}{2} - R = 0$$

Solving quadratic equation:

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

In this way, the angle β corresponding to *R*, *r* and *m* can easily be determined.

The distance from the apex of the reverse curve to the center of the main curve is determined by:

$$AO = OB = \frac{T + m}{Cos\beta} = \frac{R}{Sin\beta}$$

The central angle corresponding to the main curve of the bend is equal to: $\gamma = 360 - 2(90 - \beta) - \alpha = 180 + 2\beta - \alpha$

The length of the main curve is:

$$C = \frac{\Pi R \gamma}{180}$$

The total length of the hair pin bend is: $S = 2(C_r + m) + C$

Obtaining these parameters, the hair pin bend can be plotted on the contour map or set out on the ground.

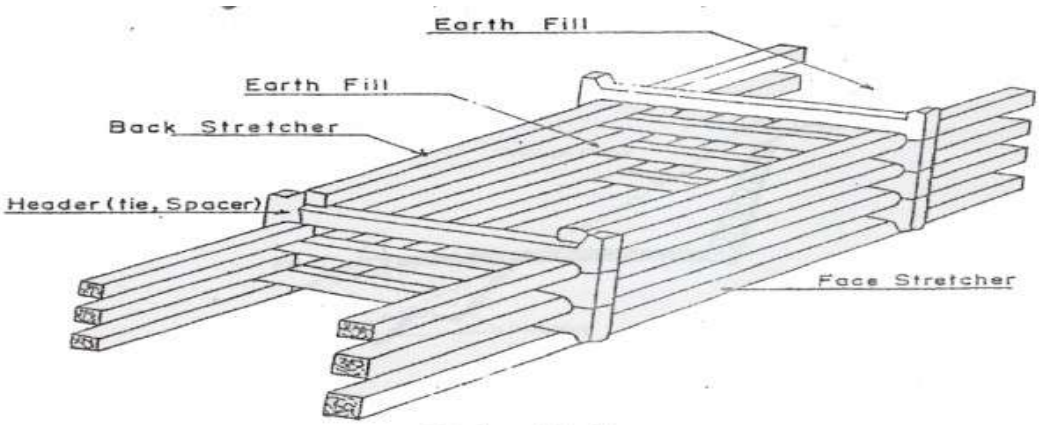
Special structures in hill roads:

Objectives:

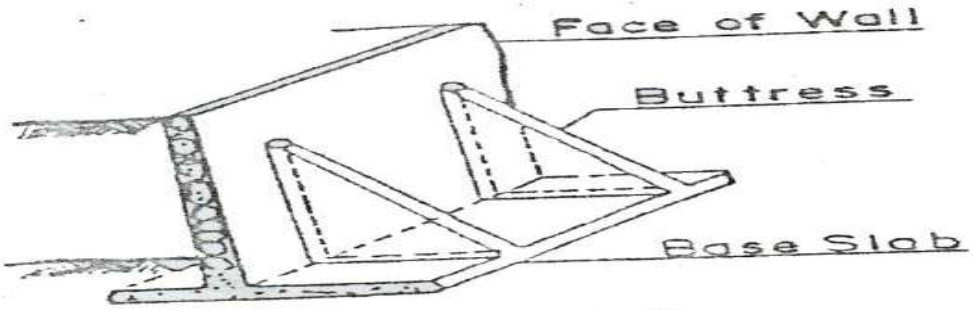
- To retain soil mass
- To increase stability of road embankment
- To accommodate road bed in steep slope
- To dissipate energy of surface water
- To provide snow avalanche control and protection system
- To river training and erosion control
- To prevent bed scouring

Special structures in hill roads:

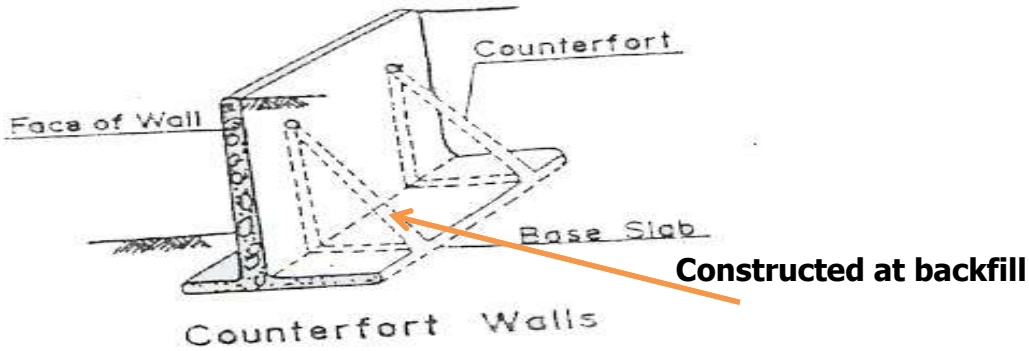
- Retaining structures
- Drainage structures
- Slope protection structures

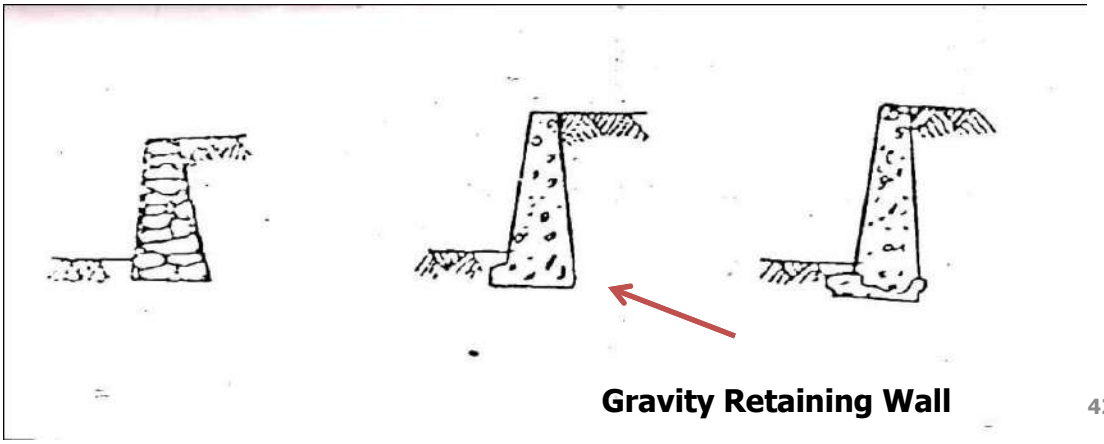


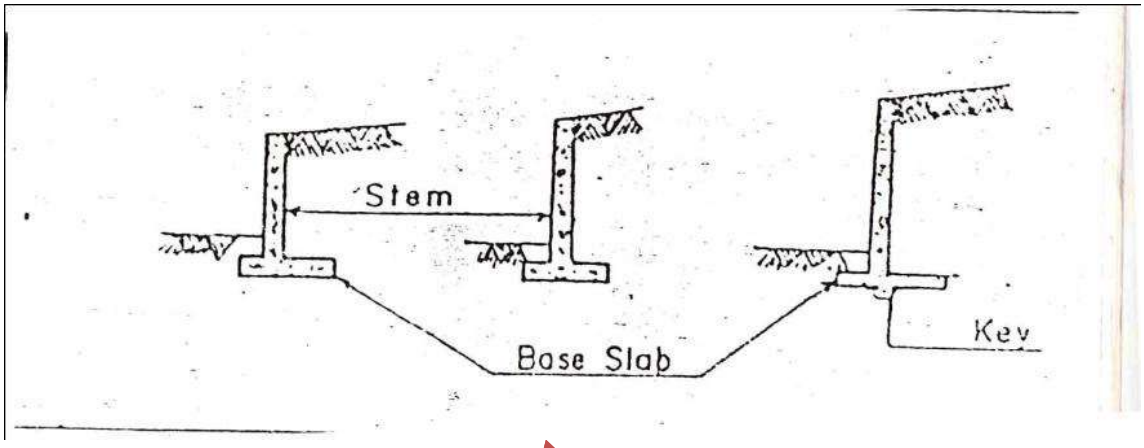
Crib Walls



Buttressed Walls


Counterfort
Face of Wall
Base Slab
Constructed at backfill
Counterfort Walls


Gravity Retaining Wall



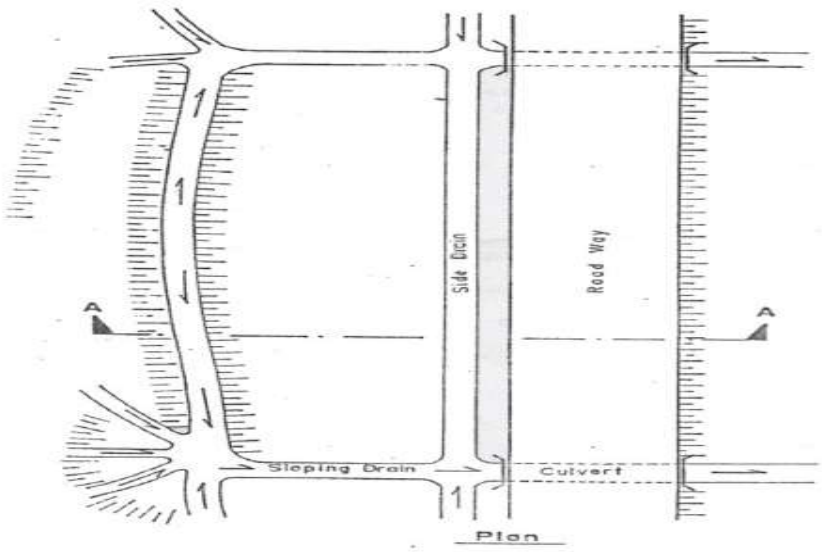
Cantilever Retaining walls

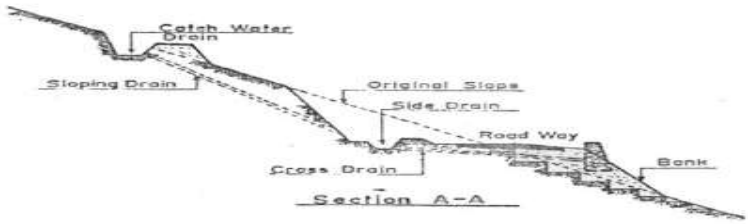
Design principles of Retaining walls:

