MALLA REDDY ENGINEERING COLLEGE (AUTONOMOUS)
(An UGC Autonomous Institution, Approved by AICTE, New Delhi & Affiliated to JNTUH, Hyderabad). Accredited by NAAC with 'A' Grade (II cycle), Maisammaguda (H), Medchal-Malkajgiri District, Secunderabad, Telangana State – 500100, www.mrec.ac.in

DEPARTMENT OF CIVIL ENGINEERING

TRANSPORTATION ENGINEERING COURSE FILE

AKELLA NAGA SAI BABA

<table>
<tr><td rowspan="1">2018-19 Onwards (MR-18)</td><td>MALLA REDDY ENGINEERING COLLEGE (Autonomous)</td><td colspan="3">B.Tech. VI Semester</td></tr>
<tr><td>Code: 80125</td><td rowspan="2">TRANSPORTATION ENGINEERING</td><td>L</td><td>T</td><td>P</td></tr>
<tr><td>Credits: 3</td><td>3</td><td>-</td><td>-</td></tr>
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Prerequisites: Nil

Course Objective: To provide the students with basic knowledge of history of roads and planning stages for highways and cross section elements along with the geometric features of highways and drainage problems and remedial measures for construction of safe, durable pavements and traffic signs, signals, markings to control the traffic and for safe flow of vehicles without accidents.

MODULE I: Highway Development and Planning and [10 Periods]

Highway Development and Planning: Highway development in India – Necessity for Highway Planning- Different Road Development Plans.

Highway Planning: Classification of Roads- Road Network Patterns – Highway Alignment- Factors affecting Alignment- Engineering Surveys – Drawings and Reports, Road Projects initiation need based planning.

MODULE II: Highway Geometic Design [10 Periods]

Importance of Geometric Design- Design controls and Criteria- Highway Cross Section Elements- Sight Distance Elements- Stopping sight Distance, Overtaking Sight Distance and intermediate Sight Distance- Design of Horizontal Alignment- Design of Super elevation and Extra widening- Design of Transition Curves- Design of Vertical alignment-Gradients- Vertical curves. Typical cross sections for different types of roads.

MODULE III: Highway Materials and Testing [10 Periods]

A: Highway Materials and Testing

Desirable properties and testing of highway materials: road aggregates, bituminous materials and subgrade soil.

B: Highway Construction & Maintenance

Construction of earth roads, WBM roads, stabilized roads, bituminous pavements, cement concrete roads and joints in cement concrete roads – Maintenance of flexible & rigid pavements - Types and causes of distress. Concept of BOT and BOOT.

MODULE IV: Railway Engineering and Geometric Design of Railway Track [09 Periods]

Introduction to Railway Engineering Permanent way components – Cross Section of Permanent Way - Functions of various Components like Rails, Sleepers and Ballast –Rail Fastenings – Creep of Rails- Theories related to creep – Ageing of Sleepers- Sleeper density.

Geometric Design of Railway Track

Gradients- Grade Compensation- Cant and Negative Super elevation- Cant Deficiency – Degree of Curve – Crossings and Turn outs.

MODULE V: Traffic Engineering [09 Periods]

Basic Parameters of Traffic-Volume, Speed and Density- Traffic Volume Studies-

Data Collection and Presentation-speed studies- Data Collection and Presentation-Parking Studies and Parking characteristics- Road Accidents-Causes and Preventive measures- Accident Data Recording – Condition Diagram and Collision Diagrams.Traffic, infrastructural and safety audits.

TEST BOOKS:

1. S.K.Khanna, C.E.G.Justo, A.Veeraragavan. –**Highway Engineering**, Nem Chand and Brothers,Roorkee, 10^{th} Edition, 2015.
2. Dr.L.R.Kadyali, –**Traffic Engineering & Transportation Planning** – Khanna publications – 6^{th} Edition 1997

REFERENCES:

1. Partha Chakraborty and Animesh das, –**Principles of Transportation Engineering**, Prentice Hall, India– 6^{th} Edition 1997
2. Flaherty, C.A.O. –**Highway Engineering**, Edward Arnold,London, – 6^{th} Edition,1986
3. Mannering, –**Principles of Highway Engineering & Traffic Analysis**, Wiley Publishers, New Delhi. , 5^{th} Edition, 1998.
4. Sharma, S.K. –**Principles, Practice& Design of Highway Engineering**, S. Chand & Company Ltd., New Delhi, 5^{th} Edition, 1985.

E RESOURCES

1. http://teacher.buet.ac.bd/cfc/CE353/Lec1_Intro_web.pdf
2. https://drive.google.com/file/d/0B-IbNSAhk4D2LXpSc2w2cFh1TGM/view
3. http://www.sciencedirect.com/science/journal/20957564
4. http://www.civilenggforall.com/2016/12/highway-engineering-by-s.k.khanna-and-c.e.g.justo-free-download-pdf-civilenggforall.com.html
5. http://nptel.ac.in/downloads/105101087/
6. http://nptel.ac.in/courses/105105107/

Course Outcomes:
At the end of the course, students will be able to

1. Understand different modes of transportation and planning stages for highways
2. Design various highway geometric elements using the knowledge of mechanics and applying the principles of equilibrium conditions.
3. Characterize highway materials and understand the various types of highway construction
4. Design various geometric elements of railway track
5. Carryout various traffic engineering studies for traffic data collection

UNIT-I

HIGHWAY DEVELOPMENT ANDPLANNING

HIGHWAY DEVELOPMENT IN INDIA

Transportation engineering

- **Transportation engineering** is a sub-discipline of civil engineering which deals with the application of technology and scientific principles to the planning, functional design, operation and management facilities for any mode of transportation in order to provide for the safe, efficient, rapid, comfortable, convenient, economical, and environmentally compatible movement of people and goods from one place to other.
- Transportation engineering, primarily involves planning, design, construction, maintenance, and operation of transportation facilities

MODES OF TRANSPORTATION

- Basic mode of Transportation are
  - Land
    - Roadway
    - railway
  - Water
  - Air

MODES OF TRANSPORTATION

- **Highways**

  Car, Bus, Truck, non- motorized ..etc

- **Railways**

  Passenger and Goods

- **Airways**

  Aircraft and Helicopters

- **Waterways**

  Ships, boats…

- **Continuous Flow systems**

  Pipelines,belts,elevetor,ropeway…etc.

- Merits and Demerits: Based on accessibility, mobility, cost, tonnage..

Airways

- Fastest among all other modes
- More comfortable
- Time saving
- Uneconomical

Waterways

- Slowest among all other modes
- It needs minimum energy to haul unit load through the unit distance.
- This can be possible between ports on the sea routes or along the river
- economical

- **Railways**
- The transportation along the railway track could be advantageous by railway between the stations both for the passengers and goods, particularly for long distance.
- It depends upon the road transport i.e. road could serve as a feeder system.
- Energy require to haul a unit load through unit distance by the railway is only ¼ to 1/5 of the required by road.
- Safety.

- **Highways**
- It gives the maximum service to one and all
- It gives maximum flexibility for travel with reference to route, direction, time and speed of travel
- It provide door to door service
- Other modes are depend on it
- It requires small investment for the government
- Motor vehicles are cheaper than other carriers like rail locomotive and wagons
- It saves the time for short distance
- High degree of accident due to flexibility of movement

TRANSPORTATION ENGINEERING

- **Course Objectives:**
- This course aims at providing a comprehensive insight of various elements of Highway transportation Engineering.
- Topics related to the highway development, characterization of different materials needed for highway construction, structural and geometric design of highway pavements along with the Challenges and possible solutions to the traffic related issues will be covered as a part of this course.

TRANSPORTATION ENGINEERING

- **Course Outcomes:** At the end of this course, the students will develop:
- An ability to apply the knowledge of mathematics, science and engineering in the areas of traffic Engineering, highway development and maintenance.
- An ability to design, conduct experiments to assess the suitability of the highway materials like Soil, bitumen, aggregates and a variety of bituminous mixtures.
- Also the students will develop the ability to interpret the results and assess the suitability of these materials for construction of highways.
- An ability to design flexible and rigid highway pavements for varying traffic compositions as well as soil sub-grade and environmental conditions using the standards stipulated by Indian Roads Congress.
- An ability to evaluate the structural and functional conditions of in-service highway pavements and provide solution in the form of routine maintenance measures or designed overlays using Indian Roads congress guidelines.
- An ability to assess the issues related to road traffic and provide engineering solutions supported with an understanding of road user psychological and behavioral patterns.

History of Highways or Roads

- Roads have been existing in India for the last 5000 years. In early stages of Indian history, Ashoka and Chandragupta made efforts to construct roads. But the real progress was made during the Mughal period.
- A number of roads were laid during the Mughal periods. Most of the present trunk routes follow the Mughal routes. These routes were essential for strengthening and consolidating the empire.
- One such road was constructed by Sher Shah Suri which connected Peshawar to Kolkata. It was named as Grand Trunk (G.T.) Road and joined Amritsar with Kolkata after partition of India in 1947. Presently, it is known as 'Sher Shah Suri Marg'.

IMPORTANCE OF HIGHWAYS OR ROADS

- The importance of highway can be easily judged from the following purposes or advantages of roads:-
- 1. Roads play a very important role in the transportation of goods and passengers for short and medium distances.
- 2. It is comparatively easy and cheap to construct and maintain roads.
- 3. Road transport system establishes easy contact between farms, fields, factories and markets and provides door to door service.
- 4. Roads can negotiate high gradients and sharp turns which railways cannot do. As such, roads can be constructed in hilly areas also.

IMPORTANCE OF HIGHWAY OR ROADS

- 5. They help in price stabilization of commodities due to mobility of products all over the country.
- 6. They help in providing improved medical facilities quickly to human beings, especially to those who live in rural areas.
- 7. They provide more employment opportunities.
- 8. They enhance land value and thus bring better revenue.
- 9. They serve as feeders for airway, waterways and railways.
- 10. They help in reducing distress among the people, caused due to famine, by supplying them food and clothing quickly.
- 11. They play a very important role in the defense of a country during war days.

  Lastly, it can be said that roads are the symbol of a country's progress and thus development made by any country can be judged by the quality and network of its road system.

CHARACTERISTICS OF ROAD TRANSPORT

1) Road transport offers complete freedom to road user to transfer the vehicle from one lane to other.
2) It gives quick and easy transportation of men, machineries, materials etc.
3) Road transport serves the agricultural area by transporting of goods.
4) Roads are used by various categories of vehicles.
5) Construction and maintenance of road transport is cheaper
6) Road transport is a basic need in case of fire and police protections.
7) It gives door step connectivity even in case of rural area or villages.
8) It is important access to reach railways, waterways and airways.

HIGHWAY DEVELOPMENT IN INDIA

- 1.Roads in Ancient India
- 2.Road development in India during Twentieth Century
- 3.Road development in India during twenty first century

HIGHWAY DEVELOPMENT IN INDIA

- **1.Roads in Ancient India**
- **1.1. Ancient Roads**:
- Ancient history of India reveals that long long ago; Indians knew the science of road construction.
- Excavation of Mohenjo-Daro and Harappa have significant information of the existence roads,2500-3000 B.C
- The excavations at Mohenjo-Daro and Harappa (Pakistan) have established that even 3500 years BC, there was a well designed network of roads, and streets were paved at that time.
- From the old records get the unknown information and they considered the necessity of the roads for administrative and military purposes

HIGHWAY DEVELOPMENT IN INDIA

- **Aryan period:** The scriptures says that existence of roads during the Aryan period in the fourth century B.C kautilya is laid down the rules that title is “ARTHASASTRA”
- In Arthasastra rules have been mentioned about the depth of road and for different kinds of traffic
- And mention the punishment for any obstruction of roads.
- In the beginning of 5^{th} century A.D *Ashoka* had improved the roads and facilities for travelers.

Ancient Greek Roads –

Note grooves and large stone blocks

HIGHWAY DEVELOPMENT IN INDIA

- ***1.2.Roads in Mughal Period:***
- The roads were very greatly improved in India during the Mughal period.
- Mughals received great appreciation from the foreign visitors.
- The road system in those days was considered as one of the best road systems in the world.
- Many of roads, constructed during Mughal period exist even today.
- During this period, roads were developed on technical basis specifications were laid down for width of roads, and given to the surface of roads.

HIGHWAY DEVELOPMENT IN INDIA

- ***1.3.Roads in Nineteenth century*:**
- After the fall of the Mughals and at the beginning of British rule, many existing roads were improved.
- At the beginning of the British period, a number of old Mughal roads, connecting important military and business centers were metal road and some new roads were constructed by Military .
- The construction of Grand-Trunk road from Calcutta, through Delhi to Peshawar is a major contribution of the British.
- However, the focus was later shifted to railways, except for feeder roads to important stations

HIGHWAY DEVELOPMENT IN INDIA

- ***2.Road development in India during Twentieth Century:***
- ***2.1.Jayakar committee recommendations:***
- After the Ist world war, motor vehicles using the road users increased and their demanded a better road network which can carry both Bullock cart traffic and Motor vehicles.
- The existing roads are not capable to withstand the mixed traffic conditions

HIGHWAY DEVELOPMENT IN INDIA

- A resolution was passed by both chambers of the Indian legislature 1927 for the appointment of a committee to examine and report on the question of road development in India.
- In response to the resolution Indian Road Development was appointed by the Government with Mr. Jayakar as the Chairman in 1927.
- The Jayakar Committee submitted its report by the year 1928

HIGHWAY DEVELOPMENT IN INDIA

- ***The most important recommendations made by the committee are*:**

1.Road development should be made a national interest since the provincial and local govt do not have financial and technical capacity for road development.

2.Levy extra tax on petrol from road users to create the road development fund.

HIGHWAY DEVELOPMENT IN INDIA

3.To establish a semi-official ,technical institutions to pool technical knowledge, sharing of ideas and to act as an advisory body.

4.To create a national level institution to carry research , development works and consultation.

- Most of the recommendations of Jayakar Committee were accepted by the Govt., and the major items were implemented subsequently.

HIGHWAY DEVELOPMENT IN INDIA

- **IMPLEMENTATIONS:**
- Majority of the recommendations were accepted by the government implemented by Jayakar Committee.
- Some of the technical bodies were formed such as,
- 1.Central Road Fund (CRF) in 1929
- 2.Indian Roads Congress (IRC) in 1934
- 3. Motor Vehicle Act
- 4. Nagpur road conference and plan
- 5.Central Road Research Institute (CRRI) in 1950.
- 6. National highway act
- 7. Second 20 year road development plan
- 8. Highway research board

HIGHWAY DEVELOPMENT IN INDIA

- ***Central Road Fund***:
- Central Road Fund (C.R.F) was formed on 1st march 1929
- Extra 2.64 Paise per litre of petrol were charged from consumers
- From this they got 20% of annual revenue to build up this roads
- Balance 80% is allotted by central govt for various works based on actual consumption petrol
- CRF are maintained by the accountant General of central revenue and control on the expenditure is by the Roads wing of Ministry of Transport

HIGHWAY DEVELOPMENT IN INDIA

- ***Indian Roads Congress:***
- Central semi official body known as Indian Road Congress (IRC) was formed in 1934
- Pooling of experience and ideas on the all matters affecting the planning, construction and maintenance
- It is active body controlling the specifications, standards and recommendations on materials, design of roads and bridges
- it publishes journals, research publications, standard specification guide lines

HIGHWAY DEVELOPMENT IN INDIA

- ***Motor* Vehicle Act:**
- It was formed in 1939
- To regulate the road traffic in the form of traffic laws, ordinances and regulations
- 3 phases primarily covered are control of driver, vehicle ownership and vehicle operation
- This was revised on 1988

HIGHWAY DEVELOPMENT IN INDIA

- ***Nagpur road conference and plan:***
- A conference of the chief engineer of all states and was convened in 1943 by the govt. of India at nagpur
- IRC has taken the initiation to finalize the first road development plan for the country as a whole.
- This is land mark in the history of road development in India.
- The First 20 year road development plan in India was finalized for the period 1943-1963 at the Nagpur.
- There fore this road development plan is popularly known as Nagpur road plan.

HIGHWAY DEVELOPMENT IN INDIA

- **Central road research institute** :
- In the year 1950 the CRRI was started at New Delhi for carrying out research pertaining to road technology.
- It came into existence for research in various aspects of highway engineering.
- It is engaged in carrying R&D projects on design, construction and maintenance of roads and runways.
- And also offers technical advise to state govt. and industries on various problems on road works.

HIGHWAY DEVELOPMENT IN INDIA

- ***Second 20 year road development plan:***
- The second 20 year road development plan for the period 1961-81 i.e initiated by the IRC in the year 1959 at mumbai.
- This plan is also called as mumbai road development plan.

HIGHWAY DEVELOPMENT IN INDIA

- ***Highway research board***
- The HRB of the Indian road congress was set up in 1973 to give proper direction and guidance to road research activities in India.
- the objectives of HRB:
  1. Find out the nature and extent of research required.
  2. To correlate research information from various organization in India and abroad
  3. Channelize the consultative services
  4. Collect and circulate results of research

HIGHWAY DEVELOPMENT IN INDIA

- ***3rd 20 year road development plan*:**
- The 3rd 20 year road development plan 1981-2001 this also called lucknow plan.

DIFFERENT ROAD DEVELOPMENT PLANS

- **The road development plans are**

1. Nagpur road development plan or 1st 20 year road development plan
2. Mumbai road development plan or 2nd 20 year road development plan
3. Lucknow plan or 3rd 20 year road development plan.
4. road development plan : vision 2021
5. Rural road development plan : vision 2025

DIFFERENT ROAD DEVELOPMENT PLANS

- ***1. Nagpur road*** **development** ***congress 1943-1963***
- The second World War saw a rapid growth in road traffic and this led to the deterioration in the condition of roads.
- To discuss about improving the condition of roads, the government arrange a conference of chief engineers of provinces at Nagpur in 1943.
- The result of the conference is famous as the Nagpur plan.
- A twenty year development programme for the period (1943-1963) was finalized. It was the first attempt to prepare a coordinated road development programme in a planned manner
- One of the objective was that the road length should be increased so as to give a road density of 16kms per 100 sq.km

DIFFERENT ROAD DEVELOPMENT PLANS

- The length of roads under the Nagpur plan was achieved by the end of it, but the road system was deficient in many respects.
- The changed economic, industrial and agricultural conditions in the country justify a review of the Nagpur plan.
- Accordingly a 20-year plan was drafted by the Roads wing of Government of India, which is popularly known as the Bombay plan.

DIFFERENT ROAD DEVELOPMENT PLANS

- The conference of chief engineer held at Nagpur in 1943 finalized the first twenty year road plan
- The road network in the country classified into five categories

✓ National highways (N.H)

✓ State highways (S.H)

✓ Major district roads (M.D.R)

✓ Other district roads (O.D.R)

✓ Village roads (V.R)

DIFFERENT ROAD DEVELOPMENT PLANS

Salient features of Nagpur road plan:

- Responsibility of construction and maintenance of N.H was assigned to the central govt
- Aim 2 lakh km of surface road remaining unsurface road, total length 5,32,700 km
- The formulae were based on star and grid pattern of road network
- At the end of this plan the target road length aimed at was 16 km per 100 Square kilometer area of the country.
- 2nd cat roads meant for linking villages with 1st cat roads.
- Length of railway track considered for deciding the first category

DIFFERENT ROAD DEVELOPMENT PLANS

2. Road development plan 1961-1981:(Bombay Plan):

- It was the second 20 year road plan (1961-1981)
- The total road length targeted to construct was about 10 lakhs.
- Rural roads were given specific attention. Scientific methods of construction was proposed for the rural roads.
- The necessary technical advice to the Panchayaths should be given by State PWD's(Public Works Dept).
- They suggested that the length of the road should be increased so as to give a road density of 32kms/100 sq.km
- The construction of 1600 km of expressways was also then included in the plan
- The target road length at the end of this second 20 year plan was almost double that of Nagpur road plan target.
- Total length of road 10,57,330 km, cost 5200 crores based on 1958 rates

DIFFERENT ROAD DEVELOPMENT PLANS

Salient features of the 2nd 20 yrs plan

- Target 32 km/ 100 sqkm
- Agricultural area would be 6.4km from metalled road 2.4km from any cat roads
- Max distance of semi development area would be 12.8km from metalled road and 4.8km any road
- Max distance of un development area would be 19.2km from metalled road and 8km any road
- Every town with population 2000 in plain,1000 in semi hilly, 500 hilly areas connect metalled road.
- Express ways have also considered in this plan 1600 km of length, included in the proposed road
- Length of track is considered independent of the road system and hence not subtracted.
- 5% was taken for development allowance for next 20 yrs

DIFFERENT ROAD DEVELOPMENT PLANS

3. Road development plan 1981-2001:

- This was the third 20 year road plan (1981-2001). It is also called Lucknow road plan
- It aimed at constructing a road length of 12 lakh kilometers by the year 1981 resulting in a road density of 82kms/100 sq.km
- The plan has set the target length of NH to be completed by the end of seventh, eighth and ninth year plan periods.

DIFFERENT ROAD DEVELOPMENT PLANS

3.Road development plan 1981-2001:

Silent features of 3rd Road Development Plan:

- ✓ It aimed at constructing a road length of 12 lakh kilometers by the year 1981 resulting in a road density of 82kms/100 sq.km
- ✓ It aims at improving the transportation facilities in villages, towns etc. such that no part of country at a distance 50 km from NH.
- ✓ Expressways should be constructed on major traffic corridors to provide speedy travel.
- ✓ Energy conservation, environmental quality of roads and road safety measures were also given due importance in this plan.
- ✓ National Highways should form a square grid of 100 km x 100 km.

DIFFERENT ROAD DEVELOPMENT PLANS

Silent features of 3rd Road Development Plan:

- ✓ State Highways should be extended to serve the district headquarters, sub-divisional (taluka) headquarters, major industrial centers, places of commercial interest, places of tourist attraction, major agricultural market centers and ports.
- ✓ The Major District Roads should serve and connect all towns and villages with a population of 1,500 and above.
- ✓ The other District Roads should serve and connect villages with a population of 1,000 to 1,500.
- ✓ An all-weather road should connect all villages or groups of villages with a population of 500 and above by 2001.
- ✓ For villages less than a population of 500, the road network shall be so planned as to result in an all-weather road being available at a distance of less than 3 km in plain areas and 5 km in hilly terrain.

DIFFERENT ROAD DEVELOPMENT PLANS

- **4.Road Development plan : Vision 2021:**
- 4^{th} 20 year Road Development plan is 2001-2021
- And it is established in the year 2000
- this road development is prepared by the IRC with the initiation of ministry of road transport and highways. (MORTH).
- This vision has considered the need for overall development of road system in the country.
- The total target length of primary and secondary road system to be achieved in the country by the year 2020

DIFFERENT ROAD DEVELOPMENT PLANS

- **5. Rural road development plan: vision 2025:**
- The above road development plan has been prepared for the 20 year period 2005-2025 with the initiation of MORTH
- Dist vise rural road development plans have been prepared.
- This vision targets to provide connectivity to all unconnected habitations (living permanently in a place) of the country in a phased manner.

NECESSITY OF HIGHWAY PLANNING

- In the present days long period planning is necessary before attempting any development programme.
- In any Engineering work planning is basic requirement for any new project or an expansion programme.
- Highway planning is also a basic need for highway development.
- Particularly planning is of great importance when the available funds are limited where as the total requirement is much higher

NECESSITY OF HIGHWAY PLANNING

- In the present days long period planning is necessary before attempting any development programme.
- In any Engineering work planning is basic requirement for any new project or an expansion programme.
- This is actually the problem in all developing countries like India for utilization of funds systematic and planned way.

NECESSITY OF HIGHWAY PLANNING

- *The objects of Highway planning are briefly given below:*

1. To provide safe and efficient roads at minimum cost.
2. To plan for future requirements and improvements of roads in view of anticipated(expected) developments.
3. To divide the overall plan into phases and to decide priorities.
4. Defining the highway planning process, establishing necessary standards, and auditing performance;
5. To optimize the usage of roads with available resources

NECESSITY OF HIGHWAY PLANNING

- *The objects of Highway planning are briefly given below:*

6. The highway should be as direct as possible between the cities to be linked, as it will result in economy in construction, maintenance and operation
7. To construct the best possible road system having maximum utility within the available resources.
8. To fix up the priorities for future development on utility basis.
9. Evolving a financing system compatible with the cost and benefits.
10. Define study constrains, e.g ,time, cost, available resources, etc.

CLASSIFICATIONS OF ROADS

- **TYPES OF ROADS**
  - ✓ Based on Seasons(Weather) of the year
  - ✓ Based on type of carriage way
  - ✓ Based on type of pavement surface
  - ✓ Based on Location and function or *Classification of Rural Roads or Non urban Roads*
  - ✓ Based on 3rd 20 year road plan
  - ✓ Classification of Urban Roads

CLASSIFICATION OF ROADS

- **Depending on whether**
- ✓ All weather roads: Those which are negotiable during all weather.
- ✓ Fair weather roads: Traffic may be interrupted during monsoon season at cause way where stream may over flow across the road

CLASSIFICATION OF ROADS

- **Depending on whether**
- All weather roads: Those which are negotiable during all weather.
- Fair weather roads: Traffic may be interrupted during monsoon season at cause way where stream may over flow across the road

CLASSIFICATION OF ROADS

ALL WEATHER ROADS

FAIR WEATHER ROADS

CLASSIFICATION OF ROADS

- **Based on the type of the carriage way :**
- Paved roads: Provided with a hard pavement course which should be atleast WBM

- Unpaved roads: Not provided with a hard pavement course which should be atleast WBM

CLASSIFICATION OF ROADS

Paved roads

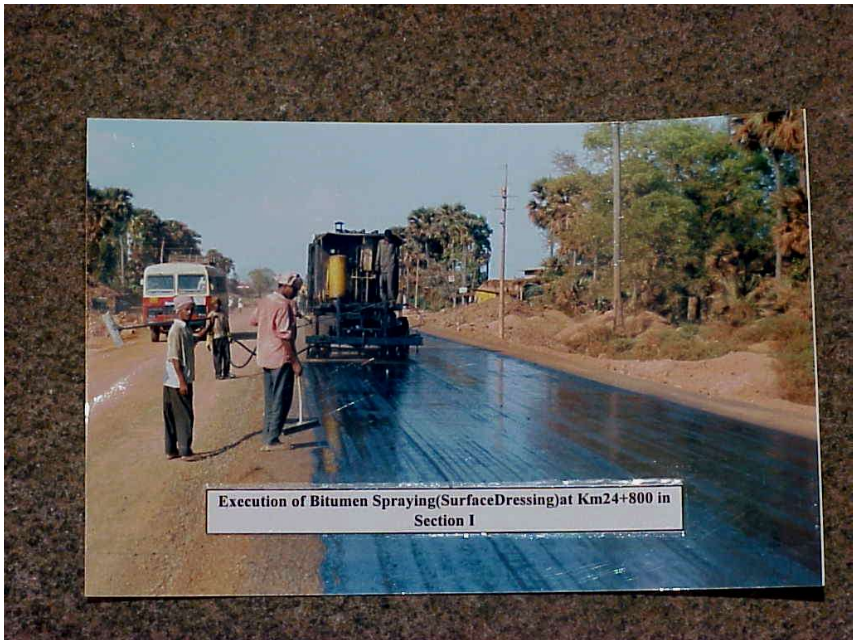
Unpaved roads

CLASSIFICATION OF ROADS

- **Based on type of pavement surfacing:**
- Surface roads: Provided with a bituminous or cement concrete surfacing.
- Unsurfaced roads: Not provided with a bituminous or cement concrete surfacing,
- the roads are provided with bituminous surfacing are also called as *black toped roads*

CLASSIFICATION OF ROADS

SURFACE ROAD **UN SURFACE ROAD**



CLASSIFICATION OF ROADS

Based on Location and function or Classification of Rural Roads:

- National Highway :
- State Highway :
- Major district Roads :
- Minor or Other District Roads :
- Village Roads :

CLASSIFICATION OF ROADS

- **National highways:**
- Major ports, foreign highways, state capitals, large industries and tourist centers
- India has a huge network of national highways.
- The national highways have a total length of 70,548 kms. Indian highways cover 2% of the total road network of India and carry 40% of the total traffic.
- The entire highway network of India is managed by the National Highway Authority of India which is responsible for development and maintenance of highways
- The shortest highway is NH47A which stretches from Ernakulam to Kochi and covers total length of 4 Kms.

CLASSIFICATION OF ROADS

- **State highways:**
- Linking the district headquarters and important cities with in the state
- They are the arterial roads of a state, connecting up with the national highways of adjacent states, district head quarters and important cities within the state.
- Total length of all SH in the country is 1,37,119 Kms.
- **Major district roads:**
- Important roads with in the district, serving areas of production and markets
- Important roads with in a district serving areas of production and markets , connecting those with each other or with the major highways.
- India has a total of 4,70,000 kms of MDR.

CLASSIFICATION OF ROADS

- **Other district roads:**
- Production-markets, taluka and tehsil head quarters
- Roads serving rural areas of production and providing them with outlet to market centers or other important roads like MDR or SH.
- **Village roads:**
- They are roads connecting villages or group of villages with each other or to the nearest road of a higher category like ODR or MDR.
- India has 26,50,000 kms of ODR+VR out of the total 33,15,231 kms of all type of roads.
-

CLASSIFICATION OF ROADS

- **Based on 3rd 20 year road plan:**
- Primary System: (Expressway & NH)
- Secondary System (SH & MDR)
- Tertiary System or Rural Roads (ODR & VR)

CLASSIFICATION OF ROADS

- **Expressways:**
- Expressways are the highest class of roads in India
- All the expressways are six or more-lane
- Connects major parts of traffic generation and long lengths between commercial, industrial and residential areas, CBD(Central Business District).etc
- They are superior type of highways and are designed for high speeds (120 km/hr is common), high traffic volume and safety.
- They are generally provided with grade separations at intersections
- Parking, loading and unloading of goods and pedestrian traffic is not allowed on expressways

CLASSIFICATIONS OF ROADS(URBAN)

- **Classification of Urban roads**
  - ✓ Arterial
  - ✓ Sub arterial
  - ✓ Collector street
  - ✓ Local street

CLASSIFICATIONS OF ROADS(URBAN)

- **Arterial Roads:**
- Exiting or proposed expressway to provide distribution and collection. Parking, loading and unloading restricted and regulated.
- No frontage access, no standing vehicle, very little cross traffic.
- Design Speed : 80km/hr
- Land width : 50 – 60m
- Spacing 1.5km in CBD(Central Business District) & 8km or more in sparsely developed areas.
- Divided roads with full or partial parking
- Pedestrian allowed to walk only at intersection

CLASSIFICATIONS OF ROADS(URBAN)

- **Sub arterial:**
- Carrying through traffic, it has less traffic mobility
- Bus stops but no standing vehicle.
- Less mobility than arterial.
- Spacing for CBD : 0.5km
- Sub-urban fringes : 3.5km
- Design speed : 60 km/hr
- Land width : 30 – 40 m

CLASSIFICATIONS OF ROADS(URBAN)

- **Collector street:**
- Collects and distributes traffic from local streets
- Provides access to arterial roads
- Located in residential, business and industrial areas.
- Full access allowed.
- Parking permitted.
- Design speed : 50km/hr
- Land Width : 20-30m

CLASSIFICATIONS OF ROADS(URBAN)

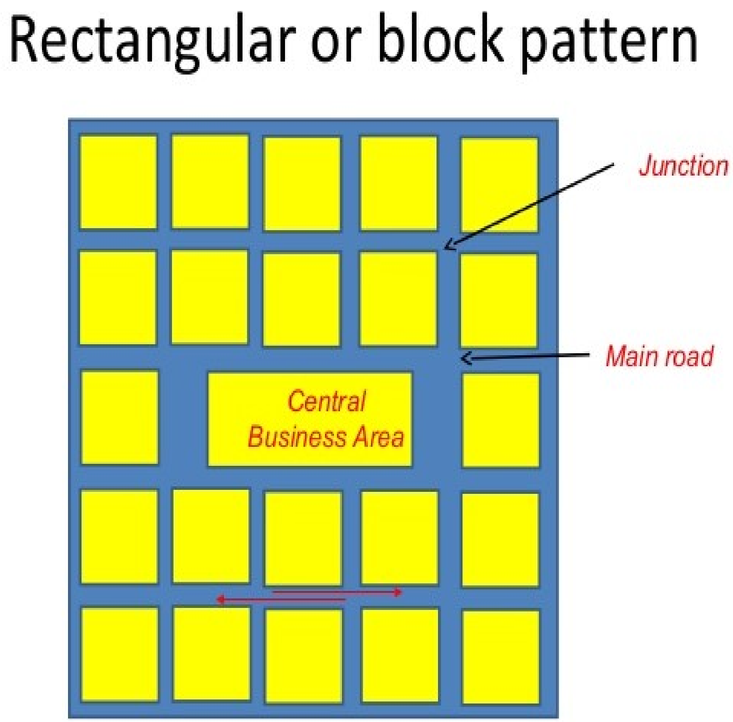
- **Local streets:**
- Design Speed : 30km/hr.
- Land Width : 10 – 20m.
- Primary access to residence, business or other abutting property
- Less volume of traffic at slow speed
- Origin and termination of trips.
- Unrestricted parking, pedestrian movements. (with frontage access, parked vehicle, bus stops and no waiting restrictions)

ROAD PATTERNS

- ***Different Road Patterns are:***
- Rectangular or block pattern
- Radial or star and block pattern
- Radial or star and circular pattern
- Radial or star and grid pattern
- Hexagonal pattern
- Min travel pattern

ROAD PATTERNS

RECTANGULAR OR BLOCK PATTERN

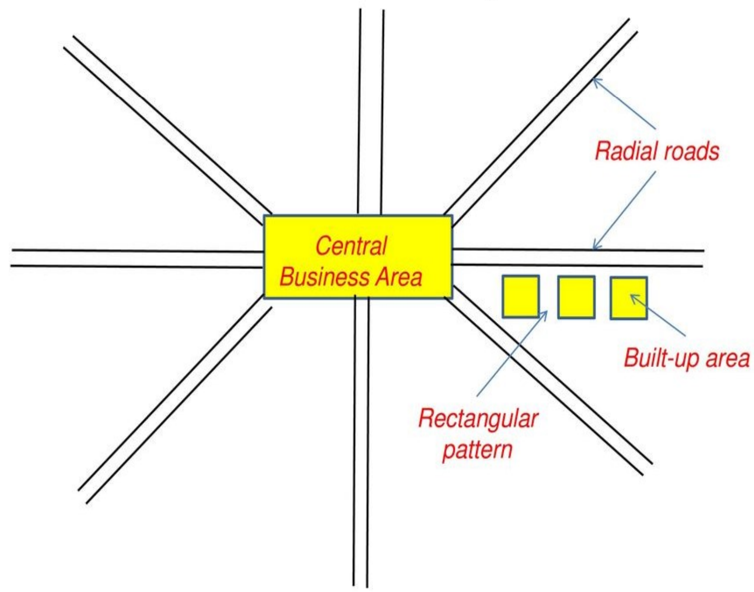


- In this pattern, the whole area is divided into rectangular blocks of plots, with streets intersecting at right angles.
- The main road which passes through the center of the area should be sufficiently wide and other branch roads may be comparatively narrow.
- The main road is provided a direct approach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

ROAD PATTERNS

Radial or star and block pattern

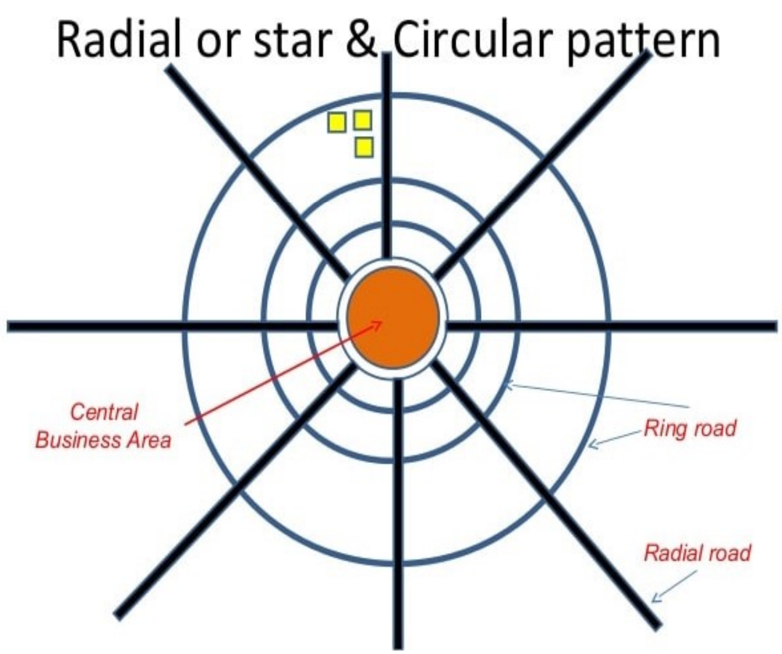
Radial or star & block pattern



- In this pattern, the entire area is divided into a network of roads radiating from the central business area.
- In between radiating main roads, the built-up area may be planned with rectangular block.

ROAD PATTERNS

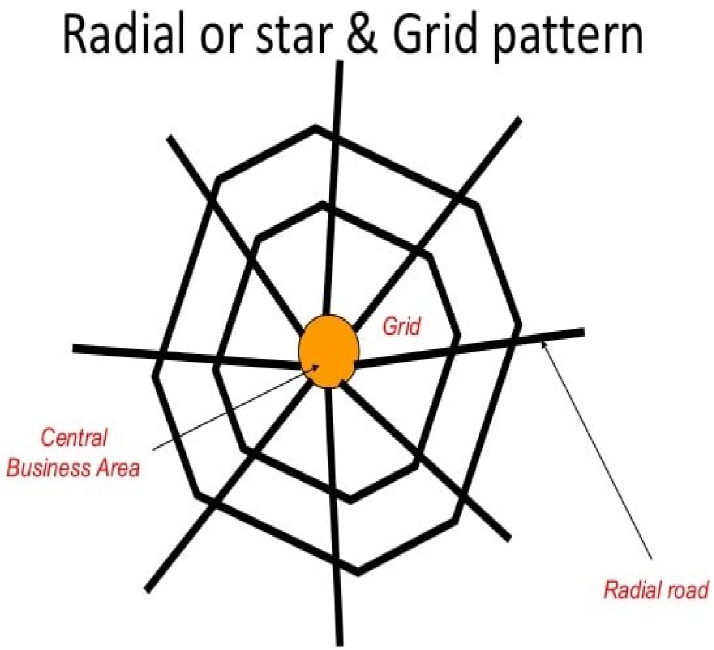
Radial or star and circular pattern



- In this system, the 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, the built-up area is planned with a curved block system.

ROAD PATTERNS

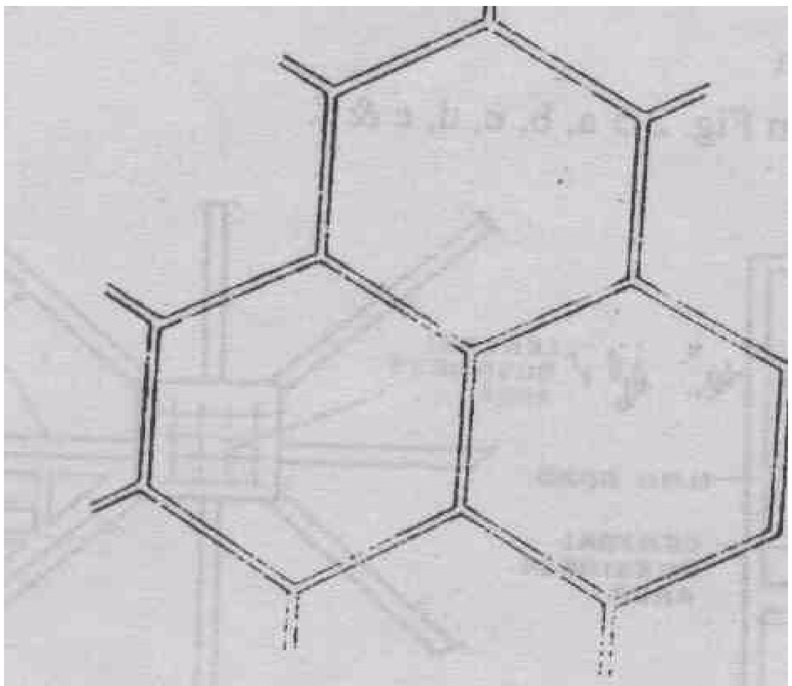
Radial or star and grid pattern



- This pattern is formed by the combination of Star and Grid Pattern.
- As in other, a radial network of road radiates from the centre business area. Then, the main radial streets are interconnected by providing a grid pattern..

ROAD PATTERNS

HEXAGONAL PATTERN

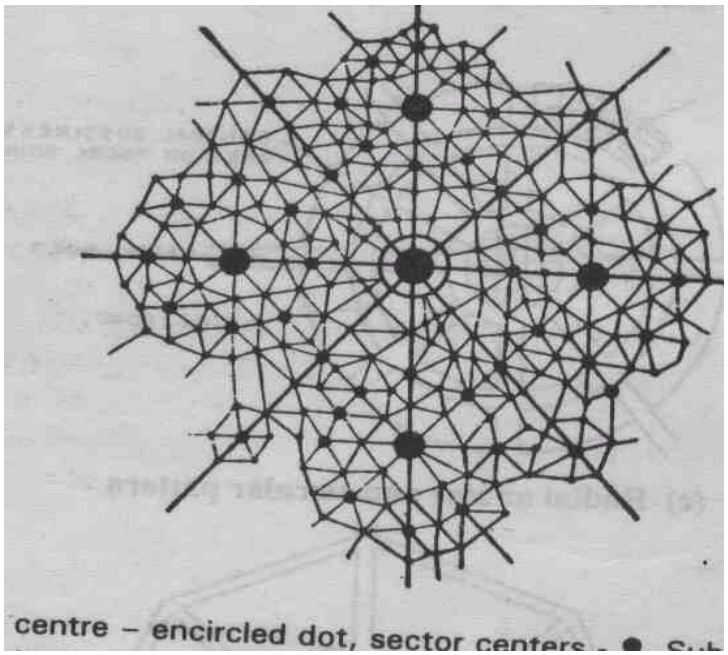


(e) Hexagonal pattern

- In this, the entire area is divided into hexagonal patterns.
- Three roads meet the built-up area boundary by the sides of the hexagons at every corner of the hexagon which can be further divided in suitable sizes.

ROAD PATTERNS

MINIMUM TRAVEL PATTERN



- In this, the city centre is connected with suburban centers and neighbor centers with the shortest roads.
- To make road short; road alignment is made straight.

HIGHWAY ALIGNMENT

- The position or lay out of centre line of the highway on the ground is called the alignment.
- It includes straight path, horizontal deviation and curves.
- Due to improper alignment ,the disadvantages are,
  - Increase in construction
  - Increase in maintenance cost
  - Increase in vehicle operation cost
  - Increase in accident cost
- Once the road is aligned and constructed, it is not easy to change the alignment due to increase in cost.

HIGHWAY ALIGNMENT

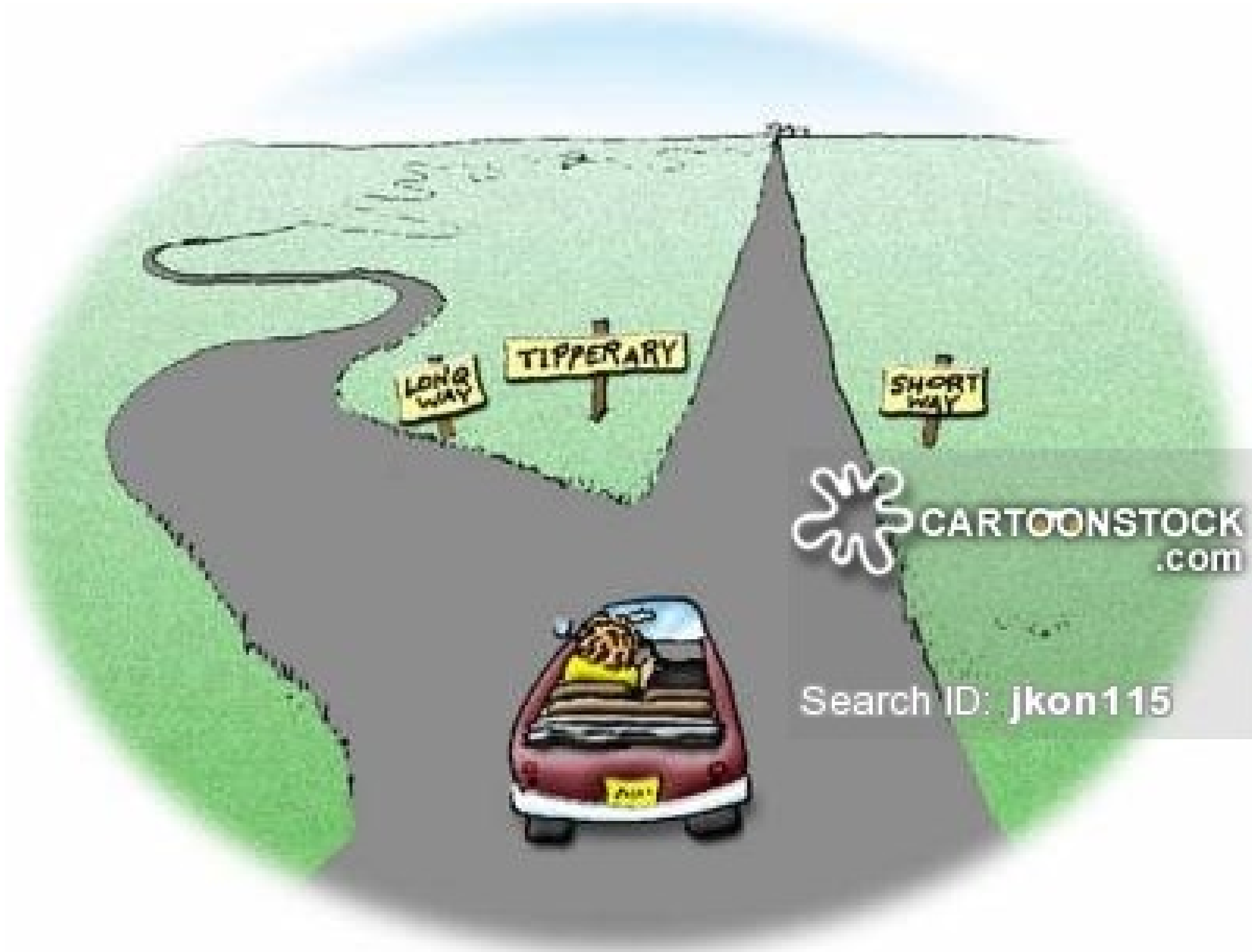
HORIZONTAL ALIGNMENT

VERTICAL ALIGNMENT

HIGHWAY ALIGNMENT

- **Requirements of highway alignment:**
- **Short**
  - Desirable to have a short alignment between two terminal stations.
- **Easy**
  - Easy to construct and maintain the road with minimum problem and also easy for operation of vehicle.
- **Safe**
  - Safe enough for construction and maintenance from the view point of stability of natural hill slope, embankment and cut slope also safe for traffic operation.
- **Economical**
  - Total cost including initial cost, maintenance cost and vehicle operation cost should be minimum.

Highway Alignment – Requirements
Short



HIGHWAY ALIGNMENT

- **Factors controlling alignment:**
- The various factors which control the highway alignment in general may be listed as:
- ✓ Obligatory points
- ✓ Traffic
- ✓ Geometric design
- ✓ Economics
- ✓ Other considerations

Additional care in hill roads

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

FACTORS CONTROLLING ALIGNMENT

- **Obligatory points**
- They are control points governing the alignment of the highways. These points may be divided into two categories
- Obligatory points through which alignment is to pass
  - Examples:-bridge site, intermediate town , Mountain pass etc…
- Obligatory points through which alignment should not pass.
  - Examples:-religious places, costly structure, unsuitable land etc…
- **Traffic**
- Origin and destination survey should be carried out in the area and the desire lines be drawn showing the trend of traffic flow.
- New road to be aligned should keep in view the desired lines, traffic flow patterns and future trends

FACTORS CONTROLLING ALIGNMENT

- **Geometric design:**
- Design factors such as gradient, radius of curve and sight distance also govern the final alignment of the highway.
- Gradient should be flat and less than the ruling gradient or design gradient.
- Avoid sudden changes in sight distance, especially near crossings
- Avoid sharp horizontal curves
- Avoid road intersections near bend

FACTORS CONTROLLING ALIGNMENT

- **Economy**
- Alignment finalized based on total cost including initial cost, maintenance cost and vehicle operation cost.
- The initial cost of construction decreased when high embankment and deep cutting are avoided and the alignment is chosen in a manner to balance the cutting and filling.
- **Other consideration**
  - Drainage consideration, political consideration
  - Surface water level, high flood level
  - Environmental consideration

ENGINEERING SURVEYS FOR HIGHWAY LOCATIONS

1) Provisional alignment Identification (Map study)
2) Reconnaissance survey
3) Preliminary survey
4) Final location to and detailed survey

ENGINEERING SURVEYS FOR HIGHWAY LOCATIONS

- **Map study:**

➢ If the topographic map of the area is available, it is possible to decide the roads of route.

➢ In India the topographic maps are available from the survey of India, with 15 or 30meter contour intervals

➢ The main features like rivers, hills, valleys etc are also shown on these maps.

➢ By careful steady of these maps, It is possible alternative routes are decided.

ENGINEERING SURVEYS FOR HIGHWAY LOCATIONS

- The possible alignment can be located on the map from the following details available

a) Alignment avoiding valleys, ponds or lakes.

b) When the road has to cross a number of hills, possibility of crossing through a mountain pass.

c) Approximate location of bridge site for crossing rivers, avoiding bend of the river if any

d) When road is to be connected two stations, one is at top and other one is foot of the hill, then alternative route can be suggested.

ENGINEERING SURVEYS FOR HIGHWAY LOCATIONS

- **RECONNAISSANCE:**

➢ The second stage of survey for highway location is the reconnaissance.

➢ It is to examine the general character of the area for deciding the most feasible routes for detailed studies.

➢ Only few simple instruments like level tangent clinometers, barometer or GPS are used by the reconnaissance party to collect additional details rapidly.

➢ Some of the details to be collected during reconnaissance are given below:

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

ENGINEERING SURVEYS FOR HIGHWAY LOCATIONS

2. Approximate values of gradient, length of gradients and radius of curves of alternative alignments.
3. Soil type along the routes from the field identification tests and observation of geological features.
4. Sources of construction materials, water and location of stone quarries.
5. When the road passes through hilly or mountainous terrain, additional data regarding the geological formation, type of rocks, seepage flow etc.

ENGINEERING SURVEYS FOR HIGHWAY LOCATIONS

- **PRELIMINARY SURVEY**:
- The main objectives of preliminary surveys are:

1. To survey the various alternative alignments proposed after the reconnaissance and to collect all the necessary physical information and details of topography, drainage and soil.
2. To compare different proposals in view of the requirements of a good alignment.
3. To estimate the quantity of earth work materials and other construction aspects and workout the cost of alternative proposals.
4. To finalise the best alignment from all considerations

ENGINEERING SURVEYS FOR HIGHWAY LOCATIONS

- **FINAL LOCATION AND DETAILED SURVEY**:
- The alignment finalised at the design office after the preliminary survey is to be first located on the field by establishing the centre line.
- The centre line of the road finalized is to be translated on the ground during the location survey
- The centre line stakes are driven at suitable intervals say 50 m in plain and rolling terrains and at 20 m in hilly terrain.
- Temporary bench marks are fixed at intervals of about 250 m and at all drainage and under pass structures
- The data collected during the detailed survey should be elaborate and complete for preparation of detailed plans, design and estimate of the project.

