GATE – CIVIL ENGINEERING

Transportation Engineering

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TRANSPORTATION ENGINEERING

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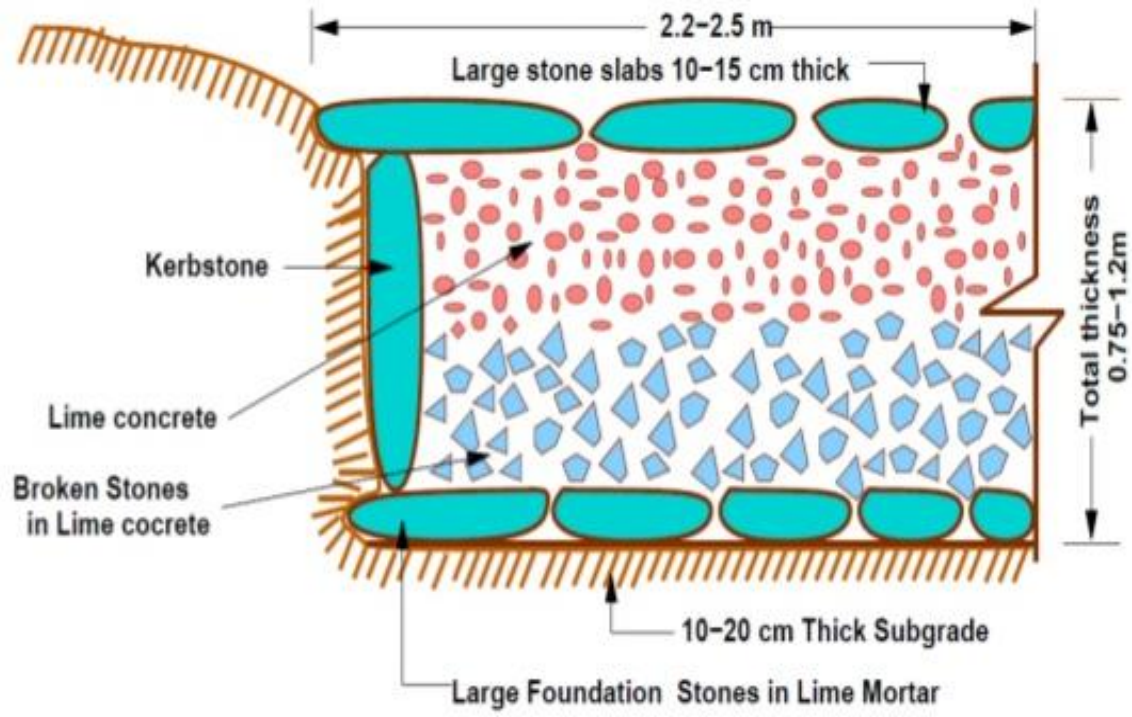
15.1 HIGHWAY PLANNING

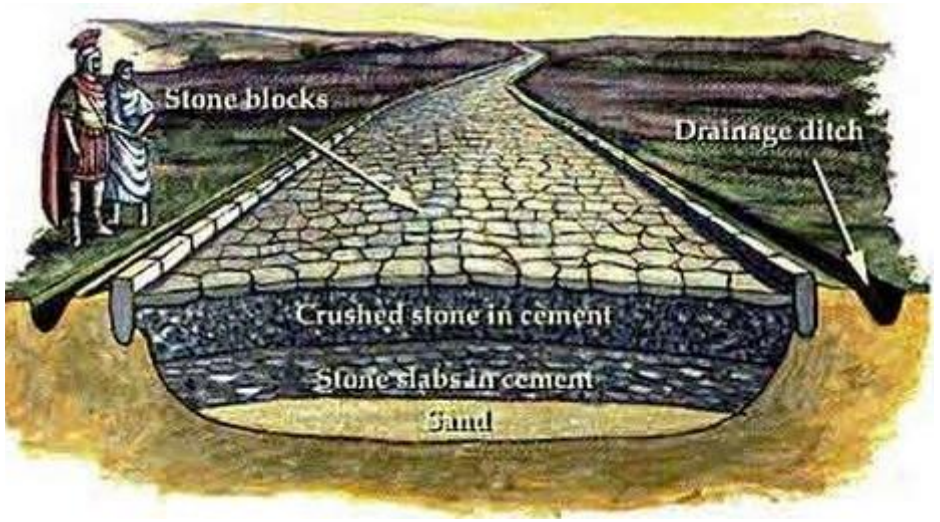
The objectives of highway planning are

- To plan a road network for efficient and safe traffic operation at minimum cost.
- To arrive at the road system and the lengths of different categories of roads for maximum utility within the available resources.
- To fix up data wise priorities for the development of each road.
- To plan for future requirement and improvement of roads in view of anticipated developments.
- To work out financing system.

Roman Roads

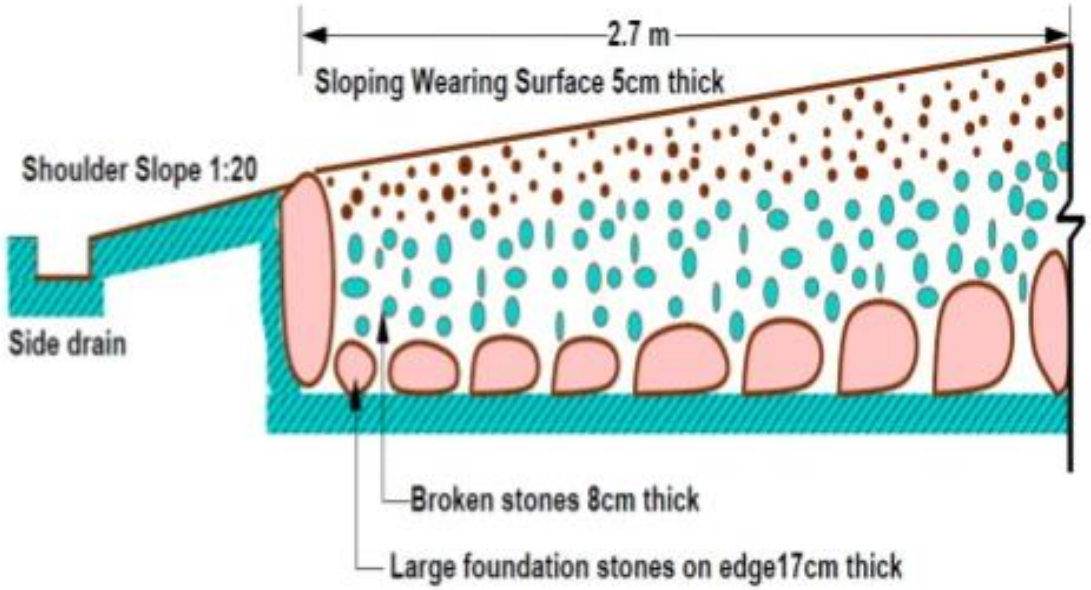
- Roman civilization- roads were built with stones of considerable thickness.
- Straight roads without considering the gradients
- Built after removal of soft soil till a hard stratum was reached.
- Wearing coat consisting of dressed large stone blocks set in lime mortar.