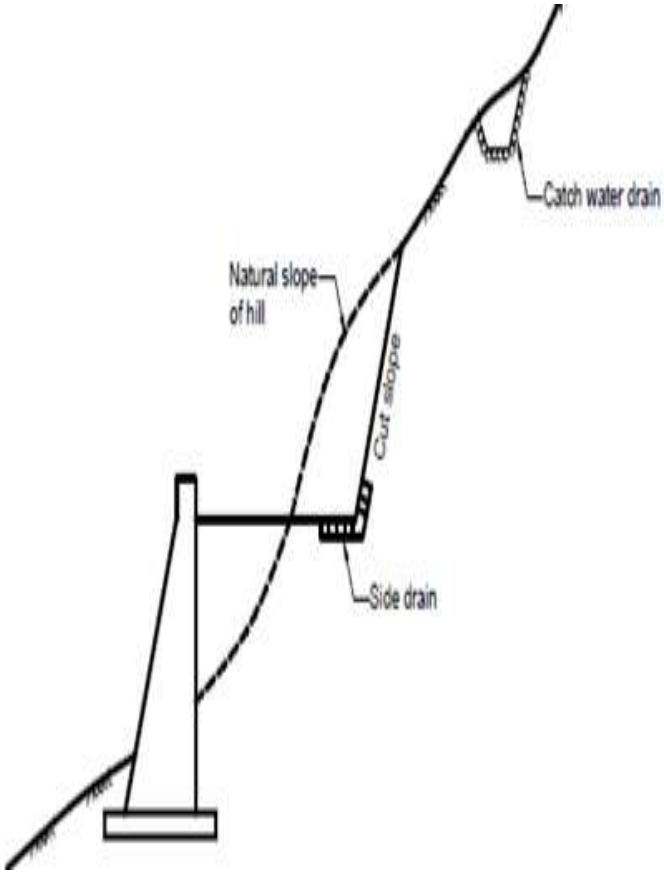
- **The stability of the wall and structural strength of each component or section of wall:** This involves the proportioning, preliminary dimensioning, determining thickness of wall, checking against overturning, sliding etc.
- **The stability of foundation soil:** it must not be overstressed. For this purpose, toe pressure, heel pressure and bearing pressure of the soil foundation must be checked against their permissible values.

The design procedure of retaining walls usually comprises of the following steps:

- Collection of general information on topography and information on physical survey
- Analyze the sub-soil condition
- Establish surcharge loads: highway, building and other structure
- Select the type and tentative proportioning of wall
- Compare the earth pressure and surcharge pressure
- Analyze the structural stability
- Analyze the foundation stability
- Design structural elements
- Select drainage in backfill
- Predict settlement and movement of wall

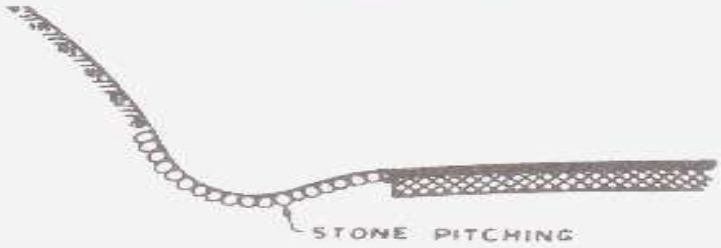

Side Drain
Road Way
A
A
Sloping Drain
Culvert
Plan


Catch Water Drain
Sloping Drain
Original Slope
Side Drain
Road Way
Cross Drain
Bank
Section A-A

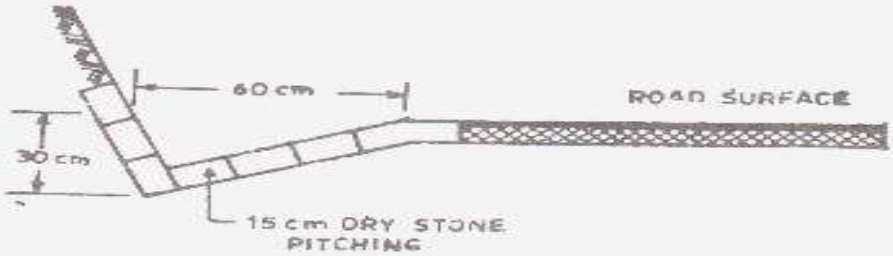

Catch water drain
Natural slope of hill
Cut slope
Side drain

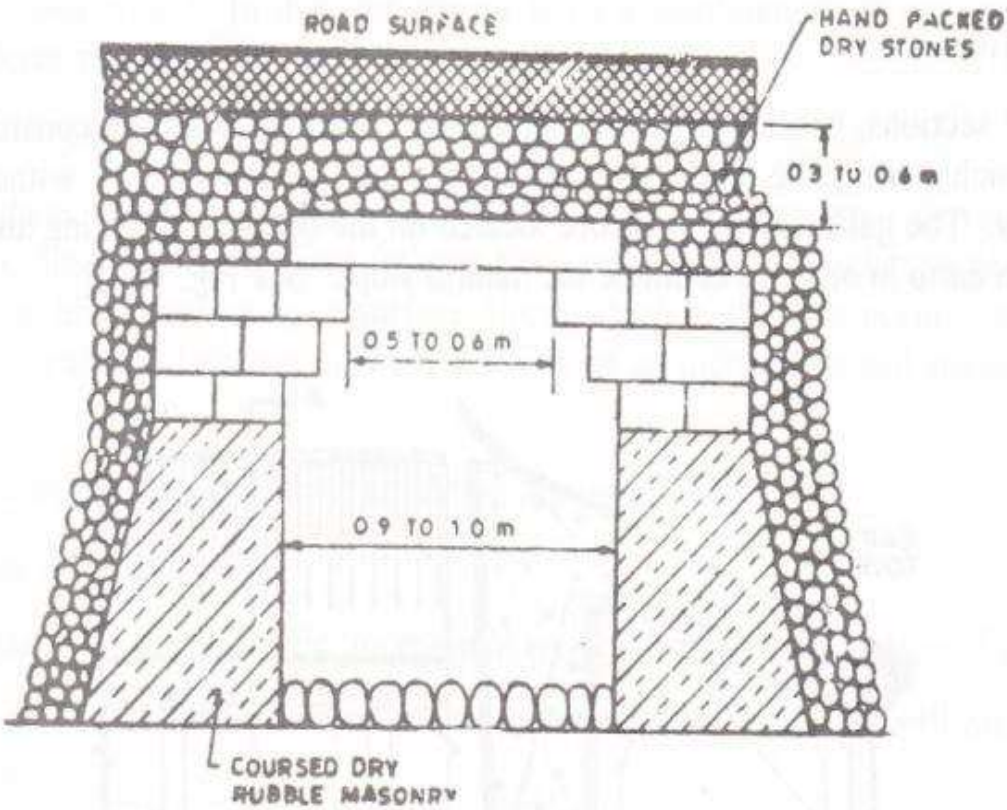
dreamstime.com

(a) Angle Drain



(b) Saucer Drain




ROAD SURFACE
HAND PACKED
DRY STONES
0.3 TO 0.6 m
0.5 TO 0.6 m
0.9 TO 1.0 m
COURSED DRY
RUBBLE MASONRY

THANK YOU

Transportation Engineering I

Er. Narayan Timilsena

Paschimanchal Campus, Pokhara

Chapter 6: Pavement Materials

Aggregate: Road Aggregate is a common term for the mineral materials such as sand, gravel, and crushed stone that are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.) to form compound materials (such as bituminous concrete and Portland cement concrete). By volume, aggregate generally accounts for **92 to 96 percent of Bituminous concrete and about 70 to 80 percent of Portland cement concrete**. Aggregate is also used for base and sub-base courses for both flexible and rigid pavements. Aggregates can either be natural or manufactured. Natural aggregates are generally extracted from larger rock formations through an open excavation (quarry). Extracted rock is typically reduced to usable sizes by mechanical crushing. Manufactured aggregate is often a bye product of other manufacturing industries.

Desirable properties:

Strength : The aggregates used in top layers are subjected to (i) Stress action due to traffic wheel load, (ii) Wear and tear, (iii) crushing. For a high quality pavement, the aggregates should possess high **resistance to crushing, and to withstand the stresses due to traffic wheel load.**

Hardness :The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic. The aggregates should be hard enough to **resist the abrasive action caused by the movements of traffic**. The abrasive action is severe when steel tyred vehicles moves over the aggregates exposed at the top surface.

Toughness: Resistance of the aggregates to impact is termed as toughness. Aggregates used in the pavement should be able to resist the effect caused by the jumping of the **steel tyred wheels** from one particle to another at different levels causes severe impact on the aggregates.

Shape of aggregates: Aggregates which happen to fall in a particular size range may have rounded, cubical, angular, **flaky(0.6*d) or elongated particles (1.6*L)**. It is evident that the flaky and elongated particles will have less strength and durability when compared with cubical, angular or rounded particles of the same aggregate. Hence too flaky and too much elongated aggregates should be avoided as far as possible.

Adhesion with bitumen: The aggregates used in bituminous pavements should have less affinity with water when compared with bituminous materials, otherwise the bituminous coating on the aggregate will be stripped off in presence of water.

