## Ancient Roads

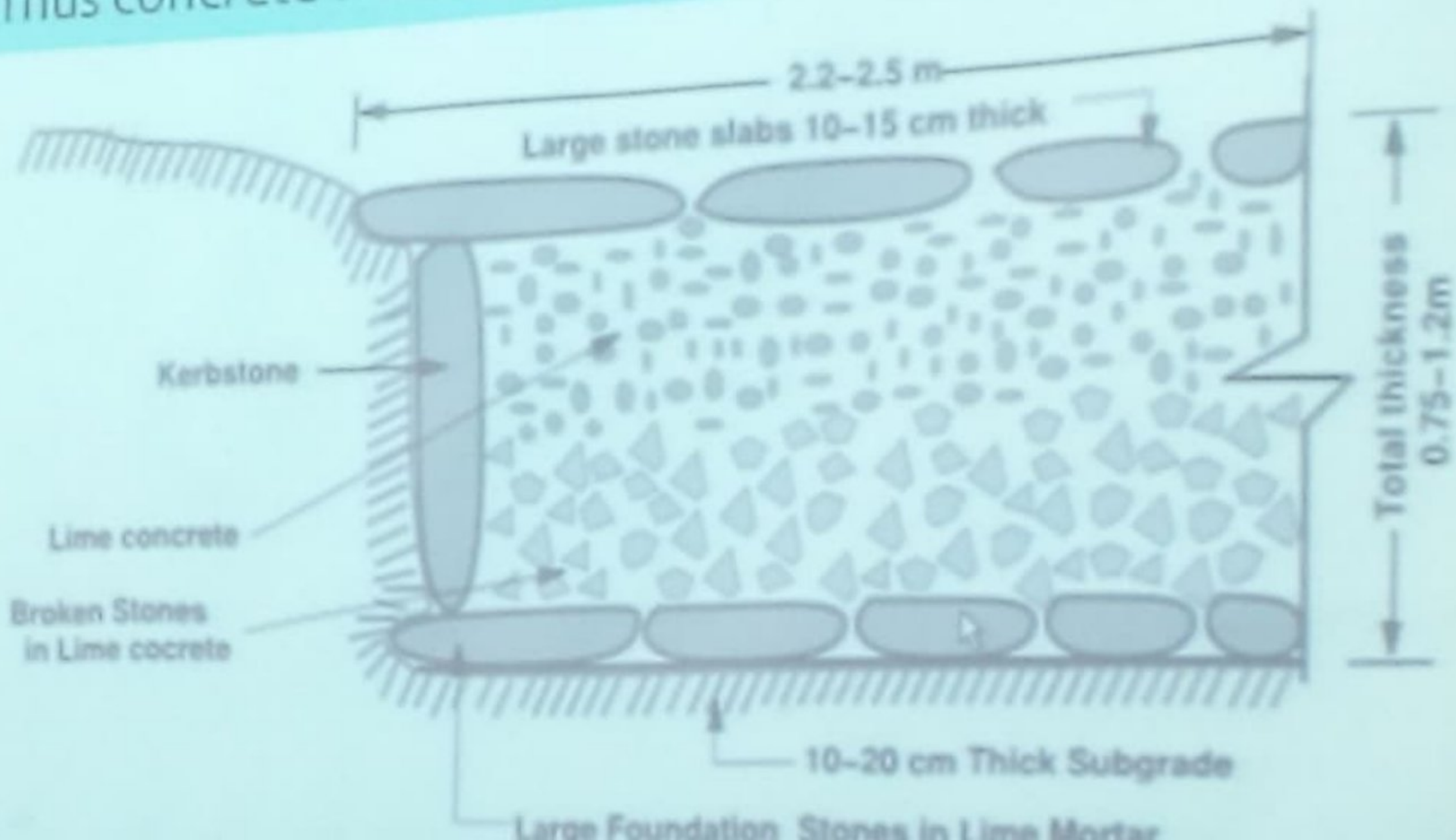
- ✓ Most primitive mode of transport was by foot
- ✓ These human pathways would have been developed for specific purposes leading to camp sites, food, streams for drinking water, etc.
- ✓ Invention of wheel in Mesopotamian civilization led to development of animal drawn vehicles
- ✓ To provide adequate strength to carry wheels, new ways tended to follow sunny drier side of a path
- ✓ After invention of wheel, animal drawn vehicles were developed and need for hard surface road emerged
- ✓ Traces of such hard roads were obtained from various ancient civilization dated as old as 3500 BC
- ✓ Earliest authentic record of road was found from Assyrian empire constructed about 1900 BC

## Roman roads

- Earliest large scale road construction is attributed to Romans who constructed an extensive system of roads radiating in many directions from Rome
- Romans recognized that fundamentals of good road construction were to provide good drainage, good material and good workmanship
- Their roads were very durable, and some still exist
- Roads were bordered on both sides by longitudinal drains
- Next step was construction of agger
- This was a raised formation up to a 1 meter high and 15 m wide and was constructed with materials excavated during side drain construction
- This was then topped with a sand leveling course
- In case of heavy traffic, a surface course of large 250 mm thick hexagonal flag stones were provided

## Roman roads

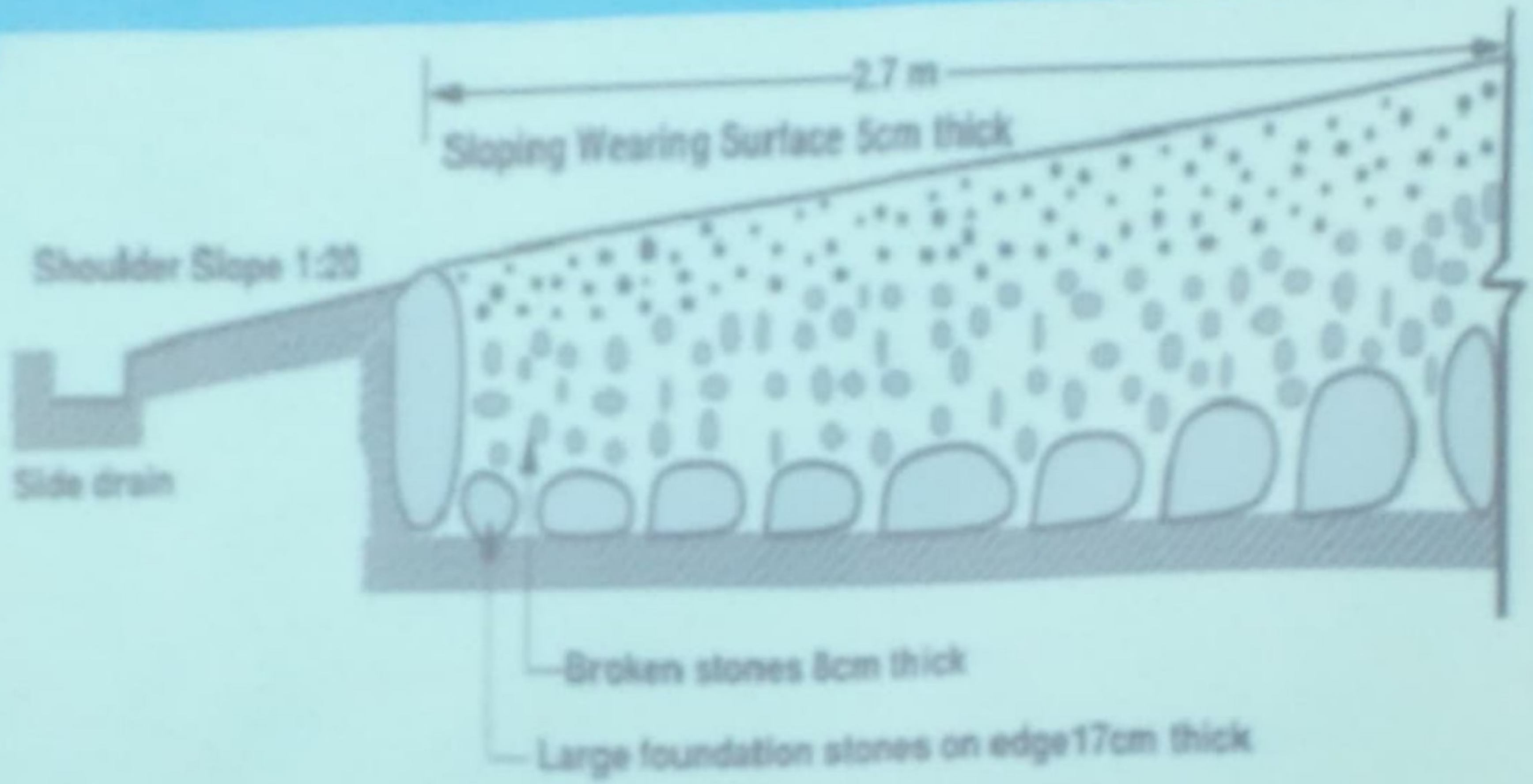
- ✓ Main features of Roman roads are that they were built straight regardless of gradient and used heavy foundation stones at bottom
- ✓ They mixed lime and volcanic puzzolana to make mortar and they added gravel to this mortar to make concrete
- ✓ Thus concrete was a major Roman road making innovation



## French roads

- ✓ Major development in road construction occurred during regime of Napoleon
- ✓ Significant contributions were given by Tresaguet in 1764
- ✓ He developed a cheaper method of construction than lavish and locally unsuccessful revival of Roman practice
- ✓ Pavement used 200 mm pieces of quarried stone of a more compact form and shaped such that they had at least one at side which was placed on a compact formation
- ✓ Smaller pieces of broken stones were then compacted into spaces between larger stones to provide a level surface
- ✓ Finally, running layer was made with a layer of 25 mm sized broken stone
- ✓ All this structure was placed in a trench in order to keep running surface level with surrounding country side

# French roads



## British roads

- British government also gave importance to road construction
- British engineer John Macadam introduced what can be considered as first scientific road construction method
- Stone size was an important element of Macadam recipe
- By empirical observation of many roads, he came to realize that 250 mm layers of well compacted broken angular stone would provide same strength and stiffness
- A better running surface than an expensive pavement founded on large stone blocks
- Thus he introduced an economical method of road construction
- The mechanical interlock between individual stone pieces provided strength and stiffness to course

## British roads

- ✓But inter particle friction abraded sharp interlocking faces and partly destroy effectiveness of course
- ✓This effect was overcome by introducing good quality interstitial finer material to produce a well-graded mix
- ✓Such mixes also proved less permeable and easier to compact

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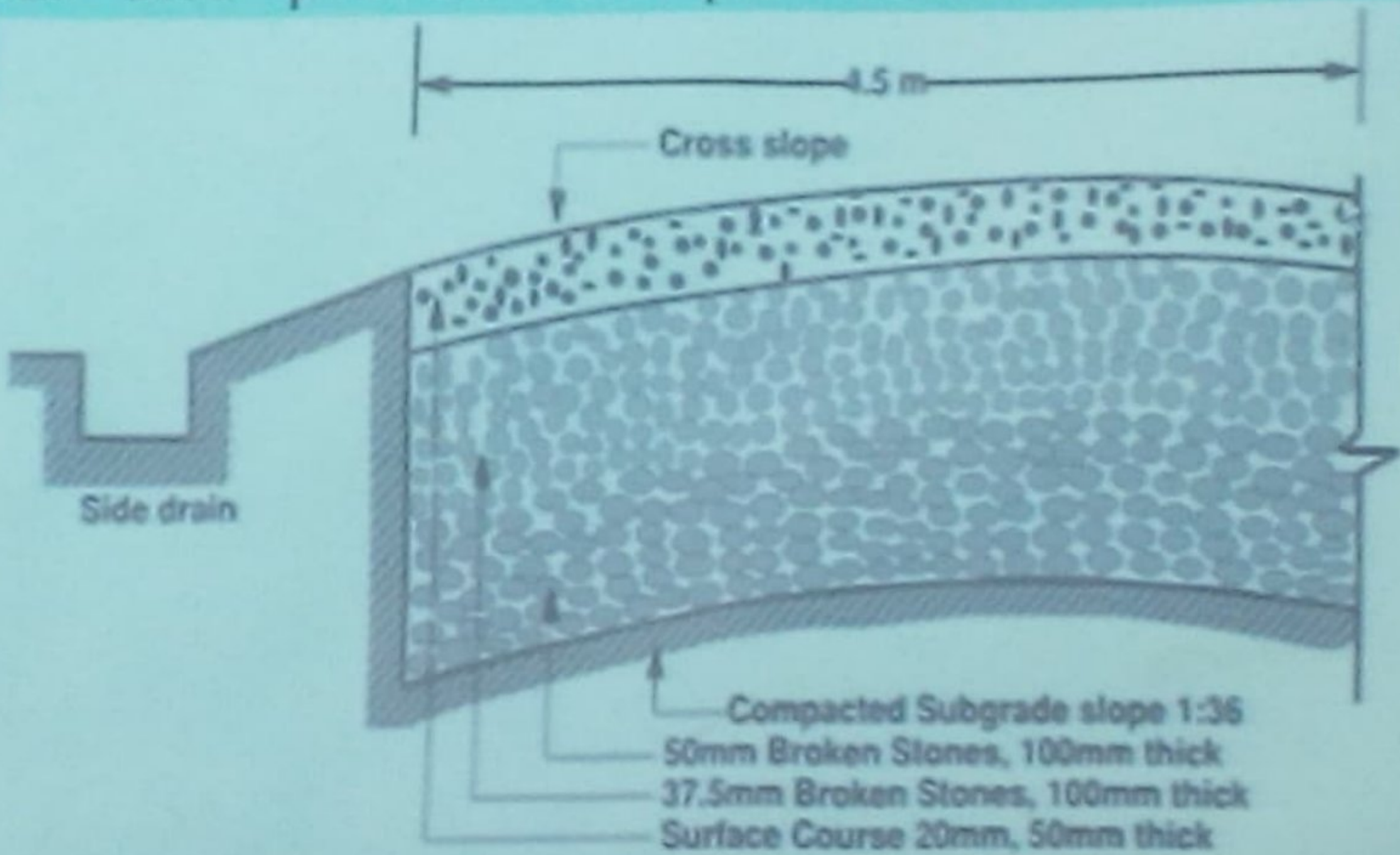
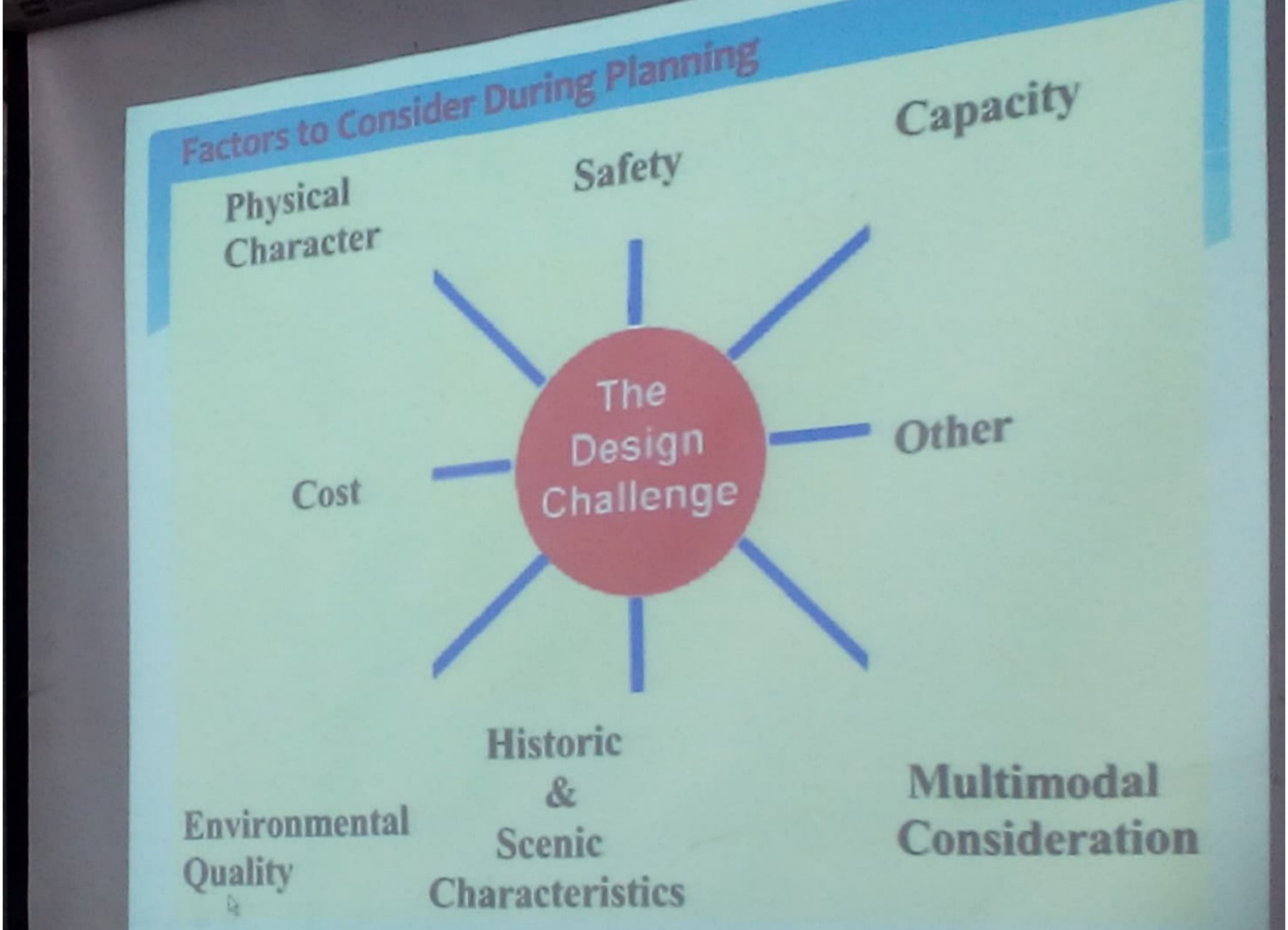


## Necessity of Highway Planning

- ✓ In present era planning is considered as a pre-requisite before attempting any development program
- ✓ Particularly true for any engineering work as planning is basic requirement for any new project or an expansion program
- ✓ Highway planning is also a basic need for highway development
- ✓ Planning is of great importance when funds available are limited whereas total requirement is much higher
- ✓ Planning helps best utilization of available funds has to be made in a systematic and planned way

## Objects of Highway Planning

- ✓ To plan a road network for efficient and safe traffic operation, but at minimum cost
- ✓ To arrive at road system and lengths of different categories of roads which could provide maximum utility and could be constructed within available resources during plan period under consideration
- ✓ To fix up date wise priorities for development of each road link based on utility as main criterion for phasing road development program
- ✓ To plan for future requirements and improvements of roads in view of anticipated developments
- ✓ To workout financing system


Factors to Consider During Planning
Physical Character
Safety
Capacity
The Design Challenge
Other
Cost
Environmental Quality
Historic & Scenic Characteristics
Multimodal Consideration

## Classifications of Roads

- Based on usage
  - All-weather roads

Roads which are negotiable during all weathers, except at major river crossings where interruption of traffic is permissible up to a certain extent

## Classifications of Roads

- Based on usage
    - All-weather roads
    - Fair-weather roads

Roads which are negotiable only during fair weather

## Classifications of Roads

- Based on usage
  - All-weather roads
  - Fair-weather roads
- Based on carriage way
  - Paved roads with hard surface

Provided with a hard pavement course (stones, Water bound macadam (WBM), Bituminous macadam (BM), concrete roads)

## Classifications of Roads

- Based on usage
  - All-weather roads
  - Fair-weather roads
- Based on carriage way
  - Paved roads with hard surface
  - Unpaved roads

Roads which are not provided with a hard course of at least a WBM layer (earth and gravel roads)

## Classifications of Roads

- Based on usage
  - All-weather roads
  - Fair-weather roads
- Based on carriage way
  - Paved roads with hard surface
  - Unpaved roads
- Based on pavement surfacing
  - Surfaced roads

Provided with a bituminous or cement concrete surfacing

## Classifications of Roads

- Based on usage
  - All-weather roads
  - Fair-weather roads
- Based on carriage way
  - Paved roads with hard surface
  - Unpaved roads
- Based on pavement surfacing
  - Surfaced roads
  - Unsurfaced roads

Not provided with bituminous or cement concrete surfacing

## ➤ Classification based on location and function

### Expressways

- ✓ Separate class of highways with superior facilities, design standards and high speeds (120 km/hr)
- ✓ Meant as through routes having very high volume of traffic
- ✓ Provided with divided carriageways, controlled, grade separations at cross roads and fencing
- ✓ Should permit only fast moving vehicles
- ✓ Parking, loading and unloading of goods and pedestrian traffic is not allowed

- Classification based on location and function
  - Expressways
  - National highways (NH)

Main highways running through a country connecting major ports, foreign highways, capitals of large states and large industrial and tourist centers including roads required for strategic movements

> Classification based on location and function

- Expressways
- National highways (NH)
- State highways (SH)

✓ Arterial roads of a state, connecting up with national highways of adjacent states, district head quarters and important cities within state

✓ Also serve as main arteries to and from district roads

➢ Classification based on location and function

- Expressways
- National highways (NH)
- State highways (SH)
- Major district road (MDR)

✓ Important roads within a district serving areas of production and markets, connecting those with each other or with major highways

✓ Has lower speed and geometric design specifications than NH or SH

- Classification based on location and function
    - Expressways
    - National highways (NH)
    - State highways (SH)
    - Major district road (MDR)
    - Other district road (ODR)

✓ Roads serving rural areas of production and providing them with outlet to market centers or other important roads like MDR or SH

✓ Lower design specifications than MDR

- Classification based on location and function
  - Expressways
  - National highways (NH)
  - State highways (SH)
  - Major district road (MDR)
  - Other district road (ODR)
  - Village road

Roads connecting villages or group of villages with each other or to nearest road of a higher category like ODR or MDR

- Classification based on traffic volume
  - Light traffic

Equivalent axle load (EAL) is less than $10^4$ or commercial vehicle per day (CVPD) is less than 50

- Classification based on traffic volume
  - Light traffic
  - Medium traffic

Equivalent axle load (EAL) is equal to $10^4$ to $10^6$ or commercial vehicle per day (CVPD) is equal to 50 to 300

- Classification based on traffic volume
  - Light traffic
  - Medium traffic
  - Heavy traffic

Equivalent axle load (EAL) is more than $10^6$ or commercial vehicle per day (CVPD) is more than 300

## Classification of urban roads

### Arterial roads

- ✓ City roads which are meant for through traffic usually on a continuous route
- ✓ Generally spaced at less than 15 km in developed business centres whereas in less important areas may be 8 km apart
- ✓ Also divided highways with fully or partially controlled access, parking, loading and unloading activities are carefully regulated
- ✓ Pedestrians are permitted to cross them at intersections only

## ➢ Classification of urban roads

- Arterial roads
- Sub-arterial roads

- ✓ City roads which provide lower level of travel mobility than arterial streets
- ✓ Their spacing may very from 0.5 km in central business districts to 3 to 5 km in sub-urban areas
- ✓ Loading and unloading are usually restricted
- ✓ Pedestrians are allowed to cross these highways at intersections

## ➢ Classification of urban roads

- Arterial roads
- Sub-arterial roads
- Collector streets

- ✓ City roads which are constructed for collecting and distributing traffic to and from local street and also to provide an access to arterial and sub-arterial streets
- ✓ Located in residential, business and industrial areas
- ✓ Accessible from building along them
- ✓ There are few parking restrictions except during peak hours

- Classification of urban roads
  - Arterial roads
  - Sub-arterial roads
  - Collector streets
  - Local streets

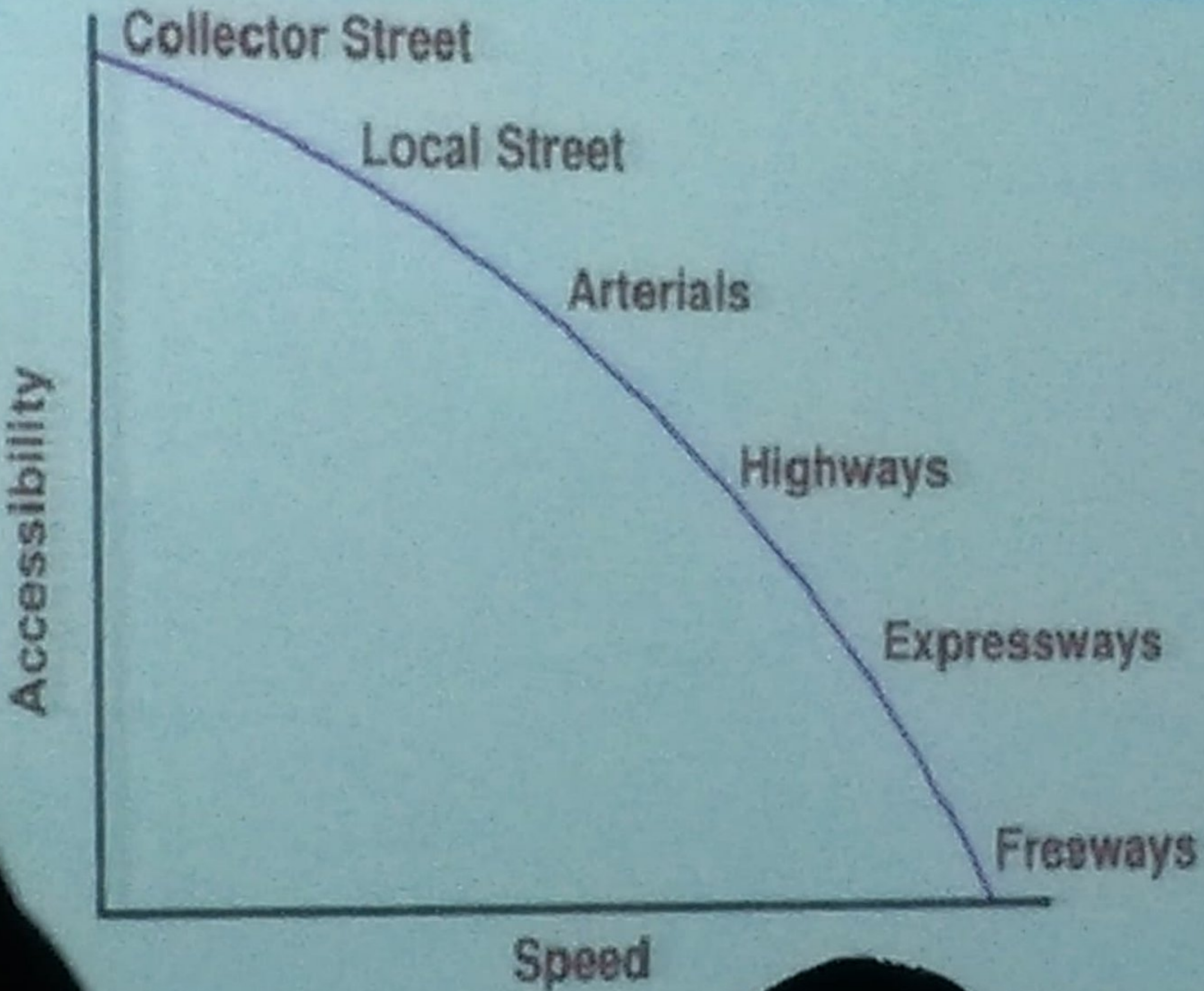
- ✓ City roads which provide an access to residence, business and other buildings
- ✓ Traffic carried either originates or terminates along local streets
- ✓ Depending upon importance of adjoining areas, a local street may be residential, commercial or industrial
- ✓ Pedestrians may move freely and parking may be permitted without any restriction

**Highways**

- ✓ Superior type of roads in a country
- ✓ Two types - rural highways and urban highways
- ✓ Rural highways are those passing through rural areas (villages)
- ✓ Urban highways are those passing through large cities and towns, i .e. urban areas

**Freeways**

- ✓ Access-controlled divided highways
- ✓ Most freeways are four lanes, two lanes each direction, but many freeways widen to incorporate more lanes as they enter urban areas
- ✓ Access is controlled through use of interchanges, and type of interchange depends upon kind of intersecting road way (rural roads, another freeway, etc.)