DRAWINGS AND REPORT

1) Key map
2) Index map
3) Preliminary survey plans
4) Detailed plan and longitudinal section
5) Detailed cross section
6) Land acquisition plans
7) Drawings of cross drainage and other retaining structures
8) Drawings of road intersections
9) Land plans showing quarries etc

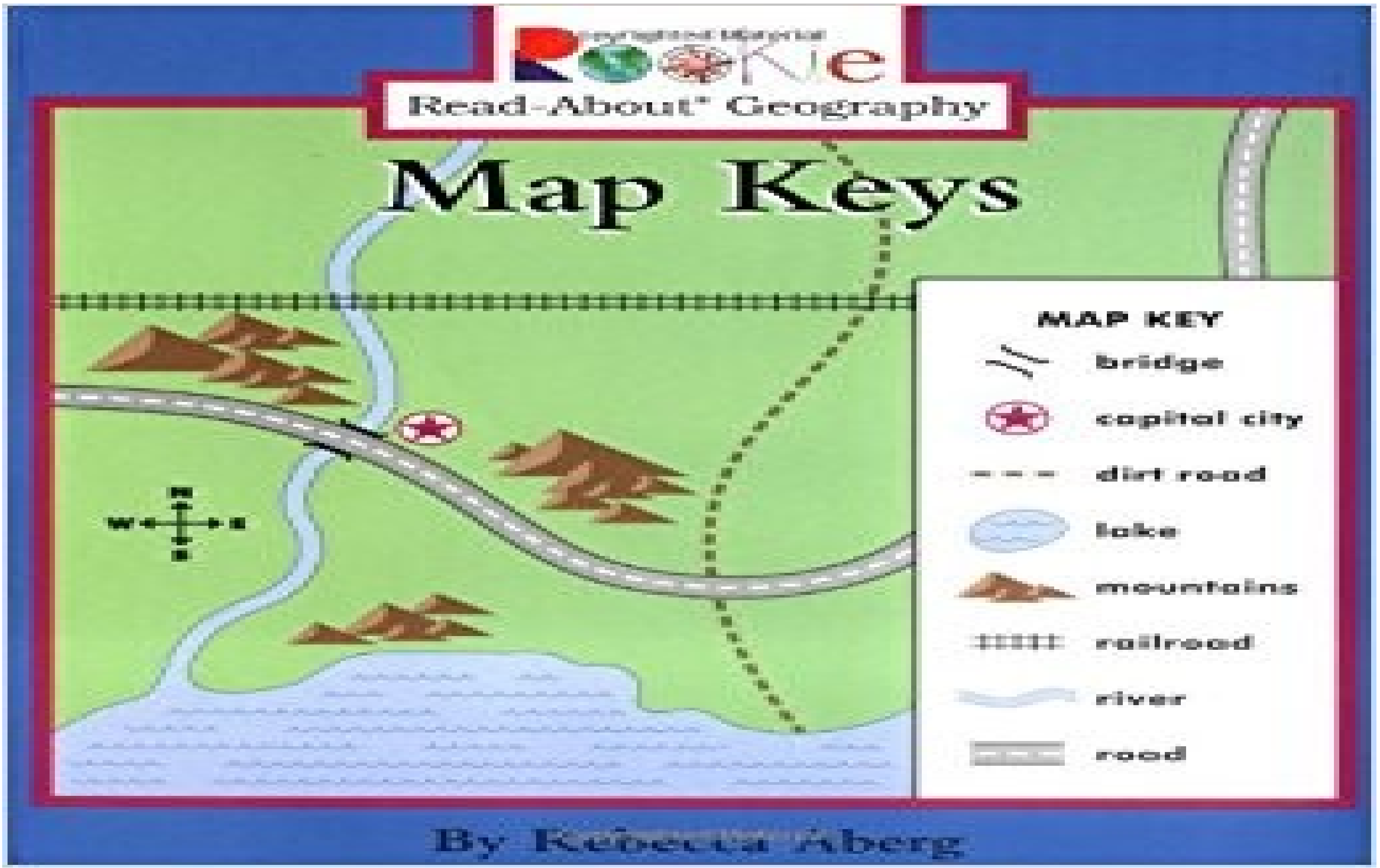
DRAWINGS AND REPORT

1) Key map
2) Index map
3) Preliminary survey plans
4) Detailed plan and longitudinal section
5) Detailed cross section
6) Land acquisition plans
7) Drawings of cross drainage and other retaining structures
8) Drawings of road intersections
9) Land plans showing quarries etc

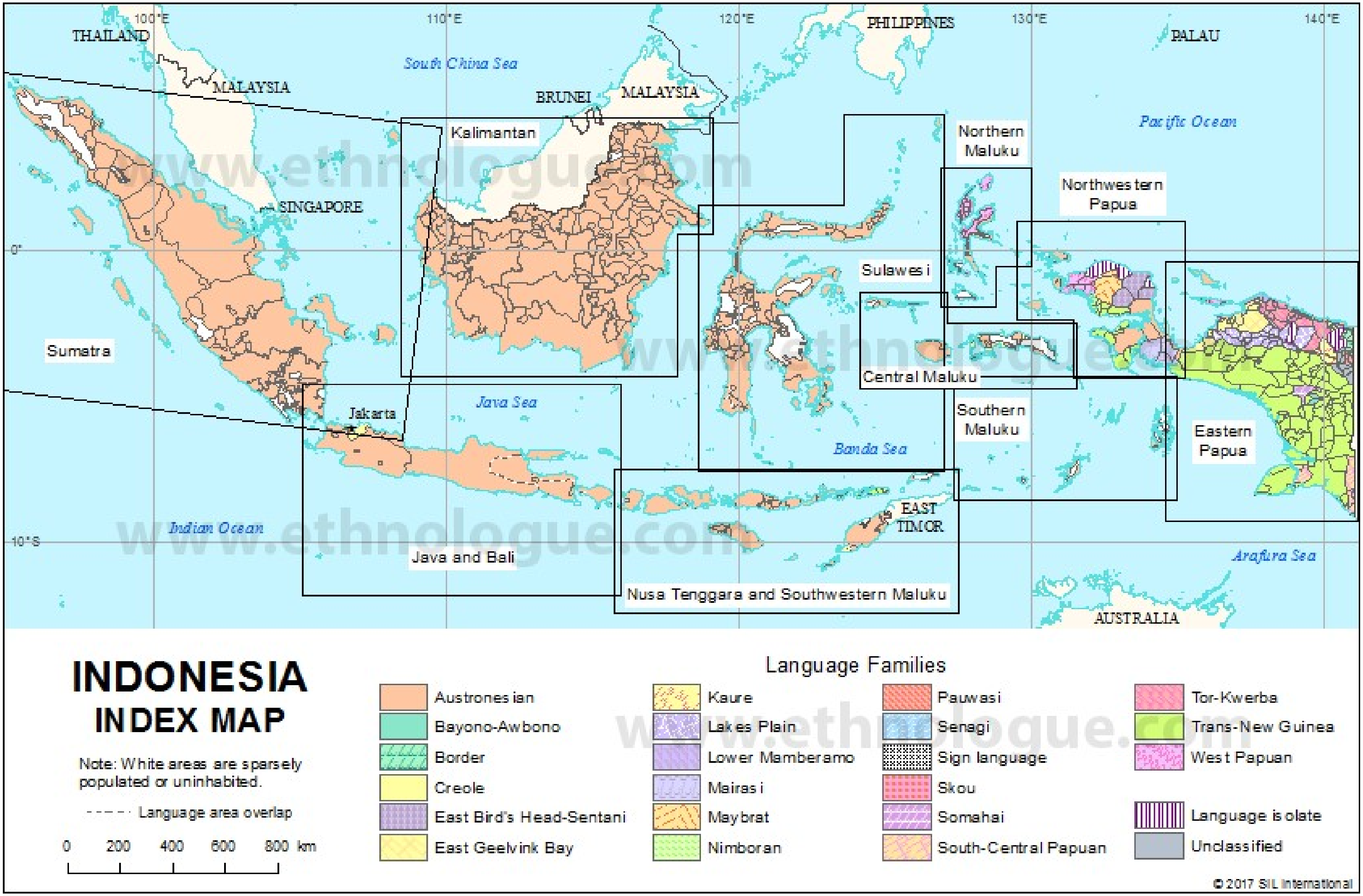
DRAWINGS AND REPORT

- **Key Map**:
- Key map shows the proposed roads and existing roads, and shows the important places to be connected
- The size of the plan generally should not exceed 22*20 cm.
- **Index Map**:
- This map shows the general topography of the area.
- The details are symbolically mentioned.
- The map size being 32*20 cm.

DRAWINGS
KEY MAP



INDEX MAP


100°E
110°E
120°E
130°E
140°E
THAILAND
MALAYSIA
South China Sea
BRUNEI
MALAYSIA
PHILIPPINES
PALAU
Pacific Ocean
SINGAPORE
Kalimantan
Northern Maluku
Northwestern Papua
Sulawesi
Sumatra
Central Maluku
Southern Maluku
Eastern Papua
Jakarta
Java Sea
Banda Sea
EAST TIMOR
Indian Ocean
Java and Bali
Nusa Tenggara and Southwestern Maluku
Arafura Sea
AUSTRALIA
0°
10°S
INDONESIA
INDEX MAP
Note: White areas are sparsely populated or uninhabited.
Language area overlap
0 200 400 600 800 km
Language Families
Austronesian
Bayono-Awbono
Border
Creole
East Bird's Head-Sentani
East Geelvink Bay
Kaure
Lakes Plain
Lower Mamberamo
Mairasi
Maybrat
Nimboran
Pauwasi
Senagi
Sign language
Skou
Somahai
South-Central Papuan
Tor-Kwerba
Trans-New Guinea
West Papuan
Language isolate
Unclassified
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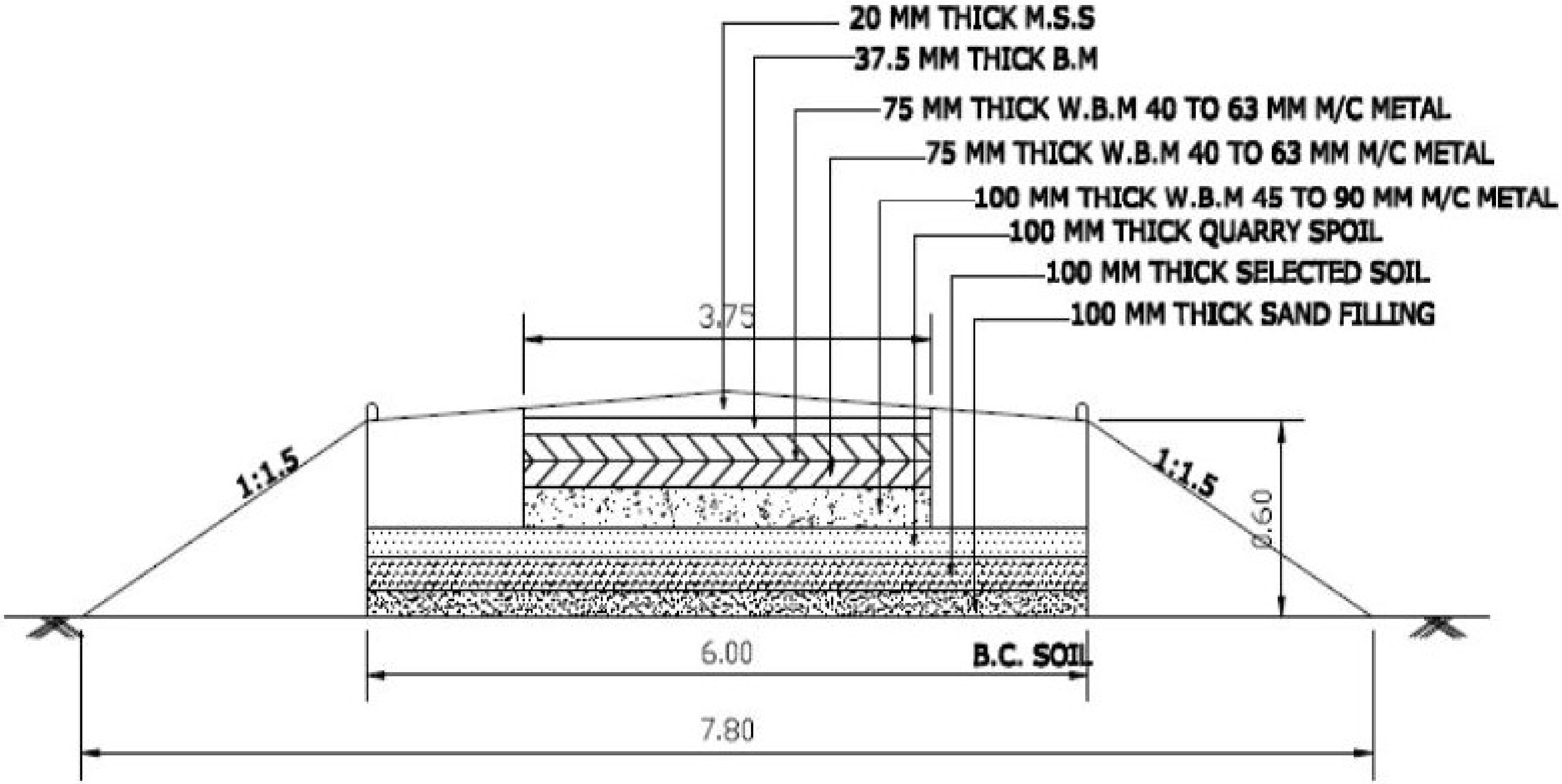
- Preliminary Survey Map
- Detailed plan
- Detailed cross section



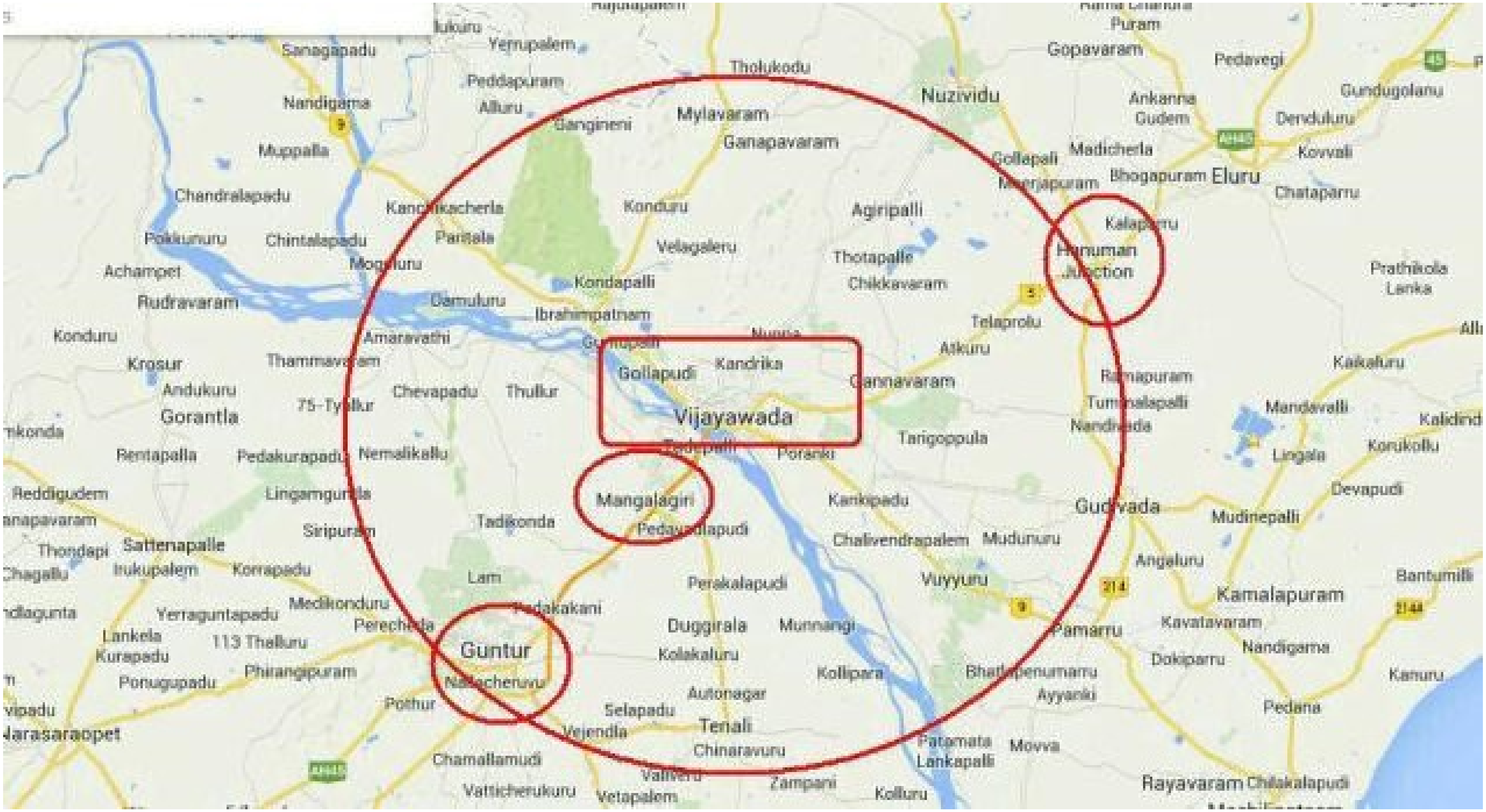
DRAWINGS AND REPORT

- **Preliminary survey plans**:
- This plans showing details of alternative alignments and all information collected.
- **Detailed plans and longitudinal sections:**
- This plans shows the ground plan with the alignment and other boundaries
- The size of the map 60*42cm
- Longitudinal section should shows the details such as datum line, existing ground surface, vertical profile of the proposed road and position of drainage crossings.

DRAWINGS AND REPORT

- **Detailed cross-sections**:
- The cross sections are generally drawn to natural scale of 1cm=2.0 to 2.5 m
- Cross section should be drawn every 100m
- In hilly roads the cross section should be drawn at closer intervals.
- **Land acquisition plans**:
- Land acquisition plans and schedules are usually prepared from the survey drawings for land acquisition details.
- This plans shows the general details of buildings, wells, and other required assessing values.

Land Acquisition Plans



DRAWINGS AND REPORT

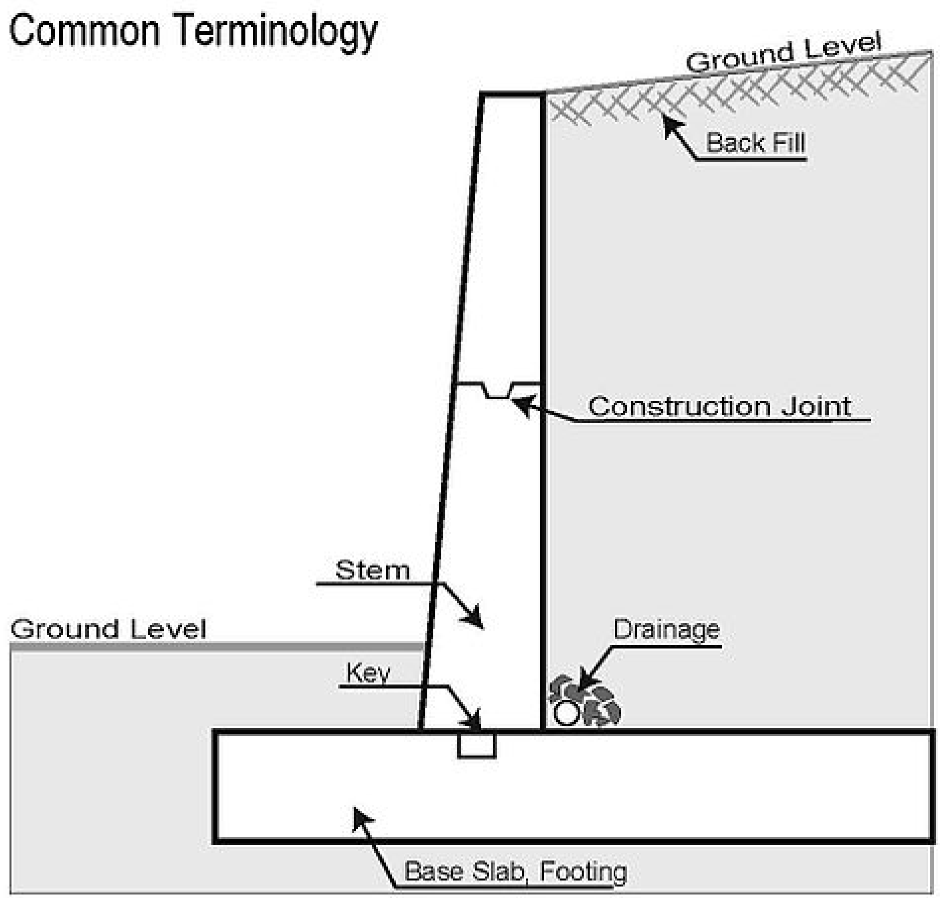
- **Drawings of cross drainage and other retaining structures:**
- Detailed design for cross drainage and masonry structures are usually drawn to scale of 1cm=1m for any complicated structures the scale enlarged upto 8cm=1m.
- **Drawings of road intersections:**
- Drawings of road intersections should be prepared showing all details of pavement, shoulders, islands etc to scale

DRAWINGS OF CROSS DRAINAGE WORKS

DRAWINGS OF CROSS DRAINAGE WORKS

Crossing works: (aqueducts)

DRAWINGS OF RETAINING STRUCTURES



DRAWINGS AND REPORT

- **Land plans for quarries:**
- Where quarries for construction materials to be available for new projects, separate land plans should be prepared.

HIGHWAY PROJECT

- **GENERAL:**
- In new highway project the engineer has to plan, design and construct the net work of a new road.
- And also projects required redesigning and realignment of existing roads for upgrading of geometric design standards
- Once highway project is constructed, development take place along the adjoining of the road.
- After development of adjoining areas, change in alignment and improving of geometric standards become very difficult.
- A badly aligned highway is not only a source of potential traffic hazard, but also causes a considerable increase in transportation cost and strain on the drivers and passengers.
- Therefore, proper investigation and planning are most important in a road project, keeping in view of the present needs as well as future needs.

HIGHWAY PROJECT

- **NEW HIGHWAY PROJECT:**
- The new highway project may be divided into the following stages:

a. Selection of route, finalisation of highway alignment and geometric design details

b. Collection of materials and testing of sub-grade soil and other construction materials, mix design of pavement materials and pavement layer design details.

c. Check the quality of all construction stages.

HIGHWAY PROJECT

- **ROUTE SELECTION:**
- The selection of route is made keeping in view the requirements of alignment and the geological, topographical and other features of the locality .
- After the alignment if finalised, the plans and working drawings are prepared.
- **MATERIALS AND DESIGN:**
- The soil samples collected from the selected route during the soil surveys are tested in the laboratory in order to design the required pavement thickness and the design of embankment and cut slopes.
- The basic construction materials such as selected soil, aggregate etc. are collected from the nearest barrow pits and quarries and stacked along the road alignment after subjecting these materials to the specified laboratory tests.
- In order to design the mixes for the pavement component layers and to specify quality control test values during road construction, mix design tests are carried out in the laboratory.

HIGHWAY PROJECT

- In India, the CBR method has been recommended by the Indian roads congress for designing the thickness of flexible pavements.
- Recommended procedure for the design of cement concrete pavement has also been specified by the Indian Road congress.
- **CONSTRUCTION:**
- The construction of the road may be divided into two stages, Viz.: (i) earth work (ii) Pavement Construction.
- The earth work consists of excavation and construction of the embankments.
- The pavement construction is subsequently taken up starting with the preparation of sub-grade and the construction of sub-base, base and surface courses of the pavement.

HIGHWAY PROJECT

- **STEPS IN A NEW PROJECT:**

  For the new highway project various steps to be summarised as given below:

1. **Map study:** This is carried out with the help of available topographic maps of the area.
2. **Reconnaissance survey:** During this survey a general topography and other features, field identification of soils and survey of construction materials by on the spot inspection of the site

HIGHWAY PROJECT

- **3.PRELIMINARY SUVEY:**
- Topographical details and soil survey for alternative alignments by consideration of geometric design elements and other requirements of alignments.
- From the above data prepare the plans and compare the alternative alignment routes.
- And then economical analysis for alternative routes and select the final alignment.
- **4.LOCATION OF FINAL ALIGNMENT:**
- Transfer the alignment to the ground from the drawings by driving pegs or marks along the centre line of the final alignment.

HIGHWAY PROJECT

- **5.DETAILED SURVEY:**
- Survey of the highway construction work for the preparation of longitudinal and highway cross sections, computations of earth work quantities and other construction material and checking the other geometric design details.
- **6.MATERIAL SURVEY:**
- Survey of construction materials, their collection and testing.
- **7.DEIGN:**
- Design details of embankment and cut slopes, foundation of embankment and bridges, and pavement layers and cross drainage structures.

HIGHWAY PROJECT

- **8.EARTH WORK:**
- Survey of cutting and filling portions and drainage system, construction of embankment.
- **9.PAVEMENT CONSTRUCTION:**
- Preparation of sub-grade, construction of sub base, base and surface courses.
- **10.CONSTRUCTION CONTROLS:**
- Conduct quality control tests during different stages of construction and checked finished road surface such as unevenness, camber, super elevation and extra widening of pavement at curves.

PPP SCHEMES OF HIGHWAY DEVELOPMENT IN INDIA

- Traditionally in India, the road projects were fully financed, controlled and supervised by the government.
- The implementation of road projects was purely dependent on the availability of funds, their allocation and release out of the budget of the government.
- As the development construction and maintenance of roads involves huge costs, the government has not been in a position to allocate the required funds to the road sector.
- For reducing the burden on the budgetary allocation of the government, commercialization also helps in increasing the efficiency of the resources extend in the projects through implementation of better management techniques under the „Public Private Partnership‟ (PPP) schemes.

PPP SCHEMES OF HIGHWAY DEVELOPMENT IN INDIA

- Several incentives have been announced by the government to attract private sector participation and foreign direct investment.
- These schemes are called „Public Private Partnership" or PPP schemes.
- The incentives announced include the following:

1. Government to bear the cost of i) project feasibility studies ii) land for the right of way and way-side amenities iii) shifting of utilities and iv)environmental clearance, cutting of trees etc.
2. Foreign direct investment up to 100% in road sector.
3. Provision of subsidy up to 40% of project cost to make projects viable.
4. 100% tax exemption in any consecutive 10 years out of 20 years after commissioning of the project.

PPP SCHEMES OF HIGHWAY DEVELOPMENT IN INDIA

5. Duty – free import of high capacity and modern road construction equipment.
6. Declaration of the road sector as an industry.
7. Easier external commercial borrowing norms.
8. Right to retain the toll; further toll rates can be revised based on the wholesale price index.

PPP SCHEMES OF HIGHWAY DEVELOPMENT IN INDIA

- **TYPES OF PUBLIC PRIVATE PARTNERSHIP ADOPTED IN INDIA FOR HIGHWAY CONSTRUCTION:**
- Many types of PPP schemes exist around the world; the common forms that are popular in the road sector in India are :

a) Built Operate Transfer (Toll Basis)

b) Built Operate Transfer (Annuity Basis)

- **(a) BOT (Toll) Model:**
- In this toll based BOT model, a road developer constructs the road and he allowed to recover his investment through toll collection.
- This toll collection will be over a period of nearly 30 years in most cases.

PPP SCHEMES OF HIGHWAY DEVELOPMENT IN INDIA

- There is no government payment to the developer as he earns his money invested from tolls.
- This model reduces the fiscal burden on the government while also allocating the traffic risk to the Concessionaire(developer)
- **(b) BOT (Annuity) Model:**
- Under BOT annuity, a developer builds a highway, operates it for a specified duration and transfers it back to the government.
- The government starts payment to the developer after the launch of commercial operation of the project.
- Payment will be made on a six-month basis.

GOVERNMENT OF INDIA INITIATIVES IN DEVELOPING THE HIGHWAYS AND EXPRESSWAYS IN IMPROVING THE MOBILITY

- India with a total road network of 5.5 million KM comprises of national & state highways and urban & rural roads. National highways account for 2% of the total road network and carry over 40% of total traffic.
- The construction pace of NHAI as noticed in last years has seen a steady growth with 3,380 Km construction in the FY 2018-19.
- Continuing the same trend with the development of 3,979 km of national highways during FY 2019-20.
- India has a well-developed framework for Public-Private-Partnerships (PPP) in the highway sector.

GOVERNMENT OF INDIA INITIATIVES IN DEVELOPING THE HIGHWAYS AND EXPRESSWAYS IN IMPROVING THE MOBILITY

- The Government of India (GoI) is planning to expand the national highway network to over 200,000 km.
- The Government launched the Bharatmala Pariyojana, which aims to build 66,100 km of economic corridors, border and coastal roads, and expressways to boost the highway network.
- This programme will provide 4-lane connectivity to 550 districts, increase the vehicular speed by 20-25% and reduce the supply chain costs(Journey to cost efficiency, Transportation cost, investment cost etc..) by 5-6%.
- The first phase of the programme will bring in $ 82 bn investments by 2022 for the development of 34,800 km of highways.

GOVERNMENT OF INDIA INITIATIVES IN DEVELOPING THE HIGHWAYS AND EXPRESSWAYS IN IMPROVING THE MOBILITY

- The Indian road network, comprising of National Highways, Expressways, State Highways, Major District Roads, Other District Roads and Village Roads, is globally the 2nd largest spanning 5.5 million kilometers.
- India's road infrastructure has seen consistent improvement in the last few years. Connectivity has improved and road transportation has become a focus of rapid development.
- Roads are providing better access to services, ease of transportation and freedom of movement to people
- Following are the major road infrastructure development initiatives in India:

1. National highways development projects (NHDP)
2. Development of roads in challenging terrain
3. Special accelerated road development programme for north-east
4. Development of roads in the remote areas in central/eastern India

VILLAGE ROAD DEVELOPMENT IN IMPROVING THE ACCESSIBILITY

- It appeared that improved mobility and accessibility in rural areas could be achieved through:

1. The development of the road network with proper planning and management systems (methodologies, procedures),
2. Improvement of the village level transport network including paths, tracks and footbridges;
3. Development of transport services
4. The development of a local transport infrastructure
5. The enhancement of rural transport services
6. The use of IMT(Intermediate means of transport –Transport for Rural development)
7. The provision of facilities which would reduce transport needs
8. Provide suitable Funding


Thank
You!

TRANSPORTATION ENGINEERING

MODULE-II

Highway Geometric Design

IMPORTANCE OF GEOMETRIC DESIGN

- The geometric design of a highway deals with the dimensions and layout of visible features of the highway such as alignment, sight distance and intersection.
- The main objective of highway design is to provide optimum efficiency in traffic operation with maximum safety at reasonable cost.
- Geometric design of highways deals with following elements :
  - Cross section elements
  - Sight distance considerations
  - Horizontal alignment details
  - Vertical alignment details
  - Intersection elements

IMPORTANCE OF GEOMETRIC DESIGN

Cross section elements:

➢Under cross section elements, the considerations for the width of the pavement, formation of land, surface characteristics and cross slope of the pavement.

Sight distance considerations:

➢Sight distance or clear distance visible ahead of a driver at horizontal and vertical curves and at intersections control the safe movements of vehicle.

Horizontal alignment details:

➢The change in the road directions are made by introducing horizontal curves.

➢Super elevation is provided by raising the outer edge of the pavement.

➢Extra pavement width is also provided in horizontal curves.

IMPORTANCE OF GEOMETRIC DESIGN

Horizontal alignment details:

- In order to introduce the centrifugal force and super elevation gradually, transition curves are introduced between straight and circular curves.

Vertical alignment details:

- The gradient and vertical curves are introduced in the vertical alignment of highway.

Intersection elements:

- Design of a road intersections gives the safe and efficient traffic movement but needs the adequate knowledge of traffic engineering.
- Highway geometrics are greatly influenced by the topography, locality, traffic characteristics and design speed.

DESIGN CONTROLS AND CRITERIA

- The geometric design of highway depends on several design factors, they are

- **Design speed**
- **Topography**
- **Traffic factors**
- **Design hourly volume and capacity**
- **Environmental and other factors**

DESIGN CONTROLS AND CRITERIA

Design speed:

- In India different speed standards have been assigned for different class of road.
- Similarly urban roads have different set of design speeds.
- Design speed may be modified depending upon the terrain conditions.
- Design of all geometric design elements depends on the design speed.
- The geometric design elements like pavement surface characteristics, cross section of road such as width and clearance requirements, sight distance requirements, horizontal alignment elements such as radius of curve, super elevation etc.

DESIGN CONTROLS AND CRITERIA

- TOPOGRAPHY :
- The topography or the terrain conditions are mainly influence the geometric design of highway.
- The design standards are differ to different classes of roads and depending on the terrain condition.
- Classified based on the general slope of the country.
  - Plane terrain- <10% and is 100 Kmph speed
  - Rolling terrain- 10-25% and is 80 Kmph speed
  - Mountainous terrain- 25-60% is 50 Kmph
  - Steep terrain- >60% is 20 to 30 Kmph.

PLAIN TERRAIN

ROLLING TERRAIN

MOUNTAINOUS TERRAIN

Steep Terrain

DESIGN CONTROLS AND CRITERIA

Traffic factor:

- The traffic factors effect the geometric design of roads, The traffic factors like vehicular characteristics and human characteristics of road users.
- Different vehicle classes have different speed and acceleration characteristics, different dimensions and weight .
- It is difficult to decide the design vehicle or standard traffic lane under mixed traffic conditions especially on urban roads of developing countries.
- The important Human factor which affect the traffic behaviour it includes the physical, mental and psychological characteristics of driver and pedestrian.

DESIGN CONTROLS AND CRITERIA

Design hourly volume and capacity:

- The Traffic flow and volume fluctuating with time
- The traffic flow Low value during off-peak hours to the highest value during the peak hour.
- A Reasonable traffic volume is decided for the design and this is called the design hourly volume.
- It is uneconomical to design the roadway for peak traffic flow.

Environmental factors:

- The environmental factors such as aesthetics(study of beauty), landscaping, air pollution, noise pollution and other local conditions should be considered for the design road geometrics.

HIGHWAY CROSS SECTION ELEMENTS

- Pavement surface characteristics
- Carriageway
- Shoulder
- Roadway width
- Right of way
- Building line
- Control line
- Median
- Camber/ cross slope
- Crown
- Side slope
- Kerb
- Guard rail

PAVEMENT SURFACE CHARACTERISTICS

Pavement surface depend on the type of pavement which is decided based on the,

- Availability of material
- Volume and composition of traffic
- Soil subgrade
- Climatic condition
- Construction facility
- Cost consideration

The important surface characteristics are:

- Friction
- Pavement unevenness
- Light reflecting characteristics
- Drainage of surface water

PAVEMENT SURFACE CHARACTERISTICS

Friction

- The friction between vehicle type and pavement surface is one of the factor determining the speed, stopping distance and accelerating the vehicles.
- When a vehicle enters a horizontal curve, the lateral friction developed counteracts the centrifugal force and thus give the safe operating speed.

- Skidding: skidding occurs when the breaks applied for fast moving vehicles, the wheels are locked partially or fully, and if the vehicle moves forward, the longitudinal skidding takes place which may be vary from 0 to 100%.
- Slipping: slip occurs when a wheel move in circle around a same point than the corresponding longitudinal movement along the road.

PAVEMENT SURFACE CHARACTERISTICS

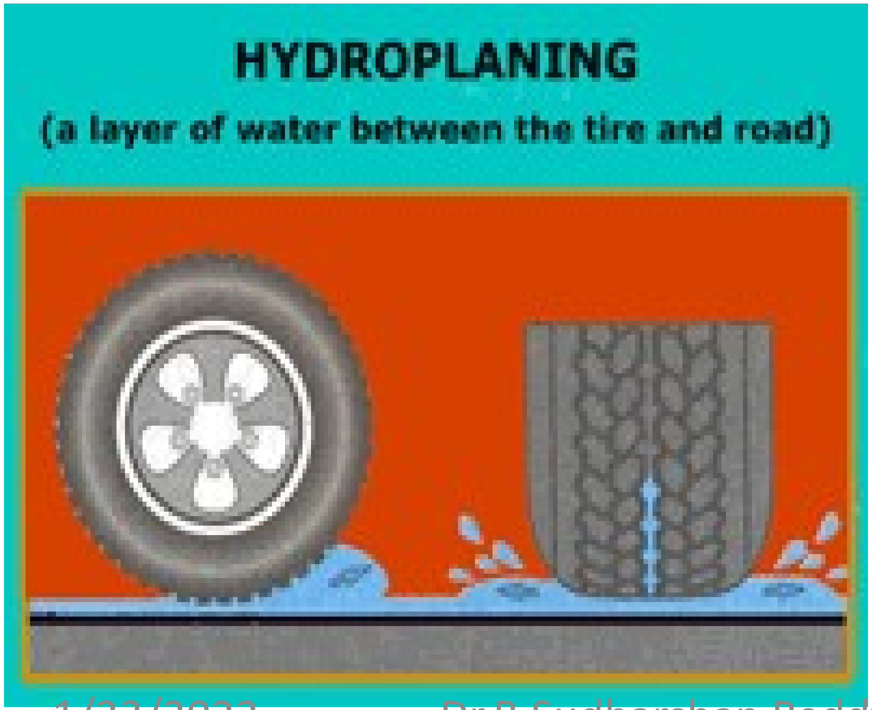
Factors affecting the friction or skid resistance

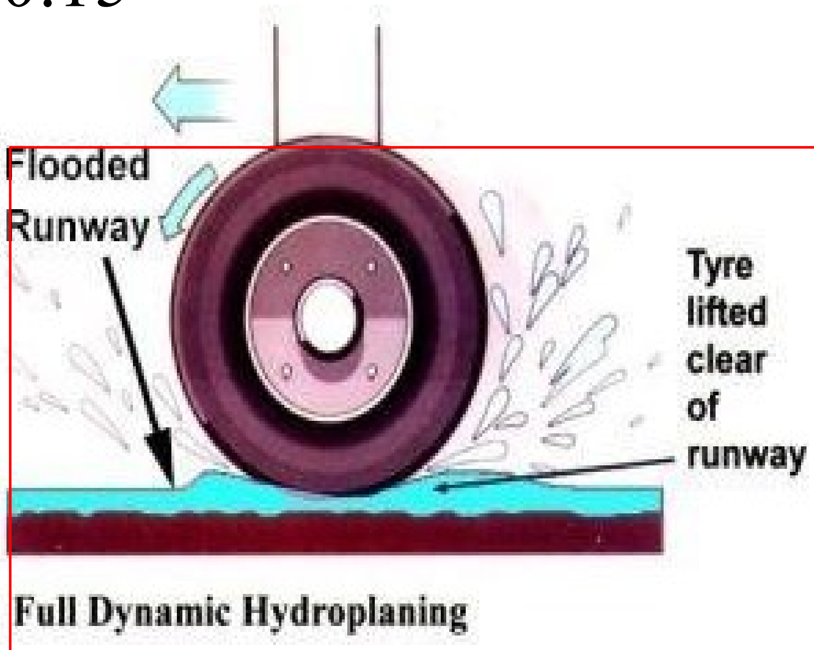
•The maximum friction offered by the pavement surface or the skid resistance depends upon the following factors:

- Types of pavement surface : cement concrete,bituminous,WBM,earth surface etc.
- Roughness of pavement
- Condition of the pavement: wet or dry, smooth or rough
- Type and condition of tyre: with new good threads or warn out tyres
- Speed of the vehicle
- Brake application or efficiency
- Load and tyre pressure
- Temperature of tyre and pavement
- Type of skid if any

❖Smooth and worn out tyres offer higher friction factor on dry pavement but new tyre with good threds gives higher friction factor on wet pavement

❖IRC recommended the longitudinal co-efficient of friction varies 0.35 to 0.4 and lateral co-efficient of friction of 0.15





PAVEMENT SURFACE CHARACTERISTICS

- PAVEMENT UNEVENNESS:
- Higher operating speed are possible on even surface than uneven surface.
- It affects,
  - Vehicle operation cost
  - Comfort and safety
  - Fuel consumption
  - Wear and tear of tyres and other moving parts
- It is commonly measure by an equipment call "Bump Integrator"
- Bump integrator is the cumulative measure of vertical undulations of the pavement surface recorded per unit horizontal length.
- 250 cm/km for a speed of 100kmph and more than 350 cm/km considered very unsatisfactory even at speed of 50 kmph.

PAVEMENT SURFACE CHARACTERISTICS

- Unevenness of pavement surface may be caused by
  - In adequate compaction of the fill, sub-grade and pavement layers.
  - Un-scientific construction practices including the use of boulder stones and bricks as soiling course over loose sub-grade soil.
  - Use of inferior pavement material.
  - Improper surface and subsurface drainage.
  - Improper construction machinery.
  - Poor maintenance


Aimil

PAVEMENT SURFACE CHARACTERISTICS

- Light reflecting characteristics:
- Night visibility very much depends upon the light reflecting characteristics of the pavement surface
- The glare caused by the reflection of head light is high on wet pavement surface than on dry pavement particularly in case of black top pavement or flexible pavement.
- Light colored or white pavement or rigid pavement surface give good visibility at night particularly during the rain, and produces glare or eye strain during bright sunlight.

HIGHWAY CROSS SECTION ELEMENTS

- Carriageway:
- It is the travel way which is used for movement of vehicle, it takes the vehicular loading .
- It may be cement concrete road or bituminous pavement.
- Width of carriageway is determined on the basis of the width of the vehicle and the minimum side clearance for safety.
- As per IRC specification, the maximum width of vehicle is 2.44m,minimum clearance of 0.68 in case of single lane and 1.02m in case of double lane.

WIDTH OF CARRIAGEWAY

SL. NO.	Class of road	Width of carriageway in 'm'
1	Single lane	3.75
2	Two lane without raised kerbs	7.0
3	Two lane with raised kerbs	7.5
4	Intermediate lane	5.5
5	Multilane pavement	3.5/lane

WIDTH OF ROADWAY OF VARIOUS CLASSES OF ROADS

SL. No.	Road classification	Roadway wisth	
		Plane and rolling terrain	Mountainous and steep terrain
1	NH & SH a) Single lane b) two lane	 12 12	 6.25 6.25
2	MDR a) Single lane b) two lane	 9 9	 4.75 4.75
3	ODR a) Single lane b) two lane	 7.5 9	 4.75 4.75
4	Village roads-single lane	7.5	4


Two lane two-way road
carriageway

HIGHWAY CROSS SECTION ELEMENTS

- Shoulder:
- It is provided along the road edge to serve as an emergency lane for vehicle.
- It act as a service lane for vehicles that have broken down.
- IRC recommended the minimum shoulder width is 2.5 m
- It should have sufficient load bearing capacity even in wet weather.
- The surface of the shoulder should be rougher than the traffic lanes so that vehicles are discouraged to use the shoulder as a regular traffic.
- The colour should be different from that of the pavement so as to be distinct.

shoulder

Cycle track

Footpath


unTreated shoulder
Treated shoulder

HIGHWAY CROSS SECTION ELEMENTS

- Width of the roadway or formation width:
- It is the sum of the width of the carriageway and including separators if any and the shoulders.
- Right of way:
- It is the total area of land acquired for the road along its alignment.
- It depends on the importance of the road and possible future development.
- It is desirable to acquire more width of land as the cost of adjoining land invariably increases very much , soon after the new highway is constructed.

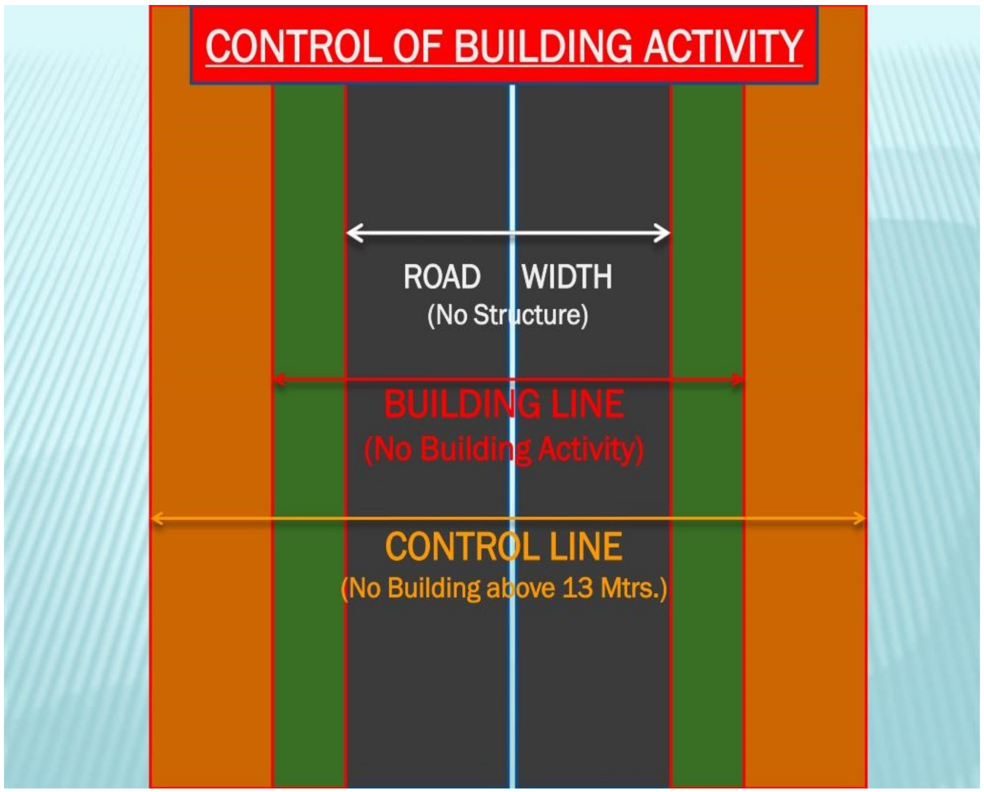
HIGHWAY CROSS SECTION ELEMENTS

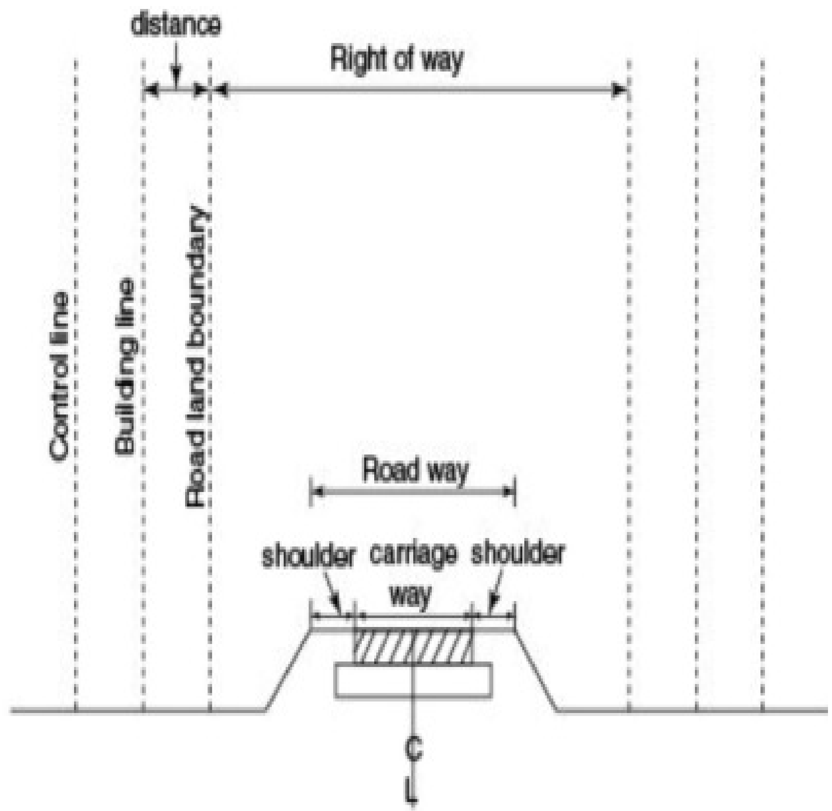
- Building line: It is desirable to control the building construction activities on either sides of the road boundary, beyond the land width acquired for the road, in order to reserve sufficient space for future improvement of roads.

Control lines:

- In addition to “building line”, it is desirable to control the nature of building upto further “set back distance” .

BUILDING LINE AND CONTROL LINE





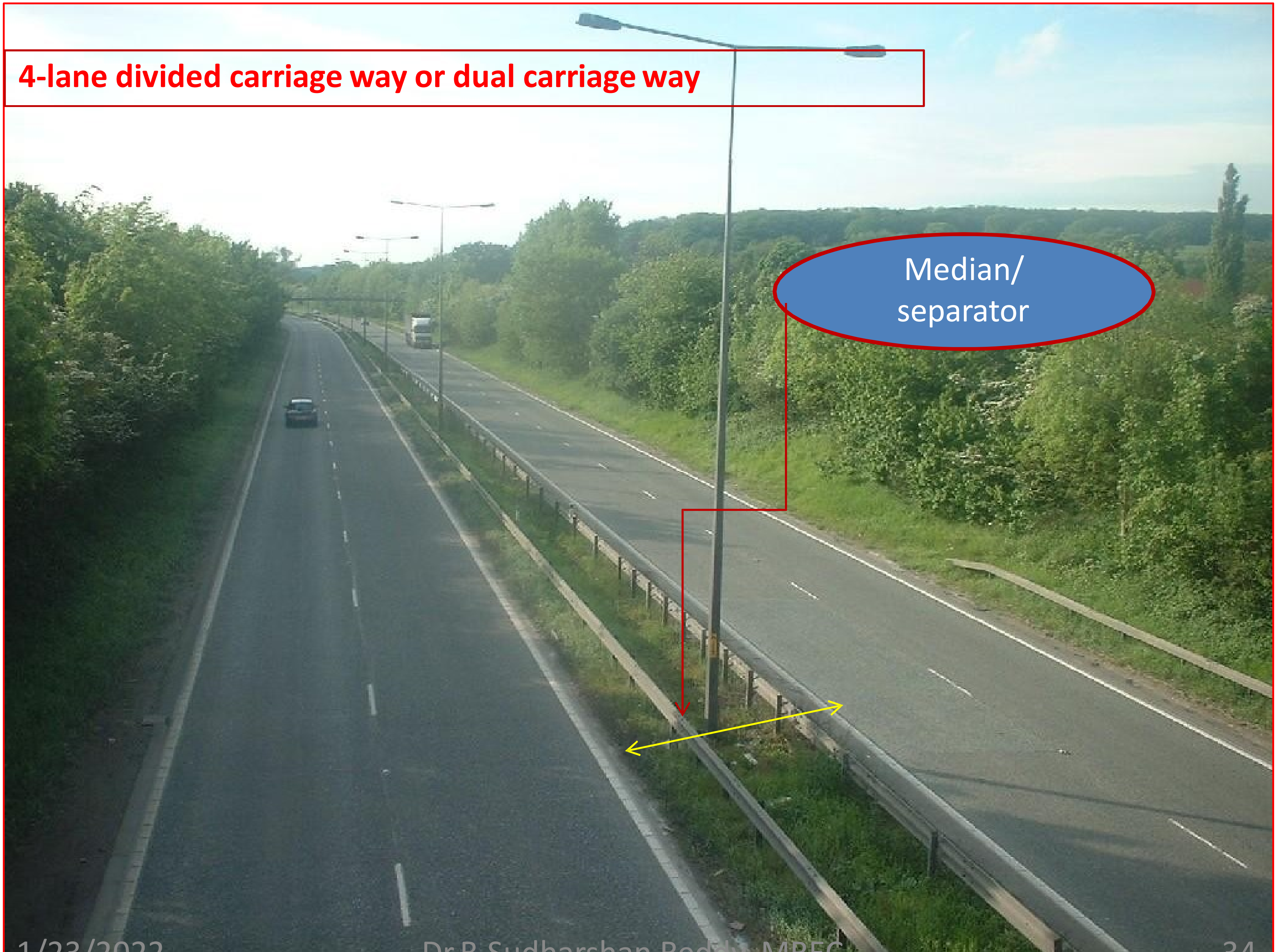
HIGHWAY CROSS SECTION ELEMENTS

Building line and Control line:

•It can be seen that the normal land width required for NH/SH on open plain terrain is 45 m and the maximum land width required is 60 m, the corresponding width b/w the building lines is 80 m and that b/w the control line is 150m, thus allowing setback distance of 10 to 45 m beyond the road boundary lines with the max. recommended road width.

HIGHWAY CROSS SECTION ELEMENTS

- Traffic separators or Median:
- The main function is to prevent head on collision between the vehicle moving in opposite direction.
- Channelize traffic into streams at intersection.
- Segregate slow traffic and to protect pedestrians.
- IRC recommends a minimum desirable width of 5 m and may be reduce to 3 m where land is restricted.
- The minimum width of median in urban area is 1.2m.


4-lane divided carriage way or dual carriage way
Median/
separator

HIGHWAY CROSS SECTION ELEMENTS

- Cross slope or camber:
- It is the slope provided to the road surface in the transverse direction to drain off the rain water from the road surface.
- To prevent the entry of surface water into the subgrade soil through pavement.
- To prevent the entry of water into the bituminous pavement layer.
- To remove the rain water from the pavement surface as quick as possible and to allow the pavement to get dry soon after the rain.
- It is expressed as a percentage or 1V:Nh. It depends on the pavement surface and amount of rainfall.

HIGHWAY CROSS SECTION ELEMENTS

- Shape of the cross slope:
- Parabolic shape(fast moving vehicle)
- Straight line
- Combination of parabolic and straight line

Recommended values of camber for different types of road surface

Sl no.	Type of road surface	Range of camber in areas of rain fall range	
		heavy	light
1	Cement concrete and high type bituminous pavement	1 in 50(2%)	1 in 60(1.7%)
2	Thin bituminous surface	1 in 40(2.5%)	1 in 50(2%)
3	Water bound macadam(WBM) and gravel pavement	I in 33(3%)	1 in 40(2.5%)
4	Earth	1 in 25(4%)	1 in 33(3%)

HIGHWAY CROSS SECTION ELEMENTS

- Too steep slope is not desirable because of the following reasons:
- Uncomfortable side thrust(push) and unequal wear of the tyres as well as road surface.
- Problem of toppling over highly laden bullock cart and truck.
- Tendency of most of vehicle travel along the centre line.

Kerb:

- It indicates the boundary between the pavement and shoulder.
- It is desirable to provide kerbs in urban areas.
- It is of three types

1-Low or mountable kerb:

- It allow the driver to enter the shoulder area with little difficulty.
- The height of the this type of shoulder kerb is about 10 cm above the pavement edge with slope to help the vehicle climb the kerb easily.

HIGHWAY CROSS SECTION ELEMENTS

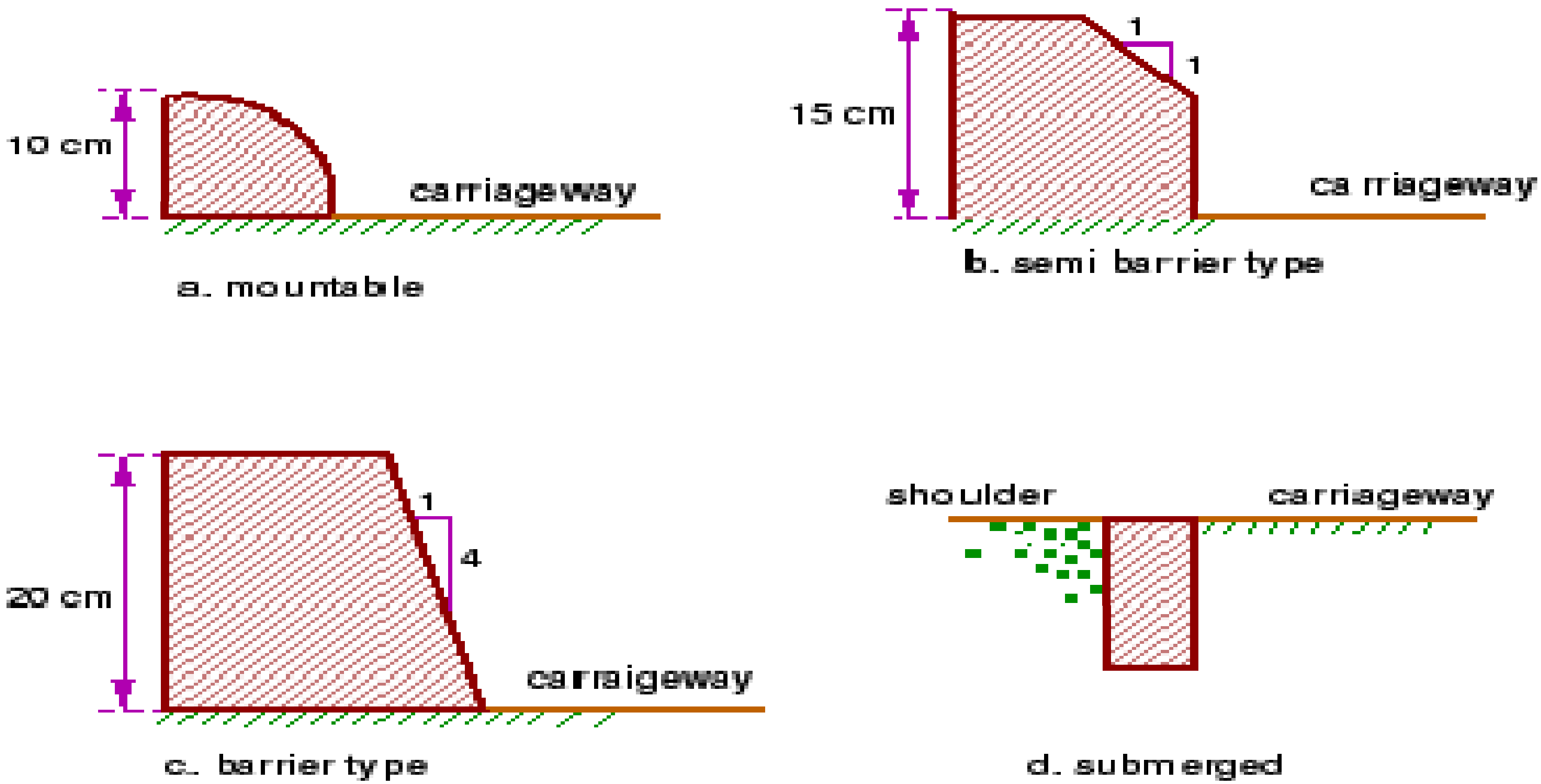
- 2-Semi-barrier kerb:
- It is provided on the periphery(edge) of a roadway where the pedestrian traffic is high.
- Height of about 15 cm above the pavement edge with a batter of 1:1 on the top 7.5 cm.
- It prevents parking the vehicle but during emergency it is possible to drive over this kerb with some difficulty.