Tresaguet construction

- Pierre tresaguet developed an improved method of construction in France in 1764 AD
- Thickness of construction is of the order of 30 cm.
- Due consideration was given to subgrade moisture condition and drainage of surface of water



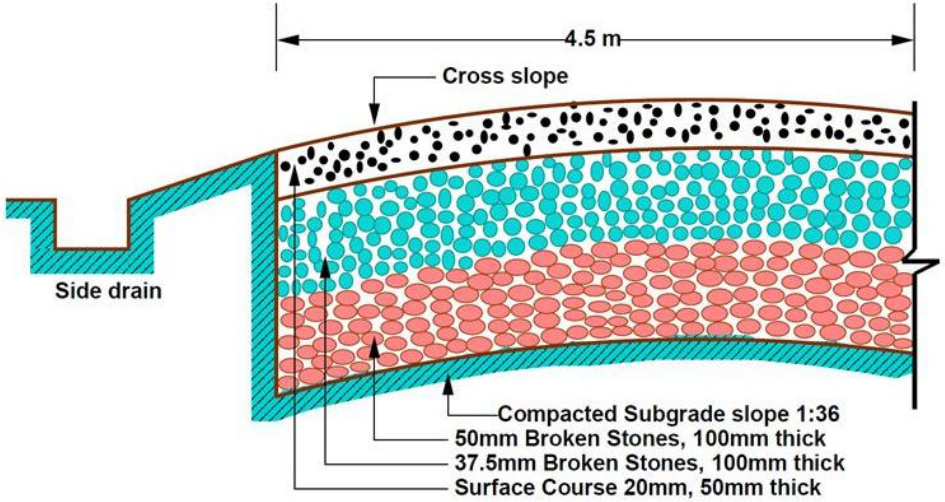
Telford construction:

- Telford provided level subgrade of width 9 m.
- Weaving course of 40 mm thick provided with a cross slope of 1 in 45.

Macadam construction:

- John Macadam suggested that heavy foundation stones are not required to be placed at bottom layer.
- Used less than 6mm size to a uniform thickness
- The subgrade drainage and compaction considered as important with cross slope of 1 in 36
- The size of stones for the top layers was decided on the basis of stability under animal drawn vehicles.
- The total thickness was kept uniform from edge to centre to a minimum of 25cm

First British Road: Grand Trunk road from Calcutta to delhi.



Jayakar committee:

- Since 1853, rail transportation mainly used for long distance transportation and roads acted as a feeder services to the railways.
- The inadequacy of the road network came into light after first world war.
- In 1927, the government appointed a road development committee headed by M.R.Jayakar

Recommendations

- Central government should take the proper change of road considering it as a matter of national interest.
- Long term planning programme for a period of 20 years (called as twenty year plan)
- Periodic road conferences to discuss about road construction and development. It paved the way for the establishment of Indian Road Congress (IRC) in 1934.
- In position of additional taxation on motor transport which included duty on motor spirit, vehicle taxation, license fee for vehicles on hire. It leads to introduction of development fund – central road fund (CRF) in 1929.
- Establishment of dedicated research organization to carry out research and development work – due to this formation of Central Road Research Institute (CRRI) in 1950.

Motor vehicle act 1939 (Revised in 1988)

- Violation of traffic laws.

Classification of roads:

- Based on usage of roads during different seasons of the year.
  i. All weather roads.
  ii. Fair weather roads
  Traffic may be interrupted during monsoon season at causeways where streams may overflow across the road.
- Based on type of carriageway or the road pavement
  i. Paved roads - hard pavement (at least WBM layer)
  ii. Unpaved roads - earth roads or gravel roads
- Based on the type of pavement surfacing
  i. Surfaced roads - Bituminous or Cement concrete surfacing.
  ii. Unsurfaced roads
- Roads with bituminous surfacing are also called black toped roads.

Roads are generally classified based on

a. Traffic volume
   - Arbitrarily fixed by different agencies
   - Traffic on roads - Heavy, Medium and Light
   - Traffic volume is expressed as vehicles per day.

b. Load transported or tonnage.
   - Class I, II...etc. or class A, B…etc.
   - Limits may be expressed as tones/day.

Traffic volume

c. Location and function

Nagpur road plan classified the roads in India based on location and function into the following five categories.

i. National Highways (NH)
ii. State Highways (SH)
iii. Major District Roads (MDR)
iv. Other District Roads (ODR)
v. Village Roads (VR)

1.National Highways (NH):

- Connecting major ports, foreign highways, capitals of large states and large industrial and tourist centers including roads required for strategic movements for the defence of India. National highways are assigned the respective numbers.
- Responsibility of construction and maintenance of NHs - Central Government.

2. State Highways (SH):

- Arterial roads of a state, connecting up with the national highways of adjacent states, district head quarters and important cities within state and serving as the main arteries for traffic to and from district roads.
- NH and SH have the same design speed and geometric design specifications.

3. Major District Roads (MDR):

- Important roads within the district.
- MDR has lower speed and geometric design specifications than NH/SH.

4. Other District Roads (ODR):

- Roads serving in rural areas.

5. Village Roads (VR):

- Roads connecting the villages.

National Highway

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Nagpur Road Conference:

- All roads should be so constructed that maintenance and capital costs over period of 20 years will be minimum.