Soundness: The property of **aggregates to withstand adverse action of weather is called soundness**. The aggregates are subjected to the physical and chemical action of rain and bottom water, impurities there-in and that of atmosphere, hence it is desirable that the road aggregates used in the construction should be sound enough to withstand the weathering action.

Freedom from deleterious particles : Specifications for aggregates used in bituminous mixes usually require the aggregates to be clean, tough and durable in nature and free from excess amount of flat or elongated pieces, dust, clay balls and other objectionable material. Similarly aggregates used in Portland cement concrete mixes must be clean and free from deleterious substances such as clay lumps, silt and other organic impurities.

Tests on Aggregate:

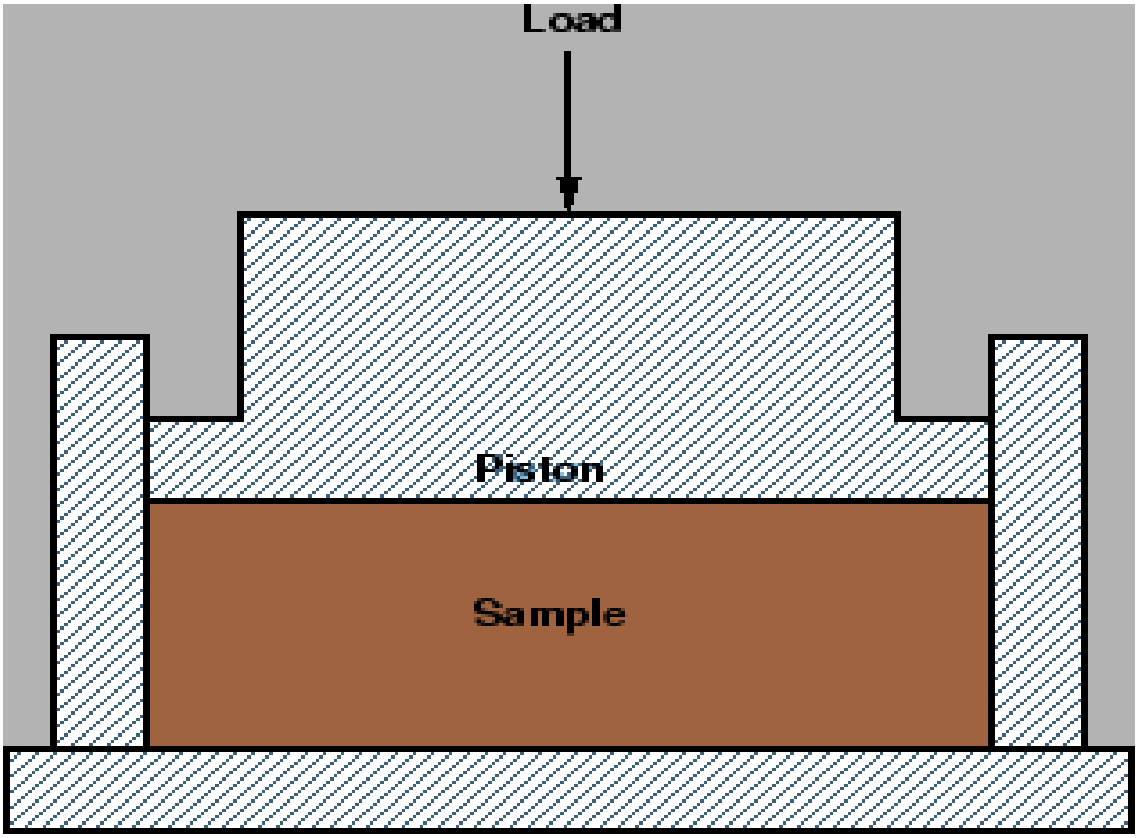
Crushing Strength Test: One of the model in which pavement material can fail is by crushing under compressive stress. A test is standardized by IS:2386 part-IV and used to determine the crushing strength of aggregates. The aggregate crushing value provides a relative measure of **resistance to crushing under gradually applied crushing load.**

Dry aggregates passing through **12.5 mm sieves and retained 10 mm** sieves are filled in a cylindrical measure of **11.5 mm diameter and 18 cm height** in three layers. Each layer is tampered 25 times with at standard tamping rod. The test sample is weighed and placed in the test cylinder in three layers each layer being tampered again.

The specimen is subjected to a **compressive load of 40 tonnes(10 minutes) gradually applied at the rate of 4 tonnes per minute.** Then crushed aggregates are then sieved through **2.36 mm sieve** and weight of passing material (W1) is expressed as percentage of the weight of the total sample (W2) which is the aggregate crushing value.

$$\text{Aggregate crushing value} = \frac{W_1}{W_2} \times 100$$

A value less than 10 signifies an exceptionally strong aggregate while above 35 would normally be regarded as weak aggregates.


Load
Piston
Sample

Abrasion test : Abrasion test is carried out to test the hardness property of aggregates and to decide whether they are suitable for different pavement construction works. Los Angles abrasion test is a preferred one for carrying out the hardness property and has been standardized in India (IS:2386 part-IV). The principle of Los Angeles abrasion test is to find the percentage wear due to relative rubbing action between the aggregate and steel balls used as abrasive charge.

Los Angeles machine consists of circular drum of internal diameter 700 mm and length 520 mm mounted on horizontal axis enabling it to be rotated. An abrasive charge consisting of cast iron spherical balls of 48 mm diameters and weight 340-445 g is placed in the cylinder along with the aggregates. The number of the abrasive spheres varies according to the grading of the sample. The quantity of aggregates (oven dried=105-110°C) to be used depends upon the gradation and usually ranges from 5-10 kg. The cylinder is then locked and rotated at the speed of 30-33 rpm for a total of 500 -1000 revolutions depending upon the gradation of aggregates.

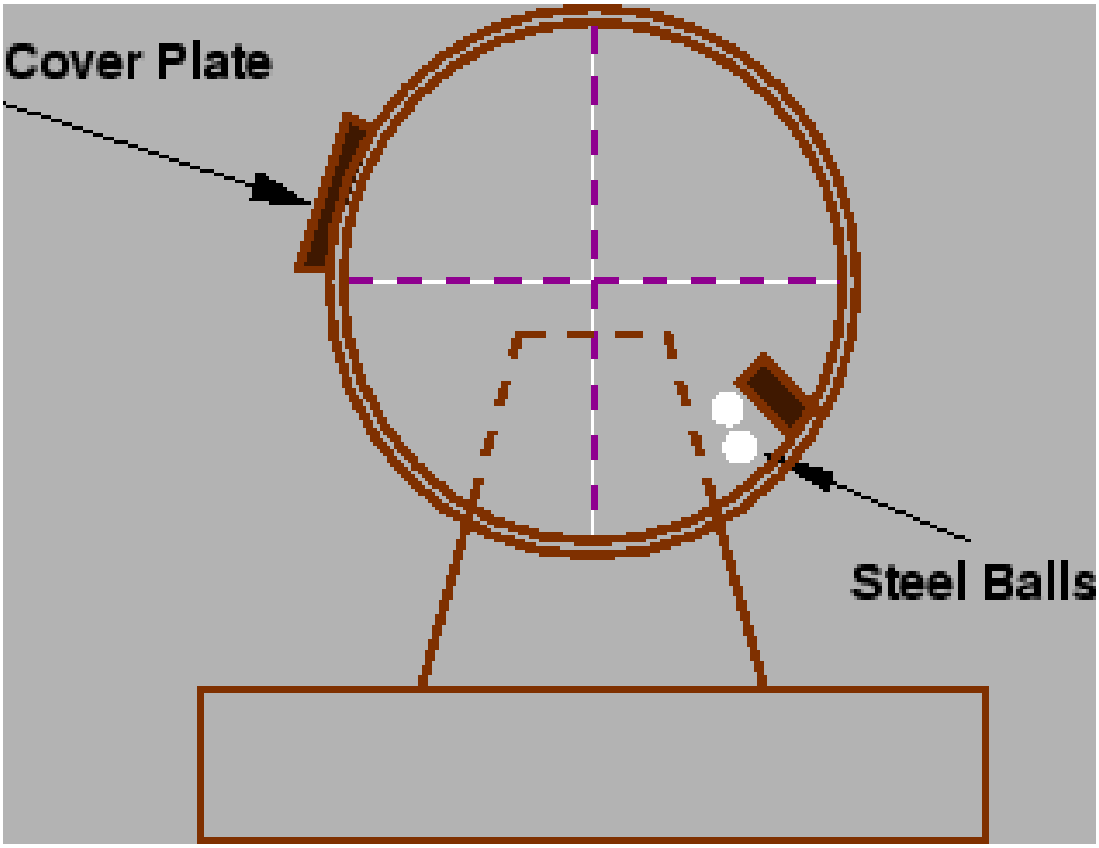
Grading	No of balls	Sample wt, gm
A	12	5000+/-25
B	12	4584+/-25
C	12	3300+/-20
D	12	2500+/-15
E	12	5000+/-25
F	12	5000+/-25
G	12	5000+/-25

Grading of test samples

Sieve size (Square hole)		Weight in g of test sample for grade						
		A	B	C	D	E	F	G
Passing through (mm)	Retained on (mm)							
80	63	-	-	-	-	2500*	-	-
63	50	-	-	-	-	2500*	-	-
50	40	-	-	-	-	5000*	5000*	-
40	25	1250	-	-	-	-	5000*	5000*
25	20	1250	-	-	-	-	-	5000*
20	12.5	1250	2500	-	-	-	-	-
12.5	10	1250	2500	-	-	-	-	-
10	6.3	-	-	2500	-	-	-	-
6.3	4.75	-	-	2500	-	-	-	-
4.75	2.36	-	-	-	5000	-	-	-