Collector Street
Local Street
Arterials
Highways
Expressways
Freeways
Accessibility
Speed

## Road patterns

- Rectangular or block pattern

✓ Whole area is divided into rectangular blocks of plots, with streets intersecting at right angles

✓ Main road which passes through centre of area should be sufficiently wide and other branch roads may be comparatively narrow

✓ Main road is provided a direct approach to outside city

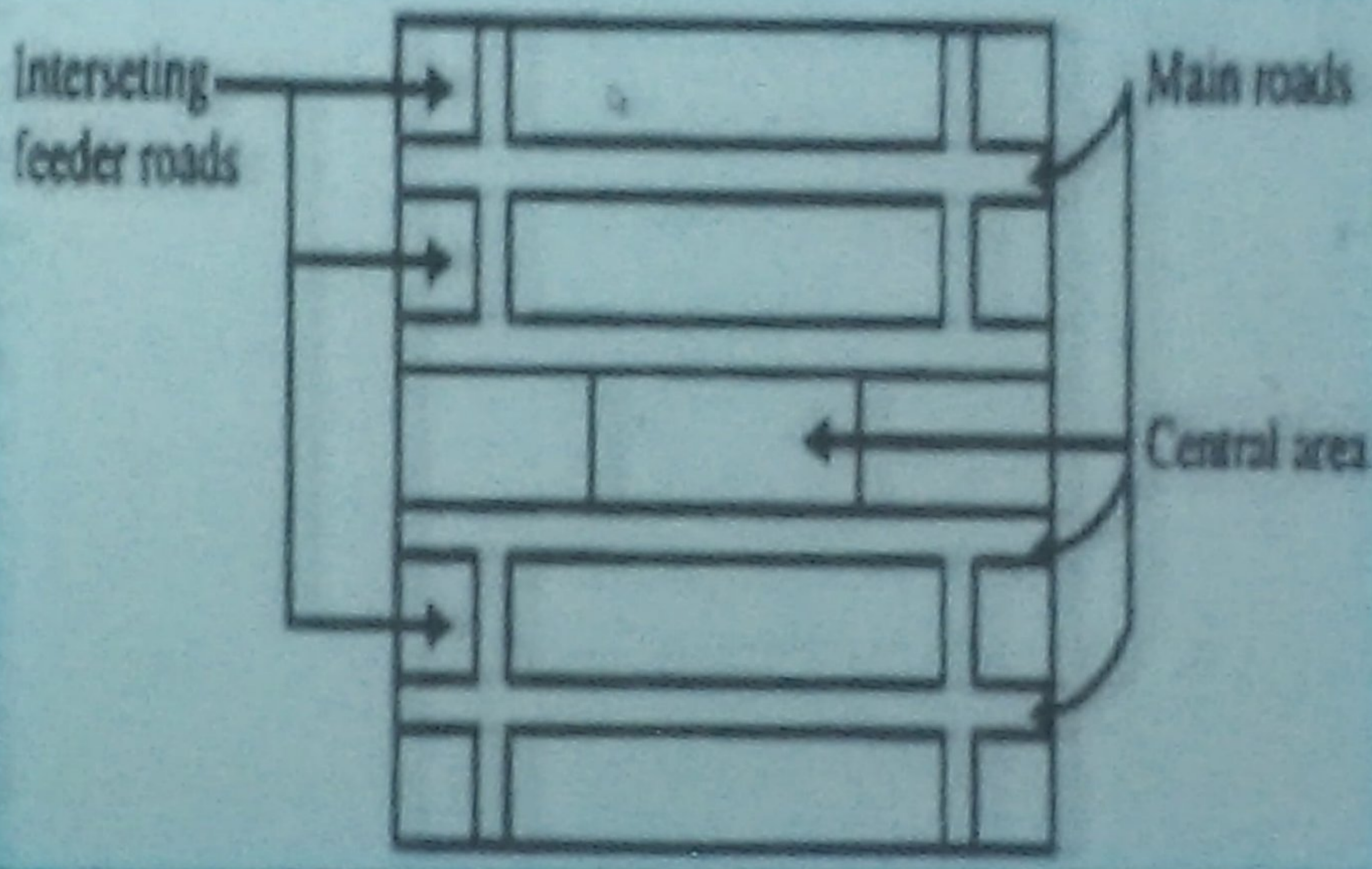
✓ May be further divided into small rectangular blocks for construction of buildings placed back to back, having roads on their front

✓ Construction and maintenance of roads is comparatively easier

✓ But, from traffic point of view, this pattern is not very much convenient because of intersections, vehicle face each other

## Road patterns

- Rectangular or block pattern



## Road patterns

- Rectangular or block pattern
- Radial or star and block pattern

✓ Entire area is divided into a network of roads radiating from business area outwardly

✓ In between radiating main roads, built-up area may be planned with rectangular blocks

## Road patterns

- Rectangular or block pattern
- Radial or star and block pattern

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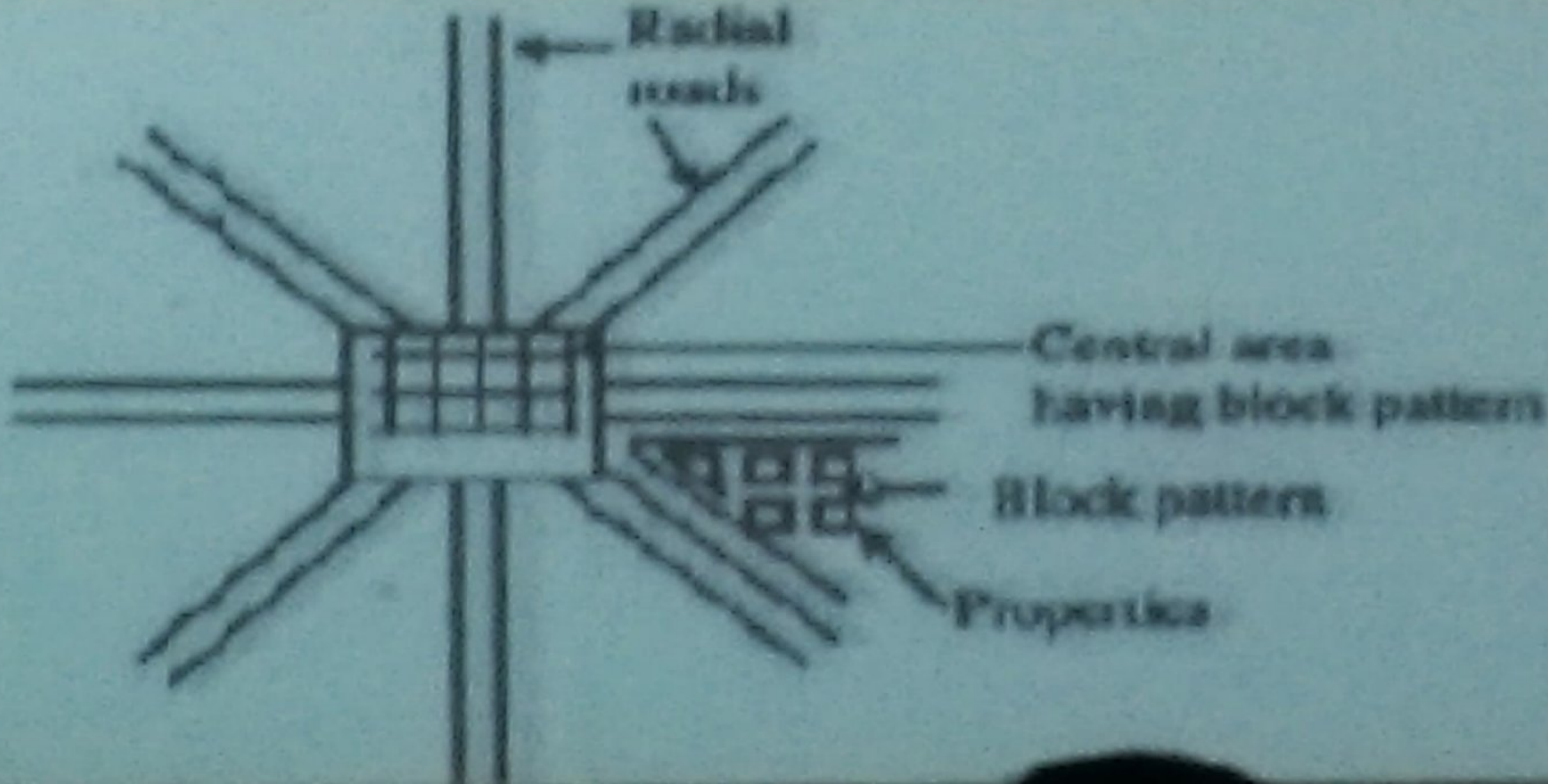


Road patterns

- Rectangular or block pattern
- Radial or star and block pattern
- Radial or star and circular pattern

✓ Main radial roads radiating from central business area are connected together with concentric roads

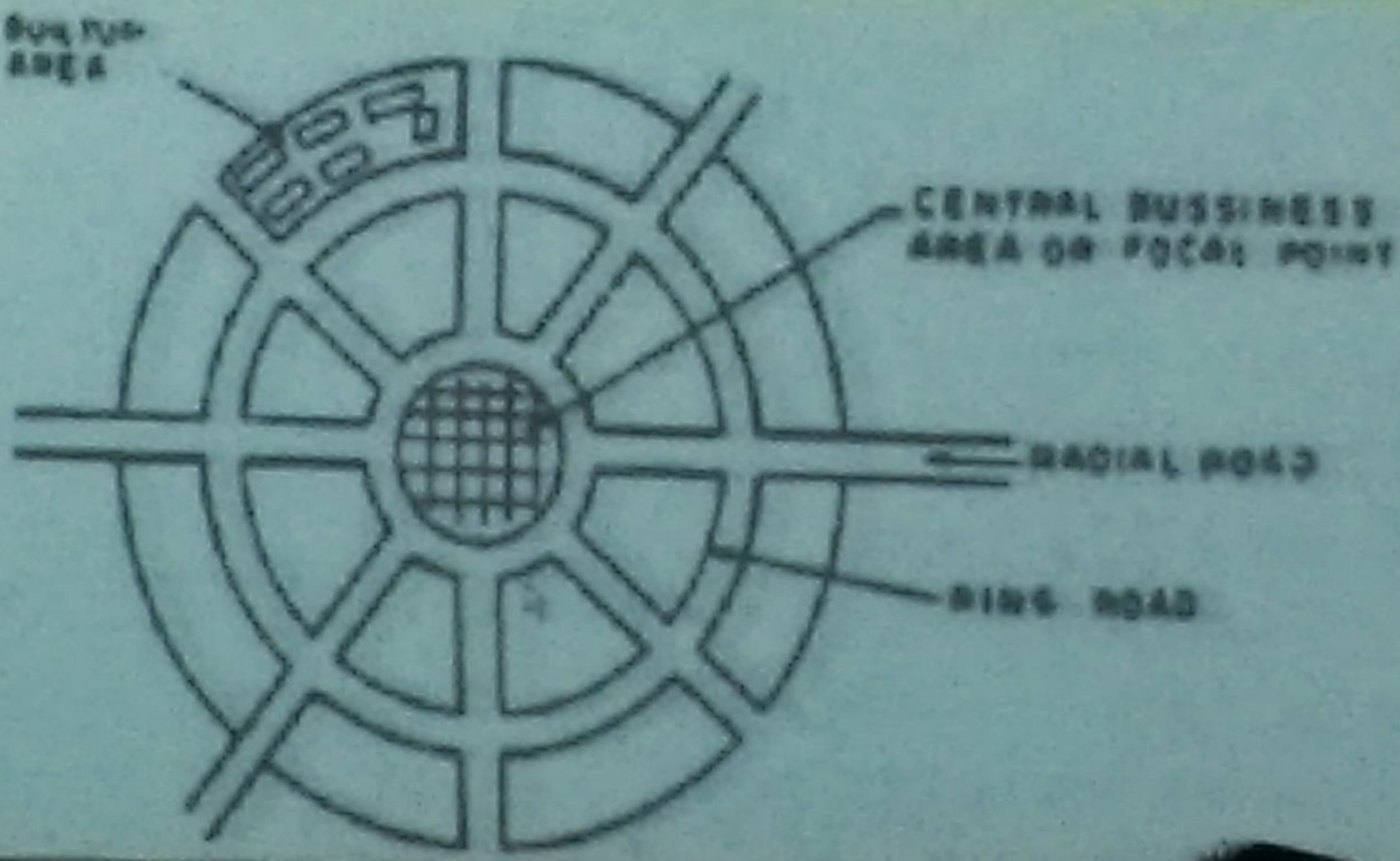
✓ In these areas, boundary by adjacent radial roads and corresponding circular roads, built-up area is planned with a curved block system

## Road patterns

- Rectangular or block pattern
- Radial or star and block pattern
- Radial or star and circular pattern

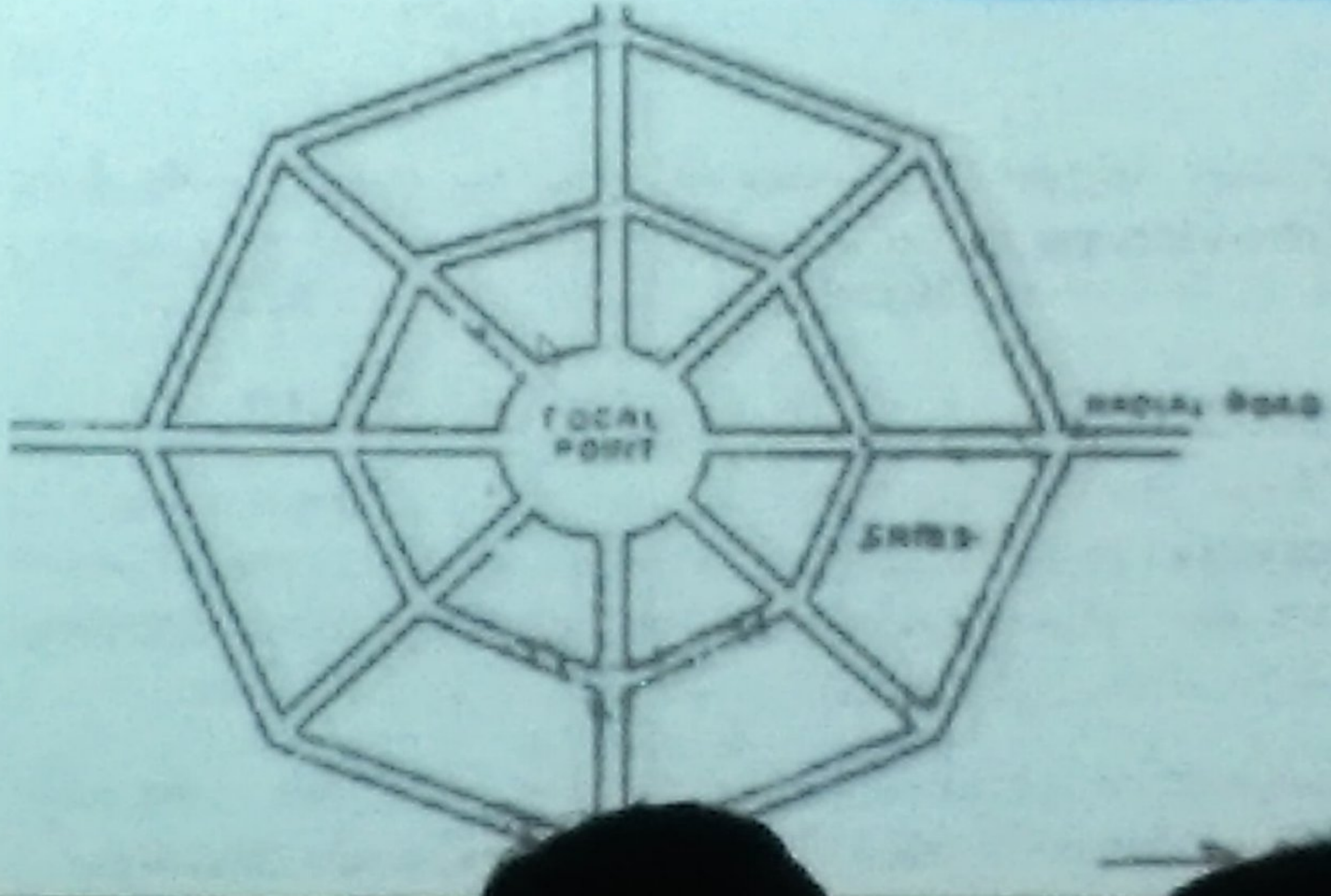
✓ Main radial roads radiating from central business area are connected together with concentric roads

✓ In ... and co ... ith a cu ...



# Road patterns

- Rectangular or block pattern
- Radial or star and block pattern
- Radial or star and circular pattern
- Radial or star and grid pattern



## Road patterns

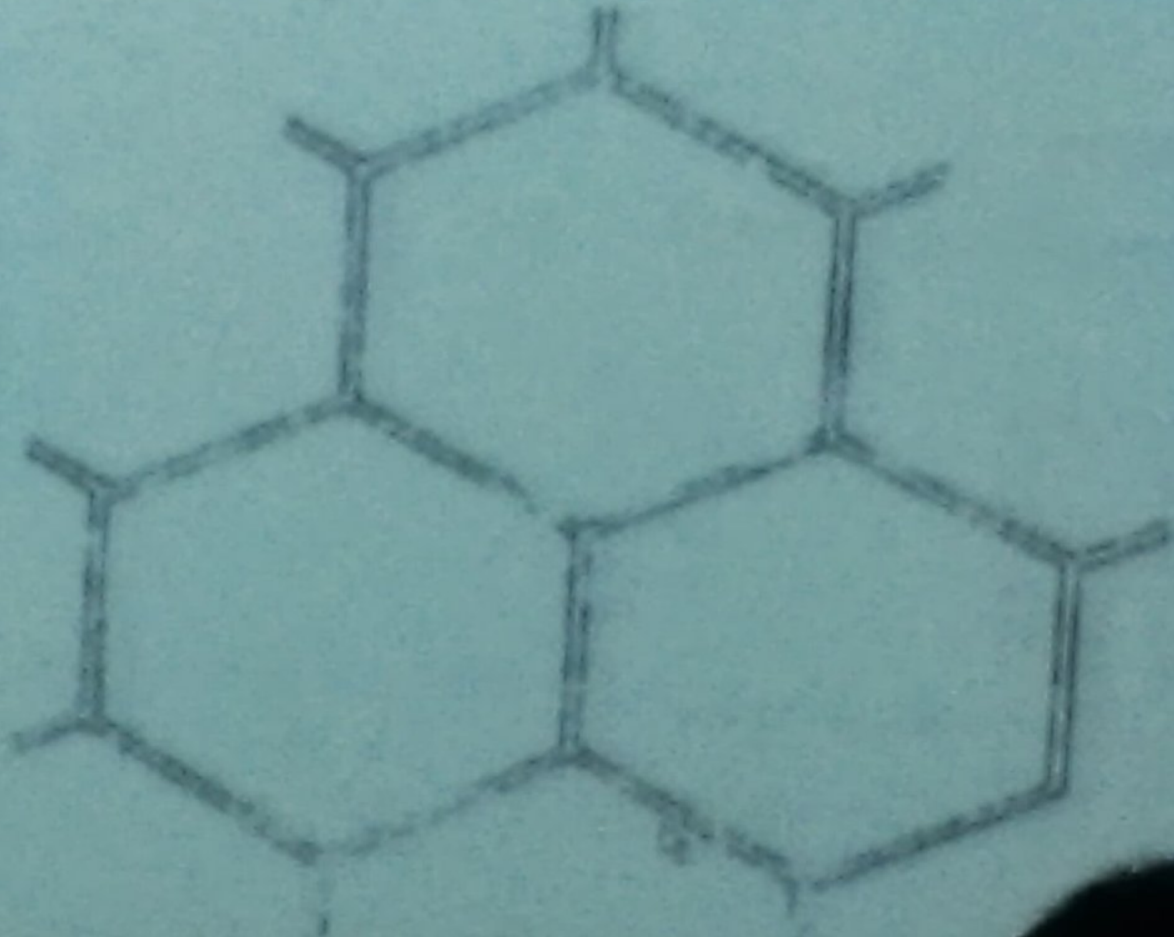
- Rectangular or block pattern
- Radial or star and block pattern
- Radial or star and circular pattern
- Radial or star and grid pattern
- Hexagonal pattern

- ✓ In this pattern centre area is provided with a network of roads forming hexagonal figures
- ✓ At each corner of hexagon three roads meet
- ✓ Built-up area bounded by sides of hexagons is further divided in suitable sizes

Road 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

- In this pa ... etwork of roads form
- At each co
- Built-up a ... is further divided in



## Road 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
- Minimum travel pattern

In this pattern, city (city centre) is connected by sector centres, suburban centres and neighborhood centres by road which require minimum travel to connect city centre

## Road 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
- Minimum travel pattern

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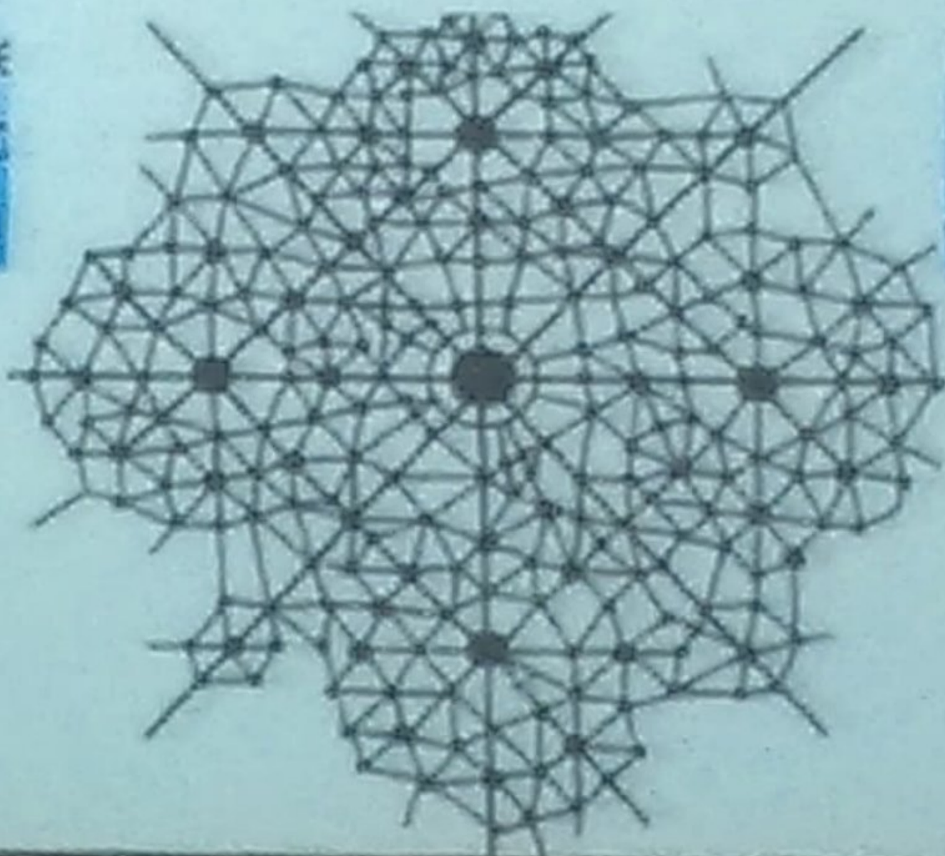


l by sector centres,

es by road which

e

## Planning surveys

- Highway planning phase includes
  - Assessment of road length requirement for an area (it may be a district, state or whole country)
  - Preparation of master plan showing phasing of plan in annual and or five year plans

- Planning surveys consist of following studies
  - Economic studies

✓ Population and its distribution in each village, town or other locality with area classified in groups

✓ Trend of population growth

✓ Agricultural and industrial products and their listing in classified groups, area wise

✓ Industrial and agricultural development and future trends

✓ Existing facilities with regard to communication, recreation and education, etc.

✓ Per capita income

- Planning surveys consist of following studies
  - Economic studies
  - Financial studies

- ✓ Sources of income and estimated revenue from taxation on road transport
- ✓ Living standards
- ✓ Resources at local level, toll taxes, vehicle registration and fines
- ✓ Future trends in financial aspects

- Planning surveys consist of following studies
  - Economic studies
  - Financial studies
  - Traffic or road user studies

- ✓ Traffic volume in vehicles per day, annual average daily traffic, peak and design hourly traffic volume
- ✓ Origin and destination studies
- ✓ Traffic flow patterns
- ✓ Mass transportation facilities
- ✓ Accidents, their cost analysis and causes
- ✓ Future trend and growth in traffic volume and goods traffic, trend in traffic pattern
- ✓ Growth of passenger trips and trend in choice of modes

- Planning surveys consist of following studies
  - Economic studies
  - Financial studies
  - Traffic or road user studies
  - Engineering studies

- ✓ Topographic surveys
- ✓ Soil surveys
- ✓ Location and classification of existing roads
- ✓ Estimation of possible developments in all aspects due to proposed highway development
- ✓ Road life studies
- ✓ Traffic studies, origin and destination studies
- ✓ Special problems in drainage, construction and maintenance of roads

# HIGHWAY
# ALIGNMENT AND SURVEYS

## Alignment

- Marking position or layout of central line on ground and giving direction to highway is called alignment
- Two components
  - Horizontal alignment – includes straight and curve path
  - Vertical alignment – includes level and gradient
- Alignment decision is important because a bad alignment will enhance construction, maintenance and vehicle operating cost, and increase in accident rate
- Once an alignment is fixed and constructed, it is not easy to change it due to increase in cost of adjoining land and construction of costly structures by the roadside

## Requirements of an ideal alignment

- Short

✓ Alignment between two terminal stations should be short and as far as possible be straight

✓ But due to some practical considerations deviations may be needed

## Requirements of an ideal alignment

- Short
- Easy

✓ Alignment should be easy to construct and maintain
✓ It should be easy for operation of vehicles
✓ Maximum extend easy gradients and curves should be provided

## Requirements of an ideal alignment

- Short
- Easy
- Safe

- ✓ It should be safe both from construction and operating point of view especially at slopes, embankments, and cutting
- ✓ It should have safe geometric features

## Requirements of an ideal alignment

- Short
- Easy
- Safe
- Economical

- ✓ Alignment should be economical
- ✓ It can be considered so only when initial cost, maintenance cost, and operating cost is minimum

## Factors controlling alignment

- Obligatory points

✓ These are control points governing highway alignment

✓ These points are classified into two categories

- Points through which it should pass

**Bridge site**

✓ Bridge can be located only where river has straight and permanent path and also where abutment and pier can be strongly founded

✓ Road approach to bridge should not be curved and skew crossing should be avoided as possible

✓ Thus to locate a bridge highway alignment may be changed

## Factors controlling alignment

➨ Obligatory points

- ✓ These are control points governing highway alignment
- ✓ These points are classified into two categories

➨ Points through which it should pass

**Mountain**

- ✓ While alignment passes through a mountain, various alternatives are to either construct a tunnel or to go round hills
- ✓ Suitability of alternative depends on factors like topography, site conditions and construction and operation cost

## Factors controlling alignment

- Obligatory points

- ✓ These are control points governing highway alignment
- ✓ These points are classified into two categories
  - Points through which it should pass

**Intermediate town**

- ✓ Alignment may be slightly deviated to connect an intermediate town or village nearby

## Factors controlling alignment

- Obligatory points

- ✓ These are control points governing highway alignment
- ✓ These points are classified into two categories
  - Points through which it should pass
  - Points through which it should not pass

**Religious places**

- ✓ These have been protected by law from being acquired for a[illegible] purpose
- ✓ Therefore, these points should be avoided while ali[illegible]

## Factors controlling alignment

- Obligatory points

- ✓ These are control points governing highway alignment
- ✓ These points are classified into two categories
  - Points through which it should pass
  - Points through which it should not pass

**Very costly structures**

- ✓ Acquiring such structures means heavy compensation which would result in an increase in initial cost
- ✓ So alignment may be deviated not to pass through that point

## Factors controlling alignment

- Obligatory points

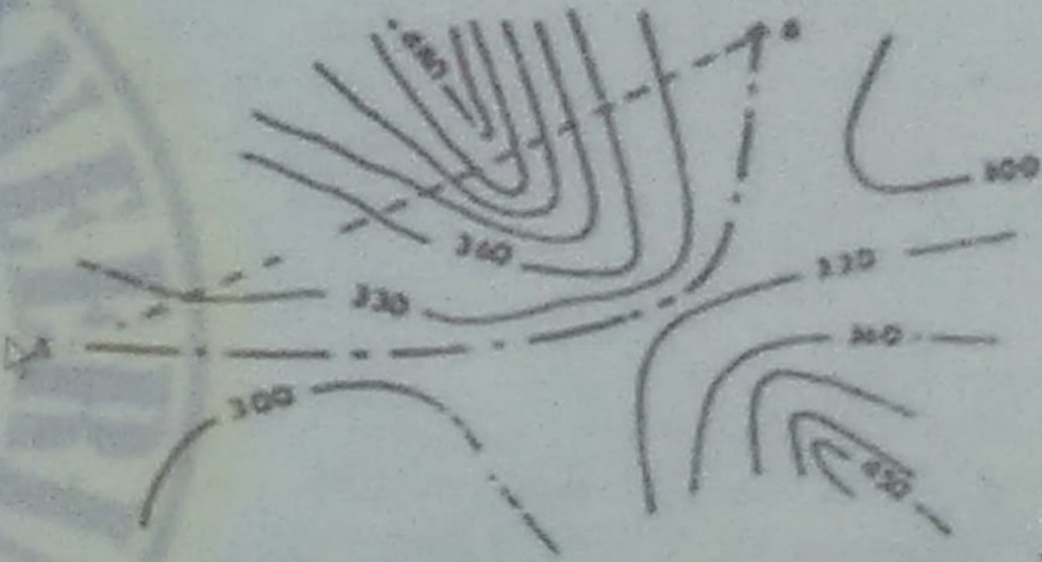
- ✓ These are control points governing highway alignment
- ✓ These points are classified into two categories
  - Points through which it should pass
  - Points through which it should not pass

**Lakes/ponds**

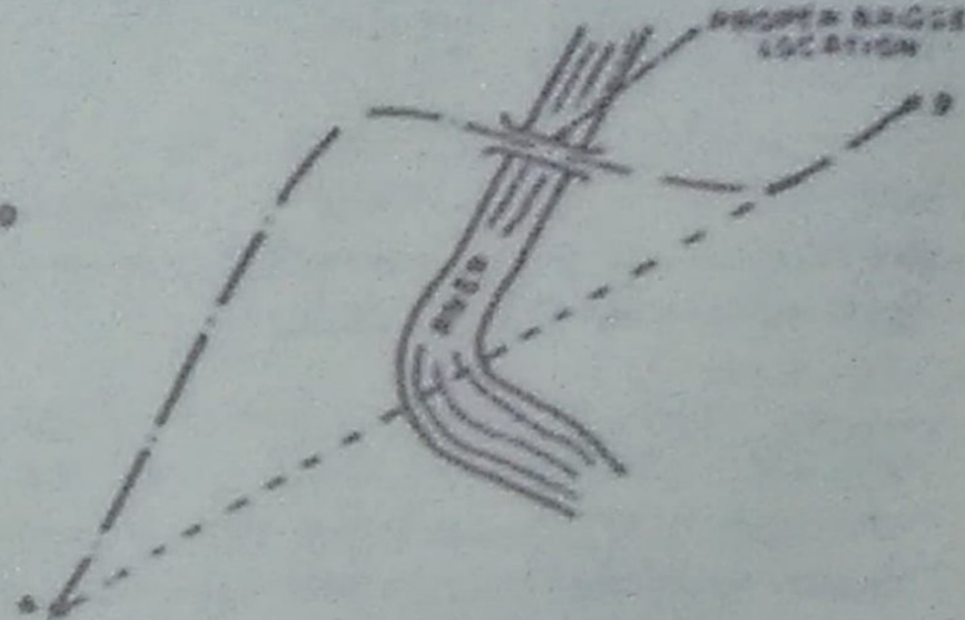
- ✓ Presence of a lake or pond on alignment path would also necessitate deviation of alignment