Modified classification of road system:(Third Road Development plan, 1981 -2001)
Classified in to three classes

1. Primary system : a. Express ways b. National Highways (NH)

2. Secondary system : a. State Highways (SH) b. Major District Roads (MDR).

3. Tertiary system of rural roads : a. Other District Roads(ODR)
b. Village Roads(VR)

Express ways:

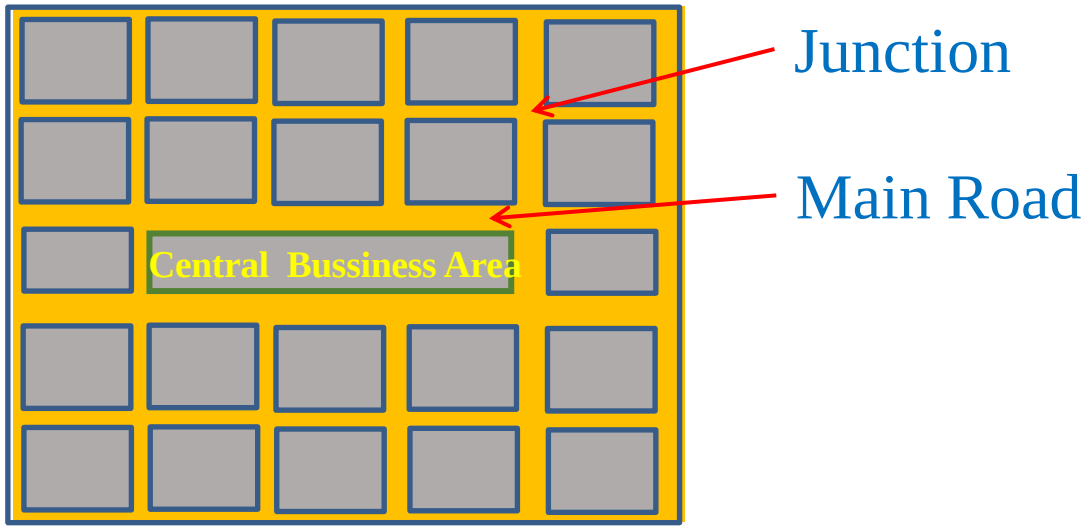
- Separate class of highways with superior facilities and design standards, through routes having very high volume of traffic.
- Provided with divided carriage ways, controlled access, grade separators at cross roads and fencing.
- Permitted only fast moving vehicles.
- Central Government - NH route.
- State Government - SH route.

Classification of urban roads:

- Urban roads taken care by respective urban authorities.
- Urban roads are not included in the Third Twenty year road Development Plan (1981-2001).
    a. Arterial roads
    b. Sub-arterial roads
    c. Collector streets
    d. Local streets
- Arterials and sub-arterials are the streets primarily for through traffic on a continuous route.
- Sub arterials have a low level of traffic mobility than the Arterials.
- Collector streets provide access to arterial streets and they collect and distribute traffic from and to local streets.

Road patterns:

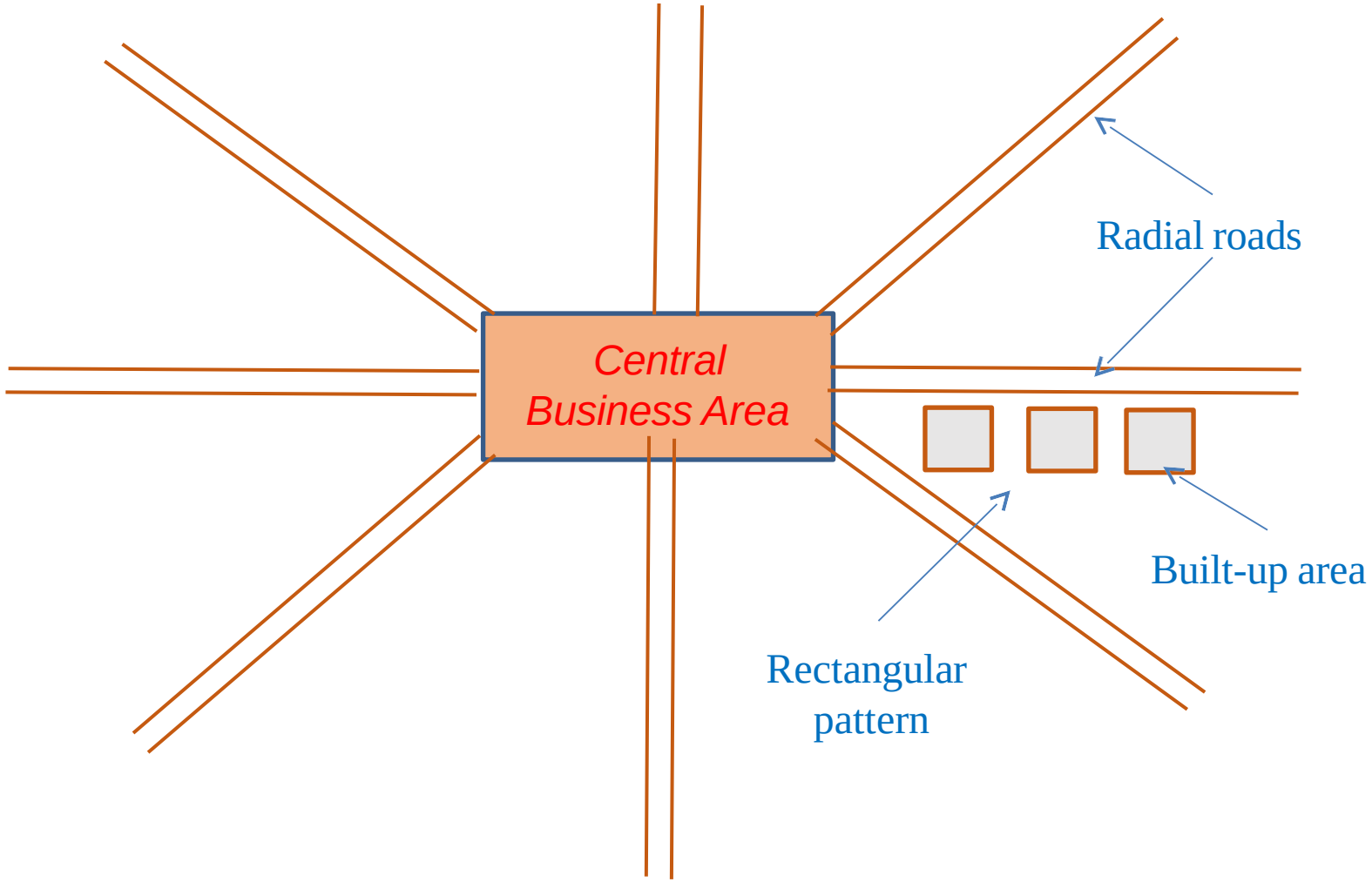
a. Rectangular or Block pattern. eg. Chandigarh city



- In this pattern, the whole area is divided into rectangular blocks of plots, with streets intersecting at right angles.
- The main road which passes through the center of the area should be sufficiently wide and other branch roads may be comparatively narrow.
- The main road is provided a direct approach to outside the city

Road patterns:

b. Radial or Star and Block pattern.