3-Barrier type kerb:

- It is provided in built-up area adjacent to the foot paths with considerable pedestrian traffic.
- The height of the kerb is about 20 cm above the pavement edge with a steep batter of 1V:0.25H.

KERB

TYPES OF KERBS:

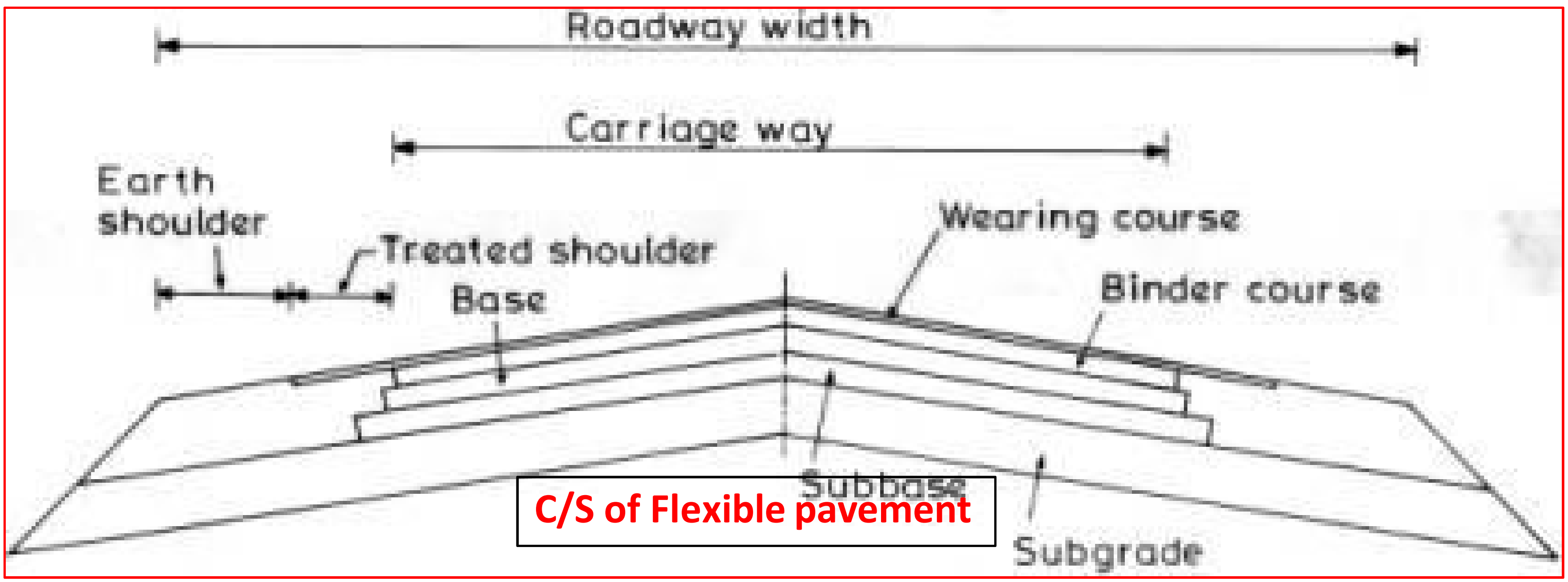


kerb

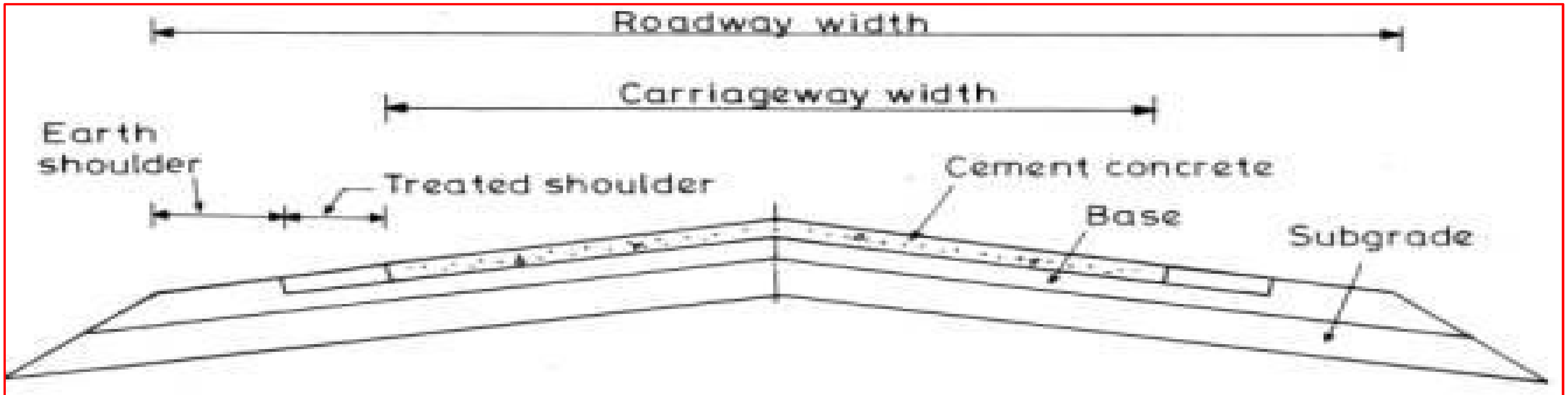
HIGHWAY CROSS SECTION ELEMENTS

- Guard rail:
- It is provided at the edge of the shoulder when the road is constructed on a fill exceeds or high Embankment of 3 m.
- It is also provided on horizontal curve so as to provide a better night visibility of the curves under the head light of the vehicle.

Guard rail



C/S of Flexible pavement



C/S of Rigid pavement

Guard rails

SIGHT DISTNCE

- Sight distance available from a point is the actual distance along the road surface, which a driver from a specified height above the carriageway has visibility of stationary or moving objects.
- It is the length of road visible ahead to the driver at any instance for the safe and efficient operation of vehicle on the length of the road visible to the driver in the direction of travel.

•Visibility is very important for safe vehicle operation on a highway.

TYPES OF SIGHT DISTANCE OR SIGHT DISTANCE ELEMENTS

- Stopping or absolute minimum sight distance(SSD)
- Safe overtaking or passing sight distance (OSD)
- Intermediate sight distance(ISD)

Stopping sight distance:

- The minimum sight distance available on a highway at any spot should be of sufficient length to stop a vehicle or traveling at design speed, safely without collision with any other obstruction.

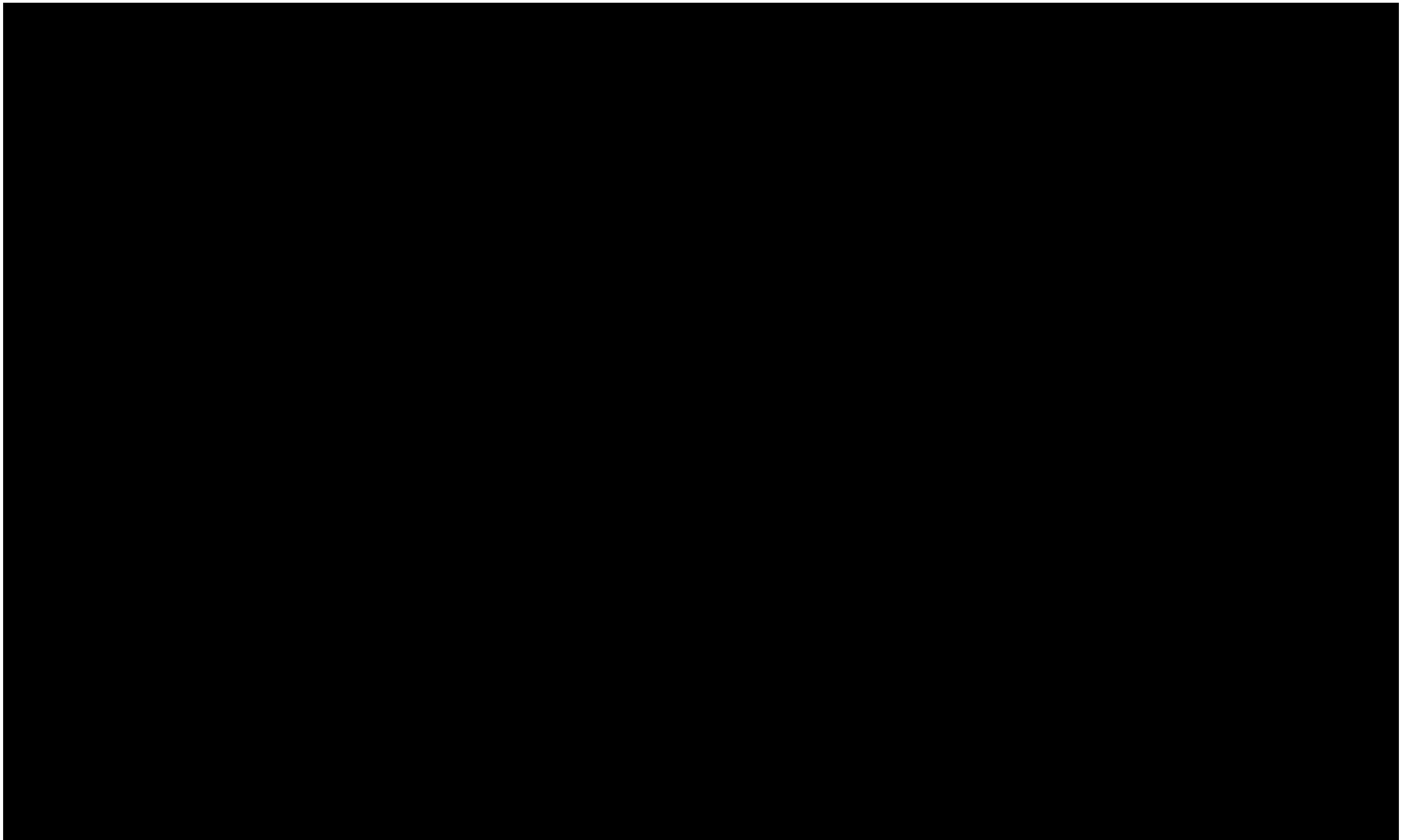
Over taking sight distance:

- The minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the opposite direction of traffic is known as the minimum overtaking sight distance (OSD) or the safe passing sight distance.

- ## Intermediate sight distance:

- This is defined as twice the stopping sight distance. When overtaking sight distance can not be provided, intermediate sight distance is provided to give limited overtaking opportunities to fast vehicles.

STOPPING SIGHT DISTANCE



STOPPING SIGHT DISTANCE

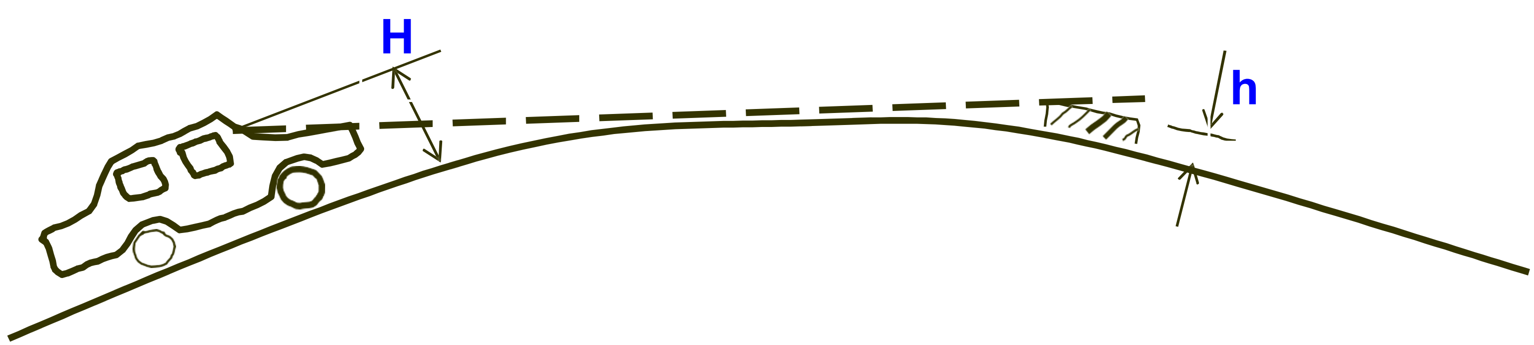
- SSD is the minimum sight distance available on a highway at any spot should be of sufficient length to stop a vehicle traveling at design speed, safely without collision with any other obstruction.

It depends on:

- Feature of road ahead(Facilities)
- Height of driver's eye above the road surface(1.2m)
- Height of the object above the road surface(0.15m)

Criteria for measurement

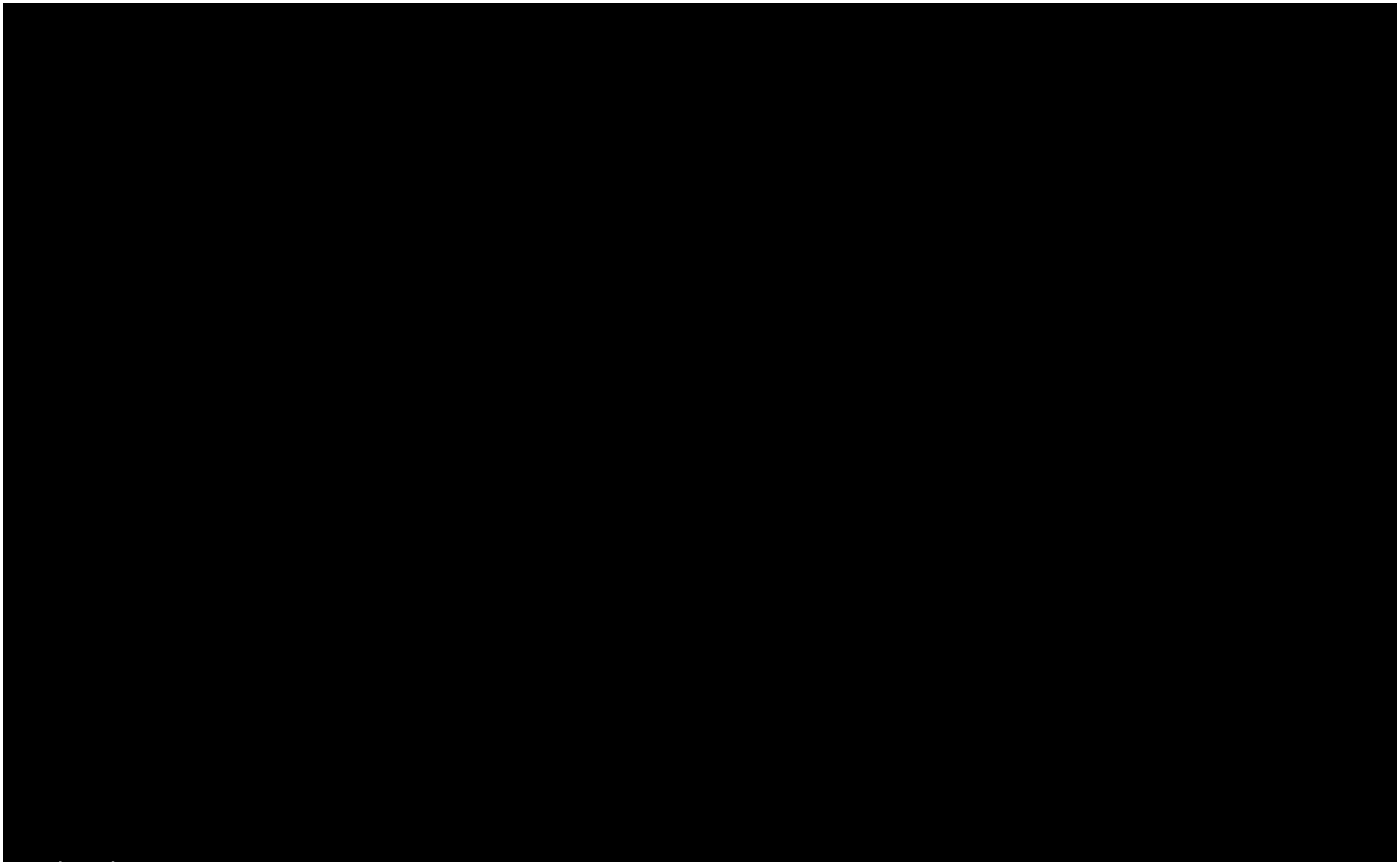
- Height of driver's eye above road surface (H)
- Height of object above road surface(h)



IRC

- **H = 1.2m**
- **h = 0.15m**

SSD ANALYSIS



ANALYSIS OF SSD

- The stopping sight distance is the sum of lag distance and the braking distance.

Lag distance:

- It is the distance, the vehicle traveled during the reaction time
- If 'V' is the design speed in m/sec and 't' is the total reaction time of the driver in seconds,

lag distance = v.t metres.
Where "v" in m/sec
t=2.5 sec

Lag distance=0.278 V.t (meters)
Where "v" in Kmph,
T= time in sec=2.5 sec

Braking distance :

- The coefficient of friction ‘f’ depends on several factors such as type and condition of the pavement surface and tyres and also value ‘f’decreases with increases in speed.
- The distance travelled by the vehicle after application of breaks, to a dead stop position which is known as the braking distance.
- If the maximum frictional force F(kg) is developed and the breaking distance is (L) meters, then work done against friction force in stopping the vehicle is given by:

$F \times L = W. f . l,$

where W is the total weight of the vehicle,

f is the frictional coefficient or skid resistance and

l is the breaking distance.

Braking distance :

- The kinetic energy at the design speed of v m/sec will be ½ m. v^2
  - The kinetic energy of the vehicle of weight W moving at the

design speed of 'v' m/s is = $\frac{1}{2}\frac{w}{g}v^2 = \frac{wv^2}{2g}$ $(\because w = mg)$

$$Hence\ w\ f\ l = \frac{1}{2}\frac{w}{g}v^2 = \frac{wv^2}{2g}\ (\because w = mg)$$

$$Hence\ w\ f\ l = \frac{wv^2}{2g}$$

$\therefore$ Braking distance l = $\frac{v^2}{2gf}$

Braking distance :

$\therefore$ Braking distance $l = \dfrac{v^2}{2gf}$

Where v = speed of vehicle m/sec

f = Coefficient of friction

g = Acceleration due to gravity = 9.8 m/ sce^2

$\therefore$SSD=lag distance + braking distance

$\boxed{SSD = v.t + v^2/2gf, \text{ where } v = m/s}$

$\boxed{SSD = 0.278V.t + V^2/254f, \text{ where } V = Kmph}$

Braking distance :

$SSD = v.t + v^2/2g(f \pm 0.01n)$,where n is % gradient, v=m/s

$SSD = 0.278v.t + v^2/254(f \pm 0.01n)$,where n is % gradient and V= Kmph

Table 2.6: Coefficient of longitudinal friction					
Speed, kmph	30	40	50	60	>80
Longitudinal coefficient of friction	0.40	0.38	0.37	0.36	0.35

- Two-way traffic single lane road: SSD=2*SSD
- In one-way traffic with single or more lane or two- way traffic with more than single lane: Minimum SSD= SSD

Example1:Calculate the safe stopping sight distance for design speed of 50kmph for(a) two-way traffic on two lane road (b)two-way traffic on single lane road

Given Data:

Design Speed of vehicle V = 50 kmph or v = $\frac{50}{3.6}$ = 13.9 m/sec

Reaction time of the driver t = 2.5 sec

Coefficient friction, f = 0.37

Assume g = 9.8

Stopping sight distance on level road $= vt + \frac{v^2}{2gf} = 13.9 \times 2.5 + \frac{13.9^2}{2\times9.8\times0.37}$

$$= 34.8 + 26.6 = 61.4\ m$$

Alternatively, Stopping sight distance may also be calculated when speed is in Kmph

SD$= 0.278Vt + \frac{V^2}{254f} = 0.278 \times 50 \times 2.5 + \frac{50^2}{254\times0.37}$ = 61.4m

a. Stopping sight distance, SSD when there are two lanes = stopping distance = 61.4m
b. Stopping sight distance, SSD on single lane road with two way traffic = 2×SSD== $2\times 61.4 = 122.8m$

Example2:Calculate the minimum sight distance required to avoid a head on collision of two cars approaching from opposite direction at 90 and 60kmph.coefficient friction of 0.7 and a brake efficiency of 50%, in either case

Given Data:

Design Speed of vehicle Car-I=V1 = 90 kmph or V1 = $\frac{90}{3.6}$ = 25 m/sec

Design Speed of vehicle Car-II =V2 = 60 kmph or V2 = $\frac{60}{3.6}$ = 16.67 m/sec

Reaction time of the driver t = 2.5 sec

Effective friction Coefficient, f with 50% brake efficiency during stopping

=0.5×0.7 = 0.35

Assume g = 9.8

Stopping sight distance for Car-I $= v_1 t + \frac{{v_1}^2}{2gf} = 25 \times 2.5 + \frac{25^2}{2\times 9.8\times 0.35} = 153.6m$

Stopping sight distance for Car-II $= v_2 t + \frac{{v_2}^2}{2gf} = 16.67 \times 2.5 + \frac{16.67^2}{2\times 9.8\times 0.35}$ = 82.2m

Total sight distance required to avoid head on collision of the two approaching cars= SD1+SD2=153.6+82.2=235.8m, say 236m.

Example3:Calculate the stopping sight distance on a highway at a descending gradient of 2% for design speed of 80 kmph, assume other data as per IRC specification

Given Data:

Design Speed of vehicle V = 80 kmph or v = $\frac{80}{3.6}$ = 22.2 m/sec

Reaction time of the driver t = 2.5 sec

Design Coefficient friction, f = 0.35

Assume g = 9.8m/sec^2

Gradient n = - 2% = - 0.02,

Stopping sight distance on level road $= vt + \frac{v^2}{2g(f \pm 0.01n)} = 22.2 \times 2.5 + \frac{22.2^2}{2 \times 9.8 \times (0.35 - 0.02)}$

$$= 55 + 76.2 = 131.7\ m, say\ 132m$$

Alternatively, Stopping sight distance may also be calculated when speed is in Kmph

SSD= $0.278Vt + \frac{V^2}{254(f \pm 0.01n)} = 0.278 \times 80 \times 2.5 + \frac{80^2}{254 \times (0.35 - 0.02)} =$

55.6+76.4=132m

OVERTAKING SIGHT DISTANCE

- If all the vehicles travel on a road at the design speed, then theoretically there should be no need for any overtaking.
- In fact all the vehicles do not move at the design speed and this is particularly true under mixed traffic conditions.
- In the above circumstances, it is necessary for fast moving vehicles to overtake the slow moving vehicles.
- The minimum distance open to the vision of the driver of a vehicle to overtake slow vehicle with safety against opposite direction of traffic is known as the "minimum overtaking sight distance".

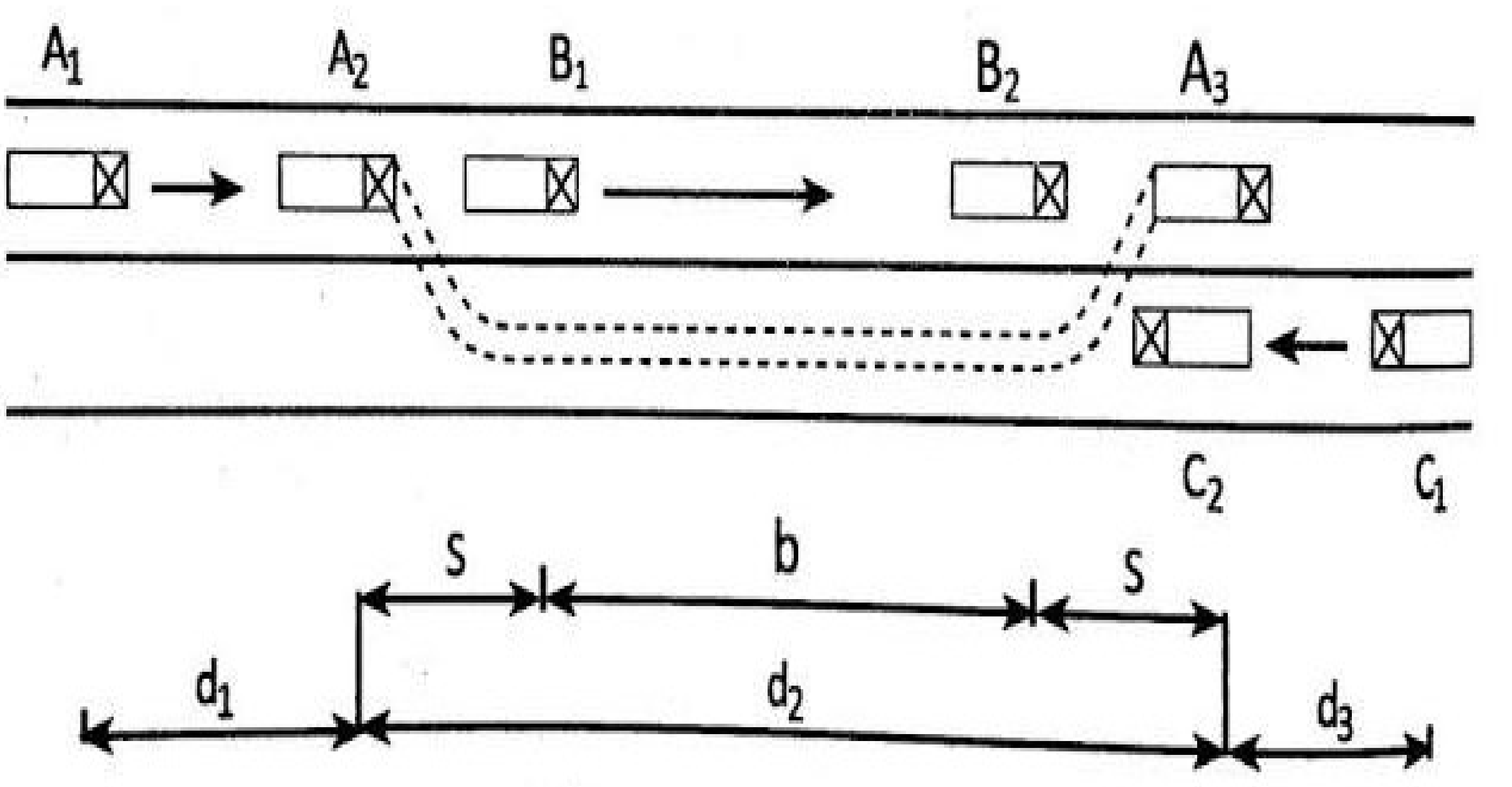
Factors affecting the OSD

- speeds of
  - overtaking vehicle
  - overtaken vehicle
  - the vehicle coming from opposite direction, if any.
- Distance between the overtaking an overtaken vehicles.
- Skill and reaction time of the driver
- Rate of acceleration of overtaking vehicle
- Gradient of the road

Analysis of OSD

- Vehicle A travelling at the design speed v m/sec or V Kmph desires to over take another slower Vehicle B moving at a speed of v_b m/sec or v_b Kmph.
- The Vehicle A has to accelerate, shift to the adjacent right side lane, complete the overtaking manoeuvre and return to the left lane, before reaching of opposite vehicle C.
- The overtaking manoeuvre may be split up into three operations, thus dividing the overtaking sight distance, OSD into three parts, d_1, d_2 and d_3.

ANALYSIS OF OVERTAKING SIGHT DISTANCE



Analysis of OSD

- d_1 is the distance traveled by overtaking vehicle "A" during the reaction time t sec of the driver from position A1 to A2.
- d_2 is the distance traveled by the vehicle A from A2 to A3 during the actual overtaking operation, in time T sec.
- d_3 is the distance traveled by on-coming vehicle C from C1 to C2 during the over taking operation of A, i.e. T sec.
- B is the 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 the design speed V m/sec or V kmph.
- The distance traveled by the vehicle A during this reaction time is d_1 and is between the positions A1 to A2, this distance will be equal to $V_b.t$ meter where 't' is the reaction time of the driver in second= 2 sec.

Analysis of OSD

Assumption made in the analysis:

- Assumption made to calculate the values of d_1, d_2 and d_3 (m) are given below:

✓ The overtaking vehicle A is forced to reduce its speed from the design speed v (m/sec) to v_b m/sec of the slow moving vehicle B and move behind it, allowing a space s (m), till there is an opportunity for safe overtaking operation.

✓ When the driver of vehicle A finds sufficient clear gap ahead, decides within a reaction time t (sec) to accelerate and overtake the vehicle B, during which the vehicle A moves at speed v_b (m/sec) through a distance d_1, from position A1 to A2.

✓ The vehicle A accelerates and over-takes the slow vehicle B with in a distance d_2 during the overtaking time, T(sec) between the position A2 to A3.

Analysis of OSD

- ✓The distance d_2 is split up into three parts as shown in above fig (i) spacing s(m) between A2 and B1 (ii) Distance b (m) travelled by the slow vehicle B between B1 and B2 during the overtaking manoeuvre of A and (iii) spacing s(m) between B2 and A3.
- ✓During this overtaking time T (sec), the vehicle C coming from opposite direction travels through a distance d3 from position C1 to C2 .

Analysis of OSD

Determination of the components of OSD:

a) From position A_1 to A_2, the distance, d_1 (m) travelled by overtaking vehicle A, at the reduced speed v_b (m/sec) during the reaction time, 't' (sec) = $v_b.t$ (m). The IRC suggests that this reaction time 't' of the driver may be taken as 2.0 sec as an average value, as the aim of the driver is only to find an opportunity to overtake.
Therefore, $d_1 = 2v_b$ (m).

a) From the position A2, the vehicle A starts accelerating, shift to the adjoining lane, overtake the vehicle B, and shifts back to it original lane ahead of B in position A3 during the overtaking time, T (sec). The straight distance between position A2 and A3 is taken as d2(m), which is further spilt into three parts viz., d2 = (s+b+s) as shown if above fig.

b) The minimum distance between position A2 and B1 may be taken as the minimum spacing 's' (m) between the two vehicles while moving with the speed v_b (m/s). The minimum spacing between vehicles depends on their speed and is given by empirical formula, $s = (0.7v_b+6)$, meter (if speed m/s) or $s = (0.2V_b+6)$ meter(if speed Kmph)

Analysis of OSD

d) The minimum distance between B2 and A3 may also be assumed equal to ‘s’ (m) as mentioned above. If the overtaking time by vehicle A for the overtaking operation from position A2 to A3 is T (sec), the distance covered by the slow vehicle B travelling at a speed of v_b(m/s)= b= v_b.T(m).Thus the distance d_2= (b+2s),m.

e) Now the time T depend on speed of overtaken vehicle B and the average acceleration ‘a’ m/sec² of overtaking vehicle A. The over taking time T (sec) may be calculated by equating the distance d_2 to (v_bT+1/2 a T²), using the general formula for the distance travelled by an uniformly accelerating body with initial speed v_b m/sec and ‘a’ is the average acceleration during overtaking in m/sec² .

$$d_2 = (b + 2s) = \left[v_b\, T + \frac{aT^2}{2} \right]$$

$$b = v_b T, \text{and therefore } 2s = \frac{aT^2}{2}$$

Analysis of OSD

Therefore, $T = \sqrt{\frac{4s}{a}}\ sec, where\ s = (0.7v_b + 6)m$

Hence, $d_2 = (v_b T + 2s), m$

f) The distance travelled by vehicle C moving at design speed v (m/sec) during the over taking operation of vehicle A i.e. During time T (sec) is the distance d_2 (m) between positions C1 to C2.

Hence, $d_3 = v\ T$ (m)

$$Thus, OSD = (d_1 + d_2 + d_3) = (v_b t + v_b T + 2s + vT)m$$

$$OSD = (0.28V_b t + 0.28V_b T + 2s + 0.28V.T)m$$

Here V_b = Initial speed of overtaking vehicle, Kmph

t = reaction time of driver = 2 sec

V = Speed of overtaking vehicle or design speed, kmph

Analysis of OSD

$$T = \sqrt{\frac{4 \times 3.6s}{A}} = \sqrt{\frac{14.4s}{A}}$$

$$s = spacing\ vehicles = (0.7\ v_b + 6)m\ If\ speed\ in \frac{m}{s}$$

$$= (0.2V_b + 6)m\ if\ Speed\ in\ Kmph$$

A= Average acceleration during overtaking, kmph/sec.

If the speed of the overtaken vehicle is not given $V_b = (v - 4.5)$ m/sec

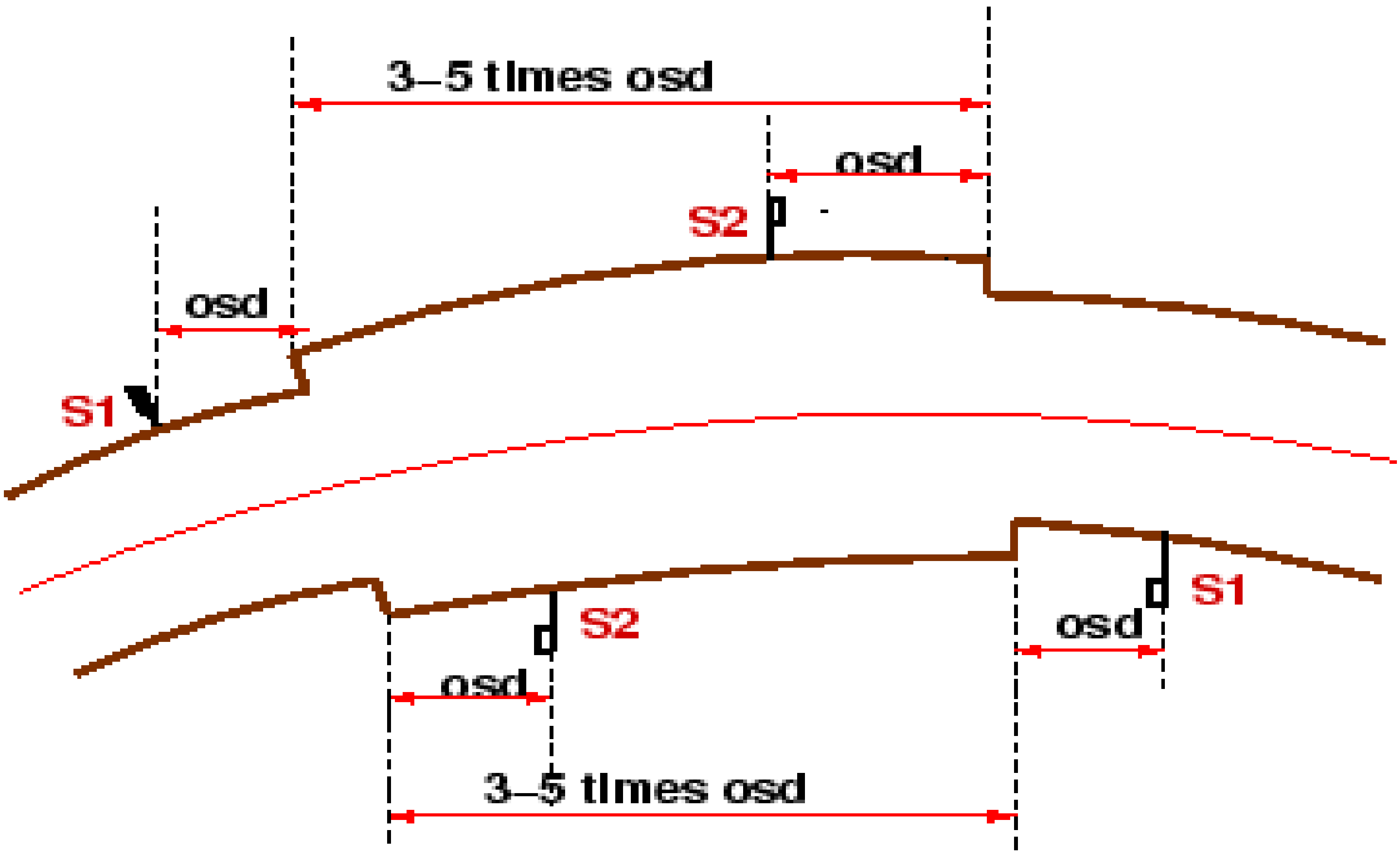
(or)

$V_b=(V-16)$ kmph, where V= speed of overtaking vehicle in kmph

- The minimum overtaking sight distance = d1+d2+d3 for two-way traffic.
- On divide highways and on roads with one way traffic regulation, the overtaking distance = d1+d2 as no vehicle is expected from the opposite direction.

Overtaking Zones

- It is desirable to construct highways in such a way that the length of road visible ahead at every point is sufficient for safe overtaking. This is seldom practicable and there may be stretches where the safe overtaking distance can not be provided. But the overtaking opportunity of vehicles moving at design speed should be given frequent intervals. These zones which are meant at overtaking are called overtaking zones.
- The minimum length of overtaking zone should be three time the safe overtaking distance i.e., 3 (d1+d2) for one- way roads and 3(d1+d2+d3) for two-way roads.
- Desirable length of overtaking zones is kept five times the overtaking sight distance. i.e., 5(d1+d2) for one-way roads and 5(d1+d2+d3) for two-way roads.



S1—– Overtaking zone begin
S2—–End of Overtaking zone

Exapmle1:The speed of the overtaking and overtaken vehicle are 70 and 40 kmph, respectively on a two way traffic road. If the acceleration of overtaking vehicle is 0.99 m/sec^2,

a. Calculate safe overtaking sight distance

b. Calculate the minimum and desirable length of overtaking zone

c. Draw the neat-sketch of the overtaking zone and show the position of the sign post.

Given Data:

Design Speed of vehicle V = 70 kmph or $v = \frac{70}{3.6} = 19.4$ m/sec

Design Speed of vehicle V_b = 40 kmph or $v = \frac{40}{3.6} = 11.1$ m/sec

Average acceleration during overtaking, a = 0.99 m/sec^2

a. Over taking sight distance for two way traffic = $d_1+d_2+d_3 = (V_b.t+V_b.T+2s+V.T)$

Reaction time for over taking, t = 2 sec

$d_1 = V_b.t = 11.1 \times 2 = 22.2$ m

$d_2 = V_b.T + 2s$

$s = (0.7V_b + 6) = (0.7\times 11.1+6) = 13.8$ m

$$T=\sqrt{\frac{4s}{a}} = \sqrt{\frac{4\times 13.8}{0.99}} = 7.47 \text{ sec}$$

$d_2 = 11.1 \times 7.47 + 2\times 13.8 = 110.5$ m

$d_3 = V.T = 19.4 \times 7.47 = 144.9$ m

$\therefore$ OSD = $d_1+d_2+d_3 = 22.2 + 110.5 + 144.9 = 277.6$ m say 278 m

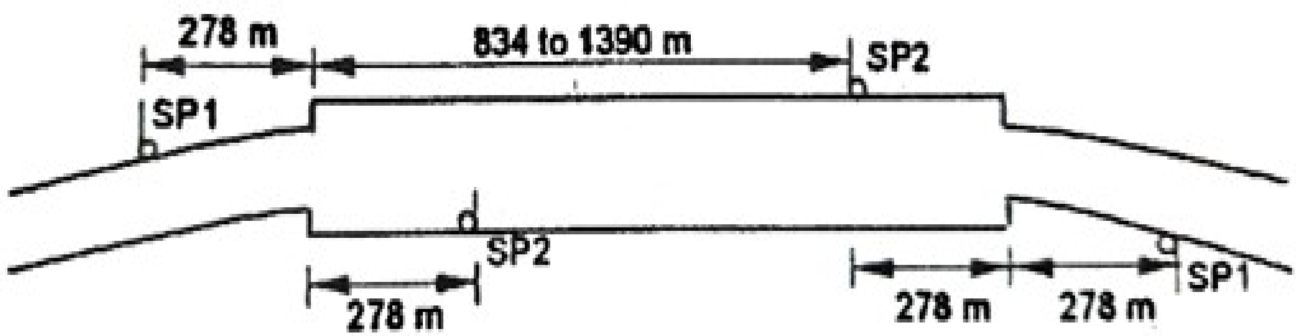
Example 1 Ans cont..

b. Minimum length of overtaking zone = 3 (OSD) = 3 × 278 = 834 m

   Desirable length of overtaking zone = 5 (OSD) = 5 × 278 = 1390 m

c. The details of the overtaking zone are shown in fig.

SIGHT DISTANCE



SP1 - SIGN POST, "OVERTAKING SIGN AHEAD"
SP2 - SIGN POST, "END OF OVERTAKING ZONE"

Example2:Calculate the safe overtaking sight distance for a design speed of 96 kmph, assume all other data

Given Data:

Design Speed of vehicle V = 96 kmph

Assume speed of overtaken vehicle, $V_b = V - 16 = 90 - 16 = 80$ Kmph,

Reaction time for over taking, t = 2 sec

Assume Acceleration A = 2.5 Kmph/sec

$d_1 = 0.28\, V_b.t = 0.28 \times 80 \times 2 = 44.8$ m

$d_2 = 0.28\, V_b.\, T + 2\, s$

$s = (0.2\, V_b + 6) = (0.2 \times 80 + 6) = 22$ m

$$T = \sqrt{\frac{4s}{a}} = \sqrt{\frac{4 \times 22}{2.5}} = 11.3 \text{ sec}$$

$d_2 = 0.28 \times 80 \times 11.3 + 2 \times 22 = 297$ m

$d_3 = 0.28\, V.\, T = 0.28 \times 96 \times 11.3 = 303.7$ m

OSD on one way traffic road = $d_1 + d_2 = 44.8 + 297 = 341.8$ m say 342 m

OSD on two way traffic road = $d_1 + d_2 + d_3 = 44.8 + 297 + 303.7 = 645.5$ m say 646 m

INTERMEDIATE SIGHT DISTANCE

- *"A distance equivalent to twice the stopping sight distance, a distance where overtaking could be attempted with reasonable safety"*.
- ISD is usually twice the stopping sight distance.
- ISD has a limited application. For example says that "*ISD is only applicable to undivided 2-way road (single lane each way*)" Other sources say that ISD is also used for rural single lane roads

DESIGN OF HORIZONTAL ALIGNMENT

Photo: Dan Nabors, VHB

Horizontal curve

DESIGN OF HORIZONTAL ALIGNMENT

General:

- Various design factors are considered they are
  - ✓ Design speed
  - ✓ Radius of circular curves
  - ✓ Type and length of transition curves
  - ✓ Super elevation and
  - ✓ Widening of pavement on curves.
- The alignment should give constant, safe and smooth movement of vehicles at design speeds.

DESIGN OF HORIZONTAL ALIGNMENT

Design speed:

- The design speed is the main factor for deciding the geometric design elements.
- The following factors are depends on design speed, they are
  - ✓The sight distance
  - ✓Radius of horizontal curve
  - ✓Super elevation
  - ✓Extra widening of pavement
  - ✓Length of horizontal transition curve etc.

DESIGN OF HORIZONTAL ALIGNMENT

- The design speed of roads depends on
  - I. Class of the Road
  - II. Terrain
- Mainly design speeds suggested for National and state highways of our country passing through plain terrain is 100Kmph and through rolling terrain is 80Kmph.
- The recommended design speeds for different classes of urban roads are:
  - For arterial Roads 80Kmph
  - Sub arterial roads 60Kmph
  - Collector streets 50Kmph
  - Local streets 30Kmph
  - ❖ Classification of terrains are shown in table

Terrain Classifications	Plain	Rolling	Mountainous	Steep
Cross slope of the country, Percent	0 - 10	10 - 25	25 - 60	Greater than 60

DESIGN OF HORIZONTAL ALIGNMENT

- **Horizontal Curves :**
- A horizontal highway curve is a curve that provide change in direction to the central line of a road.
- When a vehicle travel or traverses a horizontal curve, the centrifugal force act horizontally outwards through the centre of gravity of the vehicle.
- The centrifugal force developed depends on the radius of the horizontal curves and the speed of the vehicle through the curve.

DESIGN OF HORIZONTAL ALIGNMENT

Horizontal Curves :

The centrifugal force P is given by the equation

$$P = W\, v^2/gR$$

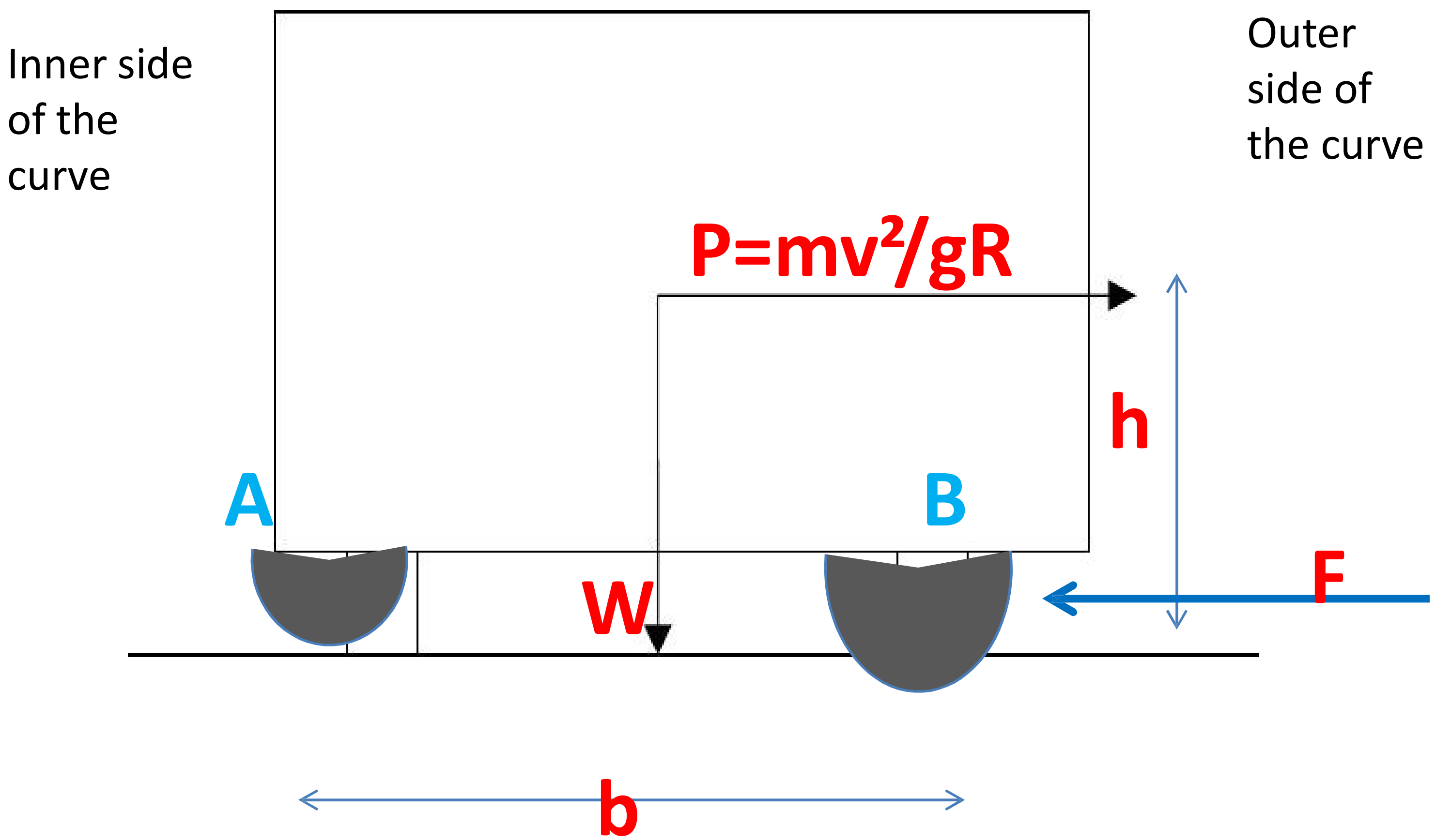
- Where,
  - P = centrifuge force, kg
  - W = weight of the vehicle, kg
  - R = radius of the circular curve, m
  - v = speed of vehicle, m/sec
  - g = acceleration due to gravity = 9.8 m/sec

Horizontal curves Cont.....

- The ratio of the centrifugal force to the weight of the vehicle, **P/W** is known as the centrifugal ratio or the impact factor. The centrifuge ratio is thus equal to **v^2/gR**
- The centrifugal force acting on a vehicle negotiating a horizontal curve has the following two effects
  - Tendency to overturn the vehicle outwards about the outer wheels
  - Tendency to skid the vehicle laterally, outwards

Overturning effect

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


Inner side
of the
curve
Outer
side of
the curve
P=mv²/gR
h
A
B
W
F
b

Horizontal Curves cont..

Overturning effect: As shown in above fig

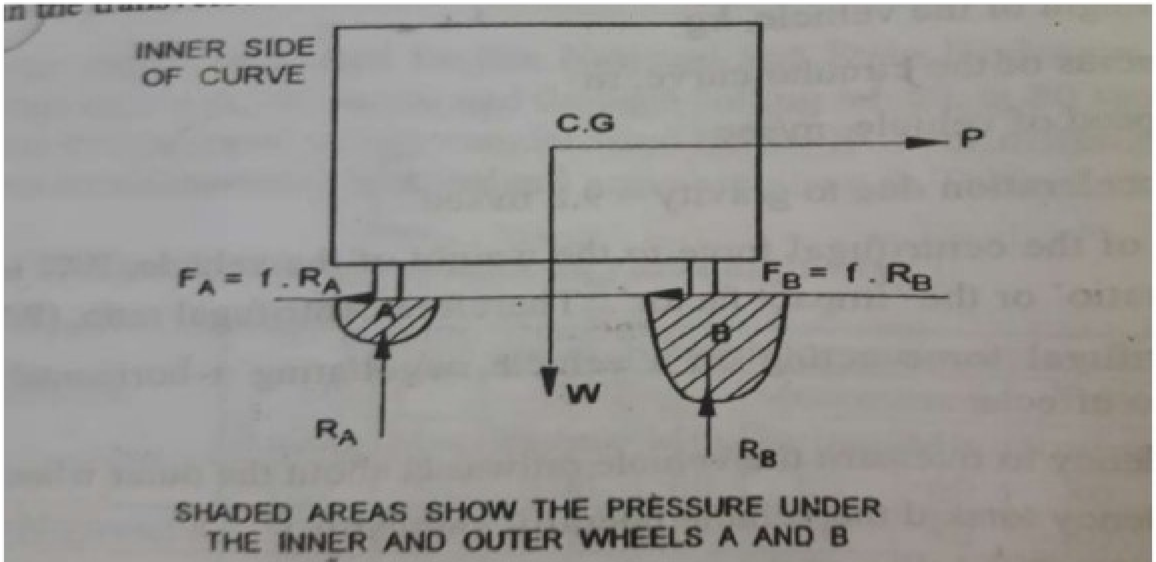
- Let 'h' be the height of the centre of gravity of the vehicle above the road surface and 'b' be the width of the wheel base or the wheel track of the vehicle.
- The over turning moment due to centrifugal force, P=P. h
- The restoring moment due to weight of the vehicle, W =W. b/2
- The equilibrium condition for overturning will occur when

  $Ph = W. b/2$, or when $P/W = b/2h$.
- This means that there is danger of overturning when the centrifugal ratio P/W or v^2/gR attains a values of $b/2h$.