# Factors controlling alignment

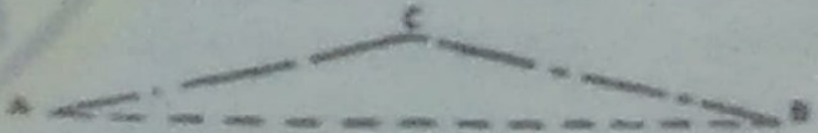
- Obligatory points



*(a) Alignment along a hill side pass*



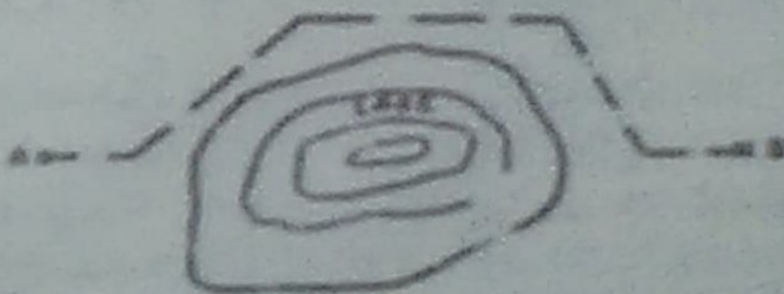
*(b) Alignment to suit proper location of bridge*



(c) CONNECTING INTERMEDIATE TOWN C

... BY LINK ROAD

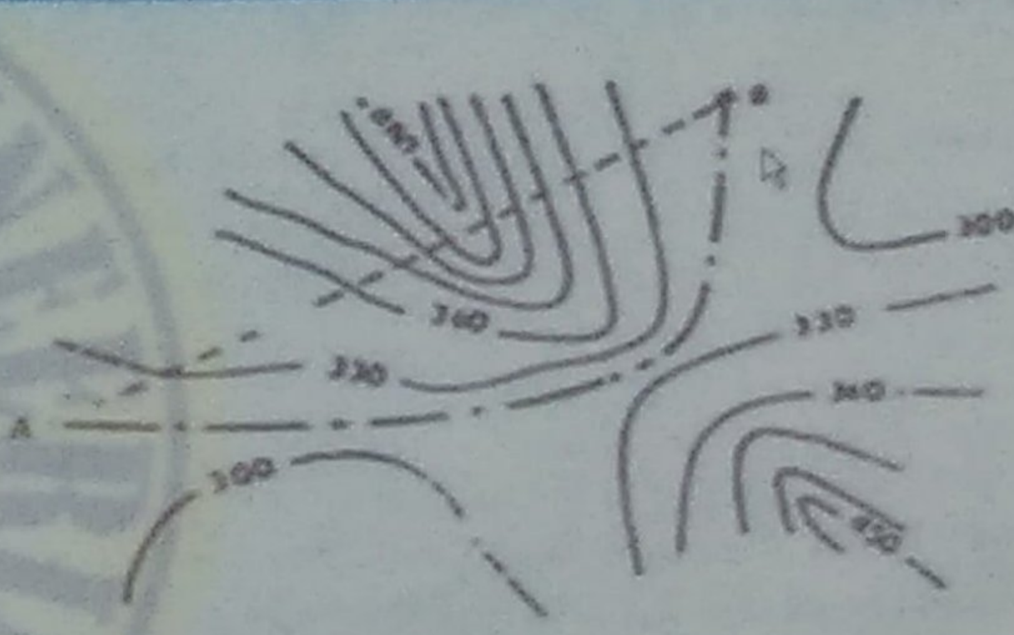
*... connect intermediate town*



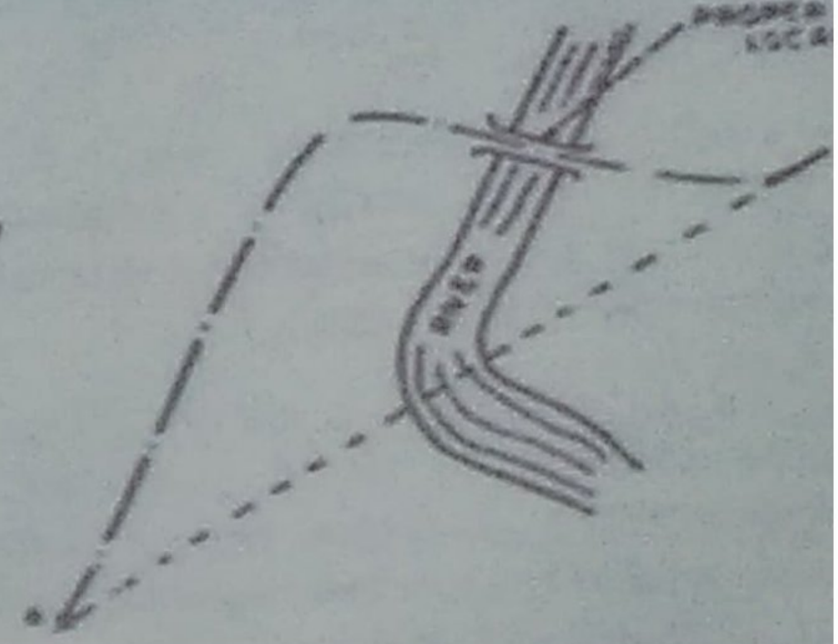
*(d) Alignment avoiding an intermediate area*

# Factors controlling alignment

## Obligatory points




*(a) Alignment along a hill side pass*



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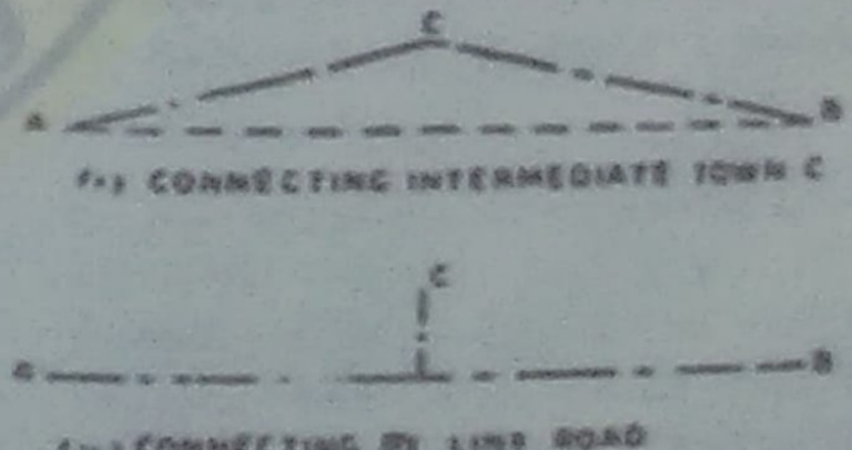
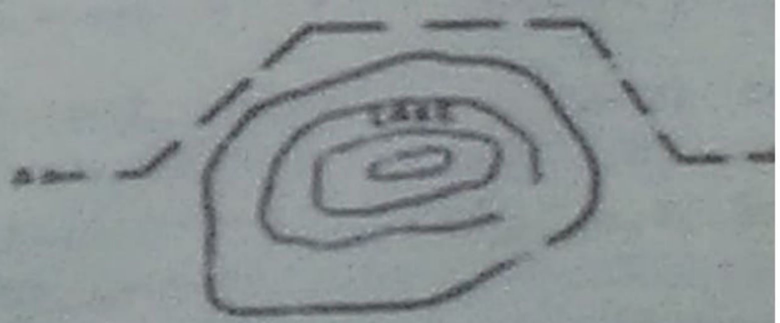



*(c) Alignment to connect intermediate town*




*(d) Alignment avoiding an intermediate ar*

## Factors controlling alignment

- Obligatory points
- Traffic

- ✓ Alignment should suit traffic requirements
- ✓ Based on origin-destination data of area, desire lines should be drawn
- ✓ New alignment should be drawn keeping in view desire lines, traffic flow pattern, etc.

## Factors controlling alignment

- Obligatory points
- Traffic
- Geometric design

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

## Factors controlling alignment

- Obligatory points
- Traffic
- Geometric design
- Economics

- ✓ Alignment finalized based on above factors should also be economical
- ✓ Initial cost, maintenance cost and vehicle operation cost should be taken into account
- ✓ Need to avoid high embankment and deep cutting to decrease initial cost
- ✓ Alignment is chosen in a manner to balance cutting and filling

## Factors controlling alignment

- Obligatory points
- Traffic
- Geometric design
- Economics
- Other considerations

✓ Drainage considerations, hydrological factors, political considerations and monotony govern alignment

✓ Subsurface water level, seepage flow and high flood level are factors to be kept in view

## Special considerations on hilly areas

- Stability

✓ While aligning hill roads, special care should be taken to align road along side of hill which is stable

✓ A common problem in hill roads is that of land slides

✓ Cutting and filling of earth to construct roads on hill-side causes steepening of existing slopes and affect its stability

## Special considerations on hilly areas

- Stability
- Drainage

✓ Numerous hill-side drains should be provided for adequate drainage facility across road

✓ Cross drainage structure being costly, attempts should be made to align road in such a way where number of cross drainage structures are minimum

## Special considerations on hilly areas

- Stability
- Drainage
- Geometric standards of hill roads

✓ Different sets of geometric standards are followed in hill roads with reference to gradient, curves and speed

✓ They consequently influence sight distance, radius of curve and other related features

✓ Route should enable ruling gradient to be attained in most of length, minimizing steep gradients, hair pin bands and needless rise and fall

## Special considerations on hilly areas

- Stability
- Drainage
- Geometric standards of hill roads
- Resisting length

✓ Resisting length of a road is its effective length taking into consideration for total work done against resistances

✓ Resisting length of a road may be calculated from total work done to move loads along route taking horizontal length, actual difference in levels between two stations and sum of ineffective rise and fall in excess of floating gradient

✓ Resisting length of alignment should be kept as low as possible

## Special considerations on hilly areas

- Stability
- Drainage
- Geometric standards of hill roads
- Resisting length

- ✓ Resisting length of a road is its effective length taking into consideration for total work done against resistances
- ✓ Resisting length of a road may be calculated from total work done to move loads along route taking horizontal length, actual difference in levels between two stations and sum of ineffective rise and fall in excess of floating gradient
- ✓ Resisting length of alignment should be kept as low as possible
- ✓ Ineffective rise and executive fall should be kept minimum

## Engineering surveys for highway locations

- Stages of engineering surveys are
  - Map study
  - Reconnaissance
  - Preliminary surveys
  - Final location and detailed surveys

Details of stages of engineering surveys → SS

# HIGHWAY GEOMETRIC DESIGN

## Importance of geometric design

- ✓ Geometric design of highways deals with dimensions and layout of visible features of highway
- ✓ Features normally considered are cross section elements, sight distance consideration, horizontal curvature, gradients, and intersection
- ✓ Design of these features is to a great extend influenced by driver behavior and psychology, vehicle characteristics, traffic characteristics such as speed and volume
- ✓ Proper geometric design will help in reduction of accidents and their severity
- ✓ Therefore, objective of geometric design is to provide optimum efficiency in traffic operation and maximum safety at reasonable cost
- ✓ Planning cannot be done stage wise like that of a pavement, but has to be done well in advance

## Elements of geometric design

- ✓ Cross-section elements - includes cross slope, various widths of roads and features in road margins
- ✓ Sight distance considerations - includes cross slope, various widths and features in the road margins
- ✓ Horizontal alignment details - includes features like super elevation, transition curve, extra widening and set back distance
- ✓ Vertical alignment details - includes gradient, sight distance and design of length of curves
- ✓ Intersection features – includes layout, capacity, etc.

# Factors affecting geometric design

## ➧ Design speed

- ✓ Defined as highest continuous speed at which individual vehicles can travel with safety on the highway when weather conditions are conducive
- ✓ Different from legal speed limit which is speed limit imposed to curb a common tendency of drivers to travel beyond an accepted safe speed
- ✓ Also different from desired speed which is maximum speed at which a driver would travel when unconstrained by either traffic or local geometry
- ✓ Single most important factor that affects geometric design
- ✓ Directly affects sight distance, horizontal curve, and length of vertical curves
- ✓ Since speed of vehicles vary with driver, terrain etc., a design speed is adopted for all geometric design

## Factors affecting geometric design

- Design speed
- Topography

- ✓ It is easier to construct roads with required standards for a plain terrain
- ✓ However, for a given design speed, construction cost increases multiform with gradient and terrain
- ✓ Therefore, geometric design standards are different for different terrain to keep cost of construction and time of construction under control

## Factors affecting geometric design

- Design speed
- Topography
- Traffic factors

- ✓ It is of crucial importance in highway design, is traffic data both current and future estimates
- ✓ Traffic volume indicates level of services (LOS) for which highway is being planned and directly affects geometric features such as width, alignment, grades etc.
- ✓ Without traffic data it is very difficult to design any highway

## Factors affecting geometric design

- Design speed
- Topography
- Traffic factors
- Vehicle

- ✓ Dimensions, weight of axle and operating characteristics of a vehicle influence design aspects such as width of pavement, radii of curve, clearances, parking geometrics etc.
- ✓ A design vehicle which has standard weight, dimensions and operating characteristics are used to establish highway design controls to accommodate vehicles of a designated type

## Factors affecting geometric design

- Design speed
- Topography
- Traffic factors
- Vehicle
- Human

Important human factors that influence geometric design are physical, mental and psychological characteristics of driver and pedestrians like reaction time

## Factors affecting geometric design

- Design speed
- Topography
- Traffic factors
- Vehicle
- Human
- Design Hourly Volume and Capacity

- ✓ General unit for measuring traffic on highway is Annual Average Daily Traffic volume, abbreviated as AADT
- ✓ Traffic flow (or) volume keeps fluctuating with time, from a low value during off peak hours to highest value during peak hour
- ✓ It will be uneconomical to design roadway facilities for peak traffic flow

## Factors affecting geometric design

- Design speed
- Topography
- Traffic factors
- Vehicle
- Human
- Design Hourly Volume and Capacity
- Environmental

Environmental factors like air pollution, noise pollution, landscaping, aesthetics and other global conditions should be given due considerations in geometric design of roads

## Factors affecting geometric design

- Design speed
- Topography
- Traffic factors
- Vehicle
- Human
- Design Hourly Volume and Capacity
- Environmental
- Economy

✓ Design adopted should be economical as far as possible

✓ It should match with funds allotted for capital cost and maintenance cost

## Factors affecting geometric design

- Design speed
- Topography
- Traffic factors
- Vehicle
- Human
- Design Hourly Volume and Capacity
- Environmental
- Economy
- Other factors

Geometric design should be such that aesthetics of region is not affected

## Cross sectional elements

- Features of cross-section of pavement influences life of pavement as well as riding comfort and safety
- Of these, pavement surface characteristics affect both of these
- Camber, kerbs, and geometry of various cross-sectional elements are important aspects to be considered in this regard

## Pavement surface characteristics

- For a safe and comfortable driving four aspects of pavement surface are important
  - Friction between wheels and pavement surface
  - Smoothness of road surface
  - Light reflection characteristics of top of pavement surface
  - Drainage of water

## Friction

- ✓ Friction between wheel and pavement surface is a crucial factor in design of horizontal curves and safe operating speed
- ✓ Further, it also affect acceleration and deceleration ability of vehicles
- ✓ Lack of adequate friction can cause skidding or slipping of vehicles
- ✓ Frictional force that develops between wheel and pavement is load acting multiplied by a factor called coefficient of friction, and denoted as $f$
- ✓ Choice of the value of $f$ is a very complicated issue since it depends on many variables
- ✓ Coefficient of longitudinal friction is 0.35-0.4 depending on speed and coefficient of lateral friction is 0.15
- ✓ Former is useful in sight distance calculation, and latter in horizontal curve design

## Skid

### Longitudinal skid

- ✓ Occurs when wheels slide without revolving or when wheels partially revolves
- ✓ Skidding happens when path traveled along road surface is more than circumferential movement of wheels due to their rotation
- ✓ When brakes are applied, wheels are locked partially or fully, and if vehicle moves forward, longitudinal skid takes place
- ✓ May vary from 0 to 100 percent

### Lateral skid

- ✓ Takes place while a vehicle negotiate a horizontal curve, if centrifugal force is greater than counteracting forces (lateral friction and component of gravity due to superelevation)
- ✓ Considered dangerous as vehicle goes out of control leading to an accident

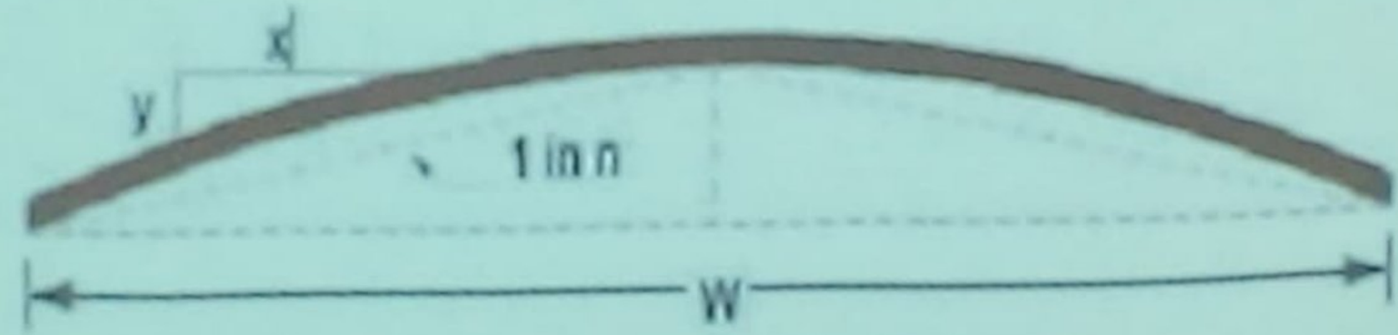
- ✓ Usually camber is provided on straight roads by raising centre of carriageway with respect to edges, forming a crown or highest point on centre line
- ✓ Rate of camber or cross slope is usually designated by 1 in $n$, which means that transverse slope is in ratio 1 vertical to $n$ horizontal
- ✓ Camber is also expressed as a percentage
- ✓ If camber is $x\%$, cross slope is $x$ in 100
- ✓ Required camber of a pavement depends on - type of pavement surface and amount of rainfall
- ✓ A flat camber of 1.7 to 2.0% is sufficient on relatively impervious pavement surface like cement concrete or bituminous concrete
- ✓ In pervious surface like WBM or earth road which may allow surface water to get into subgrade soil, steeper cross slope is required
- ✓ Steeper camber are also provided in areas of heavy rainfall

## Effect of too steep cross slope

- Too steep cross slope is not desirable because of following reasons
  - ✓ Transverse tilt of vehicles – causes uncomfortable side thrust and a drag on steering of automobiles, unequal wear of tyres and road surface
  - ✓ Discomfort causing throw of vehicle when crossing crown during overtaking operations
  - ✓ Problems of toppling over of highly laden bullock carts and trucks
  - ✓ Formation of cross ruts due to rapid flow of water
  - ✓ Tendency of most of vehicles to travel along centre line

## Types of camber

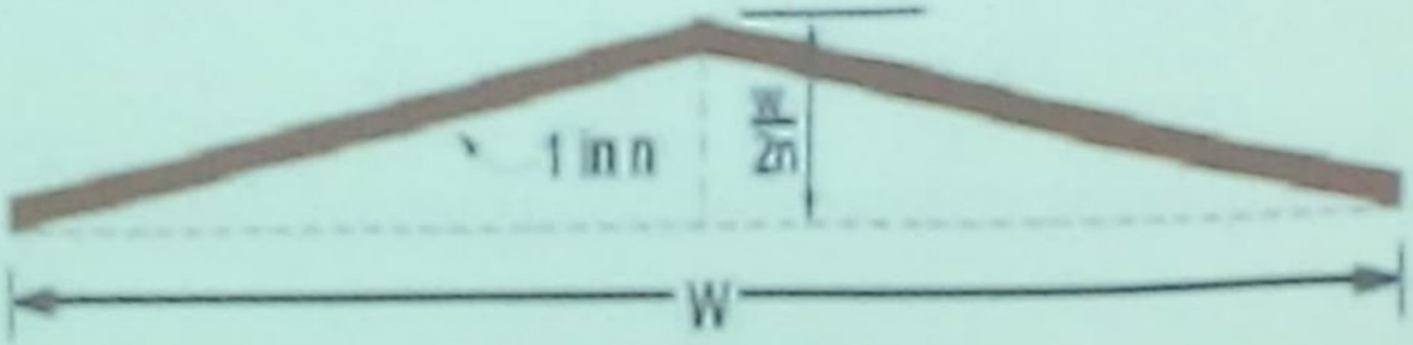
- Common types of camber are
  - Parabolic




a. Parabolic camber $y=2x^2/nw$

**Types of camber**

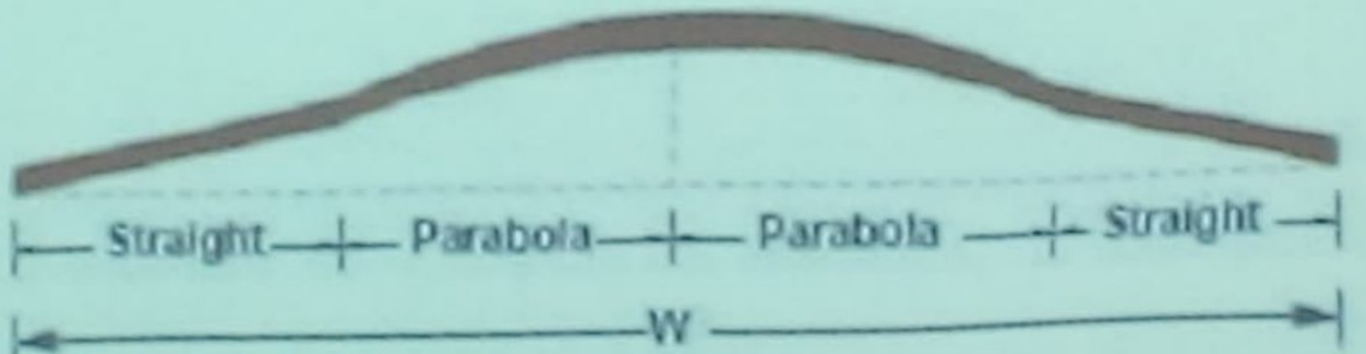
- Common types of camber are
  - Parabolic
  - Straight




b. Straight line camber

## Types of camber

- Common types of camber are
  - Parabolic
  - Straight
  - Combination of straight and parabolic




c. Combination of straight and parabolic camber

## Camber for different types of road surface

| Surface type | Heavy rain | Light rain |
|---|---|---|
| Concrete/Bituminous | 2% | 1.7% |
| Thin bituminous | 2.5% | 2.0% |
| Gravel/WBM | 3% | 2.5% |
| Earthen | 4% | 3% |

## Carriageway

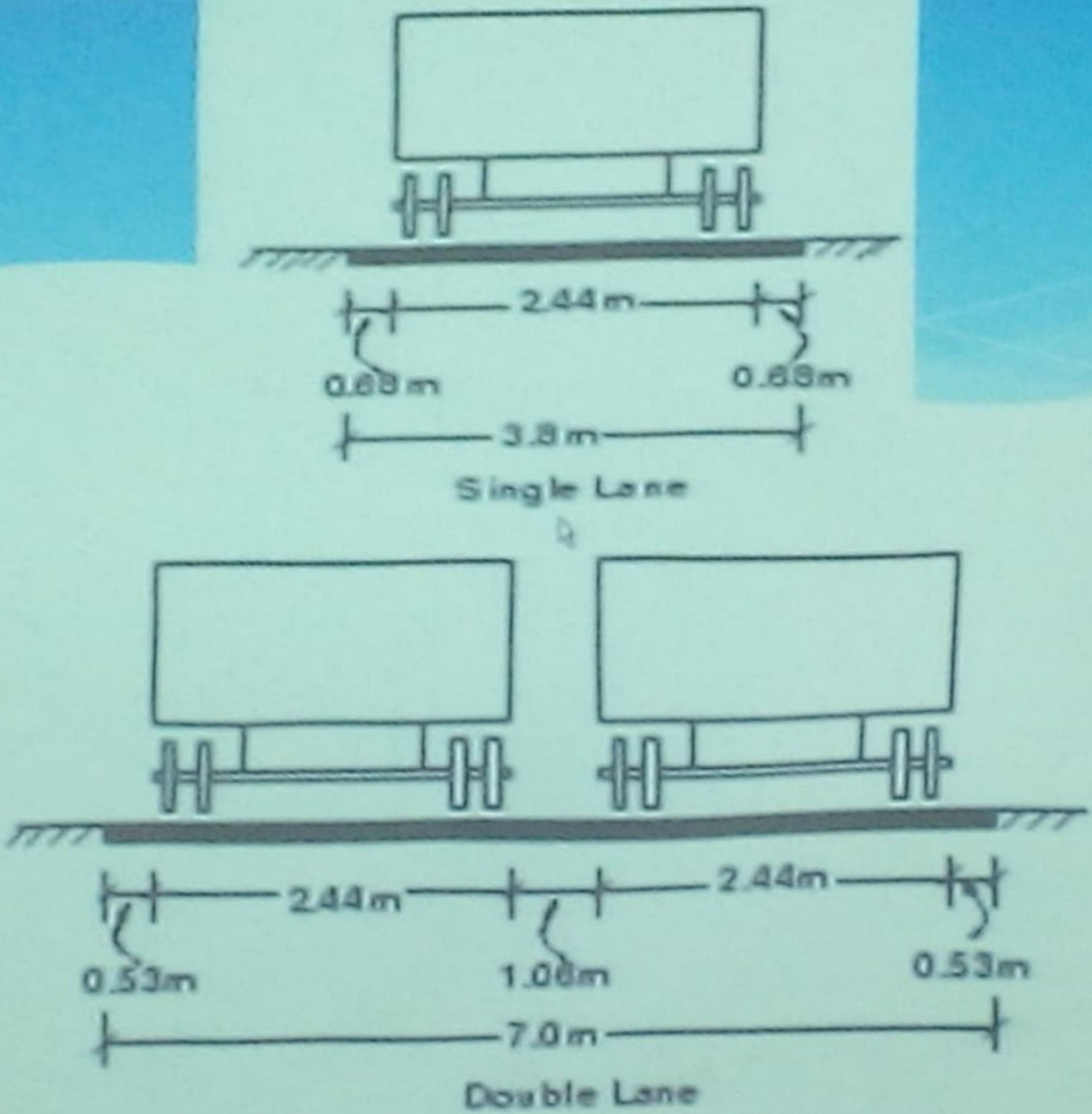
- ✓ Metalled potion of road over which vehicles are intended to move
- ✓ Different types of carriageway according to material used for construction

## Traffic lane

- ✓ Carriageway intended for one line of traffic movement is called a traffic lane

## Width of carriageway

- ✓ Width of carriage way or width of pavement depends on width of traffic lane and number of lanes
- ✓ Width of a traffic lane depends on width of vehicle and clearance
- ✓ Side clearance improves operating speed and safety
- ✓ Maximum permissible width of a vehicle is 2.44 m and desirable side clearance for single lane traffic is 0.68 m
- ✓ This require minimum of lane width of 3.75 m for a single lane road
- ✓ However, side clearance required is about 0.53 m, on either side and 1.06 m in center
- ✓ Therefore, a two lane road require minimum of 3.5 m for each lane




Lane width for single and two lane roads

## Specification for carriageway width

| Class of road | Width of carriageway (m) |
|---|---|
| Single lane | 3.75 |
| Two lane, no kerbs | 7.0 |
| Two lane, raised kerbs | 7.5 |
| Intermediate carriage | 5.5 |
| Multi-lane | 3.5 for each lane |

## Traffic separators or Medians

- Main function is to prevent head-on collision between vehicles moving in opposite direction on adjacent lanes
- Also help to
    - Channelize traffic into streams at intersections
    - Shadow crossing and turning traffic
    - Segregate slow traffic
    - Protect pedestrians
- May be in form of pavement marking, physical dividers or area separators
- Pavement marking is simplest of all traffic separators
- Mechanical separator should be designed in such a manner that even if wheels of vehicle encroach, no part of vehicle body should be damaged
- Area separators may be medians, dividing islands or parkway strips, dividing two directions of traffic flow

## Kerbs

- ✓ Indicate boundary between carriage way and shoulder or islands or footpaths
- ✓ Different types of kerbs are
    - Low or mountable kerbs
    - Semi-barrier type kerbs
    - Barrier type kerbs
- ✓ Designed to discourage vehicles from leaving pavement

## Kerbs

- Indicate boundary between carriage way and shoulder or islands or footpaths
- Different types of kerbs are
  - Low or mountable kerbs
  - Semi-barrier type kerbs
  - Barrier type kerbs
- Designed to discourage vehicles from leaving pavement
- Provided when there is considerable amount of pedestrian traffic
- Placed at a height of 20 cm above pavement edge with a steep batter

## Kerbs

- ✓ Indicate boundary between carriage way and shoulder or islands or footpaths
- ✓ Different types of kerbs are
  - Low or mountable kerbs
  - Semi barrier type kerbs
  - Barrier type kerbs
  - Submerged kerbs

- ✓ Used in rural roads
- ✓ Provided at pavement edges between pavement edge and shoulders