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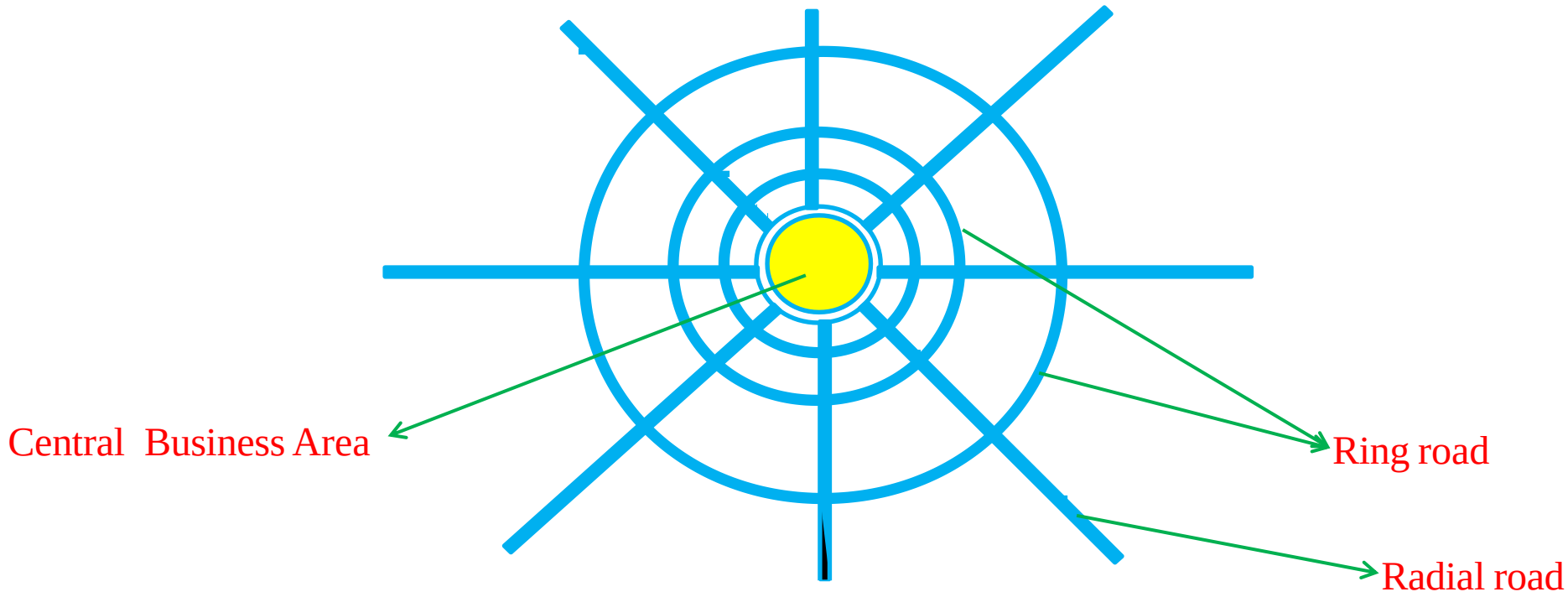
Road patterns:

c. Radial or Star and Circular pattern. eg. Connaught place in New Delhi



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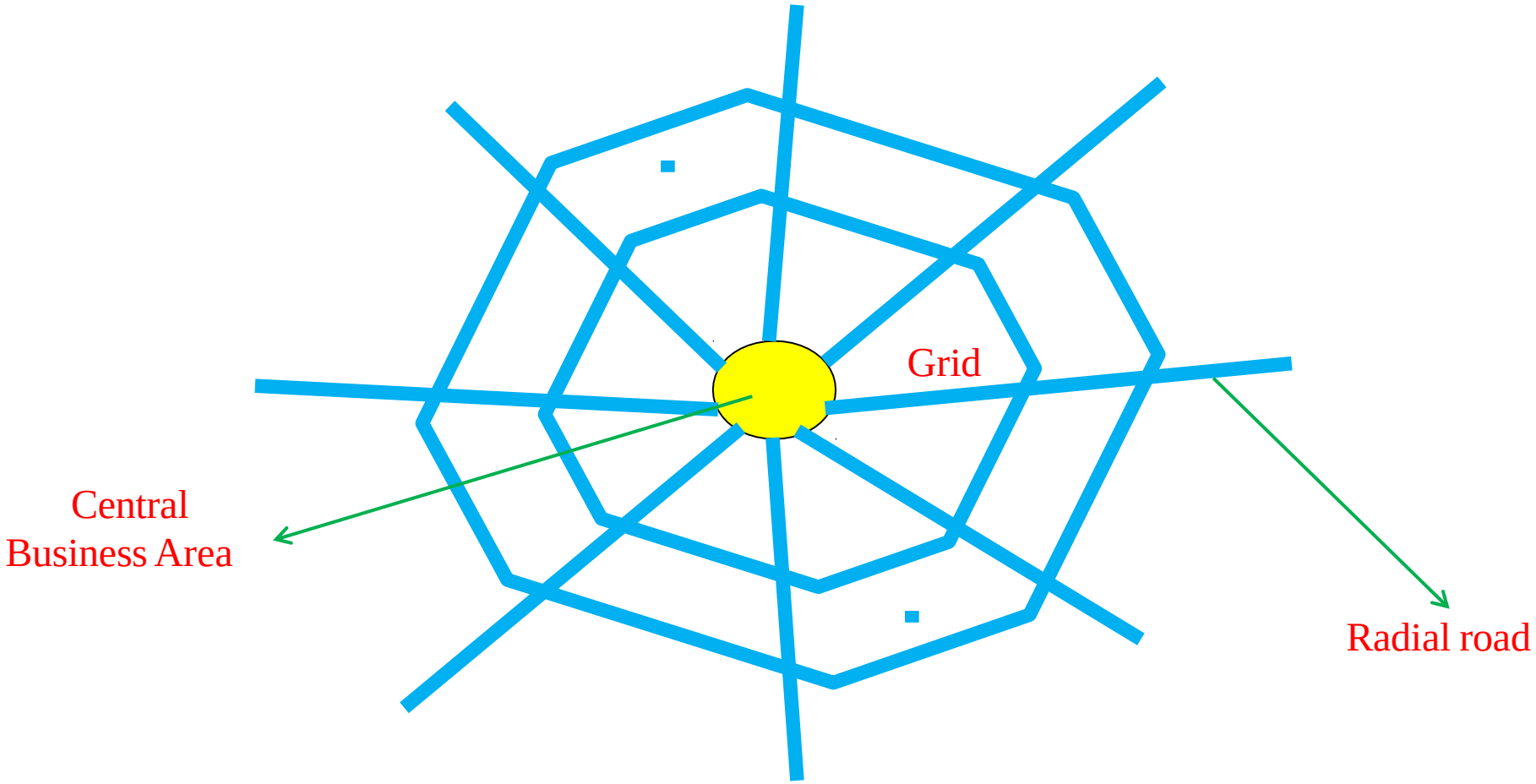
Road patterns:

d. Radial or Star and Grid pattern. eg. Nagpur road plan



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Road patterns:

e. Hexagonal pattern.

f. Minimum travel pattern.

- The choice of the pattern very much depends on the locality, the layout of different towns, villages, industrial and production centres and on the choice of the planning engineer.
- The rectangular or the block pattern has been adopted in the city roads of Chandigarh. But from traffic operation point this is not considered convenient.
- An example of radial and circular pattern is the road network of Connaught Place in New Delhi.
- The Nagpur road plan formulae were prepared assuming Star and Grid Pattern.

Highway Planning in India

1. Nagpur Road Plan or First 20 year road plan (1943-63)

- Conference held at Nagpur in 1943.
- Classified on NH, SH, DR (MDR, ODR), VR.
- Recommended Star and Grid pattern of road network throughout the country.
- Considered the geographical, agricultural and population condition.
- A length of 1/8 km of first category road is provided per km^2 of agriculture area.
- Grids of first category roads are spaced at 16 km.
- Construction and maintenance of NH by central government.
- Allowance for development by 15%
- Divides the area in to agricultural and non agricultural area.
- Target - 16 km road length per 100 Sq.km area.
- Target road length completed by 1961.

2. Second Twenty Year Road plan (1961-81)

- Also known as Bombay Road plan
- Target road length- 32 km per 100 Sq.km area.(Double the Nagpur target plan)
- The area is divided into
  a. Developed and agricultural area.
  b. Semi-developed area.
  c. Undeveloped and uncultivated area.
- Express ways have been considered and 1600 km length has been included in the proposed target of NHs.
- Traffic engineering cells should be established in each state.
- Allowance for development due to unforeseen factors is 5 %

3. Third Twenty Year Road Development Plan (1981-2001)

Shortcomings in first two road development plans are

- Not conceived to meet the needs of freight and passenger movement by road
- The plans were not part of the total transportation plan of the country
  - Also known as Lucknow Road Plan.
  - Future road development based on primary, secondary and tertiary road systems.
  - The overall road density – 82 km per 100 sq.km area.
  - No part of the country is more than 50 km away from a NH.
  - Recommended Square grids 100 km of road network.
  - Due importance given to Energy conservation, Environmental quality of roads and road safety.
  - Long term master plans for road development should be prepared at various levels.

Classification of Roads:

Primary Road system:

- Express ways total length - 2000 km to be developed.
- NH-1 km per 50 sq. km area.

Secondary road system:

- Total length of SH required for any state determined from the following
  a. By total area: SH in km = area of state in sq. km /25.
  b. By total number of towns and area in the state:
  SH in km =62.5× number of towns in the state - area of state sq. km /50
- Total length of MDR
  a. MDR in km = Area of the state in sq. km /12.5
  b. MDR in km = 90×number of towns in the state.

Tertiary Road System or Rural Roads:

- **ODR and VR**
- Total length in kM= 4.74× number of villages and towns

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Indian Road Congress (IRC)

- Established in 1934.

Objectives:

- To promote and encourage the science and practice of road building and maintenance
- To provide a forum for expression of collective opinion of its members on matters affecting roads.
- To promote the use of standard specifications and practice.
- To advise regarding education, experiment and research connected with roads.
- To hold periodic meeting to discuss technical questions regarding roads.
- To suggest legislation for the development, improvement and protection of roads.
- To suggest improved methods of administration, planning, design, operation, use and maintenance of roads
- To establish, furnish and maintain libraries and museums for science of road making.

National Highways act 1956:

- Central government is responsible for the construction of national highways.
- Central government is empowered to omit any national highway from the list of national highways or it can declare any highways as national highway.
- highways or it can declare any highways as national highway.

Highway research board 1973

National highway authority of India (NHAI)

National Highway Development program (NHDP)

- Road constructions are based on BOT (Build Operate Transfer) system.
- Contractors build the roads, operate it and transfer it to the government.

Projects under NHDP

- Golden quadrilateral
  - Delhi-Kolkatta-Chennai-Mumbai-Delhi
- North South corridor
  - Srinagar to kanyakumari
- East-west corridor
  - Silchar-porbandar
- Port connectivity and others.