Horizontal Curves

II.Transverse skidding effect

ii. Transverse skidding effect:



4.19 Transverse skidding effect due to centrifugal force

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II.Transverse skidding effect

- $P = F_A + F_B = f(R_A + R_B) = fW$
- Since $P = f\,W$, the centrifugal ratio P/W is equal to 'f '. In other words when the centrifugal ratio attains a value equal to the coefficient of lateral friction 'f ' there is a danger of lateral skidding.
- Thus to avoid overturning and lateral skidding on a horizontal curve, the centrifugal ratio should always be less than b/2h and also 'f'
- 'f' is less than b/2h.-The vehicle would skid and not overturn
- b/2h is lower than 'f'-The vehicle would overturn on the outer side before skidding

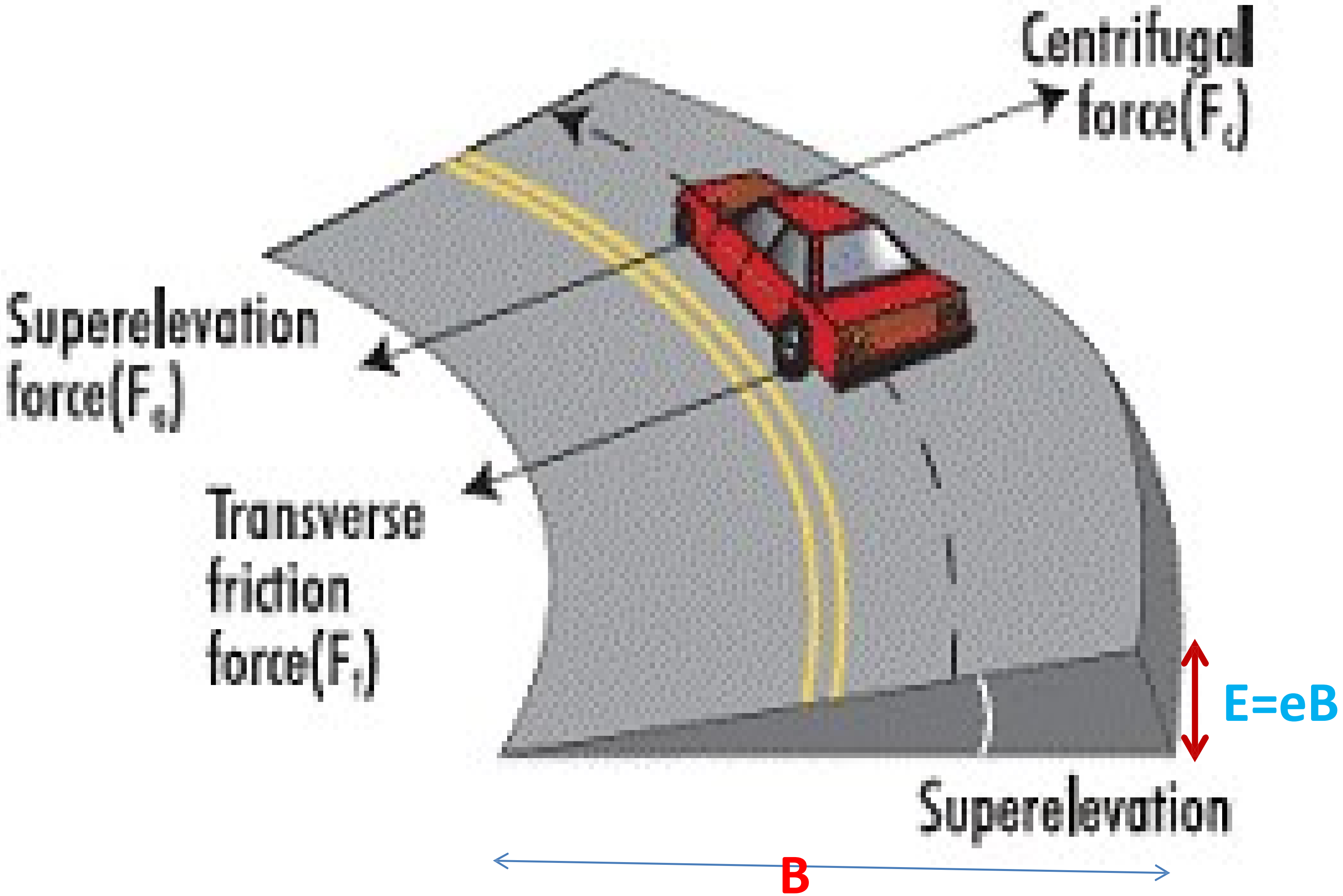
SUPERELEVATION

- In order to counteract the effect of centrifugal force and to reduce the tendency of the vehicle to overturn or skid, the outer edge of the pavement is raised with respect to the inner edge, thus providing a transverse slope throughout the length of the horizontal curve, this transverse slope of the pavement surface is known as Superelevation or cant or banking.
- The Superelevation ‘e’ is expressed as the ratio of the height of outer edge with respect to the horizontal width of the pavement.(i.e. E/B)

Sin Θ=E/B

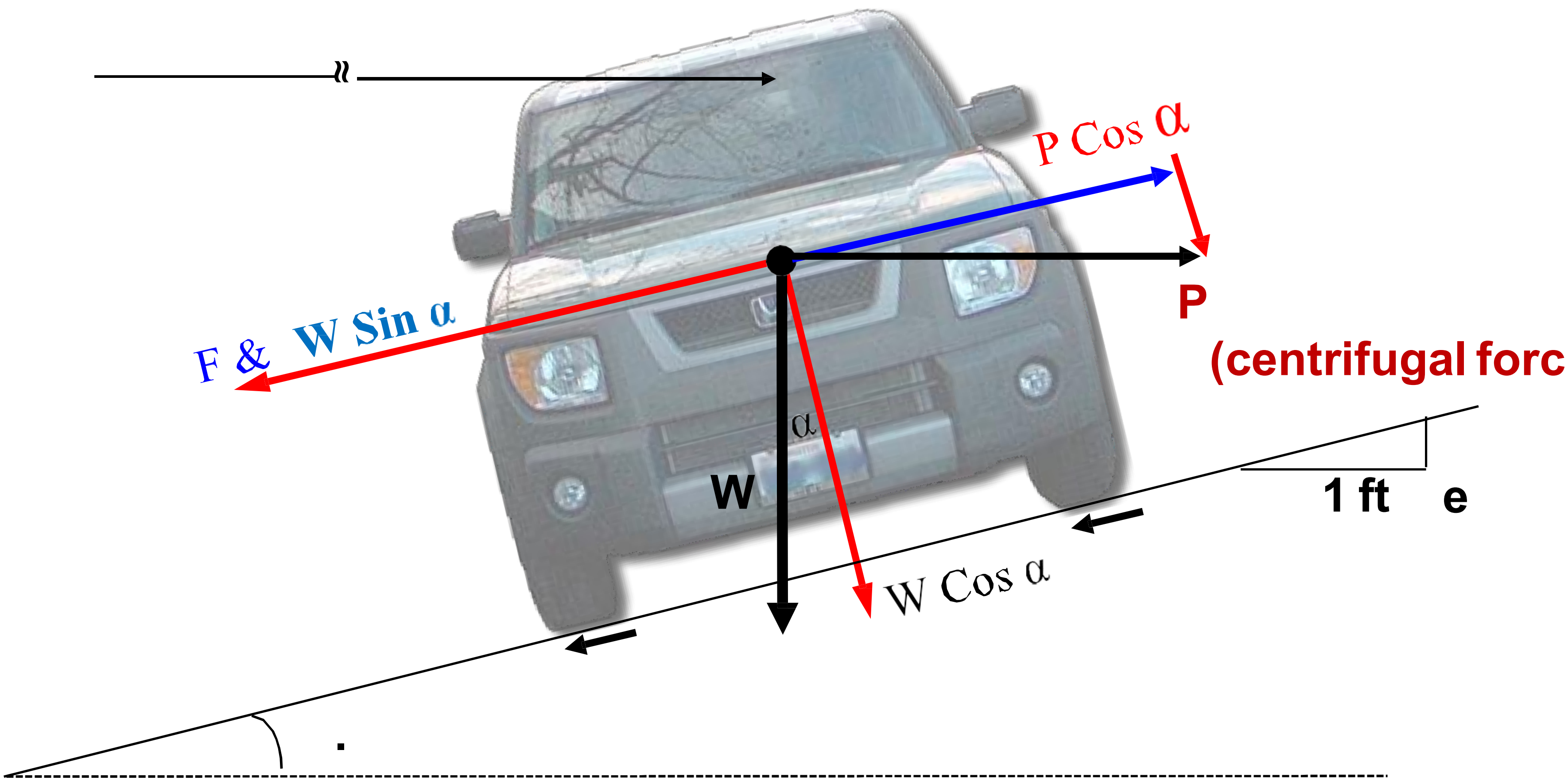
where E-Height of outer edge,

B-Width of pavement

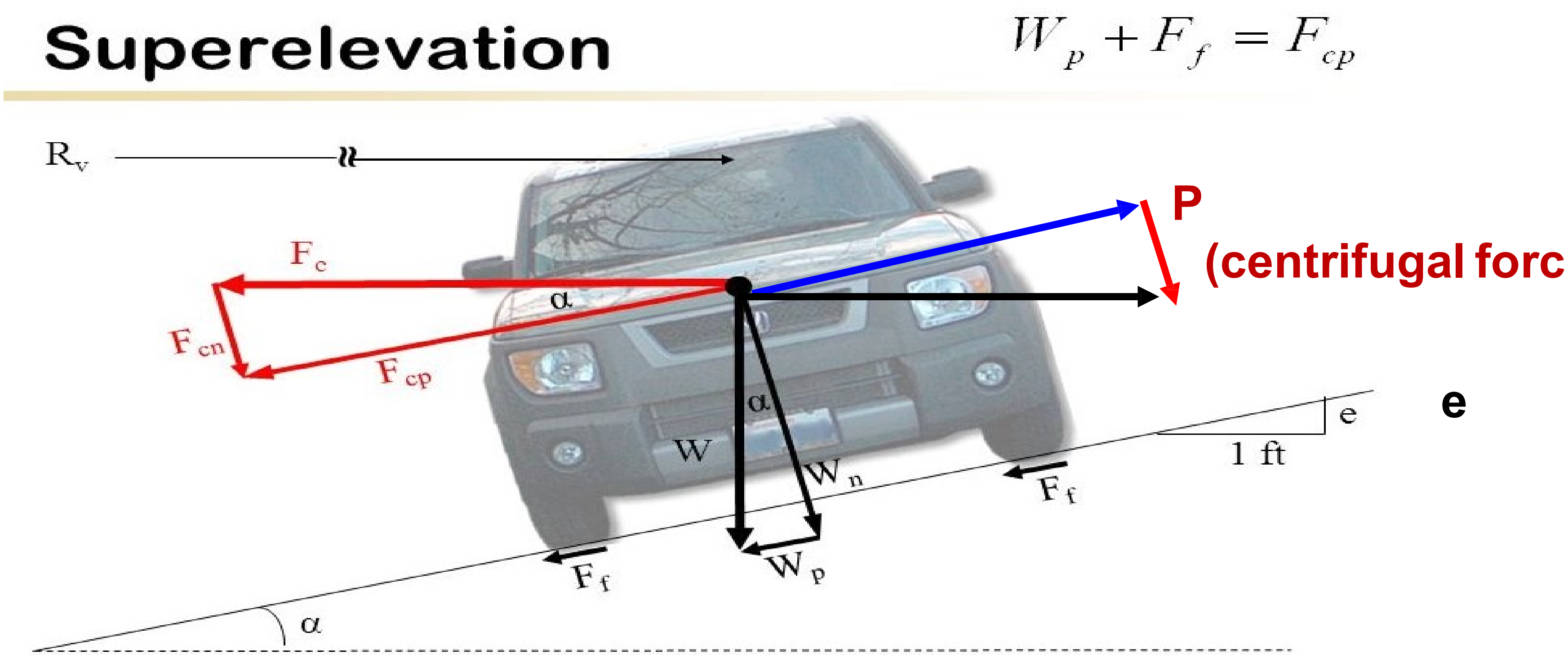


Centrifugal force(F_c)
Superelevation force(F_e)
Transverse friction force(F_f)
E=eB
Superelevation
B

Superelevation



Super elevation



$$W \sin\alpha + f_s\left(W\cos\alpha + \frac{WV^2}{gR_v}\sin\alpha\right) = \frac{WV^2}{gR_v}\cos\alpha$$

ANALYSIS OF SUPERELEVATION

- The force acting on the vehicle while moving on a circular curve of radius R meters, at speed of v m/sec are shown in fig, these forces are:
- The centrifugal force $P = Wv^2/gR$ acting horizontal outwards through the centre of gravity, CG
- The weight W of the vehicle acting vertically downwards through the CG.
- The frictional force developed between the wheels and the pavement counteractions transversely along the pavement surface towards the centre of the curve
- Considering the equilibrium of the components of forces acting parallel to the plane, the component of centrifugal force, ($P \cos\theta$) is opposed by the component of gravity, ($W \sin\theta$) and the frictional forces (F_A and F_B).

ANALYSIS OF SUPERELEVATION

➢ Analysis of Superelevation

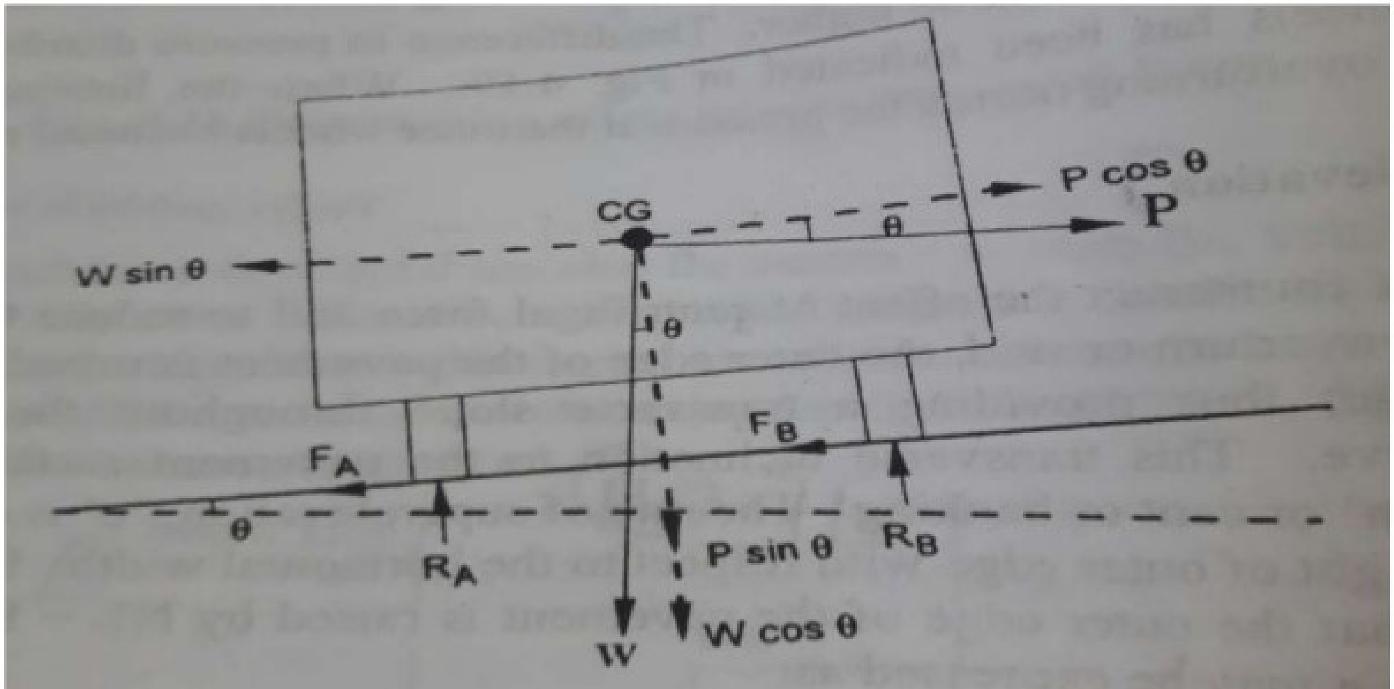


Fig. 4.21 Analysis of superelevation

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ANALYSIS OF SUPERELEVATION

- For equilibrium condition,

$P \cos\theta = W \sin\theta + F_A + F_B$

Here $F_A = f.\ R_A$ and $F_B = f.\ R_B$

Where f = Co-efficient of lateral friction, R_A and R_B are the normal reactions at wheels A and B.

Therefore, $P \cos\theta = W \sin\theta + f\ .\ R_A + f\ .\ R_B$

$P \cos\theta = W \sin\theta + f\,(R_A + R_B)$

$= W \sin\theta + f\,(W \cos\theta + P \sin\theta)$

i.e., $P(\cos\theta - f \sin\theta) = W \sin\theta + f\, W \cos\theta$

Dividing by $W \cos\theta$,

$P/W(1 - f \tan\theta) = \tan\theta + f$

i.e., the Centrifugal Ratio, $\dfrac{P}{W} = \dfrac{\tan\theta + f}{1 - f\tan\theta}$

ANALYSIS OF SUPERELEVATION

- The value of coefficient of lateral friction, f is taken as 0.15 for the design of horizontal curves.
- The value of tan ɵ or transverse slope due to super elevation seldom exceeds 0.07 or about 1/15.
- Hence the value of (f tan ɵ) is about 0.01.
- Thus the value of (1- f tan ɵ) in the above equation is equal to 0.99(1-0.01) and may be approximated to 1.0.
- Therefore, $$\frac{P}{W} = \tan\theta + f = e + f$$

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

ANALYSIS OF SUPERELEVATION

- Therefore the general equation for design of super-elevation is

given by $$e + f = \frac{v^2}{gR}$$

Here, e = rate of super elevation = tan ϴ

f = design value of lateral friction coefficient = 0.15

v = Speed of the vehicle, m/sec

R= radius of the horizontal curve, m

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

If the speed of the vehicle is represented as V kmph, the above equation may be written as follows:

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

ANALYSIS OF SUPERELEVATION

- Therefore $$e + f = \frac{V^2}{127\ R}$$

Here, V = Speed, kmph

R = radius of horizontal curve, m

- If the coefficient of friction is neglected or assumed equal to zero, i.e. If f = 0, the equilibrium super-elevation required to counteract the centrifugal force fully will be given by:

$$e = \frac{V^2}{gR} = \frac{V^2}{127\,R}$$

- Provided due to practical difficulties,

i.e. Where e = 0 and $f = \dfrac{V^2}{gR} = \dfrac{V^2}{127\ R}$, *or*

$$V = \sqrt{127\ f.R}$$

MAXIMUM SUPERELEVATION

- In the case of heavily loaded bullock carts and trucks carrying less dense materials like straw or cotton, the centre of gravity of the loaded vehicle will be relatively high and it will not be safe for such vehicles to move on a road with a high rate of Superelevation. Because of the slow speed, the centrifugal force will be negligibly small in the case of bullock carts.
- Hence to avoid the danger of toppling of such loaded slow moving vehicles, it is essential to limit the value of maximum allowable Superelevation.
- Indian Roads Congress had fixed the maximum limit of Superelevation in **plan and rolling terrains** and is snow bound areas as **7.0 %**.
- On **hill roads** not bound by snow a maximum Superelevation upto **10%** .
- On **urban road** stretches with frequent intersections, it may be necessary to limit the maximum Superelevation to **4.0 %.**

MINIMUM SUPERELEVATION

- From drainage consideration it is necessary to have a minimum cross to drain off the surface water.
- If the calculated Superelevation is equal to or less than the camber of the road surface, then the minimum Superelevation to be provided on horizontal curve may be limited to the camber of the surface.

DESIGN OF SUPER-ELEVATION

- Design of super-elevation for mixed traffic conditions is complex problem, as different vehicles ply on the road with a wide range of speeds.

Steps for super-elevation design:

- Various steps in the design of super-elevation in practice may be summarized as given below:

Step(1): The super-elevation for 75 percent of design speed (v m/sec or V Kmph) is calculated, neglecting the friction

$$e = \frac{(0.75v)^2}{gR} (or) \frac{(0.75V)^2}{127\,R} \approx \frac{V^2}{225\,R}$$

Step (2):If the calculated value of 'e' is less than 7% or 0.07 the value is so obtained is provided. If the value of 'e' exceeds 0.07 then provide the maximum super-elevation equal to 0.07 and proceed with steps 3 or 4.

DESIGN OF SUPER-ELEVATION

Step(3): Check the coefficient of friction developed for the maximum value of e=0.07 at the full value of design speed, v m/sec or V kmph.

$$f = \left(\frac{v^2}{gR} - 0.07 \right) (or) \left(\frac{v^2}{127R} - 0.07 \right)$$

- If the value of 'f' thus calculated is less than 0.15, the super-elevation of 0.07 is safe for the design speed and this is accepted as the design super-elevation. If not, calculate restricted speed as given in step 4.
- ***Step 4:*** As an alternative to step 3, the allowable speed (v_a m/sec. Or V_a kmph) at the curve is calculated by considering the design coefficient of lateral friction and the maximum super-elevation, i.e

$$\boldsymbol{e + f = 0.07 + 0.15}$$

$$\boldsymbol{= 0.22 =} \frac{v_a^2}{gR} = \frac{V_a^2}{127R}$$

DESIGN OF SUPER-ELEVATION

- Calculate the safe allowable speed,

$$v_a = \sqrt{27.94 R}\, kmph$$

or $$v_a = \sqrt{27.94 R}\, kmph$$

- If the allowable speed, as calculated above is higher than the design speed, then the design is adequate and provides a super-elevation of 'e' equal to 0.07.
- If allowable speed is less than the design speed, the speed is limited to the allowable speed V_a kmph calculated above

Example1:The radius of horizontal circular curve is 100m. The design speed is 50kmph and the design coefficient of lateral friction is 0.15.

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

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

Calculate the equilibrium super-elevation if the pressure on inner and outer wheels should be equal.

Example 1 Ans:

Given Data:

Radius of Circular Curve = 100 m

Design speed V = 50kmph = $v = \frac{50}{3.6}\, m/sec$

Design coefficient of lateral friction f = 0.15

(a) Supper elevation is given by the relation

$$e + 0.15 = \frac{50^2}{127 \times 100} = 0.197$$

$$e = 0.197 - 0.15 = 0.047$$

i.e., super elevation rate is 1 in 21.2

(b) If no Supper elevation is provided, e = 0 and friction factor developed,

$$f = \frac{V^2}{127R} = \frac{50^2}{127 \times 100} = 0.197$$

(c) For the pressure on inner and outer wheels to be equal for equilibrium super-elevation counteracting centrifugal force fully, f = 0 and

$$e = \frac{V^2}{127R} = \frac{50^2}{127 \times 100} = 0.197$$

i.e., equilibrium super elevation rate is 1 in 5.1. However this rate of super elevation being very high cannot be provided.

Example2:A two lane road with design speed 80kmph has horizontal curve of radius 480m. Design the rate of super-elevation for mixed traffic. By how much should the outer edges of the pavement be raised with respect to the centre line , if the pavement is rotated with respect to the centre line and the width of the pavement at the horizontal curve is 7.5m

Ans:

Given Data:

A two lane road with Design speed V = 80kmph = $v = \frac{80}{3.6} = 22.22\ m/sec$

Radius of Circular Curve = 480 m

Width of the pavement B = 7.5m

Step 1:For mixed traffic conditions the super-elevation should fully counteract the centrifugal force for 75% of design speed

$$e = \frac{(0.75v)^2}{gR} = \frac{(0.75 \times 22.22)^2}{9.87 \times 480} = \frac{277.72}{4737.6} = 0.059$$

$$e = 0.059$$

Since this value is less than 0.07, the super elevation of 0.059 may be adopted.

Rising of outer edge with respect to centre line

$$E = \frac{B \times e}{2} \left(\because e = \frac{E}{B} = E = Be \right)$$

$$Hiegt\ of\ outer\ edge, E = \frac{7.5 \times 0.059}{2} = 0.22\ \text{m}$$

Example3:Design the super elevation for a horizontal highway curve of radius 500m and speed 100kmph

3. Ans: Given Data: Speed, V=100kmph, Radius of the curve R= 500m

Step1: For mixed traffic conditions, super elevation is designed for 75% of design speed.

Therefore $e = \frac{(0.75v)^2}{gR} = \frac{(0.75V)^2}{127R} = \frac{V^2}{225R}$

$$e = \frac{V^2}{225R} = \frac{100^2}{225 \times 500} = 0.089$$

Step2: As this value is greater than 0.07, the actual super-elevation is restricted to 0.07, then proceed the steps 3&4

Step3: Check the coefficient of lateral friction developed for full speed

$$e + f = \frac{(V)^2}{127R} \Rightarrow f = \frac{(V)^2}{127R} - e \Rightarrow f = \frac{(100)^2}{127 \times 500} - 0.07$$

Therefore coefficient of friction 'f' = 0.157-0.07 = **0.087**

As this value is less than 0.15, the design is safe with a super-elevation of 0.07.

$\therefore$ Provide a super-elevation 'e' = 0.07

Example4:The design speed of highway is 80kmph. There is horizontal curve of radius 200m on a certain locality. Calculate the super-elevation needed to maintain this speed.

Given Data: Speed, V=80kmph, Radius of the curve R= 200m, Coefficient of friction f= 0.15

Step1: For mixed traffic conditions, super elevation is designed for 75% of design speed.

Therefore $$e = \frac{V^2}{225R} = \frac{80^2}{225\times 200} = 0.142$$

Step 2: As this value is greater than 0.07, the actual super-elevation is restricted to 0.07, then precedes the step 3sn

Step3: Check the coefficient of lateral friction developed for full speed

$$e + f = \frac{(V)^2}{127R} \Rightarrow f = \frac{(V)^2}{127R} - e \Rightarrow f = \frac{(80)^2}{127 \times 200} - 0.07$$

Therefore coefficient of friction 'f'= 0.252-0.07 = **0.18**

As this value is more than 0.15, the design is not safe, then restricted the speed

Step 4: Determine the maximum allowable speed, $V_a = \sqrt{27.94R} = \sqrt{27.94 \times 200}$ = 74.75kmph

Hence the speed may restrict to less than 75 or say 70kmph at this curve.

RADIUS OF HORIZONTAL CURVE

- Horizontal curves of Highways are generally designed for the specified ruling design speed of the Highway.
- However if this is not possible due to site restrictions, the horizontal curves may be designed considering the specified minimum design speed of the highway.
- Particular speed of vehicle the centrifugal force is dependent on the radius of the horizontal curve.
- The centrifugal force ‘p’ developed due to a vehicle negotiating a horizontal curve of radius, R at a speed, v m/sec or V kmph is counteracted by the super elevation, e and lateral coefficient of friction ‘f ’.
- The relation ship between the above e, f and P is

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

RADIUS OF HORIZONTAL CURVE

- The ruling minimum radius of the curve for ruling design speed v m/sec. or V kmph is given by.

$$R_{Rulling} = \frac{V^2}{127(e+f)} \qquad R_{Minimum} = \frac{V'^2}{127(e+f)}$$

- Where, V= Ruling Design speeds, in m/sec and kmph respectively
- V'=Minimum Design Speed
- e = Rate of super elevation=0.07
- f= Coefficient of lateral friction=0.15
- g=Acceleration due to gravity=9.8m/sec 2

➢Calculate the values of ruling minimum and absolute minimum radius of horizontal curve of a national highway plain terrain. Assume ruling design speed and minimum design speed values as 100 and 80 kmph respectively.

Ans: Given Data:

Ruling Design speed = 100 kmph,

Minimum design speed = 80kmph

The Ruling and Minimum design speed are the maximum values of 'e' = 0.07 and f = 0.15.

The Ruling minimum radius of the curve for ruling design speed v m/sec. or V/ kmph is given by

$$R_{ruling} = \frac{V^2}{127(e+f)} = \frac{100^2}{127(0.07+0.15)} = 357.9\ m\ say\ 360\ m$$

The absolute minimum radius of the curve for minimum design speed v m/sec. or V/ kmph is given by

$$R_{ruling} = \frac{V'^2}{127(e+f)} = \frac{80^2}{127(0.07+0.15)} = 229.1\ m\ say\ 230\ m$$

Therefore provide rulling minimum radius of 360 m and absolute minimum radius of 230 m.

WIDENING OF PAVEMENT ON HORIZONTAL CURVES

- On horizontal curves, especially when they are not of very large radii, it is common to widen the pavement slightly more than the normal width,
- Widening is needed for the following reasons :
  - ✓ The driver experience difficulties in steering around the curve.
  - ✓ The vehicle occupies a greater width as the rear wheel don't track the front wheel. known as 'Off tracking'
  - ✓ For greater visibility at curve, the driver have tendency not to follow the central path of the lane, but to use the outer side at the beginning of the curve.
  - ✓ While two vehicle cross or overtake at horizontal curve there is psychological tendency to maintain a greater clearance between the vehicle for safety.

OFF TRACKING

- An automobile has a rigid wheel base and only the front wheels can be turned, when this vehicle takes a turn to negotiate a horizontal curve, the rear wheel do not follow the same path as that of the front wheels. This phenomenon is called off tracking.
- The required extra widening of the pavement at the horizontal curves depends on the length of the wheel base of the vehicle 'l', radius of the curve 'R' and the psychological factors.

Analysis of extra widening on curves

- It is divided into two parts;
  - ✓ Mechanical widening (W_m): the widening required to account for the off tracking due to the rigidity of wheel base is called mechanical widening
  - ✓ Psychological widening (W_{ps}): extra width of the pavement is also provided for psychological reasons such as , to provide for greater maneuverability of steering at high speed, to allow for the extra space for overhangs of vehicles and to provide greater clearance for crossing and overturning vehicles on curve.
- Total widening $W = W_{ps} + W_m$

Mechanical Widening

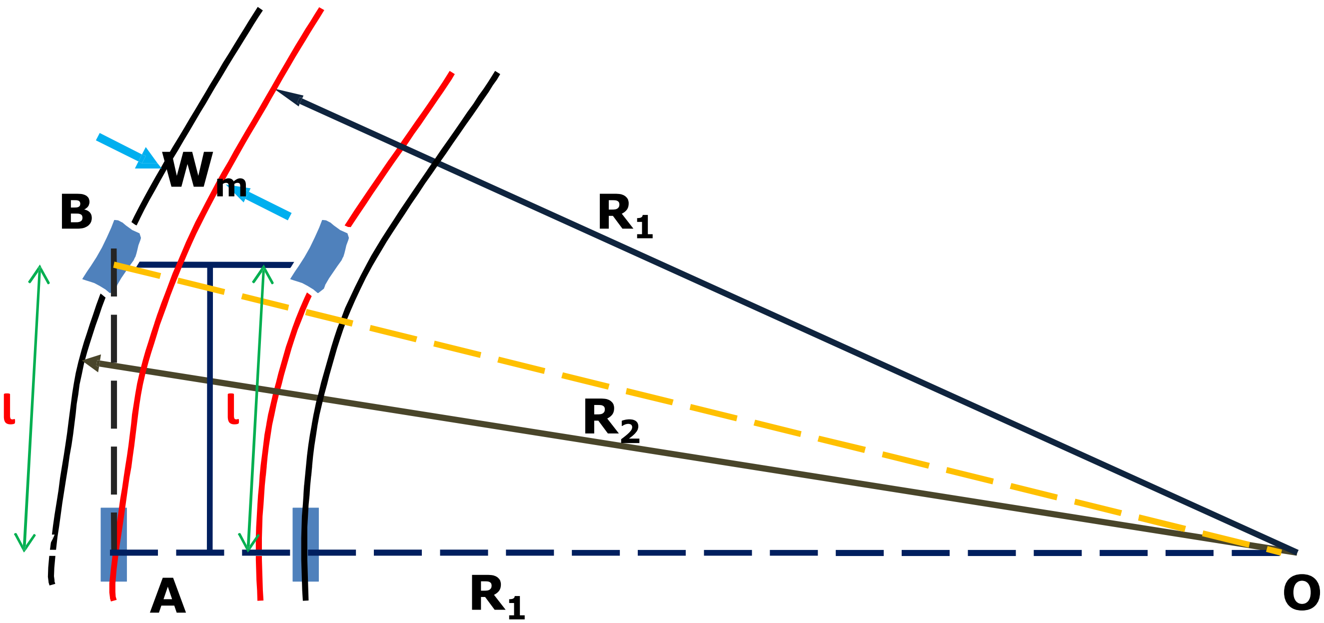
$W_m = R_2 - R_1$

From Δ OAB,

$OB^2 = OA^2 + BA^2$

$OA^2 = OB^2 - BA^2$

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



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

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

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

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

$W_m = l^2 / 2R$ (Approx.) or $W_m = nl^2/2R$ (for n traffic lanes and n vehicles can travel simultaneously)

Where, R = Mean radius of the curve in m,

n=no. of traffic lanes

R = Mean radius of the curve, m

l = Length of Wheel base of longest vehicle , m

(l = 6.0 m or 6.1m for commercial vehicles)

V= design speed, kmph

Psychological Widening

➢An Empirical formula has been recommended by IRC for finding the additional psychological widening '(W_{ps})' which is dependent on the design speed V of the vehicle and the radius of R of the curve. The psychological widening is given by the formula:

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

V = Design speed of the vehicle, km/h R = Radius of the curve, m

Hence the total widening W_e = Mechanical widening + Psychological Widening in meters

∴ Required horizontal curve is given by $\underline{W_e = W_m + W_{ps}}$

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

Where, n=number of traffic lanes, l = length of wheel base of longest vehicle, m. (The value of l may be taken as 6.0 m or 6.1m for commercial vehicles). V= Design Speed, kmph, R= Radius of horizontal curve, m


Transunion

Example-1:Calculate the extra widening required for a pavement of width 7m on a horizontal curve of radius 250m if the longest wheel base of vehicle expected on the road is 7.0 m. design speed is 70 kmph.

Ans: Given Data:

Pavement Width = 7m, Horizontal Curve R= 250m

Length of Longest wheel base l= 7.0m Design Speed V=70kmph

Extra widening required $W_e = W_m + W_{ps} = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$

Hence n=2(Two lanes for pavement width of 7.0m)

$W_e = \frac{2\times7^2}{2\times250} + \frac{70}{9.5\sqrt{250}} = 0.196 + 0.466 = \mathbf{0.662m}$

∴ Extra widening required for the pavement width=0.662m

∴Total pavement Width is required on horizontal curve =7+0.662=7.662m

Example-2:Find the total width of two lane road on a horizontal curve for a new National highway to be aligned along a rolling terrain with a ruling minimum radius having ruling design speed of 80 kmph. Assume necessary data as per IRC

Ans: Assume the following Data:

1. National highway on rolling terrain, ruling design Speed V=80 kmph

2. Normally Pavement Width W = 7.0 m,

3. Length of Longest wheel base l= 6.0m

4. Maximum value of super elevation e=0.07, and coefficient of friction f= 0.15

$$R_{ruling} = \frac{V^2}{127(e+f)} = \frac{80^2}{127(0.07+0.15)} = 229\ m\ say\ 230\ m$$

Extra widening required $W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}} = \frac{2\times 6^2}{2\times 230} + \frac{70}{9.5\sqrt{230}}$

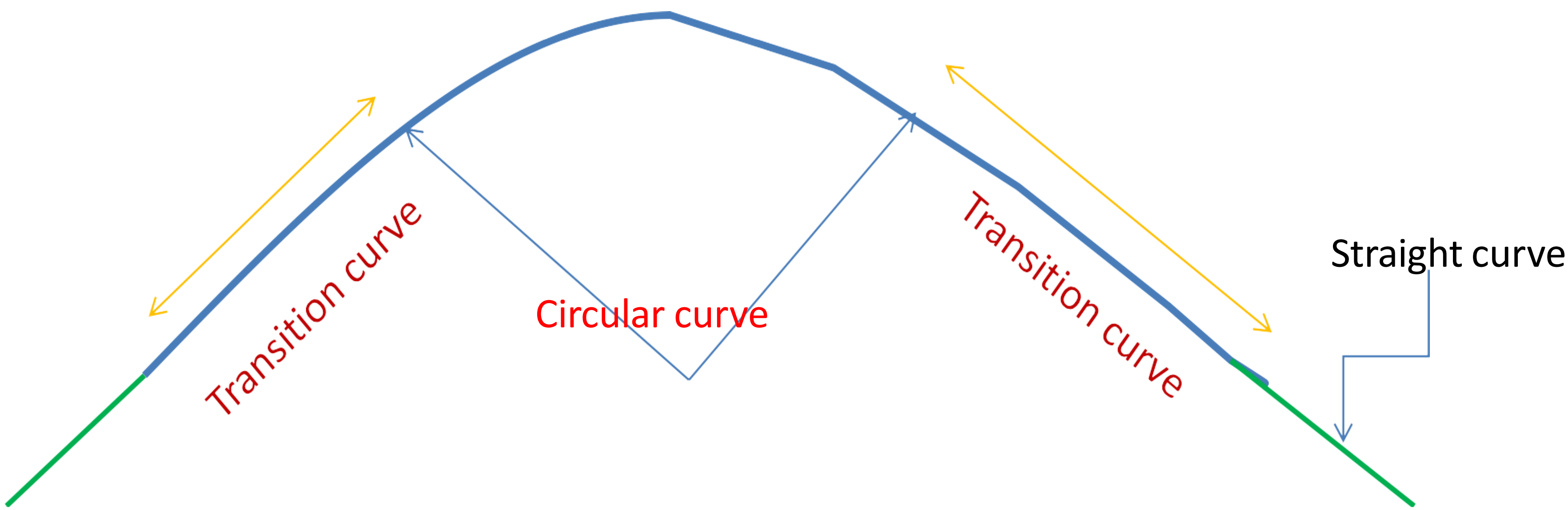
$$\text{We} = 0.157 + 0.555 = \mathbf{0.712m}$$

∴ Extra widening required for the pavement width=0.712m

∴Total pavement Width is required on horizontal curve =7+0.712=7.712m

Horizontal transition curves

- When a non circular curve is introduce between a straight and a circular curve has a varying radius from the straight end (tangent point) to the desired radius of the circular curve at the other end (curve point) for the gradual introduction of centrifugal force is known as transition curve.



Objectives for providing transition curve

- ✓ To introduce gradually the centrifugal force between the tangent point and the beginning of the circular curve, avoiding sudden jerk on the vehicle. This increases the comfort of passengers.
- ✓ To provide comfort for the driver that is to enable smooth vehicle operation on road.
- ✓ To provide gradual introduction of super elevation
- ✓ To provide gradual introduction of extra widening.
- ✓ To enhance the aesthetic appearance of the road.

Design of transition curve

- **Type of transition curve:**
- They are:
  - ✓Spiral clothoid
  - ✓Cubic parabola
  - ✓Lemniscates
- IRC recommends spiral is the ideal transition curve due to the following reasons:

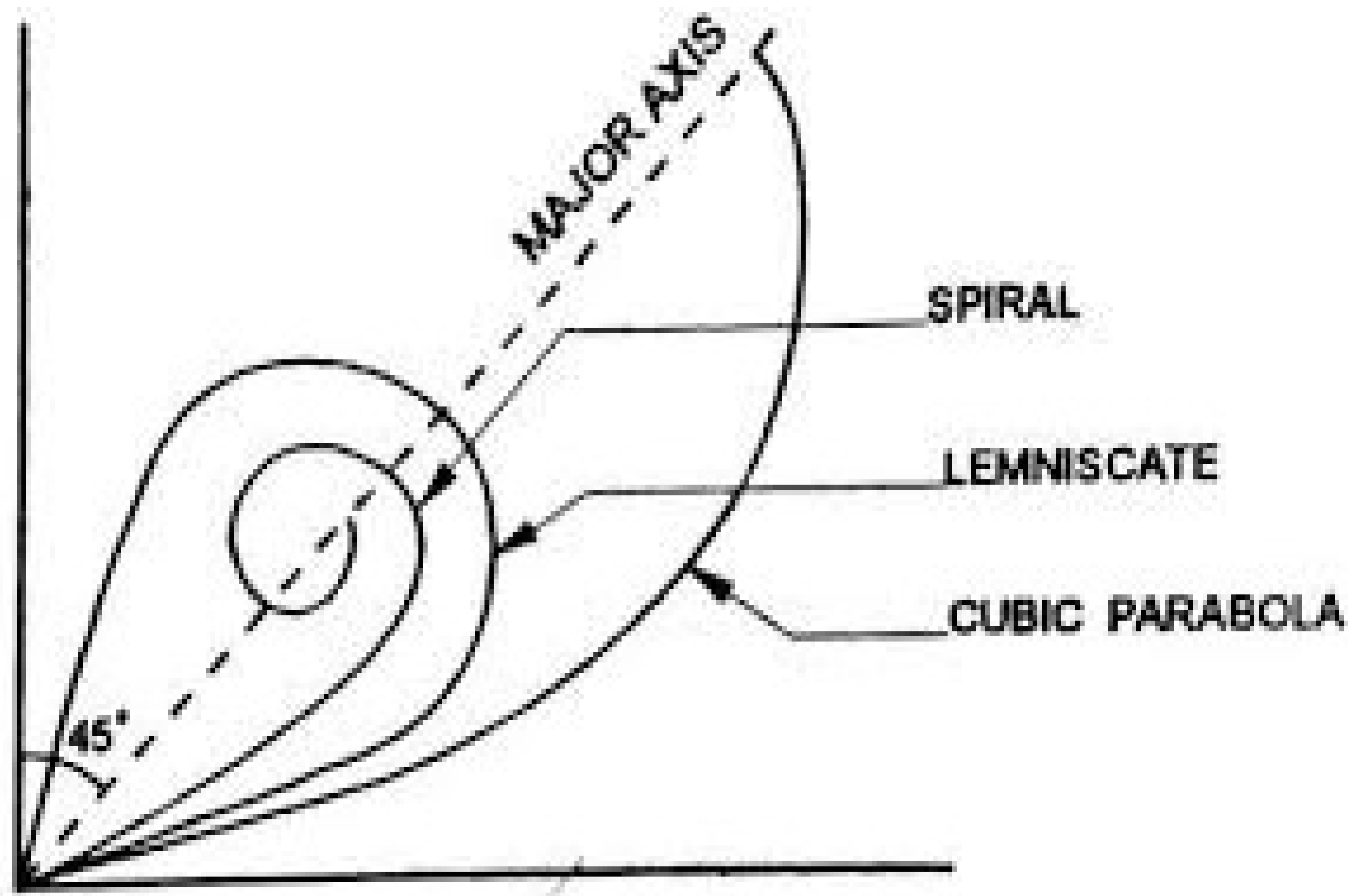
•It satisfies that rate of change of centrifugal acceleration is uniform throughout the length

•The calculation and field implementation of spiral curves is simple and easy.

•It enhances aesthetics also

- The general shapes of these three curves are shown in below fig.

Different types of transition curves



DESIGN OF TRANSITION CURVES

- Determining the length of transition curve:
  - The length of transition curve can be calculated by 3 conditions.
    - ✓ Based on rate of change of acceleration
    - ✓ Based on rate of change of super elevation and extra widening
    - ✓ Based on IRC empirical formula

•Based on rate of change of acceleration:

- Radius of curve is infinity at the tangent point and hence centrifugal acceleration is zero.
- Similarly at the straight end radius of curve has minimum value means centrifugal acceleration is maximum. So, the rate of change of centrifugal acceleration should be adopted such that the design should not cause any discomfort to the drivers.

DESIGN OF TRANSITION CURVES

- Let L_s be the length of transition curve and a vehicle is moving with a speed of V m/sec.

  Force $P = mV^2/R$

  Hence, it is similar to F=ma

  ($\because$ F=ma, which means that force (F) acting on an object is equal to the mass (m) of an object times its acceleration 'a').

  Therefore, centrifugal acceleration = V^2/R
- Let "C" be the coefficient of rate of change of centrifugal acceleration it is given by

  $C= (V^2/R)\times(1/t)$

  Where t= time taken to travel the transition curve of length L_s, with a speed of V

  $t = L_s / V$

  $C = (V^2/R)\times(V/ L_s)$

  $L_S = V^3/CR$
- According to IRC, C= 80/(75+V) and C should be 0.5 < C < 0.8

DESIGN OF TRANSITION CURVES

- If the design speed is V kmph,

$$L_s = \frac{v^3}{(3.6)^3 CR}$$

$$L_s = \frac{V^3}{46.5\,CR} = \frac{0.0215\,V^3}{CR}$$

- Here, Ls = Length of Transition Curve, m
  C = Allowable rate of change of centrifugal acceleration
  R = radius of the circular curve, m

DESIGN OF TRANSITION CURVES

- **Based on rate of change of super elevation and Extra widening:**
- Let 1in N is the allowable rate of introduction of super elevation and 'E' is the raise of the outer edge with respect to inner edge. 'W' is the normal width of pavement in meters. W_e is the extra width of the pavement in meters. And 'e' is the rate of super elevation.

$$E = B \times e = (W + We) \times e$$

- Therefore length of transition curve, Ls=EN= (W + We) × e × N

$$L_s = EN = eN(W + W_e)$$

- If the pavement is rotated about the center line.

$$L_s = \frac{EN}{2} = \frac{eN}{2}(W + W_e)(\because E = B \times e = (W + W_e) \times e$$

DESIGN OF TRANSITION CURVES

- **Based on IRC empirical formula:**
- IRC given some direct formulae for finding the length of transition
  curve.
  - ✓ For plain and ruling terrain: $Ls = 2.7(V^2/R)$
  - ✓ For Mountainous and steep terrain: $Ls = V^2/R$

- The design length of transition curve(Ls) will be the highest value of case-1,2 and 3

Shift of the transition curve
or
Setting out Transition Curve

Shift of the transition curve 'S': For the main circular curve to fit in the transition curve, which is laid in the shape of a cubic parabola, it is required be moved inward by a measure known as the 'shift as shown in fig

$$\boxed{S = \frac{L_S^{\,2}}{24\,R}}$$

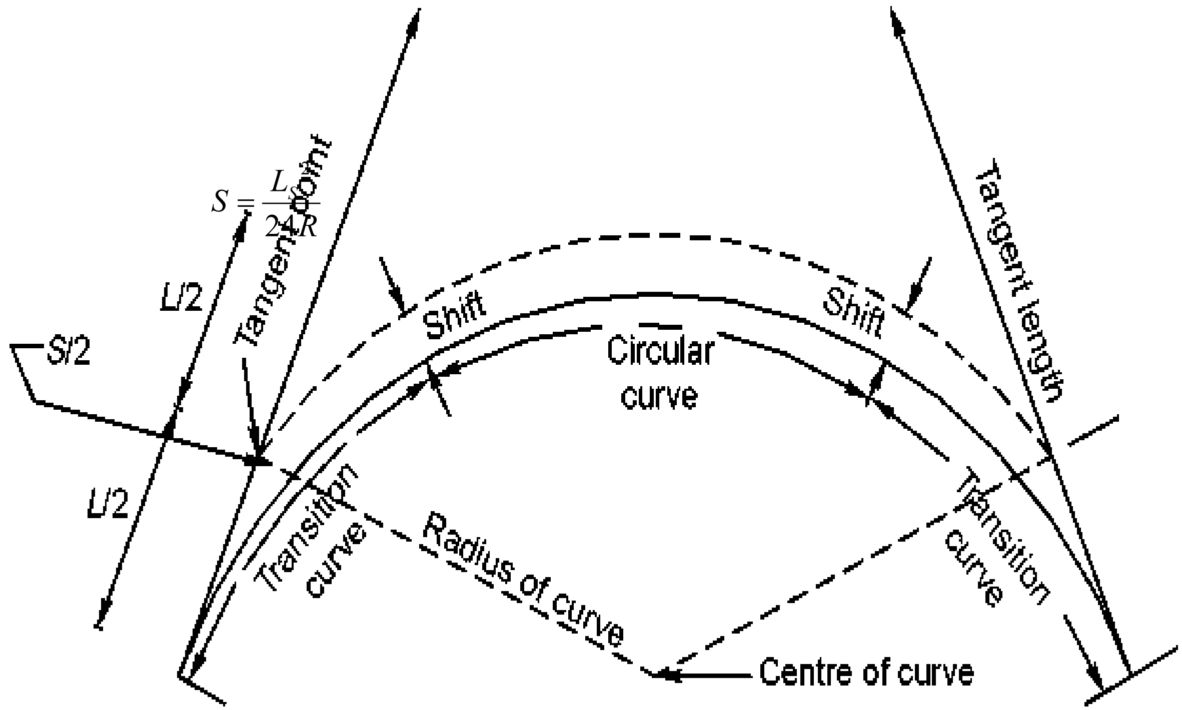


Fig.13.12 Shift

Calculate the length of the transition curve and shift using the following data;

Design speed= 65 kmph, Radius of circular curve= 220 m

Allowable rate of super-elevation= 1 in 150

Pavement rotated about the centre line of the pavement

Pavement width including extra widening= 7.5 m

Given Data:

Design speed V= 65 kmph

Radius of circular curve R= 220 m

Allowable rate of super-elevation 1 in N= 1 in 150

Pavement rotated about the centre line of the pavement

Pavement width including extra widening (W + We) = 7.5 m

Length of Transition Curve, Ls

(a) Based the rate of centrifugal acceleration

Length based on allowable rate of centrifugal acceleration, C

$$C = \frac{80}{75+V} = \frac{80}{75+65} = 0.57\ m/sec^3$$

As the C value is between 0.5 and 0.8, C= 0.57 is accepted.

Therefore Length of Transition Curve Ls = $\frac{0.0215V^3}{CR} = \frac{0.0215 \times 65^3}{0.57 \times 220} = 47.1\ meter$

Continue problem

(b) Based on the rate of introduction of Super-elevation

Super elevation Rate 'e'$=\dfrac{V^2}{225R}=\dfrac{65^2}{225\times220}=0.085$

As this value is greater than the maximum allowable rate of 0.07, limit the value of e= 0.07.

Check the safety against transverse skidding by finding by finding the friction coefficient developed, f for the design speed of 65kmph:

$$e+f=\frac{V^2}{127R}\Rightarrow f=\frac{V^2}{127R}-e$$

$$f=\frac{65^2}{127\times220}-0.07=0.151-0.07=0.081$$

Therefore this value is less than 0.15, hence e =0.07 is safe with design speed of 65kmph

Total width of the pavement at the curve, B = 7.5m

The raise of outer edge of pavement with respect to centre line =E/2

$$\therefore\frac{E}{2}=\frac{e.B}{2}=\frac{0.07\times7.5}{2}=0.26m$$

If the pavement is rotated about the center line.

$$Length\ of\ transition\ Curve, L_s=\frac{EN}{2}=0.26\times150=39m$$

Continue problem

(c). Based on the Empirical formula

$$Length\ of\ transition\ Curve, L_s = \frac{2.7V^2}{R} = \frac{2.7 \times 65^2}{220} = 51.9m$$

Therefore the highest value of three is 51.9 meters say 52 meters length of transition curve is adopted.

Shift of Transition Curve 'S' $= \frac{{L_s}^2}{24R} = \frac{52^2}{24 \times 220} = \mathbf{0.51m}$

Example-2: A national highway passing through rolling terrain in heavy rain fall area has a horizontal curve of radius 500 m. Design the length of transition curve using the following data.

Design speed of vehicle= 80 kmph, Allowable rate of super-elevation= 1 in 150

Pavement rotated about the inner edge of the pavement.

Pavement width excluding extra widening= 7 m.

Ans: Given Data: Radius of horizontal curve R =500 meter

Design speed of vehicle= 80 kmph

Allowable rate of super-elevation= 1 in 150

Pavement rotated about the inner edge of the pavement.

Pavement width excluding extra widening= 7 m.

Allowable rate of change of centrifugal acceleration $C = \frac{80}{75+V} = \frac{80}{75+80} = 0.52\ m/sec^3$

This value is in between 0.5 to 0.8 it is accepted for design.

(a) Length of transition curve by rate of change of centrifugal acceleration:

$$\text{Length of Transition Curve Ls} = \frac{0.0215V^3}{CR} = \frac{0.0215\times80^3}{0.52\times500} = 42.34\ meter$$

Continue Problem

(b) Length of transition curve by the rate of introduction of Super-elevation

Super elevation Rate 'e'$=\frac{V^2}{225R} = \frac{80^2}{225\times 500} = \mathbf{0.057}$

As this value is less than the 0.07, super elevation rate of 0.057 may be accepted for design.

Extra widening at curve (Assuming two lanes and wheel base of 6m).

$$W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}} = \frac{2\times 6^2}{2\times 500} + \frac{80}{9.5\sqrt{500}}$$

$$\text{We} = 0.072 + 0.377 = \mathbf{0.45m}$$

$$Length\ of\ transition\ Curve, L_s = EN = eN(W + W_e) = 0.057 \times 150 \times (7 + 0.45)$$

$$Length\ of\ transition\ Curve, L_s = 0.057 \times 150 \times 7.45 = 63.7\ meter$$

(c). Length of transition curve as per IRC Empirical formula

$$Length\ of\ transition\ Curve, L_s = \frac{2.7V^2}{R} = \frac{2.7\times 80^2}{500} = 34.6\ meter$$

Therefore the highest value of three is 63.7 meters say 64 meters length of transition curve is adopted.

Therefore, the design length of transition curve, Ls is 64 meter.

VERTICAL ALIGNMENT

- The vertical alignment is the elevation or profile of the centre line of the road.
- The vertical alignment consist of grade and vertical curve and it influence the vehicle speed, acceleration, sight distance and comfort in vehicle movements at high speed.

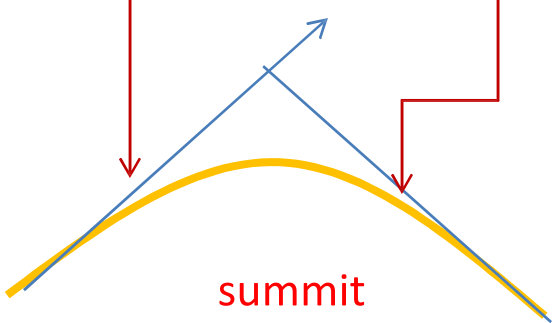
GRADIENT

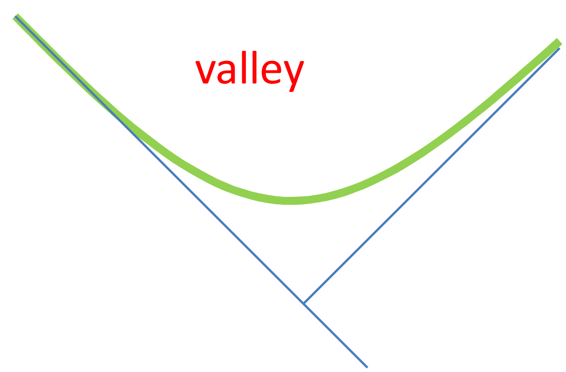
- It is the rate of rise or fall along the length of the road with respect to the horizontal. It is expressed as a ratio of 1 in x (1 vertical unit to x horizontal unit). Some times the gradient is also expressed as a percentage i.e. n% (n in 100).

- Represented by:

+n %   + 1 in X (+ve or Ascending)

or -n%   - 1 in X (-ve or descending)





TYPICAL GRADIENTS (IRC)

- Ruling Gradient
- Limiting Gradient
- Exceptional gradient
- Minimum Gradient
- Ruling gradient (design gradient):
- It is the maximum gradient within which the designer attempts to design the vertical profile of road, it depends on
  - Type of terrain
  - Length of grade
  - Speed
  - Pulling power of vehicles
  - Presence of horizontal curves
  - Mixed traffic

TYPICAL GRADIENTS (IRC)

- Limiting Gradient: Steeper than ruling gradient. In hilly roads, it may be frequently necessary to exceed ruling gradient and adopt limiting gradient, it depends on
  - Topography
  - Cost in constructing the road

Exceptional Gradient:

- Exceptional gradient are very steeper gradients given at unavoidable situations. They should be limited for short stretches not exceeding about 100 m at a stretch.
- A minimum of 1 in 500 may be sufficient for concrete drain and 1 in 200 for open soil drains found to give satisfactory performance.

