

ATME College of Engineering

13th K M Stone, Bannur Road, Mysore – 570028



DEPARTMENT OF CIVIL ENGINEERING

(ACADEMIC YEAR 2025 - 26)

SUBJECT NAME: TRANSPORTATION ENGINEERING

SUBJECT CODE: BCV403

SEMESTER: 4

INSTITUTIONAL MISSION AND VISION

Vision of the Institute

Development of academically excellent, culturally vibrant, socially responsible and globally competent human resources.

Mission of the Institute

- To keep pace with advancements in knowledge and make the students competitive and capable at the global level.
- To create an environment for the students to acquire the right physical, intellectual, emotional and moral foundations and shine as torch bearers of tomorrow's society.
- To strive to attain ever-higher benchmarks of educational excellence

DEPARTMENT VISION AND MISSION

Vision of the Department

To develop globally competent civil engineers who excel in academics, research and are ethically responsible for the development of the society.

Mission of the Department

- To provide quality education through faculty and state of art infrastructure
- To identify the current problems in society pertaining to Civil Engineering disciplines and to address them effectively and efficiently
- To inculcate the habit of research and entrepreneurship in our graduates to address current infrastructure needs of society

Program outcomes (POs)

Engineering Graduates will be able to:

PO1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO2. Problem analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO4. Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO5. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO6. The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO7. Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO9. Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO10. Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO11. Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO12. Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change

Program Specific Outcomes (PSOs)

PSO1: Provide necessary solutions to build infrastructure for all situations through competitive plans, maps and designs with the aid of a thorough Engineering Survey and Quantity Estimation.

PSO 2: Assess the impact of anthropogenic activities leading to environmental imbalance on land, in water & in air and provide necessary viable solutions revamping water resources and transportation for a sustainable development

Program Educational Objectives (PEOs)

PEO 1- Engaged in professional practices, such as construction, environmental, geotechnical, structural, transportation, water resource engineering by using technical, communication and management skills.

PEO 2- Engaged in higher studies and research activities in various civil engineering fields and life time commitment to learn ever changing technologies to satisfy increasing demand of sustainable infrastructural facilities.

PEO 3- Serve in a leadership position in any professional or community organization or local or state engineering board

PEO 4- Registered as professional engineer or developed a strong ability leading to professional licensure being an entrepreneur.

IV Semester

TRANSPORTATION ENGINEERING			
Course Code	BCV403	CIE Marks	50
Teaching Hours/Week(L:T:P:S)	3:0:2:0	SEE Marks	50
Total Hours of Pedagogy	40	Total Marks	100
Credits	03	Exam Hours	03
Course objectives: <ul style="list-style-type: none">• Gain knowledge of different modes of transportation systems and to learn the introductory concepts on Highway Engineering.• Get insight to different highway materials and pavement design elements of a highway network.• Realize the significance of road safety by incorporating the concepts of Traffic Engineering.• Understand to different aspects of geometric elements of railway system and evaluate the material quantity required for track laying• Gain knowledge about various components of an Airport and its runway design.			
Teaching-Learning Process (General Instructions) <p>These are sample Strategies; which teacher can use to accelerate the attainment of the various course outcomes.</p> <ol style="list-style-type: none">1. Apart from conventional lecture methods various types of innovative teaching techniques through videos, animation films may be adopted so that the delivered lesson can progress the students in theoretical, applied and practical skills.2. Arrange field visits to give brief information about the water and wastewater treatment plant.3. Encourage collaborative (Group Learning) Learning in the class.4. Ask at least three HOTS (Higher-order Thinking) questions in the class, which promotes critical thinking and enhance the knowledge of treatment processes.5. Adopt Problem Based Learning (PBL), which fosters students, Analytical skills, develop thinking skills such as the ability to evaluate, generalize, and analyze information rather than simply recall it.6. Seminars, surprise tests and Quizzes may be arranged for students in respective subjects to develop skills			
Module -1			
Transportation Engineering: Introduction, Different Modes of Transportation, M R Jayakar Committee recommendations, Road Classifications and Road Patterns. Highway Alignment: Factors affecting highway alignment, Engineering surveys for alignment conventional and modern methods. Highway Geometric Design: Factors affecting geometric design of roads, Cross Sectional Elements, Sight distances, Horizontal alignment- Transition curve, superelevation, Extra widening, Vertical alignment–gradients, summit and valley curves. (No derivations) Problems on Sight distance, Super elevation, extra widening of curves, Length of transition curve, Length of summit and valley curve.			
Module -2			
Highway Materials and Pavements: Desirable properties of aggregates, soil subgrade & Bitumen, Application of bituminous emulsion, Desirable properties of Bituminous Mixes			

<p>Pavement Design: Factors Controlling design of highway pavements, Pavement types, component parts of pavements and their functions; types of joints used in rigid pavement. Critical stresses in flexible and rigid pavement.</p> <p>Highway Drainage: Significance and requirements, Surface drainage system and design- Examples, sub surface drainage system, Types of cross drainage structures their choice and location.</p> <p>Problems on design of Longitudinal drain.</p>
<p>Module -3</p>
<p>Traffic Engineering: Objectives and scope of Traffic Engineering. Traffic Characteristics: Road user characteristics, vehicular characteristics – static and dynamic characteristics, Reaction time of driver and PIEV theory, Types of traffic engineering studies-volume, spot speed, speed and delay, parking, accident, origin & destination, objectives of studies and data collection, method of study, analysis. PCU concept, factors affecting and PCU at different locations and applications. Traffic signs, Signal design by IRC method; Types of intersections.</p> <p>Problems on Spot speed studies, Speed and delay studies, accident studies, Signal design by IRC method.</p>
<p>Module -4</p>
<p>Railway Engineering: Permanent way and its requirements, Gauges and types, Typical cross sections single and double-line BG track, Coning of wheels and tilting of rails, Rails- Functions requirements, types and defects of rails. Sleepers and Ballast: Functions, requirements, Track fitting and fasteners, Calculation of quantity of materials required for laying a track, Points & crossings, Railway Station and Yards. Metro train & high speed train- Design factors considered.</p> <p>Problem on Quantity calculation for laying railway track. Super-elevation</p>
<p>Module -5</p>
<p>Airport Engineering: Layout of an airport with component parts and functions, Site selection for airport, Aircraft characteristics affecting the design and planning of airport, Airport classification, Runway orientation using wind rose with examples.</p> <p>Runway-Basic runway length-Corrections and examples, Runway geometrics, Taxiway- Factors affecting the layout - geometrics of taxiway-Comparison between Runway and Highway, Design of exit taxiway with examples.</p> <p>Problems on Runway orientation, Basic Runway length, Exit taxiway design</p>
<p>PRACTICAL COMPONENT OF IPCC</p>
<p>Experiments</p>
<p>1. Tests on Aggregates</p> <ol style="list-style-type: none"> a. Aggregate Crushing value b. Los Angeles abrasion test c. Aggregate impact test d. Aggregate shape tests (combined index and angularity number) <p>2. Tests on Bituminous Materials</p> <ol style="list-style-type: none"> a. Penetration test b. Ductility test

- c. Softening point test
- d. Specific gravity test
- e. Viscosity test by tar viscometer
- f. Flash and fire point test

3. Tests on Soil

- a. Wet sieve analysis
- b. CBR test

4. Design of flexible pavement as per IRC 37-2018

5. Design of Rigid pavement as per IRC 58-2015

6. Tests on Bituminous Mixes

- a. Marshall Method (Demo Experiment)

7. Traffic Engineering studies

Course outcomes:

Course outcome (Course Skill Set)

At the end of the course the student will be able to:

1. Explain the basic principles of geometric design in the context of transportation engineering and planning.
2. Select the appropriate pavement materials for construction and design the pavement as per standard practices.
3. Conduct traffic studies and analyse traffic data for practical applications.
4. Identify the Components parts of Railway Track and design the suitable runway for an Airport.
5. Able to interpret the experimental results of highway materials based on laboratory tests and design the pavement as per IRC guidelines.

Assessment Details (both CIE and SEE)

The weightage of Continuous Internal Evaluation (CIE) is 50% and for Semester End Exam (SEE) is 50%. The minimum passing mark for the CIE is 40% of the maximum marks (20 marks). A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to each subject/ course if the student secures not less than 35% (18 Marks out of 50) in the semester-end examination(SEE), and a minimum of 40% (40 marks out of 100) in the sum total of the CIE (Continuous Internal Evaluation) and SEE (Semester End Examination) taken together

CIE for the theory component of the IPCC (maximum marks 50)

- IPCC means practical portion integrated with the theory of the course.
- CIE marks for the theory component are **25 marks** and that for the practical component is **25 marks**.
- 25 marks for the theory component are split into **15 marks** for two Internal Assessment Tests (Two Tests, each of 15 Marks with 01-hour duration, are to be conducted) and **10 marks** for other assessment methods mentioned in 22OB4.2. The first test at the end of 40-50% coverage of the syllabus and the second test after covering 85-90% of the syllabus.
- Scaled-down marks of the sum of two tests and other assessment methods will be CIE

marks for the theory component of IPCC (that is for **25 marks**).

- The student has to secure 40% of 25 marks to qualify in the CIE of the theory component of IPCC.

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CIE for the practical component of the IPCC

- **15 marks** for the conduction of the experiment and preparation of laboratory record, and **10 marks** for the test to be conducted after the completion of all the laboratory sessions.
- On completion of every experiment/program in the laboratory, the students shall be evaluated including viva-voce and marks shall be awarded on the same day.
- The CIE marks awarded in the case of the Practical component shall be based on the continuous evaluation of the laboratory report. Each experiment report can be evaluated for 10 marks. Marks of all experiments' write-ups are added and scaled down to **15 marks**.
- The laboratory test (**duration 02/03 hours**) after completion of all the experiments shall be conducted for 50 marks and scaled down to **10 marks**.
- Scaled-down marks of write-up evaluations and tests added will be CIE marks for the laboratory component of IPCC for **25 marks**.
- The student has to secure 40% of 25 marks to qualify in the CIE of the practical component of the IPCC.

SEE for IPCC

Theory SEE will be conducted by University as per the scheduled timetable, with common question papers for the course (**duration 03 hours**)

1. The question paper will have ten questions. Each question is set for 20 marks.
2. There will be 2 questions from each module. Each of the two questions under a module (with a maximum of 3 sub-questions), **should have a mix of topics** under that module.
3. The students have to answer 5 full questions, selecting one full question from each module.
4. Marks scored by the student shall be proportionally scaled down to 50 Marks

The theory portion of the IPCC shall be for both CIE and SEE, whereas the practical portion will have a CIE component only. Questions mentioned in the SEE paper may include questions from the practical component.

Suggested Learning Resources:

Text Books

1. S K Khanna and C E G Justo, "Highway Engineering", Nem Chand Bros, Roorkee.
2. L R Kadiyali, "Highway Engineering", Khanna Publishers, New Delhi.
3. "A Text Book of Railway Engineering" by S C Saxena and S P Arora
4. "Airport Engineering" by S C Rangwala
5. "Airport Planning and Design" by Khanna Arora and Jain, Nem Chand Bros, Roorke.
6. "Roads, Railways, Bridges, Tunnels and Harbour Dock Engineering by B L Gupta, Amit Gupta.
7. S K Khanna, C E G Justo and A Veeraragavan, "Highway Materials Testing Laboratory

Manual”, Nem Chand Bros, Roorkee.