State highway research laboratories

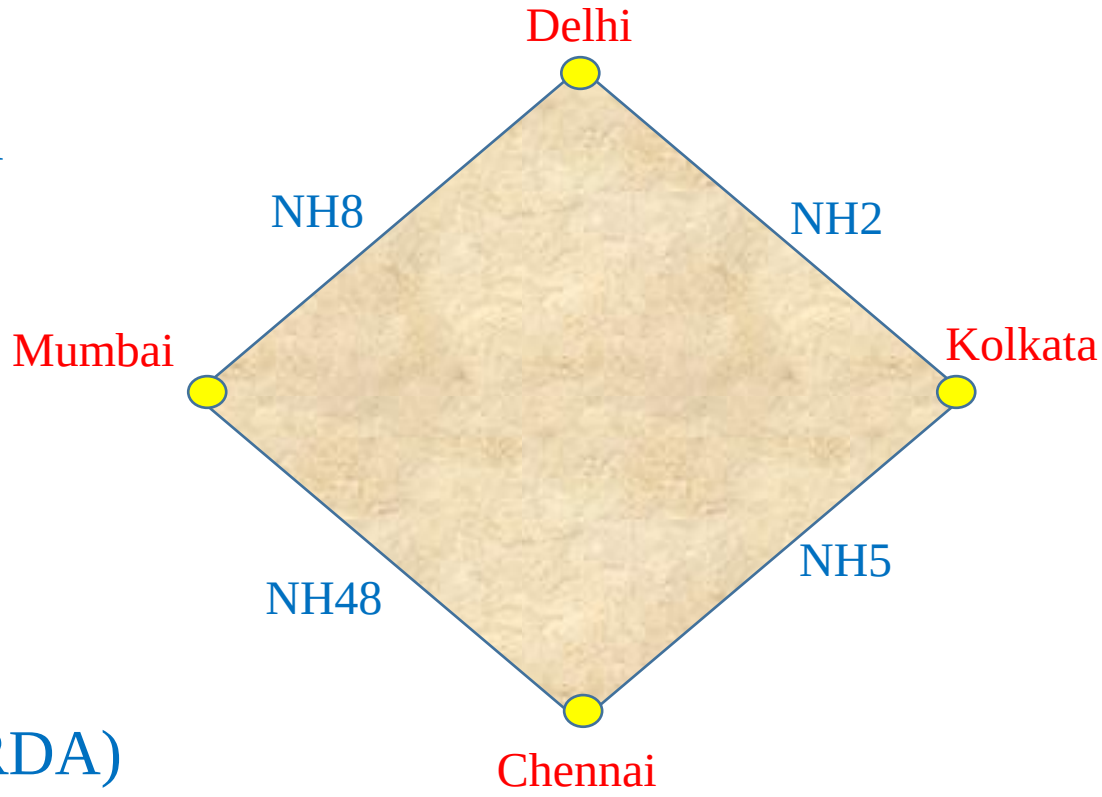
Highway staff training Institutes

National Rural road Development Agency (NRRDA)

NH1: Delhi to Amritsar via Ambala

NH3: Agra to Mumbai

NH7: Varanasi to Kanyakumari (largest NH)



Highway alignment:

Factors controlling alignment

a. Obligatory points:

- Obligatory points through which the road alignment has to pass may cause the alignment to often deviate from the shortest or easiest path.

  Eg. Bridge site, a maintain pass, a quarry

b. Traffic:

- Alignment should suit traffic requirements
- Origin and destination survey should be carried out in the area and desire lines be drawn showing
- The trend of traffic flow.
- Alignment of new road – desire lines, traffic flow patterns and future trends.

c. Geometric design:

- Satisfying the geometric design requirements

d. Economy:

- Final alignment should be economical
- High embankments and deep cuttings – uneconomical
- Alignment chosen to balance cutting and filling

e. Other considerations:

- Drainage conditions, hydrological factors, political considerations, etc.,

Planning surveys:

- Planning surveys or Fact Finding surveys are the field surveys required for collecting the factual data.
- Planning based on the factual data is scientific and sound.

Planning surveys consists of the following studies

a. Economic studies

b. Financial studies

c. Traffic or road user studies

d. Engineering studies

Preparation of master plan

- Master plan is the final road development plan for the area under study.
- Saturation system or Maximum utility system is used to find the optimum road length based on the concept of obtaining maximum utility per unit length of road.

Factors for obtaining the utility per unit length of road are

a. Population served by the network
b. Productivity served by the network

Engineering surveys for Highway locations:

The stages of engineering are

a. Map Study

- Alignment avoiding valleys, ponds etc.,
- When a road has to cross hills, possibility of crossing through a mountain pass.
- Appropriate locations of bridge site for crossing rivers, avoiding bend of the river, if any
- When a road is to be connected between two stations, one as the top of hill and the other on foot of hill, then alternate routes can be suggested keeping in view of permissible gradient.

b. Reconnaissance:

- To examine the general characteristics of the area for deciding the most feasible routes for detailed studies.

Details to be collected during reconnaissance

- Valleys, ponds, lakes, marshy land, ridge, hills, permanent structures and other obstructions along the route which are not available in map.

Approximate gradients, length of gradients and radius of curves for alternate alignments.

- Number and type of cross drainage structure, maximum flood level, natural ground water levels along the possible routes.
- Soil type along the routes
- Availability of construction materials.
- After reconnaissance , the proposed alignment may be altered or changed.

c. Preliminary survey:

- To survey the various alternate alignments proposed after reconnaissance and to collect all the necessary physical information and details of topographs, drainage and soil
- To compare the different proposals in view of the requirement of a good alignment.
- To estimate quantity of earthwork and to workout the cost of alternate proposals.
- To finalize the best alignment from all considerations.

d. Final locations and detailed survey:

- The alignment finalized after preliminary survey is to be located on the field by establishing the centre line.
- Detailed survey should be carried out for collecting the necessary information for the preparation of plans and construction details for the highway project.
- The centre line of the road finalized in the drawings is to be transferred on the ground during the location survey.

Detailed survey:

- Temporary bench marks are fixed at suitable intervals (250m) and at all drainage and under pass structures.
- Levels along the final centre line should be taken for calculation of earthwork and drainage details.
- The cross section level are taken upto the desired width at suitable intervals.
- The data during detailed survey should be elaborate and complete for preparing detailed plans, design and estimate of the project.