After specified revolutions, the material is sieved through 1.7 mm sieve and **passed fraction is expressed as percentage total weight of the sample. This value is called Los Angeles abrasion value.**

WBM sub base course=60, WBM base course with bituminous base course=50, BBM=50,WBM Surface course=40, bituminous penetration macadam=40, bituminous surface dressing/cement concrete surface course=40, bituminous concrete surface course=35

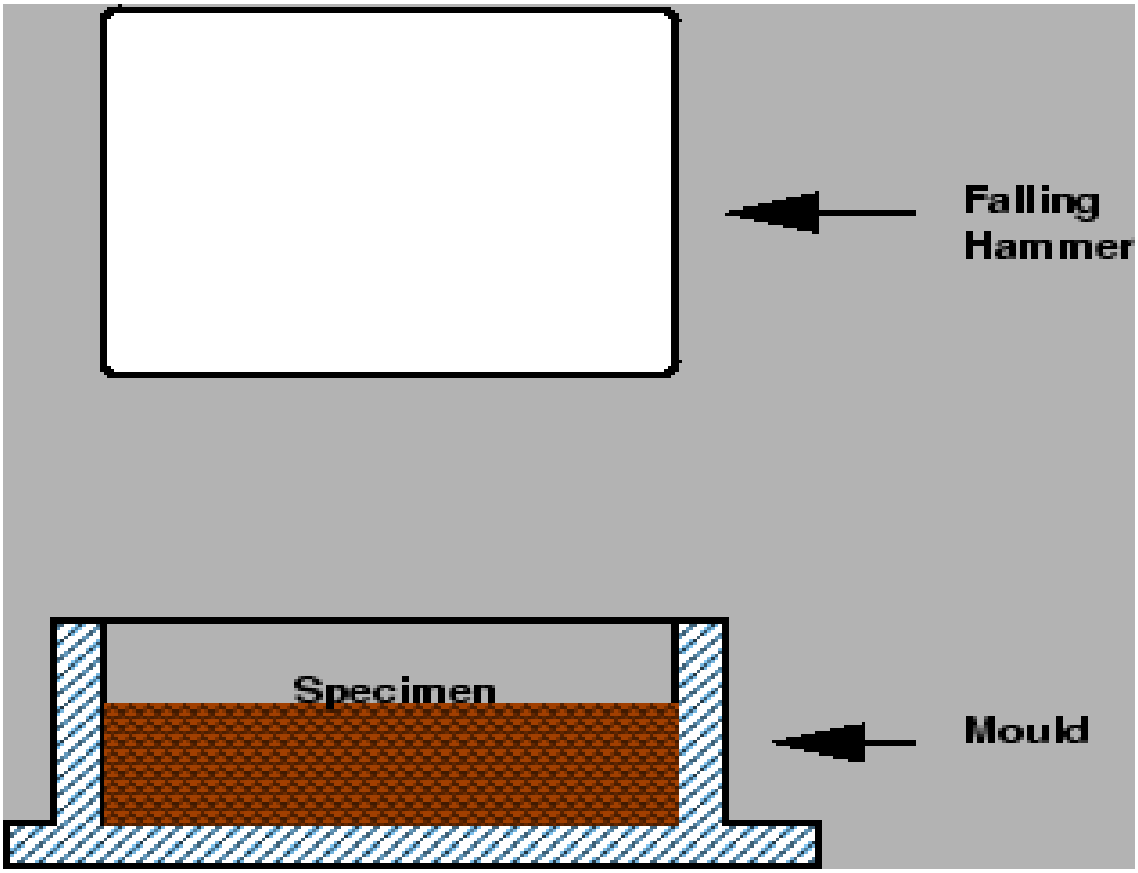

Cover Plate
Steel Balls

Impact Test : The aggregate impact test is carried out to evaluate the resistance to impact of aggregates. Aggregates passing 12.5 mm sieve and retained on 10 mm sieve is filled in a cylindrical steel cup of internal dia 10.2 mm and depth 5 cm which is attached to a metal base of impact testing machine. The material is filled in 3 layers where each layer is tamped for 25 number of blows.

Metal hammer of weight 13.5 to 14 Kg is arranged to drop with a free fall of 38.0 cm by vertical guides and the test specimen is subjected to 15 number of blows. The crushed aggregate is allowed to pass through 2.36 mm IS sieve. And the impact value is measured as percentage of aggregates passing in sieve (W1) to the total weight of the sample (W2).

$$\text{Aggregate impact value} = \frac{W_1}{W_2} \times 100$$

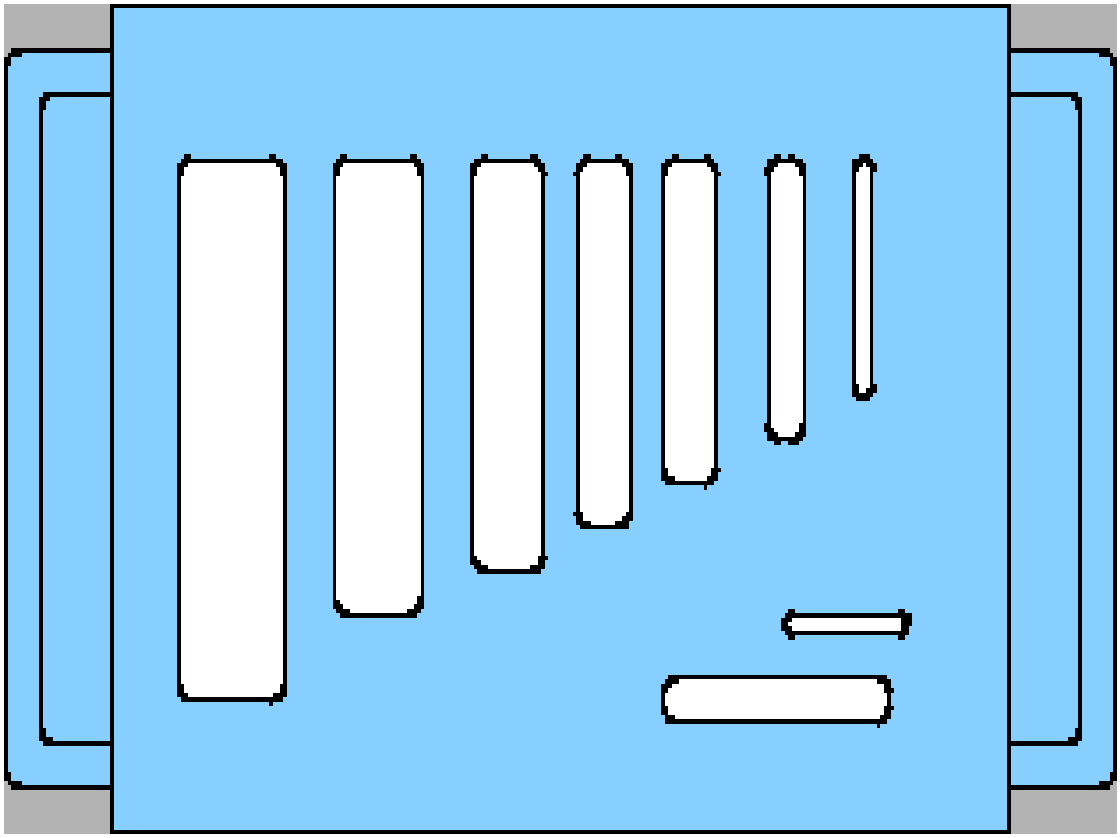
Aggregates to be used for **wearing course, the impact value shouldn't exceed 30%**. For **bituminous macadam** the maximum permissible value is **35%**. For **Water bound macadam** base courses the maximum permissible value defined by IRC is **40 %.**


Falling
Hammer
Specimen
Mould

Soundness Test: Soundness test is intended to study the resistance of aggregates to weathering action, by conducting accelerated weathering test cycles. The Porous aggregates subjected to freezing and thawing are likely to disintegrate prematurely. To ascertain the durability of such aggregates, they are subjected to an accelerated soundness test as specified in IS:2386 part-V.