Web links and Video Lectures (e-Resources):

1. <https://nptel.ac.in/courses/105101087>
2. https://onlinemanuals.txdot.gov/txdotmanuals/rdw/horizontal_alignment.htm#BGBHGEGC
3. www.civil.iitb.ac.in/tvm/1111_nptel/567_Grade/plain/plain.html
4. <https://www.pavementinteractive.org/>
5. <https://www.eng.auburn.edu/research/centers/ncat/research/other-publications.html>
6. <https://nptel.ac.in/courses/105/106/105106203/>
7. <https://nptel.ac.in/courses/105/101/105101008>
8. <https://nptel.ac.in/courses/105/104/105104098>
9. <https://www.classcentral.com/course/edx-intro-to-traffic-flow-modeling-andintelligenttransport-systems-12728>
10. <https://www.aai.aero/>
11. <https://www.faa.gov/>
12. <https://www.icao.int>

Activity Based Learning (Suggested Activities in Class)/ Practical Based learning

- Visit to a road construction project

Module – 1

Transportation Engineering

Structure

- 1.0 Introduction
- 1.1 Objectives
- 1.2 Different modes of transportation
- 1.3 M R Jayakar Committee Recommendations
- 1.4 Road Classifications and Road Patterns
- 1.5 Highway Alignment
- 1.6 Factors affecting geometric design of roads
- 1.7 Highway cross section elements
- 1.8 Sight distances
- 1.9 Horizontal alignment:
- 1.10 Vertical alignment:
- 1.11 Recommended questions
- 1.12 Outcomes
- 1.13 Further Reading

1.0 Introduction

Mobility is a basic human need. From the times immemorial, everyone travels either for food or leisure. A closely associated need is the transport of raw materials to a manufacturing unit or finished goods for consumption. Transportation fulfils these basic needs of humanity. Transportation plays a major role in the development of the human civilization. In other words, the solution to transportation problems must be analytically based, economically sound, socially credible, environmentally sensitive, practically acceptable and sustainable. Alternatively, the transportation solution should be safe, rapid, comfortable, convenient, economical, and eco-friendly for both men and material.

1.1 Objectives

Gain knowledge of different modes of transportation systems and to learn the introductory concepts on Highway Engineering.

1.2 Different modes of transportation and comparison

Three basic modes of transport are by land, water and air. Land has given development of road and rail transport. Water and air have developed waterways and airways respectively. Apart from these major modes of transportation, other modes include pipelines, elevators, belt conveyors, cable cars, aerial ropeways and monorails. Pipe lines are used for the transportation of water, other fluids and even solid particles.

Airways:

1. The transportation by air is the fastest among the four modes.
2. Air also provides more comfort apart from saving in transportation time for the passengers and the goods between the airports.

Waterways:

1. Transportation by water is the slowest among the four modes.
2. This mode needs minimum energy to haul load through unit distance
3. The transportation by water is possible between the ports on the sea routes or along the rivers or canals where inland transportation facilities are available.

Railways:

1. The transportation along the railway track could be advantageous by railways between the stations both for the passengers and goods, particularly for longer distances.
2. The energy requirement to haul unit load through unit distance by the railway is only a fraction (one fourth to one sixth) of the required by road.
3. Hence, full advantage of this mode of transportation should be taken for the transportation of bulk goods along land where the railway facilities are available.

Roadways:

1. The transportation by road is the only mode which could give maximum service to one and all.
2. The road or highways not only include the modern highway system but also the city streets, feeder roads and village roads, catering for a wide-range of road vehicles and the pedestrians.
3. This mode has also maximum flexibility for travel with reference to route, direction, time and speed of travel etc. through any mode of road vehicle.
4. It is possible to provide door to door service by road transport.
5. The other three modes (railways; water ways; airways) have to depend on the roadway for the service.
6. Ultimately, road network is therefore needed not only to serve as feeder system for other modes of transportation and to supplement them, but also to provide independent facility for road travel by a well-planned network of roads throughout the country.
7. Perishable commodities like vegetables, fruits and milk are transported more easily and quickly by roads than by railways.
8. It is comparatively easy and cheap to construct and maintain roads.

Pipelines

Primarily, pipeline is used for the transport of crude petroleum, refined petroleum and natural gas. Pipelines are also used for the transportation of certain types of chemicals, Pulverized dry bulk materials such as cement and flour via hydraulic suspension system, and sewage and water in cities. E.g.: pipeline may be best suited to transport crude petroleum from the port to the refinery. But, to transport refined petrol to a gas station does not justify the use of a pipeline and this is better done by a truck. There is a talk going on between India, Iran and Pakistan regarding the transportation of crude oil from Iran to India with the help of a pipeline which will pass through Pakistan. This will reduce the cost of transporting crude oil from Iran to India.

In comparison with the other modes of transport, pipelines operate on a 24 hour basis, seven days a week. They stop functioning due to change in the commodity to be transported, or due to maintenance. Unlike other modes of transport, pipeline does not have any 'empty containers' or vehicles' which are to be returned to the origins.

Rope ways

A ropeway is a form of naval lifting device used to transport light stores and equipment across rivers or ravines. It comprises a jackstay, slung between two sheers or gyps, one at either end, from which is suspended a block and tackle, that is free to travel along the rope and hauled back and forth by inhauls (ropes attached to the pulley from which the block and tackle are suspended).

Comparison different modes of transportation

Mode	Product Options	Speed	Accessibility	Cost	Capacity	Intermodal Capability
Road	Very Broad	Moderate	High	Moderate	Low	Very High
Railroad	Broad	Slow	Moderate	Low	Moderate	Very High
Air	Narrow	Fast	Low	Very High	Very Low	Moderate
Water	Broad	Very Slow	Moderate	Very Low	Very High	Very High
Pipeline	Very Narrow	Very Slow	Low	Low	Very High	Very Low
Digital	Very Narrow	Very Fast	Very High	Very Low	Moderate	Very Low

1.3 M R Jayakar Committee Recommendations

Over a period after the First World War, motor vehicles using the roads increased and this demanded a better road network which can carry mixed traffic conditions. The existing roads when not capable to withstand the mixed traffic conditions. For the improvement of roads in India government of India appointed Mr. Jayakar Committee to study the situations and to recommend suitable measures for road improvement in 1927 and a report was submitted in 1928 with following recommendations:

1. Road development in the country should be considered as a national interest. As the provincial and local government do not have the financial and technical capacity for road development.
2. Extra tax to be levied from the road users as fund to develop road.
3. A Semi-official technical body has to be formed to collect and pool technical Knowhow from various parts of the country and to act as an advisory body on various aspects of the roads.
4. A research organization should be instituted at National level to carry out research and development work and should be available for consultation.

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. Central Road Research Institute (CRRI) in 1950.

Central Research Fund (CRF):

1. Central Research Fund (CRF) was formed on 1st March 1929
2. The consumers of petrol were charged an extra levy of 2.64 paisa/litre of petrol to build up this road development fund.
3. From the fund collected 20 percent of the annual revenue is to be retained as meeting expenses on the administration of the road fund, road experiments and research on road and bridge projects of special importance.
4. The balance 80 percent of the fund to be allotted by the Central Government to the various states based on actual petrol consumption or revenue collected
5. The accounts of the CRF are maintained by the Accountant General of Central Revenues.
6. The control of the expenditure is exercised by the Roads Wings of Ministry of Transport.

Indian Road Congress (IRC):

1. It is a semi-official technical body formed in 1934.
2. It was formed to recommend standard specifications.
3. It was constituted to provide a forum of regular technical pooling of experience and ideas on all matters affecting the planning, construction and maintenance of roads in India.
4. IRC has played an important role in the formulation of the 20-year road development plans in India.
5. Now, it has become an active body of national importance controlling specifications, guidelines and other special publications on various aspects of Highway Engineering.

Central Road Research Institute (CRRI):

1. CRRI was formed in the year 1950 at New Delhi
2. It was formed for research in various aspect of highway engineering
3. It is one of the National laboratories of the Council of Scientific and Industrial Research.
4. This institute is mainly engaged in applied research and offers technical advice to state governments and the industries on various problems concerning roads.

1.4 Road Classifications and Road Patterns

1.4.1 Road Classifications

1.4.1.1 Types of roads:

1. Classification based on weather:
 - All weather roads: All weather roads are those which are negotiable during all weather, except at major river crossings where interruption to traffic is permissible up to a certain extent, the road pavement should be negotiable during all weathers.
 - Fair-weather roads: Fair weather roads are which thee traffic may be interrupted during monsoon season at causeways where streams may overflow across the road.

2. Classification based on the type of carriage way:
 - Paved roads: If they are provided with a hard pavement course which should be at least water bound macadam (WBM) layer.
 - Unpaved roads: If they are not provided with a hard pavement course which should be at least water bound macadam (WBM) layer. Thus earth roads and gravel roads may be called unpaved roads.
3. Classification based on type of pavement surface:
 - Surface roads: Which are provided with a bituminous or cement concrete surfacing.
 - Un-surfaced roads: Which are not provided with a bituminous or cement concrete surfacing.

1.4.1.2 Methods of classification of roads:

The roads are generally classified as

- Traffic volume: The roads are classified as Heavy, Medium and Light traffic roads.
- Load transported or tonnage: The roads are classified as class I, class II or class A or class B etc. And the limits may be expressed as tonnes per day.

1.4.1.3 Classification of Roads by Nagpur Road plan:

The Nagpur Road Plan classified the roads in India based on location and function into five categories.

National Highways (NH): National Highways are main highways running through the length and breadth of India, connecting major ports, foreign highways, capitals of large state and large industrial and tourists centres including roads required for strategic movements for the defence of India.

- NH-1 Delhi-Ambala-Amritsar
- NH-3 Bombay-Agra
- NH-7 Varanasi to Kanyakumari
- NH-49 Maduri-Rameshwaram

State Highway: State Highways are arterial roads of a state, connecting up with the national highways adjacent state, district head quarters and important cities within the state and serving as the main arteries for traffic to and from district roads.

The NH and SH have the same design speed and geometric design specifications.

Major District Roads: MDR are important roads within a district serving areas of production and marketing and connecting those with each other or within the main highways of a district. The MDR has lower speed and geometric design specifications than NH/SH.

Other District Roads: ODR are serving rural areas of production and providing them with outlet to market centres, Taluk head quarters, block development head quarters or other main roads. ODR are of lower design specifications than MDR.

Village Roads: VR roads connecting villages or group of villages with each other to the nearest road of a higher category.

1.4.1.4 Modified classification of Road system by Lucknow plan:

The roads in the country are now classified into three classes, for the purpose of transport planning, functional identification, earmarking, administrative jurisdiction and assigning priorities on the road network.

1. Primary system consists of two categories:

- Expressways
- National Highways (NH)

Expressways are a separate class of highways with superior facilities and design standards and are meant as through routes having very high volume of traffic. The expressways are to be provided with divided carriage ways, controlled access, grade separations at cross roads and fencing. These highways should permit only fast moving vehicles.