TYPICAL GRADIENTS (IRC)

- **Minimum Gradient:**
- This is the important only at locations where surface drainage is important.
- Camber will take care of the lateral drainage
- But the longitudinal drainage along the side drains require some slope for smooth flow of water.
- Therefore minimum gradient is provided for drainage purpose and its depends upon the rainfall, type of soil and other site conditions.

Value of gradient as per IRC

Terrain	Ruling gradient	Limiting gradient	Exceptional gradient
Plain and Rolling	**3.3% (1 in 30)**	**5%**	**6.70%**
Mountainous terrain	**5% (1 in 20)**	**6%**	**7%**
Steep terrain up to 3000m (MSL)	**5% (1 in 20)**	**6%**	**7%**
Steep terrain (>3000m)	**6% (1 in 16.7)**	**7%**	**8%**

VERTICAL CURVES

OBJECTS AND TYPES:

- Vertical curves are used in highway vertical alignment to provide a gradual change between two adjacent grade lines.
- Due to changes in grade in the vertical alignment of highway, it is necessary to introduce vertical curves at the intersections of different grades to smoothen out the vertical profile and thus ease off the changes in gradients for the fast moving vehicles.
- The vertical curves used in highway may be classified into two categories:
  - ✓ Summit curves or crest curves with convexity upwards
  - ✓ Valley curves or sag curves with concavity upwards

VERTICAL CURVES

SUMMIT CURVES:

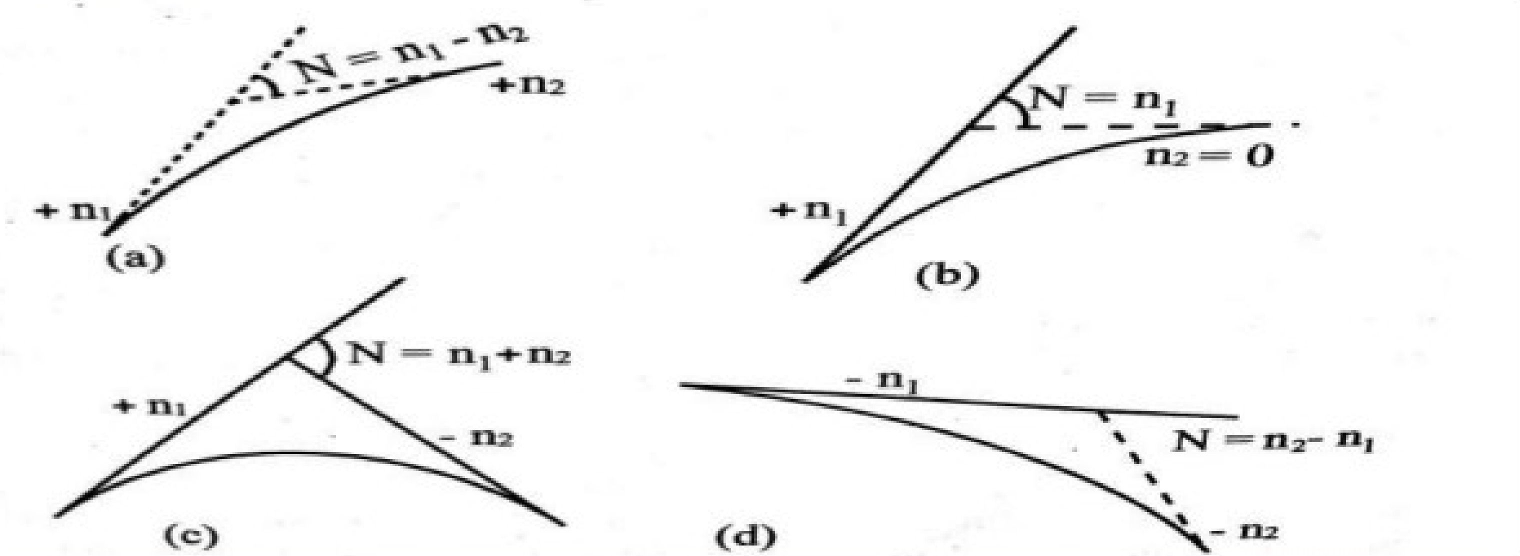
- Summit curves with convexity upwards are formed in any one of the cases illustrated in figs. a, b, c , and d.
- The deviation angle, N between the two intersecting gradients is equal to the algebraic difference between them.
- Of all the cases, the deviation angle will be maximum when an ascending gradient, ($+ n_1$) meets with a descending gradient, ($- n_2$).
- Therefore deviation angle, $N=n_1 - (- n_2)=n_1+n_2$
- When a fast moving vehicle travels along a summit curve, the centrifugal force will act upwards, against gravity and hence a part of the self weight of the vehicle is relieved resulting in reduction in pressure on the tyres and on the suspension springs of the vehicle suspensions.
- So there is no problem of discomfort to passengers on summit curves, particularly because the deviation angles on roads are quite small.

VERTICAL CURVES

Summit Curve

- **Objective –**

To join 2 different grades of roads with smooth vertical curve. Four different conditions for formation summit curve which are shown below -



VERTICAL CURVES

Length of Summit Curve:

- *Length of summit curve for stopping sight distance(SSD):*
- Two cases are to be considered in deciding the length:

  (a) When the length of the curve is greater than the sight distance (L > SSD)

  (b) When the length of the curve is less than the sight distance (L < SSD)

- (a) **When l > SSD**
- The general equation for length L of the parabolic curve is given by:

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

Here,

L= length of summit curve, m, S= stopping sight distance SSD, m

N= deviation angle, equal to algebraic difference in grades, or tangent of the deviation angle

H= height of eye level of driver above roadway surface, m

h= height of subject above the pavement surface, m

VERTICAL CURVES

- The value of H, the height of the driver's eye above roadway surface is taken as 1.2m and the height of object 'h' above the pavement surface is taken as 0.15 m as per IRC standards.
- Substituting these values in Length of summit curve equation and it is obtained as:

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

- **(b) When L < SSD**

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

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

- If substitute H= 1.2 and h=0.15m

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

VERTICAL CURVES

- ***Length of summit curve for over taking sight distance (OSD) or intermediate sight distance (ISD):***
- Two cases to be considered in deciding the length are:
  (a) When the length of the curve, L is greater than the OSD or ISD (L > S)
  (b) When the length of the curve is less than the OSD or ISD (L < S)
- (a) ***When L > S:***
- From the general equation for the length of the parabolic curve

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

- In the above equation, the values of H and h, both are taken as 1.2m. Substituting h=H in the above equation and simplifying.

$$\boxed{L = \frac{NS^2}{8H}} \qquad \boxed{L = \frac{NS^2}{9.6}}$$

- Substituting H=1.2 m,

VERTICAL CURVES

(b) ***When L < S:***

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

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

- May be substituting H = h and simplifying, when L is less than OSD/ISD

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

- Here again substituting the value of H as 1.2 m, the equation reduces to:

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

Example 1: A vertical summit curve is formed at the intersection of two gradients, + 3.0 and – 5.0 percent. Design the length of summit curve to provide a stopping sight distance for a design speed of 80 Kmph. Assume other data.

Solution: Given data:

Design speed V= 80Kmph

Gradients $n_1 = +3\%$ and $n_2 = -5.0\%$

(a) Determine the safe stopping sight distance SSD:

$$SSD = 0.278Vt + \frac{V^2}{254f}$$

Assuming t=2.5sec and f=0.35 for 80 kmph

$$SSD = 0.278 \times 80 \times 2.5 + \frac{80^2}{254 \times 0.35} = 55.6 + 72.0 = 127.6 \text{ say } \mathbf{128m}$$

(b) Determine the Length of the summit curve:

Deviation angle $N = n_1 - (-n_2) = 0.03 - (-0.05) = 0.03 + 0.05 = 0.08$

When L > SSD

$$L = \frac{NS^2}{4.4} = \frac{0.08 \times 128^2}{4.4} = \mathbf{297.9M\ say\ 298m}$$

This value of summit curve length L is greater than SSD of 128 m as per the assumption and therefore the calculated length may be accepted for design.

The length of summit curve, **L= 298m**

Example 2: An ascending gradient of 1 in 100 meets a descending gradient of 1 in 120. A summit curve is to be designed for a speed of 80kmph so as to have an overtaking sight distance of 470m.

Solution: Given data

Design speed V= 80Kmph, OSD = 470 m, $n_1 = +\frac{1}{100}$ and $n_2 = -\frac{1}{120}$

Deviation angle, $N = \frac{1}{100} - \left(-\frac{1}{120}\right) = \frac{11}{600}$

(i) When Assume, L > OSD

Length of summit curve, $L = \frac{NS^2}{9.6} = \frac{11 \times 470^2}{600 \times 9.6} = 422m$

As this value of L is less than OSD of 470 m, this assumption is not correct

(ii) When Assume, L < OSD

Length of summit curve, $L = 2S - \frac{9.6}{N} = 2 \times 470 - \frac{9.6 \times 600}{11} = 416.4\ m\ say\ 417\ m$

As this value of L = 417 m is less than OSD of 470 m, this assumption is correct.

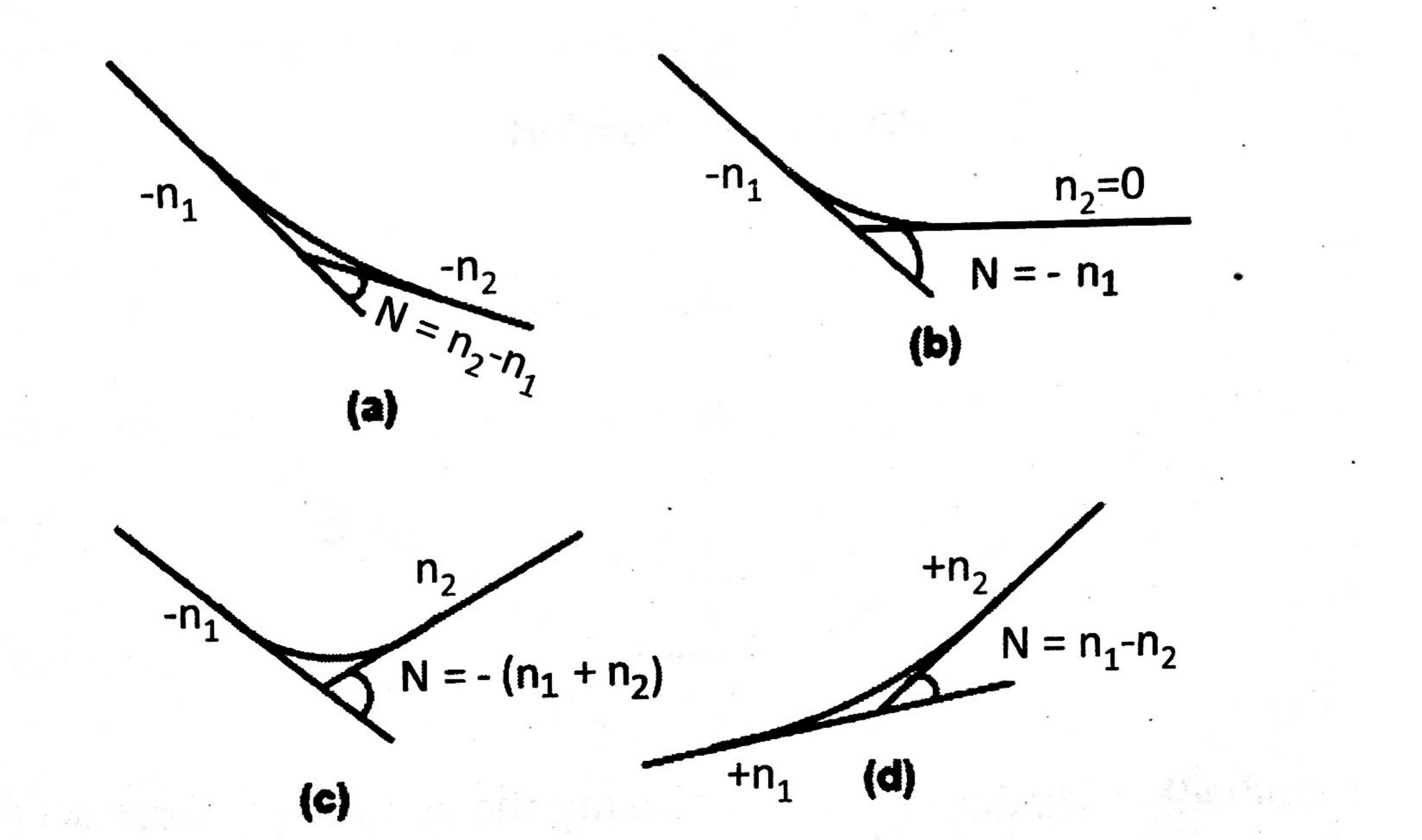
Therefore the design length of summit curve = 417 m.

VERTICAL CURVES

VALLEY CURVES:

- Valley curves or sag curves with convexity downwards are formed in any one of the cases illustrated fig a, b, c and d
- The deviation angle, N between the two intersecting gradients is equal to the algebraic difference between them.
- Among all the cases the maximum possible deviation angle is obtained when descending gradient ($-n_1$) meets with an ascending gradient ($+ n_2$).
- Therefore deviation angle, $N = - n_1 - (+n_2) = - (n_1 + n_2)$
- As fast moving vehicle negotiate valley curves, the centrifugal force developed acts down ward in addition to the self weight, thus adding additional pressure on the suspension systems of the vehicle and discomfort to the passengers due to impact, unless the valley curve is properly designed and laid.

TYPES OF VALLEY CURVES



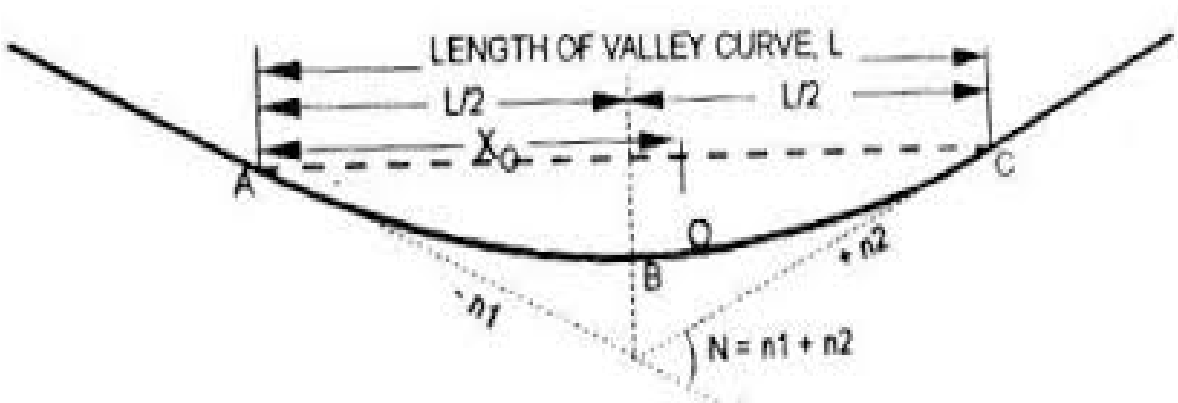
VERTICAL CURVES

Length of Valley Curve:

- The valley curve and its length are designed as a transition curves to full fill the two criteria,

(i) The allowable rate of change of centrifugal acceleration and
(ii) The required head light sight distance for night driving.

- The higher of the above two values is adopted.
- As shown in below fig ABC is the valley curve of total length L and AB and BC are two equal transition curves each of length Ls=L/2, having the minimum radius R at the common point B.



VERTICAL CURVES

- **Length of valley curve:**
- The determination of valley curve length fulfilling the two requirements of comfort and head lights sight distance are given below:
- **(a) The length of transition curve Ls for comfort condition:**
- The length of transition curve, Ls full filling allowable rate of change of centrifugal acceleration, C has been given by the equation

$$Ls = V^3/CR$$

Value of R (at length, Ls) = Ls/N = L/2N

$$L_S = \frac{v^3}{CL_S} \times N = L_s^{\,2} = \frac{Nv^3}{C}$$

Therefore $\boxed{L_S = \left[\frac{Nv^3}{C}\right]^{\frac{1}{2}}}$ $\boxed{\therefore\ L = 2L_S = 2\left[\frac{Nv^3}{C}\right]^{\frac{1}{2}}}$

VERTICAL CURVES

length of transition curve for comfort condition:

$$\therefore \ L = 2L_S = 2\left[\frac{Nv^3}{C}\right]^{\frac{1}{2}}$$

Here,

L= total length of valley curve = 2Ls

N= deviation angle in radians or tangent of the deviation angle or the algebraic difference in the two gradients.

v= design speed in m/sec

C= the allowable rate of change of centrifugal acceleration; the value of C may be taken as 0.6m/sec ^{3} so as to full fill the comfort condition at valley curves.

•

VERTICAL CURVES

When the design speed, V is expressed in Kmph

$$\text{V Kmph} = \frac{\text{v}}{3.6}\,\text{m/sec}$$

$$L_s^{\,2} = \frac{Nv^3}{0.6 \times 3.6^3} \Rightarrow L_s = 0.19\,(NV^3)^{\frac{1}{2}}$$

$$\therefore\ L = 2L_s = 2 \times 0.19\,(NV^3)^{\frac{1}{2}} = 0.38\,(NV^3)^{\frac{1}{2}}$$

- Hence the total length of Valley curve

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

VERTICAL CURVES

(b) Length of valley curve for head light distance:

•The length of valley curve for head light sight distance may be determined for the two conditions:

i. When the total length of valley curve L is greater than the stopping sight distance SSD and
ii. When the length L is less than SSD, as given below:

(i) L > SSD

- The length of valley curve L is assumed to be greater than the head light sight distance which should be at least equal to SSD, as shown in fig.

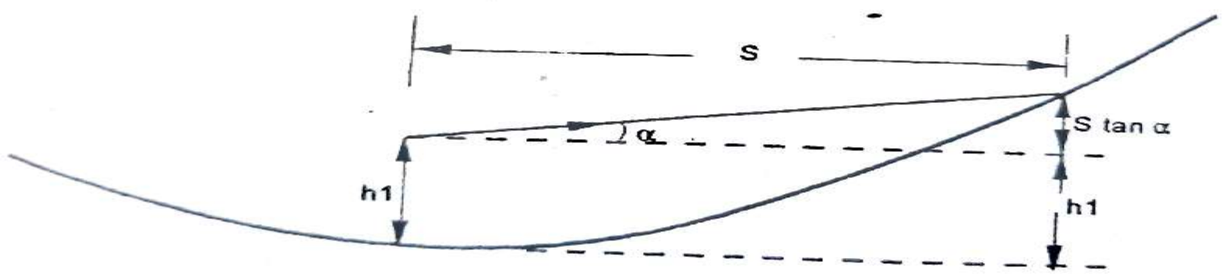


Fig. 4.38 Head light sight distance when L > SSD

VERTICAL CURVES

- Let the height of the head light be 'h_1' and the focused portion of the beam of light be inclined at an angle 'α' upwards.
- The sight distance available will be minimum when the vehicle is at the lowest point on the sag curve.
- If the valley curve is assumed to be of parabolic shape, with equation $y = a\,x^2$, where $a = N/2L$.

$$h_1 + S\tan\alpha = aS^2 = NS^2/2L$$

- if the average height of the head light is taken as h1 = 0.75 m and the beam angle $\alpha = 1^{o}$, by substituting these values in the above equation,

$$\boxed{L = \frac{NS^2}{(1.5 + 0.035\,S)}}$$

Here,

L = total length of valley curve, m ($L > S$)

S = SSD, m

N = deviation angle = (n_1+n_2), with slope $-n_1$ and $+n_2$

VERTICAL CURVES

(ii) L < SSD:

- As shown in below figure. Let the vehicle be at the start of the valley curve or at the tangent point TP, for minimum sight distance. Therefore,

$$\boxed{h_1 + S\tan\alpha = \left(S - \frac{L}{2}\right)N}$$

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

- Substituting h_1=0.75 m and $\alpha = 1^o$, when $L < S$

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

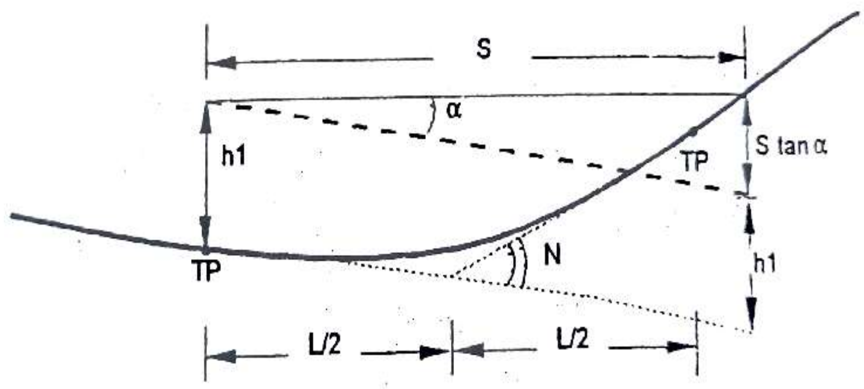


Fig. 4.39 Head light sight distance when L < S

Example: A valley curve is formed by a descending grade of 1 in 25 meeting an ascending grade of 1 in 30. Design the length of valley curve to fulfil both comfort conditions and head light sight distance requirements for a design speed of 80 Kmph. Assume allowable rate of change of centrifugal acceleration C = 0.6 m/sec^3.

Solution: Given data: Design speed, V=80Kmph = $\frac{80}{3.6}$ =22.2 m/sec.

Gradients n_1 = -1/25 and n_2 = +1/30, Deviation angle, N = $-\frac{1}{25} - \frac{1}{30} = -\frac{11}{150}$

(a) Valley curve length, L for comfort Condition:

From equation $L = 2\left[\frac{Nv^3}{C}\right]^{\frac{1}{2}} = 2\left[\frac{11 \times 22.2^3}{150 \times 0.6}\right]^{\frac{1}{2}} = 73.1\ m$

(b) Valley Curve length for head light sight distance:

Neglecting the ascending and descending gradients at the valley curve and assuming t = 2.5 sec, and f = 0.35, **SSD** = $vt + \frac{v^2}{2gf} = 22.2 \times 2.5 + \frac{22.2^2}{2 \times 9.8 \times 0.35} = 127.3\ m$

Assuming L > SSD = 127.3 m and using the equation

$$L = \frac{NS^2}{(1.5 + 0.035S)} = \frac{11 \times 127.3^3}{(1.5 + 0.035 \times 127.3)} = 199.5m$$

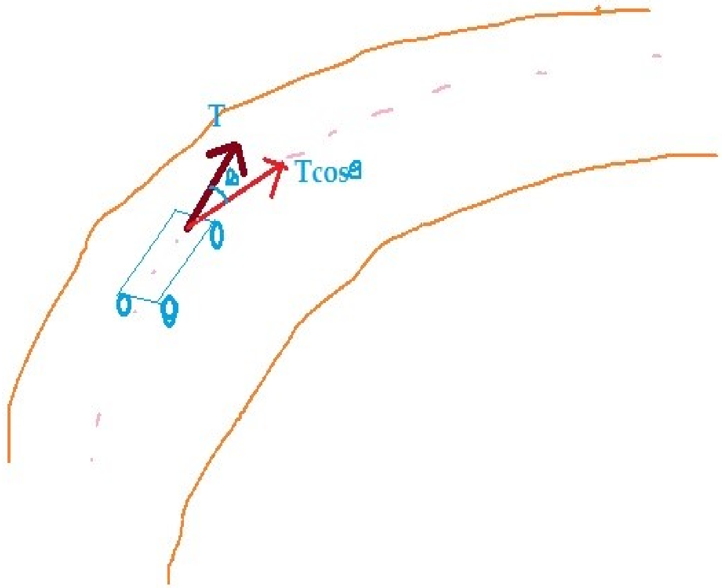
As this value of L is higher than the SSD of 127.3 m, the assumption is correct. The valley curve lengths based on head light sight distance being higher than that based on comfort condition, the design length of valley curve is 199.5 or say 200 m.

GRADE COMPENSATION

- Grade or Gradient is the ratio of vertical rise or fall of the road center line with respect to its length. It has to be provided for the vertical alignment of the road.
- When we provide gradient to the road, vehicle has to apply more power to overcome the component of the gravity force. Higher the grade/slope, larger is the effort required.
- When sharp horizontal curve is to be introduced on a road which has already the maximum permissible gradient, then the gradient should be decreased to compensate for the loss of tractive effort (force required to haul a load) due to the curve. This reduction in gradient at horizontal curve is called grade compensation or compensation in gradient at the horizontal curve.

GRADE COMPENSATION

- Suppose 'T' is the tractive effort of the vehicle, and the turning angle of the front wheel is 'Θ' then the tractive effort in that direction will be less.
- There will be a loss of tractive effort equal to (T-T. cosΘ). This loss in the tractive effort has to be compensated at the horizontal curves which also have the vertical grade. It is done by reducing the grade, this is known as the grade compensation.



Cont….

- IRC gave the following specification for the grade compensation.
    1. Grade compensation is not required for grades flatter than 4% because the loss of tractive force is negligible.
    2. Grade compensation is (30+R)/R %, where 'R' is the radius of the horizontal curve in meters.
    3. The maximum grade compensation is limited to (75/R)%.
    4. Compensated gradient = (Ruling gradient – grade compensation)

GRADE COMPENSATION

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

Solution: Given data

Ruling gradient = 6%

Radius of Horizontal curve R = 60 m

Grade compensation, % = $\frac{30+R}{R} = \frac{30+60}{60} = 1.5\%$

Maximum limit of grade compensation = 75/R=75/60=1.25%

Therefore provide a grade compensation = 1.25%

Compensated gradient = (Ruling gradient – grade compensation)

= 6.0 – 1.25 = **4.75%**

Thank you

BSR

III - MODULE

HIGHWAY MATERIALS & TESTING

TESTS ON SOILS

- **Sub -Grade Soil:**
- **CBR(California Bearing Ratio) Test:** The CBR test is conducted to determine the pavement thickness required on a given soil as there is a correlation between the CBR of soil and pavement thickness.
- **Specifications:**

1. Loading machine is a compression machine which operates at the rate of 1.25mm/minute. The capacity of the proving ring is 1000kg. Its plunger has a diameter of 50mm.
2. The cylindrical mould has 150mm diameter and 175 mm height and a detachable perforated base.
3. Compaction rammer has 4.84kg weight and fall of 310mm.

TESTS ON SOILS

- **Procedure:**

1. Take 5kg of clean and dry soil and add the water equal to given moisture content. Mix it thoroughly either with hands or a towel and separate the sample into five parts.
2. Grease all the internal parts of the cylindrical mould, collar and spacer disc. Then fix the cylindrical mould and collar to the stand.
3. Pour the soil sample into the cylindrical mould in 5 layers compacting each layer 56 times with the heavy compaction hammer.
4. Remove the collar , cut off excess soil above the level of cylindrical mould with a sharp cutting edge.
5. Reverse the mould, take out the spacer disc. To simulate the field condition of the over lying pavement, keep the annular weight of 5kg as surcharge weight at the top of the sample.
6. Soak the specimen in water for 4 days.
7. After the soaking period, keep the mould with sample and weights on the machine.
8. Bring the plunger to be in contact with the surface of soil and apply a seating load of 4kg.

TESTS ON SOILS

- 9. Set the proving ring to zero. Fix a dial gauge to measure the penetration and set it to zero.
- 10. Now allow the plunger to penetrate the specimen, record the proving ring readings for 0.5, 1.0, 1.5, ………..12.5mm penetration in the dial gauge.
- 11. Convert the proving ring reading into unit pressure from the given CBR chart (or) multiply the proving ring division by the P.R. Constant to get the load in kg. Divide this load by the area of the plunger in Sq.cm to get the unit pressure in kg/Sq.cm
- **CBR (in %) = [**(*Actual Load)/ (standard Load)*]× *100*

TESTS ON SOILS

CBR TEST SETUP

CBR SAMPLE PREPARATION

TESTS ON SOILS

- **Determination of Modulus of Sub-grade reaction of soil/Plate Load Test:** In this test, the strength of soil is determined in the form of modulus of sub-grade reaction (K), which is extensively used in the design of rigid pavement. It is a field test.
- 1. Clean the ground surface at which the test is to be done.
- 2. Keep the standard test plate of 750mm size on the ground.
- 3. Above this keep some stacking plates on which keep the hydraulic jack.
- 4. At the top keep the reaction beam.
- 5. Apply a seating load of 0.75N/mm^2 for a few minutes and release.
- 6. Now apply a load increment sufficient to cause a settlement of 0.75mm. Keep the load until the rate of settlement becomes less than 0.025mm/min.

TESTS ON SOILS

- 7. Record the average settlement using a set of dial gauges placed on the stacking plates.
- 8. Now increase the load to cause a further settlement of 0.75mm and repeat the procedure.
- 9. Repeat the test for a few more loads.
- 10. Now plot the settlement values along X-axis and corresponding Bearing pressure values along Y-axis.
- 11. From this plot find the Bearing pressure corresponding to an average settlement of Δ=0.025cm (0.25mm).

$$K = \frac{P}{0.125}\ (kg/cm^2$$

- **Summary**
- The quality of any pavement is affected by the materials used for construction. Coming to the sub-grade, soil is the most important material. Here we have seen various tests used for finding the strength of soil, the prominent ones being CBR and plate load test.
- CBR test assesses the strength of soil, whereas plate load test is used to evaluate its support capability.

TESTS ON SOILS

Plate Load Test

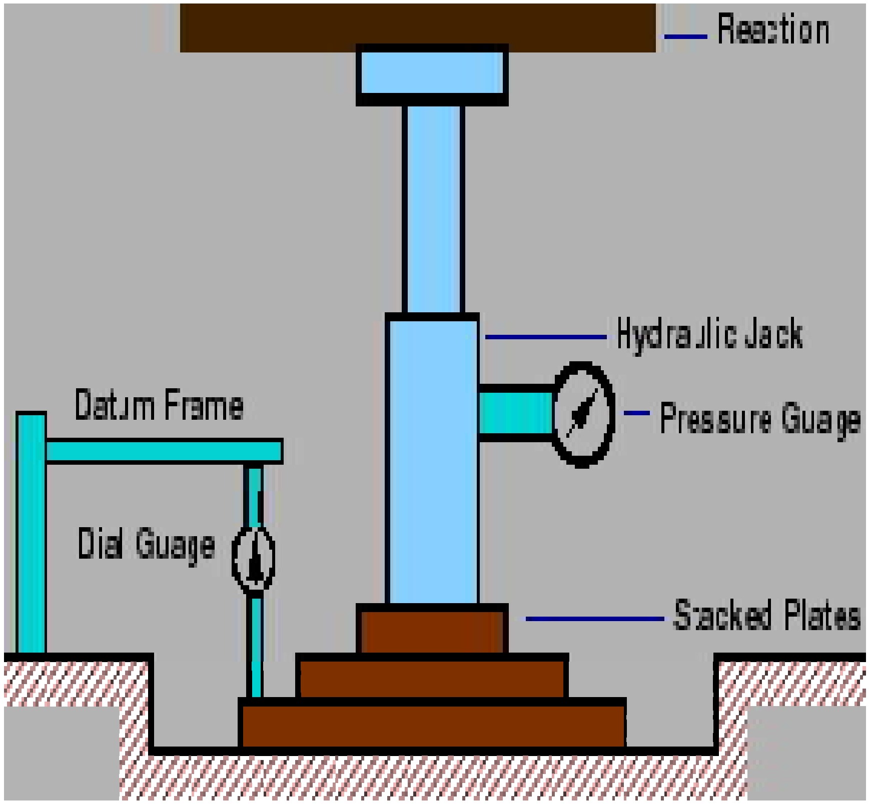


Plate load test procedure

ROAD AGGREGATES TETS

- **Aggregate Crushing Value Test:**
- **Aim:** To determine the crushing value of the given sample of aggregate.
- **Apparatus:**
- a) Steel cylinder with open ends and a square plate
- b) Plunger with piston
- c) Cylindrical measure
- d) Weighing balance
- e) IS sieves (12.5 mm, 10.0mm & 2.36 mm)
- f) Compression testing machine
- g) Steel Tamping Rod.

ROAD AGGREGATES TETS

Procedure:

1. Select clean and dry aggregate passing through IS 12.5 mm and retained on IS 10.0 mm sieve.
2. Weight the empty cylindrical measure. Let the weight be ‘a’ g
3. Fill the aggregate in the cylindrical measure in three layers, tamping each layer 25 times with the rounded end of the tamping rod. Weigh the cylindrical measure with aggregate. Let the weight be ‘b’ grams. Thus the weight of aggregate = W_1 g
4. Transfer the aggregate into the steel cylinder again in three layers tamping each layer 25 times
5. Place the plunger in the steel cylinder such that the piston rests horizontally over the aggregate surface.
6. Keep the assembly of steel cylinder with plunger in the compression testing machine.
7. Set the pointer to read zero and apply the compressive load of 40 tonnes.
8. Stop the machine. Take out the assembly.
9. Sieve the crushed material on IS 2.36 mm sieve and find he weight of material passing this sieve. Let the weight be W2 g.
10. Then Aggregate crushing value= W_2 / W_1 *100 %

ROAD AGGREGATES TETS

ROAD AGGREGATES TETS

- **Los Angeles Abrasion Test:**
- **Aim:** To determine the abrasion of the given aggregate sample.
- **Apparatus:**
- Los Angles Abrasion Machine
- Steel balls-11no.
- Weighing balance
- IS Sieves: 20, 12.5, 10, 1.7mm

ROAD AGGREGATES TETS

Procedure:

1) Take the clean and dried aggregates in an oven at 105-110° C.
2) Sieve the given aggregates in sieve size 20-12.5mm and weigh that aggregate in 2.5kg.
3) Again sieve the aggregate in sieve size is 12.5-10mm and take that aggregates in 2.5 k. i.e., W_1 gm (2.5+2.5=5kg)
4) Pour the given taking aggregates into the los angles abrasion machine.
5) Put the steel balls into the abrasion machine after pouring the aggregates.
6) Start the machine and rotating the drum for 500 revolutions and stop the machine.
7) After stopping the machine, take out the aggregates and sieve the aggregates in 1.7mm sieve size and take the retained aggregates and note down its weight i.e. W_2

ROAD AGGREGATES TETS

Spears

ROAD AGGREGATES TETS

Shape Test:

Aim : To determine the Flakiness Index, Elongation Index and Angularity Number of the given sample of aggregate.

1. Flakiness Index: The Flakiness index of aggregate is the percentage by weight of particles whose least dimension [thickness] is less than three- fifths [0.6] times of their mean dimension. The test is not applicable to aggregate size smaller than 6.3 mm

Apparatus:

a) Thickness gauge

b) Weighing balance

c) IS Sieves of sizes 63 mm, 50 mm, 40 mm, 31.5 mm,25 mm,20 mm, 16 mm, 12.5 mm, 10 mm and 6.3 mm

ROAD AGGREGATES TETS

- **Procedure:**

1. The sieves are arranged such that the largest size sieve (63 mm) is at the top and the smallest size sieve (6.3 mm) is at the bottom.
2. The given aggregate are sieved. A minimum of 200 pieces of each fraction to be tested are taken and weighed = W_1 g.
3. In order to separate flaky aggregate, each fraction is then gauged for thickness through the respective opening on the thickness gauge. For example, if the aggregate is from 50 – 40 fraction, it is gauged through the opening of 27.00 mm on the thickness gauge.
4. The flaky aggregate passing the respective openings are collected and accurately weighed = w_1 g.
5. The procedure is repeated for other fractions having weights W_2, W_3, etc. and the flaky aggregate in them having weights w_2, w_3 respectively are weighed.
6. Then Flakiness Index = $\dfrac{(w_1+w_2+w_3+\text{------})}{(W_1+W_2+W_3+\text{-------})} \times 100$

ROAD AGGREGATES TETS

Flakiness

ROAD AGGREGATES TETS

- **2. Elongation Index**
- The elongation index of an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than one and four fifth times [1. 8] times their mean dimension. The elongation test is not applicable to size smaller than 6.3 mm.
- **Apparatus**
- a) Length gauge
- b) Weighing balance
- c) IS Sieve of size as in flakiness Index test.

ROAD AGGREGATES TETS

Procedure:

1. The sample is sieved through the IS sieves specified and a minimum of 200 pieces of each fraction are taken and weighed = W_1 g.
2. In order to separate elongated aggregate , each fraction is then gauged individually for length through the respective opening on the length gauge
3. In each fraction, the aggregate retained on the respective opening on the length gauge is collected and weighed =X_1 g.
4. The procedure is repeated for other fractions having weights W_2, W_3, etc, and the weights of elongated aggregate in them X_2, X_3 etc, are found.

5.Then Elongation Index = $\dfrac{(X_1+X_2+X_3 + \text{----------------})}{\text{------------------------------------}}$

ROAD AGGREGATES TETS

Angularity Number : Angularity in general is the absence of rounding of particles of an aggregate. This test is performed to determine the angularity number i.e. the absence of roundedness.

- Angularity number of an aggregate is the amount by which the percentage of voids in it after compacting in a prescribed manner exceeds 33.
- Where, “33” is the percentage of volume of voids, in a perfectly rounded aggregate. “67” is the percentage of volume of solids in a perfectly rounded aggregate.

Apparatus:

a) A metal cylinder closed at one end having 3 liter capacity, diameter and height approximately equal

b) A metal tamping rod, 16 mm in diameter and 600 mm long.

c) Weighing balance

ROAD AGGREGATES TETS

Procedure:

- 10 Kg of the sample is taken for the test. The material should be oven dried. The aggregate is compacted in three layers, each layer being given 100 blows using the standard tamping rod.
- The blows are uniformly distributed over the surface of the aggregate. After compacting the third layer, the cylinder is filled to overflowing and excess material is removed off with temping rod as a straight edge.
- The aggregate with cylinder is then weighed. Three separate determinations are made and mean weight of the aggregate in the cylinder is calculated.
- Then Angularity number may be calculated from the expression,

Angularity number = 67 – (100 W / CG)

or

Angularity Number = (Volume of water added/Total volume) x 100-33

Where, W= Mean weight of aggregate in the cylinder

C = Weight of water required to fill the cylinder

G= Average Specific gravity of aggregate.

ROAD AGGREGATES TETS

Specific Gravity and Water Absorption Test on Aggregates:

Aim: To determine the specific gravity and water absorption of given sample of aggregates.

Apparatus:

a) Density basket

b) Weighing balance

c) Water tank

d) Tray

e) IS sieves- 10mm and 20mm.

ROAD AGGREGATES TETS

Procedure:

1) Take about 2kg of given aggregates passing IS 20mm sieve and retained on 10mm sieve.
2) Keep the aggregate in density basket and then keep the basket in water.
3) Allow the aggregate and basket to be in water for 24 hours.
4) After 24 hours find the suspended weight(W_1)of basket with aggregate.
5) Remove the basket out of water and remove the aggregate.
6) Keep the empty basket back in water and find the suspended weight(W_2).
7) Wipe the surface of aggregate using a cotton cloth to make them surface dry.
8) Find the weight(W_3) of surface dry aggregate in air.
9) Keep the aggregate in oven at 110° C for 24 hours.
10) Now find the weight(W_4) of dried aggregate in air.
11) Then specific gravity and Water absorption is calculated from the relation:

- Specific gravity $= \dfrac{W_4}{W_1 - (W_1 - W_2)}$

ROAD AGGREGATES TETS

Aggregate Impact Test:

Aim: To determine the impact value of the given aggregate

Apparatus:

- Aggregate impact apparatus
- IS sieves (12.5 mm, 10.0 mm and 2.36 mm)
- Cylindrical measure and cylindrical cup
- Weighing balance.
- Tamping rod.
- **Procedure**
- 1. Take clean and dry aggregate and sieve on IS 12.5 mm and 10.00 mm sieve.
- 2. Collect the aggregate passing IS 12.5mm sieve and retained on IS 10.0 mm Sieve.

ROAD AGGREGATES TETS

3. Find the weight of empty cylindrical measure. Let the weight be „a‟ g.
4. Fill the aggregate in the cylindrical measure in three layers, tamping each layer 25 times with the rounded end of the tamping rod.
5. Roll the tamping rod over aggregate surface and remove excess aggregate, if any.
6. Find the weight of the cylindrical measure with aggregate. Let the weight be „b‟ g. Thus the weight of aggregate = W1 = (b-a)
7. Transfer all the aggregate from the cylindrical measure to the test cylinder in one layer and tamp the layer 25 times with the rounded end of the tamping rod.
8. Fix the test cylinder firmly to the base of the impact tester.
9. Adjust the height of fall of the plunger to 380+ 5mm and set the blow counter to zero.
10. Lift the plunger gently and allow it to drop. This is one blow. Give 15 such blows.
11. Take out the test cylinder and sieve the crushed material on IS 2.36 mm sieve. Find the weight of material passing the sieve. Let weight be W2 g.
12. Find the weight of aggregate retained on this sieve. Let the weight be W3 g.
    Then, Aggregate impact value = W2 / W1 * 100 %
    And percentage of dust = W3 / W1* 100 %

ROAD AGGREGATES TETS

Aggregate Impact Value

ROAD AGGREGATES TETS

- **DURABILITY TEST OR SOUNDNESS TEST:**
- **Aim:** To study the resistance of aggregates to weathering action, by conducting accelerated weathering test cycle
- **Apparatus :** a) Sodium sulphate or magnesium sulphate ,b) Oven, c) Weighing balance, d) IS sieves
- **Procedure :**
- 1) The resistance to disintegration of aggregate is determined by using saturated solution of sodium sulphate or magnesium sulphate.
- 2) Clean, dry aggregates of specified size is weighed and counted. Then immersed in the saturated solution of sodium sulphate or magnesium sulphate for 16 to 18 hours.
- 3) Then the aggregates are dried in an oven at 105-110°C to a constant weight, thus making one cycle of immersion and drying.
- 4) The number of such cycles is decided by prior agreement and then the specimens are tested. After completing the final cycle, the sample is dried and each fraction of aggregate is examined visually to see if there is any evidence of excessive splitting, crumbling or disintegration of the grains.
- 5) Sieve analysis is carried out to note the variation in gradation from original. The coarse aggregate fraction of each size range is sieved on specified sieve sizes.

ROAD AGGREGATES TETS

Normal Aggregate (Before Test)

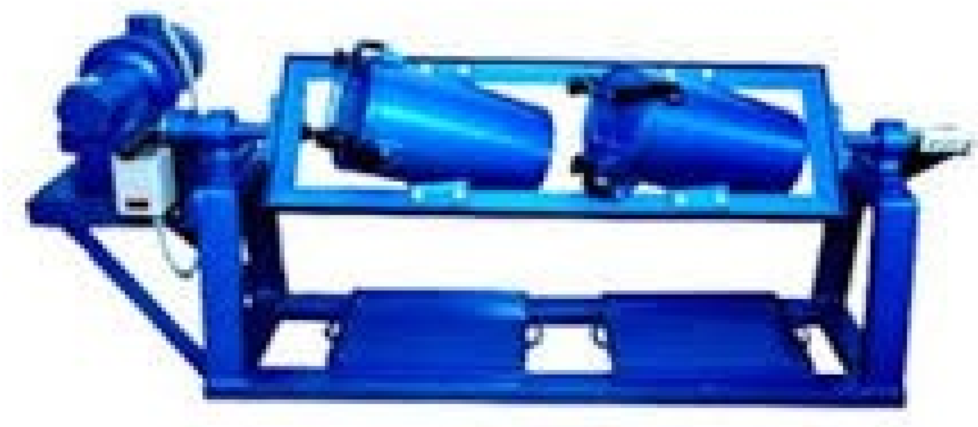
Splitting, crumbling or disintegration of Aggregates

ROAD AGGREGATES TETS

- **ATTRITION TEST:**
- **AIM:** Determination of the percentage of resistance of a granular material to wear by carrying out the Attrition test.
- **APPARATUS :** Oven, 1.5mm sieve, weighing balance and etc.
- **PROCEDURE**
- For the attrition test, 14mm passing and 12.5 Passing material is placed in both the cylinders of Deval's attrition testing machine.
- The cylinders are kept in an inclined position such that their axis makes an angle of 30 degrees with the horizontal.
- Now, the cylinders are rotated at the rate of 30 r.p.m (Revolution per minute) for 5 Hours.
- Later on, these pieces are removed from the cylinders and passed through a 1.5 mm sieve. The quantity of stones pieces retained on the sieve is weighed.
- The Loss of weight of the sample can be calculated. The percentage of wear can be calculated as
- Attrition value = (Passing weight in 1.5mm sieve/Total sample weight)×100

ROAD AGGREGATES TETS

ATTRITION TEST:



TESTS ON BITUMEN

- **Tests on bitumen:**
- There are a number of tests to assess the properties of bituminous materials. The following tests are usually conducted to evaluate different properties of bituminous materials.

1. Spot
2. Penetration test
3. Softening point test
4. Ductility test

TESTS ON BITUMEN

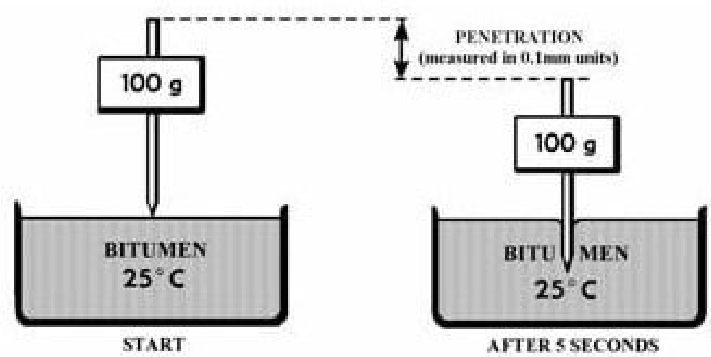
- **Spot Test:**
- The spot test is used to determine whether or not an asphalt cement has been damaged during processing due to over heating.
- This damage, called “Cracking”, occurs because the actual molecules are thermally broken apart.
- Cracked asphalt cements tend to be less ductile and more susceptible to aging effects. Since modern refining practices rarely cause cracking, the spot test is not often specified.
- Basically, the spot test is a form of paper chromatography.
- A small drop of prepared asphalt cement is dropped on to a filter paper. If the spot formed is uniformly brown then the test is negative.
- If the spot formed is brown with a black centre then the test is positive.
- Today, the spot test is rarely used.

TESTS ON BITUMEN

- **Penetration test:**
- The test measures the hardness or softness of bitumen in terms of penetration expressed in mm.
- Temperature= 25ºC [test to be performed after sample is kept for 1hr in $H2O$ bath at this temperature]
- Load on needle = 100 g
- Time in which penetration is recorded = 5 s
- The penetration is measured by a graduated dial.
- Bitumen is softens to a poring consistency a depth more than 15mm in the container is poured. The expected penetration sample is cooled in 60 min in air and 60 min in water before testing. The standard needle is positioned to get a penetration value for 5sec and is noted.
- The penetration value obtained is represented in 80-100 or 80/100 grade bitumen at standard consistence and it range from 20-225mm.

TESTS ON BITUMEN

Penetration test setup:



TESTS ON BITUMEN

Viscosity:

Viscometer

- **Aim:** To determine the viscosity of bitumen by tar viscometer as per IS: 1206 (Part-2)
- **APPARATUS:** Tar viscometer, cup, valve, receiver, thermometer etc.
- **Procedure:** Heat the bitumen sample to a temperature not more than 90° C above its and then Pour the hot bitumen in the Canni Manning vacuum viscometer.
- Maintain the test bath temperature at 60° u min.
- After 30 minutes open the valve and collec bitumen from the viscometer and note the required to collect the 50 ml of bitumen.
- The **viscosity** expressed in seconds is the ti taken by the 50 ml **bitumen** material to pa through the orifice of a cup, under standard **test** conditions and specified temperature.

TESTS ON BITUMEN

- **Flash and Fire Point Test:**
- **AIM:** To determine the Flash point and Fire point of the given bitumen.
- **APPARATUS:** Pensky-Martins Closed Tester consist of cup, lid, stirring device, cover, shutter, flame exposure device etc.
- **PROCEDURE:**
- Heat the bitumen to above its softening point generally 75°C to 100°C and stir this softened bitumen thoroughly to remove air bubbles.
- Fill the cup with softened bitumen up to the filling mark provided on the cup. Now place the lid and close the cup.
- The bitumen getting heated and preferred rate of heating should be 5°C to 6°C per minute.
- The rate of stirring should be approximately 60 revolutions per minute.
- Observe the thermometer carefully and when the temperature is 17°C below the actual flash point (175°C) lit up the test flame.
- Apply the test flame for every 1°C rise from this point and remember during application of test flame the stirring should be stopped.

TESTS ON BITUMEN

Flash and Fire Point Test:

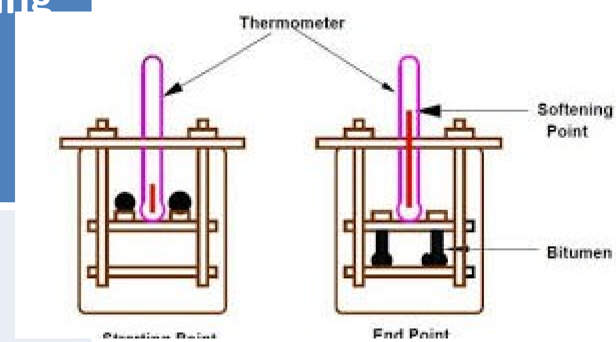
- When the sample catches the flame and forms Flash, note down the temperature at that point which is Flash point of the bitumen.
- Heat the sample further with the same previous rate and apply the test flame for every $2^{O}C$ rise when the material catches the fire and burns at least for 5 seconds, note the temperature at this point which is the fire point of the bitumen.
- Repeat the experiment for 2 more times and the average of the three readings should be taken as Flash point and Fire point of the given sample.

TESTS ON BITUMEN

- **SOFTENING POINT TEST:**
- **AIM:**
- To determine the Softening point of the given bitumen
- **APPARATUS:**
- The apparatus consists of Ring & Ball apparatus
- **PROCEDURE:**
- Sample material is heated to a temperature between 75^0 to 100^0C above the approximate softening point until it is completely fluid and is poured in heated rings placed on metal plate.
- To avoid sticking of the bitumen to metal plate, coating is done with this with a solution of glycerin and dextrin.
- After cooling the rings in air for 30 minutes, the excess bitumen is trimmed and rings are placed in the support. At this time the temperature of distilled water is kept at 5^0 C. This temperature is maintained for 15 minutes after which the balls are placed in position.
- The temperature of water is raised at uniform rate of 5^0 C per

TESTS ON BITUMEN

Test Property	Sample no. 1		Sample no. 2		Mean value, Softening point
	Ball No:1	Ball No:2	Ball No:1	Ball No:2	
Temperature at which sample touches bottom plate					

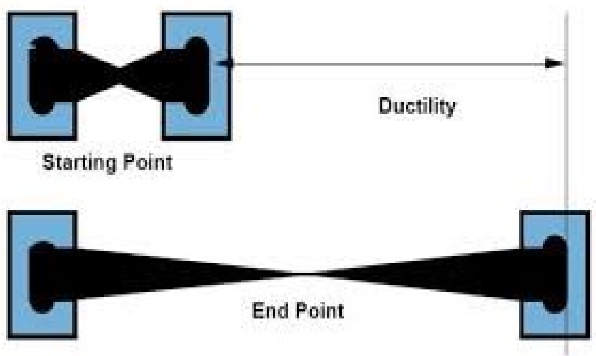


TESTS ON BITUMEN

- **DUCTILITYTEST:**
- **AIM:**
- To determine the ductility value of the given bitumen
- **APPARATUS:**
- The Ductility test apparatus consists of items like sample (briquette moulds), water bath, square-end trowel or putty knife sharpened on end and ductility machine.
- **PROCEDURE:**
- The bitumen sample is melted to a temperature of 75° to 100°C above the approximate softening point until it is fluid. Poured in the mould assembly and placed on a brass plate, after a solution of glycerin and dextrin is applied at all surfaces of the mould exposed to bitumen.
- Thirty to forty minutes after the sample is poured into the moulds, the plate assembly along with the sample is placed in water bath maintained at 27°C for 30 minutes.
- The sample and mould assembly are removed from water bath and excess bitumen material is cut off by leveling the surface using hot knife.
- After trimming the specimen, the mould assembly containing sample is replaced in water bath maintained at 27°C for 85 to 95 minutes. The sides of the mould are now removed
- Two or more specimens may be prepared in the moulds and clipped to the machine so as to conduct these tests simultaneously.

TESTS ON BITUMEN

- The pointer is set to read zero. The machine is started and the two clips are thus pulled apart horizontally. While the test is in operation, it is checked whether the sample is immersed in water at depth of at least 10mm.
- The distance at which the bitumen thread of each specimen breaks, is recorded (in cm) to report as ductility value.



Test Property	Briquette Number			Mean Value
	1	2	3	
Ductility value				

REFERENCE BOOKS

- 1. Highway Engineering by S.K Khanna,C.E.G.Justo, A.Veeraraghavan
- 2.Highway Engineering By L.R Kadiyali
- 3. Highway Materials and Pavement Testing by S.K Khanna,C.E.G.Justo, A.Veeraraghavan
- 4.https://nptel.ac.in/content/storage2/courses/105101087/downloads/Lec-22.pdf
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MODULE – III
PART-B

Highway Construction & Maintenance

Highway Construction & Maintenance

- Construction of Earth Roads:
- First of all what is an earth road? Earth road is a type of road whose whole pavement section is constructed with the locally available earth material preferably.
- Sub-grade and the surface of the earth roads are given larger camber of 1in 33 to 1 in 20 because they need faster drainage to be safe from the moisture.
- **Specifications of Materials:**
- The earth material used for the construction of earth roads are termed as satisfactory if they possess the following properties:

Highway Construction & Maintenance

- **Specifications of Materials continue…**

	Base Course	Wearing Course
Clay Content	<5%	10 to 18%
Silt Content	9 to 32%	5 to 15%
Sand content	60 to 80%	65 to 80%
Liquid Limit	<35%	< 35%
Plasticity Index	<6%	4 to 10%

Earthen Roads

Highway Construction & Maintenance

- **Earthen Roads continue….**
- Constructed with the locally available earth material preferably.
- Sub-grade and the surface of the earth roads are given larger camber of 1in 33 to 1 in 20 because they need faster drainage to be safe from the moisture.
- A maximum value of camber of 1 in 20 is the limit because higher camber will result in the formation of cross ruts and corrosion of pavement soils.