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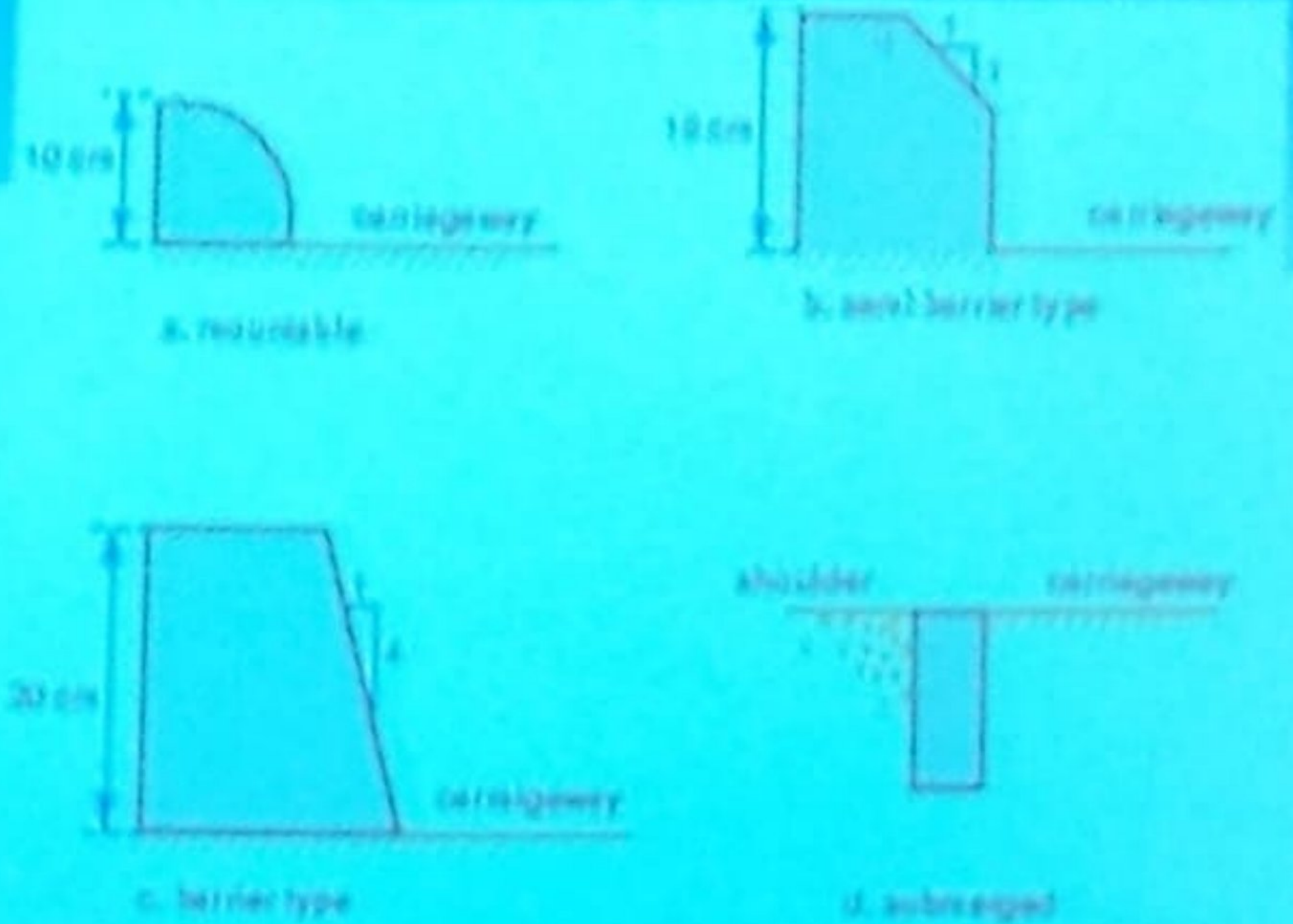
- ✓ Used in rural roads
- ✓ Provided at pavement edges between pavement edge and shoulders
- ✓ Provide lateral confinement and stability to pavement

# Kerbs




Different types of kerbs

Road margins

- ✓ Portion of road beyond carriageway and on roadway
- ✓ Various elements that form road margins are
  - Shoulders

- ✓ Provided along road edge and are intended for accommodation of stopped vehicles
- ✓ Serve as an emergency lane for vehicles
- ✓ Provide lateral support for base and surface courses
- ✓ Should be strong enough to bear weight of a fully loaded truck even in wet conditions
- ✓ Width should be adequate for giving working space around a stopped vehicle
- ✓ It is desirable to have a width of 4.6 m for shoulders

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- ✓ Width should be adequate for giving working space around a stopped vehicle
- ✓ It is desirable to have a width of 4.6 m for shoulders
- ✓ A minimum width of 2.5 m is recommended for 2-lane rural highways

Road margins

- ✓ Portion of road beyond carriageway and on roadway
- ✓ Various elements that form road margins are
  - Shoulders
  - Parking lanes

- ✓ Provided in urban lanes for side parking
- ✓ Parallel parking is preferred because it is safe for vehicles moving on road
- ✓ Should have a minimum of 3.0 m width in case of parallel parking

## Road margins

- ✓ Portion of road beyond carriageway and on roadway
- ✓ Various elements that form road margins are
  - Shoulders
  - Parking lanes
  - Lay byes

- ✓ Provided near public conveniences with guide maps to enable drivers to stop clear off carriage
- ✓ Should normally be of 3.0 m width and at least 30 m length with 15 m end tapers on both sides

## Road margins

- ✓ Portion of road beyond carriageway and on roadway
- ✓ Various elements that form road margins are
  - Shoulders
  - Parking lanes
  - Lay-byes
  - Bus bays

- ✓ Provided by recessing kerbs for bus stops
- ✓ Provided so that they do not obstruct movement of vehicles in carriage way
- ✓ Should be at least 75 meters away from intersection so that traffic near intersection is not affected

## Road margins

- ✓ Portion of road beyond carriageway and on roadway
- ✓ Various elements that form road margins are
  - Shoulders
  - Parking lanes
  - Lay-byes
  - Bus bays
  - Frontage roads/service roads

- ✓ Provided to give access to properties along an important controlled highways like freeways and expressways
- ✓ Run parallel to highway and will be usually isolated by a separator and access to highway will be provided only at selected points

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- ✓ Provided to give access to properties along an important controlled highways like freeways and expressways
- ✓ Run parallel to highway and will be usually isolated by a separator and access to highway will be provided only at selected points
- ✓ Provided to avoid congestion in expressways and also speed of traffic in those lanes is not reduced

## Road margins

- ✓ Portion of road beyond carriageway and on roadway
- ✓ Various elements that form road margins are
  - Shoulders
  - Parking lanes
  - Lay-byes
  - Bus bays
  - Frontage roads/service roads
  - Driveways
- ✓ Connect highway with commercial establishment like fu stations, service stations etc.
- ✓ Should be properly designed and located, fairly away from ar intersection
- ✓ Radius of drive way curve should be kept as large as possible
- ✓ Width of drive way should be minimized to reduce length of cross walks

## Road margins

- ✓ Portion of road beyond carriageway and on roadway
- ✓ Various elements that form road margins are
  - Shoulders
  - Parking lanes
  - Lay-byes
  - Bus bays
  - Frontage roads/service roads
  - Driveways
  - Cycle track

- ✓ Provided in urban areas when volume of cycle traffic on road is very high
- ✓ A minimum width of 2 m is provided and width may be increased by 1.0 m for each additional cycle lane
- ✓ Layout of cycle tracks should be carefully decided in large highway intersections and traffic rotaries

## Road margins

- ✓ Portion of road beyond carriageway and on roadway
- ✓ Various elements that form road margins are
  - Shoulders
  - Parking lanes
  - Lay-byes
  - Bus bays
  - Frontage roads/service roads
  - Driveways
  - Cycle track
  - Footpath

- ✓ Exclusive right of way to pedestrians, especially in urban areas
- ✓ Provided for safety of pedestrians when both pedestrian traffic and vehicular traffic is high
- ✓ Minimum width is 1.5 m and may be increased based on traffic
- ✓ Should be either as smooth as pavement or more smoother than that to induce pedestrian to use footpath

## Road margins

- ✓ Portion of road beyond carriageway and on roadway
- ✓ Various elements that form road margins are
  - Shoulders
  - Parking lanes
  - Lay-byes
  - Bus bays
  - Frontage roads/service roads
  - Driveways
  - Cycle track
  - Footpath
  - Guard rails

- ✓ Provided at edge of shoulder when road is constructed on a fill so that vehicles are prevented from running off embankment, especially when height of fill exceeds 3 m
- ✓ Various designs of guard rails are in use

## Road margins

- ✓ Portion of road beyond carriageway and on roadway
- ✓ Various elements that form road margins are
  - Shoulders
  - Parking lanes
  - Lay-byes
  - Bus bays
  - Frontage roads/service roads
  - Driveways
  - Cycle track
  - Footpath
  - Guard rails
- ✓ Guard stones are installed at suitable intervals along outer edge of formation at horizontal curves of roads running on embankments
- ✓ Painted with black and white strips so as to provide better night visibility of curves under head light of vehicles

**Road margins**

- ✓ Portion of road beyond carriageway and on roadway
- ✓ Various elements that form road margins are
  - Shoulders
  - Parking lanes
  - Lay-byes
  - Bus bays
  - Frontage roads/service roads
  - Driveways
  - Cycle track
  - Footpath
  - Guard rails
  - Embankment slope

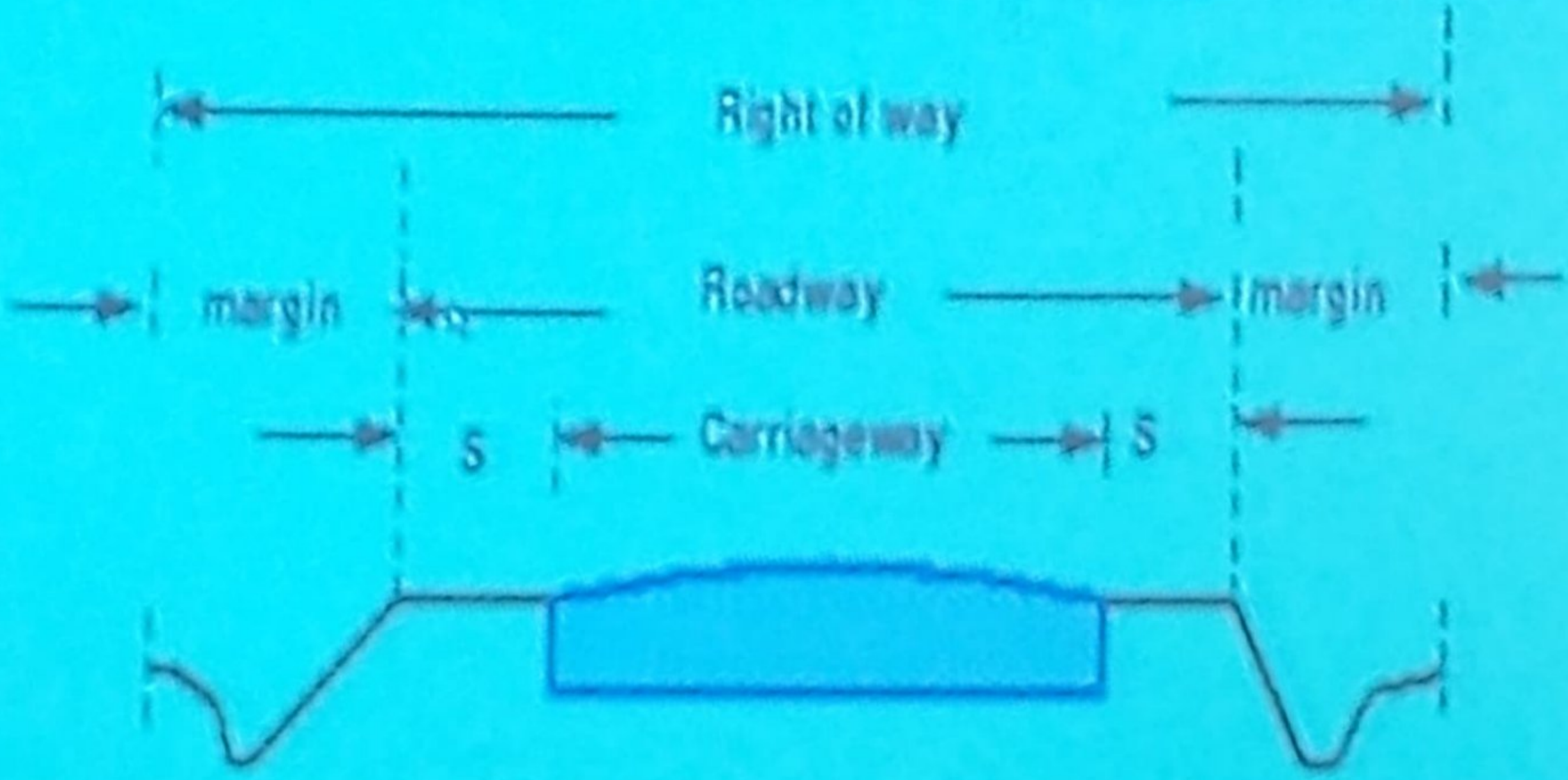
Width of Roadway or Formation

- ✓ It is sum of widths of pavements or carriageway including separators if any and shoulders
- ✓ It is top width of highway embankment or bottom width of highway cutting excluding side drains

## Right of way

- ✓ Right of way (ROW) or land width is width of land acquired for road, along its alignment
- ✓ It should be adequate to accommodate all cross-sectional elements of highway and may reasonably provide for future development
- ✓ To prevent ribbon development along highways, control lines and building lines may be provided
- ✓ Control line is a line which represents nearest limits of future uncontrolled building activity in relation to a road
- ✓ Building line represents a line on either side of the road, between which and road no building activity is permitted at all

## Right of way




S - shoulder

## Right of way width

- It is governed by
  - **Width of formation** - depends on category of highway and width of roadway and road margins
  - **Height of embankment or depth of cutting** - governed by topography and vertical alignment
  - **Side slopes of embankment or cutting** - depends on height of slope, soil type etc.
  - **Drainage system and their size** - depends on rainfall, topography etc.
  - **Sight distance considerations** - On curves etc. there is restriction to visibility on inner side of curve due to presence of some obstructions like building, structures etc.

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- ✓ **Reserve land for future widening** - Some land has to be acquired in advance anticipating future developments like widening of road

(iv) Drainage system and their size — depends on rainfall, topography etc.

(v) sight distance consideration → On curves etc, there is restriction to visibility on inner side of curve due to presence of som obstructions like building, structures etc.

(vi) Reserve Land for future widening → Some Land has to be acquired in advance, anticipating future developments like widening of road.

## SIGHT DISTANCE

- ✓ Safe and efficient operation of vehicle on roads depends, among other factor on road length at which an obstruction, if any, becomes visible to driver in direction of travel
- ✓ In other words feasibility to see ahead or visibility is very important for safe vehicle operation on a highway
- ✓ Sight distance available from a point is actual distance along road surface, which a driver from a specified height above carriageway has visibility of stationary or moving objects
- ✓ In other words, sight distance is length of road visible ahead to driver at any instance
- ✓ Restrictions to sight distance may be caused at horizontal curves, by objects obstructing vision at inner side of road or at vertical summit curves or at intersections
- ✓ Sight distance required by drivers applies to both geometric design of highways and for traffic control

## SIGHT DISTANCE

- ✓ Safe and efficient operation of vehicle on roads depends, amon… ion, if any,
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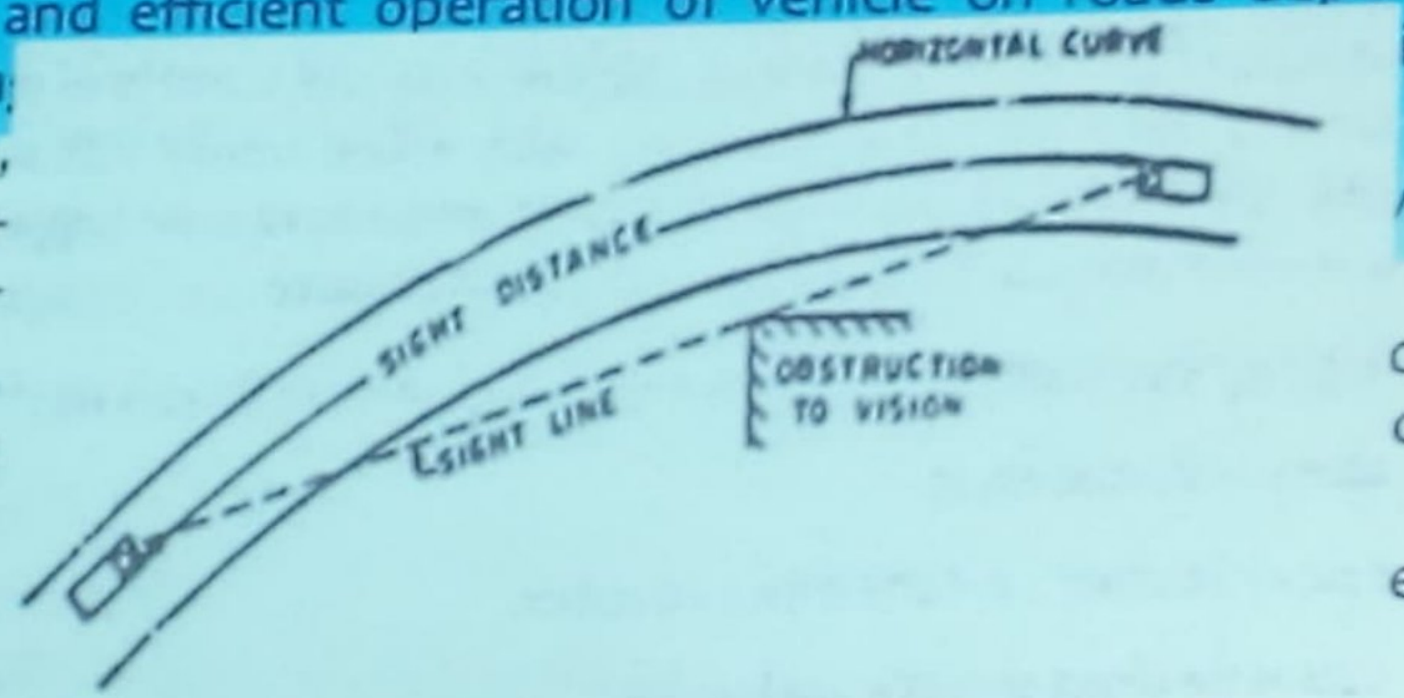


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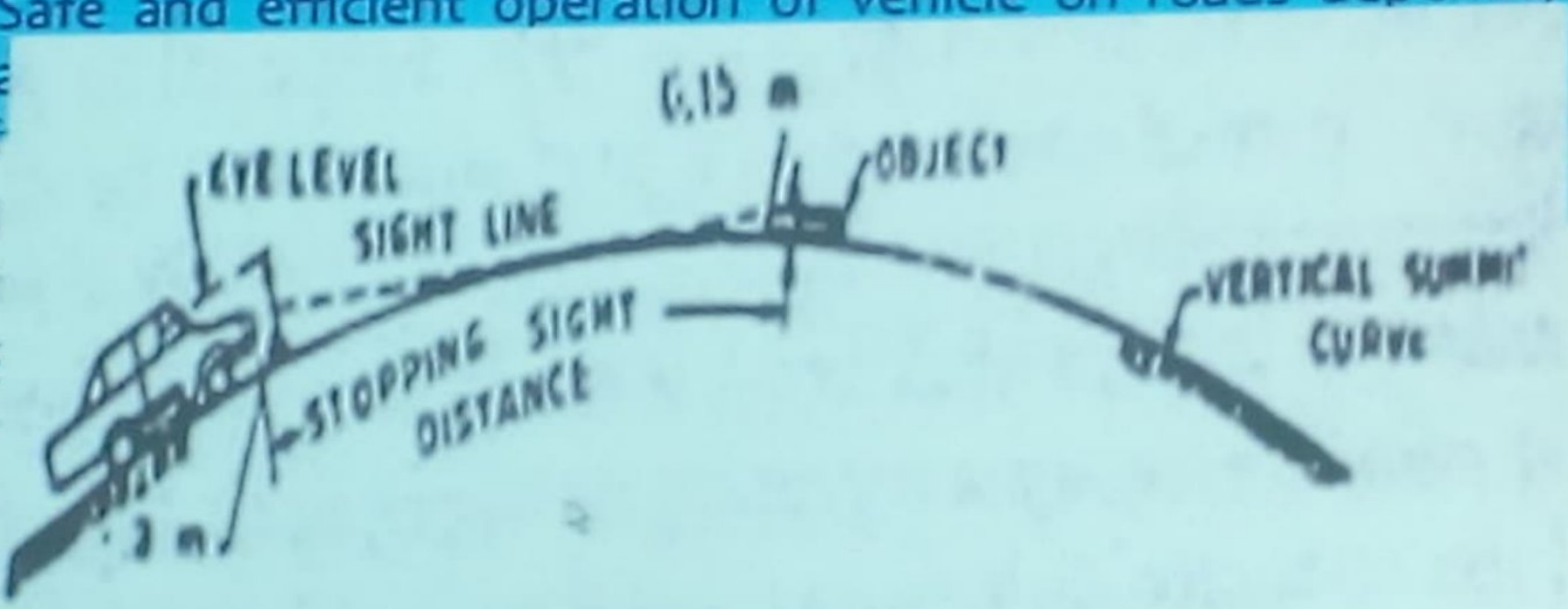


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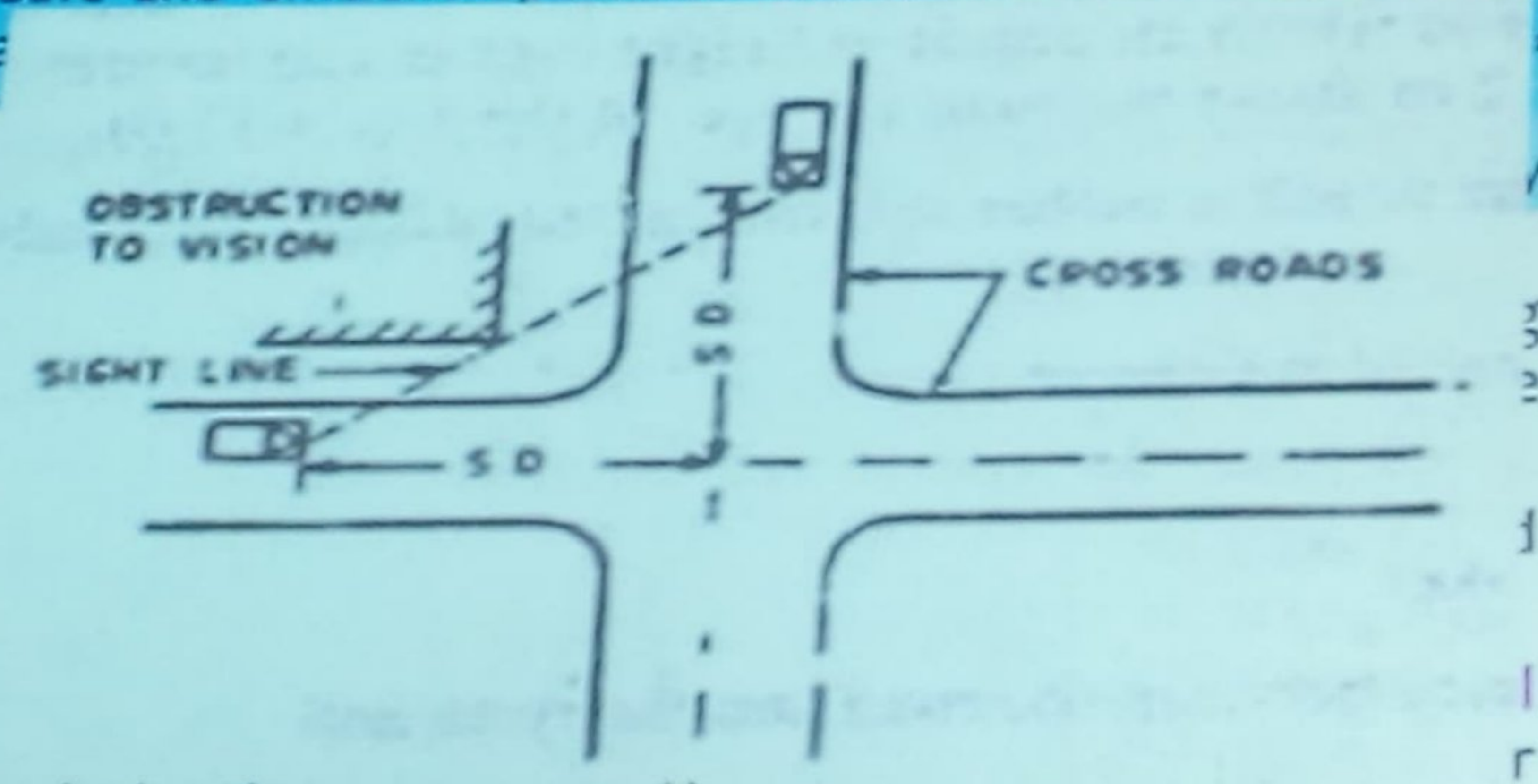


at vertical summit curves or at intersections

- Sight distance required by drivers applies to both geometric design of highways and for traffic control

## Types of sight distance

- Three sight distance situations are considered in design
  - ✓ Stopping sight distance (SSD) or the absolute minimum sight distance
  - ✓ Overtaking sight distance (OSD) for safe overtaking operation
  - ✓ Safe sight distance for entering into uncontrolled intersections
- Apart from three situations mentioned above, following sight distances are considered
  - ✓ Intermediate sight distance – defined as twice of SSD; when OSD cannot be provided intermediate sight distance is provided to give limited overtaking opportunities to fast vehicles
  - ✓ Head light sight distance – distance visible to a driver during night driving under illumination of vehicle head lights; is critical at up-gradients and at ascending stretch of valley curves

- Standards for sight distance should satisfy following three conditions:
  - ✓ Driver travelling at design speed has sufficient sight distance or length of road visible ahead to stop vehicle, in case of any obstruction on road ahead
  - ✓ Driver travelling at design speed should be able to safely overtake, at reasonable intervals, slower vehicles without causing obstruction or hazard to traffic of opposite direction
  - ✓ Driver entering an uncontrolled intersection has sufficient visibility to enable him to take control of his vehicle and to avoid collision with another vehicle

## Stopping sight distance

- ✓ Stopping sight distance is defined as distance needed for drivers to see an object on roadway ahead and bring their vehicles to safe stop before colliding with object
- ✓ Distances are derived for various design speeds based on assumptions for driver reaction time, braking ability of most vehicles under wet pavement conditions, and friction provided by most pavement surfaces, assuming good tyres
- ✓ A roadway designed to criteria employs a horizontal and vertical alignment and a cross section that provides at least minimum stopping sight distance through entire facility

- Sight distance available on a road to a driver at any instance depends on
  - ✓ Features of road ahead – horizontal alignment, vertical profile of road, traffic condition and position of obstructions
  - ✓ Height of driver's eye above road surface – at summit curves more important factor affecting visibility
  - ✓ Height of object above road surface – indicates what might be a source of danger to moving vehicle

Height of driver's eye above road surface → 1.2 m

Height of object above road surface → 0.15 m

- Distance within which a motor vehicle can be stopped depends upon
    - Total reaction time of driver
    - Speed of vehicle
    - Efficiency of brakes

## Total reaction time of driver

- It is time taken from instant object is visible to driver to instant when brakes are applied
- Amount of time gap depends on several factors
- During this time vehicle travels a certain distance at original speed or design speed
- Thus stopping distance increases with increase in reaction time of driver
- Many of the studies show that drivers require about 1.5 to 2 secs. under normal conditions
- However, taking into consideration variability of driver characteristics, a higher value is normally used in design for example 2.5 secs.