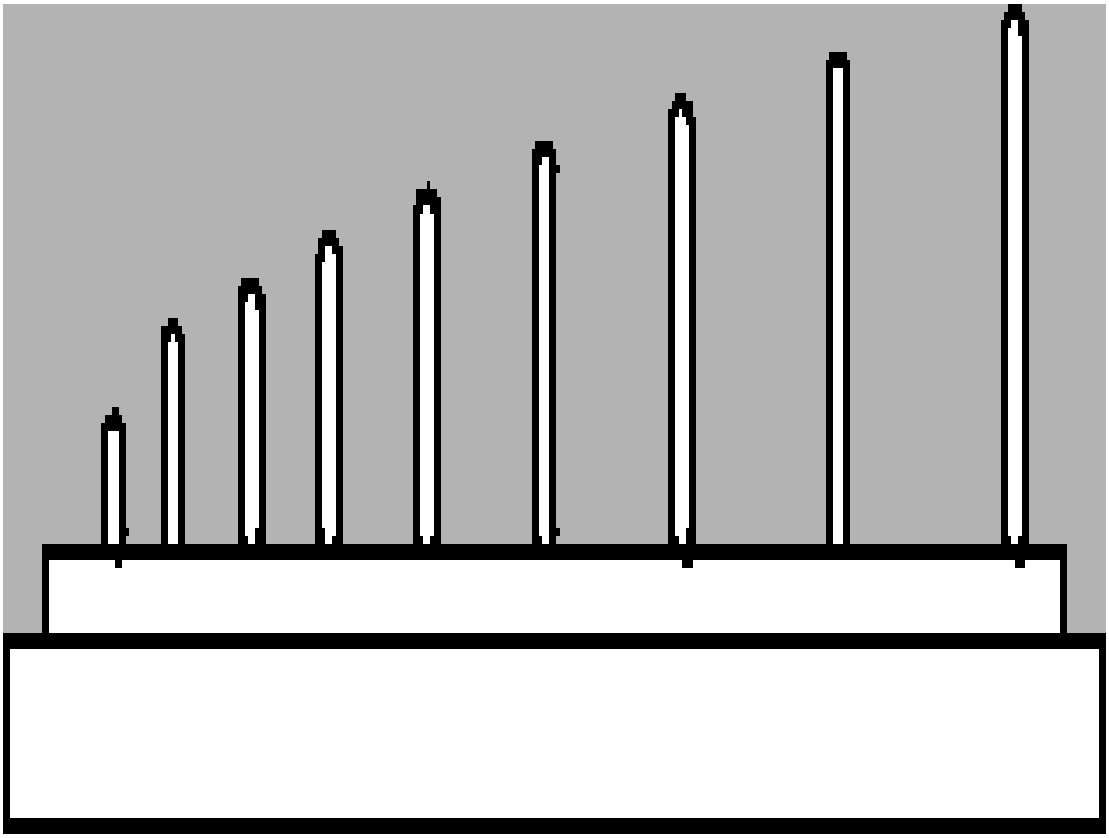
Aggregates of specified size are subjected to cycles of alternate wetting in a **saturated solution** of either **sodium sulphate or magnesium sulphate for 16 - 18 hours and then dried in oven at 105-110°C to a constant weight.** After five cycles, the loss in weight of aggregates is determined by sieving out all undersized particles and weighing. And the loss in weight should not exceed 12 percent when tested with sodium sulphate and 18 percent with magnesium sulphate solution.

Shape Tests :The particle shape of the aggregate mass is determined by the percentage of flaky and elongated particles in it. Aggregates which are flaky or elongated are detrimental to higher workability and stability of mixes. The flakiness index is defined as the **percentage by weight of aggregate particles whose least dimension is less than 0.6 times their mean size (Diameter).** Test procedure had been standardized in India (IS:2386 part-I)



The flakiness index (for 16-20mm size aggregate, 18*0.6mm=10.8mm slot) of an aggregate is defined as the percentage by weight of particles whose greatest dimension (Diameter) is less than 0.6 times their mean dimension to the original weight. Range: <15% (<25)

The elongation index of an aggregate is defined as the percentage by weight of particles whose greatest dimension (length) is 1.8 times their mean dimension. This test is applicable to aggregates larger than 6.3 mm. This test is also specified in (IS:2386 Part-I). However there are no recognized limits for the elongation index. Range:<15%



Specific Gravity and water absorption: The specific gravity and water absorption of aggregates are important properties that are required for the design of concrete and bituminous mixes. The **specific gravity** of a solid is the ratio of its mass to that of an equal volume of distilled water at a specified temperature. Because the aggregates may contain water-permeable voids, so two measures of specific gravity of aggregates are used: *apparent* specific gravity and *bulk* specific gravity.

Apparent Specific Gravity, G_{app} , is computed on the basis of the net volume of aggregates i.e the volume excluding water-permeable voids. Thus $G_{app} = \frac{M_D/V_N}{W}$

Bulk Specific Gravity, , is computed on the basis of the total volume of aggregates including water permeable voids. Thus $G_{bulk} = \frac{M_D/V_B}{W}$

Water absorption, The difference between the apparent and bulk specific gravities is nothing but the water-permeable voids of the aggregate

$$\text{water absorption} = \frac{M_W}{M_D} \times 100$$

The specific gravity of aggregates normally used in road construction ranges from about 2.5 to 2.9. Water absorption values ranges from 0.1 to about 5 percent for aggregates normally used in road surfacing.

Bitumen adhesion test: Bitumen adheres well to all normal types of road aggregates provided they are dry and free from dust. In the absence of water there is practically no adhesion problem of bituminous construction. Adhesion problem occurs when the aggregate is wet and cold. This problem can be dealt with by removing moisture from the aggregate by drying and increasing the mixing temperature. Further, the presence of water causes stripping of binder from the coated aggregates.

This problems occur when bitumen mixture is permeable to water. Several laboratory tests are conducted to arbitrarily determine the adhesion of bitumen binder to an aggregate in the presence of water. Static immersion test is one specified by IRC and is quite simple. The principle of the test is by immersing aggregate fully coated with binder in water maintained at temperature 40°C for 24 hours. The result is reported as the % of stone surface that is stripped off after specified time.IRC has specified maximum stripping value of aggregates should not exceed 5%.

Property of Aggregate	Type of Test	Test Method
Crushing strength	Crushing test	IS : 2386 (part 4) -1963
Hardness	Los Angeles abrasion test	IS : 2386 (Part 5)-1963
Toughness	Aggregate impact test	IS : 2386 (Part 4)-1963
Durability	Soundness test- accelerated durability test	IS : 2386 (Part 5)-1963
Shape factors	Shape test	IS : 2386 (Part 1)-1963
Specific gravity and porosity	Specific gravity test and water absorption test	IS : 2386 (Part 3)-1963
Adhesion to bitumen	Stripping value of aggregate	IS : 6241-1971

Dry mix design: The objective of dry mix design is to determine the amount of various sizes of mineral aggregates used to get a mix of **maximum density**. The dry mix design involves three important steps, viz. selection of aggregates, aggregates gradation, and proportion of aggregates.

Selection of aggregates: The function of the **coarse aggregates** in contributing to the stability of a bituminous paving mixture is largely due to **interlocking** and **frictional resistance** of adjacent particles. Similarly, **fines or sand** contributes to **stability failure function** in **filling the voids between coarse aggregates**. Mineral filler is largely visualized as a void filling agent.

Aggregate gradation: It might be reasonable to believe that the best gradation is one that produces maximum density. This would involve a particle arrangement where smaller particles are packed between larger particles, thus reducing the void space between particles. This creates more particle-to-particle contact, which in bituminous pavements would increase stability and reduce water infiltration.

However, some minimum amount of void space is necessary to:

- provide adequate volume for the binder to occupy,
- promote rapid drainage
- provide resistance to frost action for base and sub base courses.

A dense mixture may be obtained when this particle size distribution follows Fuller law

$$p = 100 \left(\frac{d}{D} \right)^n$$

where, d is the percent by weight of the total mixture passing any given sieve sized, D is the size of the largest particle in that mixture, and n is the parameter depending on the shape of the aggregate (0.5 for perfectly rounded particles).

Proportioning of aggregates : After selecting the aggregates and their gradation, proportioning of aggregates has to be done.

Trial and error Method, Graphical Methods and Analytical Method:

Table: Specified gradation of aggregates for BC surface course of 40 mm		
Sieve size	Wt passing (%)	Wt passing (%)
(mm)	Grade 1	Grade 2
20	-	100
12.5	100	80-100
10.0	80 – 100	70 – 90
4.75	55 – 75	50 – 70
2.36	35 – 50	35 – 50
0.60	18 – 29	18 – 29
0.30	13 – 23	13 – 23
0.15	8 – 16	8 – 16
0.075	4 – 10	4 – 10
Binder*	5 - 7.5	5 - 7.5

Pavement Materials: Bitumen

Bituminous materials or asphalts are extensively used for roadway construction, primarily because of their **excellent binding characteristics, water proofing properties and relatively low cost**. Bituminous materials consists of bitumen which is a **black or dark colored solid or viscous cementing** substances consists chiefly high molecular weight **hydrocarbons derived from distillation (Fractional & Destructive) of petroleum or natural asphalt**, has adhesive properties, and is soluble in **carbon disulphide/Carbon Tetrachloride**.

Production of Bitumen: Bitumen is the residue or by-product when the crude petroleum is refined. A wide variety of refinery processes, i.e. the **straight distillation process, solvent extraction process** etc. may be used to produce bitumen of different consistency and other desirable properties. Depending on the sources and characteristics of the crude oils and on the properties of bitumen required, more than one processing method may be employed.

Vaccum steam distillation of petroleum oil: In the vacuum-steam distillation process the crude oil is heated and is introduced into a large cylindrical still. Steam is introduced into the still to aid in the **vaporization of the more volatile constituents** of the petroleum and to minimize decomposition of the distillates and residues. The volatile constituents are collected, condensed, and the various fractions stored for further refining, if needed.

The residues from this distillation are then fed into a vacuum distillation unit, where residue pressure and steam will further separate out heavier gas oils. The bottom fraction from this unit is the vacuum-steam-refined asphalt cement. The consistency of asphalt cement from this process can be controlled by the amount of heavy gas oil removed. Normally, asphalt produced by this process is **softer**. As the asphalt cools down to room temperature, it becomes a semi solid viscous material.

Different forms of bitumen

Cutback bitumen: Cut-backs are bitumen preparations in which the **viscosity of the binder has been reduced** by the addition of a volatile solvent, normally derived from petroleum. Typically the solvents used are **white spirit and kerosene.** Cut-back products are typically used for spraying and some mixing applications. From the environmental point of view also cutback bitumen is most preferred. The solvent from the bituminous material will evaporate and the bitumen will bind the aggregate.

Cutback bitumen is used for cold weather bituminous road construction and maintenance. There are different types of cutback bitumen **like rapid curing (RC), medium curing (MC), and slow curing (SC)**.

RC is recommended for surface dressing and patchwork. MC is recommended for premix with less quantity of fine aggregates. SC is used for premix with appreciable quantity of fine aggregates.