Highway Construction & Maintenance

- **Construction Procedure:**

1. **Preparing the subgrade :-** The subgrade is prepared and the surface is brought to the required camber and gradient.
2. **Rolling and watering :-** The surface is rolled properly and well wetted with water.
3. **Spreading the soil :-** After watering, a layer of graded soil, about 10 cm thick is evenly spread.
4. **Rolling :-** The layer of soil is rolled at optimum moisture content (OMC) with a suitable roller and finally finished with a light roller. The type of roller for compaction is decided based on soil type, desired amount of compaction and availability of equipment. At least 95 per cent of dry density of its light compaction is considered desirable.

Highway Construction & Maintenance

5. **Checking :-**The camber of the finished surface is checked an corrected, if necessary.
6. **Curing :-** The rolled surface is watered for **four or five days** for curing. No traffic should be allowed to pass over the road surface during this period.
7. **Opening to traffic :-** After curing, the traffic is allowed to pass but the surface is sprinkled over with water for a period of 10 days.

Highway Construction & Maintenance

- **WBM ROADS:**
- Pavement base course made of crushed or broken aggregate mechanically interlocked by rolling and the voids filled with screening and binding material with the assistance of water.
- May be used as a sub-base, base course or surfacing course.
- Thickness ranges from 10.0 cm to 7.5 cm depending on the size and gradation of the aggregates used.
- To prolong life, bituminous surfacing course will be laid over the WBM layer

Highway Construction & Maintenance

WBM Roads

Highway Construction & Maintenance

- **Construction Procedure for WBM Road:**
- **1) Preparation of Foundation for WBM Road :**
- The sub-grade or base course is properly prepared for the required grade and camber for WBM road. The potholes and the depressions on the surface of the road are properly filled up and compacted.
- **2) Provision for Lateral Confinement :**
- Before laying of aggregates the shoulders having thickness as that of compacted WBM layer should be constructed. They should be constructed with proper quality of murum or earth.
- The main purpose of constructing shoulders is that the road surface to be constructed retain in between them and it becomes easy for further laying of course aggregates.

Highway Construction & Maintenance

- Preparation of Sub Grade
- Provision of Lateral Confinement

Highway Construction & Maintenance

- **3) Spreading of Course Aggregates :**
- The course aggregates are uniformly spread on the prepared base after the construction of the shoulders. Total number of layers and thickness of WBM road depends upon the details of design pavement.
- In general for ordinary roads, single layer of compacted thickness 75 mm may be sufficient. For special roads, 2 layers of 150 mm each compacted thickness may be provided.
- **4) Rolling Operation :**
- Rolling operation is carried out for compacting the course aggregates. Generally it is done with the help of 3- wheeled power rollers weighing 6-10 tonnes or with the help of vibratory rollers.
- Skilled operators should be used for driving the rollers as the fault rolling operations causes formation of corrugations, unequal finish of road surface, wearing of road surface in few months of construction.

Highway Construction & Maintenance

- **Spreading of Coarse Aggregate**
- **Rolling Operation**

Highway Construction & Maintenance

- **5) Application of Screenings :**
- After the rolling operation is properly finished screenings is applied to properly fill the voids remained after the compaction of aggregates. The screening may be applied in 3 or more layers as per the site conditions.
- After uniformly spreading of screening compaction is carried out with the help of dry rollers for each layer of screenings. After compaction brooming of the each layer should be properly done to remove the un-compacted screening material
- **6) Sprinkling of Water and Grouting :**
- After the application of screening the road surface is properly sprinkled with plenty of water. After the water is sprinkled brooming is done to sweep the wet screening properly into the voids.
- Rolling operation is further carried out for proper compaction. If the voids are still visible then additional screenings can also be applied and properly compacted.

Highway Construction & Maintenance

- **Application of Screening**

- **Sprinkling of Water and Grouting**

Highway Construction & Maintenance

- **7) Application of Binding Material :**
- Same procedure is used for the application of binding material as that of screenings. Here after each layer water is sprinkled and rolling operation is carried out.
- **8) Setting and Drying of Surface :**
- After the final rolling operation the road is allowed to cure or set over-night. The next day if the depressions or voids are visible then again sufficient amount of screenings or binding materials can be used and compaction is done.
- **9) Preparation of Shoulders :**
- At the time of Curing of a road, shoulders are constructed alongside by filling earth to specified cross slope. They are properly compacted.
- **10) Open for Traffic :**
- After proper drying and without any depressions, the road is then made upon for traffic. For few days the traffic should be well distributed over full width of road by placing obstacles longitudinally in the form of drums, barricade etc.

Highway Construction & Maintenance

- **Application of Binding Material :**

The usual Practice of W B Macadam Construction

Due to high internal friction dry rolled coarse aggregates develop great strength

Internal friction reduced due to application of gravel

Gravel on water absorption likely to turn plastic at some spots and make aggregates slide or rotate

The usual Practice of W B Macadam Construction

The usual Practice of W B Macadam Construction

The usual Practice of W B Macadam Construction

Brooming with hand brooms , to fill voids in the coarse aggregates

Sprinkling of water is in progress

The usual Practice of W B Macadam Construction

Rolling after sprinkling of water

The usual Practice of W B Macadam Construction

Highway Construction & Maintenance

- **Stabilization of Roads:**
- It is required when the soil available for construction is not suitable to carry structural loads.
- Stabilization can increase the shear strength of a soil and there by improving the load bearing capacity of a sub-grade to support pavement and its foundations.
- Soil stabilization is used to reduce permeability and compressibility of the soil mass in earth structures and to increase its shear strength.
- Therefore, these soil stabilization processes are suggested for most construction systems and can be accomplished by several methods.

Highway Construction & Maintenance

- **Soil Stabilization Methods with Different Materials:**
- Following are the various soil stabilization methods and materials:
- **Soil Stabilization with Cement**
- The soil stabilized with cement is known as soil cement.
- The important factors affecting the soil-cement are nature of soil content, conditions of mixing, compaction, curing and admixtures used.
- The appropriate amounts of cement needed for different types of soils may be as follows:
- Gravels - 5 to 10%
- Sands - 7 to 12%
- Silts - 12 to 15%, and
- Clays - 12 - 20%

Highway Construction & Maintenance

- **Soil Stabilization using Lime:**
- Lime may be used alone or in combination with cement for soil stabilization
- bitumen or fly ash combination should be used for Sandy soils stabilization.
- Lime has been mainly used for stabilizing the road bases and the sub-grade.
- Plasticity index of highly plastic soils are reduced by the addition of lime with soil.
- There is an increase in the optimum water content and a decrease in the maximum compacted density and the strength and durability of soil increases.
- Normally 2 to 8% of lime may be required for coarse grained soils and 5 to 8% of lime may be required for plastic soils.
- The amount of fly ash as admixture may vary from 8 to 20% of the weight of the soil.

Highway Construction & Maintenance

- **Soil Stabilization with Bitumen:**
- Asphalts and tars are bituminous materials which are used for stabilization of soil, generally for pavement construction.
- Bituminous materials when added to a soil, it imparts both cohesion and reduced water absorption.
- Depending upon the above actions and the nature of soils, bitumen stabilization is classified in following four types:
- Sand bitumen stabilization
- Soil Bitumen stabilization
- Water proofed mechanical stabilization, and
- Oiled earth.

- **Soil Stabilization by Grouting:**
- In this method, stabilizers are introduced by injection into the soil.
- This method is not useful for clayey soils because of their low permeability.
- This is a costly method for soil stabilization.
- This method is suitable for stabilizing buried zones of relatively limited extent.
- The grouting techniques can be classified as following:
- Clay grouting
- Chemical grouting
- Chrome lignin grouting
- Polymer grouting, and
- Bituminous grouting

Highway Construction & Maintenance

- **Construction of Flexible Pavements:**

  Or

- **Bituminous Pavements:**
- Steps in Construction of flexible pavement:

1. Clearing of site.
2. Earthwork (Preparation, compaction and shaping of sub-grade in cut and fill).
3. Construction of sub base and base courses.
4. Prime Coat & Tack Coat
5. Surface courses of bitumen
6. Seal Coat

Highway Construction & Maintenance

- **1. Clearing Site:**
- Removing natural waste material.
- Shifting of public utilities, removing of structures, buildings, foot-paths etc.
- Removing of all tress, tree stumps, vegetation, and rubbish material is removed.
- Filling of holes formed.
- Bull dozers, rooter, stumper type equipment is used.

Highway Construction & Maintenance

- **2. Earthwork, Preparation, compaction & Shaping of Sub-grade:**
- Construction of embankment and preparation of sub-grade are part of earthwork.
- Sub-grade should be prepared to required stability and density.
- Embankments are necessary depending upon the flooding conditions. It is 0.6 to 1 m above the Max. flood level.
- Shape the rough surface to the final shape of the carriageway.

Highway Construction & Maintenance

- **3. Construction of Sub Base and Base Courses:**
- Can be made of different materials like stones, aggregates, stabilized soils and waste materials from industry like clinkers, quarry waste, shale's, slag etc.
- **4.Prime Coat:**
- Application of bituminous binder on previously untreated porous layer such WBM, earth or gravel road etc.
- Is done so that it penetrates the top of the layer and fills the voids is called a prime coat.
- Used on porous surfaces.
- Helps in providing bonding between the base and surface coarse.
- Low viscosity cut back bitumen's are used

Highway Construction & Maintenance

- **Tack Coat:**
- Application of a bituminous material is done on an existing old bituminous road, to ensure proper bond between it and superimposed layer.
- It is not a surface treatment.
- Purpose is to bind the old and new layers.
- Bituminous binders a cutback bitumen, emulsion or low viscosity tar is used as a single application for tack coat, on old bituminous or cement concrete surface.
- **5. Surface Courses of Bitumen Functions:**
- Protecting the lower layers from damage due to weather and moisture.
- Provide smooth, quiet, non slippery, and impermeable running surfaces to vehicles.
- Dust and mud free.
- Layers underneath are not overstressed.
- Highly resistant to surface wear and deformation.

Highway Construction & Maintenance

- Use of mixture of bitumen/tar and aggregates.
- Techniques
  1. Spreading of tar/bitumen and aggregates and compacting.
  2. Mixing of bitumen/tar and aggregates, then spreading of the mix and compacting.
- Aggregates used in bituminous mixes
  - Coarse: retained on 2.36 mm
  - Fine: passing 2.36 mm and retained on 75 micron
  - Filler: passing 75 micron
- **6.Seal Coat:**
- Thin layer of bituminous binder applied on an existing or new bituminous surface.
- With the object of closing (seal) the voids and rendering it water proof.
- Emulsions are used for this purpose.
- It provides dust mud free surface

Prime coat

Seal coat

Highway Construction & Maintenance

- **Maintenance of Flexible Pavements:**

1. **Patch Repair**
   - Patching up pot-holes and localised depressions
   - For patch repair - sand premix, open-graded premix, dense graded premix, or penetration patching may be adopted

Highway Construction & Maintenance

2. **Surface Treatment**
   - When patch repair becomes uneconomical, to improve skid resistance tack coat, prime coat and seal coat along with surface dressing should be used.

Highway Construction & Maintenance

- **3. Resurfacing:**
- This is taken up when the pavement has deteriorated badly and may involve the renewal of not only the surface course but also the base course.

- **Construction of Cement Concrete Pavements:**
- **Steps in Construction of CC Roads:**

1. Preparation of Sub-grade and Sub base
2. Placing of forms
3. Batching of Material and Mixing
4. Transporting and Placing of Concrete
5. Compaction and Finishing
6. Curing of Cement Concrete

Highway Construction & Maintenance

- **1. Preparation of Sub-grade and Sub base:**
- The sub-grade or sub base for laying of the concrete slabs should comply with the following requirements.
- No soft spots are present.
- Extends Atleast 30 cm on either side of the width to be concreted.
- Subgrade is suitable for properly drained.
- Min value of ‘k’(modulus of sub grade Reaction) = 5.54 kg/cm^2
- Is kept in moist condition at the time when cement concrete is placed, Water proof paper need to be placed if concrete slab is directly placed on sub-grade.

Highway Construction & Maintenance

Preparation of Sub-grade and Sub base:

Highway Construction & Maintenance

- **2. Placing of Forms:**
- The steel or wooden forms are used.
- Depth is equal to the thickness of the pavement.
- The sections have a length of 3m except on curves.
- Maximum deviation of the top surface < 3mm
- Wooden forms are dressed on one side.
- They should be rigidly connected.

Highway Construction & Maintenance

- **3. Batching of Material and Mixing:**
- Ingredients are proportioned by weight in a weight-batching plant and placed.
- All batching of material is done on the basis of one or more whole bags of cement (50 kg).
- The mixing of each batch is commenced within one and half minute after all the materials are placed in the mixer.
- The mix should be uniform in colour and is homogenous

Highway Construction & Maintenance

- **4. Transporting and Placing of Concrete:**
- Care is taken to see that no segregation b/w mixing to its placing.
- The spreading of concrete is done uniformly.
- A certain amount of re-distribution is done with shovels.
- Needle vibrators can be used.

Highway Construction & Maintenance

4. Transporting and Placing of Concrete

Highway Construction & Maintenance

4. Transporting and Placing of Concrete

- **5. Compaction and Finishing:**
- Either by means of a power driven finishing machine or by a vibrating hand screed.
- Concrete as soon as placed, is struck off uniformly and screened to the crown and cross section of the pavement to conform the grade.
- The tamper is placed on the side forms an is drawn ahead in combination with a series of lifts and drops to compact the concrete.
- Further compacted by means of the longitudinal float.
- The longitudinal float is held in a position parallel to carriageway centre line passed gradually from one side of the pavement to the other.
- The slab surface is tested for its grade and level with the straight edge

Highway Construction & Maintenance

Highway Construction & Maintenance

- **6. Curing of Cement Concrete:**
- **Initial Curing:** the surface of the pavement is entirely covered with burlap, cotton or jute mats.
- **Final Curing:** Curing with wet soil.
- Impervious membrane method:
- **Opening to traffic:** 28 days

Curing of Cement Concrete

Highway Construction & Maintenance

- **Types of Joints in CC pavements and Their function:**
- Different types of joints are

1. Transverse joints.
2. Longitudinal joints.

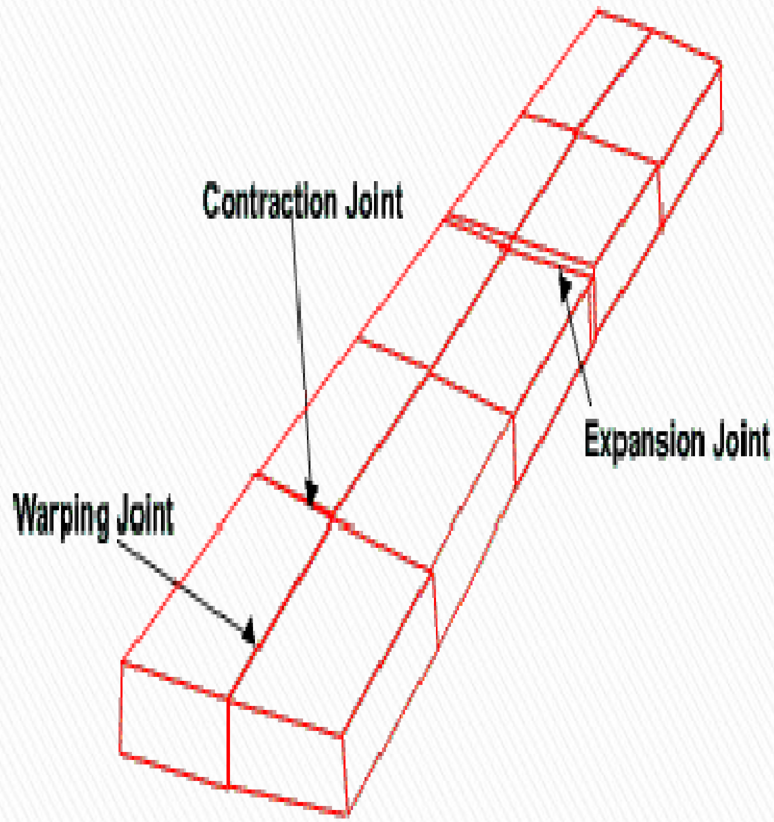
1. Transverse joints: Transverse joints are

a. Expansion joints.
b. Contraction joints.
c. Warping or hinged joints.
d. Construction joints.

Highway Construction & Maintenance

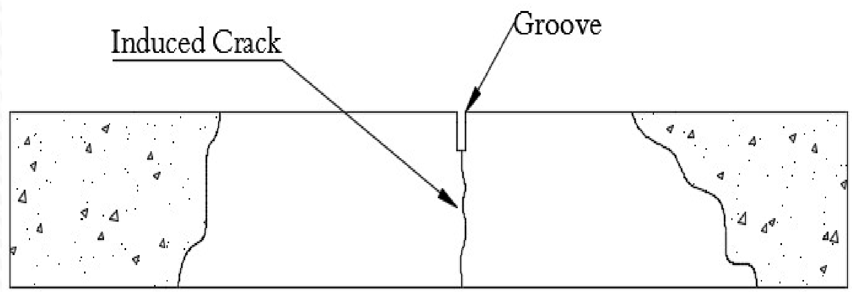
a. Expansion joints:

- A concrete expansion joint – or control joint – is a gap which allows the concrete to expand and contract as/when the temperature changes.
- The gap at these expansion joints provide space into which the pavement slabs could expand longitudinally, thus preventing possible buckling of the long CC slabs.
- These joints may be provided at the intervals of 60 to 120 m.
- Steel dowel bar system are installed at the expansion joints to facilitate load transfer from one slab to the adjoining slab.



b. Contraction joints:

- Once the concrete gets poured and hardened, the water in it starts to evaporate and makes the concrete to shrink and develop shrinkage cracks, especially on longer slabs.
- Contraction joints are also called control joints. Control joints are the joints which allow horizontal movement of the slabs.
- If no joints were used, random cracking in the slab would occur when the tensile stress exceeds the tensile strength of concrete.

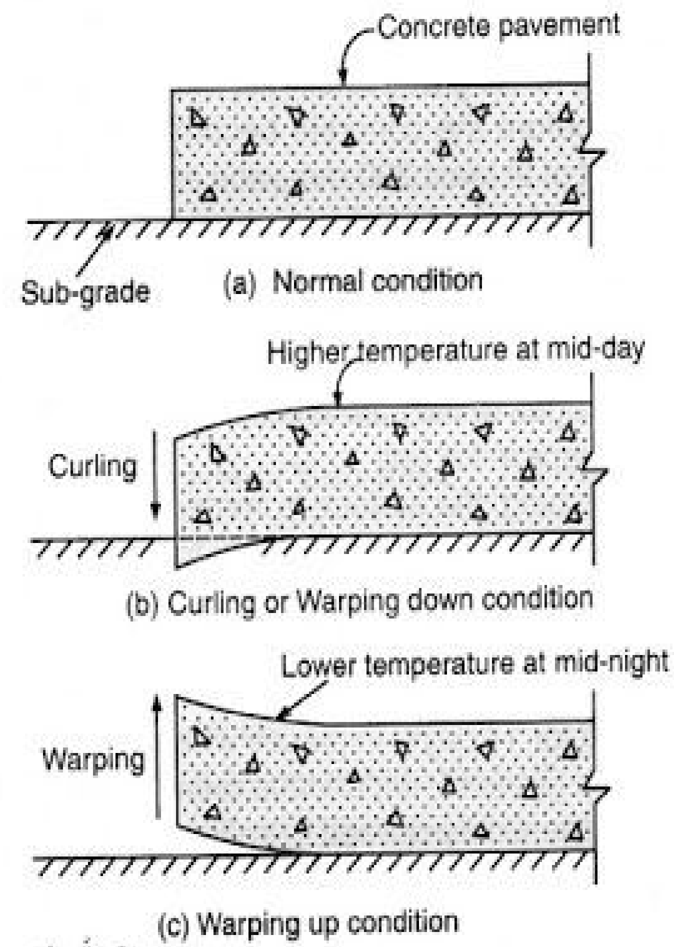


Contraction Joint

Contraction or Control joints are provided to avoid this crack from developing to the entire area.

c. Warping joints:

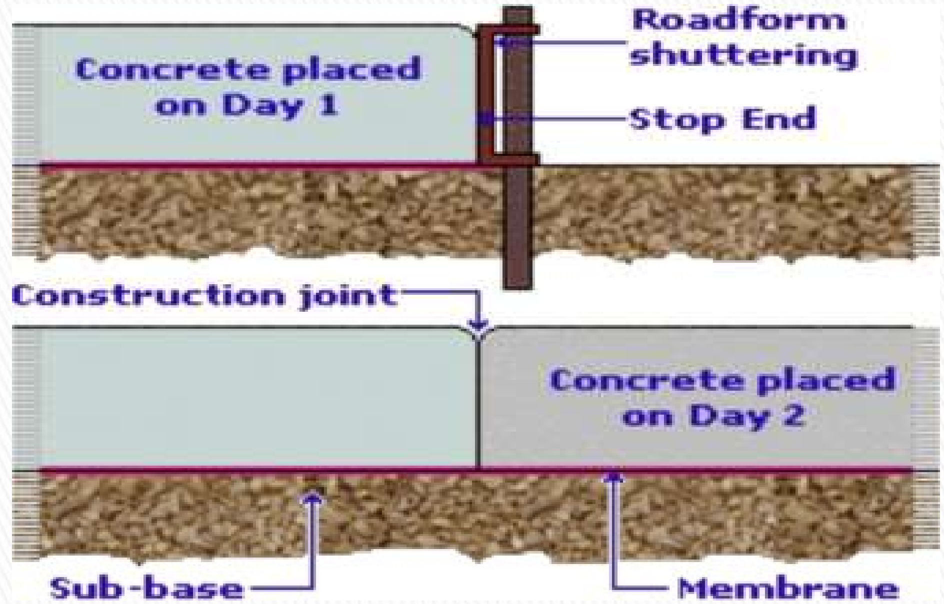
- Warping joints relieve stresses due to the warping effect developed in the slab. These joints are commonly used for longitudinal joints dividing the pavement into lanes.
- At 12 noon the temperature at the top surface of the slab will be higher than that at the bottom. This causes the top fibers of the slab to expand by a larger amount than the bottom fibers and the slab warps downwards at the edges.
- Similarly, at 12 nights the temperature of the bottom of the slab is higher than the temperature at the top of the slab and the slab warps upwards at the edges.



Warping of concrete pavement

d. Construction joints:

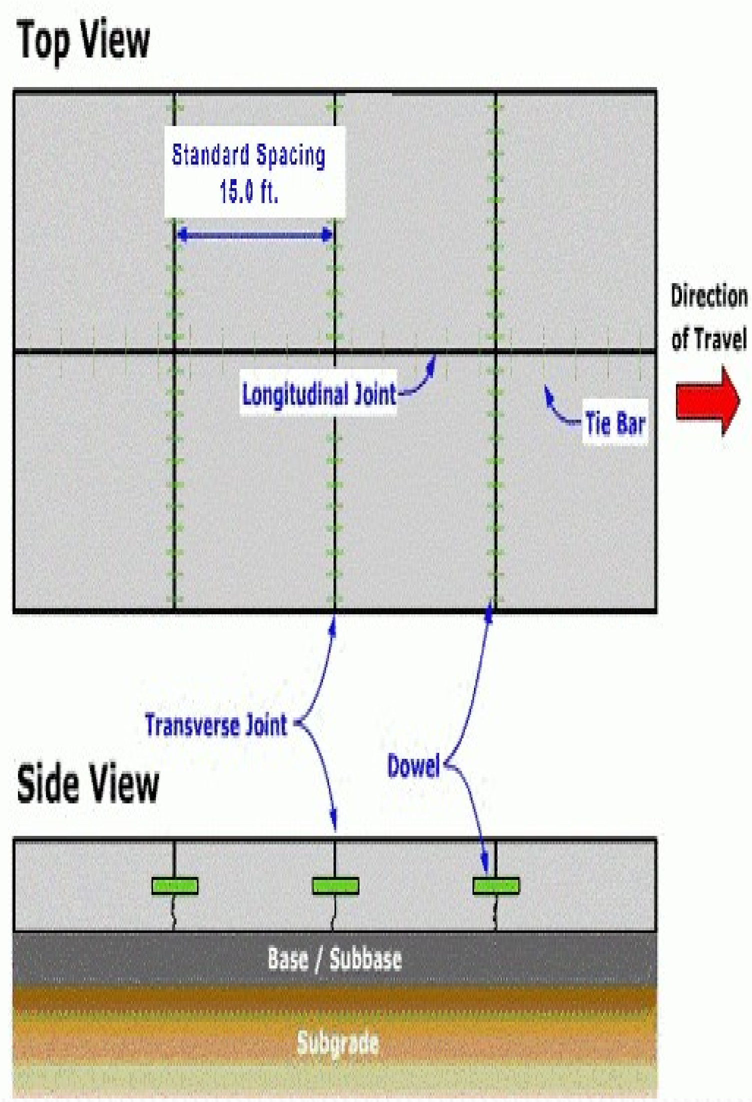
- Due to the interruption in the continuity of the concreting, at the end of the day or otherwise, a joint has to be provided.
- A tie bar is provided, in the unreinforced concrete pavement to prevent the opening of the joint.
- I've reinforced cement concrete pavement the reinforcement should project out at least 0.3m beyond the end of this joint.



Construction joints

2. Longitudinal joints:

- Lanes are jointed together by joint is known as longitudinal joint.
- Longitudinal joints are provided in multilane pavements and also when the pavement is more than 4.5m wide.
- They are provided normally at 3.5m c/c to
  a. Relieve stresses due to warping.
  b. To allow differential shrinkage & swelling due to changes of sub-grade moisture.
  c. To prevent longitudinal cracking.



Highway Construction & Maintenance

- **Maintenance of Rigid Pavements or Cement Concrete Pavements:**
- Needs very little maintenance
- The usual maintenance measures are
  - Crack repair
  - Joint maintenance
  - Patch repair
  - Control of Mud pumping
  - Restoration of anti skid surface.

Highway Construction & Maintenance

1. **Crack Repair**
   - Common in cement concrete pavements.
   - May be shrinkage or warping cracks
   - May also be structural cracks when they appear at corners and edges
   - Hair cracks are not harmful
   - Medium and wide cracks allow water to enter into lower layers.
   - Such cracks are filled with low-viscosity epoxy grout, after thoroughly cleaning with compressed air, and topped up with sand or fine aggregate chips to prevent disturbance due to traffic.

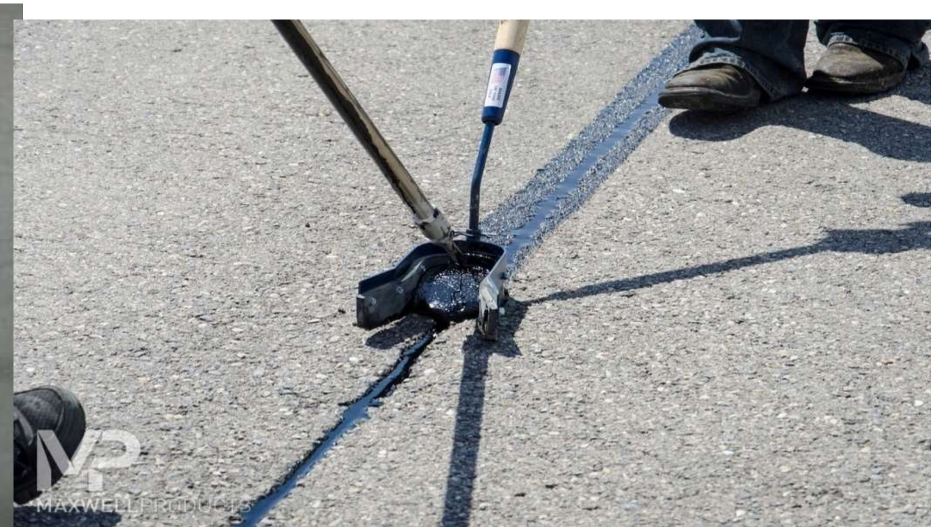
Crack Repair

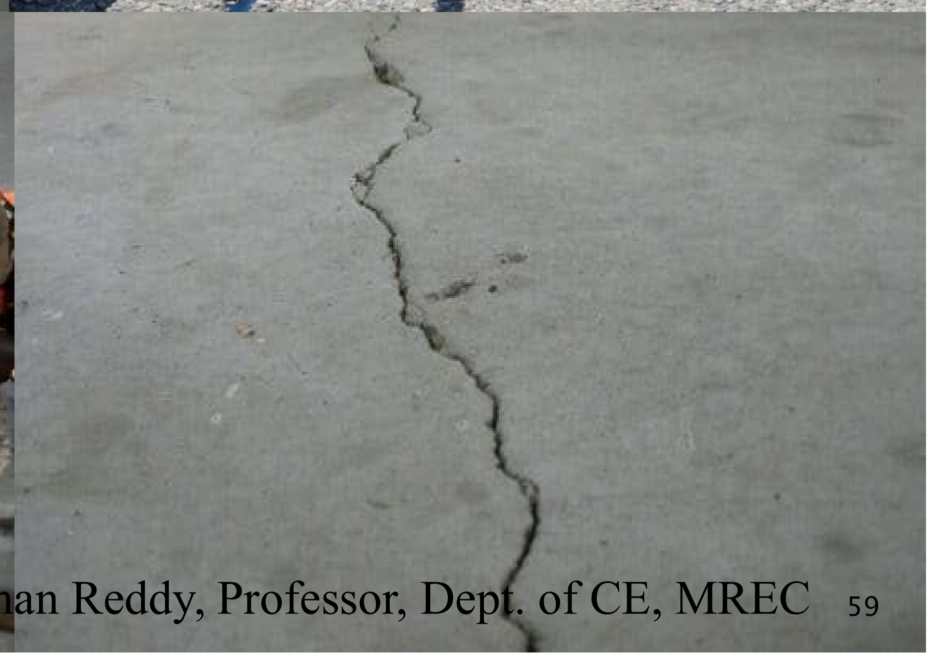
Highway Construction & Maintenance

2. **Joint Maintenance**
   - Consists of replenishing lost sealant, removing deteriorated joint filler and making provision of fresh filler material.
   - The sealant is then poured to an excess height of about 3 mm and sand sprinkled for it to be compressed by the traffic to the level of the pavement surface.
   - This type of treatment is adequate only when the crack depth is not more than one-third of the slab depth.
   - When the crack extends to a greater depth, cross-stitching with inclined tie-bars may be adopted.

Highway Construction & Maintenance

- **Joint Maintenance**





Highway Construction & Maintenance

3. **Patch Repair**
   - Involves the patching up of scales, spalls, depressions and other irregularities in the slab when they are localised.
   - Premix bituminous materials are commonly used. If not satisfactory Epoxy resin mortars are the best option.
   - The sides of the slab area to be patched are trimmed;
   - Fresh concrete is laid and tamped

Scaling of Concrete

spalling of Concrete

Highway Construction & Maintenance

4. **Control of Mud-Pumping**
   - Defective joints and wide cracks should be refilled and sealed.
   - To prevent further damage and recurrence, the slab is grouted through holes drilled in it.
   - The grout may be of cement mortar, 1:3:5 mix or of bituminous material.
   - This process is known as 'Mud-jacking' and is popular in advanced countries.
5. **Restoration of anti-skid surface**
   - When the surface become smooth and slippery, anti-skid surface can be restored by cutting grooves with the aid of grooving machines or by grinding machines

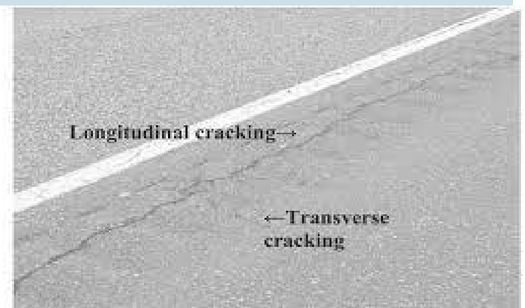
Highway Construction & Maintenance

- **Flexible Pavement Distress and its Causes:**

TYPE OF DISTRESS	POSSIBLE CAUSE	Structural Failure
Fatigue (Alligator) Cracking	1. Excessive loading , 2. Weak surface, base, or sub-grade 3. Thin surface or base, 4. Poor drainage 5. Any combination of 1-4	
Block Cracking	1. Old and dried out mix , 2. Mix was placed too dry 3. Fine aggregate mix with low penetration asphalt & absorptive aggregates	
Edge Cracks	1. Lack of lateral support , 2. Settlement of underlying material 3. Weak base or sub-grade layer 4. Poor drainage, 5. Heavy traffic or vegetation along edge	

Highway Construction & Maintenance

- **Flexible Pavement Distress and its Causes :**

TYPE OF DISTRESS	POSSIBLE CAUSE	Structural Failure
Longitudinal (Linear) & Transverse Cracking	1. Poorly constructed paving joint crack 2. Shrinkage of the asphalt layer 3. Daily temperature cycling 4. Cracks in an underlying layer that reflect up through the pavement	
Reflection Cracking	1. Differential movement between the asphalt and concrete layers 2. Can deteriorate further under heavy traffic Crack seal/fill	
Upheaval/Swell	1. Expansive soils (which swell in the presence of moisture) 2. Frost heave (in which ice lenses grow beneath the pavement, causing the pavement to crack)	

Highway Construction & Maintenance

TYPE OF DISTRESS	POSSIBLE CAUSE	STRUCTURAL FAILURE
Corrugations & Shoving	1. Mixtures too high in asphalt, 2. Low air voids ,3. Fine aggregate content too high 4. Excessive moisture or contamination in the granular base,5. Smooth or rounded aggregate, 6. Incorrect asphalt grade	
Rutting	1. Consolidation or lateral movement of any of the pavement layers or the sub-grade under traffic ,2. Insufficient design thickness , 3. Lack of compaction ,4. Weaknesses in the pavement layers due to moisture infiltration.	
Settlement/Grade Depressions	1. Settlement or failure in the lower pavement layers 2. Improper construction techniques	

Highway Construction & Maintenance

- **Flexible Pavement Distress and its Causes :**

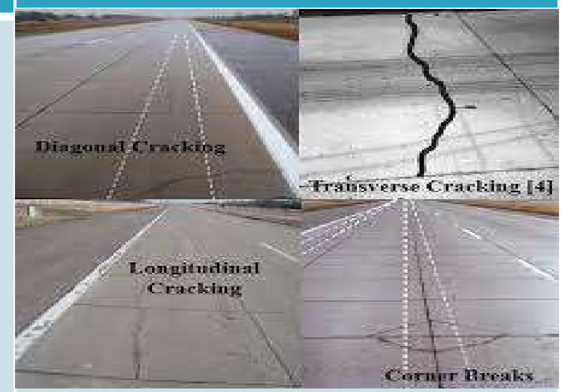
TYPE OF DISTRESS	POSSIBLE CAUSE	STRUCTURAL FAILURE
Utility Cuts/Patch Failure	1. Poor installation techniques such as inadequate compaction, inferior or improper materials 2. Failure of the surrounding or underlying pavement	
Pot Hole	1. Poor surface mixtures 2. Weak spots in the base or sub-grade 3. Severity of the surrounding distress and traffic action accelerate potholes	
Slippage Cracks	1. Lack of a good bond between surface layer and the course beneath due to dust, oil, dirt, rubber, water and other non-adhesive material 1. Tack coat has not been used 2. Mixture has a high sand content	

Highway Construction & Maintenance

Flexible Pavement Distress and its Causes :

TYPE OF DISTRESS	POSSIBLE CAUSE	STRUCTURAL FAILURE
Raveling/ Weathering	1. Asphalt binder has hardened excessively 2. Poor-quality mixture 3. Usually requires the presence of both traffic and water to occur	
Bleeding	1. Improperly constructed seal coat 2. Too much asphalt in a mix 3. Too heavy a prime or bond/tack coat 4. Traffic can contribute to bleeding if the asphalt layers become over compacted and excess asphalt is forced to the surface	
Polished Aggregate	Soft aggregates that polish quickly under traffic	

Cement Concrete Pavement Distress and its Causes:

TYPE OF DISTRESS	POSSIBLE CAUSE	Structural Failure
Longitudinal, Transverse, and Diagonal Cracks	These types of cracks can be formed due to poor construction techniques or weak underlying pavement layers.	
Corner Breaks	Load repetition, combined with loss of support and curling stresses.	
Durability "D" Cracking	It is caused by the concrete's inability to withstand environmental factors such as freeze-thaw cycles.	

Highway Construction & Maintenance

- **Cement Concrete Pavement Distress and its Causes:**

TYPE OF DISTRESS	POSSIBLE CAUSE	Structural Failure
Disintegration of Concrete Pavements	Improper curing and finishing of the concrete, Usage of unsuitable aggregates, and improper mixing of the concrete can cause this distress.	
Corrosion distress in a concrete structure	Corrosion distress in concrete members occurs with age due to corrosion in reinforcement, loading, settlement of foundations, etc	
Joint Seal Damage	Joint seal damage is any condition that enables soil or rocks to accumulate in the joints or that allows infiltration of water. Accumulation of materials prevents the slabs from expanding and may result in buckling or spalling.	

Cement Concrete Pavement Distress and its Causes:

TYPE OF DISTRESS	POSSIBLE CAUSE	Structural Failure
Pumping distress in a concrete structure	Pumping distress occurs due to the movement of material underneath the slab or ejection of material from underneath the slab as a result of water pressure.	
Skid Resistance of Concrete Pavements	Skid resistance refers to the ability of a pavement to provide a surface with the desired friction characteristics under all weather conditions.	
Crazing distress in a concrete structure	Crazing distress is a pattern of random fine cracks that occur at the surface of the concrete at an early age when the unhardened surface mortar dries out faster than the concrete below.	

Highway Construction & Maintenance

- **Cement Concrete Pavement Distress and its Causes:**

TYPE OF DISTRESS	POSSIBLE CAUSE	Structural Failure
Shattered slab distress in a concrete structure	Intersecting cracks are cracks that break the slab into four or more pieces due to overloading or inadequate support, or both.	
Blowup distress in a concrete structure	Blowup distress occurs in hot weather, usually at a transverse crack or joint that is not wide enough to permit expansion by the concrete slabs.	
Distortion distress in a concrete structure	Distortion distress occurs when there is a severe weakness in the sub-grade of your concrete pavement	

Highway Construction & Maintenance

- **Concept of BOT & BOOT:**
- BOT (Build–operate–transfer) or BOOT (Build–own–operate–transfer) is a project financing method in which a private corporation acquires a concession from the private or public sector to finance, design, construct, and operate a facility specified in the concession contract. This allows the project proponent(Promoter) to recoup their investment as well as the facility's running and maintenance costs.
- **BOT (build–operate–transfer):**
- The BOT is widely used in infrastructure projects and public–private partnerships.
- A third party, such as the government, delegated the design and construction of infrastructure, as well as the operation and maintenance of these facilities, to a private sector organization under the BOT framework. During this time, the private party is in charge of raising funds for the project, has the right to keep all project income, and is the owner of the property.

Highway Construction & Maintenance

In a BOT Project, the project operator often earns money by charging a fee to the utility/government rather than charging tariffs to customers.

BUILT	OPERATE	TRANSFER
Set up Facilities and infrastructure, staff, the development centre and establish knowledge transfer	Manage the organisation: Programme management, Development, maintenance, Quality Assurance, enhancements, and complete support, process expertise.	The facility will be then transferred to the public administration at the end of the concession agreement.

Highway Construction & Maintenance

- **BOOT (build–own–operate–transfer):**
- A BOOT structure differs from BOT in that the private entity owns the works.
- During the concession period the private company owns and operates the facility with the prime goal to recover the costs of investment and maintenance while trying to achieve higher margin on project.
- The specific characteristics of BOOT make it suitable for infrastructure projects like highways, roads mass transit, railway transport and power generation.
- BOOT & BOT are methods which find very extensive application in countries which desire ownership transfer and operations including.

Highway Construction & Maintenance

- Some advantages of BOOT projects are:
- Encourage private investment
- Inject new foreign capital to the country
- Transfer of technology and know-how Completing project within time frame and planned budget
- Providing additional financial source for other priority projects
- Releasing the burden on public budget for infrastructure development

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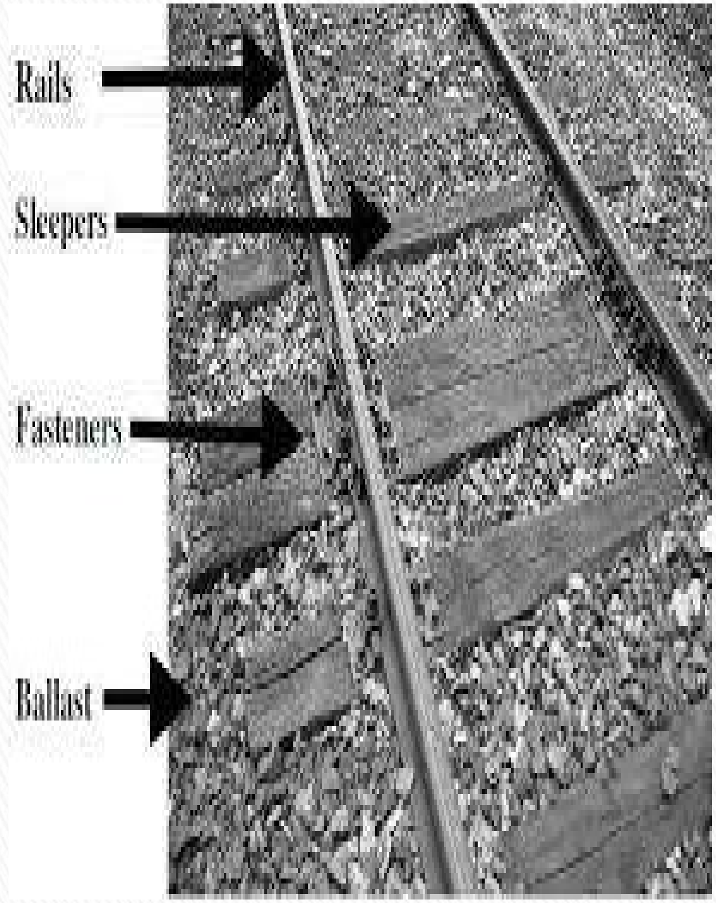
MODULE -IV

RAILWAY ENGINEERING
AND
GEOMETRIC DESING OF RAILWAY TRACK

INTRODUCTION TO RAILWAY ENGINEERING

- Permanent way components:
- Railway track is also known as a permanent way.
- Following are the components of a permanent way
  - ✓ Sub-grade
  - ✓ Ballast
  - ✓ Sleepers
  - ✓ Rails
  - ✓ Fixture and Fastenings
- In a permanent way, rails are joined either by welding or by using fish plates and are fixed with sleepers by using different types of fastenings.
- Sleepers are properly placed and packed with ballast.
- Ballast is placed on the prepared sub-grade called formation.



Permanent way components

INTRODUCTION TO RAILWAY ENGINEERING

- **Cross- section of permanent way:**
- The name permanent way is shown in fig.

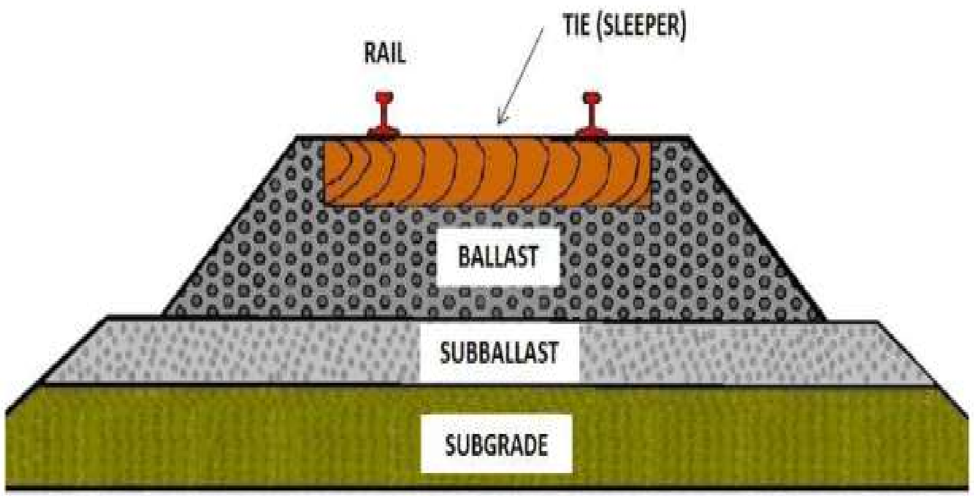


Fig: typical cross-section of a permanent way on embankment.

INTRODUCTION TO RAILWAY ENGINEERING

- **Functions of the rails:-**
- Rails provide a continuous and level surface for the movement of trains with minimum friction with steel wheels of the rolling stock.
- Rails provide strength, durability and lateral guidance of the track.
- Rails transmit the wheel load to sleepers, which transfer the same load to underlying ballast and formation.
- Rails bear the stresses developed due to heavy vertical loads, breaking forces and temperature variance.
- To resist the breaking forces caused due to stoppage of trains.

INTRODUCTION TO RAILWAY ENGINEERING

- **Sleepers:-**
- Sleepers are transverse members of the track placed below the rails to support and fix them in position.
- **Functions of sleepers**
- *Sleepers serve the following requirements:*
- To hold the rails to proper gauge.
- To transfer the loads from rails to the ballast.
- To support and fix the rails in proper position.
- To keep the rails at a proper level in straight tracks and at a proper super-elevation on curves.
- To provide elastic medium between the rails and ballast.
- To provide stability to the permanent way on the whole.

INTRODUCTION TO RAILWAY ENGINEERING

- **Ballast:-**
- Ballast is the granular material usually broken stone or any other suitable material which is spread on the top of railway formation and around the sleepers.
- **Functions of Ballast:-**
- *Ballast in railway perform the following functions:*
- To hold the sleepers in position and preventing the lateral and longitudinal movement.
- To distribute the axle load uniformly from sleepers to a large area of formation.
- To provide elasticity to the track, it acts as elastic mat between Sub-grade and sleepers.
- It is to provide, maintaining the correct levels of the two rails in a track.
- To drain rain water from the track.
- To prevent the growth of weeds inside the track.

- **Rail fastenings:**
- **Requirements of an ideal fastenings:-**
- A good fastening connecting rail and sleeper and it plays vital role in improving the efficiency of the railway track.
- *Following are the requirements of an ideal fastening connecting a rail and sleeper:*
- It should be capable of absorbing shocks and vibrations.
- It should be capable of giving protection to the sleeper against the actions of vertical and horizontal forces.
- It should be capable of resisting creep.
- It should be cheap, durable and non-corrosive
- It should be consists of a small number of components.
- It should be easy to fix and adjust and It should not be too rigid.
- It should be of sufficient strength to resist damage due to derailment.
- It should be keep the rail in the correct position, level and alignment.
- It should possess adequate strength to resist lateral forces.

INTRODUCTION TO RAILWAY ENGINEERING

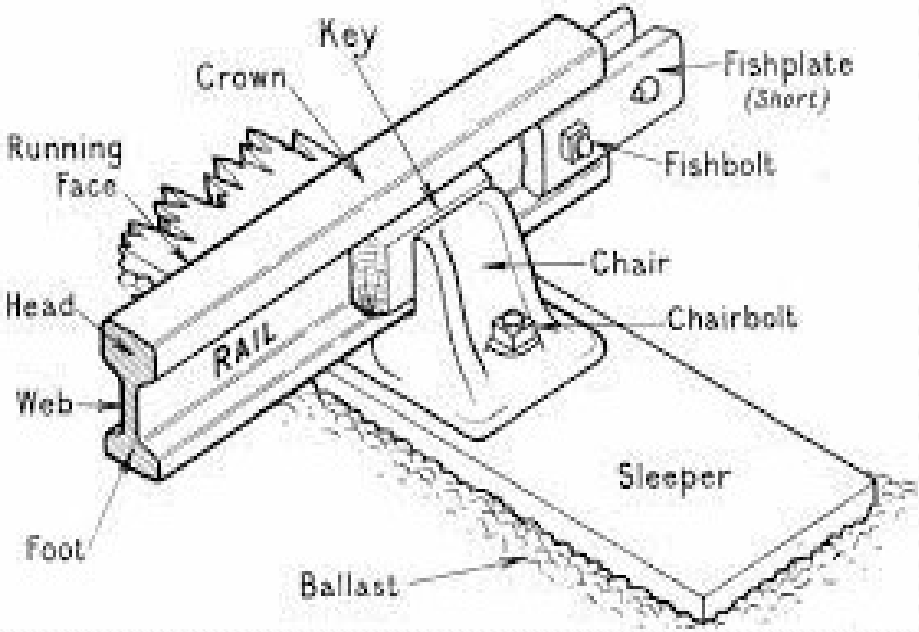
- **Fastenings for rails:-**
- *Following are the fastenings which are used to keep the rails in their correct position:*
  - ✓ fish plates
  - ✓ spikes, fang bolts and hook bolts
  - ✓ chairs and keys
  - ✓ bearing plates
- **1. Fish plates:**
- Fish plate is a metal bar that is bolted to the ends of rails to join them together in a track.
- And it is also allow the expansion and contraction of rail due to temperature difference (variations).
- Maintain correct alignment of line both horizontally and vertically.
- It provides easy renewal and replacement.

2. Spikes, fang bolts and hook bolts:-

- Spikes are used for holding the rails to the wooden sleepers.
- A rail spike is a large rail and it is used to secure rails and base plates to sleepers.
- Fan bolt is alternative to round spikes.
- But fang bolt is not in much use due to difficulty in fixing and removing bolt.
- This fang bolt has 19mm in dia and of sufficient length to pass through sleeper.
- The hook bolts are used to fix the sleepers to girders of the bridges.
- Usually two hook bolts are quite adequate for each sleeper.

3. Chairs and keys:-

- Chairs are fixed to sleepers using 3 spikes.
- Keys may be of wood or metal and may be either straight or tapered.
- Wooden keys are cheap.
- Initial cost of steel keys is high, but life is about ten times more than wooden keys, so steel keys are preferred.



Chairs and keys

4. Bearing plates:-

- It is used below flat footed rails to distribute the load on a larger area of timber sleepers.
- It is distribute load to sleepers over a large area and prevent sinking of rail in soft wooden sleepers.
- The cost of bearing plates is small, and it helps to increase the life of sleepers.

Bearing plates

INTRODUCTION TO RAILWAY ENGINEERING

- **Creep of rails:-**
- **Definition of creep:-** It is defined as the longitudinal movement of rails with respect to sleepers in a track. Creep is common to all railways and its value varies from almost nothing to about 6 inches or 16cm.
- **Theories of creep:-(or)causes of creep**
- Various theories of creep are proposed to explain the different causes of creep in rails are:

✓ Wave action(or) wave theory

✓ Percussion theory

✓ Drag(or)dragging theory

- **1. Wave theory:**
- Wave motion is setup (formed) by moving loads of wheels.
- Creep is developed due to wave motions, when the wheels of the vehicles strikes the crests creep is developed.
- As the wheels move, lifts (or) crests are formed immediately at the rear and front of the wheels as shown in fig.
- The above action pushes the rail forward resulting creep in the direction of motion.

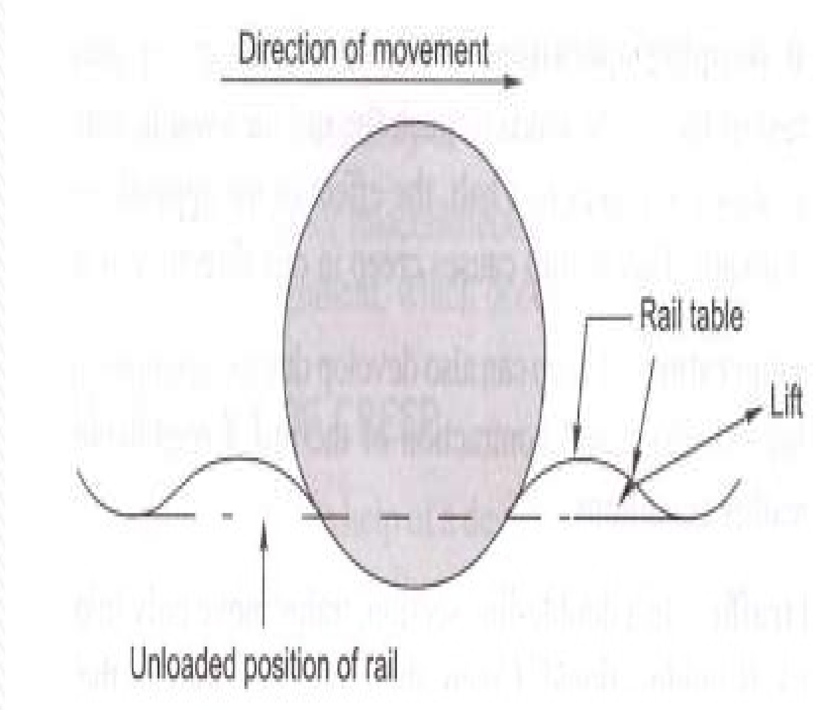
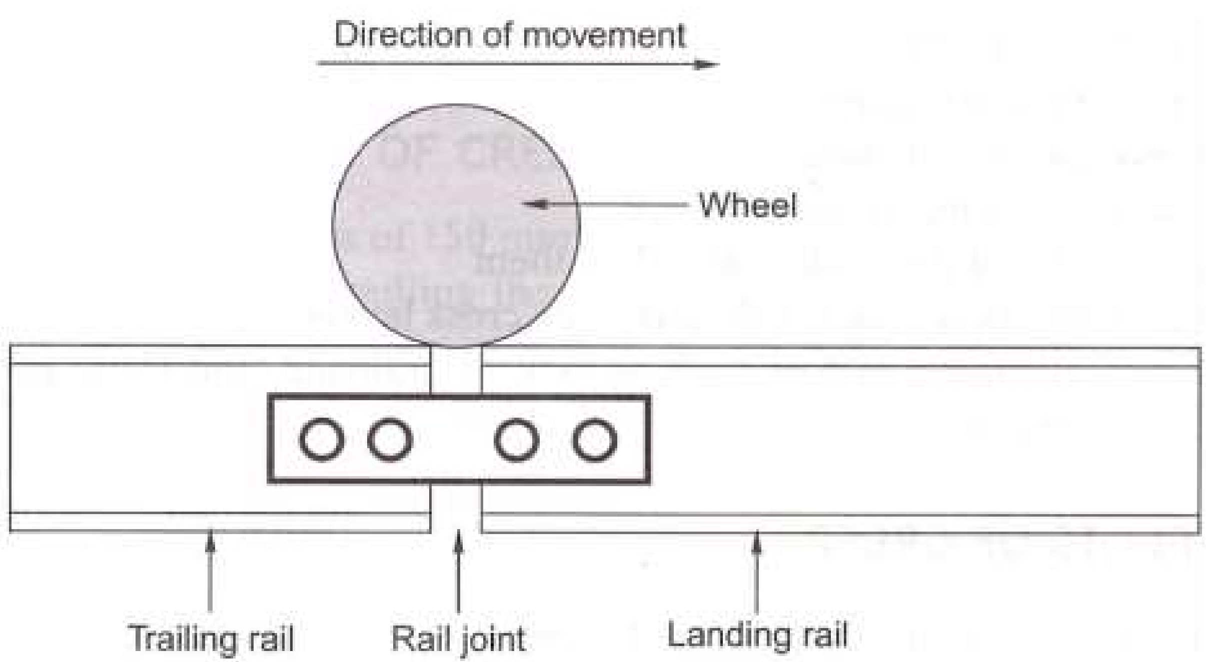


Fig: wave theory of creep (formation of wave)

INTRODUCTION TO RAILWAY ENGINEERING

- *The pitch and depth of wave depends on the following:*
- Track modulus
- Stiffness of track
- Stability of formation
- *For the reducing of wave action (or creep is reduced)by adopting the following measures:*
- Angular and heavy ballast are used that should be develops the good interlocking.
- By increasing the stiffness of track.
- By giving lesser sleeper spacing.
- By providing bigger section of the rail.