- Total reaction time may be split up into two parts
    - Perception time

- ✓ It is time required for a driver to realize that brakes must be applied
- ✓ It is time from instant object comes on line of sight of driver to instant he realizes that vehicle needs to be stopped
- ✓ It varies from driver to driver and on several other factors such as speed of vehicle, distance of object and environmental conditions

- Total reaction time may be split up into two parts
  - Perception time
  - Brake reaction time

- ✓ It is time from instant brake is applied by driver to instant vehicle is deadly stopped
- ✓ It depends on several factors including skill of driver, type of problems and environmental factors

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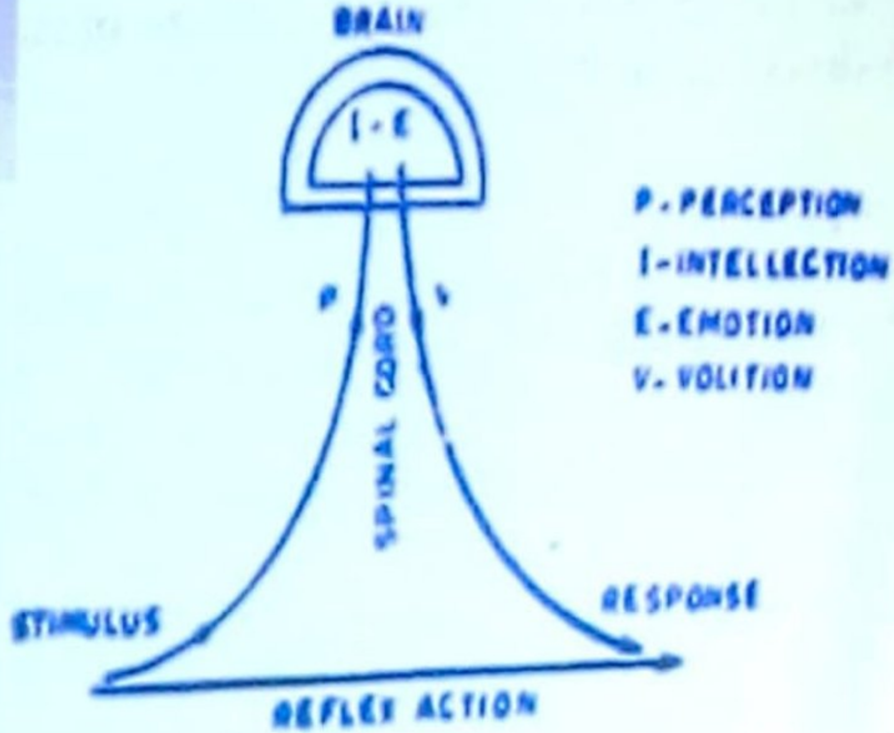
  - Perception time
  - Brake reaction time

- ✓ It is time from instant brake is applied by driver to instant vehicle is deadly stopped
- ✓ It depends on several factors including skill of driver, type of problems and environmental factors

# PIEV Theory

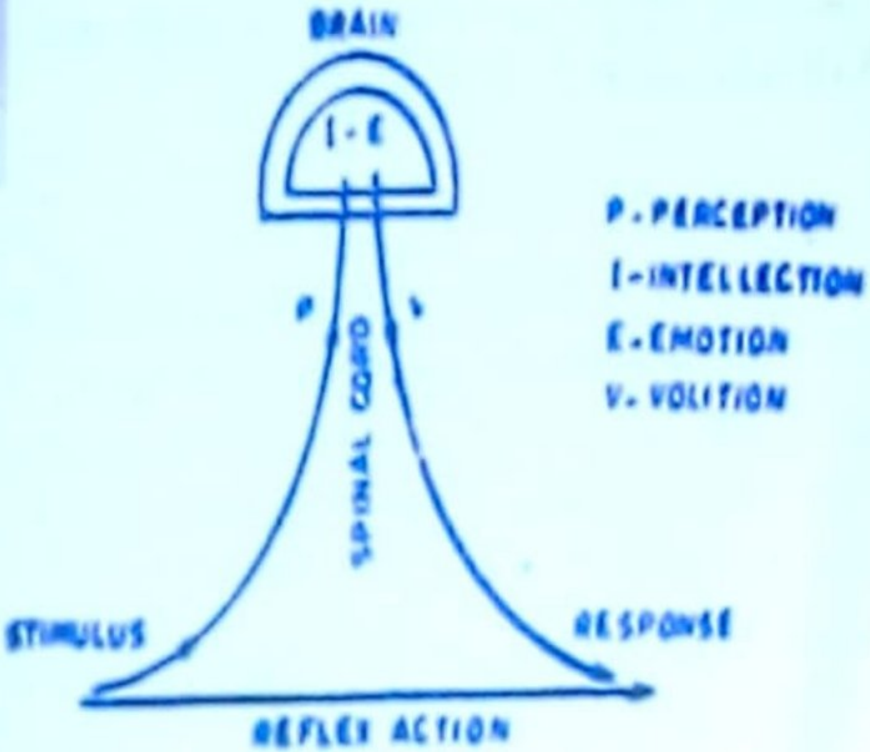
- According to this theory total reaction time of driver is split into four parts
  - Perception
- ✓ It is time required for sensation received by eyes or ears to be transmitted to brain through nervous system and spinal chord
- ✓ In other words, it is time required to perceive an object or situation



## PIEV Theory

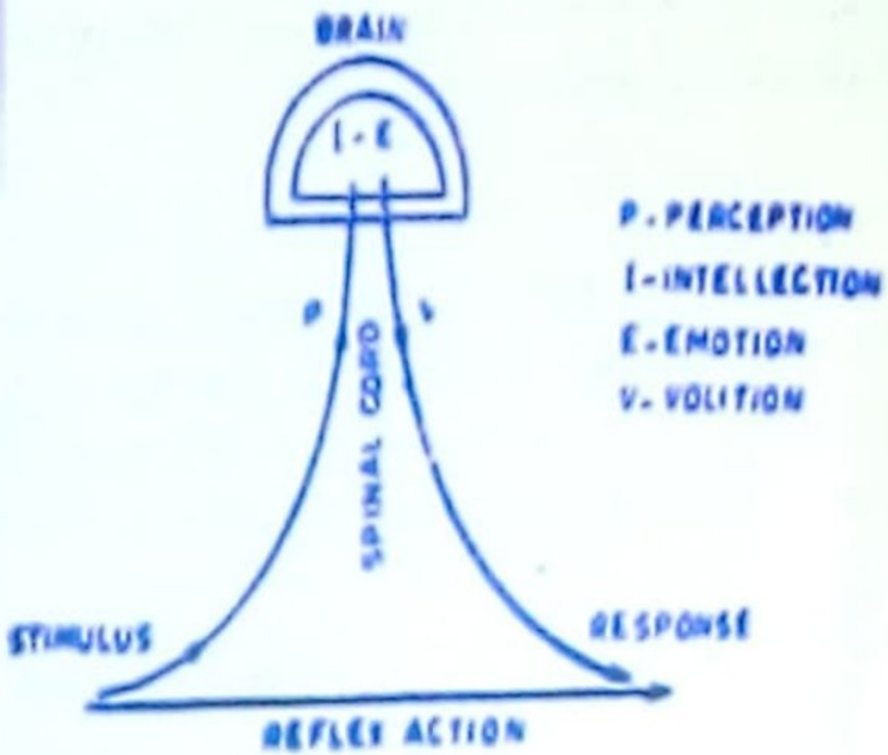
- According to this theory total reaction time of driver is split into four parts
  - Perception
  - Intellection

- ✓ It is time required for understanding situation
- ✓ It is also time required for comparing different thoughts, regrouping and registering new sensation



## PIEV Theory

- According to this theory total reaction time of driver is split into four parts
  - Perception
  - Intellection
  - Emotion

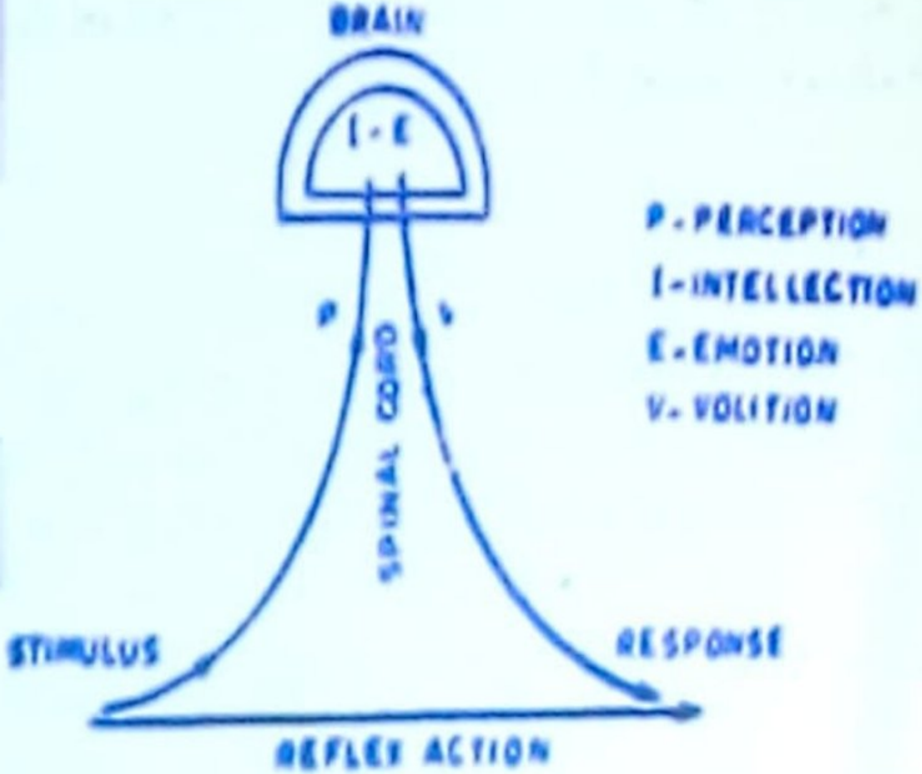



- ✓ It is time elapsed during emotional sensation and disturbance such as fear, anger or any other emotional feelings such as superstition etc. to situation
- ✓ Emotion time of a driver is likely to vary considerably depending upon problems involved

# PIEV Theory

- According to this theory total reaction time of driver is split into four parts
  - Perception
  - Intellection
  - Emotion
  - Volition

It is time taken for final action



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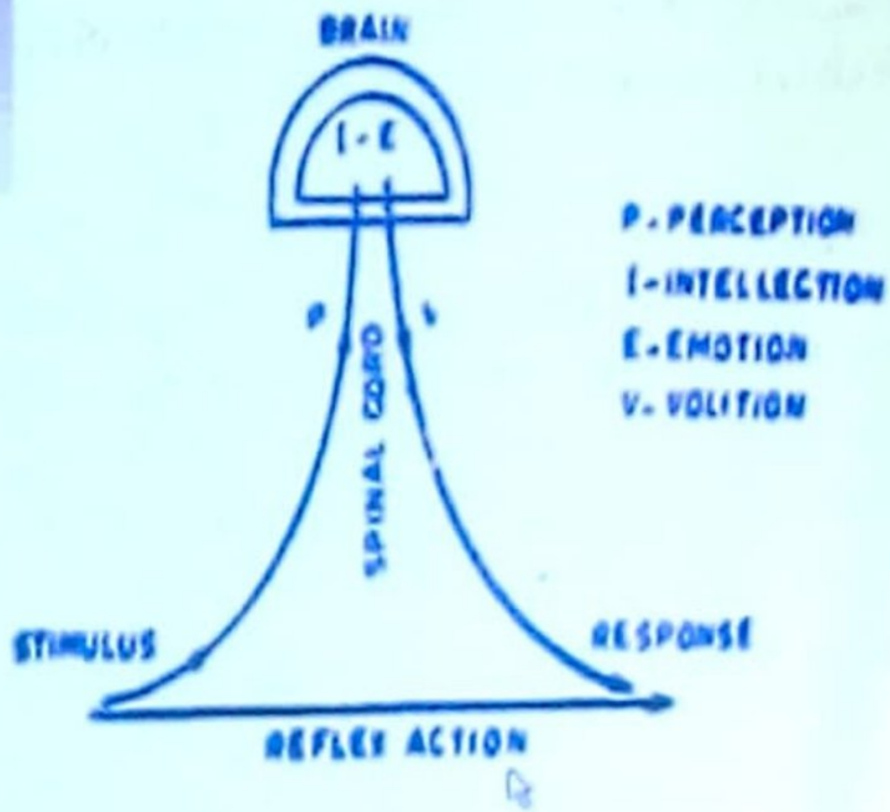



✓ It is also possible that driver may apply brakes or take any avoiding action by reflex action, even without thinking

- PIEV time of a driver depends on several factors such as
  - Physical and psychological characteristics of driver
  - Type of problem involved
  - Environmental condition
  - Temporary factors (motive of trip, travel speed, fatigue, consumption of alcohol, etc.)
- Total reaction time of an average driver may vary from 0.5 second for simple situations to as much as 3 to 4 seconds or even more in complex problems

## Efficiency of brakes

- ✓ Efficiency of brakes depends upon age of vehicle, vehicle characteristics etc.
- ✓ If brake efficiency is 100%, vehicle will stop at moment brakes are applied
- ✓ But practically, it is not possible to achieve 100% brake efficiency
- ✓ Therefore sight distance required will be more when efficiency of brakes are less
- ✓ Also for safe geometric design, it is assumed that vehicles have only 50% brake efficiency

## Frictional resistance between tyre and road

- ✓ Frictional resistance between tyre and road plays an important role to bring vehicle to stop
- ✓ When frictional resistance is more, vehicles stop immediately
- ✓ Thus sight distance required will be less
- ✓ No separate provision for brake efficiency is provided while computing sight distance
- ✓ This is taken into account along with factor of longitudinal friction
- ✓ Value of longitudinal friction is between 0.35 to 0.4

**Gradient of road**

- ✓ It also affects sight distance
- ✓ While climbing up a gradient, vehicle can stop immediately
- ✓ Therefore, sight distance required is less
- ✓ While descending a gradient, gravity also comes into action and more time will be required to stop vehicle
- ✓ Sight distance required will be more in this case

## Analysis of stopping sight distance

✓ Stopping sight distance is sum of

- Lag distance – distance travelled by vehicle during total reaction time
- Braking distance – distance travelled by vehicle after application of brakes to a dead stop position

## Lag distance

- ✓ During total reaction time or PIEV time vehicle may be assumed to proceed forward with a uniform speed (design speed) at which vehicle has been moving
- ✓ If design speed is $V$ kmph and $t$ is reaction time then

$$\textbf{Lag distance} = V \times \frac{1000}{60 \times 60} \times t = \mathbf{0.278}\boldsymbol{Vt} \text{ meters}$$

- ✓ Total reaction time of driver depends on a variety of factors and a value of 2.5 seconds is considered reasonable for most situation

## Braking distance

- ✓ It is distance traveled by vehicle during braking operation
- ✓ For a level road this is obtained by equating work done in stopping vehicle and kinetic energy of vehicle
- ✓ If $F$ is maximum frictional force developed and braking distance is $l$, then work done against friction in stopping vehicle is

$$Fl = fWl$$

where $W$ = total weight of vehicle

- ✓ Kinetic energy at design speed of $v$ m/sec will be

$$\frac{1}{2}mv^2 = \frac{Wv^2}{2g}$$

Hence $fWl = \frac{Wv^2}{2g}$

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

- Stopping distance = lag distance + braking distance

$$SD = vt + \frac{v^2}{2gf} \text{ meters}$$

If speed is $V$ kmph, stopping distance

$$SD = 0.278Vt + \frac{v^2}{254f} \text{ meters}$$

- Stopping distance = lag distance + braking distance

$$SD = vt + \frac{v^2}{2gf} \text{ meters}$$

If speed is $V$ kmph, stopping distance

$$SD = 0.278Vt + \frac{v^2}{254f} \text{ meters}$$

$f$ = design coefficient of friction

= 0.4 to 0.35 depending on speed, from 30 to 80 kmph

$g$ = acceleration due to gravity

= 9.8 m/sec$^2$

## Stopping distance at slopes

- When there is an ascending gradient of say, $+n\%$ component of gravity adds to braking action
- Hence, braking distance is decreased
- Component of gravity acting parallel to surface which adds to braking force is equal to

$$W sin\alpha = W tan\alpha = \frac{Wn}{100}$$

- Equating kinetic energy and work done

$$\left(fW + \frac{Wn}{100}\right) l = \frac{1}{2}\frac{Wv^2}{g}$$

$$\text{or } l = \frac{v^2}{(f + \frac{n}{100})}$$

- Similarly, in descending gradient of $-n\%$ braking distance increases as component of gravity now opposes braking forces
- Hence equation is given by

$$\left(fW - \frac{Wn}{100}\right) l = \frac{Wv^2}{2g}$$

$$\text{or } l = \frac{v^2}{2g(f - \frac{n}{100})}$$

- Hence, general equation for stopping distance may now be modified for n% gradient and may be written as

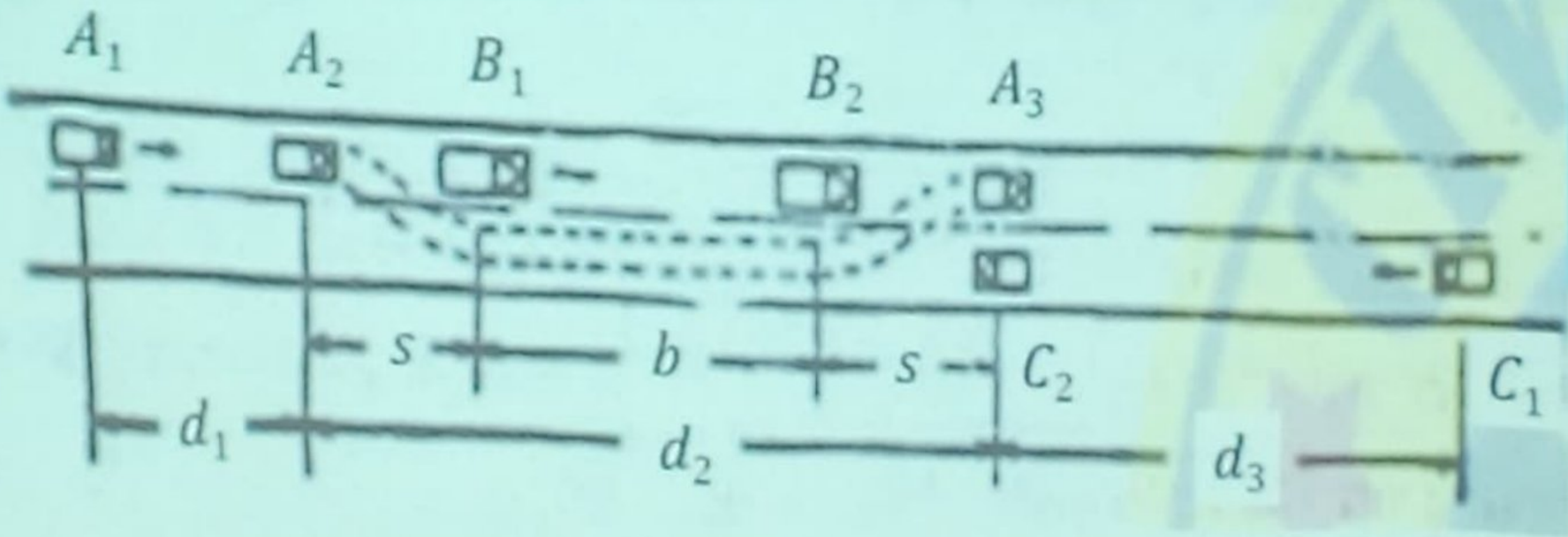
$$SD = [vt + \frac{v^2}{2g(f \pm 0.01n)}] \text{ meter}$$

- If speed is $V$ kmph and gradient is $n$ %

$$SD = 0.278Vt + \frac{v^2}{254(f \pm 0.01n)} \text{ meter}$$

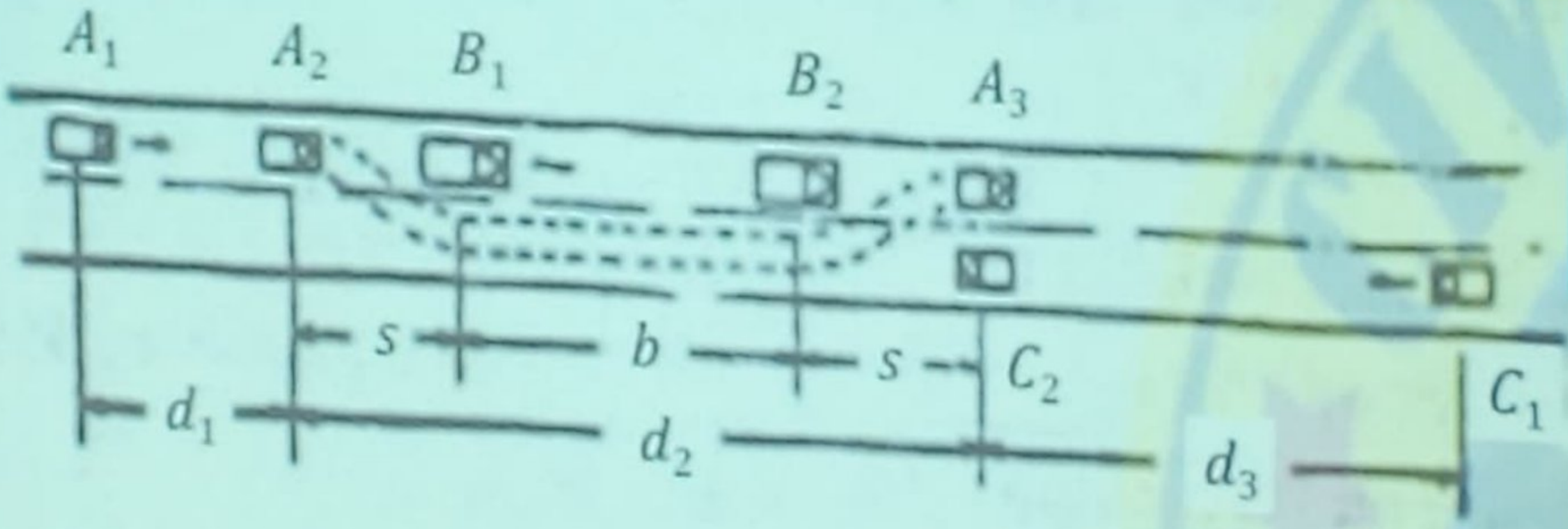
- ✓ Minimum stopping sight distance should be equal to stopping distance in one-way traffic lanes and also in two-way traffic roads where there are two or more traffic lanes
- ✓ On single lane roads when two-way movement of traffic is permitted, minimum stopping sight distance should be equal to twice stopping distance
- ✓ When stopping sight distance for design speed is not available on any section of a road, speed should be restricted by a warning sign and a suitable speed-limit regulation sign (temporary measure)

# Analysis of Overtaking Sight Distance



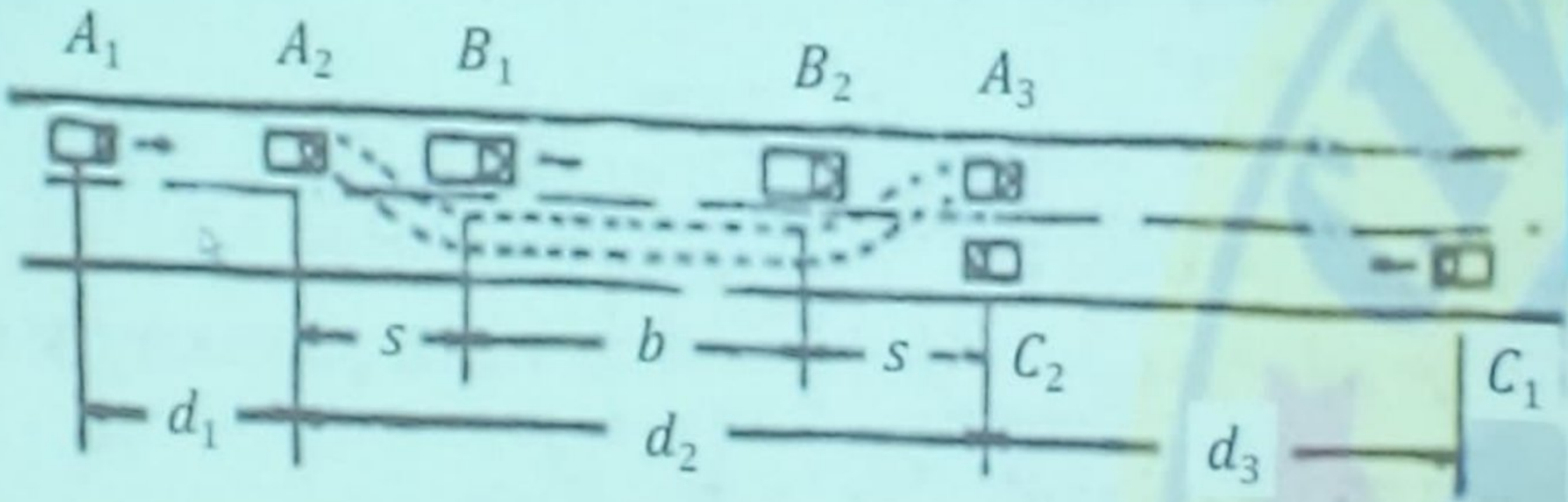

- ✓ *A* traveling at design speed, and another slow vehicle *B* on a two-lane road with two-way traffic
- ✓ Third vehicle *C* comes from opposite direction
- ✓ Overtaking manoeuver may be split up into three operations, thus dividing overtaking sight distance into three parts, $d_1$ , $d_2$ and $d_3$

## Analysis of Overtaking Sight Distance



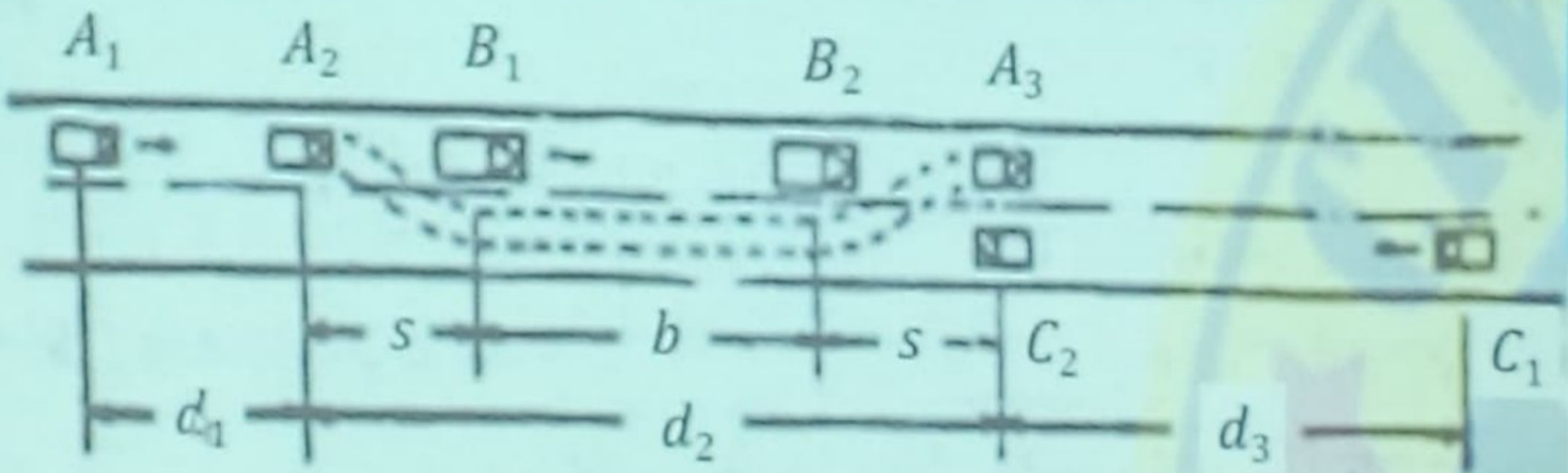

- ✓ $d_1$ is distance travelled by overtaking vehicle $A$ during reaction time t sec of driver from position $A_1$ to $A_2$
- ✓ $d_2$ is distance travelled by vehicle $A$ from $A_2$ to $A_3$ during actual overtaking operation in time $T$ secs.
- ✓ $d_3$ is distance travelled by on-coming vehicle $C_1$ to $C_2$ during overtaking operation of $A$, i.e. $T$ secs.
- ✓ Certain assumptions are made in order to calculate values of $d_1$, $d_2$ and $d_3$

## Analysis of Overtaking Sight Distance




- ✓ $A$ is overtaking vehicle originally traveling at design speed $v$ m/sec or $V$ kmph
- ✓ $B$ is overtaken or slow moving vehicle moving with uniform speed $v_b$ m/sec or $V_b$ kmph
- ✓ $C$ is a vehicle coming from opposite direction at design speed $v$ m/sec or $V$ kmph
- ✓ In a two-lane road opportunity to overtake depends on frequency of vehicles from direction and overtaking sight distance available at any instant

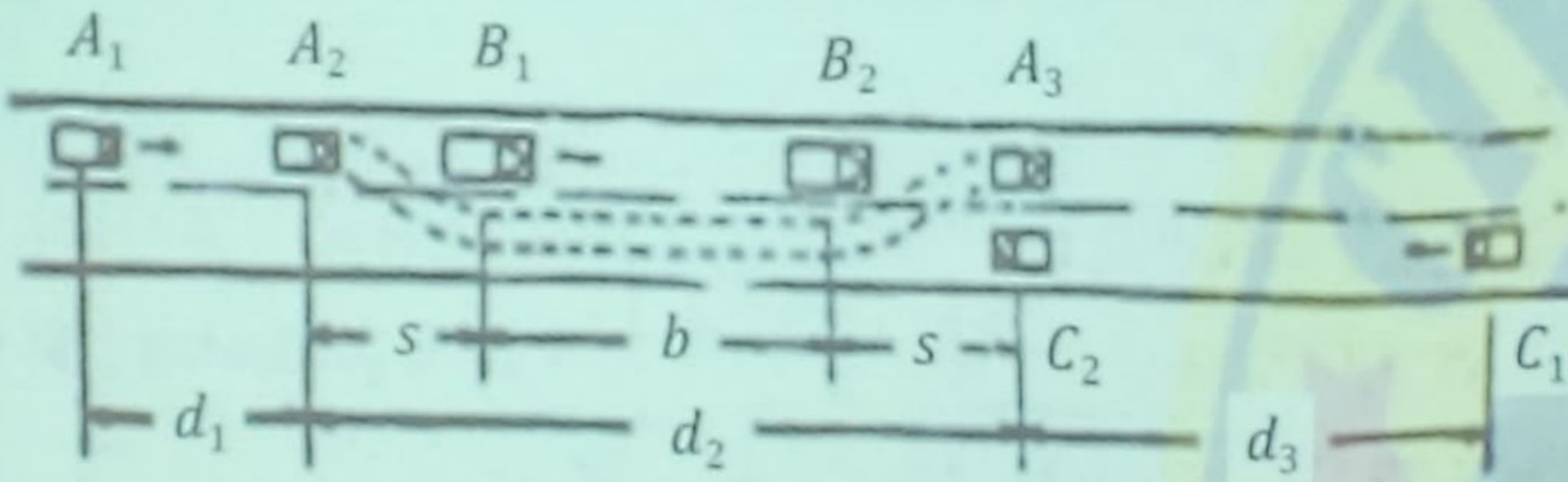
## Analysis of Overtaking Sight Distance




- ✓ It may be assumed that vehicle $A$ is forced to reduce its speed to speed $v_b$ of slow vehicle $B$ and moves behind it allowing a space $s$, till there is an opportunity for safe overtaking operation
- ✓ Distance travelled by vehicle $A$ during this reaction time is $d_1$ and is between positions $A_1$ and $A_2$
- ✓ This distance will be

$$d_1 = v_b t \text{ m}$$

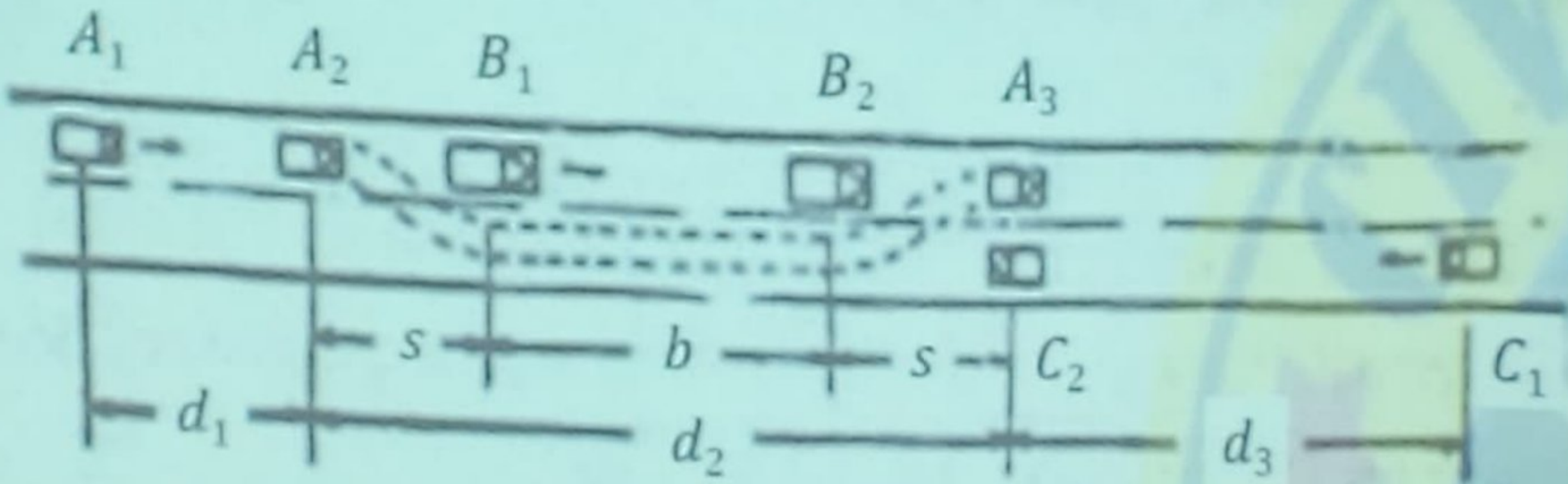
## Analysis of Overtaking Sight Distance