2. Secondary system consists of two categories:

- State Highways (SH)
- Major District Roads (MDR)

3. Tertiary system consists of two categories:

- Other District Roads (ODR)
- Village Roads (VR)

1.4.1.5 Classification of Urban Roads:

The urban roads are

- Arterial roads
- Sub-arterial roads
- Collector streets
- Local streets

Arterial roads and Sub-arterial roads are streets primarily for through traffic on a continuous route, but the sub-arterials have a lower level of traffic mobility than the arterials.

Collector streets provide access to arterial streets and they collect and distribute traffic from and to local streets which provide access to abutting property.

1.4.2 Road patterns:

1.4.2.1 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 centre 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.

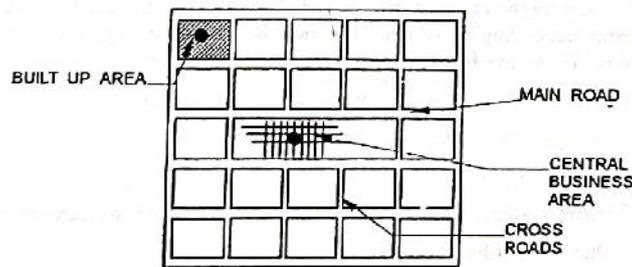
Advantages:

- The rectangular plots may be further divided into small rectangular blocks for construction of buildings placed back to back, having roads on their front.
- In this pattern has been adopted for the city roads.

Limitations:

- This pattern is not very much convenient because at the intersections, the vehicles face each other.

Example: Chandigarh has rectangular pattern.



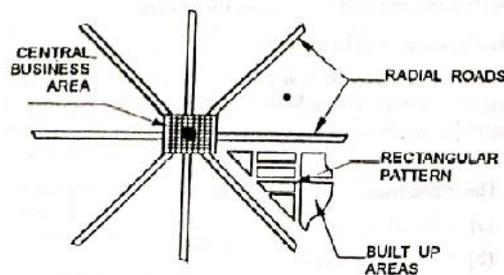
1.4.2.2 Radial or Star and block Pattern: In this pattern, the entire area is divided into a network of roads radiating from the business outwardly. In between radiating main roads, the built-up area may be planned with rectangular block.

Advantage

- Reduces level of congestion at the primary bottleneck location.
- If one is block then other side traffic can move.

Limitations

- Proves particularly effective if two-lane ramp traffic does not have to merge at downstream end of ramp.



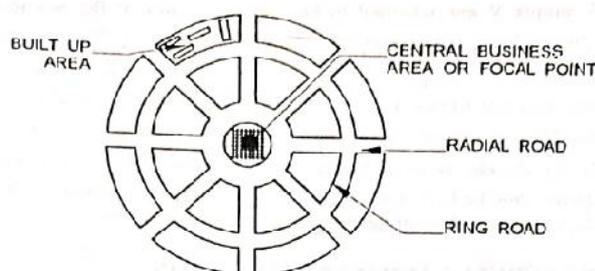
1.4.2.3 Radial or Star and Circular Pattern: In this system, the main radial roads radiating from central business area are connected together with concentric roads. In these areas, boundary by adjacent radial roads and corresponding circular roads, the built-up area is planned with a curved block system.

Advantages

- Installing circular pattern in place of traffic signals can also reduce the likelihood of rear-end crashes.
- Removing the reason for drivers to speed up as they approach green lights and by reducing abrupt stops at red lights.

Limitations:

- Center lines of roads leading to circular pattern should be properly aligned with the central island.



1.4.2.4 Radial or Star and Grid Pattern: Change in direction, and because street patterns are the most enduring physical element of any layout, it could potentially contribute to systematic site planning and, consequently, deserves a closer look. Though the network is entirely interconnected, north-south movement becomes circuitous, indirect, and inconvenient, making driving an unlikely choice and vividly illustrating that interconnectedness by itself is insufficient to facilitate movement.

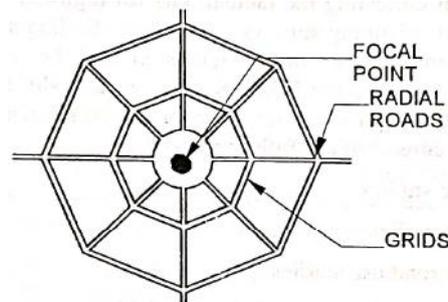
Advantages:

- Keep vehicular traffic safe with a high proportion of 3-way intersections.
- Reduce cut-through traffic by similar or other means.

Limitations:

- Islands separating the approach and exit lanes, known as splitter islands, should extend far enough.
- Traffic signs, pavement markings, and lighting should be adequate so that drivers are aware that they should reduce their travel speed.

Examples: The Nagpur road plan formulae were prepared on the assumption of Grid pattern.



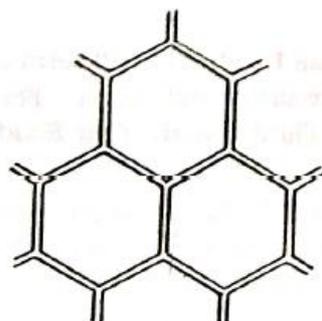
1.4.2.5 Hexagonal Pattern: In this pattern, the entire area is provided with a network of roads formatting hexagonal figures. At each corner of the hexagon, three roads meet the built-up area boundary by the sides of the hexagons is further divided in suitable sizes.

Advantages:

- Three roads meet the built-up area boundary by the sides of the hexagons.

Limitation:

- Traffic signs, pavement markings, and lighting should be adequate so that drivers are aware that they should reduce their travel speed.



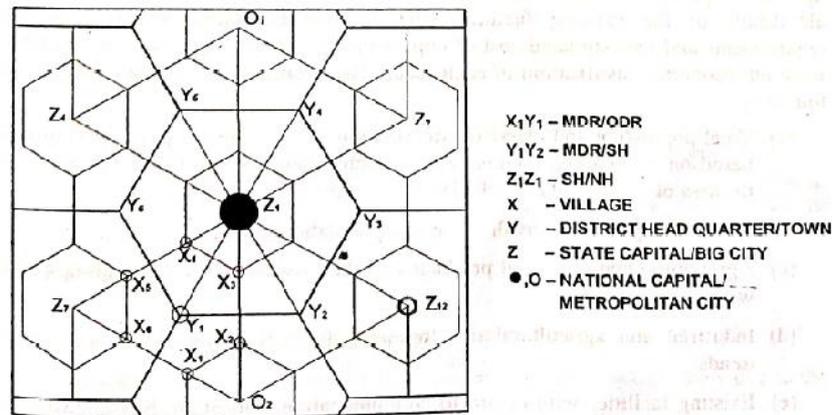
1.4.2.6 Minimum Travel Pattern: In this road pattern, city is contented by sector center, suburban enter and neighbourhood center by the road which required minimum to connect the city center.

Advantages:

- These types of potentially serious crashes essentially are eliminated.

Limitations:

- Traffic signs, pavement markings, and lighting should be adequate so that drivers are aware that they should reduce their travel speed.
- Intersections can be especially challenging for older drivers.



1.5 Highway Alignment

1.5.1 Ideal Alignment

An ideal alignment between two stations should offer maximum utility by serving maximum population and products and also should possess following requirements:

- **Short:** it is desirable to have a short alignment between two stations. A straight path between the two terminals would provide this.
- **Easy:** it should be easy to construct and maintain the road with minimum problems and also the alignment should be easy for vehicle to operate with easy gradient and curves.
- **Safe:** it should be safe enough for construction and maintenance from the view point of stability of natural hill slopes, embankment and cut slopes. It should be safe for the traffic operation with safe geometric features.
- **Economical:** The road alignment could be considered economical only if the total cost including initial cost, maintenance cost and VOC is lowest.

1.5.2 Factors affecting highway alignment

The various factors which control the highway alignment are:

Obligatory Points: there are control points governing the alignment of the highways. These control points may be divided broadly into two categories.

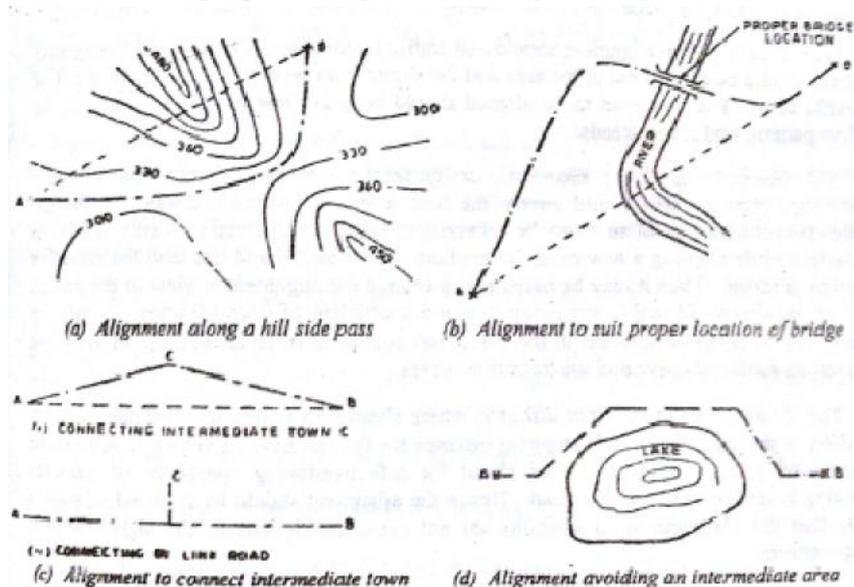
a) Points through which the alignment is to pass:

This may cause the alignment to often deviate from the shortest or easiest path. The various examples of this category may be bridge site, intermediate town, a mountain pass or quarry.

Case 1: When it is necessary to cross hill range, mountains the various alternatives are to cut a tunnel or to go around the hill. This suitability depends on many factors like site condition, topography, cost consideration etc. The figure shows how the alignment AB deviated to ACB.

Case 2: due to the position of the bridge the alignment deviated from CD to CFD. Because the bridge are constructed at narrow gap and where the intensity of water force is low.

Case 3: when connecting a road network between two station. It always beneficial to provide a link road or to connect the proposed alignment through nearby station



- b) Points through which the alignment should not pass: also make it necessary to deviate from the proposed shortest alignment. The obligatory points which includes religious places (temples church, mosque and grave), very costly structure, unsuitable land (lakes, ponds, marshy soil)

Traffic: the alignment should suit traffic requirements. Origin and destination study should be carried out in the area and the desire lines be drawn showing the traffic flow. The new alignment should keep in view of desired lines, flow patterns and future trends.

Geometric design: geometric design factors such as gradient, radius of curve and sight distance, overtaking sight distance, ruling gradient on hilly region also would govern the final alignment of the highway.

Economics: the alignment finalised based on the above factors should be economical compared to other alignment. The safety, saving and returns should be more compared to investment. It is based on the initial cost of construction and maintenance cost of the road, if it a shortest path the cost of construction will be reduced. (Decision is based on Quantity of Cutting and Filling of Earth.)

Other consideration: factors like drainage consideration, hydrological factors, water table, seepage flow, high flood level, political considerations and monotony also affect in deciding the alignment.