- **2. Percussion theory:**
- Creep is due to impact of wheels at the rail end ahead at the joints as shown in fig Hence as and when the wheel leave the trailing rail and strike the facing rail end at each joint, it pushes the rail forward resulting in creep.



INTRODUCTION TO RAILWAY ENGINEERING

- Generally the creep is very small in single impact but cumulative number of impacts may get sufficient creep.
- *The creep by this theory will increase due to following factors:*
- Due to weak and loose fish bolts
- Due to worn out fish plates
- Due to lose packing at joints
- Due to wide expansion gap
- Due to heavy axle loads moving at high speed.

- **3. Drag(or) Dragging Theory:**
- It starts that backward thrust on driving wheels of locomotive of train push the rail off track backward.
- Meanwhile other wheel of locomotive and vehicles push the rail in the direction of travel.
- Since drag effect is more as explained in wave action theory resultant creep of rails in forward direction.
- **Effects of creep:-**
- *Common effects of creep are:*
- Difficulty in re fixing of rail
- Operation of switches becomes difficult
- Points and crossings get pulled or pushed
- Rail joints get opened
- Surface of the track gets disturbed
- Alignment of track gets disturbed

- **Ageing of sleepers:**
- The sleepers mostly used on indian railways with the age (service life) are

I. Wooden sleeperes-12 to 15 years

II. Cast iron sleepers- 40 to 50 years

III. Steel sleepers-40 to 50

IV. Concrete sleepers-50 to 60 years

- The service life can be increased by proper packing, clean ballast, providing coal tar to tie-bar , using over sized keys etc

- **Spacing of sleepers and Sleeper Density:**
- The spacing of sleepers is fixed depending upon the sleeper density. Spacing is not kept uniform throughout the rail length.
- It is closer near the joints because of the weakness of the joints and impact of moving loads on them.
- In suspended joints, the space between the joints sleepers is 30cm to 45cm and intermediate sleepers is kept 75cm to 90cm.
- Sleeper density is the number of sleepers per rail length. It is specified as M + x or N + x, where M or N is the length of the rail in meters and x is a number that varies according to factors such as:
- (a) axle load and speed,
- (b) type and section of rails,
- (c) type and strength of the sleepers,
- (d) type of ballast and ballast cushion, and
- (e) nature of formation.

INTRODUCTION TO RAILWAY ENGINEERING

- If the sleeper density is $M + 7$ on a broad gauge route and the length of the rail is 13 m, it means that 13 + 7 = 20 sleepers will be used per rail on that route.
- The number of sleepers in a track can also be specified by indicating the number of sleepers per kilometre of the track.
- Example- For a Broad Gauge track, total number of sleepers required for 1km length of railway track if sleeper density = N+5
- Length of one rail = 12.8m =13m
- Sleeper Density = N+5 = 13+ 5 = 18
- Total number of sleepers required for 1km length = (18/12.8)x1000 = 1406 sleepers.

- Example: Find out the expression for sleeper density for a B.G. track if 19 sleepers are used under a rail length.
- **Solution:** Length of a rail for B. G. track=12.8m say 13meters
- Sleeper density = M + x
- Where M= length of rail in meters
- x= a factor depending upon several factors, axle load, section of rails etc.
- So 19=13+x
- ∴ x=6.
- The expression for sleeper density, therefore, **is M+6**

- Example: Using a sleeper density of M+5, find out the number of sleepers required for constructing a railway track 640 meters long.(B.G.track)
- Solution: length of each rail on a B.G track = 12.8 m
- Total number of rails required will be

  =(640/12.8) =50 rails

Given sleeper density is M+5.

Number of sleepers under each rail = 12.8+5=17.8 say 18meters

∴ Total number of sleepers required will be = 50×18=900 Sleepers.

GEOMETRIC DESIGN OF RAILWAY TRACK

- Introduction:
- Geometric design of railway track, it includes the design of geometric cross sections, horizontal alignment, vertical alignment, intersections and various design details.
- Geometric design should be such that as to provide maximum efficiency in the traffic operation with maximum safety at reasonable cost.
- **Gradient:**
- Gradients are provided to negotiate the rise or fall in the level of the railway track.
- Purpose of providing gradient:-
- To provide uniform rate of rise or fall
- To reduce cost of earth work
- To reach different stations at different level

GEOMETRIC DESIGN OF RAILWAY TRACK

- Rising gradient: - When the track rises in the direction of movement is called rising gradient.
- Falling gradient: - When the track falls in the direction of movement is called falling gradient.
- **Types of gradient:** - Various gradients are classified under the following heads:
- Ruling gradient
- Momentum gradient
- Pusher or helper gradient
- Gradient at station yards

GEOMETRIC DESIGN OF RAILWAY TRACK

- 1. **Ruling gradient:** - Which is steepest (maximum) gradient allowed on the track section.
- It depends on the load of the train and additional power of the locomotive. The ruling gradients adopted.
- The steep gradient needs more powerful locomotives, smaller train loads, lower speed, resulting in costly hauling.
- Indian standards do not specify any fixed ruling gradient due to the varying nature of the country, speed and track.
- Generally, with one locomotive train, the following gradients are adopted.
- In plain terrain 1 in 150 to 1 in 200
- In hilly terrain 1 in 100 to 1 in 150
- **2. Momentum gradient:-**
- These gradients on a section are more severe than the ruling gradient.
- The gradient on a section which are steeper than the ruling gradient acquire sufficient momentum to negotiate them are known as momentum gradient.

GEOMETRIC DESIGN OF RAILWAY TRACK

- **3. Pusher gradient:-**
- Pusher gradient is the gradient where an extra engine is required to push the train.
- These are steeper gradient than ruling gradient and are provided at certain places of mountains to avoid heavy cutting or to reduce the length of the track.[Where extra engine is required to push the train, the gradient provided is known as pusher gradient]
- **4. Gradient at station yard:-**
- Station yard gradient is the minimum gradient provided in station yard for easy draining of rainwater. Gradients are avoided as far as possible in station yard due to following reasons:
- To prevent movement of standing vehicle.
- The locomotives will require an extra force of pull the train on gradients at the time of starting the trains.
- On Indian railways, maximum gradient permitted is 1 in 400 in station yards.

GEOMETRIC DESIGN OF RAILWAY TRACK

- **Grade compensation on curves:-**
- If curve is provided on a track with ruling gradient, the resistance (an opposing) of track will be increased this curve.
- In order to avoid resistance beyond the allowable limits, the gradients are reduced on curves.
- The reduction in gradient is known as grade compensation on curves.
- In India ,compensation for curvature is given by the following:

Type of gauge	Width of gauges as per Indian standard	Grade compensation
1.Broad gauge	1676 mm	0.04% per degree of curve
2.Meter gauge	1000 mm	0.03% per degree of curve
3.Narrow gauge	762mm	0.02% per degree of curve

GEOMETRIC DESIGN OF RAILWAY TRACK

- Example: If the ruling gradient is 1 in 150 on a particular section of broad gauge and at the same time a curve of 4 degree is situated on this ruling gradient, what should be the allowable ruling gradient?
- **Solution:** As per I.S grade compensation of B.G is 0.04% per degree of curve
- Therefore compensation on 4 degree curve =4*0.04
- =0.16%
- Now ruling gradient 1 in 150 =1/150 *100
- =0.67%
- Therefore maximum allowable gradient or actual gradient to be provided =0.67-0.16
- =0.51% i.e.; 1 in 196.

GEOMETRIC DESIGN OF RAILWAY TRACK

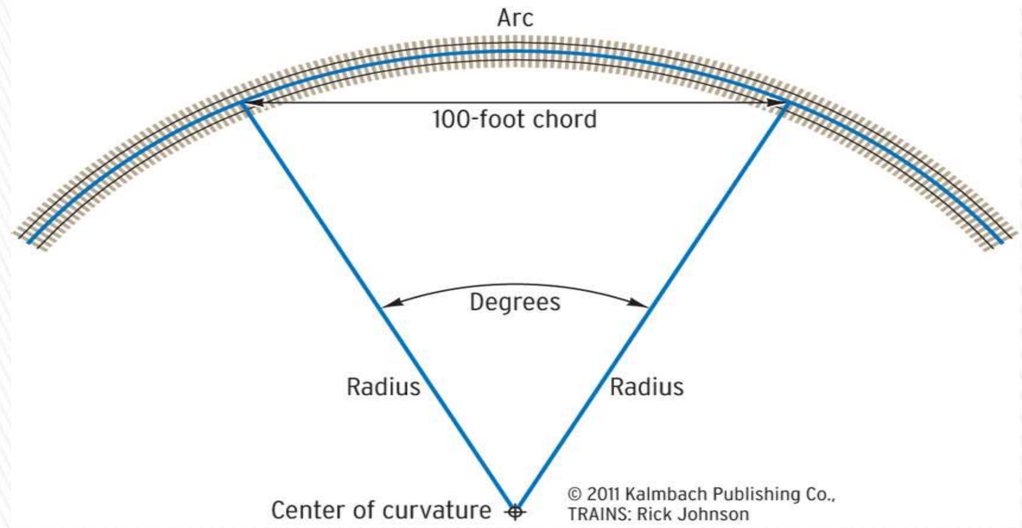
- The ruling gradient on a particular section of M.G track is 1 in 250. If a 5 degree curve is situated on this gradient, determine the permissible gradient on the curve.
- Solution: Given data,
- Gradient of M.G track = 1 in250=(1/250)×100=0.4
- Grade compensation for M.G =0.03% per degree curve
- Degree of curve on this gradient = 5 degree
- Permissible gradient on the curve = gradient on the curve -
- Grade compensation.
- Grade compensation =0.03*5 =0.15%
- Permissible gradient =0.40-0.15 =0.25% i.e., 1 in 400.

GEOMETRIC DESIGN OF RAILWAY TRACK

- To what extent should a ruling gradient of 1 in 150 on a broad gauge line be downward to accommodate a 3 degree curve?
- **Solution:** Given data,
- Ruling gradient on broad gauge =1 in 150 =(1/150)×100= =0.67%
- Degree of curve =3 degree
- The reduction in the ruling gradient =(The grade compensation × Degree of curve)
- Grade compensation on B.G =0.04% per degree
- Reduction in ruling gradient =0.04*3 =0.12%
- Permissible gradient =0.67%-0.12% =0.55% i.e., 1 in 182.

GEOMETRIC DESIGN OF RAILWAY TRACK

- ***<u>Radius and degree of curve:</u>*-**
- The main curved portion of a railway track is kept circular i.e., the radius at every point of the curve is same.
- The radius of a railway curve is sometimes represented by the degree of curve.
- <u>Degree of a railway curve</u>:-
- A curve is defined either by its radius or by its degree. The degree of a curve (D) is the angle subtended at its centre by a 30-m or 100-ft chord.

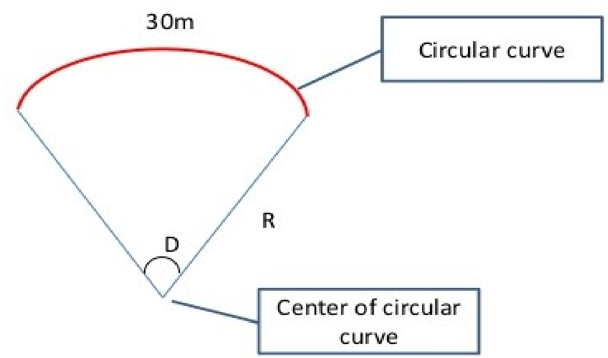


Radius or Degree of Curve

- Degree of curve (D) is defined as the angle subtended at the center by a chord of length 100ft or 30.48m

$$\frac{D}{30} = \frac{360°}{2\pi R}$$

$$D = \frac{1720}{R}$$



GEOMETRIC DESIGN OF RAILWAY TRACK

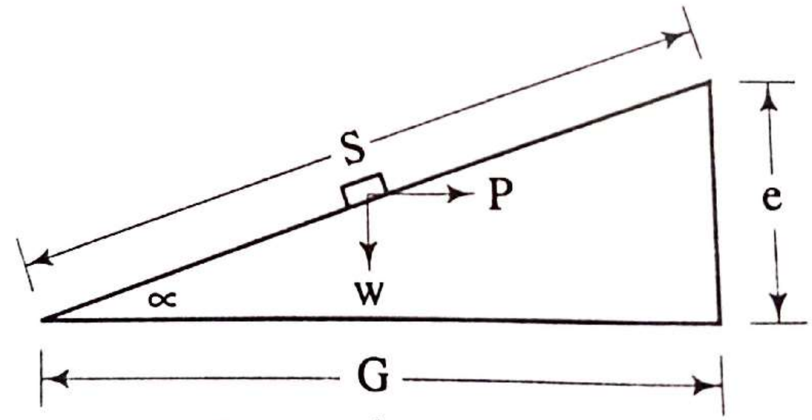
- The value of the degree of the curve can be determined as indicated below. Circumference of a circle = $2\Pi R$
- Angle subtended at the centre by a circle with this circumference = 360 o
- Angle subtended at the centre by a 30-m chord, or degree of curve = [(360/2ΠR)×30]
- = 1720/R (Approximate R is in meters)
- In cases where the radius is very large, the arc of a circle is almost equal to the chord connecting the two ends of the arc. The degree of the curve is thus given by the following formulae
- $D = 1720/R$ (when R is in meters)
- $D = 5730/R$ (when R is in feet)
- A 2^{o} curve, therefore, has a radius of 1720/2 = 860 m.

GEOMETRIC DESIGN OF RAILWAY TRACK

- **Cant and negative super elevation:-**
- **Cant or super elevation:-**
- As for as a train is running along a straight track, the heads of the rails must be kept absolutely at the same level.
- But it is moving on a curved path, it has a constant radial acceleration which produces centrifugal force.
- For counteract this force the outer rail of the track is raised slightly higher than the inner rail, this is known as a super elevation or cant.
- *And it serves the following purposes:*
- It gives the smooth and safe movement of passengers and goods on the track.
- It introduces the centripetal force to counteract the centrifugal force and hence the faster movement of trains on curves can safely be permitted.
- It prevents derailment and reduces creep as well aside wear of rails.
- It results in the decrease of maintenance cost of the track.
- It provides equal distribution of wheel loads on two rails.

GEOMETRIC DESIGN OF RAILWAY TRACK

- The amount of super elevation can easily be worked out the theoretically as shown in fig.
- Let
- w= Weight of moving train
- V= Velocity in meters per second
- P= Centrifugal force acting on the vehicle through its centre of gravity
- g= acceleration due to gravity in m/sec^2
- R= Radius of the curve in m
- G= Gauge of track in m
- e=Super-elevation in cm
- α=Angle of inclination
- S=Length of inclined surface



Super-elevation

➢ **Analysis of Superelevation**

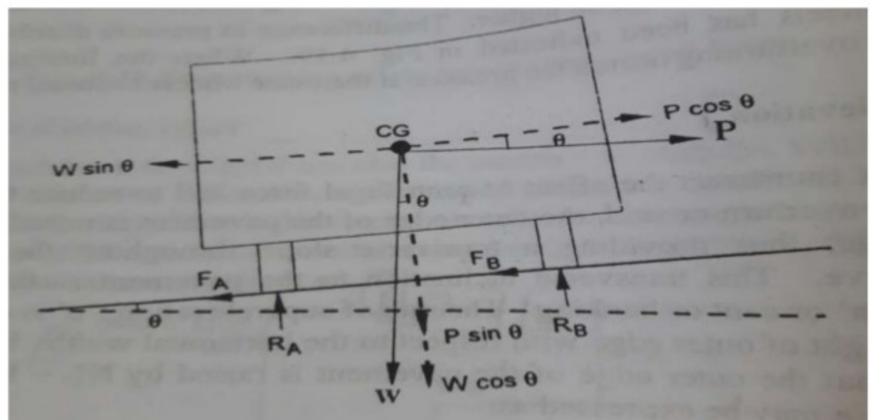


Fig. 4.21 Analysis of superelevation

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Analysis of SE for Highways

GEOMETRIC DESIGN OF RAILWAY TRACK

- Then, Centrifugal Force, $P = Wv^2/gR$
- For Resolving the forces along the inclined surface, we get $P \cos\alpha = W \sin \alpha$
- $\therefore (Wv^2/gR) \times (G/S) = W \times (e/S)$
- $\therefore e = (v^2/gR) \times G$ meters
- Where v is in m/sec.
- If v=velocity in km per hour
- $e = (v^2G/127R)$ meters or $e = (v^2G/1.27R)$ cm
- Where, G in meters
- v is in Kmph,
- R is in meters(The degree of curvature is in terms of radius of the curve will be as $D=1720/R \approx R=1720/D$

GEOMETRIC DESIGN OF RAILWAY TRACK

- The S.E can be worked out for Indian conditions, from the equation $e = (v^2G/1.27R)$ cm---------------(1)
- For B.G(Broad Gauge), $S.E=[(V^2 \times 1.676)/1.27R]=1.315V^2/R$
- For M.G(Meter Gauge), $S.E=[(V^2 \times 1.00)/1.27R]=0.80V^2/R$
- For N.G(Narrow Gauge), $S.E=[(V^2 \times 0.762)/1.27R]=0.60V2/R$
- The amount of super elevation or cant obtained by equation (1) is known as the equilibrium super elevation or equilibrium cant.

GEOMETRIC DESIGN OF RAILWAY TRACK

- **Cant Deficiency:**
- Cant deficiency is the difference between the actual cant provided and equilibrium cant necessary for the maximum permissible speed on a curve.
- *Cant deficiency should be as low as possible and is limited due to following reasons:*
- Higher discomfort to passengers due to higher cant deficiency
- Higher cant deficiency results in higher unbalanced centrifugal force and hence extra pressure and lateral thrust on the outer rails, requiring strong track and more fastening for stability.
- Side wear and creep of outer rails of the track are more due to higher cant deficiency. Maximum values of cant deficiency as prescribed on Indian Railways on BG
- For speeds up to 100kmph = 76mm
- For speeds up to higher than 100kmph = 100mm

GEOMETRIC DESIGN OF RAILWAY TRACK

- **Negative super elevation**:-
- When a main line on a curve and a branch line diverges from a main line.
- As shown in figure, AP &BQ are the inner and outer rails respectively of a main line, and BD & AC are the inner and outer rails respectively of branch line.

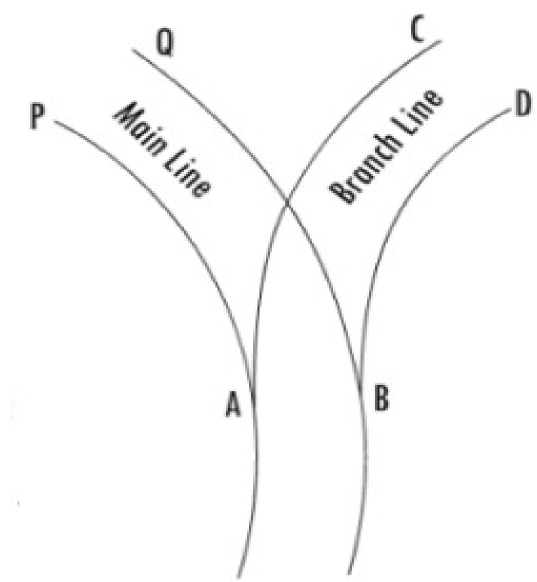


Fig: Negative super elevation.

GEOMETRIC DESIGN OF RAILWAY TRACK

- As per figure, BQ is the outer rail of the main line, curve must be higher than the inner rail AP in other words for branch line AC is the outer rail is higher than the inner rail BD.
- These two conditions cannot be met at the same time within one layout.
- So instead of outer rail AC of branch line being higher, it is kept lower than the inner rail BD.
- In such cases, the branch line curve has a "Negative super elevation "and therefore speed of both tracks must be restricted particularly on branch line.

GEOMETRIC DESIGN OF RAILWAY TRACK

- The method of working out the speeds on main line, branch line and negative super elevation on branch line, will be clear from the following steps:
  1. The equilibrium super elevation (cant) on branch line is calculated by usual formula by assuming suitable speed on branch line.
  2. The permissible cant deficiency is deducted from the equilibrium cant.
  3. The result obtained (equilibrium cant – permissible cant deficiency) will represent the negative super elevation to be given on the branch line.
  4. This negative super elevation is also equal to maximum super elevation permitted on the main curved track.
  5. The permissible cant deficiency is added to the maximum cant permitted on the main line and correspondingly the restricted speed on main line is worked out.

GEOMETRIC DESIGN OF RAILWAY TRACK

- Example: A 6 degree curve branches off from a 3 degree main curve in an opposite direction in the layout of a B.G yard .If the speed on the branch line is restricted to 35 KMPH, Determine the speed restriction on the main line, Assume permissible deficiency in cant as 75mm.
- Solution: Given data
- Degree of curve on branch line =6 degree
- Degree of curve on main line =3 degree
- Speed of branch line restricted = 35 kmph
- Speed of main line restricted = ?
- Permissible deficiency in cant =75mm =7.5 cm

GEOMETRIC DESIGN OF RAILWAY TRACK

- ***Calculation :***
- S.E on branch line is calculated by using the formula
- Super elevation (S.E) $=(GV^2/1.27R)$
- Where G=gauge width for B.G =1.676 m
- V=speed =35kmph R=radius of curve =1720/D (Degree of curve)
  =1720/6 =286.67
- Therefore S.E=$1.676*35^2/1.27*286.67$ =2053/364=**5.63cm**
- The permissible cant deficiency is deducted from the equilibrium S.E
- Negative super elevation =5.63-7.50 = **-1.87 cm**
- Maximum S.E can be given on main line =**1.87 cm**
- Theoretical S.E on main line =1.87 +7.50 =9.37 cm
- Hence S.E $=GV^2/1.27R$
- $9.37=1.676*V^2/1.27*(1720/3)$
- V=63.80 kmph.
- Speed on mainline =64 kmph.

GEOMETRIC DESIGN OF RAILWAY TRACK

- Find the speed for which super elevation is to be maintained on a 3^0 curve of a BG Track, if the speeds of several trains running on a main curve track are as follows
- 15 trains at a speed of 50 kmph,10 trains at a speed of 60 kmph
- 5 trains at a speed of 70 kmph and 2 trains at a speed of 80 kmph
- ***Solution***: The weighted average of different trains at different speeds is calculated from the equation

  Weighted average speed = $\dfrac{n1v1 + n2v2 + n3v3 + n4v4}{n1 + n2 + n3 + n4}$
- $= \dfrac{15 \times 50 + 10 \times 60 + 5 \times 70 + 2 \times 80}{15 + 10 + 5 + 2}$
- =58.125 kmph
- Degree of Curve $=3^0$, R=1720/3=573.33($\because$ D=1720/R)
- Actual Cant Provided, e = $GV^2/1.27R$
- e $=[(1.676\times 58.125^2)/(1.27\times573.33)]$
- e =5662.39/728.1291=7.78 cm.
- $\therefore$ Actual Cant is provided 7.78 cm with a average speed of 58.125 kmph

GEOMETRIC DESIGN OF RAILWAY TRACK

- What is the equilibrium cant on a 2 degree curve on a B.G.? If 15 train, 10 trains, 5 trains and 2 trains are running at speed of 50kmph, 60 kmph, 70kmph, and 80 kmph respectively.

- ***Solution***: Radius of 2 degree curve =1720/2 =860 m
- Weighted average speed = $\frac{15 \times 50 + 10 \times 60 + 5 \times 70 + 2 \times 80}{15 + 10 + 5 + 2}$
- =58.125 kmph

- Super elevation =e = $\frac{GV^2}{1.27R}$
- = $\frac{1.676V^2}{1.27 \times 860}$
- = $\frac{1.676 \times 58.125^2}{1.27 \times 860}$
- e=5.18 cm

GEOMETRIC DESIGN OF RAILWAY TRACK

- ***Points and crossings:-***
- Points and crossings are provided to help transfer railway vehicles from one track to another.
- The tracks may be parallel to, diverging from, on converging with each other.
- **Types of crossings:-**
- A crossings may be of the following types:

1. An acute angle crossing or V crossing
2. An obtuse or diamond crossing
3. A square crossing

GEOMETRIC DESIGN OF RAILWAY TRACK

- **<u>1. An acute angle crossing or V crossing</u>:-**
- This crossing in which the intersection of the two gauges faces forms an acute angle.
- For example, when a right rail crosses a left rail, it makes an acute angle crossing. Thus , unlike rail crossings forms an acute crossing as shown in figure of point A & C
- Points A & C are V crossing; points B & D are diamond crossing

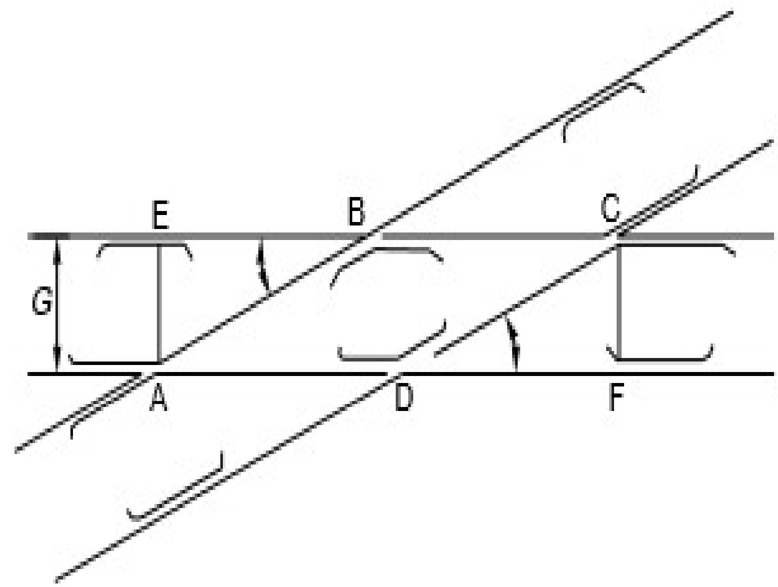
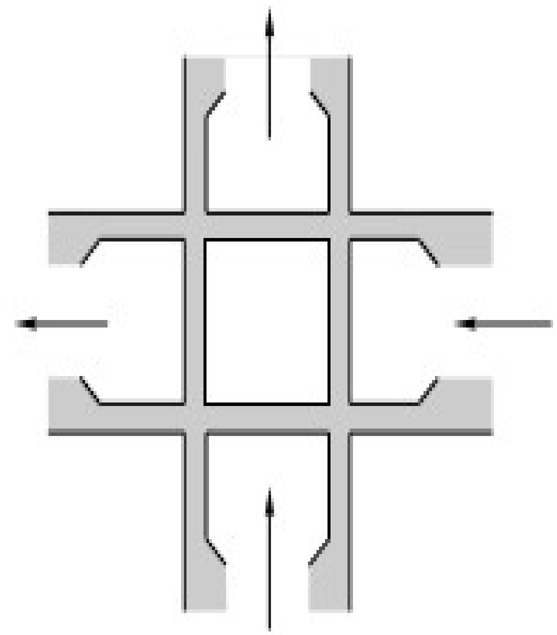


Fig: V and Diamond crossing

GEOMETRIC DESIGN OF RAILWAY TRACK

- **2. An obtuse or diamond crossing:-**
- This crossing in which the two gauge faces meet at an obtuse angle.
- When a right or left rail crosses a similar rail, it makes an obtuse angle crossing as shown in above figure of point B & D.
- **3. A square crossing:-**
- This crossing in which two tracks cross at right angles.
- Such crossings are rarely used in actual practice as shown in figure.



square crossing

GEOMETRIC DESIGN OF RAILWAY TRACK

- **Turnouts:-**
- Turnout is the simplest combination of points and crossings for diverting the train from one track to another or to siding is known as "turnout".
- So that the object of turnout is to provide facilitate for safe movement of trains in both directions on both the tracks.
- Depending upon the situation a turnout may be classified into two categories:

  a. Right hand turnout (RH turnout)

  b. Left hand turnout (LH turnout)

GEOMETRIC DESIGN OF RAILWAY TRACK

- **Right hand turnout** :-
- If a train from main track is diverted to the right of the main route as shown in figure.

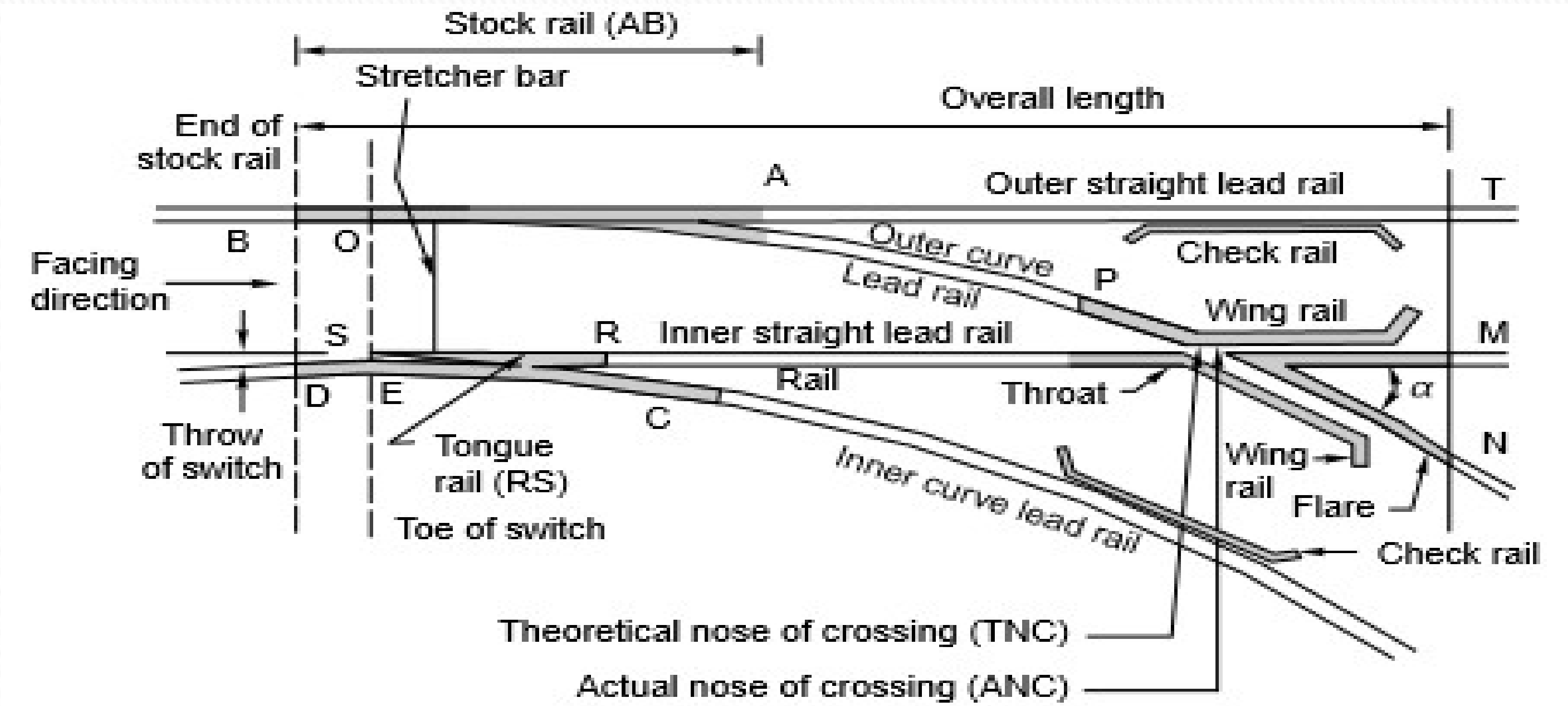


Fig: Layout of Right Hand Turnout.

GEOMETRIC DESIGN OF RAILWAY TRACK

- ***Left hand turnout***:-
- If a train from main track is diverted to the left of the main route as shown in figure.

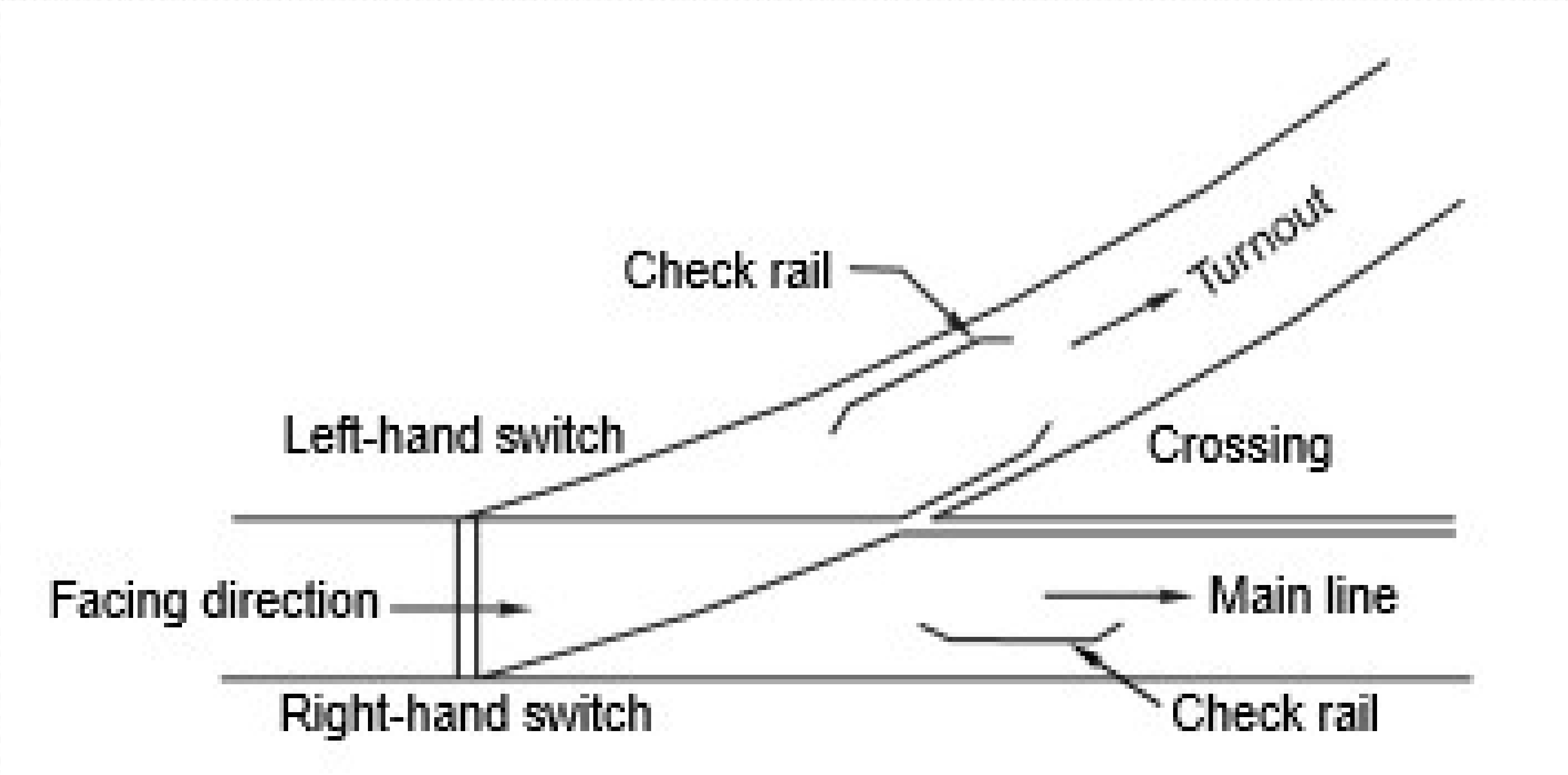


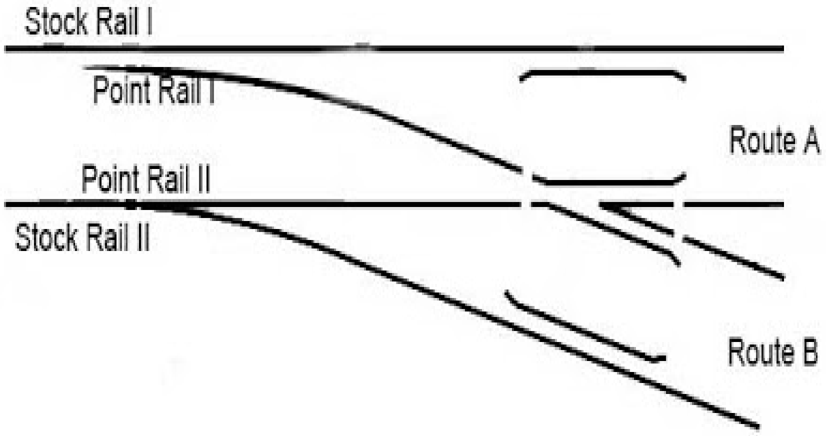
Fig: Layout of Left Hand Turnout

GEOMETRIC DESIGN OF RAILWAY TRACK

- **Important terms for turnout or turnout component parts and functions**:-
- The following are the terms used for design of points and crossings
- 1. Tongue rail
- 2. Stock rail
- 3. Points or switch
- 4. Crossing
- 5.Two check rails
- 6.side chairs
- 7. Rods, cranks, lever.

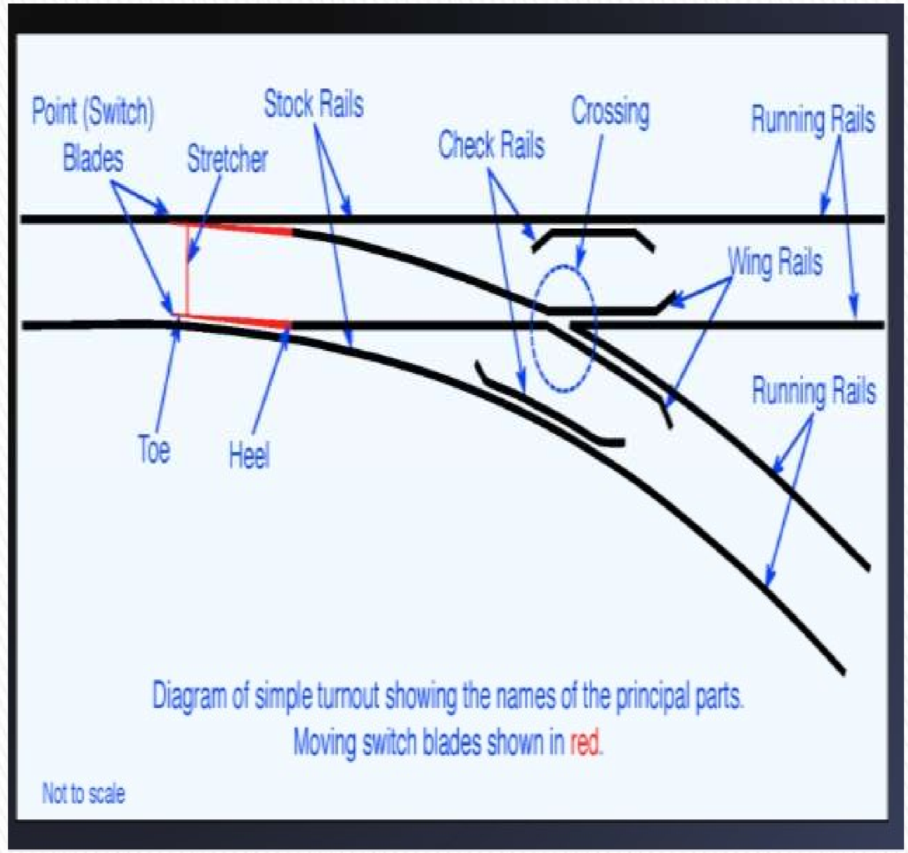
GEOMETRIC DESIGN OF RAILWAY TRACK

- 1. <u>Tongue rail</u>: - It is a tapered movable rail, made of high carbon or manganese steel to withstand wear.
- It is attached to a running rail. A tongue rail is also called a switch rail.
- 2. <u>Stock rail</u>: - It is the running rail against which a tongue rail operates.



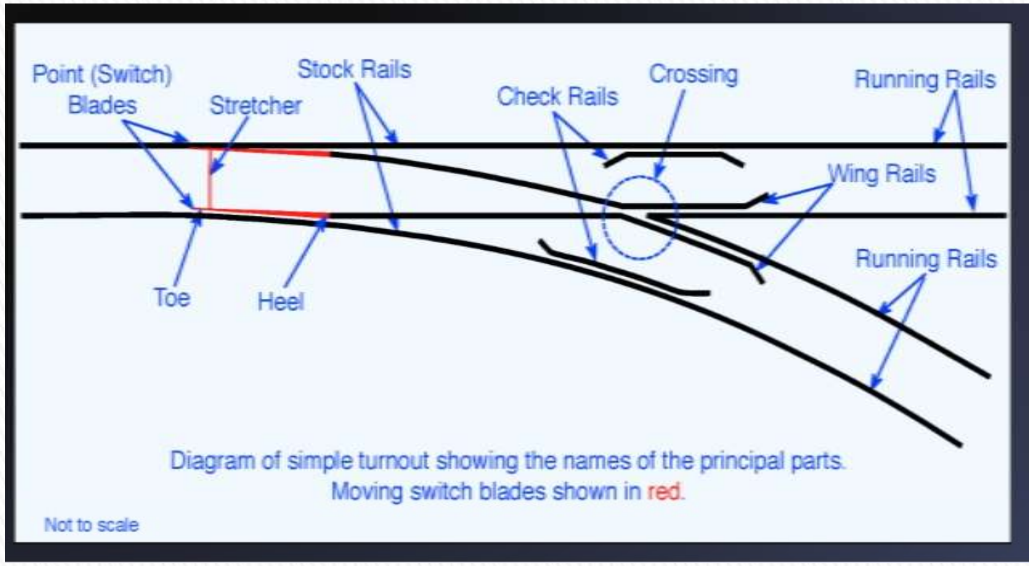
GEOMETRIC DESIGN OF RAILWAY TRACK

- 3. <u>Points or switch</u>:-A pair of tongue and stock rails with the necessary connections and fittings forms a switch.
- 4. <u>Crossing</u>:-A crossing is a device introduced at the junction where two rails cross each other to permit the wheel of vehicle to pass from one track to another.



GEOMETRIC DESIGN OF RAILWAY TRACK

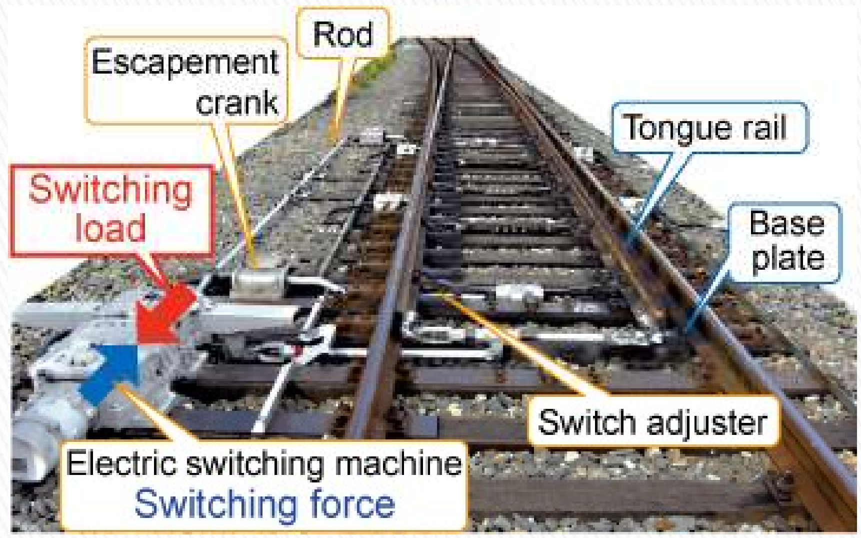
- 5. <u>Two check rails</u>:-
- Function of these rails is to check the tendency of wheels to climb over the crossings.
- 6. <u>Chairs</u>:-Function of side chair is to support the tongue rails throughout their length.



Chairs :

GEOMETRIC DESIGN OF RAILWAY TRACK

- 7. Rods, cranks, lever:- Function of rods, cranks, and lever is to operate the points.



GEOMETRIC DESIGN OF RAILWAY TRACK

- **Reference Books:**
- 1. A Text Book of Railway Engineering by S.C.SAXENA & S.P ARORA
- 2. Railway Engineering by RANGWALA.

TRAFFIC ENGINEERING

V-UNIT

- **Traffic engineering** is that branch of engineering which deals with the improvement of traffic performance in road networks and terminals.

Definitions:

- "Traffic engineering is a branch of civil engineering that uses engineering techniques to achieve the safe and efficient movement of people and goods on roadways. It focuses mainly on research for safe and efficient traffic flow, such as road geometry, sidewalks and crosswalks, cycling infrastructure, traffic signs, road surface markings and traffic lights. Traffic engineering deals with the functional part of transportation system, except the infrastructures provided.

- **Basic Traffic Parameters:**
- The basic parameters are

  (i) Traffic Volume or Traffic Flow

  (ii) Speed

  (iii) Density and Concentration (k)

TRAFFIC PARAMETERS

1.Traffic Volume or Traffic Flow:

- It is defined as the number of vehicles passing over a given point of a road way during specified interval of time.
- Normally it is indicated as vehicles/hour, some times it is called as vehicles/day or vehicles/sec.
- And it is also known as traffic flow rate.
- This Traffic volume is denoted as q or Q
- If there is no moment on the road, the traffic volume is zero.

2. Speed:

- Distance moved in interval of time or Rate of displacement in interval of time i.e. in kmph or m/sec.

TRAFFIC PARAMETERS

3. Density and Concentration (k):

- It is the 3rd parameter of traffic and it is defined as the number of vehicles physically presented in a length of given road section at a given point of time. And also it is called as Vehicles/km.
- In jammed condition density is maximum and it is denoted by 'K'

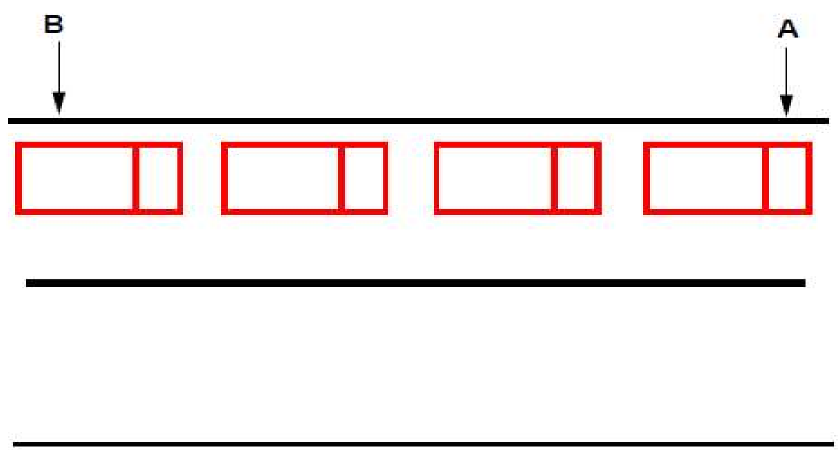
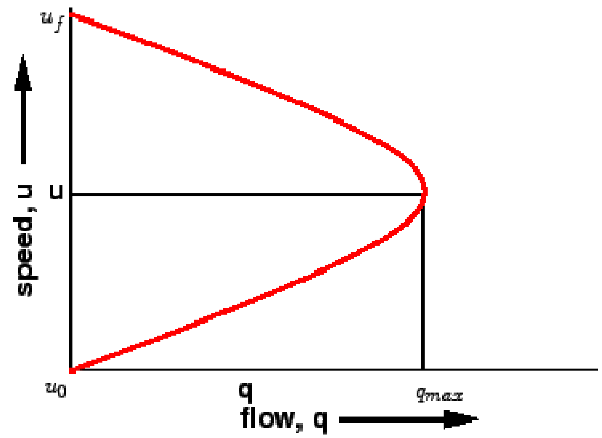


Figure Illustration of density

TRAFFIC PARAMETERS

1. Relationship between the Traffic Parameters
2. **Relation ship between speed and flow:**

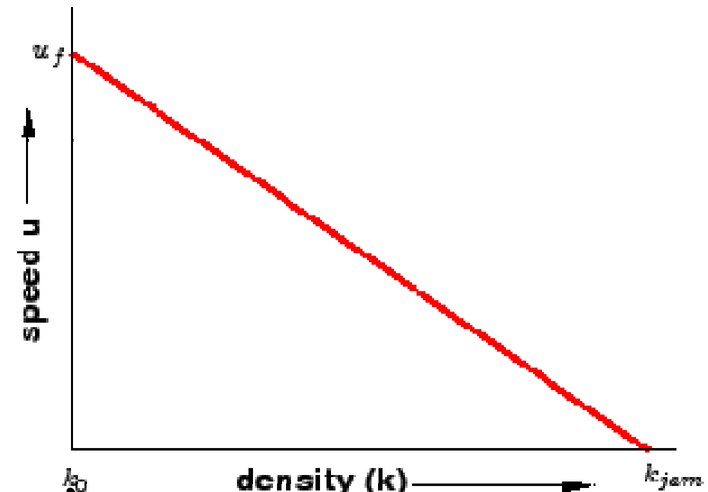
- The curve expressing the relationship between and speed and flow as shown fig.
- The curve should start at the origin zero, since the speed is zero when the flow is zero.
- The curve should also pass through (u_f) when the flow is zero and speed is maximum corresponding to free flow conditions.
- $\therefore q = u\,k$ ------ (1)
- Where, q = Traffic Volume (veh/hr)
- u = speed in kmph
- k = density in vehicles/km



TRAFFIC PARAMETERS

2. Relation ship between speed and density:

- **Free flow speed (u_f):-**
- It is the maximum speed possible for a given road where density is zero
- **Jam density(k_j):**
- Green shields has proposed a linear relationship between speed and density which is as shown in fig.



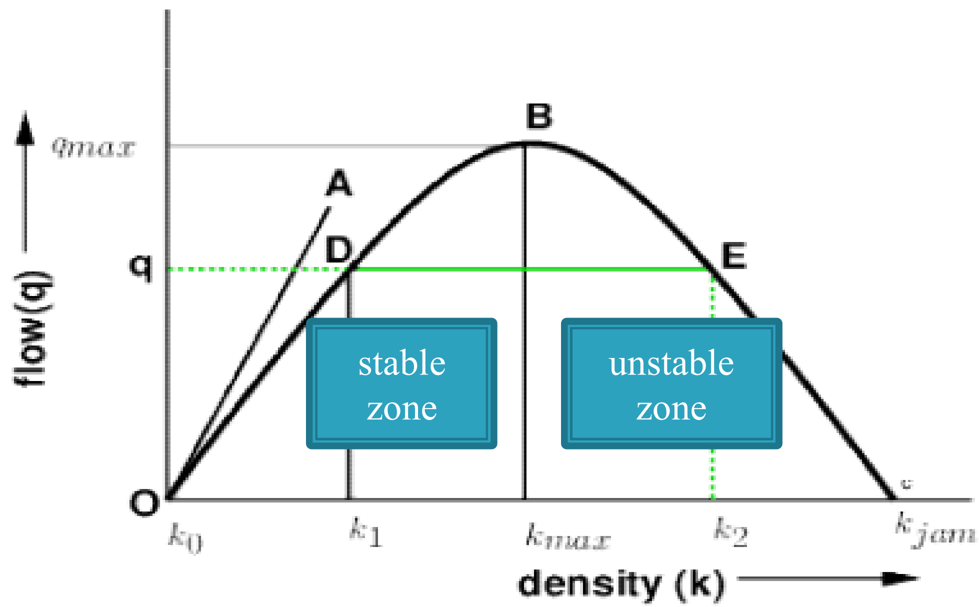
- Maximum density is possible on a road.

  The relation ship between 'u' and 'k'
- $u = u_f\,(1 - k/k_j)$----- (2)
- From the graph, when the density is zero, maximum speed is possible which is called free flow speed & it is denoted by 'u_f'
- When the density is maximum level, all the vehicles are in jammed condition and their will not be any vehicular moment.

TRAFFIC PARAMETERS

- **Relation ship between flow and density:**
- From the fig. q_m= Maximum flow: it is the maximum number of vehicles that can flow in a given interval time.

  k_m= Optimum density: It is the density corresponding to capacity of given road section.