Bitumen Emulsion: Bitumen emulsion is a liquid product in which bitumen is suspended in a finely divided condition in an aqueous medium (dispersed phase) and stabilized by suitable material. Normally cationic type emulsions are used i.e. **soap**. The bitumen content in the emulsion is around 60% and the remaining is water. When the emulsion is applied on the road it breaks down resulting in release of water and the mix starts to set. The time of setting depends upon the grade of bitumen. The viscosity of bituminous emulsions can be measured as per IS: 8887-1995.

Three types of bituminous emulsions are available, which are Rapid setting (RS), Medium setting (MS), and Slow setting (SS). Bitumen emulsions are ideal binders for hill road construction where heating of bitumen or aggregates are difficult.

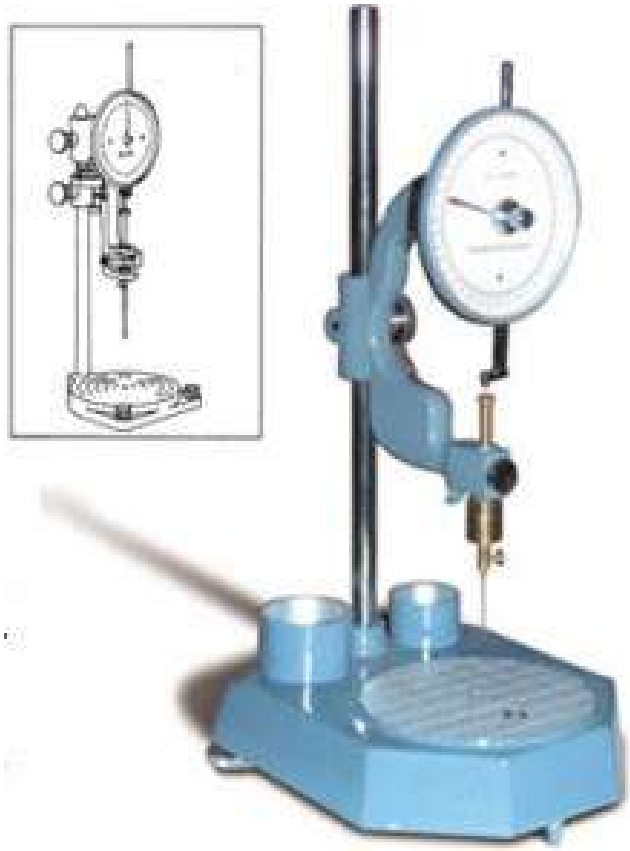
RS emulsions are used for surface dressing work. MS emulsions are preferred for premix jobs and patch repairs work. SS emulsions are preferred in rainy season.

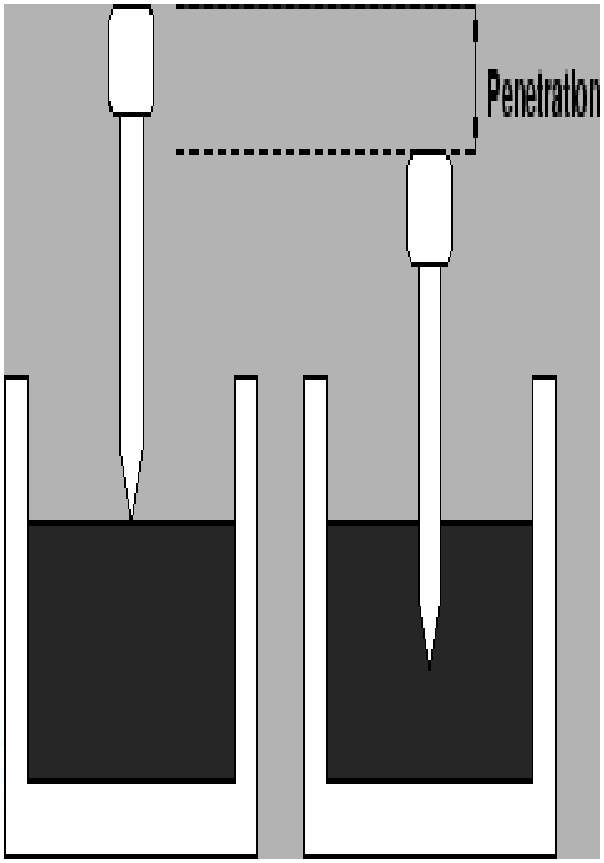
Requirements of Bitumen: The desirable properties of bitumen depend on the mix type and construction. In general, Bitumen should posses following desirable properties.

- The bitumen should not high temperature susceptible: during the hottest weather the mix should not become too soft or unstable, and during cold weather the mix should not become too brittle causing cracks.
- The viscosity of the bitumen at the time of mixing and compaction should be adequate. This can be achieved by use of cutbacks or emulsions of suitable grades or by heating the bitumen and aggregates prior to mixing.
- There should be adequate affinity and adhesion between the bitumen and aggregates used in the mix.

Tests on bitumen:

Penetration test: It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds. The penetrometer consists of a needle assembly with a total weight of 100g and a device for releasing and locking in any position. The bitumen is softened to a pouring consistency(between 75 and 100°C), stirred thoroughly and poured into containers at a depth at least 15 mm in excess of the expected penetration.




Penetration

Procedure to determine the penetration of bitumen

i) Soften the bitumen above the softening point (between 75 and 100°C). Stir it thoroughly to remove air bubbles and water.

ii) Pour it into a container to a depth of at least 15mm in excess of the expected penetration.

iii) Cool it at an atmospheric temperature of 15 to 30°C for $1^{1/2}$ hours. Then place it in a transfer dish in the water bath at 25.0 + 0.1^{o}C for $1^{1/2}$ hrs.

iv) Keep the container on the stand of the penetration apparatus.

v) Adjust the needle to make contact with the surface of the sample.

vi) Adjust the dial reading to zero.

vii) With the help of the timer, release the needle for exactly 5 seconds.

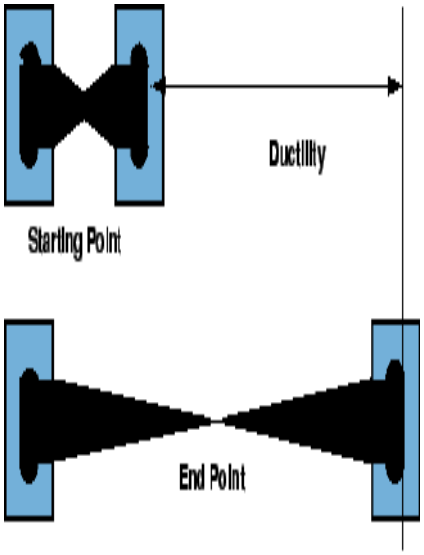
viii) Record the dial reading.

ix) Repeat the above procedure thrice(10mm apart).

A grade of 30/40 bitumen means the penetration value is in the range 30 to 40 at standard test conditions. In hot climates, a lower penetration grade is preferred. Value: 20-225, 30/40 and 80/100.

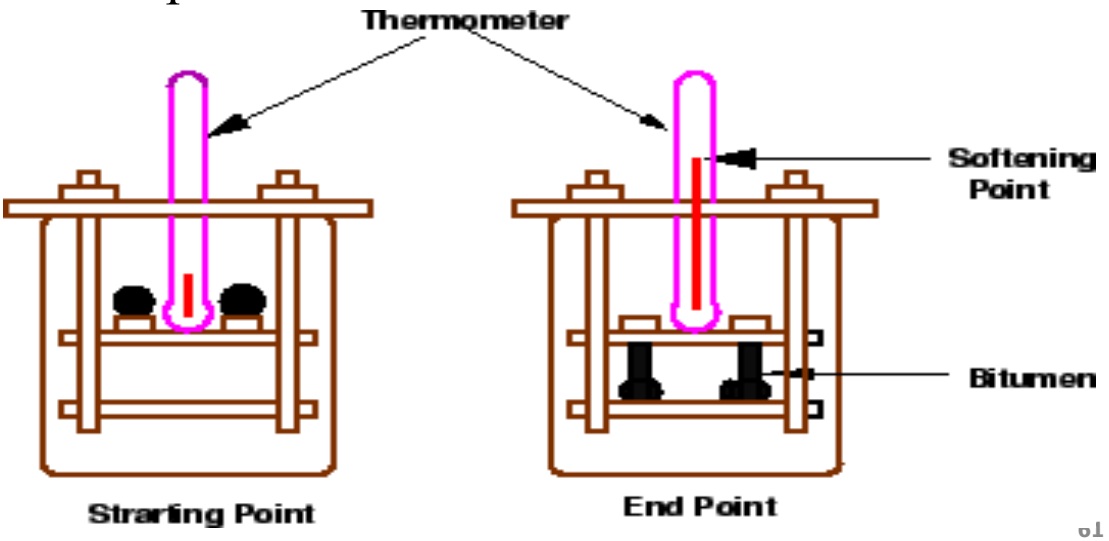
Ductility test :Ductility is the property of bitumen that permits it to **undergo great deformation or elongation**. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking. Dimension of the briquette thus formed is exactly 1 cm square. The bitumen sample is heated and poured in the mould assembly placed on a plate. These samples with moulds are cooled in the air and then in water bath at 27 °C temperature. The excess bitumen is cut and the surface is leveled using a hot knife.