In hill roads additional care has to be given for:

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

1.5.3 Engineering surveys

The stages of engineering surveys for Highway locations:

1. Map study
2. Reconnaissance
3. Preliminary surveys
4. Final location and detailed surveys

Map study: By careful study of topographical map, it is possible to have an idea of several possible alternate routes so that further details of these may be studied later at the site. The features like river, hills valleys, and counter intervals can be observed.

By knowing these feature it can fairly assign the alignment avoiding valleys, lakes and possible location of bridge (avoiding sharp turns etc.). It is also possible to suggest permissible gradient considering counter intervals.

Reconnaissance: it is to examine the general character of the area for deciding the most feasible routes for detailed studies. A field survey party may inspect a fairly broad stretch of land along the proposed alternative routes of the map in the field. Only few simple instruments like abney level tangent clinometers, barometer or GPS are used by the reconnaissance party to collect additional details rapidly.

Some of the following details are collected;

- Valleys, ponds, lakes, marshy land, hills, permanent structures and other obstruction along the route which are not available in the map.
- Approximate values of gradient, length of gradient and radius of curves of alternate alignments.
- Number and type of cross drainage structures, maximum flood level and natural ground water level along the probable routes.
- Sources of construction materials, water and location of stone quarries
- When the alignment passes through hill, additional details like type of rocks, dip of strata, seepage flow.

Preliminary Survey: this survey can be done either by Conventional approach or aerial survey if the area is more.

The main objectives of preliminary survey are:

- To survey the various alternate alignments proposed after the reconnaissance and to collect all the necessary physical information and details of topography, drainage and soil.
- To compare the different proposals in view of the requirements of a good alignment.
- To estimate quantity of earth work materials and other construction aspects and to work out the cost of alternate proposals.
- To finalise the best alignment from all consideration.

Final Location and Detailed survey:

- The alignment finalized at the design office after the preliminary survey is to be 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 levels are taken along longitudinal section and cross section at very 50 – 100 m intervals. The cross section should take at curves and where there is a gradient change.
- The data collected during the detailed survey should be elaborate and complete for preparation of detailed plans, design and estimate of the project.

Highway Geometric Design**1.6 Factors affecting geometric design of roads**

Design speed: Design speed is the single most important factor that affects the geometric design. It directly affects the sight distance, horizontal curve, and the length of vertical curves. Since the speed of vehicles vary with driver, terrain etc, a design speed is adopted for all the geometric design.

Topography: It is easier to construct roads with required standards for a plain terrain. However, for a given design speed, the construction cost increases multi form with the gradient and the terrain.

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

Design Hourly Volume and Capacity: The general unit for measuring traffic on highway is the Annual Average Daily Traffic volume, abbreviated as AADT. The traffic flow (or) volume keeps fluctuating with time, from a low value during off peak hours to the highest value during the peak hour. It will be uneconomical to design the roadway facilities for the peak traffic flow.

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

1.7 Highway cross section elements:**1.7.1 Unevenness:**

It is always desirable to have an even surface, but it is seldom possible to have such a one. Even if a road is constructed with high quality pavers, it is possible to develop unevenness due to pavement failures. It affects the vehicle operating cost, speed, riding comfort, safety, fuel consumption and wear and tear of tires.

Unevenness index is a measure of unevenness which is the cumulative measure of vertical undulation of the pavement surface recorded per unit horizontal length of the road. An unevenness index value less than 1500mm/km is considered as good, a value less than 2500 mm/km is satisfactory up to speed of 100 kmph and values greater than 3500 mm/km is considered as uncomfortable even for 50 kmph.

1.7.2 Friction:

Friction between the wheel and the pavement surface is a crucial factor in the design of horizontal curves and thus the safe operating speed. Further, it also affects the acceleration and deceleration ability of vehicles. Lack of adequate friction can cause skidding or slipping of vehicles.

Factors affecting friction or skid resistance:

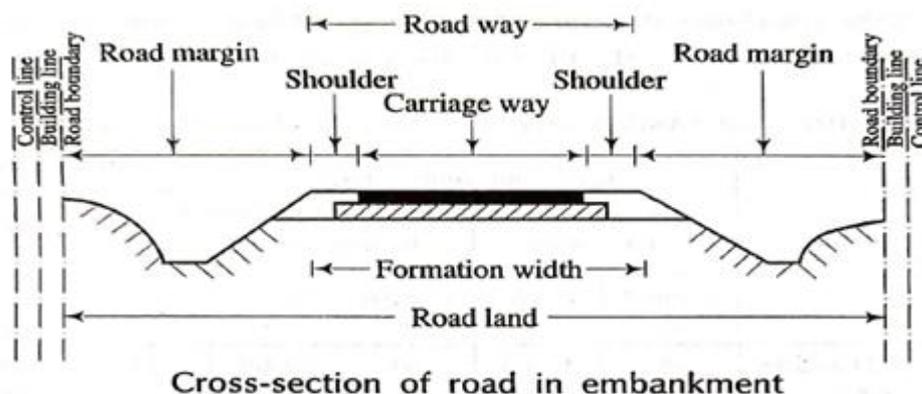
The maximum friction offered by pavement surface or the skid resistance depends upon the following factors,

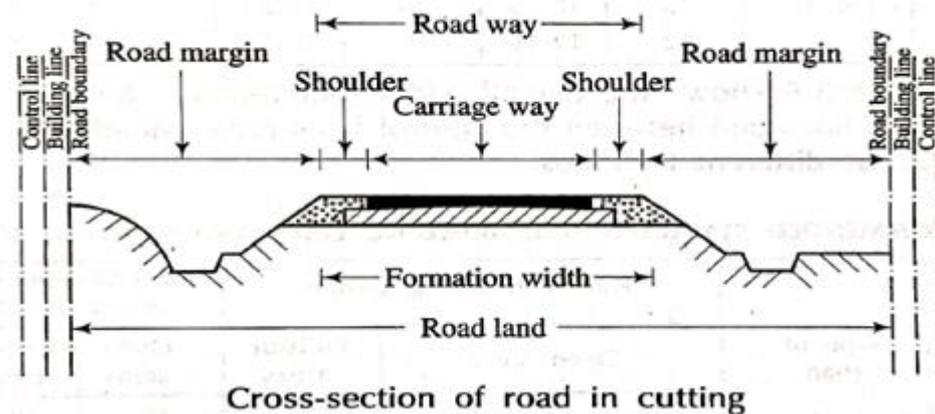
- Types of surface namely cement concrete, bituminous, WBM, earth surface.
- Condition of pavement namely wet or dry, smoothed or rough, mud or dry sand on pavement.
- Type and condition of tyre i.e. new with good treads or smoothed and worn out tyre.
- Speed of vehicle.
- Extent of brake application or brake efficiency.
- Load and tyre pressure.
- Temperature of tyre and pavements.

1.7.3 Right of way:

Right of way (ROW) or land width is the width of land acquired for the road, along its alignment. The width of this acquired land is known as land width and it depends on the importance of the road and possible future development.

- Width of formation: It depends on the category of the highway and width of roadway and road margins.
- Height of embankment or depth of cutting: It is governed by the topography and the vertical alignment.
- Side slopes of embankment or cutting: It depends on the height of the slope, soil type etc.
- Drainage system and their size which depends on rainfall, topography etc.





The right of way for various roads according to IRC are given below

Sl no.	Road classification	Plain and rolling terrain				Mountainous & steep terrain	
		Open area		Built-up area		Open area	Built-up area
		Normal	Range	Normal	Range	Normal	Normal
1	NH & SH	45	30-60	30	30-60	24	20
2	MDR	25	25-30	20	15-25	18	15
3	ODR	15	15-25	15	15-20	15	12
4	VR	12	12-18	10	10-15	9	9

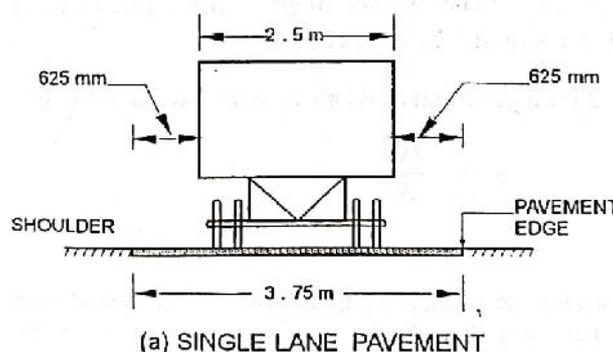
1.7.4 Width of carriageway or pavement:

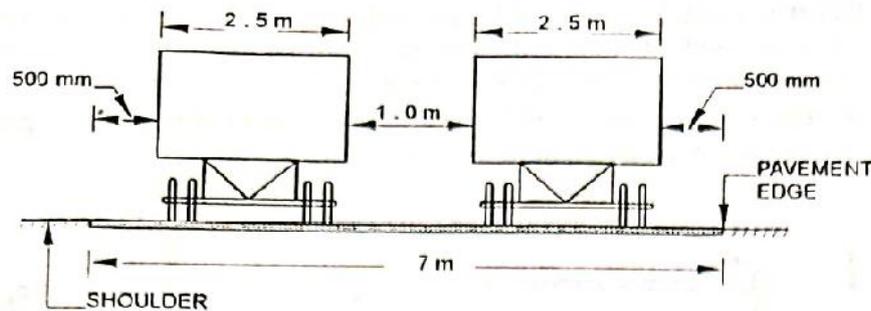
Carriage way or the width of the pavement depends on the width of the traffic lane and number of lanes. Width of a traffic lane depends on the width of the vehicle and the clearance. Side clearance improves operating speed and safety. The maximum permissible width of a vehicle is 2.50 and the desirable side clearance or single lane traffic is 0.625 m.

The number of lanes required in a highway depends on the predicted traffic or the design traffic volume and the desired level of service.

The width of carriageway for various roads according to IRC are given below

Sl No	Class of Road	Width of carriageway, m
1	Single lane road	3.75
2	Two lanes without raised kerbs	7.0
3	Two lanes with raised kerbs	7.5
4	Intermediate carriageway	5.5
5	Multi-lane pavements	3.5 per lane





(b) TWO LANE PAVEMENT

1.7.5 Camber or cross slope or Cant:

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

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

Too steep slope is undesirable for it will erode the surface. Camber is measured in 1 in n or n% (Eg. 1 in 50 or 2%) and the value depends on the type of pavement surface.

Recommended values of camber for different types of road surface by IRC are as follows

Sl no	Types of road surface	Range of camber in areas of	
		Heavy rainfall	Low rainfall
1	CC and high type bituminous surface	1 in 50 or 2.0%	1 in 60 or 1.7%
2	Thin bituminous surface	1 in 40 or 2.5%	1 in 50 or 2.0%
3	WBM and gravel pavement	1 in 33 or 3.0%	1 in 40 or 2.5%
4	Earth road	1 in 25 or 4.0%	1 in 33 or 3.0%

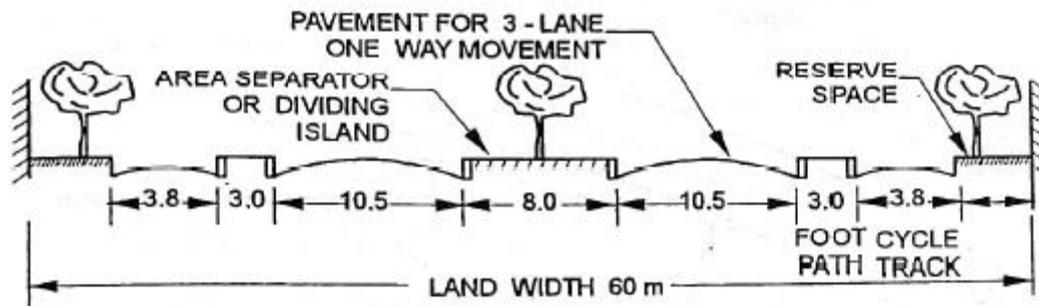
1.7.6 Width of roadway or formation:

Width of roadway or formation is the sum of widths of pavement or carriageway including separators and the shoulders. Formation or roadway width is the top width of the highway embankment or the bottom width of highway cutting excluding the side drains.