TRAFFIC PARAMETERS

- **Stable Zone:** In the stable zone, traffic flow can increase, density can increase certain extent
- **Un-Stable Zone:** The traffic is so un stable that there is always a possibility of a traffic jam.
- While substituting above equation 2 in 1 we get the relationship between flow and density given by equation 3.
- $\therefore q = u \times k$
- $q = u_f \times (1 - k/k_j) \times k$
- $q = u_f \times (k - k^2/k_j)$ -------- (3)

Traffic Studies:

- Traffic studies or surveys are carried out to analyze the traffic characteristics.
- These studies help in deciding the geometric design and traffic control for safe and efficient traffic movements.
- The traffic surveys for collecting traffic data are also called *traffic census*.

TRAFFIC VOLUME STUDY

- The various traffic studies generally carried out they are:
- Traffic volume study
- Speed studies
  (i) Spot speed study
  (ii) Speed and delay study
- Origin and destination (O & D)study
- Traffic flow characteristics
- Traffic capacity study
- Parking study
- Accidents studies or the traffic flop

TRAFFIC VOLUME STUDY

- Traffic volume is a measure to quantify the traffic flow.
- Traffic volume or traffic flow is expressed as the number of vehicles that pass across a given transverse line of the road during unit time.
- Different classes of vehicles make use of the same roadway, particularly in developing countries like India; thus the traffic stream consists of mixed traffic flow.

TRAFFIC VOLUME STUDY

- The vehicles of the traffic stream may be classified into different vehicle classes. They consists of:

1. Fast moving vehicles such as a) passenger cars, b) buses, c) trucks or heavy commercial vehicles (HCV), d) light commercial vehicles (LCV), e) auto rickshaws, f) two wheeler automobiles (motor cycles and scooters) and
2. Slow moving vehicles such as animal drawn vehicles like bullock carts, cycle rickshaws, pedal cycles etc.

- Determination of the volume of each vehicle class separately and finding the total volume is called “classified traffic volume studies.”
- In order express the total traffic flow, it will convert the class of vehicles into standard vehicle type such as the passenger car unit (PCU)

TRAFFIC VOLUME STUDY

- Therefore each vehicle class is assigned an equivalency factor, called passenger car unit (PCU) in terms of a standard passenger car
- Standard PCU conversion factor for each class of vehicle as shown in table:

S.No	Class of vehicle	PCU Factor
1	Car	1
2	Motorcycle	0.5
3	Tractor and trailor	5
4	Horse-drawn vehicle	4
5	Bus/ truck	2.2
6	Auto	1.2
7	Lcv	2
8	Cycle rickshaw	1.5

TRAFFIC VOLUME STUDY

- Traffic volume is the number of vehicles crossing a section of road per unit time at any selected period.
- Traffic volume is used as a quantity measure of traffic flow and commonly units are vehicles /day or vehicles/hr.
- The objects and uses of traffic volume studies are given below:

a. To decide the priority for improvement and up-gradation of roads

b. Traffic volume is generally useful for giving the importance of that road and improvement and expansion of that road.

c. Traffic volume is used for planning, operation of traffic and control the existing facilities and develop the designing facilities for getting smooth and safe traffic movement.

TRAFFIC VOLUME STUDY

d. This study is used for analysis of traffic patterns and growth of traffic.

e. This study is useful for design of pavement and computing the road capacity and etc.

f. This volume study is used for planning one way streets and providing other regulatory measures.

g. And this data is useful for the design of intersections, planning signal timings etc.

h. Pedestrian traffic volume study is used for planning side walks, cross walks and pedestrian signals.

i. For structural design/strengthening of pavements and other roadways structures.

TRAFFIC VOLUME STUDY

- Methods of traffic volume studies:
- Traffic volume counts may be carried out either manually or by using mechanical or automatic counters.
- **Manual Counts:**
- This method record the traffic volume on the prescribed record sheets.
- This method is possible to obtain data i.e. vehicle count, vehicle classification, loading condition, turning movements etc. But this is not possible to count the traffic volume throughout the day.
- However and it is not possible to count the traffic volume throughout the year.

TRAFFIC VOLUME STUDY

- **Mechanical counters:**

- These are may be fixed type or portable type
- The mechanical counter can automatically record the total number of vehicles crossing a section of the road in a desire or specific period.
- Traffic count is recorded by electrically operated counters and records of recording the impulses.
- Other mechanical detectors are photo electric cells, magnetic detector and radar detectors.
- The main advantage of mechanical counter, that can work throughout the day i.e. day and night.

TRAFFIC VOLUME STUDY

- **PRESENTATION OF TRAFFIC VOLUME DATA :**

- The data collected during the traffic volume studies i.e. presented in any of the following forms depending upon the requirements:

a. Annual average daily traffic (AADT or ADT) of the total traffic as well as classified traffic is calculated.
   - This data is helpful for relative importance of route and road development program.
b. Trend chart showing volume trends over period of years are prepared.
   - This data is helpful for future expansion, design and regulations.
c. Variation charts showing hourly, daily, and seasonal variations are also prepared.
   - These are helpful for providing facilities on peak or off peak hours.
d. Traffic flow maps along the routes are drawn
   - These helpful for finding traffic volume distribution

TRAFFIC VOLUME STUDY

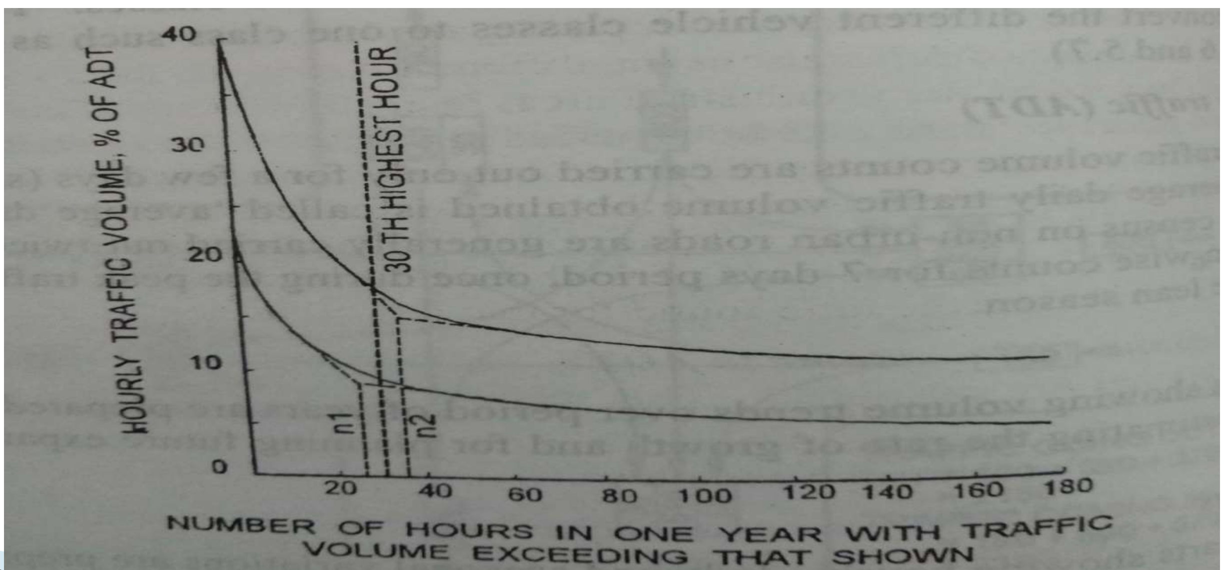
e. Volume flow diagrams at intersections drawn to a certain scale,

- These data helpful for intersection design.

f. Thirtieth highest hourly volume or the design hourly volume:

- Is found from the plot between hourly volume and the number of hours in an year as shown in fig

- The 30th highest hourly volume is the hourly volume that will be exceeded only 29 times in a year and all other hourly volumes of the year will be less than this value.



SPEED STUDIES

Speed Studies:

- The actual speed of the vehicle over a particular route may fluctuate widely depends on several factors such as - Geometric features, traffic conditions, time, place, environment and driver.
- ***Travel time*** is depends upon the speed of the vehicle, if the speed is high travel time can be reduce and also the travel time depends upon the road network operation.
- ***Spot speed*** is the instantaneous speed of a vehicle at a specific section or location.
- ***Average speed*** is the average speed of the spot speeds of all vehicles passing over a specified section or location.

SPEED STUDIES

- There are two definition for average spot speed i.e.

1. Space mean speed
2. Time mean speed

- **Space mean speed** represents the average speed of vehicles in certain road length at any specific time.
- **Time mean speed** represents the speed distribution of vehicles at a point on the roadway and it is the average of instantaneous speeds of observed vehicles at the spot.
- Space mean speed is calculated from

$$V_s = \frac{3.6 d n}{\sum_{i=1}^{n} t_i}$$

- Where Vs= space mean speed, Km/hr

    d= Length of road, considered in meters

    n= number of individual vehicle observation

    t_i= observed travel time sec for the vehicle travel distance, d meters.

SPEED STUDIES

- Time mean speed is calculated from

$$V_t = \frac{\sum_{i=1}^{n} V_i}{n}$$

- V_t = Time mean speed ,Kmph

  V_i = Observed instantaneous speed of i^{th} vehicles, Kmph

  n= number vehicles observed

SPEED STUDIES

- **Mainly speed studies are two types:**

a. Spot speed study   b. Speed and delay study

a. Spot speed study:

- Spot speed is the instantaneous speed of a vehicle at a specified section or location.
- Spot speed study may useful in any following aspects of traffic engineering:

  1.Planning traffic regulations and control measures such as speed limit etc.

  2. Design or redesign of various geometric elements of the road.

  3.To decide the design speed of existing or new facilities.

  4. In accident studies and preventive measures.

  5. Study of traffic capacity.

  6. To find the speed trends with respect to last several years.

  7. To compare the behaviour of various types of drivers and vehicles under specified set of conditions.

SPEED STUDIES

- **Data collection or methods of measuring Spot speeds:**

- The methods are available for measuring of spot speed can be grouped as under

  1. Direct timing procedure
  2. Enoscope
  3. Pressure contact tubes.
  4. Radar speed meters
  5. Photographic method & video camera method

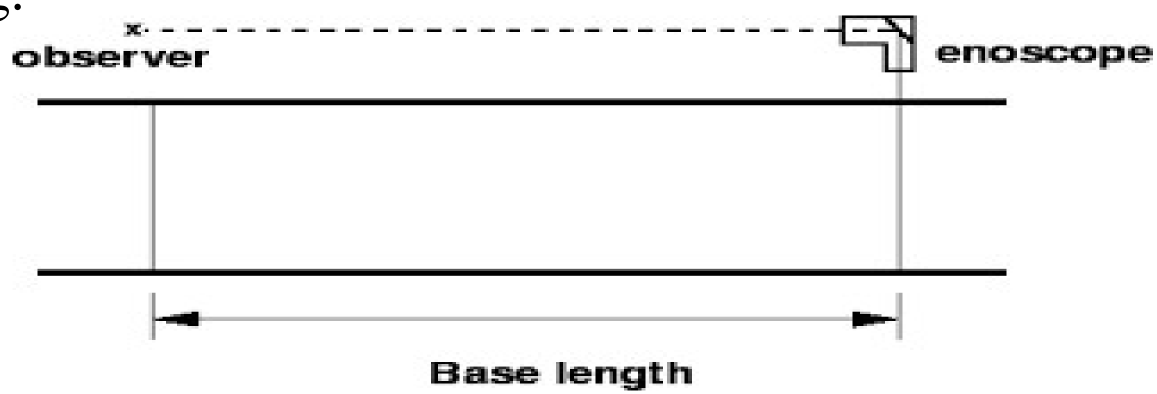
SPEED STUDIES

- **1. Direct timing procedure:**
- This is simplest method for determining spot speed.
- Take known reference points and marked on the pavement with known distance
- From that known distance, measure the time using stop watch, When the vehicle reaches or cross the second point from starting point.
- Spot speed=Known distance/Observed time in KMPH

SPEED STUDIES

2. Enoscope:

- A simple device is called enoscope, using this we can eliminate the parallax errors. This device is also known as the mirror box, is an L shaped box, open at both ends, with a mirror set at a 45° as shown in fig.



- Using this directly taking reading with one observer.
- The stop watch is started as soon as the vehicle passes the first reference point and is stopped as son as it crosses the second reference point.
- We know the distance and time and then calculate the spot speed.

SPEED STUDIES

- **3. Pressure contact Tubes:**
- In this method usually pneumatic tubes are used to indicate the time of entering and leaving for that base length.
- When the vehicle passes over the first reference point an air impulse is sent, which activates the electromagnetic controlled stopwatch and passes the second reference point stopwatch can stop.

- Based on the above method take the time and then calculate the spot speed with known distance.

SPEED STUDIES

- **4. Radar speed meters:**

- This meters work on Doppler principle that when a signal is transmitted onto a moving vehicle, the change in frequency between the transmitted signal and the reflected signal is proportional to the speed of the moving vehicle.
- The difference between the frequency of the transmitted signal and that of the reflected signal is measured by the equipment, then converted to speed in mph or kmph.
- By this instrument directly measure the speed and an accuracy of at least ± 1.5 to 3 kmph is possible
- The instrument is battery operated and portable.
- The speeds of vehicles in both directions can be observed by this method.

Radar speed meters:

SPEED STUDIES

- **5.Photographic method & video camera method:**
- Time lapse camera photography has been used successfully to determine the speeds of vehicles accurately in crowded street.
- According to this method, photographic are taken as fixed intervals of time on a special camera.
- By projecting the film on camera, the passage of any vehicle can be traced with reference to the time.
- Images by video cameras can also be used.

SPEED STUDIES

- **PRESENTATION OF SPOT SPEED DATA** The data collected during the spot speed studies i.e. presented in any of the following forms depending upon the requirements:
- 1. Average speed of vehicles
- 2.Cumulative speed of vehicles
- 3.Model average.
- **1.Average speed of vehicles:**
- From the speed data of the selected samples, frequency distribution tables are for arranging the data with various speed ranges and the number of vehicles in such range.
- Example:

Speed range in KMPH	No of vehicles observed
0 to 10	12
10 to 20	18
50 to 60	285
90 to 100	9

SPEED STUDIES

$$\text{average speed} = \bar{S} = \frac{\sum_{i=1}^{n} n_i S_i}{N}$$

Where

S_i = observed speed of i^{th} vehicle

n_i = number of observations for speed group 'i'

N = the no of observations recorded.

$$\therefore S = \frac{5\times12 + 15\times18 + 55\times285 + 95\times9}{324}$$

$\therefore S = 52$ kmph.

SPEED STUDIES

- **2.Cumulative speed of vehicles:**
- A graph is plotted between the average values of each speed (on X- axis) and the cumulative percent of vehicles or below the design speed (on Y- axis).

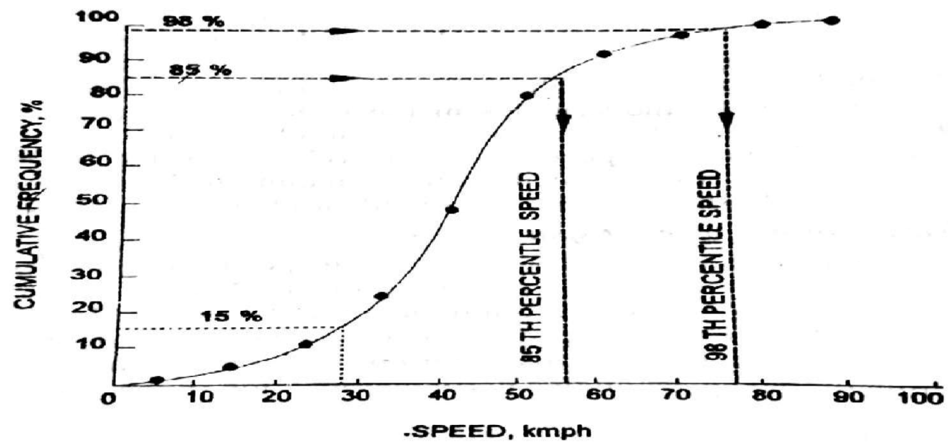


Fig. 5.5 Cumulative frequency distribution diagram of spot speeds

- From this graph, 85th percentile speed is the speed below which 85 percent of all the vehicles travel on the highway or only 15 percent of the vehicles exceed the speed at that spot as shown in above fig.
- The drivers exceeding 85th percentile speed, the drivers drive the vehicle faster than the safe speed under existing conditions. Hence this speed is adopted for the safe speed limit at this zone
- However for the purpose of highway geometry design , the 98th percentile speed is taken.

SPEED STUDIES

- **3.Model average:**
- A frequency distribution curve of spot speeds is plotted between speed of vehicles (X-axis) and the percentage of vehicles observed (Y-axis) as shown in fig.
- This graph is called speed distribution curve.
- This curve will have a definite peak value of travel speed across the section and this speed is denoted as Model speed or average speed.
- The speed distribution curve is helpful for determining the speed at which the maximum possible vehicles move on that spot or section.

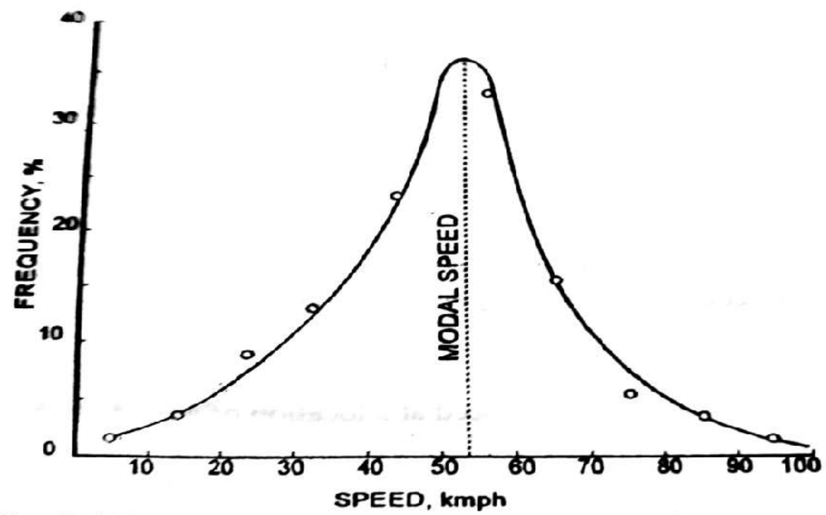


Fig. 5.4 Frequency distribution diagram of spot speeds

SPEED STUDIES

- **Speed and delay studies:**
- The speed and delay studies give the running speeds, overall speeds, fluctuations in speeds and the delay between two stations of a road.
- They also give the information such as condition of location, traffic facilities on that road, duration frequency and causes of delay in that traffic stream.
- The studies are also useful for finding the travel time and in benefit cost analysis.
- The traffic delays are two types

1. Fixed delays 2. Operational delays

- Fixed delays occurs primarily at intersections due to traffic signals and at crossings.
- Operational delays occurred due to interference of traffic movements, such as turning vehicles, parking, imparking vehicles, pedestrian etc.
- There are various methods of carrying out speed and delay studies namely.

  a. Floating car or riding check method

  b. License plate or vehicle number method.

  c. Interview technique

  d. Elevated observations

  f. Photographic techniques.

SPEED STUDIES

a. Floating car or riding check method:

- On the floating car method a test vehicle travel over a given direction with average speed of the stream, thus trying to float with the traffic stream.
- The first observer is seated in the floating car with two stop watches. One of the stop watch is used to record the time at various control points like intersections and bridges. The other stop watch is used to find the duration of individual delays.
- The second observer record the time, location and causes of delays in suitable table form.
- The number of vehicles overtaking the test vehicle and over taken by the test vehicle are noted by the third observer.
- The fourth observer noted, the number of vehicles travelling the opposite direction.
- However in mixed traffic flow, more number of observers are required for different class of vehicles.

SPEED STUDIES

b. License plate or vehicle number method:

- Stop watches or voice recording equipments are used.
- Observers are stationed at the entrance and exit of test section (Where information of travel time is required).
- The timings and vehicle numbers are noted by the observers of the selected samples and travel time of each vehicle could be found.
- But this method does not give important details such as causes of delays and the duration and the number of delays with in the test section.

c. Interview technique:

- The work can be completed in a short time by interviewing and collecting details from the road users on the spot.
- However the data collected may not provide with all the details correctly.

d. **Elevated observations and Photographic techniques:**

- Elevated observations and Photographic techniques are useful for studying short test sections like intersections etc.
- Such studies at each intersection will help in evaluating the efficiency and effectiveness of control device like signal system, the remedial measures for accident etc.

Origin and Destination studies

The origin and destination (O&D) study is carried out mainly to

(i) plan the road net work and other facilities for vehicular traffic

(ii) plan the schedule of different modes of transportation for the trip demand of commuters.

- These studies are most essential in planning new highway facilities and in improving some of the existing systems.
- These studies provide basic data for determining the desired directions of flow or the desired lines
- O&D study data is considered to solve many traffic problems in a zone and mostly important to plan the highway system in a region.

SPEED STUDIES

- The various applications of origin and destination studies may be summed up as follows:

1. To judge the adequacy of existing routes and to use in planning new net work of roads.
2. To plan transportation system and mass transit facilities in cities including routes and schedule of operation.
3. To locate expressway or major routes along the desired lines.
4. To establish preferential routes for various categories of vehicles including by pass.
5. To locate terminals and plan terminal facilities.
6. To locate new bridge as per traffic demand.
7. To locate intermediate stops of public transport.
8. To establish design standards for the road, bridges and culverts along the route.

SPEED STUDIES

The methods for collecting the O & D data are:

Some of the methods commonly adopted are:

(i) Road side interview method

(ii) License plate or vehicle number method

(iii) Return post card method

(iv) Tag on car method

(v) Home interview method

(VI) Work spot interview method

SPEED STUDIES

i. Road side interview method:

- The vehicles are stopped at previously decided interview stations, by a group of persons and answers to prescribed questionnaire are collected on the spot.
- The information collected include the place and time of origin and destination, route, location of stoppages , the purpose of trip, type of vehicle and number of passengers in each vehicle.
- In this method data is collected quickly in short duration and field organization is simple and team can be trained quickly.
- The main draw back of this method is that the vehicles are stopped for interview, and there is delay to the vehicular movement.

ii. License plate or vehicle number method:

- The entire area under study is cordoned out and the observers are stationed at all points of entry and exit on all routes of surrounding selected area.
- Each party at observation station in a given time, they note the license plate numbers of the vehicles entering and leaving the cordoned area and time.
- After collecting the field data major work remains that is done in the office, that is analysis, tracking each vehicle number and its time of entering leaving the cordoned area.
- This method is quite easy and quick as far as the field work is concerned. The field organization can also be trained quickly.
- This method however involves a lot of office computations in tracing the trips through a net of stations.

SPEED STUDIES

iii. Return post card method:

- Pre- paid business reply post cards with return address are distributed to the road users at some selected points along the route or the cards are mailed to the owners of vehicles.
- The questionnaire to be filled in by the road user is printed on the card, along with a request for co-operation and purpose of the study.
- The distributing stations for the cards may be selected where vehicles have to stop as incase of a toll booth.
- The method is suitable where the traffic is heavy.
- Only part of the road users may return the cards promptly after filling in the required details properly and correctly.

iv. Tag on car method:

- In this method a pre coded card is stuck on the vehicles as it enters the area under study.
- When the car leaves the cordon area the other observations are recorded on the tag.
- This method is useful where the traffic is heavy and moves continuously.
- But only this method gives the information about entry and exit time of cordoned area.

SPEED STUDIES

v. Home interview method:

- A random sample of 0.5 to 10 percent of the population it selected and the residences are visited by the trained persons who collect the travel data from each member of the house hold.
- Collect the detailed information made by the members is obtained on the spot.
- The data collected may be useful either for planning the road net work and other roadway facilities for the vehicular traffic or for planning the mass transportation requirements of the passengers.
- The present travel needs are clearly known and the analysis is also simple.
- But to complete coverage of the entire cross section of the population is very tedious.

vi. Work spot interview method:

- The transportation needs of work trips can be planned by collecting the O&D data at work spot like officers, factories, educational institutions, etc. by personal interviews.

PARKING STUDIES

Parking studies:

- The demand by vehicle users of parking space is one of the major problem of highway transportation, especially in metropolitan cities.
- In industrial, commercial and residential places with multi storied buildings, parking demand is particularly high.
- Various aspects to be investigated during parking studies are:
- Parking demand
- Parking characteristics
- Parking space inventory

Parking demand:

- The parking demand may be evaluated by different methods.
- One of the method is by making cordon counts of the selected area and recording accumulation of vehicles during the peak hours and subtracting the outgoing traffic from the traffic volume entering the cordoned area.

PARKING STUDIES

- **Parking demand Continue…**
- One of the other method is by counting the number of vehicles parked in the area under study during different periods of the day.

  - This method is very useful where parking demand is less than the space available for parking. By noting the registration number of each parked vehicle at any desired time interval(such as 30 minutes, one hour etc.). It is possible to estimate the duration of parking of each vehicle at the parking area.
- Another useful method of field study is by interviewing the drivers of parked vehicles, shop owners and other vehicle owners in the locality.

  - This method is very useful when the parking demand in the study area is higher than the parking space is available.

PARKING STUDIES

- **Parking characteristics:**
- This study is useful to find out the characteristics of the parking practices of the area.
- In case of kerb parking, it is also necessary to study the parking pattern, interference to smooth flow of traffic and the accidents involved during parking and un parking operations.
- Psychological and parking characteristics play important roles in parking choice.
- In the last three decades, ample studies have been done to evaluate parking characteristics, to estimate the demand for parking and on driver's behavior while choosing the parking space.

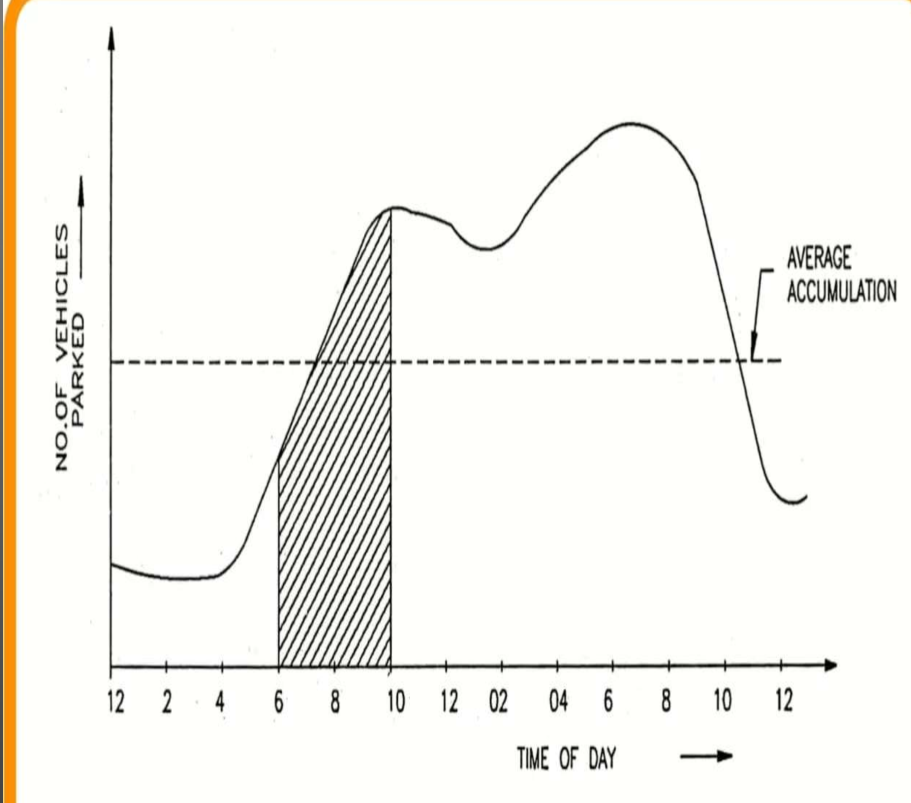
PARKING STUDIES

- **Parking space inventory:**
- The area under study is fully surveyed and map is prepared and showing all places. where kerb parking and off street parking facilities can be provided to meet the parking demand.
- The traffic engineer is balance between capacity and parking demand and to design for proper facilities for parking.

PARKING STUDIES

Parking Characteristics :

- **1. Parking accumulation:** is the number of vehicles parked at any given instantaneous time. Normally it is conveyed through accumulation curve. Accumulation curve is the graph obtained by plotting the number of vehicles parked with respect to time.
- **2. Peak parking saturation:** It is the ratio of the number of vehicles parked at peak time to the capacity of parking space in terms of number of bays.
- **3. Parking load:** Parking load is the total area under the accumulation curve during the specified period. For example as shown in fig. hatched area represents the parking load in vehicle-hour for a period of 4 hours from 6AM to 10AM.



Parking Accumulation Diagram

PARKING STUDIES

- **4. Parking volume:** The number of vehicles parking in a particular area over a given period of time. It is usually measured in vehicles per day.
- **5. Parking Index:** Percentage of Parking bays actually occupied by parked vehicles as compared to the theoretical number of bays available.
- Parking Index = (Number of bays occupied / Theoretical number available)×100
- **6. Parking turnover:** It is the ratio of number of vehicles parked in a duration to the number of Parking bays available.

  Parking turnover = Parking volume/No: of bays available
- This can be expressed as number of vehicles per bay per time duration.
- **7. Average parking duration:** It is the ratio obtained by dividing the parking load (vehicle-hours) by the total parking volume throughout the survey period.

  Parking duration = parking load/parking volume

PARKING STUDIES

- **Parking surveys:**
- Parking surveys are conducted to collect the above said parking statistics or Characteristics . The most common parking surveys conducted are in-out survey, fixed period sampling and license plate method of survey.
- **1. In-out survey:** In this survey, the occupancy count in the selected parking lot is taken at the beginning.
- Then the number of vehicles that enter the parking lot for a particular time interval is counted. The number of vehicles that leave the parking lot is also taken. The final occupancy in the parking lot is also taken. But we wont get any data regarding the time duration for which a particular vehicle used that parking lot. Parking duration and turn over is not obtained. Hence we cannot estimate the parking fare from this survey.
- **2. Fixed period sampling:** This is almost similar to in-out survey. All vehicles are counted at the beginning of the survey. Then after a fixed time interval that may vary between 15 minutes to 1 hour, the count is again taken. Here there are chances of missing the number of vehicles that were parked for a short duration.

PARKING STUDIES

- **License plate method of survey:** This results are most accurate and realistic data. In this case of survey, every parking stall is monitored at a continuous interval of 15 minutes or so and the license plate number is noted down.
- This will give the data regarding the duration for which a particular vehicle was using the parking bay.
- This will help in calculating the fare because fare is estimated based on the duration for which the vehicle was parked. If the time interval is shorter, then there are less chances of missing short-term parkers.
- But this method is very labor intensive compare to above two methods.

PARKING STUDIES

- **Types of Parking:**
- Mainly Two types, they are On-street Parking and Off -Street Parking
- **On street parking**
- On street parking means the vehicles are parked on the sides of the street itself. This will be usually controlled by government agencies itself. Common types of on-street parking are as listed below. This classification is based on the angle in which the vehicles are parked with respect to the road alignment. As per IRC the standard dimensions of a car is taken as 5× 2.5 meters and that for a truck is 3.75× 7.5 meters.
- Common methods of on-street Parking: They are

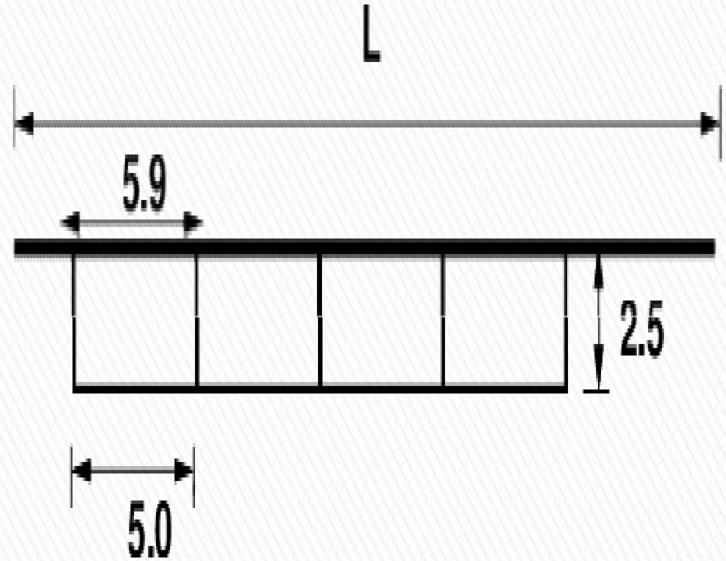
1. Parallel Parking
2. 30º angle Parking
3. 45º angle Parking
4. 60º angle Parking
5. Right Angle Parking

PARKING STUDIES

1. Parallel parking:

- The vehicles are parked along the length of the road. Here there is no backward movement involved while parking or un-parking the vehicle. Hence, it is the most safest parking from the accident perspective.
- However, it consumes the maximum curb length and therefore only a minimum number of vehicles can be parked for a given kerb length.
- This method of parking produces least obstruction to the on-going traffic on the road since least road width is used. Parallel parking of cars is shown in figure
- The length available to park N number of vehicles, L = N/5.9

Parallel parking:



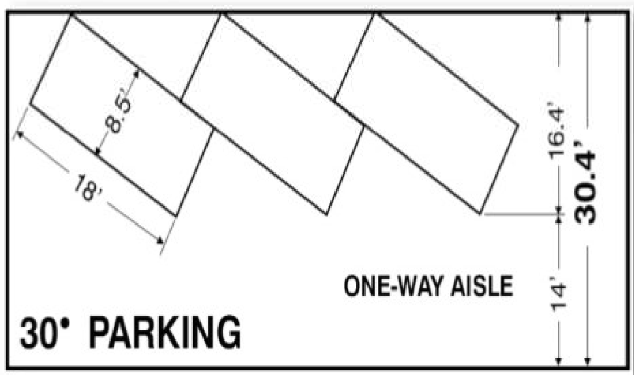
PARKING STUDIES

2. 30º angle Parking

- In thirty degree parking, the vehicles are parked at 30° with respect to the road alignment.
- In this case, more vehicles can be parked compared to parallel parking. Also there is better maneuverability.
- Delay caused to the traffic is also minimum in this type of parking. An example is shown in figure

30º angle Parking

30 degree parking

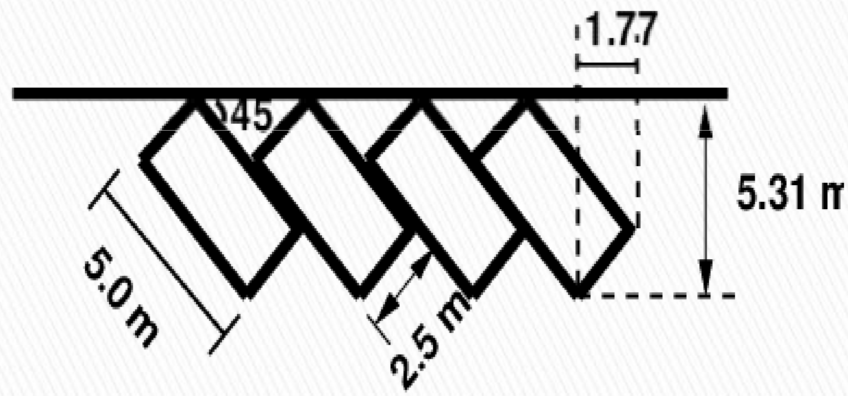


PARKING STUDIES

3. 45º angle Parking

- As the angle of parking increases, more number of vehicles can be parked.
- Hence compared to parallel parking and thirty degree parking, more number of vehicles can be accommodated in this type of parking.
- From figure, length of parking space available for parking, *N* number of vehicles in a given kerb is *L* = 3.54 N+1.77

45º angle Parking



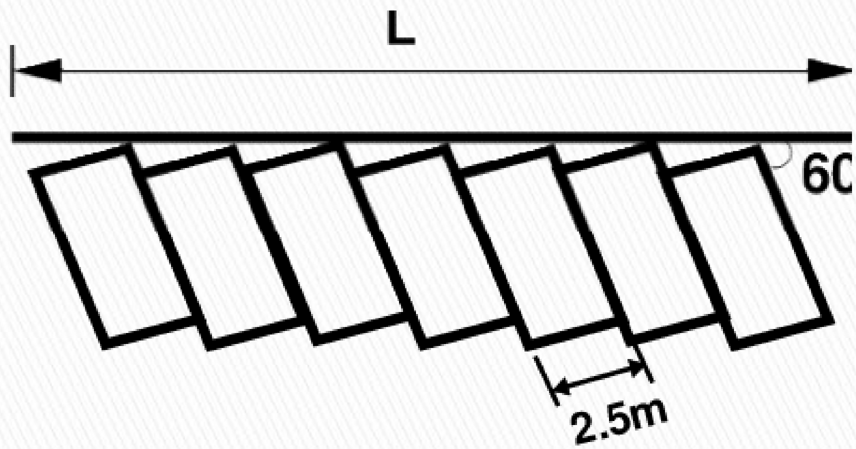
PARKING STUDIES

4. 60° Angle parking

The vehicles are parked at 60° to the direction of road. More number of vehicles can be accommodated in this parking type.

- From the figure , length available for parking for *N* vehicles =2.89N+2.16.

60° Angle parking

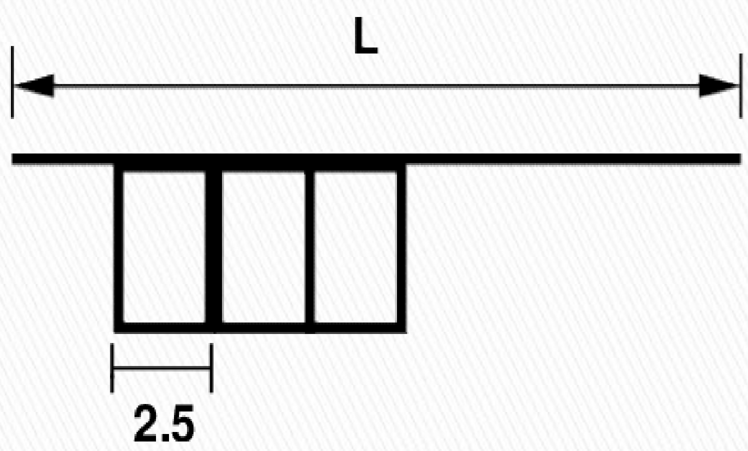


PARKING STUDIES

5. Right angle parking

- In right angle parking or 90° parking, the vehicles are parked perpendicular to the direction of the road.
- Although it consumes maximum width kerb length required is very little. In this type of parking, the vehicles need complex maneuvering and this may cause severe accidents.
- This arrangement causes obstruction to the road traffic particularly if the road width is less. However, it can accommodate maximum number of vehicles for a given kerb length. An example is shown in figure.
- Length available for parking for N number of vehicles is L = 2.5N.

Right angle parking

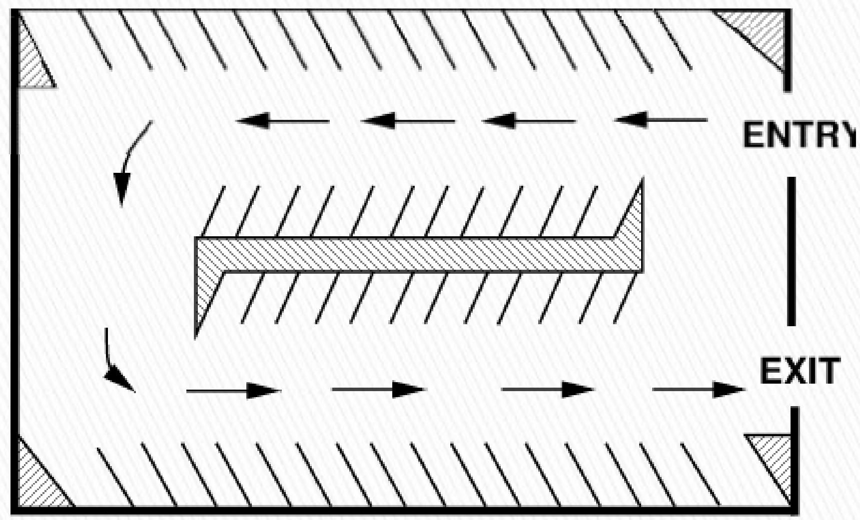


PARKING STUDIES

Off street parking

- In many urban centers, some areas are exclusively allotted for parking which will be at some distance away from the main stream of traffic.
- Such a parking is referred to as off-street parking.
- They may be operated by either public agencies or private firms. A typical layout of an off-street parking is shown in figure

Off street parking



ACCIDENT STUDIES

- **Importance of accident studies:**
- The problem of accident is very acute in road transportation due to

1. Complex flow patterns of vehicular traffic
2. Presence of mixed type of vehicles and
3. The pedestrian on the Roads

- Traffic accidents may involve property damages, personal injuries also deaths.

ACCIDENT STUDIES

- **Causes of Accidents:** There are five basic elements in a traffic accident, namely:

a. Road User
b. Vehicle
c. Road and its condition
d. Traffic
e. Environmental factors such as weather, visibility, etc.

- Road user responsible for the accident may be the driver, Pedestrians or the passengers.
- Vehicles involved in the accident may also be defective.
- The condition of the road surface or other existing geometric features or any of the environmental conditions are involved the accidents.
- The traffic flow and their characteristics could also cause undue strain on the driver.

ACCIDENT STUDIES

- **Various causes of accidents may be listed as given below:**

a) **Drivers:** Excessive speed and rash driving, carelessness, violation of rules and regulations, failure to understanding the traffic situation, sign or signal, sleep or effect of consuming alcohol.

b) **Pedestrians:** Violating regulations, carelessness while using the carriageway.

c) **Passengers:** Alighting from or getting into moving vehicles.

d) **Vehicle defects:** Failure of breaks, steering system, or lighting system, tyre burst and any other defect in the vehicles

e) **Road Condition:** Slippery or skidding road surface, pot holes, ruts and other damaged conditions of the road surface, temporary obstruction to line of sight resulting in reduction in normal sight distance.

f) **Road Design:** Defective Geometric design like inadequate sight distance at horizontal or vertical curves, improper curve design, inadequate width of shoulders, improper lighting and improper traffic control devices.

ACCIDENT STUDIES

g) **Traffic Condition:** Other vehicles of stream, such as a vehicle moving ahead getting involved in accident, presence of disabled vehicle on the roadway.

h) **Weather:** Unfavourable weather condition like fog, snow, dust, smoke or heavy rainfall which restrict normal visibility and render driving unsafe.

i) Animals: Stray Animals on the road.

j) Other Causes: Incorrect signs or signals, gate of level crossing not closed when required, ribbon development, badly located advertisement boards or service station, etc.

ACCIDENT STUDIES

- **Preventive Measures for Accidents:** Road deaths and injuries are preventable. A wide range of effective road safety interventions exist and a scientific system approach to road safety is essential to tackle the problem
- The following preventive measures were taken to reduce the accidents:

Vehicles:

- Well-maintained vehicles with good breaks, lighting, tyres etc. will reduce accidents.
- Older vehicles and highly polluting vehicles should be phased out.
- Vehicles should be provided with seat belts and other necessary safety provisions (like airbags).

Condition of roads:

- Roads should be well maintained with frequent relaying of road surfaces and markings of road safety signs.
- Provide proper footpaths for pedestrians and pedestrian crossings at intersections.
- Provide separate lanes for slow-moving and fast-moving vehicles.
- Roads and junctions should be wide and well lit so that visibility is good.

ACCIDENT STUDIES

- **Human factor:**
- Drivers can significantly contribute to reducing the accidents.
- Issuing of the driving license should be strictly based on the minimum proficiency acquired by the learners from designated driving schools.
- Minimum qualifications should be fixed for different categories of drivers.
- All drivers should be properly trained and should posses a valid driving license.
- Educate the drivers and traveling public about traffic rules.
- Carry out periodic medical checkup especially vision and hearing for the drivers.
- Training on first aid should be compulsory along with heath education and traffic education for the general public to prevent accidents.
- **Legislation:**
- Rules for compulsory wearing of helmets by two wheelers and seat belts by four wheelers must be implemented.
- Enforce traffic rules by the concerned authorities strictly.
- Removal of stray animals like cattle and removal of encroachments on footpath and road margins will enable smooth flow of traffic.
- Preventing haphazard parking of vehicles on busy roads and intersections to ensure free flow of traffic.

ACCIDENT DATA RECORDING

- **Accident Studies and Records:**
- The various steps involved in traffic accident studies are,

i. Collection of accident data
ii. Preparation of accident reports
iii. Preparation of Accident Records

ACCIDENT DATA RECORDING

- **i. Collection of accident data:**
- Collection of accident data is the first step in the accident study. Standard form for collecting the data has been suggested by the Indian Road Congress vide IRC:53-1982. The details to be collected are briefly mentioned under:

a. **General:** Date, time, persons involved in the accident and their particulars, classification of accident like fatal, serious, minor, property damage only, etc
b. **Location:** Description and details of the location of accident supported by diagrams.
c. **Detailed of vehicles involved:** Registration number, make and description of the vehicles, loading details, vehicular defects.
d. **Nature of accident:** Condition of vehicles involved, details of collision, and pedestrians or objects involved, damages, injuries, casualty, etc

ACCIDENT DATA RECORDING

e. Road Condition: Details of road geometrics, whether the road stretch is straight or curved, surface characteristic such as dry, wet or slippery, etc

f. Traffic Condition: Type of vehicles in the traffic flow, traffic volume and density, etc

g. Primary causes of accident: Various possible causes and the primary cause of the accident.

h. Other probable causes/secondary and contributing causes of the accident

i. Accident Cost: The total cost of the accident, such as property damages, personal injuries and causalities, computed in terms of Rupees.

ACCIDENT DATA RECORDING

- **ii. Preparation of Accident Report:**
- The accident should be reported to police authorities who would further collect required details and take legal action especially in more serious accidents involving injuries, causalities or severe damage to property.
- Accident report of the individuals involved may be separately taken.
- The accident data should be collected as given above and the accident report is prepared with all facts which might be useful in subsequent analysis, claims for compensation, evaluation of accident cost, etc.

ACCIDENT DATA RECORDING

- **iii. Preparation Accident Records:**
- Accidents records are maintaining giving all particulars of the accidents, location and other details.
- The records may be maintained by means of location files, spot maps, collision diagrams and condition diagrams as given below:
- **Location files:** These are useful to keep a record of the locations where accidents have taken place within the concerned zone.
- Location files should be maintained by each police station for the respective jurisdiction.
- **Spot maps:** Accident location spot maps shows accidents by spots, pins or symbols on the road map of the locality.
- A map of suitable scale, say 1mm = 4 to 6 m, may be used for the preparation of spot maps of urban accidents.

ACCIDENT DATA RECORDING

Collision Diagram:

- These diagrams shows the details of the accident location and show the approximate path of the vehicles and pedestrians involved in the accident and also other objects with which the vehicles have collided.
- Collision diagrams are most useful to compare the accident pattern before and after the remedial measures have been taken. A typical collision diagram and symbol used are shown in fig.

Collision Diagram:

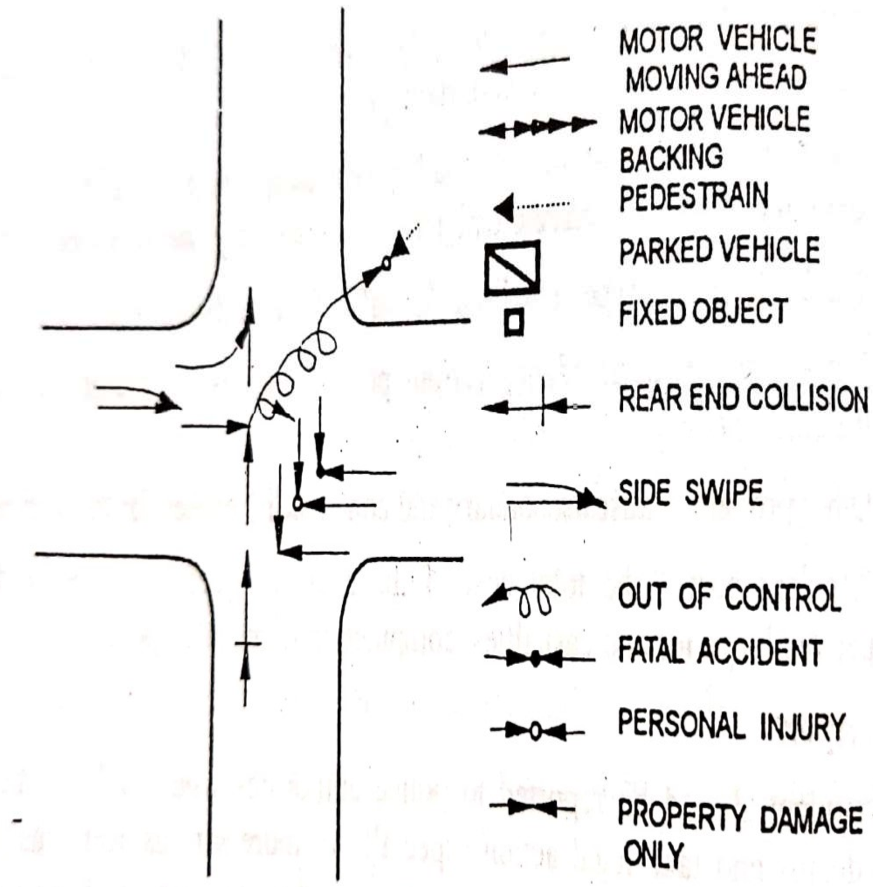


Fig. 5.8 Collision diagram and symbols

ACCIDENT DATA RECORDING

- **Condition Diagram:**
- A condition diagram is a drawing of the accident location drawn to scale, showing all the important physical features of the road and adjoining area.
- The important features generally to be shown in the condition diagram with their dimensions marked there in are: *the width of the road way, shoulders, median if any other geometric details such as curves, kerb lines, bridges, culverts, electric posts, trees and all details of roadway condition, 0bstruction to vision, property lines, signs, signals etc.*
- The condition and collision diagrams may be combined together in a single sketch, if necessary.

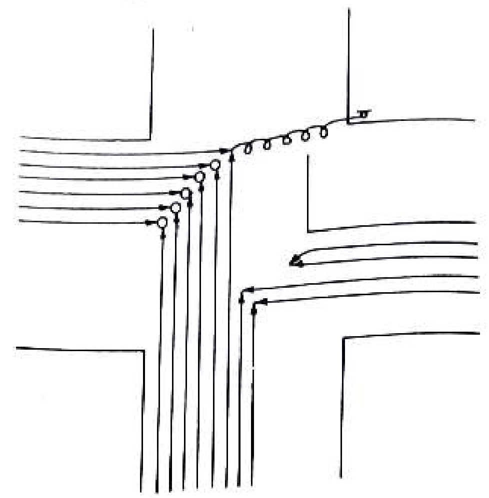


Fig. 18.3. Typical collision diagram at a junction.

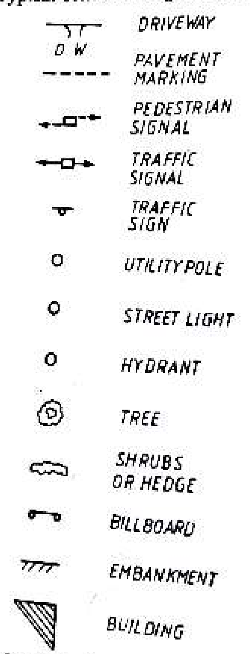


Fig. 18.4. Symbols for condition diagrams.

ROAD SAFETY AUDIT

- Traffic, Infrastructural and safety audits or Road safety Audit:
- Road safety audit is a systematic procedure for the assessment of accident potential and safety performance in the road improvement or rehabilitation or up-gradation of works, both before and after the implementation of the project.
- The major purpose of a road safety audit is to provide Safer Journeys and the Safe System approach, which means minimizing death and serious injury.
- The key objective of a road safety audit is summarized as:

i. To Minimise the risk of accidents occurring on the road improvement scheme.

ii. To Minimize the severity of accidents.

ACCIDENT DATA RECORDING

iii. To minimize collision rates, and severity rates, and to reduce the risk of collisions on the road network

iv. To enhance the importance of safety in highway design

v. To reduce the whole-life costs of a scheme by preventing future accidents

vi. The identification of hazardous features of an existing road so that they can be eliminated or otherwise treated before they become accident prone locations.

vii. To ensure that all road users' safety needs are taken into account during the planning, design, building, and operation of road projects.

viii. To reduce the overall community's life expenditures of a road project.

ix. Eliminating bottlenecks due to inadequate road geometry

x. To improve road users behavior and acceptance of traffic rules and enforcement initiatives.

ROAD SAFETY AUDIT

- BENEFITS OF ROAD SAFETY AUDITS :
- **Road safety audits will:**
- It will help to achieve the objectives of a safe system by providing a safer road network with self explaining roads ·
- Minimize the risk of high-severity crashes that may result from design deficiencies in a proposed road project ·
- Minimize the need for rework and physical remedial works caused by road safety deficiencies at the various stages of project development, including construction ·
- Reduce the whole-of-life costs of the project ·
- Improve the awareness of, and contribute to, improvements in safe design practices.
- The cost of a road safety audit and the consequent cost of changing a design are significantly less than the cost of remedial treatments after works have been constructed, or the social cost of road crashes.
- It is easier to change design plans than to move or alter construction works

ROAD SAFETY AUDIT

- **Stages of Road Safety audit:**
- **The stages of road safety audit for new road construction project are listed below:**

1. During Feasibility study
2. During preliminary study(Draft Stage)
3. On completion of Detailed design
4. During construction stage
5. On completion of construction(before opening to traffic)
6. Monitoring of existing roads.

ROAD SAFETY AUDIT

1. **Feasibility (Planning) Stage** - Before granting planning permission, all team members should go to the site and inspect the existing highway layout and characteristics, as well as how the new highway development scheme connects to the current highway. Based on the existing features and requirements, the main design concepts can be modified.
2. **Draft (Preliminary design)Stage** - In this stage horizontal and vertical alignment, junction layout are determined. After the completion of this stage decision about land acquisition is taken.
3. **Detailed design stage** - In this stage the Audit Team will be able to assess concerns such as junction layout, sign placement, road markings, lighting provision, and other difficulties.
4. **During Construction:** Audit are carried out to ensure that the traffic management and construction works carried out according to specifications.
5. **Pre-opening stage or before opening to traffic** - Before opening a new or modified road should be driven, walked or cycled. It should be done at different condition like bad weather, darkness.
6. **Monitoring of the road in use** - Assessment is done at the final stage after the road has been in operation for few months to determine whether the utilization is obtained as intended and whether any adjustment to the design are required in the light of the actual behavior of road users.

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