Selection of proposed roads based on utility

Proposed Road	Length	Number of towns and villages				Production 10^3 tonnes	Total Utility	Utility per unit length
		1000 - 2000 0.5	2000 - 5000 1	5000 - 10,000 2	>10,000 4			
P	30	16	8	3	1	10	36	1.20
Q	40	38	10	6	1	14	59	1.475
R	50	24	16	10	2	20	76	1.52
S	60	32	15	7	1	24	73	1.22

For proposal at P:

Total utility = 16×0.5 + 8×1 +3×2 + 1×4 + 10×1 = 36

Utility per unit length = $\frac{36}{30} = 1.2$

Utility factor for proposal R is more and is best suited for the given proposals

The order of Priority: R,Q,S,P

15.1 Highway Planning
Previous IES Questions

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15.1 Highway Planning (IES)

01.The length of National Highways as per 3rd 10 years (Lucknow) road plan is given by IES 2000

a. area of the country / 75
b. area of the country / 50
c. area of the country / 40
d. area of the country / 25

02. Match List I (Study) with List II (Purpose) and select the correct answer using the code given below the Lists: IES 2005

List I	List II
A. Primary road system	1. Population distribution
B. Economic studies	2. Expressways
C. Engineering studies	3. Traffic volume
D. Road use studies	4. Topographic details

a. A2 B1 C4 D3 b. A4 B3 C2 D1 c. A2 B3 C4 D1 d. A4 B1 C2 D3

03. Under the Nagpur Road Plan, which of the following are NOT relevant in planning the road development programme in a backward district? IES 2013

1. Existing agriculture drainage network of drain canals
2. Existing number of Panchayat unions
3. Existing length of mud-track roads
4. Number of villages with population of 10000 and above

a. 1, 2, 3 and 4 b. 1, 2 and 3 only

c. 1, 2 and 4 only d. 2, 3 and 4 only

04.A transportation trip survey was undertaken between private car, and public car transportation. The proportion of those using private cars is 0.45. While using the public transport, the further choices available are Metro Rail and Mono Rail, out of which commuting by a Mono Rail has a proportion of 0.55. In such a situation, the choice of interest in using a Metro Rail, Mono Rail and private car would be, respectively. IES 2016

a. 0.25, 0.3 and 0.45

b. 0.45, 0.25 and 0.3

c. 0.25, 0.45 and 0.3

d. 0.3, 0.25 and 0.45

04.a

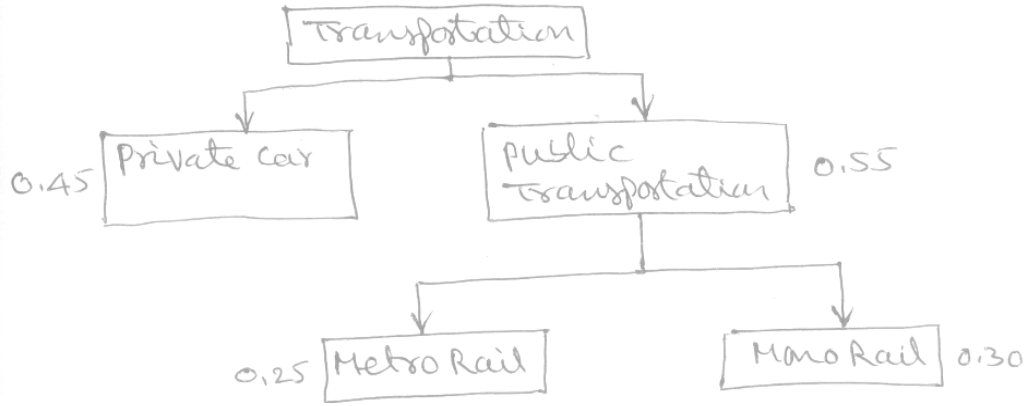
Proportion of using private cars = 0.45

Proportion of using public transportation = 0.55

Proportion of using Mono Rail = 0.55 public transportation = 0.55 × 0.55 = 0.30

Proportion of using metro rail = 0.55 – 0.30 = 0.25

Proportion of metro rail, mono rail and private car = 0.25, 0.30 and 0.45



05.The following purposes served by a transition curve in a highway alignment include

1. Gradual introduction of the centrifugal force on moving vehicles from zero on the straight alignment to a constant final value on the circular curve.
2. Enabling the gradual introduction of superelevation on the roadway

Select the correct answer using the codes given below IES 2017

a. 1 only b. 2 only **c.** Both 1 and 2 d. Neither 1 nor 2

15.2 GEOMETRIC DESIGN OF HIGHWAYS

Geometric design of highways deals with the dimensions and layout of visible features of the highway such as alignment, sight distances and intersections.

- Designed to provide optimum efficiency in traffic operations with maximum safety at reasonable cost.
- Very expensive and difficult to improve the geometric elements of a highway in stages at a later date.

Design of a highway is based on

- future growth of traffic flow.
- possibility of the road being upgraded to a higher category.
- possibility of road being upgraded to a higher design speed standard.

Geometric design of highways deals with following elements.

a. Cross section elements

- width of pavement, formation and land, the surface characteristics, cross slope.

b. Sight distance considerations

- visibility for safe movement of vehicles.
- at horizontal and vertical curves and at intersections.

c. Horizontal alignment details

- Horizontal curves.
- Super elevation is provided by raising the outer edge of pavement to counteract the centrifugal force developed on a vehicle traversing a horizontal curve.
- Extra pavement width is required at horizontal curves
- Transition curves are introduced between the straight road and horizontal curves.

d. Vertical alignment details.

e. Intersection elements.

- Highway geometrics are influenced by Topography, locality, traffic characteristics and the design speed.

Geometric design requirements are controlled by Speed, Road user, Vehicular characteristics, Design traffic, traffic capacity and benefit cost.

The geometric design of highways depends on

a. Design speed

- Most important factor
- Decided by taking the overall requirements of highways.
- Based on the importance or the class of the road
- Every geometric design element depends on design speed
- Depends on Pavement surface characteristics, the cross section element such as width and clearance requirement , sight distance, horizontal alignment elements such as radius of curve, super elevation, transition curve length, vertical alignment elements such as gradient, summit and valley curve lengths etc.

b. Topography

- Plain, Rolling, Mountainous and Steep terrains.

c. Traffic factors

- Vehicular characteristics different vehicles such as cars, buses, trucks, motor cycles etc.
- Human characteristics such as physical, mental and psychological characteristics of drivers and pedestrians.

d. Design hourly volume and capacity

- Traffic flow or volume fluctuating with time as low-off peak hours; high-peak hours
- Uneconomical design - based on peak traffic flow
- Design hourly volume - reasonable value of traffic volume for design.
- The ratio of volume to capacity affects the level of service of the road

e. Environmental and other factors.

- Aesthetics, land spacing, air pollution, noise pollution and other local conditions.