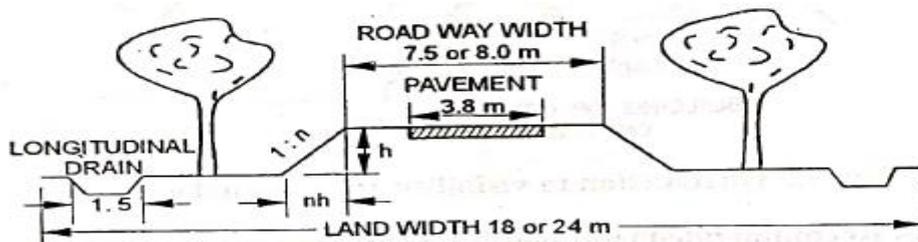
Recommended values of roadway or formation for different types of road surface by IRC are as follows

Sl no.	Road classification	Road way width, m		
		Plain & terrain	Rolling	Mountainous & steep terrain
1	NH & SH			
	Single lane	12.0		6.25
	Double lane	12.0		8.80
2	MDR			
	Single lane	9.0		4.75
	Double lane	9.0		-
3	ODR			
	Single lane	7.5		4.75
	Double lane	9.0		-
4	Village roads	7.5		4.0

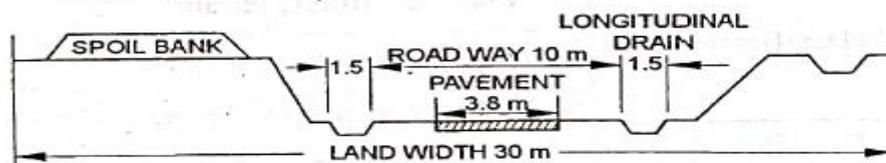
1.7.7 Typical cross-sections:



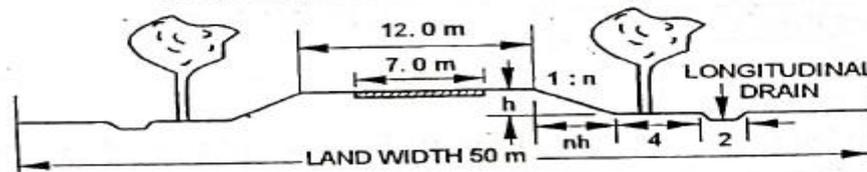
Cross section of divided highway in urban area



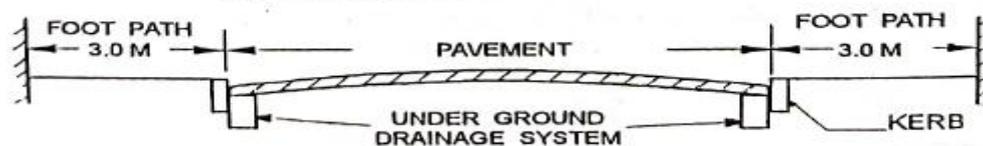
Cross section of VR or ODR in embankment in rural area



Cross section of MDR in cutting in rural area



Cross section of NH or SH in rural area



Cross section of two-lane city road in built-up area

1.7.8 Kerbs: Kerbs indicate the boundary between the carriage way and the shoulder or islands or footpaths. Different types of kerbs are

- **Low or mountable kerbs:** These types of kerbs are provided such that they encourage the traffic to remain in the through traffic lanes and also allow the driver to enter the shoulder area with little difficulty. The height of this kerb is about 10 cm above the pavement edge with a slope which allows the vehicle to climb easily. This is usually provided at medians and channelization schemes and also helps in longitudinal drainage.

- **Semi-barrier type kerbs:** When the pedestrian traffic is high, these kerbs are provided. Their height is 15 cm above the pavement edge. This type of kerb prevents encroachment of parking vehicles, but at acute emergency it is possible to drive over this kerb with some difficulty.
- **Barrier type kerbs:** They are designed to discourage vehicles from leaving the pavement. They are provided when there is considerable amount of pedestrian traffic. They are placed at a height of 20 cm above the pavement edge with a steep batter.
- **Submerged kerbs:** They are used in rural roads. The kerbs are provided at pavement edges between the pavement edge and shoulders. They provide lateral confinement and stability to the pavement.

1.8 Sight distances

Visibility is very important for safe vehicle operation on a highway. Restrictions to sight distance may be caused at horizontal curves, by objects obstructing vision at the inner side of the road or at vertical summit curves or at intersections. Three sight distance situations are considered in the design,

1.8.1 Stopping sight distance:

SSD is the minimum sight distance available on a highway at any spot having sufficient length to enable the driver to stop a vehicle travelling at design speed, safely without collision with any other obstruction.

1.8.1.1 Factors affecting sight distance:

Speed of the vehicle: The speed of the vehicle very much affects the sight distance. Higher the speed, more time will be required to stop the vehicle. Hence it is evident that, as the speed increases, sight distance also increases.

Efficiency of brakes: The efficiency of the brakes depends upon the age of the vehicle, vehicle characteristics etc. If the brake efficiency is 100%, the vehicle will stop the moment the brakes are applied. But practically, it is not possible to achieve 100% brake efficiency.

Therefore it could be understood that sight distance required will be more when the efficiency of brakes are less. Also for safe geometric design, we assume that the vehicles have only 50% brake efficiency.

Frictional resistance between the tire and the road: The frictional resistance between the tire and road plays an important role to bring the vehicle to stop. When the frictional resistance is more, the vehicles stop immediately. Thus sight required will be less.

No separate provision for brake efficiency is provided while computing the sight distance. This is taken into account along with the factor of longitudinal Friction. IRC has specified the value of longitudinal friction in between 0.35 to 0.4.

Gradient of the road: Gradient of the road also affects the sight distance. While climbing up a gradient, the vehicle can stop immediately. Therefore sight distance required is less. While

descending a gradient, gravity also comes into action and more time will be required to stop the vehicle. Sight distance required will be more in that case.

1.8.1.2 Reaction time of the driver:

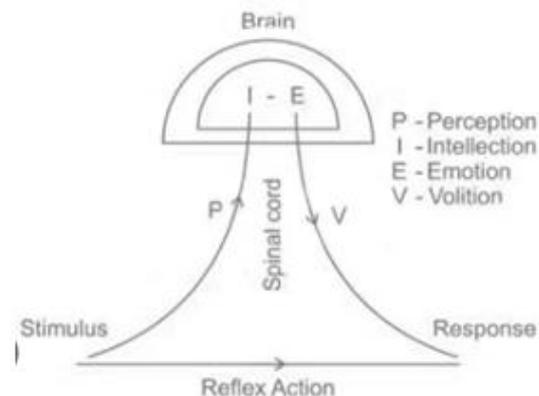
Reaction time of a driver is the time taken from the instant the object is visible to the driver to the instant when the brakes are applied. The total reaction time may be split up into four components based on PIEV theory.

Perception time is the time required for the sensations received by eyes or ears to be transmitted to the brain through nervous system and the spinal cord.

Intellection time is the time required for understanding the situation. It is also the time required for comparing the different thoughts, regrouping and registering new sensations.

Emotion time is the time elapsed during emotional sensations and disturbance such as fear, anger or any other emotional feelings such as superstition etc.

Volition time is the time taken for the final action.



In practice, all these times are usually combined into a total perception- reaction time suitable for design purposes as well as for easy measurement. Many of the studies show that drivers require about 1.5 to 2 sec under normal conditions. However taking into consideration the variability of driver characteristics, a higher value is normally used in design. For example, IRC suggests a reaction time of 2.5 sec.

1.8.2 Overtaking Sight Distance (OSD):

The minimum distance to open the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the traffic of opposite direction.

Factors required for the safe overtaking manoeuvre depends, are

- Speed of (i) overtaking vehicle (ii) overtaken vehicle (iii) the vehicle coming from opposite direction
- Distance between the overtaking and overtaken vehicle: the minimum spacing depends on the speeds
- Skill and reaction time of driver
- Rate of acceleration of overtaking vehicle
- Gradient of the road

Maximum overtaking acceleration at different speeds

Speed, kmph		Maximum overtaking acceleration	
V, kmph	v, m/s	A, kmph / sec	a, m/s ²
25	6.93	5.00	1.41
30	8.34	4.80	1.30
40	11.10	4.45	1.24
50	13.86	4.00	1.11
65	18.00	3.28	0.92
80	22.20	2.56	0.72
100	27.80	1.92	0.53

1.9 Horizontal alignment:**1.9.1 Super elevation:**

In order to counteract the effect of centrifugal force and to reduce the tendency of the vehicle to overturn or skid, the outer edge of the pavement is raised with respect to the inner edge, thus providing a transverse slope throughout the length of the horizontal curve. This transverse inclination to the pavement surface is known as super elevation or cant or banking.

1.9.2 Widening of pavement on horizontal curve:

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. The extra widening of pavement on horizontal curves is divided into two parts,

Mechanical widening: The widening required to account for the off-tracking due to the rigidity of wheel based is called mechanical widening.

Psychological widening: Extra width of pavement is also provided for psychological reasons such as, to provide for greater manoeuvrability of steering at higher speeds, to allow for the extra space requirements for the overhangs of vehicles and to provide greater clearance for crossing and overtaking vehicles on the curves. Psychological widening is therefore important in pavements with more than one lane.

1.10 Vertical alignment:**1.10.1 Gradient:**

Gradient 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 to x horizontal units). It is also expressed as a percentage n i.e. n in 100.

Gradients are divided into the following categories:

Ruling gradient:

The ruling gradient or the design gradient is the maximum gradient with which the designer attempts to design the vertical profile of the road. This depends on the terrain, length of the grade, speed, pulling power of the vehicle and the presence of the horizontal curve. The ruling gradient is adopted by the designer by considering a particular speed as the design speed and for a design vehicle with standard dimensions.

The IRC recommended ruling gradient values of 1 in 30 on plain and rolling terrain, 1 in 20 on mountainous terrain and 1 in 16.7 on steep terrain.

Limiting gradient:

This gradient is adopted when the ruling gradient results in enormous increase in cost of construction. On rolling terrain and hilly terrain it may be frequently necessary to adopt limiting gradient. But the length of the limiting gradient stretches should be limited and must be sandwiched by either straight roads or easier grades.

Exceptional gradient:

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

Minimum gradient:

This is 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 requires some slope for smooth flow of water. Therefore minimum gradient is provided for drainage purpose and it depends on the rain fall, type of soil and other site conditions. A minimum of 1 in 500 may be sufficient for concrete drain and 1 in 200 for open soil drains is found to give satisfactory.