- From position $A_2$ vehicle $A$ starts accelerating, shifts to adjoining lane, overtakes vehicle $B$, and shifts back to it original lane ahead of $B$ in position $A_3$ in time $T$ secs.
- Straight distance between position $A_2$ and $A_3$ is taken as $d_2$
- Minimum distance between position $A_2$ and $B_1$ may be taken as minimum spacing s of two vehicles while moving with speed $v_b$ m/sec

$$s = (0.7v_b + 6) \text{ m}$$

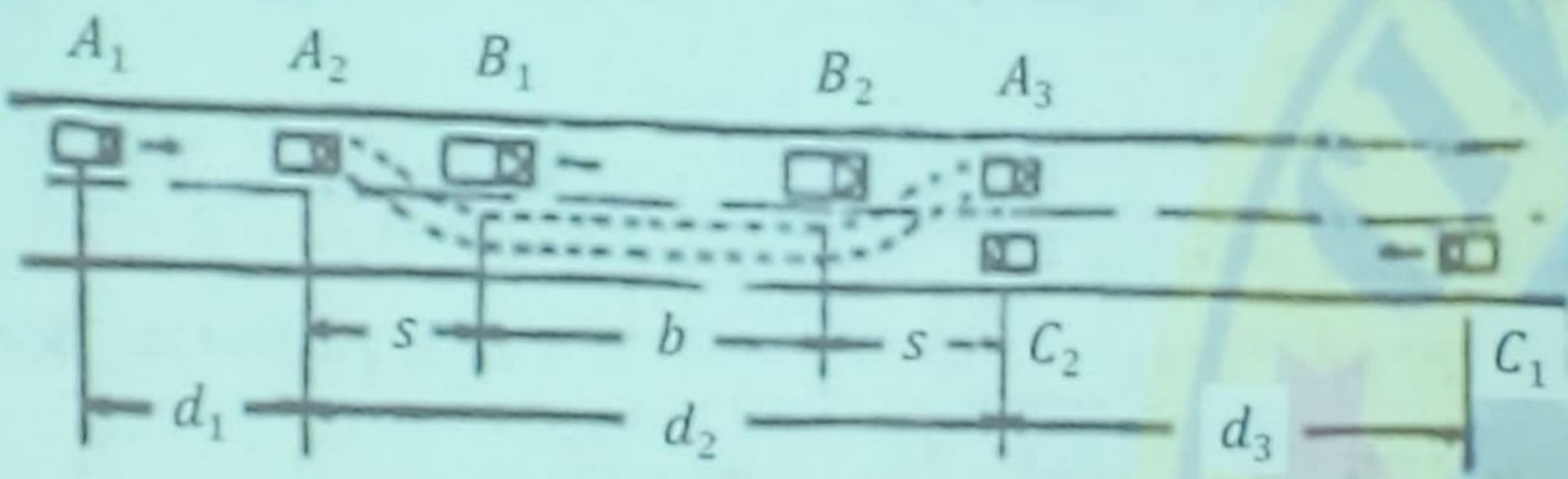
## Analysis of Overtaking Sight Distance




- ✓ Minimum distance between $B_2$ and $A_3$ may also be assumed to $s$ as mentioned above
- ✓ If time taken by vehicle $A$ for overtaking operation from position $A_2$ to $A_3$ is $T$ second
- ✓ Distance covered by slow vehicle $B$ traveling at a speed of $v_b$ m/sec

$$b = v_b T \text{ m}$$

## Analysis of Overtaking Sight Distance



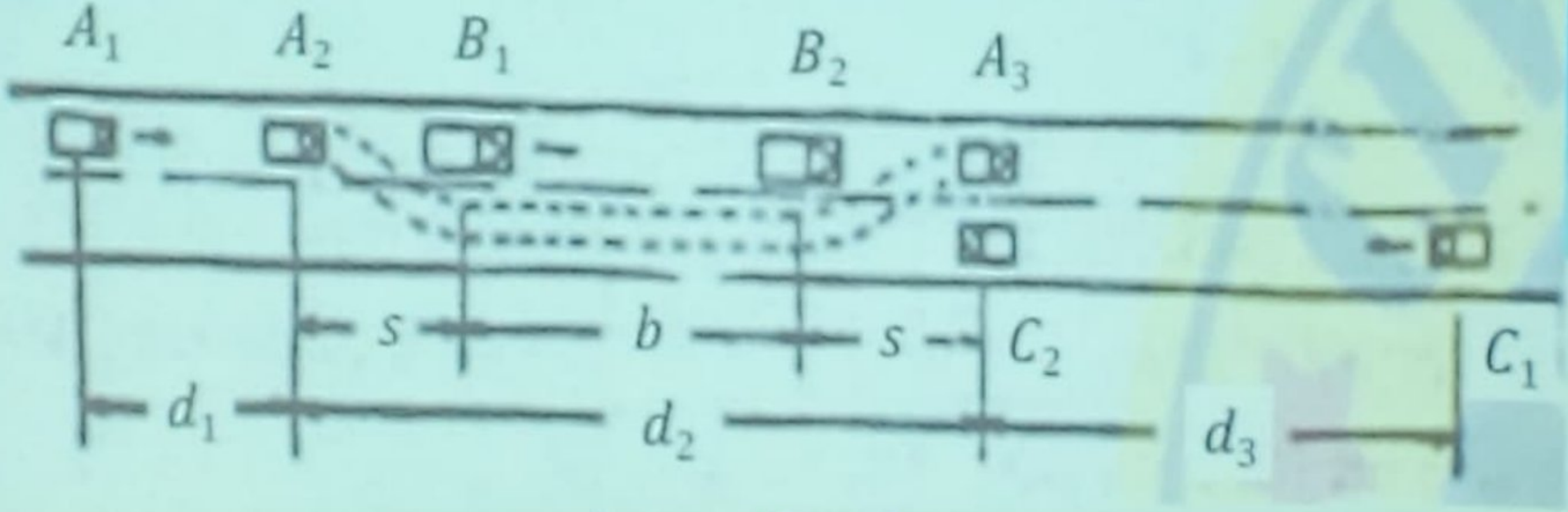

- ✓ Time $T$ depends on speed of overtaken vehicle $B$ and acceleration of overtaking vehicle $A$
- ✓ This time $T$ may be calculated by equating distance $d_2$ with initial speed $v_b$ m/sec and $a$ is acceleration in m/sec$^2$

$$d_2 = (b + 2s) = (v_b T + \frac{aT^2}{2})$$

$$b = v_b T$$

$$\text{Therefore, } 2s = \frac{aT^2}{2} \quad \text{or} \quad T = \sqrt{\frac{4s}{a}} \text{ sec}$$

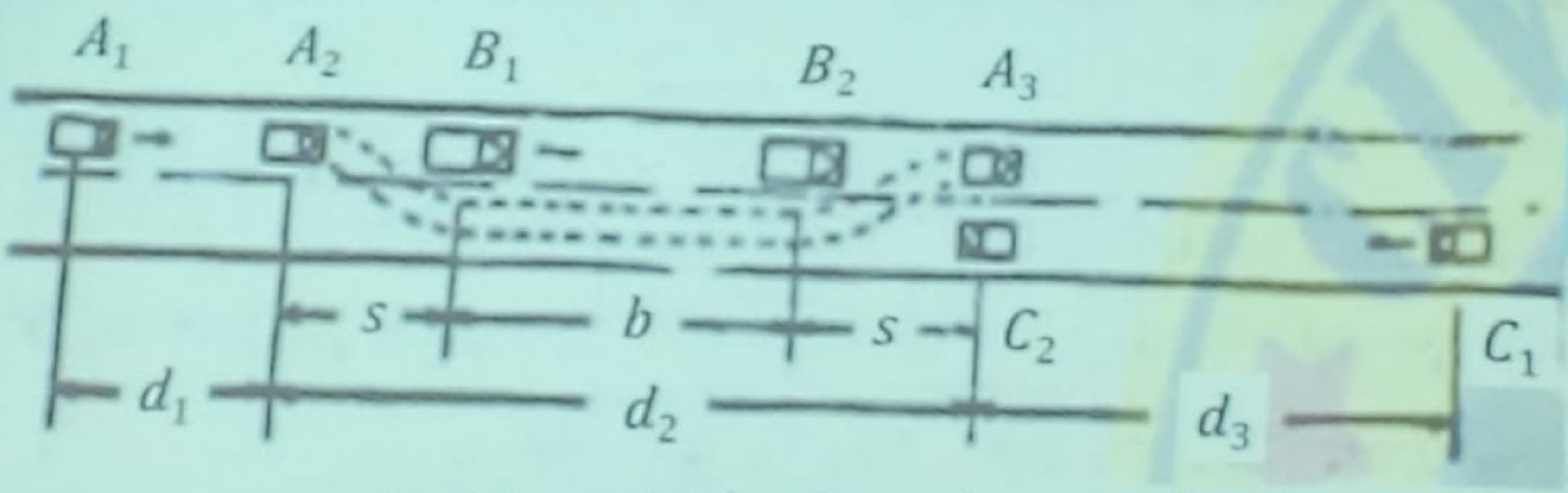
## Analysis of Overtaking Sight Distance




$$d_2 = v_b T + 2s$$

where $s = (0.7v_b + 6)$

## Analysis of Overtaking Sight Distance




- ✓ Distance travelled by vehicle $C$ moving at design speed $v$ m/sec during overtaking operation of vehicle $A$ i.e. during time $T$ is distance between position $C_1$ to $C_2$

$$d_3 = v \times T$$

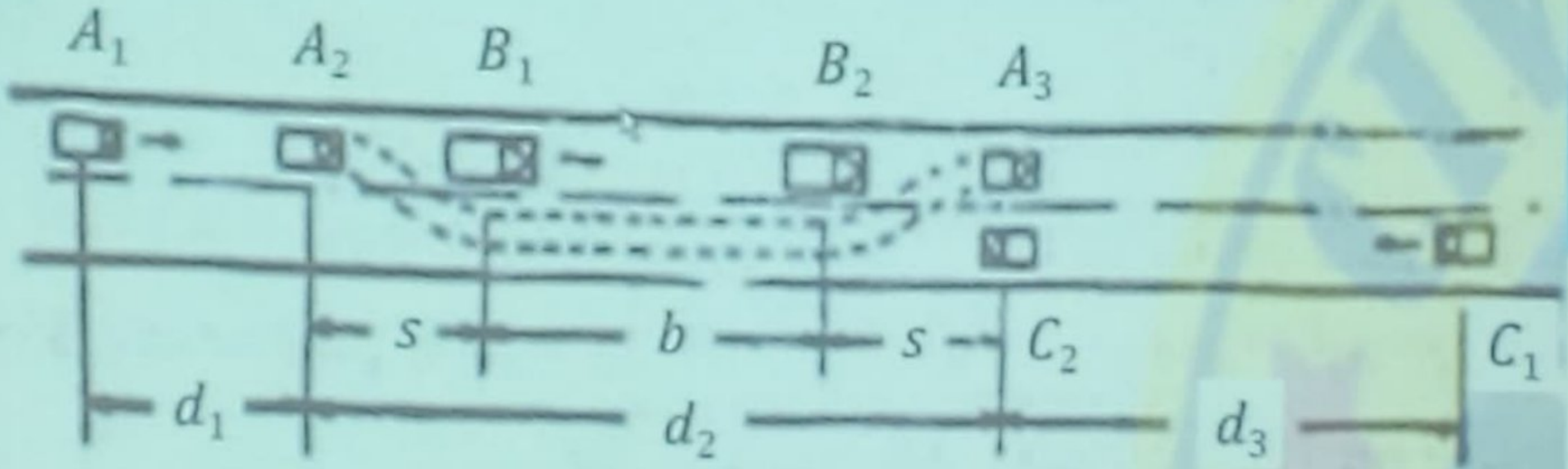
$$OSD = (d_1 + d_2 + d_3)$$

$$= (v_b t + v_b T + 2s + vT)$$

- ✓ In kmph units $OSD = 0.28V_b t + 0.28V_b T + 2s + 0.28VT$

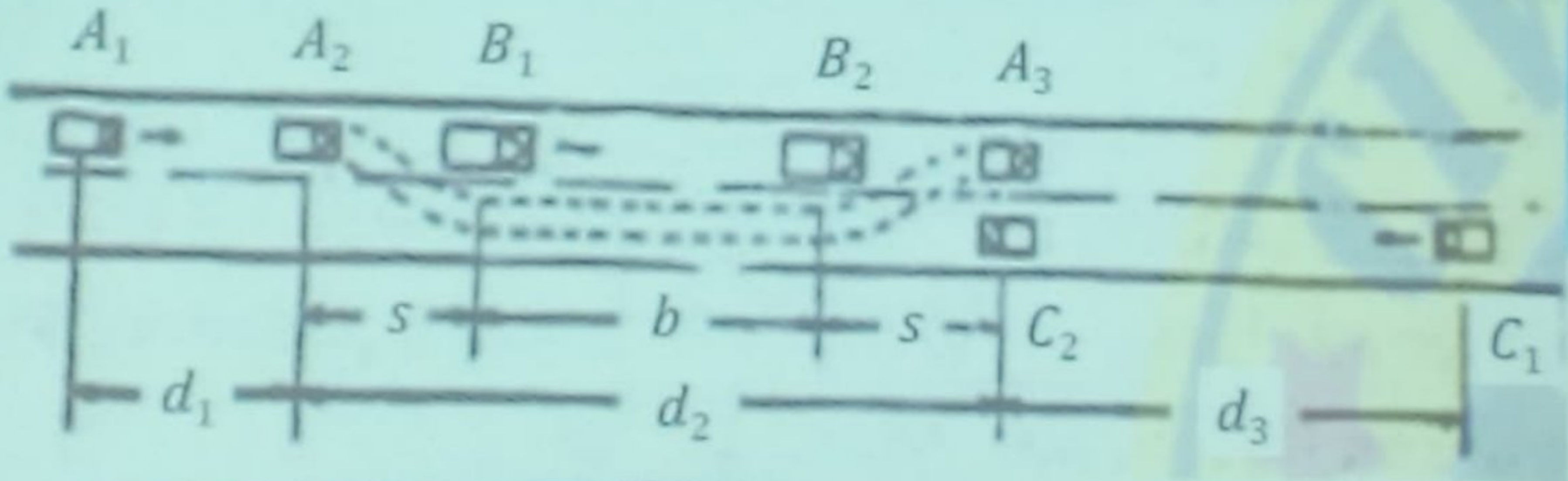
$T = \sqrt{\frac{14.4s}{A}}$ where $A$ = acceleration in kmph/sec $s = (0.2V_b + 6)$

# Analysis of Overtaking Sight Distance




- ✓ In case speed of overtaken vehicle $V_b$ is not given then assume $(V - 16)$ kmph, where $V$ is design speed in kmph

# Analysis of Overtaking Sight Distance




...vertaken vehicle $V_b$ is not given then ... $(V - 16)$ kmph, where $V$ is design speed in kmph

✓ Assume $v_b = (v - 4.5)$ m/sec and $v$ is design speed in m/sec

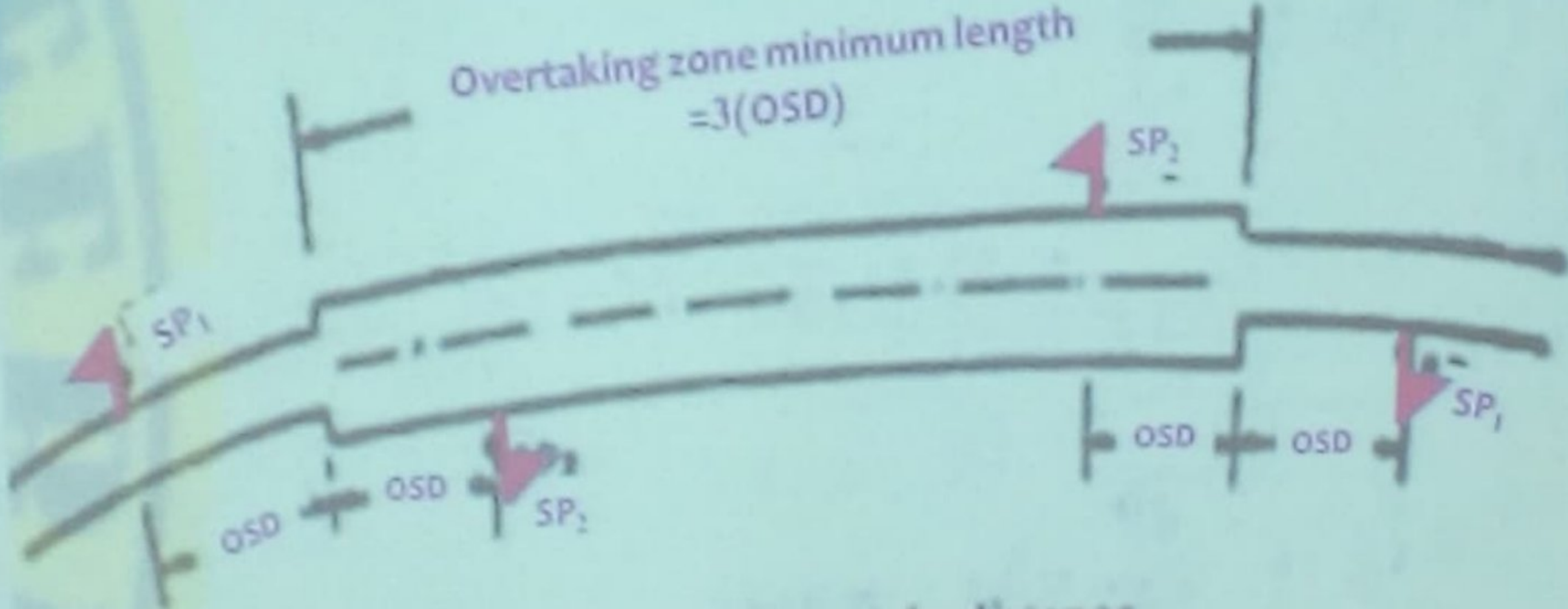
## Overtaking zones

- ✓ It is desirable to construct highways in such a way that length of road visible ahead at every point is sufficient for safe overtaking
- ✓ This is seldom practicable and there may be stretches where safe overtaking distance can not be provided
- ✓ In such zones where overtaking or passing is not safe or is not possible , sign posts should be installed indicating "No Passing" or "Overtaking Prohibited" before such restricted zones starts
- ✓ But overtaking opportunity for vehicles moving at design speed should be given at frequent intervals
- ✓ These zones which are meant for overtaking are called overtaking zones
- ✓ OSD and pavement width should be sufficient for safe overtaking operations

## Overtaking zones

- Sign posts should be installed at sufficient distance in advance to indicate start of overtaking zones
- This distance may be equal to $(d_1 + d_2)$ for one-way roads and $(d_1 + d_2 + d_3)$ for two-way roads
- Similarly end of overtaking zones should also be indicated by appropriate sign posts installed ahead at distances specified above
- Minimum length of overtaking zone should be three time safe overtaking distance i.e., $3(d_1 + d_2)$ for one-way roads and $3(d_1 + d_2 + d_3)$ for two-way roads
- It is desirable that length of overtaking zones is kept five times overtaking sight distance

# Overtaking zones




O.S.D = Overtaking sight distance

= $(d_1 + d_2)$ for one way traffic

= $(d_1 + d_2 + d_3)$ for two way traffic

$SP_1$ = Sign post "over taking zone ahead"

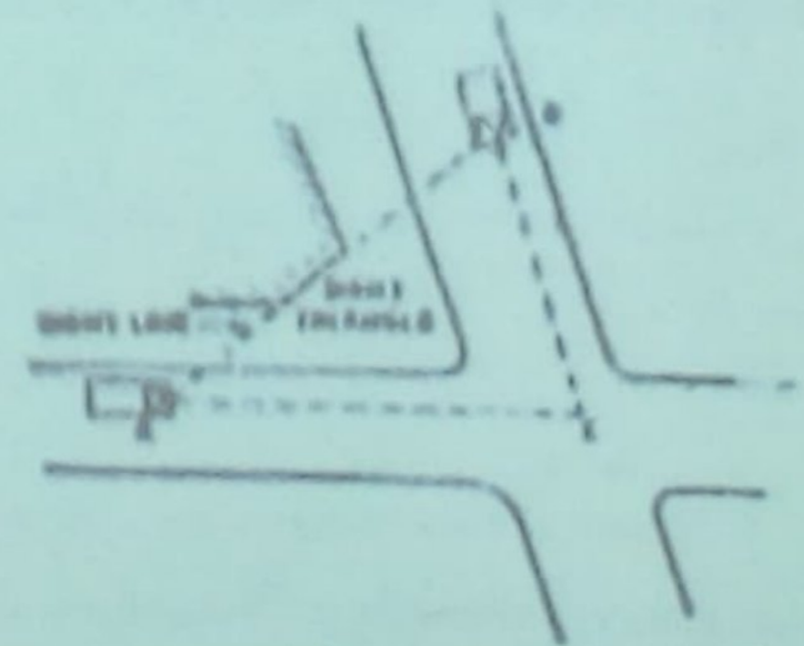
$SP_2$ = Sign post "end of overtaking zone"

## Overtaking zones

**Example 4.6 and 4.7**

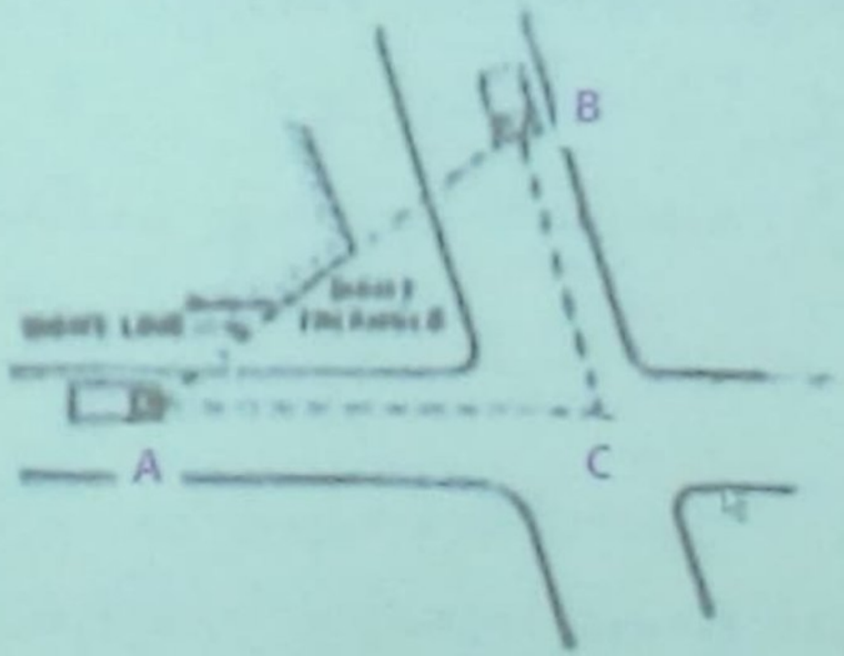
# Sight Distance at Intersection

- It is important that on all approaches of intersecting roads, there is a clear view across corners from a sufficient distance so as to avoid collision of vehicle
- This is all more important at uncontrolled intersections
- Sight line is obstructed by structures or other objects at corner of intersections
- Area of unobstructed sight formed by lines of vision is called sight triangle



Sight Distance at Intersection

- Design of sight distance at intersections may be based on three possible conditions
  - ✓ Enabling approaching vehicle to change speed
  - ✓ Enabling approaching vehicle to stop
  - ✓ Enabling stopped vehicle to cross a main road

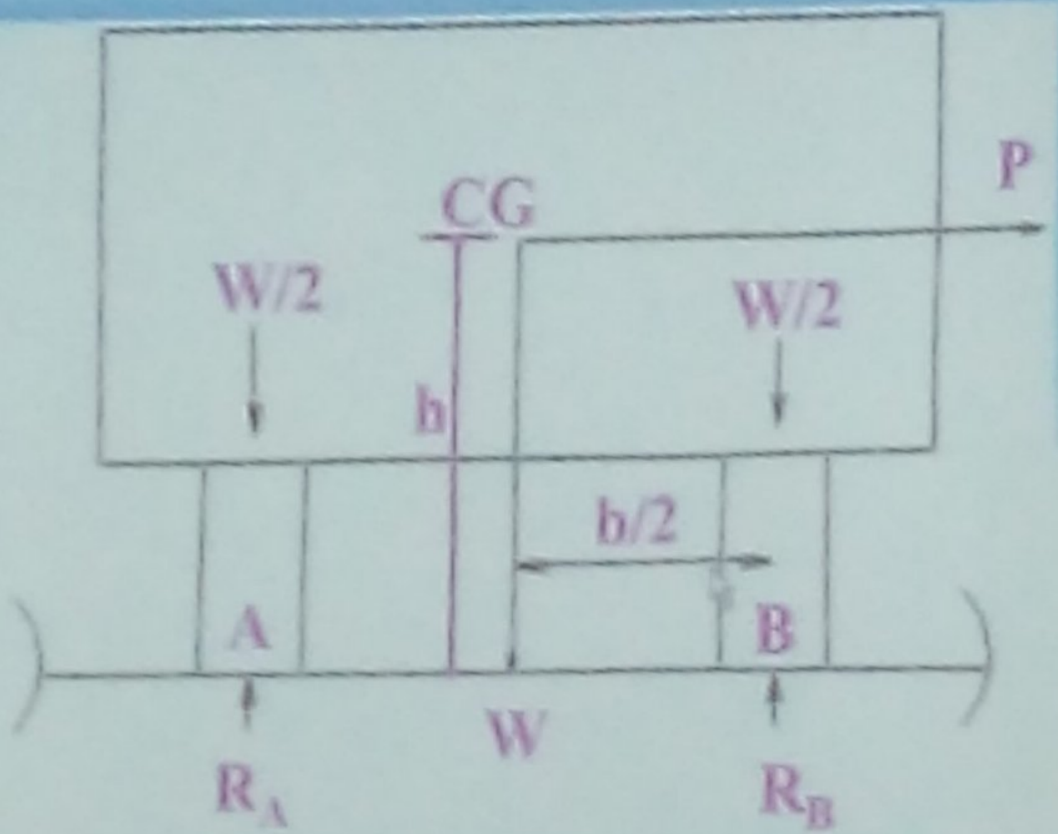



Sight Distance at Intersection

## Horizontal curve

- ✓ Presence of horizontal curve imparts centrifugal force which is a reactive force acting outward on a vehicle negotiating it
- ✓ Centrifugal force depends on speed and radius of horizontal curve and is counteracted to a certain extent by transverse friction between tyre and pavement surface
- ✓ On a curved road, this force tends to cause vehicle to overrun or to slide outward from centre of road curvature
- ✓ For proper design of curve, an understanding of forces acting on a vehicle taking a horizontal curve is necessary

Various forces acting on vehicle are illustrated in figure below




Effect of horizontal curve

- ✓ Centrifugal force (P) acting outward, weight of vehicle (W) ac
downward, and reaction of ground on wheels ($R_A$ and $R_B$)
- ✓ Centrifugal force and weight is assumed to be from centre
gravity which is at h units above ground
- ✓ Let wheel base be assumed as b units

- Centrifugal force $P$ in kg/m$^2$ is given by

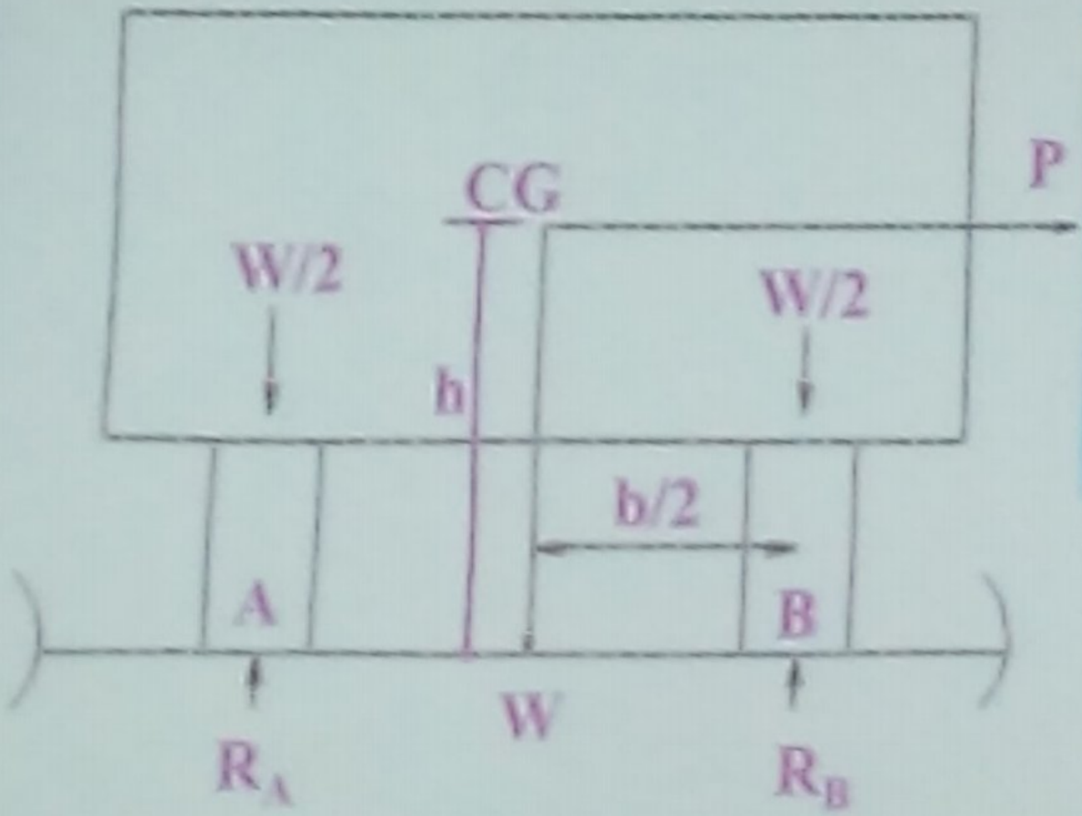
$$P = \frac{Wv^2}{gR}$$

where $W$ is weight of vehicle in kg, $v$ is speed of vehicle in m/sec, $g$ is acceleration due to gravity in m/sec$^2$ and $R$ is radius of curve in m