Pavement surface characteristics

- Pavement surface depends on pavement type.
- Availability of materials and funds, volume and composition of traffic, sub grade, climatic conditions and construction facilities.
- Pavement surface characteristics: friction, unevenness, light reflecting characteristics, drainage of surface water

Flexible pavement

Rigid pavement

Friction:

- Frictional force is an important factor in the acceleration and retardation abilities of vehicles.
- In roads, friction is judged by the surface roughness of the roads.
- The coefficient of friction or skid resistance offered by the pavement surface under various driving and surface conditions are with reference to the safety.
- The maximum coefficient of friction comes into play at low speeds where the breaking efficiency is high enough to partially arrest the rotation of the wheels on application of brakes.

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Skid

Skid occurs when the path traveled along the road surface is more than the circumferential movements of the wheels due to their rotation.

- Skid occurs when the wheels slide without revolving or when the wheels partially revolve.
- Longitudinal skidding takes place for the vehicle moves forward due to locking of wheels partially or fully when brakes are applied.
- IRC recommended value of longitudinal friction coefficient 0.35 to 0.40 for stopping distance calculation.

- IRC recommended value is based on minimum coefficient of friction in the longitudinal direction on wet pavements and after allowing a suitable factor of safety.
- Lateral skidding occurs when a vehicle negotiates in a horizontal curve and if the centrifugal force is greater than the counteracting forces.
- Lateral skidding is dangerous leading to accident.
- The maximum lateral skid coefficient is equal to or slightly higher than the forward skid coefficient.
- IRC recommended lateral coefficient of friction is 0.15.
- IRC recommended value is based on the worst possible surface condition such as mud on pavement surface at horizontal curve with super elevation, during the rains.

Factors affecting friction or skid resistance

a. Type of pavement surface
- Cement concrete, Bituminous, WBM, Earth surface, etc.

b. Macro-texture of the pavement surface or its relative roughness

c. Condition of pavement
- Wet or dry, smoothened or rough, oil spilled, mud or dry sand.
- Coefficient of friction decreases slightly with increase in temperature, tyre pressure and load.

Dry pavement
- Smooth and worn out tyres offers higher friction factors than the new types with treads because of a large area of contact.

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Wet pavement

- New tyres with goods treads give higher friction factors than a worn out tyres
- Because the lubricating effect of water on the wet pavement is reduced as the water entrapped between the tyre and pavement escapes into the treads of the tyre.
- New tyres are more dependable than smooth ones in adverse surface and other conditions promote skidding.
- The minimum anticipated value of coefficient of friction under worst possible pavement condition is generally taken for design purpose.
- The friction coefficient decreases with skid skid/speed of vehicle and brake efficiency.

d. Type and condition of tyre
- New with good threads or smoothened and worn out type.

e. Speed of vehicle.

f. Extent of brake application or brake efficiency

g. Load and tyre pressure

h. Temperature of tyre and pavement

i. Type of skid

Slip:

Slip occurs when a wheel revolves more than that of the corresponding longitudinal movement along the roads.

Slipping occurs in the driving wheel of a vehicle

- when the vehicle rapidly accelerates from stationary position.
- from slow speed on pavement surface which is slippery and wet.
- when the road surface in loose with mud.

Pavement unevenness:

- Higher operating speeds are possible on even pavement surfaces with less undulations than on uneven or poor surfaces.
- Pavement unevenness affects Vehicle operation cost, comfort and safety
- Fuel consumption, wear and tear of tyres and other moving parts increases with increase in pavement unevenness.
- Loose road surfaces increase the tractive resistance and hence cause increase in fuel consumption
- Uneven surfaces increases fatigue and accidents.

- Pavement surface condition measured by Bump integrator in terms of unevenness index.
- Unevenness index is the cumulative measure of vertical undulations of the pavement surface recorded per unit horizontal length of the road
- Unevenness index measured in cm\km.
- Unevenness index

  <150 cm/km Good pavement surfaces of high speed highways

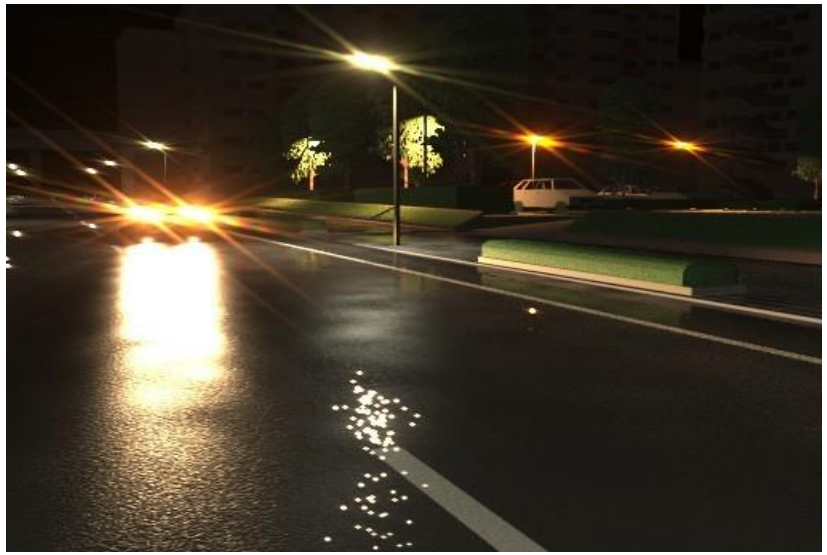
  250 cm/km Satisfactory up to a speed of 100 kmph

  >350 cm/km Very uncomfortable even at a speed of 50 kmph
- Unevenness indicator - useful to indicate unevenness values from 3 to 20 mm

- Unevenness or undulations on pavement surface caused by Inadequate or improper compaction of the fill, sub grade and pavement layers
  a. Unscientific construction practices
  b. Use of inferior pavement materials
  c. Improper surface and sub surface drainage
  d. Use of improper construction machinery
  e. Poor maintenance practices
  f. Localized failures due to combination of causes

Light reflecting characteristics:

- Night visibility depends on the light reflecting characteristics of the pavement surface
- The glare caused by the reflection of head lights is high on wet pavement surface than on the dry pavement
- Light colored or white pavement surfaces give good visibility at night particularly during rains.



Night Time

day Time

Prof. B. Jayarami Reddy

- Produce glare and eye strain during bright sunlight
- Black top pavement surface provides very poor visibility at nights especially
- when the surface is wet.
- White roads have good visibility at night, but caused glare during day time.
- Black roads has no glare during day, but has poor visibility at night
- Concrete roads has better visibility and less glare.