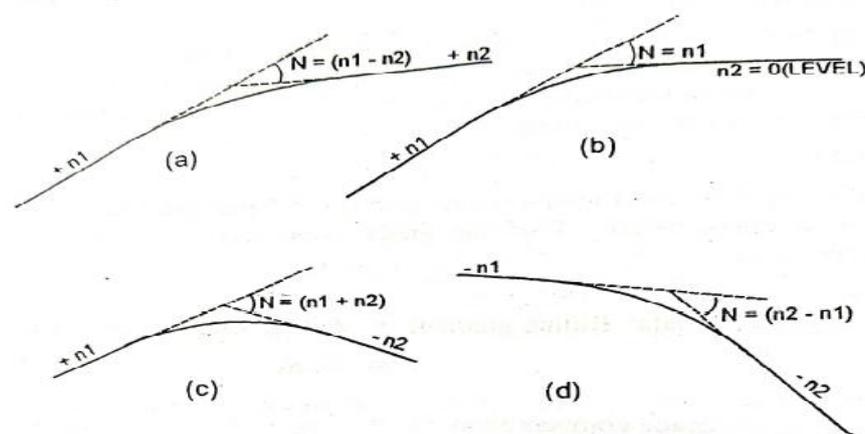
1.10.2 Vertical curves:

Due to changes in grade in the vertical alignment of highway, it is necessary to introduce vertical curve at the intersection 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

1. Summit curves or crest curves with convexity upwards
2. Valley or sag curves with concavity upwards

Summit curves:

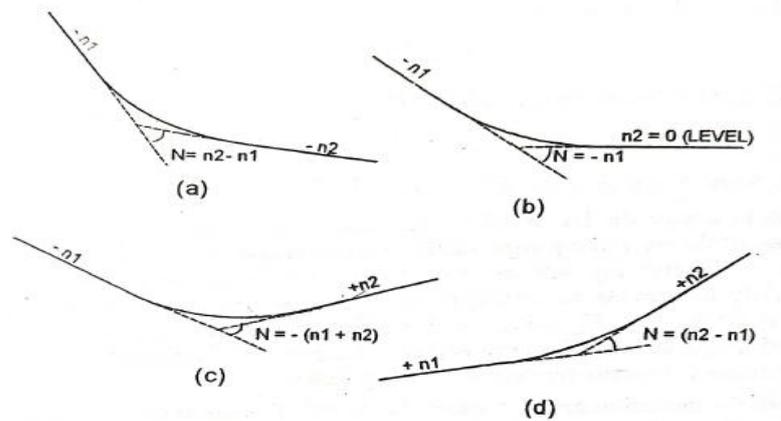


Types of summit curves

The deviation angle between the two interacting gradients is equal to the algebraic difference between them. Of all the cases, the deviation angle will be maximum when an ascending gradient meets with a descending gradient i.e. $N = n_1 - (-n_2) = (n_1 + n_2)$

Valley curve:

In all the cases the maximum possible deviation angle is obtained when a descending gradient meets with an ascending gradient.



Types of valley curves

1.11 Recommended questions

1. What are the different modes of transportation? Explain the specific functions of each of them
2. What are the various methods of classifying roads? Briefly outline the classification based on location and function as suggested in the Nagpur Road Plan.
3. What are the significant recommendations of Jayakar Committee Report? Mention how this helped in road development in India?
4. Briefly outline the main features of various road patterns commonly in use.
5. What are the various requirements of an ideal highway alignment? Discuss briefly.
6. Explain obligatory points. With sketches, discuss how these control the alignment.
7. Write a note on carriage way, right of way and camber with sketches.
8. Explain sight distance and factors causing restrictions to sight distance.

1.12 Outcomes

Explain the basic principles of geometric design in the context of transportation engineering and planning.

1.13 Further Reading

1. <http://nptel.ac.in/courses/105101087/downloads/Lec-1.pdf>
2. <http://nptel.ac.in/downloads/105101087/>
3. <http://omms.nic.in/>
4. <http://nptel.ac.in/courses/105101087/downloads/Lec-12.pdf>
5. <https://www.civilengineeringnews.tk/2014/09/highway-alignment.html>

Module – 2

Highway Materials and Pavements

Structure

- 2.0 Introduction
- 2.1 Objectives
- 2.2 Highway Materials
- 2.3 Pavement Design
- 2.4 Highway Drainage
- 2.5 Recommended questions
- 2.6 Outcomes
- 2.7 Further Reading

2.0 Introduction

Pavements are a conglomeration of materials. These materials, their associated properties, and their interactions determine the properties of the resultant pavement. Thus, a good understanding of these materials, how they are characterized, and how they perform is fundamental to understanding pavement. The materials which are used in the construction of highway are of intense interest to the highway engineer. This requires not only a thorough understanding of the soil and aggregate properties which affect pavement stability and durability, but also the binding materials which may be added to improve these pavement features.

2.1 Objectives

- Get insight to different highway materials and pavement design elements of a highway network.

2.2 Highway Materials

2.2.1 Subgrade soil

Soil is an accumulation or deposit of earth material, derived naturally from the disintegration of rocks or decay of vegetation that can be excavated readily with power equipment in the field or disintegrated by gentle mechanical means in the laboratory. The supporting soil beneath pavement and its special under courses is called sub grade. Undisturbed soil beneath the pavement is called natural sub grade. Compacted sub grade is the soil compacted by controlled movement of heavy compactors.

Subgrade soil

1. Subgrade soil is considered as the integral part of the road structure.
2. It provides support to the pavement from beneath.
3. The properties of subgrade soil are important to the design of pavement structure.
4. Its main function is to give adequate support to the pavement.
5. It should possess sufficient stability under adverse climate and loading conditions.

Desirable Properties

The desirable properties of sub grade soil as a highway material are

1. Stability
2. Incompressibility
3. Permanency of strength
4. Minimum changes in volume and stability under adverse conditions of weather and ground water
5. Good drainage
6. Ease of compaction

The soil should possess adequate stability or resistance to permanent deformation under loads, and should possess resistance to weathering, thus retaining the desired subgrade support. Minimum variation in volume will ensure minimum variation in differential expansion and differential strength values of the subgrade.

Good drainage is essential to avoid excessive moisture retention and to reduce the potential frost action. Ease of compaction ensures higher dry density and strength under particular type and amount of compaction.

2.2.2 Road Aggregates

Aggregate is a collective term for the mineral materials such as sand, gravel, and crushed stone that are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.) to form compound materials (such as bituminous concrete and Portland cement concrete). By volume, aggregate generally accounts for 92 to 96 percent of Bituminous concrete and about 70 to 80 percent of Portland cement concrete. Aggregate is also used for base and sub-base courses for both flexible and rigid pavements. Aggregates can either be natural or manufactured.

Desirable properties of road aggregates:

1. Strength
2. Hardness
3. Toughness
4. Durability
5. Shape of aggregates
6. Adhesion with bitumen

Strength The aggregates to be used in road construction should be sufficiently strong to withstand the stresses due to traffic wheel load. The aggregates which are to be used in top layers of the pavements, particularly in the wearing course have to be capable of withstand wear and tear; hence they should possess sufficient strength resistance to crushing.

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

Toughness Aggregates in the pavements are also subjected to impact due to moving wheel loads. Sever impact like hammering is quite move on water bound macadam roads where stones protrude out especially after the monsoons.

Durability The stone used in pavement construction should be durable and should resist disintegration due to the action of weather. The property of the stones to withstand the adverse action of weather may call soundness.

Shape of Aggregates The size of the aggregates is first qualified by the size of square sieve opening through which an aggregate may pass, and not by the shape. Aggregates which happen to fall in a particular size range may have rounded, cubical, angular flaky or elongated shape of particles. It is e and donated particles will have less strength and durability when compared with cubical angular or rounded articles of the same Stone. Hence too flaky and too much elongated aggregates should be avoided as far as possible.

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

2.2.3 Desirable Properties of Bitumen

Viscosity: The viscosity of the bitumen at the time of mixing and compaction should be adequate. This is achieved by heating the bitumen and aggregate prior to mixing or by use of cutbacks or emulsions of suitable grade.

Temperature Susceptibility: The bituminous material should not be highly temperature susceptible. During the hottest weather of the region the bituminous mix should not become too soft or unstable. During cold weather the mix should not become too hard and brittle, causing cracking. The material should be durable.

Adhesion Property: In presence of water the bitumen should not strip off from the aggregate. There has to be adequate affinity and adhesion between the bitumen and aggregate used in the mix.

2.2.4 Applications of Bitumen Emulsion

Bitumen emulsion is a liquid product in which bitumen is suspended in a finely divided condition in an aqueous medium and stabilised by suitable material. Normally cationic type emulsions are used in India. The bitumen content in the emulsion is around 60% and the remaining is water. When the emulsion is applied on the road it breaks down resulting in release of water and the mix starts to set. The time of setting depends upon the grade of bitumen. The viscosity of bituminous emulsions can be measured as per IS: 8887-1995. Three types of bituminous emulsions are available, which are Rapid setting (RS), Medium setting (MS), and Slow setting (SC). Bitumen emulsions are ideal binders for hill road construction. Where heating of bitumen or aggregates are difficult. Rapid setting emulsions are used for surface dressing work. Medium setting emulsions are preferred for premix jobs and patch repairs work. Slow setting emulsions are preferred in rainy season.

2.3 Pavement Design

2.3.1 Factors Affecting Pavement Design

There are so many factors which influencing the pavement design. The factors may be of loading, environment, materials used etc. Which are as follows.

Wheel Load Influence on Pavements: Wheel load on pavement is an important factor to determine the pavement thickness to be adopted. By providing adequate thickness, the load coming from wheels doesn't affect the subgrade soil. The wheel load is acts at particular point on pavement and cause deformations.

Axle Configuration: Axles are the important part of the vehicles which enables the wheels to rotate while moving. By providing multiple axles, vehicles can carry more load. So, the axle load also influences the design of pavement.

Tire Contact Pressure on Pavement: When the vehicle is moving on pavement, the pressure developed between the tire and pavement. If the tire is low-pressure tire, then contact pressure will be greater than tire pressure.

Vehicle Speed: If the vehicle is moving at creep speed then also damage occurs to the pavement. If the vehicle speed is gradually increased then it will cause smaller strains in the pavement.

Repetition of Loads: Constructed pavement is used by several vehicles in its design life. The wheel loads are repeated all the time due to this some deformation occurs on the pavement. Total deformation is the sum of all-wheel loads acting on it.

Subgrade Type: To construct pavement subgrade soil need to be tested. Various test like CBR, Tri-axial, etc. will help to determine the quality of subgrade. From this, we can adapt the required thickness to the pavement. If subgrade soil is poor then the pavement should damage easily.

Temperature Effects on Pavements Design: Temperature is the important environmental factor to be considered in the design of pavement. In the case of asphalt roads, temperature affects the resilient modulus of the surface course. In very hot conditions asphalt layers lose their stiffness. At low temperatures, asphalt layers become brittle and cracks are formed. In case of rigid pavement, temperature stresses are developed. Curling of concrete is also possible due to variation of temperature in the top and bottom layers of pavement.