- Centrifugal ratio or impact factor $\frac{P}{W}$ is given by:

$$\frac{P}{W} = \frac{v^2}{gR} \text{-----------------} (1)$$

- Centrifugal force has two effects:
  - A tendency to overturn vehicle about outer wheels
  - A tendency for transverse skidding




Tendency to overturn vehicle about outer wheels

✓ Taking moments of forces with respect to outer wheel when vehicle is just about to override,

$$Ph = W\frac{b}{2} \text{ or } \frac{P}{W} = \frac{b}{2h}$$

✓ At equilibrium overturning is possible when

$$\frac{v^2}{gR} = \frac{b}{2h}$$

- For safety following condition must satisfy:

$$\frac{b}{2h} > \frac{v^2}{gR} \quad \text{———} (2)$$

- Second tendency of vehicle is for transverse skidding i.e. when centrifugal force $P$ is greater than maximum possible transverse skid resistance due to friction between pavement surface and tyre
- Transverse skid resistance ($F$) is given by:

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

where $F_A$ and $F_B$ is frictional force at tyre $A$ and $B$, and is reaction at tyre $A$ and $B$, $f$ is lateral coefficient of friction, and $W$ is weight of vehicle

- Transverse skid resistance is counteracted by centrifugal force ($P$), and equating:

$$P = fW \quad \text{or} \quad \frac{P}{W} = f$$

- At equilibrium, when skidding takes place

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

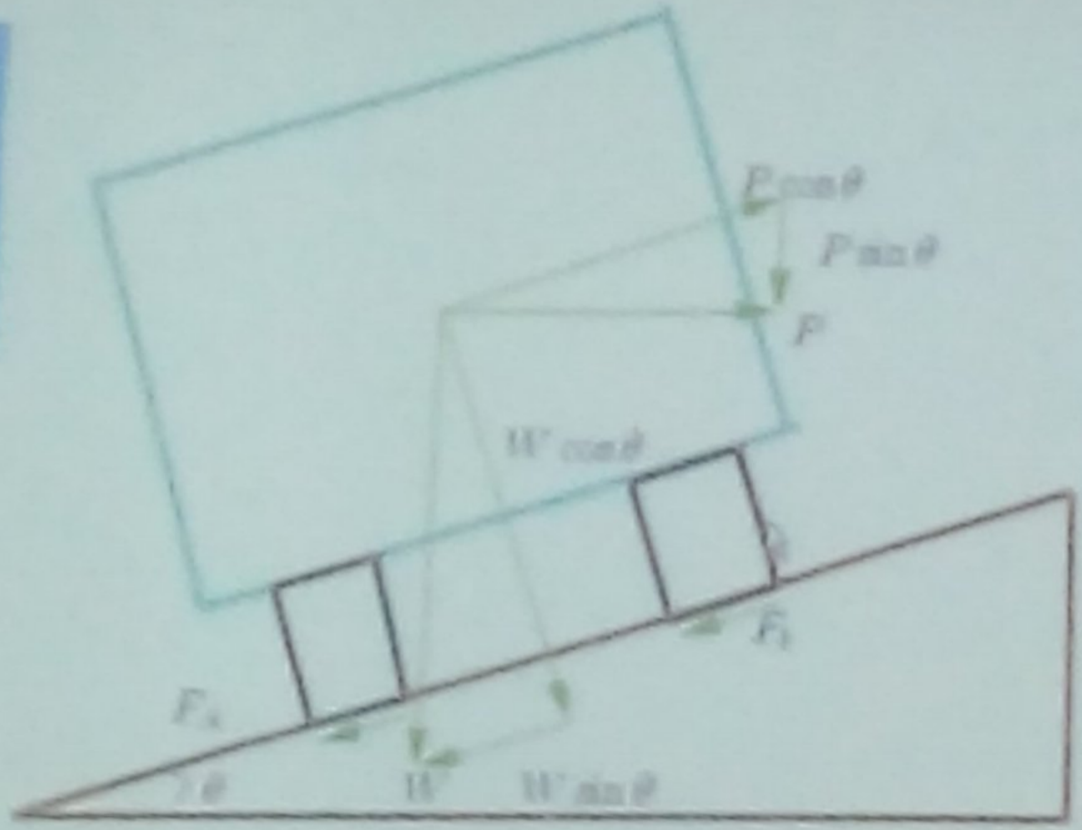
- For safety following condition must satisfy:

$$f > \frac{v^2}{gR} \text{-----------------} (3)$$

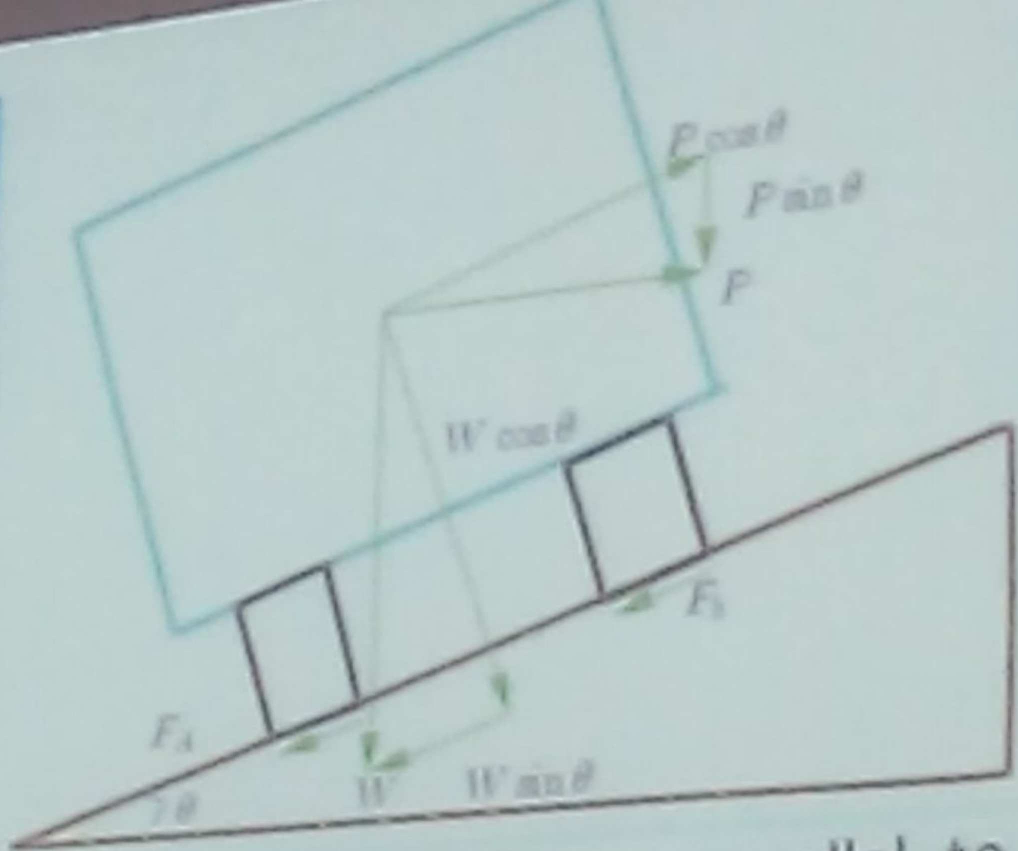
- Equations 2 and 3 give stable condition for design
- If equation 2 is violated, vehicle will overturn at horizontal curve and if equation 3 is violated, vehicle will skid at horizontal curve

## superelevation

- Super-elevation or cant or banking is transverse slope provided at horizontal curve to counteract centrifugal force, by raising outer edge of pavement with respect to inner edge, throughout length of horizontal curve
- When outer edge is raised, a component of curve weight will be complimented in counteracting effect of centrifugal force
- In order to find out how much this raising should be, following analysis may be done



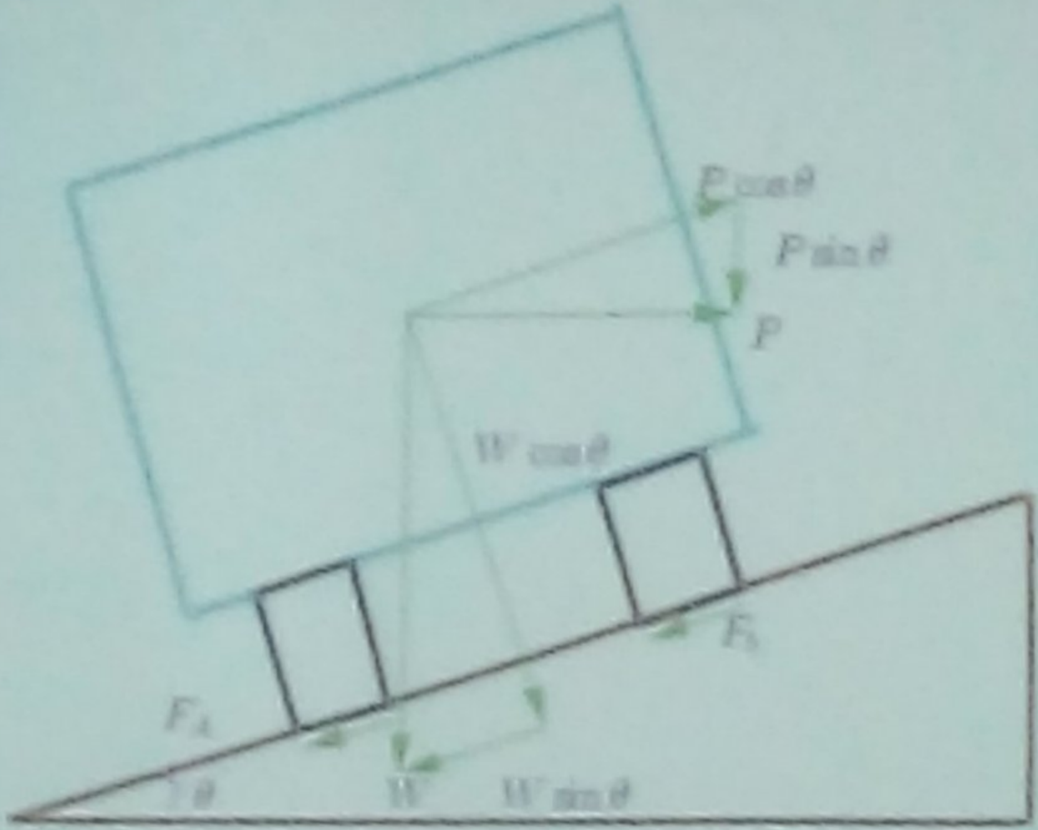

- Forces acting on a vehicle on horizontal curve of radius $R$ m at a speed of $v$ m/sec$^2$ are:
- $P$ centrifugal force acting horizontally outwards through center of gravity,
- $W$ weight of vehicle acting downwards through center of gravity, and
- $F$ friction force between wheels and pavement, along surface inward




✓At equilibrium, by resolving forces parallel to surface of pavement we get,

$$P\cos\theta = W\sin\theta + F_A + F_B$$
$$= W\sin\theta + f(R_A + R_B)$$
$$= W\sin\theta + f(W\cos\theta + P\sin\theta) \text{——(a)}$$

where $W$ is weight of vehicle, $P$ is centrifugal force, $f$ is coefficient of friction, $\theta$ is transverse slope due to superelevation



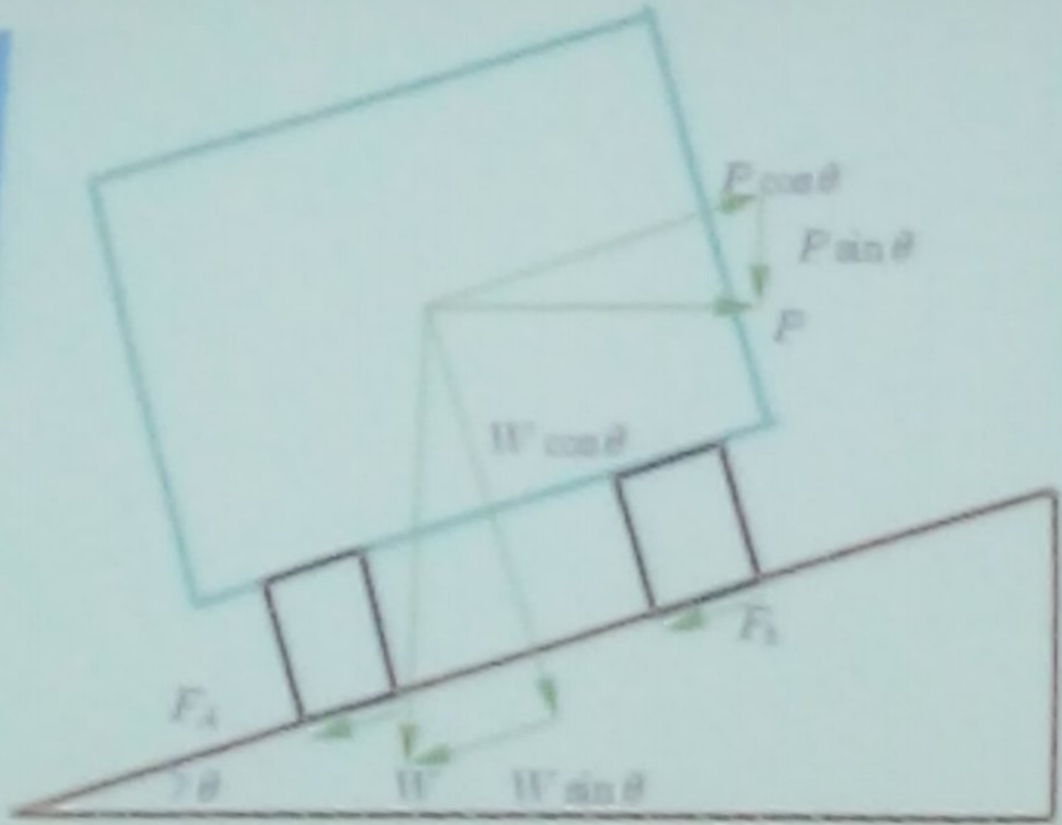

Dividing both sides of equation (a) by $W\cos\theta$, we get:

$$\frac{P\cos\theta}{W\cos\theta} = \frac{W\sin\theta}{W\cos\theta} + \frac{fW\cos\theta}{W\cos\theta} + \frac{fP\sin\theta}{W\cos\theta}$$

$$\text{or } \frac{P}{W} = \tan\theta + f + f\frac{P}{W}\tan\theta$$

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

$$\text{or } \frac{P}{W} = \frac{\tan\theta + f}{1 - f\tan\theta} \quad \text{————(b)}$$



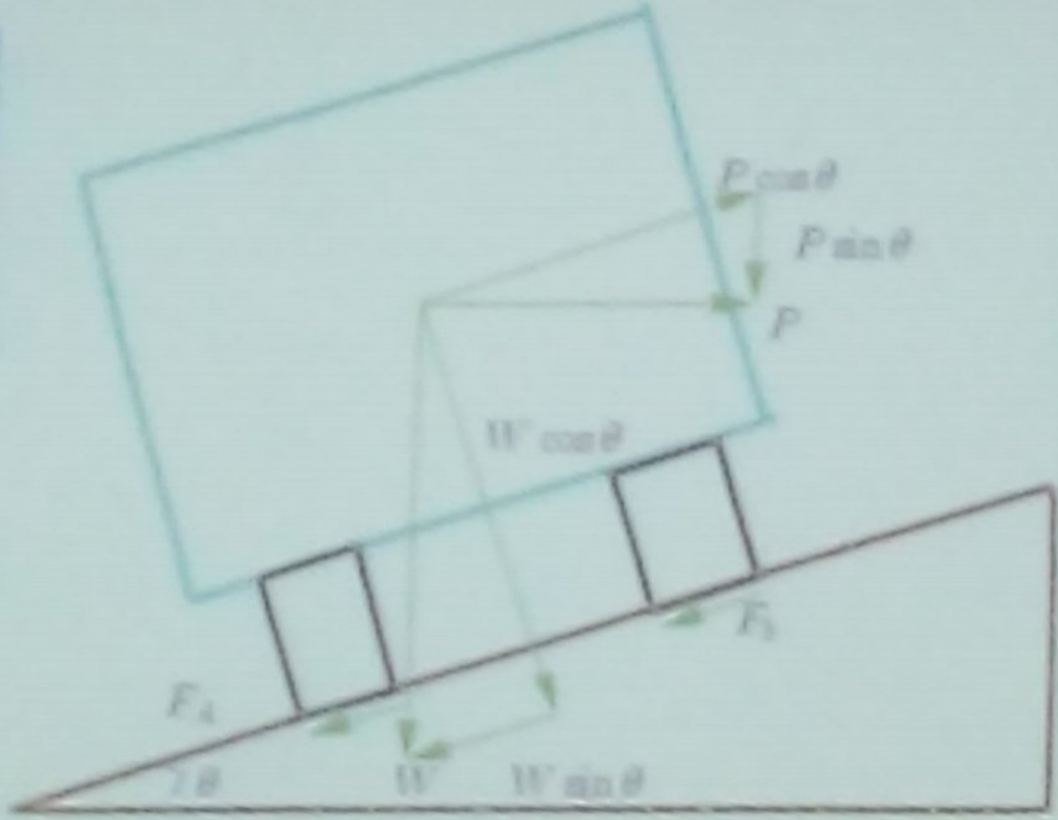

Also, $\frac{P}{W} = \frac{v^2}{gR}$ ——————— (c)

Equating equations (b) and (c), we get

$$\frac{v^2}{gR} = \frac{\tan\theta + f}{1 - f\tan\theta} \quad \text{———— (d)}$$

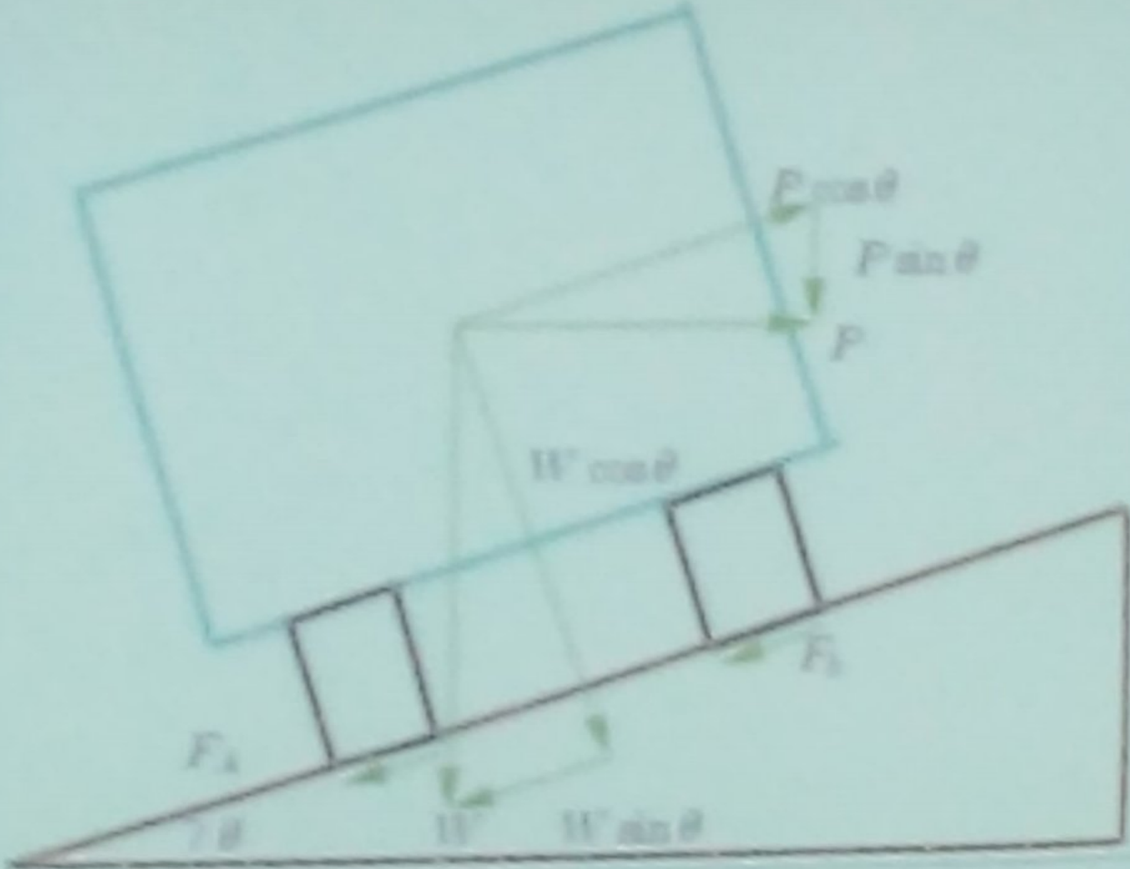
But normally, $f = 0.15$ and $\theta < 4^0$ , $1 - f\tan\theta \approx 1$ and for small $\theta$ , $\tan\theta \approx \sin\theta = e$ , then equation (d) becomes:

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




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

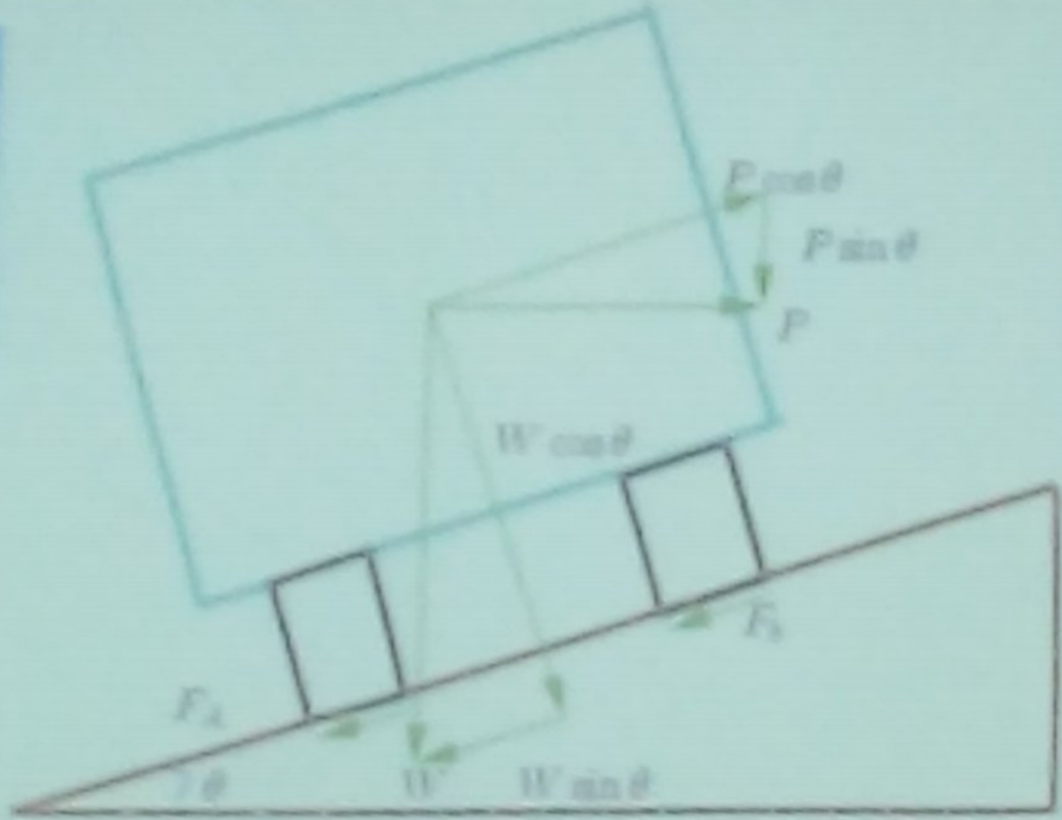
where, $e$ is rate of super elevation, $f$ is coefficient of lateral friction 0.15, $v$ is speed of vehicle in $m/sec$ , $R$ is radius of curve in $m$, and $g = 9.8\ m/sec^2$




Three specific cases that can arise from equation (e) are as follows:

- If there is no friction due to some practical reasons, then $f = 0$ and equation (e) becomes $e = \frac{v^2}{gR} = \frac{V^2}{127R}$

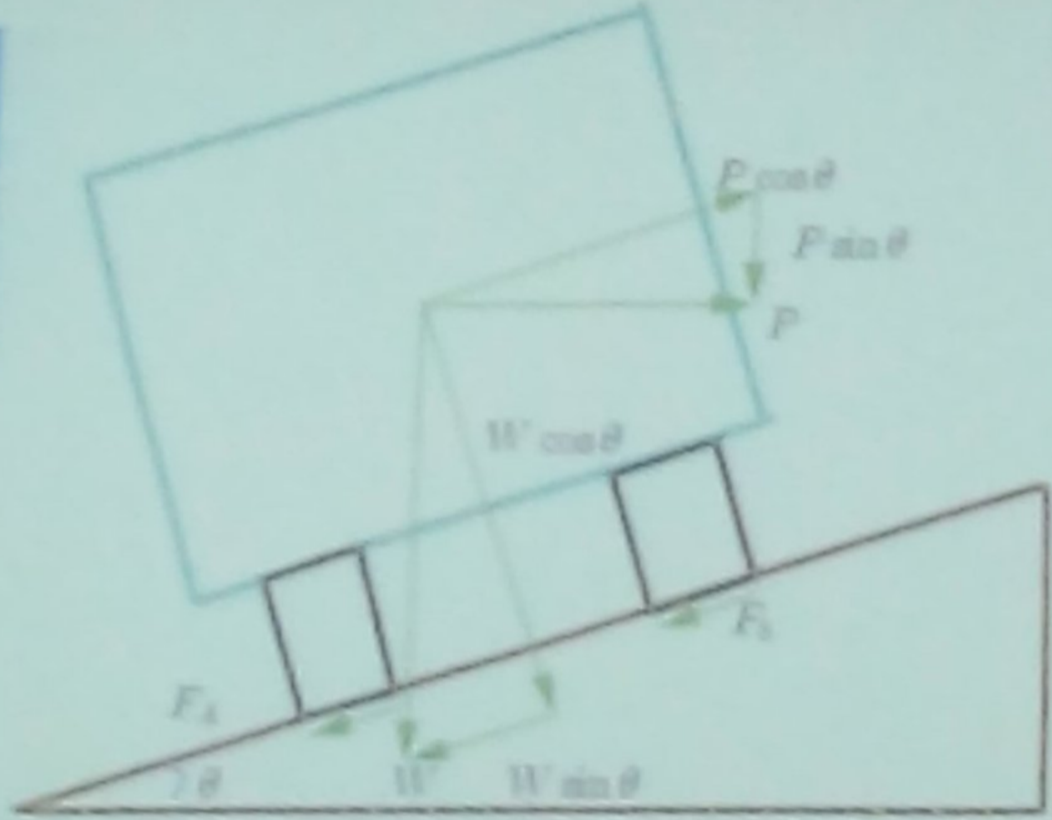
This results in situation where pressure on outer and inner wheels are same; requiring very high superelevation $e$




Three specific cases that can arise from equation (e) are as follows:

- If there is no super-elevation provided due to some practical reasons, then $e = 0$ and equation (e) becomes $f = \frac{v^2}{gR} = \frac{V^2}{127R}$

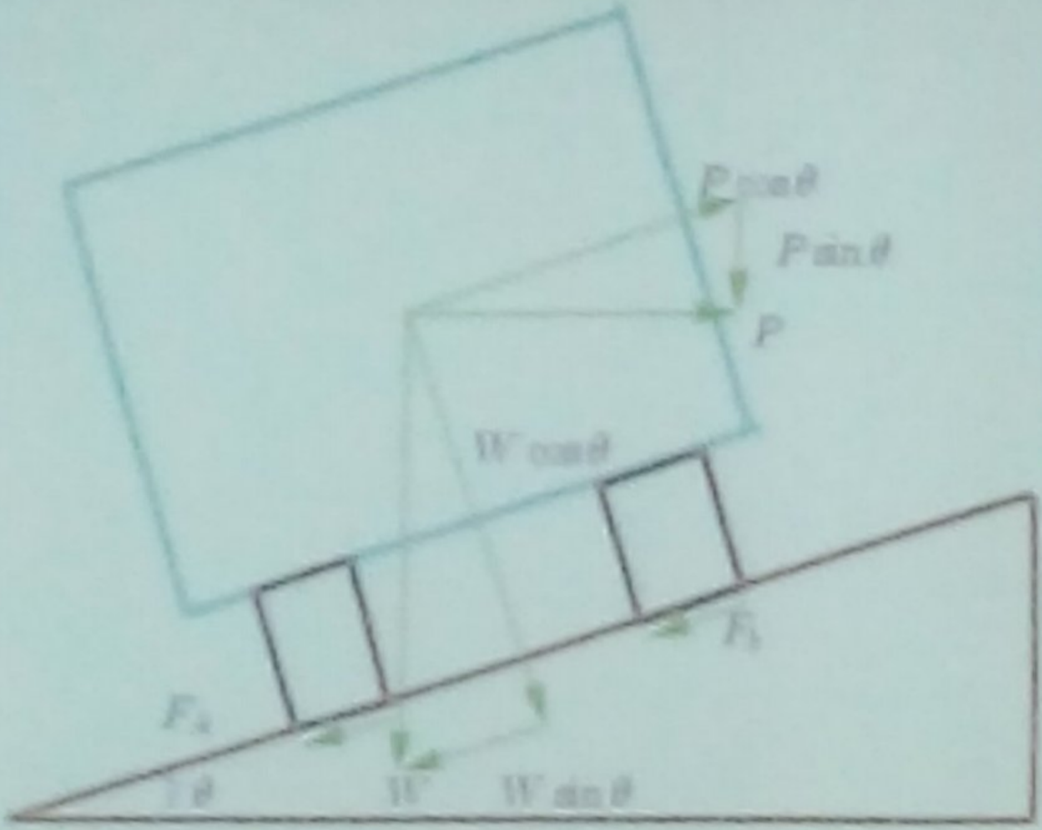
This results in a very high coefficient of friction




Three specific cases that can arise from equation (e) are as follows:

- If $e = 0$ and $f = 0.15$ then for safe traveling speed from equation (e) is given by $v_b = \sqrt{fgR}$

where $v_b$ is restricted speed


P cos θ
P sin θ
P
W cos θ
F_b
F_a
θ
W
W sin θ

Example 4.8 (Khanna and Justo)

## Design of super-elevation

Step 1: Find $e$ for 75 percent of design speed, neglecting $f$, i.e.