Then the mould with assembly containing sample is kept in water bath of the ductility machine for about **90 minutes**. The sides of the moulds are removed, the clips are hooked on the machine and the machine is operated. The distance up to the point of breaking of thread is the ductility value which is reported in cm. The ductility value gets affected by factors such as pouring temperature, test temperature, rate of pulling etc. A minimum ductility value of **75 cm** has been specified by the BIS. **Value:5-100cm**


Ductility
Starting Point
End Point

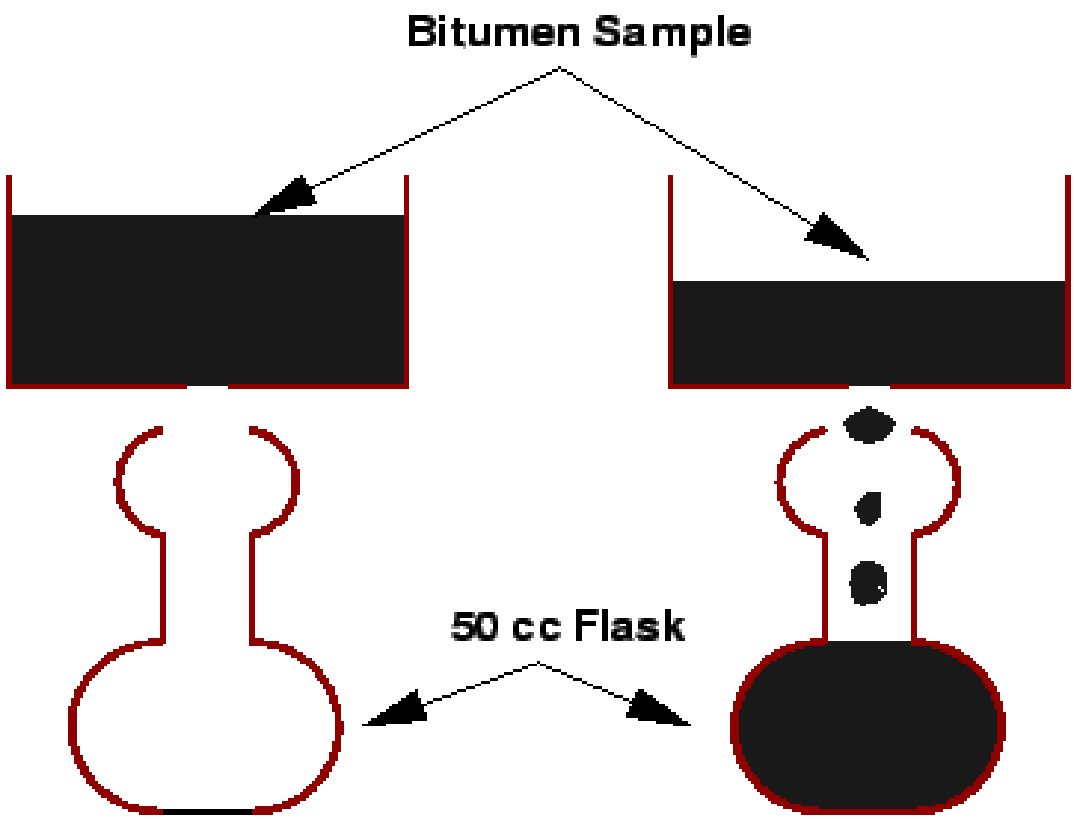
Softening point test : **Softening point denotes the temperature at which the bitumen attains a particular degree of softening** under the specifications of test. The test is conducted by using Ring and Ball apparatus. A brass ring containing test sample of **bitumen is suspended in liquid like water or glycerin at a given temperature.** A steel ball is placed upon the bitumen sample and the liquid medium is heated at a rate of 5° C per minute.

Temperature is noted when the softened bitumen touches the metal plate which is at a specified distance below. Generally, higher softening point indicates lower temperature susceptibility (hard) and is preferred in hot climates. **Value: 35-70 °C**

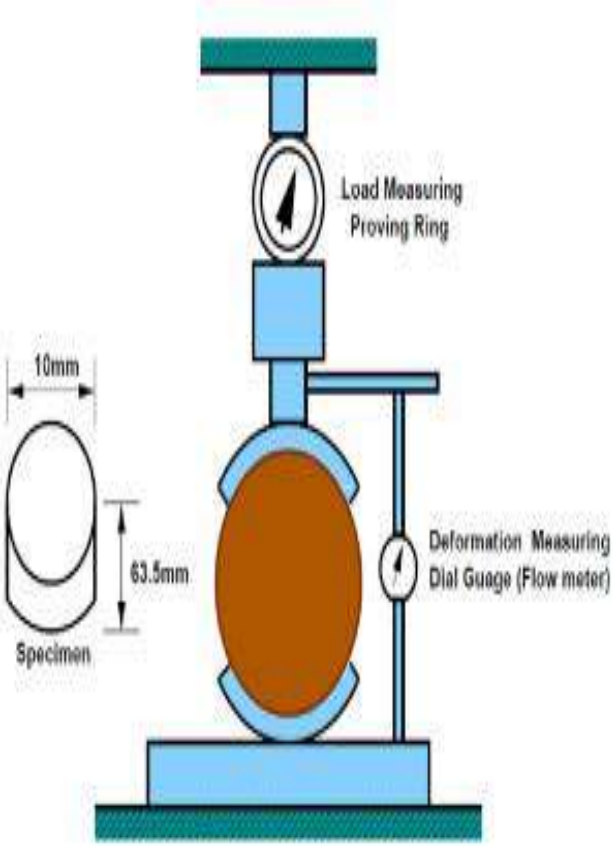


Viscosity test: Viscosity is the measure of resistance to flow. At the application temperature, this characteristic greatly influences the strength of resulting paving mixes. Low or high viscosity during compaction or mixing has been observed to result in lower stability values. At high viscosity, it resist the compactive effort and thereby resulting mix is heterogeneous, hence low stability values. And at low viscosity instead of providing a uniform film over aggregates, it will lubricate the aggregate particles.

Orifice type viscometers are used to indirectly find the viscosity of liquid binders like cutbacks and emulsions. The viscosity expressed in **seconds is the time taken by the 50 ml bitumen material** to pass through the orifice of a cup, under standard test conditions and specified temperature. Viscosity of a cutback can be measured with either 4.0 mm orifice at 25°C or 10 mm orifice at 25,40 and 60°C. Limit=40-100 seconds


Bitumen Sample
50 cc Flask

Marshall Mix Design (Wet Mix): The Marshall Stability/flow test provides the performance prediction measure for the Marshall Mix design method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. Load is applied to the specimen till failure, and the maximum load is designated as stability. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) due to the loading. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded.


Load Measuring
Proving Ring
10mm
63.5mm
Specimen
Deformation Measuring
Dial Guage (Flow meter)

Specimen preparation:

Approximately 1200gm of aggregates and filler is heated to a temperature of 175-190°C. Bitumen is heated to a temperature of 121-125°C with the first trial percentage of bitumen (say 3.5 or 4% by weight of the mineral aggregates).

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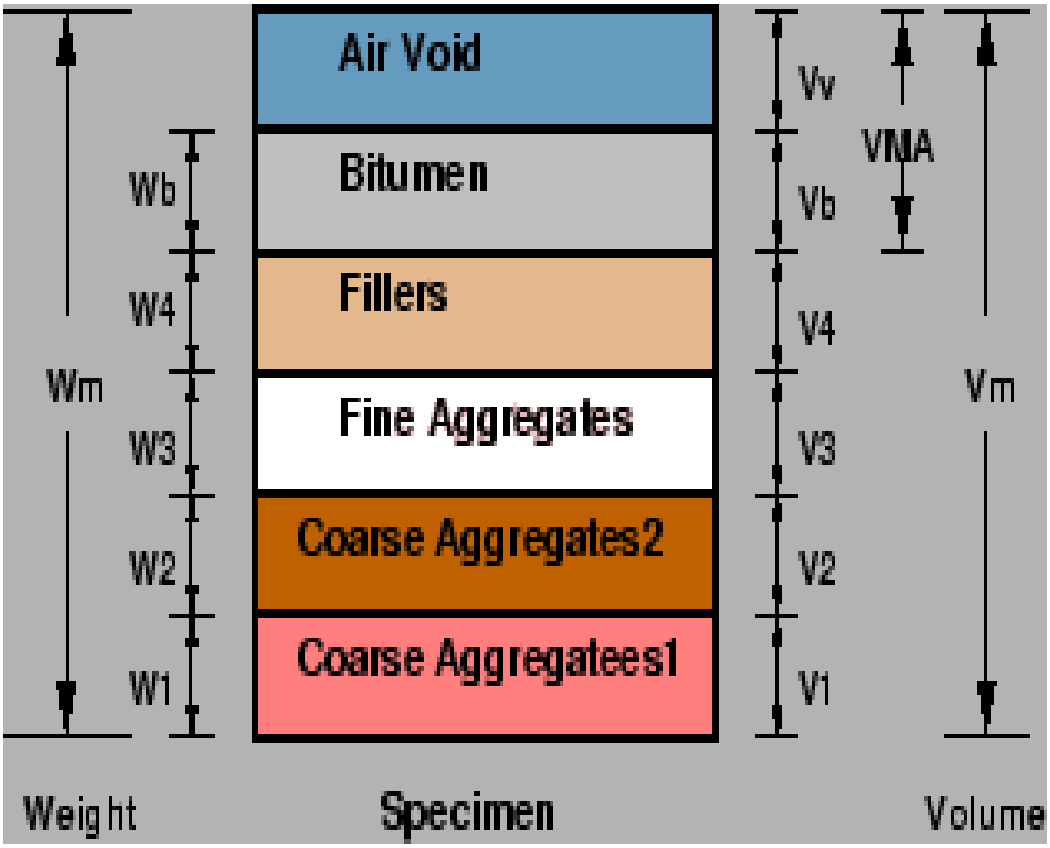
The heated aggregates and bitumen are thoroughly mixed at a temperature of 154-160°C. The mix is placed in a preheated mould and compacted by a rammer with **50 blows on either side at temperature of 138 to 149°C** . The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5+/-3 mm. Vary the bitumen content in the next trial by +0.5%and repeat the above procedure. Number of trials are predetermined. The prepared mould is loaded in the Marshall test setup.