Precipitation: Moisture variations or precipitation from rain affects the depth of the groundwater table. Good drainage facilities should be provided for good strength and support. The groundwater table should be at least below 1m from the pavement surface

2.3.2 Pavement types

The pavements can be classified based on the structural performance into two,

1. Flexible pavements
2. Rigid pavements.

In flexible pavements, wheel loads are transferred by grain-to-grain contact of the aggregate through the granular structure. The flexible pavement, having less flexural strength, acts like a flexible sheet (e.g. bituminous road).

In rigid pavements, wheel loads are transferred to sub-grade soil by flexural strength of the pavement and the pavement acts like a rigid plate (e.g. cement concrete roads).

2.3.2.1 Flexible Pavement:



Typical cross section of a flexible pavement

Surface course: Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete (AC). The functions and requirements of this layer are:

- It provides characteristics such as friction, smoothness, drainage, etc. Also it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade,
- It must be tough to resist the distortion under traffic and provide a smooth and skid-resistant riding surface,
- It must be water proof to protect the entire base and sub-grade from the weakening effect of water.

Binder course: This layer provides the bulk of the asphalt concrete structure. Its chief purpose is to distribute load to the base course. The binder course generally consists of aggregates having less asphalt and doesn't require quality as high as the surface course, so replacing a part of the surface course by the binder course results in more economical design.

Base course: The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage. It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials.

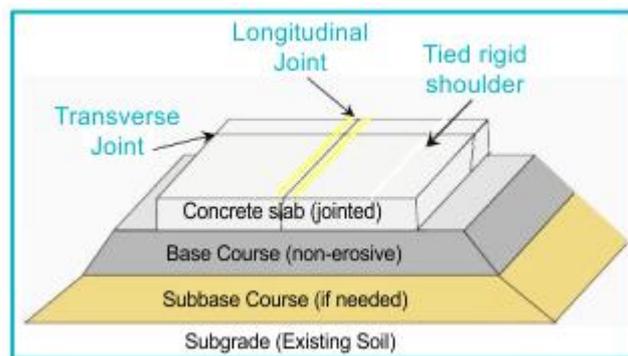
Sub-Base course: The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the

intrusion of fines from the sub-grade in the pavement structure. If the base course is open graded, then the sub-base course with more fines can serve as a filler between sub-grade and the base course. A sub-base course is not always needed or used. For example, a pavement constructed over a high quality, stiff sub-grade may not need the additional features offered by a sub-base course. In such situations, sub-base course may not be provided.

Sub-grade: The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed. It should be compacted to the desirable density, near the optimum moisture content.

2.3.2.2 Rigid pavements

Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below. A typical cross section of the rigid pavement is shown in Figure. Compared to flexible pavement, rigid pavements are placed either directly on the prepared sub-grade or on a single layer of granular or stabilized material. Since there is only one layer of material between the concrete and the sub-grade, this layer can be called as base or sub-base course.



Surface Course: The uppermost layer of rigid pavement, also known as the surface course, is a concrete slab that directly withstands vehicle loads. Its water resistance prevents water penetration into the underlying layers. The concrete slab provides friction to vehicles, preventing skidding. Typically, the thickness of the concrete slab ranges from 150 to 300 mm.

Granular Base or Stabilized Base Course: Positioned as the second layer from the top, the base course, also called the granular base or stabilized base, is constructed using crushed aggregates. This layer allows for additional load distribution on the surface course and provides a solid foundation for the rigid pavement. The foundation course should have a minimum thickness of 100 mm.

Granular Sub-base or Stabilized Sub-base Course:

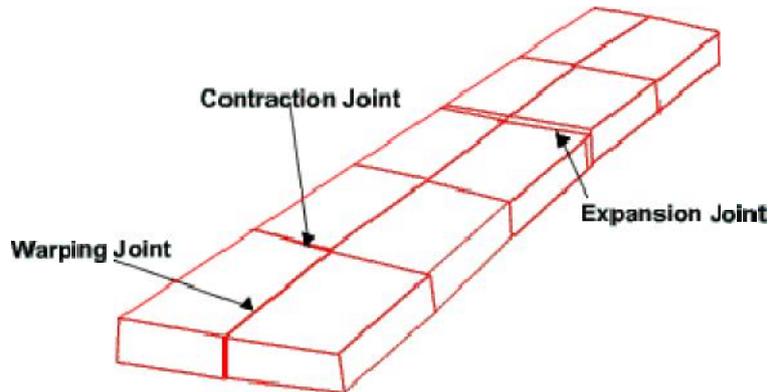
The third layer, in contact with the base course and subgrade soil, is the granular sub-base or stabilized sub-base course. While of lower quality compared to the base course aggregates, they are of higher quality than the subgrade soil. In low-traffic situations, a sub-base course may not be necessary, but when the loading exceeds 45,000 kg, it should be included. Its primary function is to support the upper layers, control frost action, and prevent fines from

the subgrade soil from infiltrating the surface layers. Additionally, the sub-base course improves drainage capabilities.

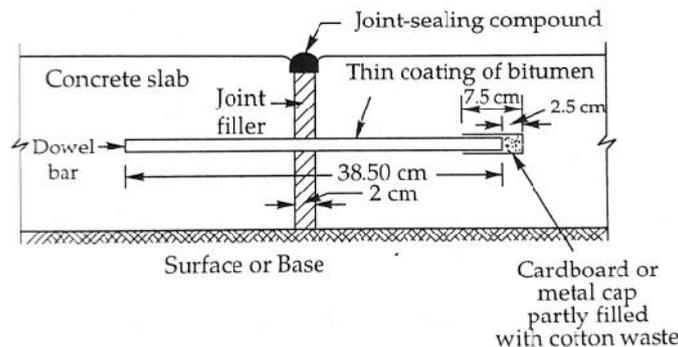
Subgrade Soil: The subgrade soil forms the existing soil layer that undergoes compaction using machinery to establish a strong foundation for the rigid pavement. Subgrade soils experience less stress compared to the top layers as tensions decrease with depth. Subgrade soils can vary significantly, and their response to forces from the upper layers depends on factors such as texture, density, moisture content, and strength.

No	Flexible Pavement	Rigid Pavement
1.	It consists of a series of layers with the highest quality materials at or near the surface of pavement.	It consists of one layer Portland cement concrete slab or relatively high flexural strength.
2.	It reflects the deformations of subgrade and subsequent layers on the surface.	It is able to bridge over localized failures and area of inadequate support.
3.	Its stability depends upon the aggregate interlock, particle friction and cohesion.	Its structural strength is provided by the pavement slab itself by its beam action.
4.	Pavement design is greatly influenced by the subgrade strength.	Flexural strength of concrete is a major factor for design.
5.	It functions by a way of load distribution through the component layers	It distributes load over a wide area of subgrade because of its rigidity and high modulus of elasticity.
6.	Temperature variations due to change in atmospheric conditions do not produce stresses in flexible pavements.	Temperature changes induce heavy stresses in rigid pavements.
7.	Flexible pavements have self healing properties due to heavier wheel loads are recoverable due to some extent.	Any excessive deformations occurring due to heavier wheel loads are not recoverable, i.e. settlements are permanent.
8	Black top pavement provides poor visibility at night	These possess good visibility at night
9	Maintenance cost is high	Maintenance cost is low
10	Thickness is more	Thickness is less
11	Suitable for all types of traffic	These become noise under heavy wheeled traffic
12	Less durable	More durable
13	Moderate skill and less supervision is needed	High skill and more supervision is needed
14	These can be opened soon after construction	These require minimum 1 month for curing after construction which delay to opening traffic
15	Life of pavement is 1 – 15 years	Life of pavement is 30 - 60 years

2.3.3 Types of joints

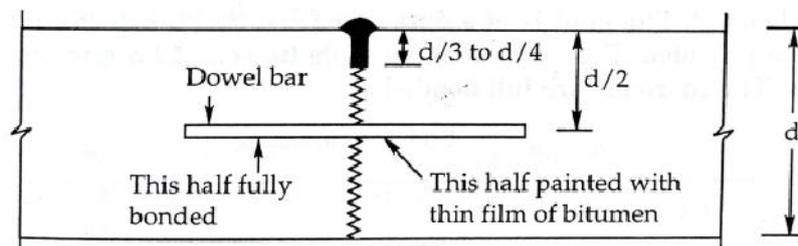


Expansion joint: Expansion joints as the name itself signifies are intended to provide space in the pavement for expansion of the slabs. Expansion takes place when the temperature of the slab rises above the value when it was laid. It is normally a traverse joint. Expansion joint also relieve stresses caused by contraction and warping. Expansion joints are omitted altogether in modern practice.



Expansion joint.

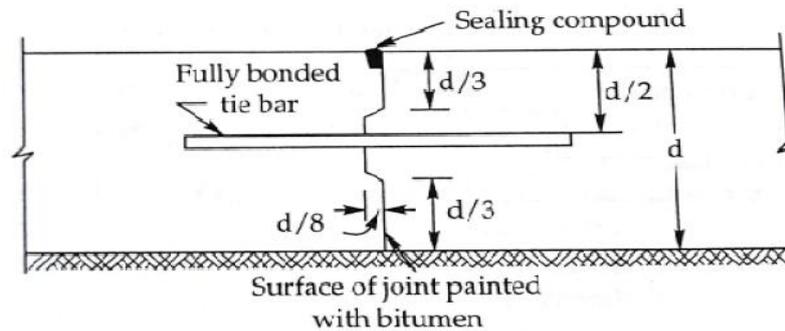
Contraction joint (Dummy joint): When the temperature of concrete falls below the laying temperature, the slab contracts. If a long length of slab is laid, the contraction induces tensile stresses and the slab cracks. If joints are provided at suitable intervals transversely, the appearance of cracks at places other than the joints can be eliminated. Contraction joints also relieve warping stresses to some extent.



Dummy contraction joint.

Warping joint: Warping joints also known as hinge joints are joints which are intended to relieve warping stresses. They permit hinge action but no appreciable separation of adjacent slabs. Warping joints can be longitudinal or traverse. A major difference between the warping joints and the expansion or contraction joints is that in the former appreciable changes in the

joint width are prevented. This is achieved by continuation of reinforcing steel through the joint or by the installation of the bars across the joint.

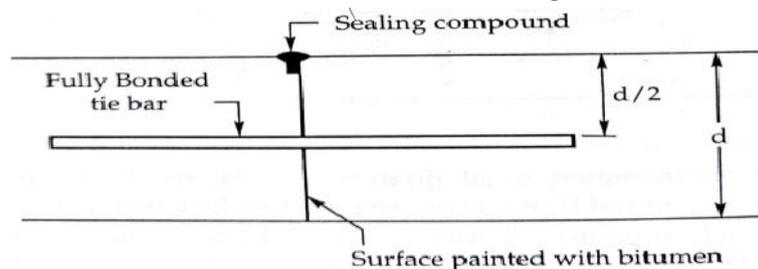


Tongue and groove longitudinal warping joint.

Construction joint: A contraction joint becomes necessary when work has to be stopped at a point where there would be no other joint. It is advisable to plan a day's work such that the work stops at an expansion or contraction joint. Such joints should be regular in shape, by placing a cross-form in position. The reinforcement should be continued across the joint. A groove in the joint with a sealing compound will arrest the entry of foreign matter and is desirable.