$$e_1 = \frac{(0.75v)^2}{gr}$$

Step 2: If $e_1 \leq 0.07$, then $e = e_1 = \frac{(0.75v)^2}{gr}$, else if $e_1 > 0.07$ go to step 3

Step 3: Find $f_1$ for design speed and max $e$, i.e

$$f_1 = \frac{v^2}{gr} - e = \frac{v^2}{gr} - 0.07$$

✓ If $f_1 < 0.15$, then maximum $e = 0.07$ is safe for design speed, else go to step 4

Step 4: Find allowable speed $v_a$ for maximum $e = 0.07$ and $f = 0.15$, $v_a = \sqrt{0.22gR}$

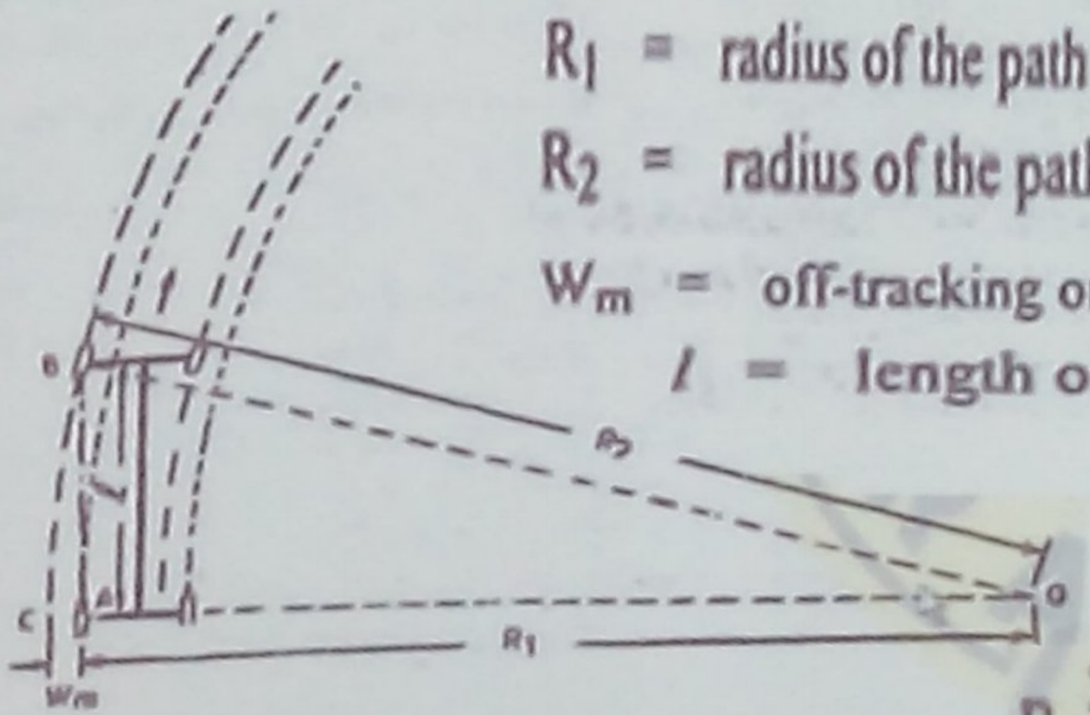
✓ If $v_a \geq v$ then design is adequate, otherwise use speed adopt control measures or look for speed control measures

## Analysis of extra widening on curves

- ✓ Divided into two parts
  - ➡ Mechanical widening

## Mechanical widening

- ✓ Widening required to account for off tracking due to rigidity of wheel base is called mechanical widening ($W_m$)




$R_1$ = radius of the path traversed by the outer rear wheel, m

$R_2$ = radius of the path traverse by the outer front wheel, m

$W_m$ = off-tracking or the mechanical widening, m

$l$ = length of wheel base, m

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

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

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

$$R_1 = R_2 - W_m$$

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

$$R_2^2 - 2R_2W_m + W_m^2 = R_2^2 - l^2$$

$$W_m = \frac{l^2}{2R_2 - W_m}$$

$$= \frac{l^2}{2R} \text{ (approximately)}$$

## Mechanical widening

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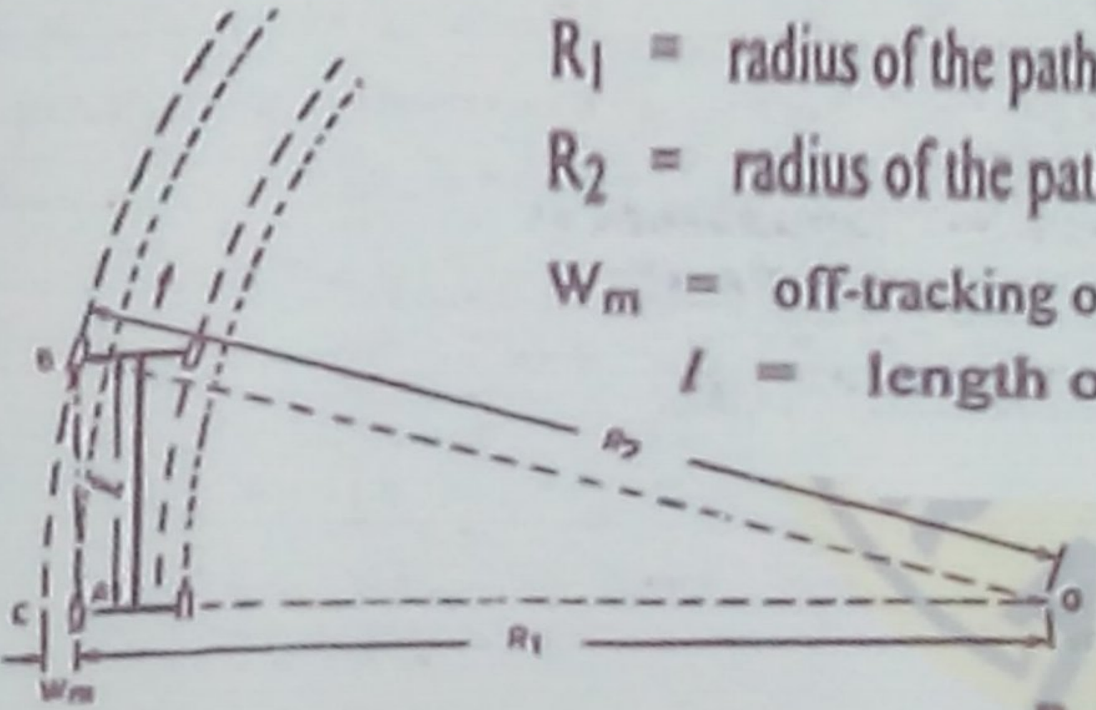

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$W_m$ = off-tracking or the mechanical widening, m

$l$ = length of wheel base, m

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

$$R_2^2 - 2R_2 W_m + W_m^2 = R_2^2 - l^2$$

$$W_m = \frac{l^2}{2R_2 - W_m}$$

$$= \frac{l^2}{2R} \text{ (approximately)}$$

In a road having $n$ lanes

$$W_m = \frac{nl^2}{2R}$$

## Psychological widening

- Widening of pavements has to be done for some psychological reasons
- To provide for greater maneuverability of steering at higher speeds to allow for extra space requirements for overhangs of vehicle
- To provide greater clearance for crossing and overtaking vehicle
- An empirical relation for psychological widening, $W_{ps}$ at horizontal curves

$$W_{ps} = \frac{V}{9.5\sqrt{R}}$$

- Hence total widening required on a horizontal curve is given by

$$W_e = W_m + W_{ps}$$

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

V = design speed, kmph

R = radius of horizontal curve, m

n = number of traffic lanes

$l$ = length of wheel base, m

## Psychological widening

- Widening of pavements has to be done for some psychological reasons
- To provide for greater maneuverability of steering at higher speeds to allow for extra space requirements for overhangs of vehicle
- To provide [obscured] overtaking vehicle

**Example 4.14 to 4.15**

- An empirical relation for psychological widening, $W_{ps}$ at horizontal curves

$$W_{ps} = \frac{V}{9.5\sqrt{R}}$$

- Hence total widening required on a horizontal curve is given by

$$W_e = W_m + W_{ps}$$

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

V = design speed, kmph

R = radius of horizontal curve, m

n = number of traffic lanes

$l$ = length of wheel base, m

## Horizontal Transition Curves

- ✓ Provided to change horizontal alignment from straight to circular curve gradually
- ✓ Has a radius which decreases from infinity at straight end (tangent point) to desired radius of circular curve at other end ( curve point)

➢ There are five objectives for providing transition curve and are given below:

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

## Type of transition curve

- Spiral (also called clothoid)
- Lemniscate
- Cubic parabola

Details of different types of transition curve ⟶ SS

## Type of transition curve

- Spiral (also called clothoid)
- Lemniscate
- Cubic parabola

## Length of transition curve

- Rate of change of centrifugal acceleration
- Rate of introduction of super-elevation
- By empirical formula

Details of length of transition curve ⟶ SS

## Vertical alignment

- ✓ Consists of gradients (straight lines in a vertical plane) and vertical curves
- ✓ Usually drawn as a profile, which is a graph with elevation as vertical axis and horizontal distance along centre line of road as horizontal axis
- ✓ Just as a circular curve is used to connect horizontal straight stretches of road, vertical curves connect two gradients
- ✓ When these two curves meet, they form either convex or concave
- ✓ Former is called a summit curve, while latter is called a valley curve

## Gradient

- ✓ Rate of rise or fall along length of road with respect to horizontal
- ✓ While aligning a highway, gradient is decided for designing vertical curve
- ✓ Before finalizing gradients, construction cost, vehicular operation cost and practical problems in site also has to be considered
- ✓ Usually steep gradients are avoided as far as possible because of difficulty to climb and increase in construction cost

## Effect of gradient

- ✓ Effect of long steep gradient on vehicular speed is considerable
- ✓ This is particularly important in roads where proportion of heavy vehicles is significant
- ✓ Due to restrictive sight distance at uphill gradients speed of traffic is often controlled by these heavy vehicles

## Representation of gradient

- ✓ Positive gradient or ascending gradient is denoted as $+n$ and negative gradient or descending gradient as $-n$
- ✓ Deviation angle $N$:

when two grades meet, angle which measures change of direction and is given by algebraic difference between two grades $n_1 - (-n_2) = n_1 + n_2$

## Types of gradient

- ✓ Many studies have shown that gradient upto seven percent can have considerable effect on speeds of passenger cars
- ✓ On contrary, speeds of the heavy vehicles are considerably reduced when long gradients as flat as two percent is adopted
- ✓ Although, flatter gradients are desirable, it is evident that cost of construction will also be very high
- ✓ Steeper gradients are permitted for short duration
- ✓ Gradients are divided into following categories
  - Ruling gradient
  - Limiting gradient
  - Exceptional gradient
  - Minimum gradient

## Ruling gradient

- ✓ Ruling gradient or design gradient is maximum gradient with which designer attempts to design vertical profile of road
- ✓ This depends on terrain, length of grade, speed, pulling power of vehicle and presence of horizontal curve
- ✓ In flatter terrain, it may be possible to provide flat gradients, but in hilly terrain it is not economical and sometimes not possible also
- ✓ Ruling gradient is adopted by designer by considering a particular speed as design speed and for a design vehicle with standard dimensions
- ✓ But our country has a heterogeneous traffic and hence it is not possible to lay down precise standards for country as a whole
- ✓ Hence, some values for ruling gradient for different types of terrain are recommended

## Exceptional gradient

- ✓ Exceptional gradient are very steeper gradients given at unavoidable situations
- ✓ They should be limited for short stretches not exceeding about 100 metres at a stretch
- ✓ In mountainous and steep terrain, successive exceptional gradients must be separated by a minimum 100 metre length gentler gradient
- ✓ At hairpin bends, gradient is restricted to 2.5%

## Minimum gradient

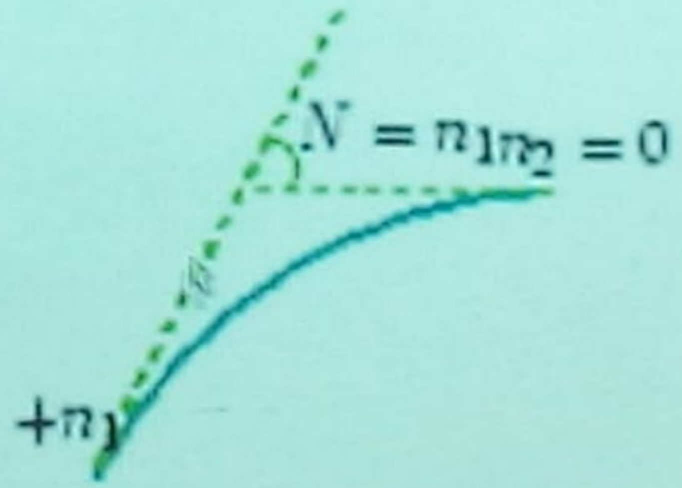
- ✓ This is important only at locations where surface drainage is important
- ✓ Camber will take care of lateral drainage
- ✓ But, longitudinal drainage along side drains require some slope for smooth flow of water
- ✓ Therefore, minimum gradient is provided for drainage purpose and it depends on rain fall, type of soil and other site conditions
- ✓ A minimum of 1 in 500 may be sufficient for concrete drain and 1 in 200 for open soil drains are found to give satisfactory performance

## Critical length of grade

- ✓ Maximum length of ascending gradient which a loaded truck can operate without undue reduction in speed is called critical length of grade
- ✓ A speed of 25 kmph is a reasonable value
- ✓ This value depends on size, power, load, grad-ability of truck, initial speed, final desirable minimum speed

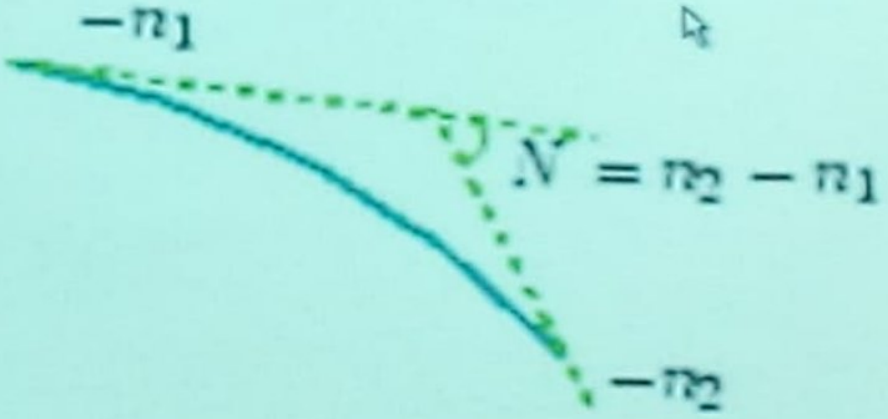
## Summit curve

- ✓ Summit curves are vertical curves with gradient upwards
- ✓ They are formed when two gradients meet in any of following four ways:
  - when a positive gradient meets another positive gradient
  - when positive gradient meets a flat gradient



## Summit curve

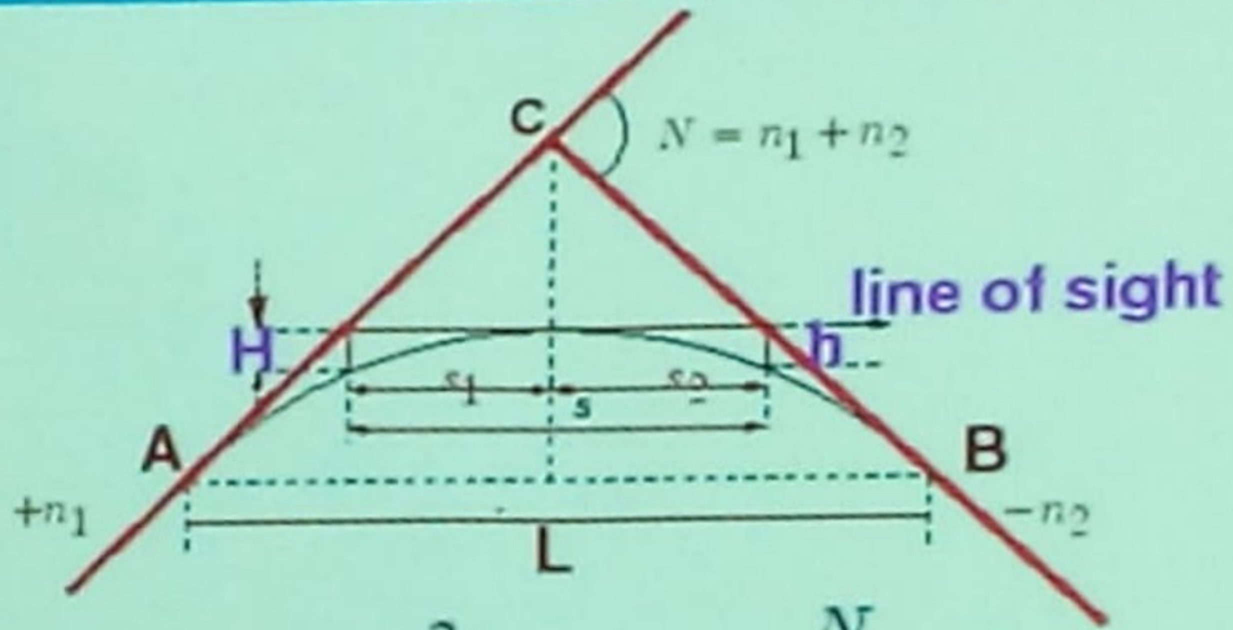
- ✓ Summit curves are vertical curves with gradient upwards
- ✓ They are formed when two gradients meet in any of following four ways:
  - when a positive gradient meets another positive gradient
  - when positive gradient meets a flat gradient
  - when an ascending gradient meets a descending gradient
  - when a descending gradient meets another descending gradient



## Length of summit curve

- ✓ Important design aspect of summit curve is determination of length of curve which is parabolic
- ✓ As noted earlier, length of curve is guided by sight distance consideration
- ✓ That is, a driver should be able to stop his vehicle safely if there is an obstruction on other side of road
- ✓ Equation of parabola is given by $y = ax^2$, where $a = \frac{N}{2L}$, where $N$ is deviation angle and $L$ is length of summit curve
- ✓ In deriving length of curve, two situations can arise depending on uphill and downhill gradients when length of curve is greater than sight distance and length of curve is less than sight distance
- ✓ Let $L$ is length of summit curve, $S$ is SSD/ISD/OSD, $N$ is deviation angle, $H$ is driver's eye height (1.2 m), and $h$ is height of obstruction (0.15 m)

## Case I. Length of summit curve greater than SSD ( $L > S$ )




$$y = ax^2 \qquad a = \frac{N}{2L}$$

$$H = aS_1^2 \qquad h = aS_2^2$$

$$S_1 = \sqrt{\frac{H}{a}} \qquad S_2 = \sqrt{\frac{h}{a}}$$

$$S_1 + S_2 = \sqrt{\frac{H}{a}} + \sqrt{\frac{h}{a}} \qquad S^2 = \left(\frac{1}{\sqrt{a}}\right)^2 \left(\sqrt{H} + \sqrt{h}\right)^2$$

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

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

$$\boxed{L = \frac{NS^2}{4.4}}$$

Case II. Length of summit curve less than SSD ($L < S$)

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

$$L = 2S - \frac{4.4}{N}$$

- Length of summit curve for safe OSD or ISD

Case I. Length of summit curve greater than OSD or ISD ( $L > S$)

$$L = \frac{NS^2}{8H}$$

$$L = \frac{NS^2}{9.6}$$

Case II. Length of summit curve less than OSD or ISD ( $L < S$)

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

$$L = 2S - \frac{9.6}{N}$$

Example 4.22 to 4.24 (Khanna and Justo)

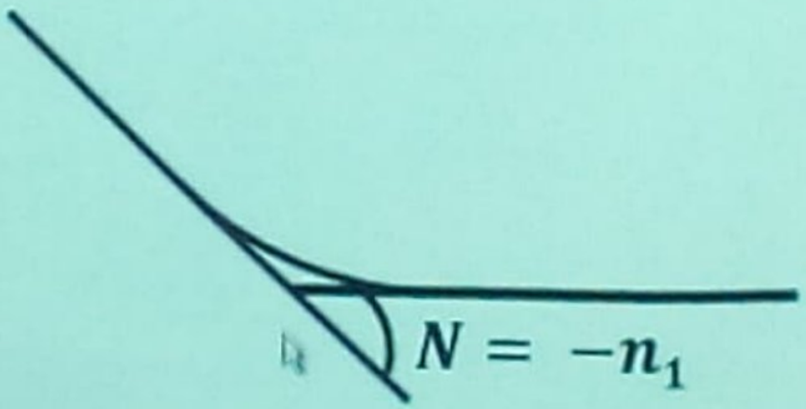
## Valley curve

- ✓ Valley curve or sag curves are vertical curves with convexity downwards
- ✓ They are formed when two gradients meet in any of following four ways:
  - when a descending gradient meets another descending gradient

$$N = -n_1 + n_2$$

## Valley curve

- ✓ Valley curve or sag curves are vertical curves with convexity downwards
- ✓ They are formed when two gradients meet in any of following four ways:
  - ➧ when a descending gradient meets another descending gradient
  - ➧ when a descending gradient meets a flat gradient



## Valley curve

- ✓ Valley curve or sag curves are vertical curves with convexity downwards
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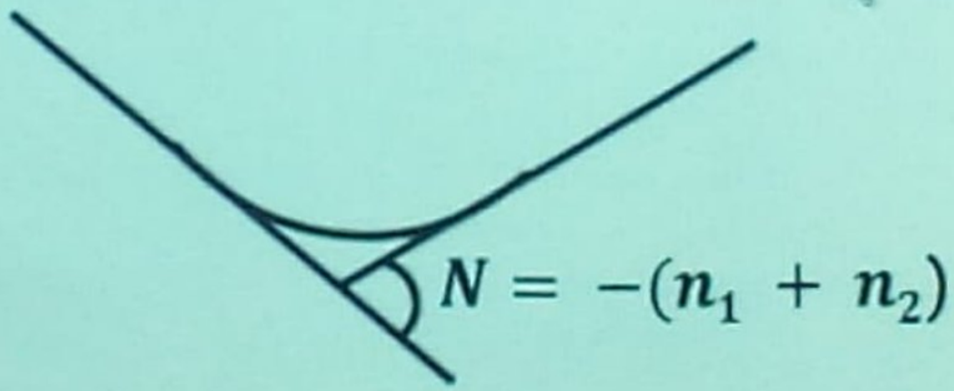
  - when a descending gradient meets another descending gradient
  - when a descending gradient meets a flat gradient
  - when a descending gradient meets an ascending gradient



## Valley curve

- ✓ Valley curve or sag curves are vertical curves with convexity downwards
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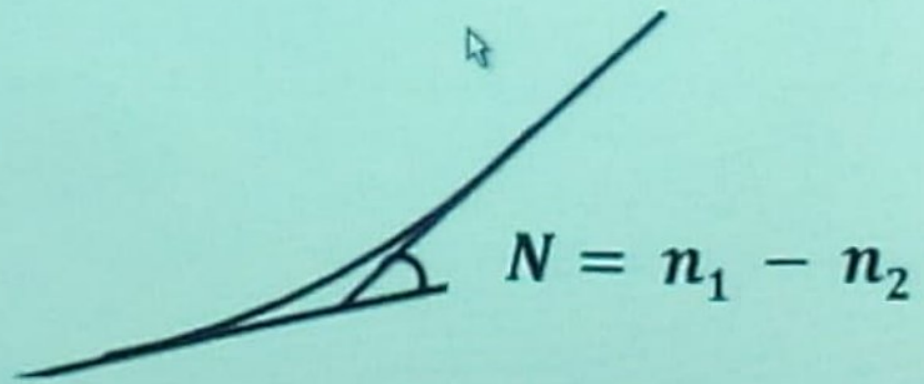
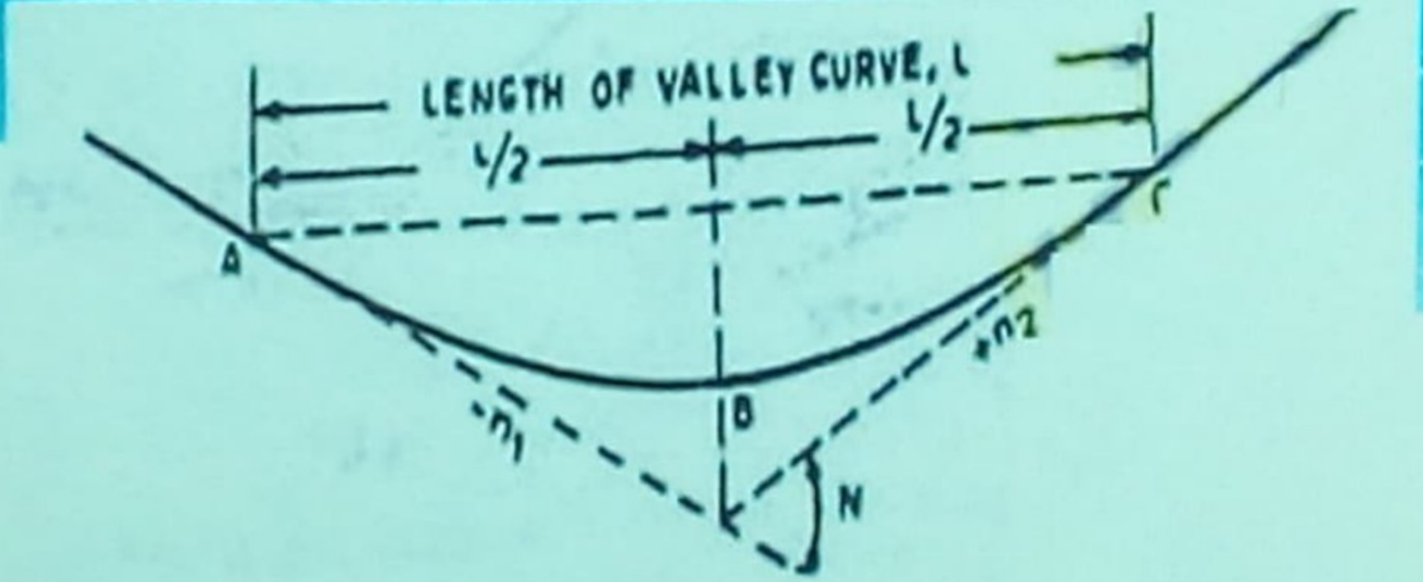
  - when a descending gradient meets a flat gradient
  - when a descending gradient meets an ascending gradient
  - when an ascending gradient meets another ascending gradient



## Length of valley curve for comfort condition (with allowable rate of change of centrifugal acceleration)



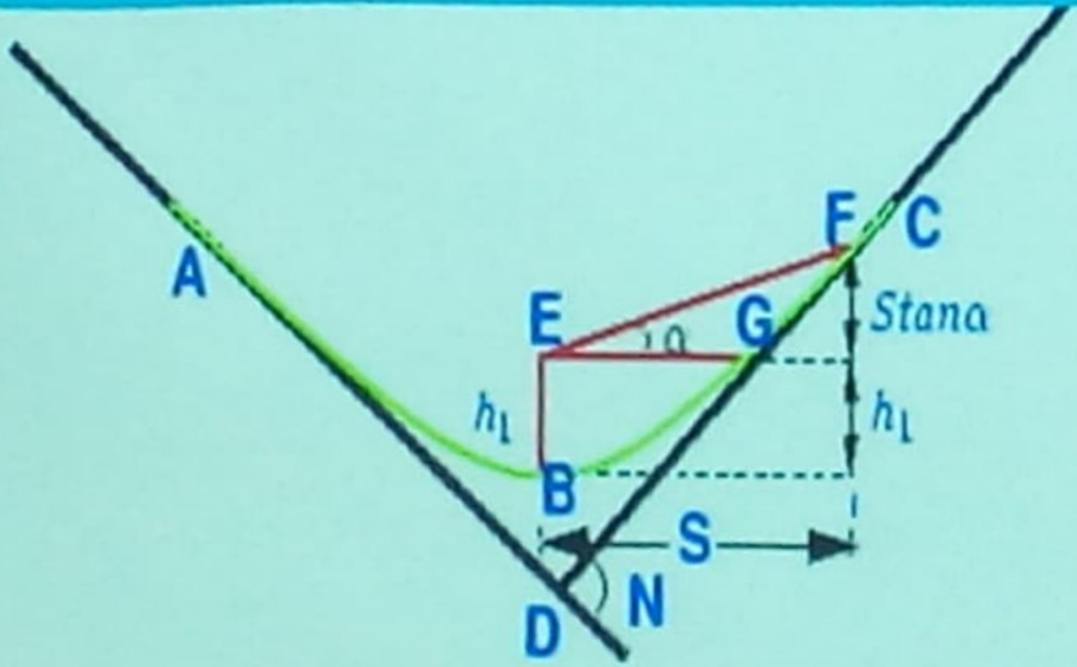

For comfort condition $L = 2\left[\frac{Nv^3}{C}\right]^{\frac{1}{2}} = 0.38\,(NV^3)^{1/2}$

where $L$ is total length of valley curve, $N$ is deviation angle in radians or tangent of deviation angle or algebraic difference in grades, $V$ is design speed in kmph, and $C$ rate of change of centrifugal acceleration in m/sec$^3$ (= 0.06 m/sec$^3$)

✓ Minimum radius of valley curve $R = \frac{L}{2N}$

## Length of the valley curve for head light sight distance

**Case I. Length of valley curve greater than SSD ( $L > S$ )**




$$L = \frac{NS^2}{2h_1 + 2S\tan\alpha}$$

where $L$ is length of valley curve in metre, $N$ is deviation angle in radians, $h_1$ is height of head light beam, $\alpha$ is head light beam inclination in degrees, and $S$ is stopping sight distance

- ✓ If average height of head light is taken as $h_1 = 0.75$ m and beam angle Inclination is $\alpha \approx 1°$, then

$$L = \frac{NS^2}{1.5 + 0.035S}$$

## Case II. Length of valley curve less than SSD ($L < S$)

$$L = 2S - \frac{2h_1 + 2S\tan\alpha}{N}$$

- ✓ If average height of head light is taken as $h1 = 0.75$ m and beam angle Inclination is $\alpha \approx 1°$, then

$$L = 2S - \frac{(1.5 + 0.035S)}{N}$$

Maximum length of valley curve obtained between above two conditions will be adopted

Example 4.25 (Khanna and Justo)