Marshall Mould:

Properties of the mix: The properties that are of interest include the theoretical specific gravity **Gt,** the bulk specific gravity of the mix **Gm,** percent air voids **Vv ,** percent volume of bitumen **Vb** , percent void in mixed aggregate **VMA** and percent voids filled with bitumen **VFB**.


Air Void
Bitumen
Fillers
Fine Aggregates
Coarse Aggregates2
Coarse Aggregatees1
Wb
W4
Wm
W3
W2
W1
Vv
Vb
V4
V3
V2
V1
VMA
Vm
Weight
Specimen
Volume

70

Theoretical specific gravity of the m

$$G_t = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_b}{G_b}}$$

Bulk specific gravity of mix,

$$G_m = \frac{W_m}{W_m - W_w}$$

Where, Wm=wt of mix in air

Ww=wt of mix in water

Air voids percent, $V_v = \frac{(G_t - G_m)100}{G_t}$

Percent volume of bitumen,

$$V_b = \frac{\frac{W_b}{G_b}}{\frac{W_1+W_2+W_3+W_b}{G_m}}$$

Voids in mineral aggregate: Voids in mineral aggregate is the volume of voids in the aggregates, and is the sum of air voids and volume of bitumen.

$$VMA = V_v + V_b$$

Vv= percent air voids in the mix

Voids filled with bitumen,

$$VFB = \frac{V_b \times 100}{VMA}$$

Determine Marshall stability and flow: Marshall stability of a test specimen is the maximum load required to produce failure when the specimen is preheated to a prescribed temperature placed in a special test head and the load is applied at a constant strain (5.08 cm per minute). While the stability test is in progress dial gauge is used to measure the vertical deformation of the specimen. The deformation at the failure point expressed in units of 0.25 mm is called the Marshall flow value of the specimen.

Apply stability correction: It is possible while making the specimen the thickness slightly vary from the standard specification of 63.5 mm. Therefore, measured stability values need to be corrected to those which would have been obtained if the specimens had been exactly 63.5 mm. This is done by multiplying each measured stability value by an appropriated correlation factors as given in Table below.

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Table: Correction factors for Marshall stability values		
Volume of specimen (cm)	Thickness of specimen (mm)	Correction Factor
457 - 470	57.1	1.19
471 - 482	68.7	1.14
483 - 495	60.3	1.09
496 - 508	61.9	1.04
509 - 522	63.5	1.00
523 - 535	65.1	0.96
536 - 546	66.7	0.93
547 - 559	68.3	0.89
560 - 573	69.9	0.86

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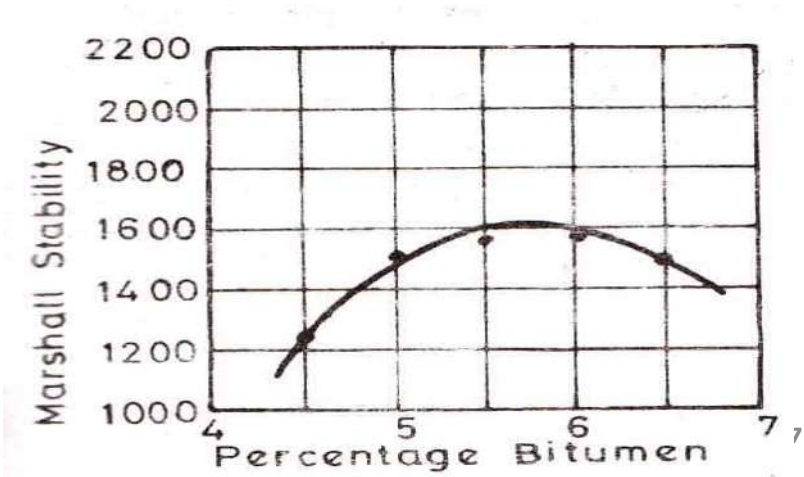
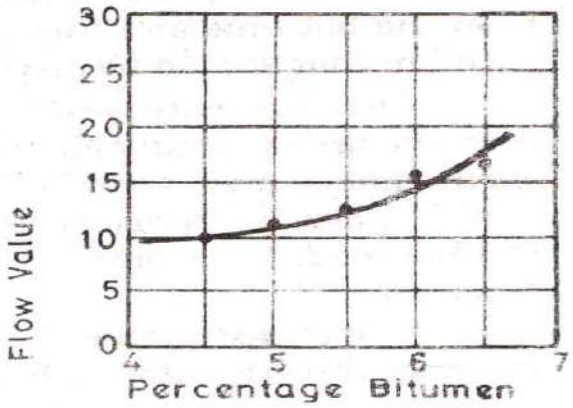
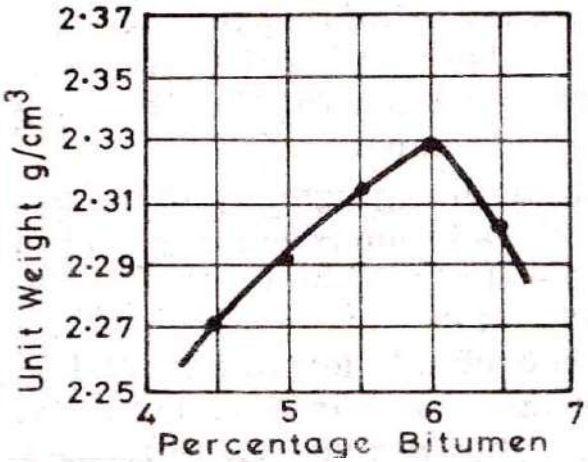
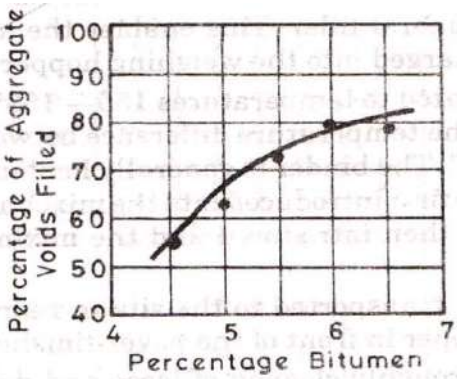
3

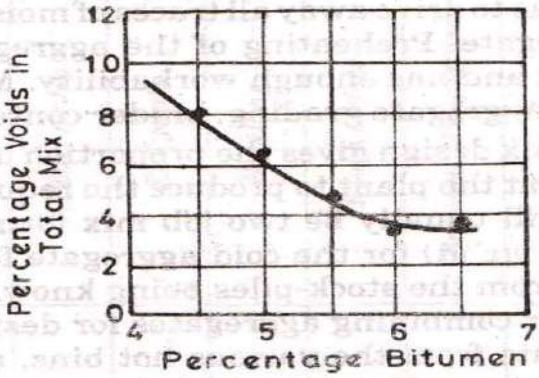
Prepare graphical plots : The average value of the above properties are determined for each mix with different bitumen content and the following graphical plots are prepared




Flow Value
30
25
20
15
10
5
0
4
5
6
7
Percentage Bitumen


Unit Weight g/cm3
2·37
2·35
2·33
2·31
2·29
2·27
2·25
4
5
6
7
Percentage Bitumen


Percentage of Aggregate Voids Filled
100
90
80
70
60
50
40
4
5
6
7
Percentage Bitumen


Percentage Voids in Total Mix
12
10
8
6
4
2
0
4
5
6
7
Percentage Bitumen

Determine optimum bitumen content:

Determine the optimum binder content for the mix design by taking average value of the following three bitumen contents found form the graphs obtained in the previous step.

- Binder content corresponding to maximum stability
- Binder content corresponding to maximum bulk specific gravity (Gm)
- Binder content corresponding to the median of designed limits of percent air voids (Vv) in the total mix (i.e. 4%)

The stability value, flow value are checked with Marshall mix design specification chart given in Table below. Mixes with very high stability value and low flow value are not desirable as the pavements constructed with such mixes are likely to develop cracks due to heavy moving loads.

V_v

Table: Marshall mix design specification	
Test Property	Specified Value
Marshall stability, kg	340 (minimum)
Flow value, 0.25 mm units	8 - 17
Percent air voids in the mix %	3 - 5
Voids filled with bitumen %	75 - 85

81

V_v

Table: Marshall mix design specification	
Test Property	Specified Value
Marshall stability, kg	340 (minimum)
Flow value, 0.25 mm units	8 - 17
Percent air voids in the mix %	3 - 5
Voids filled with bitumen %	75 - 85

82

Numerical example : The specific gravities and weight proportions for aggregate and bitumen are as under for the preparation of Marshall mix design. The volume and weight of one Marshall specimen was found to be 475 cc and 1100 gm. Assuming absorption of bitumen in aggregate is zero, find Vv, Vb, VMA and VFB.

Item	A_1	A_2	A_3	A_4	B
Wt (gm)	825	1200	325	150	100
Sp. Gr	2.63	2.51	2.46	2.43	1.05

$$
\begin{aligned}
G_t &= \frac{825 + 1200 + 325 + 150 + 100}{\frac{825}{2.63} + \frac{1200}{2.51} + \frac{325}{2.46} + \frac{150}{2.43} + \frac{100}{1.05}} \\
&= \frac{2600}{1080.86} \\
&= 2.406 \\
G_m &= \frac{1100}{475} \\
&= 2.316 \\
V_v &= \frac{2.406 - 2.316}{2.406} \times 100 \\
&= 3.741\ \% \\
V_b &= \frac{100}{1.05} \times \frac{2.316}{1100} \\
&= 20.052\ \% \\
VMA &= (3.741 + 20.05) \\
&= 23.793\ \% \\
VFB &= \frac{20.052}{23.793} \times 100 \\
&= 84.277\ \%
\end{aligned}
$$

THANK YOU