Longitudinal joint: When the pavement width is more than 5m it is necessary to provide a longitudinal joint and construct the pavement in strips. These joints allow for warping and uneven settlement of the subgrade.

The purpose of longitudinal joints is to reduce warping stresses and uneven settlements, it is very necessary to provide for some form of load transferring device. Load transferring is done by tie bars (12.5 mm to 25 mm) at 60 cm centres and of a length of 1 m. Tie bars are fully bonded. The joint is a butt-type. Alternatively a tongue and groove joint may be provided with suitable tie bars 12.5 mm diameter, 1 m long and at 60 – 70 cm centres.



Butt type longitudinal joint with tie bar.

2.3.4 Stresses in Flexible Pavement:

Vertical stress: Vertical stress affects the pavement by compressing the pavement material. When pavement compresses, then material in a pavement gets crushed and as a result rutting becomes visible on the top horizontal pavement.

Rutting: Rutting is the depression in the surface of wheel path. Along the sides of the rutting, pavement may uplift (due to shear). These ruts are very clear in the pavement after rain when ruts are filled up with water.

Shear stress: Shear stress occurs in the pavement when load is more than the capacity of the pavement. When load approaches the critical point, then as a result movement occurs in the base layer and that movement is responsible for the shear stress in the top pavement.

Radial stresses: When tension occurs at the bottom of layers due to seepage, removal of material from particular layer or by any other mean. As a result fatigue cracking occurs in the pavement due to wear and tear of loads. That cracking leads to radial stresses in the pavement.

2.3.5 Stresses in Rigid Pavement:

Temperature Stresses: Temperature differential between the top and bottom of the slab causes curling (warping) stress in the pavement

If the temperature of the upper surface of the slab is higher than the bottom surface then top surface tends to expand and the bottom surface tends to contract resulting in compressive stress at the top, tensile stress at bottom and vice versa

Frictional stresses: The friction between a concrete slab and its foundation causes tensile stress

- In the concrete,
- In the steel reinforcements and
- In tie bars

For plain concrete pavements, the spacing between contraction joints is so chosen that the stresses due to friction will not cause the concrete to crack.

Longer joint spacing than that above requires the provision of temperature steel to take care of the stresses caused by friction.

The numbers of tie bars are also determined by frictional stresses.

Wheel Load Stresses: Wheel load stresses caused by the heavy wheel loads applied at the critical locations of interior, edge and corner of the pavement.

2.4 Highway Drainage

2.4.1 Significance of Drainage

An increase in moisture content causes decrease in strength or stability of a soil mass the variation in soil strength with moisture content also depends on the soil type and the mode of stress application. Highway drainage is important because of the following reasons:-

- Excess moisture in soil subgrade causes considerable lowering of its stability the pavement is likely to fail due to subgrade failure.
- Increase in moisture cause reduction in strength of many pavement materials like stabilized soil and water bound macadam.
- In some clayey soils variation in moisture content causes considerable variation in flume of subgrade. This sometimes contributes to pavement failure.
- One of the most important causes of pavement failure by the formation of waves and corrugations in flexible pavements is due to poor drainage.

- Sustained contact of water with bituminous pavements causes failures due to stripping of bitumen from aggregates like loosening or detachment of some of the bituminous pavement layers and formation of pot holes.
- In places where freezing temperatures are prevalent in winter, the presence of water in the subgrade and a continuous supply of water from the ground water can cause considerable damage to the pavement due in frost action.
- Excess water on shoulder and pavement edge causes considerable damage.
- Erosion of soil from top of un-surfaced roads and slopes of embankment, cut and hill side is also due to surface water.
- The prime cause of failure in rigid pavements by mud pumping is due to the presence of water in fine sub-grade soil

2.4.2 Requirements of highway drainage system:

- The surface water from the carriageway and shoulder should effectively be drained off without allowing it to percolate to sub-grade.
- The surface water from the adjoining land should be prevented from entering the roadway.
- The side drains should have sufficient capacity and longitudinal slope to carry away all the surface water collected.
- Flow of surface water across the road and shoulders and along slopes should not cause formation of cross ruts or erosion.
- Seepage and other sources of underground water should be drained off by the subsurface drainage system.
- Highest level of ground water table should be kept well below the level of sub-grade, preferably by at least 1.2 m.
- In water logged areas special precautions should be taken, especially if detrimental salts are present or if flooding is likely to occur.

2.4.3 Surface drainage:

The surface water is to be collected and then disposed off. The water is first collected in longitudinal drains, generally in side drains and then the water is disposed off at the nearest stream, valley or water course. Cross drainage structures like culverts and small bridges may be necessary for the disposal of surface water from the road side drains.

Collection of surface water:

Camber or cross slope

The water from the pavement surface is removed by providing the camber or cross slope to the pavement. Rate of this cross slope is decided based on type of pavement surface and amount of rainfall. The values of camber range from 1 in 25 or 40% for earth road to 1 in 60 or 1.7% for high type bituminous surface and CC pavements.

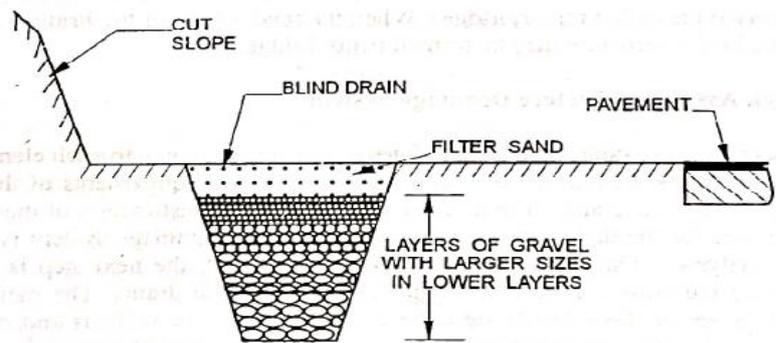
Road side drains

Road side drains of highways passing through rural areas are generally open, unlined or kutchra drains of trapezoidal shape, cut to suitable cross section and longitudinal slopes. These

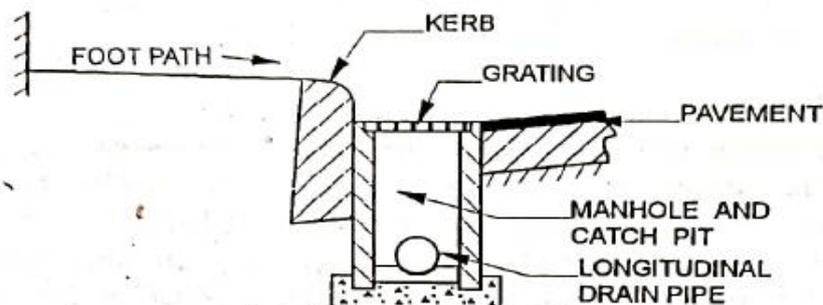
side drains are provided parallel to the road alignment and hence these are also called longitudinal drains.

In embankments the longitudinal drains are provided on one or both sides beyond the toe.

In cuttings, drains are installed on either side of the formation. But in places where there is restriction of space, construction of deep open drains may be undesirable. This is particularly true when the road formation is in cutting. In such cases covered drains or drainage trenches properly filled with layers of coarse sand and gravel may be used.



In urban roads because of the limitation of land and also due to the presence of foot path, dividing islands and other road facilities, it is necessary to provide underground longitudinal drains. Water drained from the pavement surface can be carried forward in the longitudinal direction between the kerb and the pavement for short distance.



Drainage of surface water is all the more important in hill roads. If the drainage system in hill road is not adequate and efficient, it will result in complex maintenance problems.

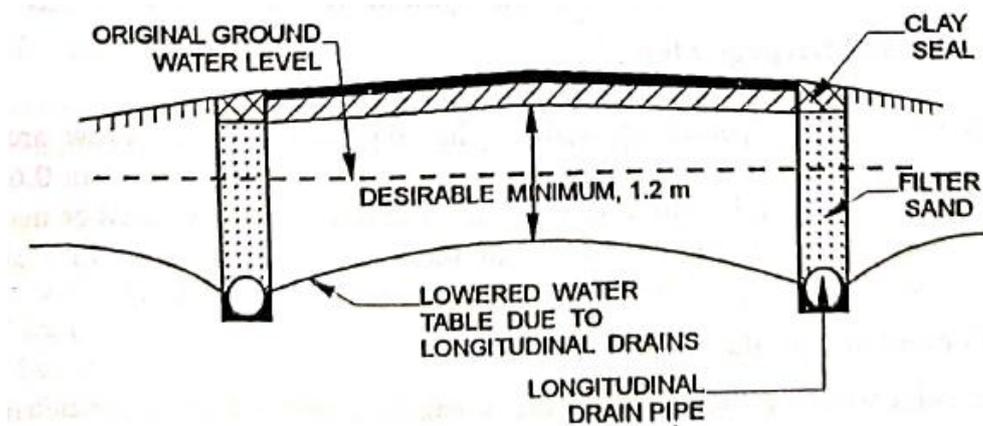
2.4.4 Sub-surface drainage:

Changes in moisture content of sub-grade are caused by fluctuations in ground water table seepage flow, percolation of rain water and movement of capillary water and even water vapour.

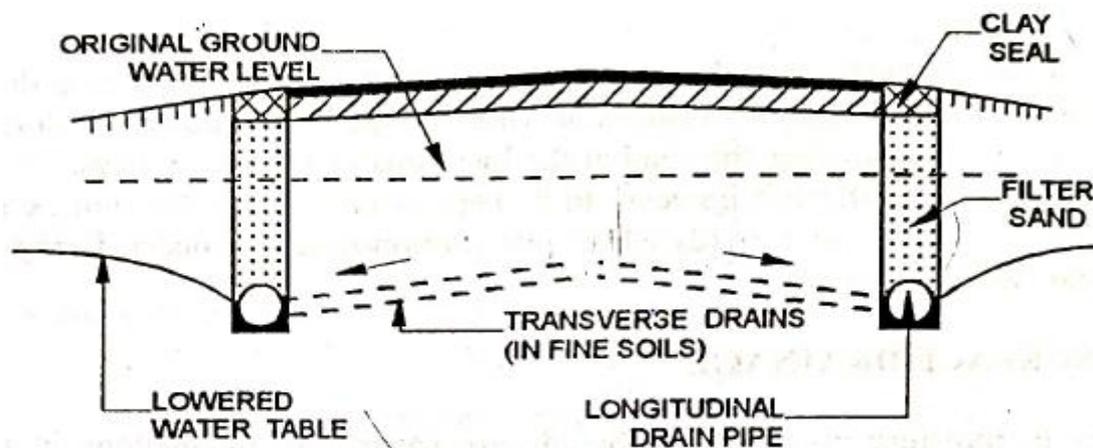
Lowering of water table:

The highest level of water table should be fairly below the level of sub-grade. From practical considerations it is suggested that the water table should be kept at least 1.0 to 1.2 m below the sub-grade. In places where water table is high the best remedy is to take the road formation on embankment of height not less than 1.0 to 1.2 m.

If the soil is relatively permeable, it may be possible to lower the high water table by merely construction of longitudinal drainage trenches with drain pipe and filter sand.

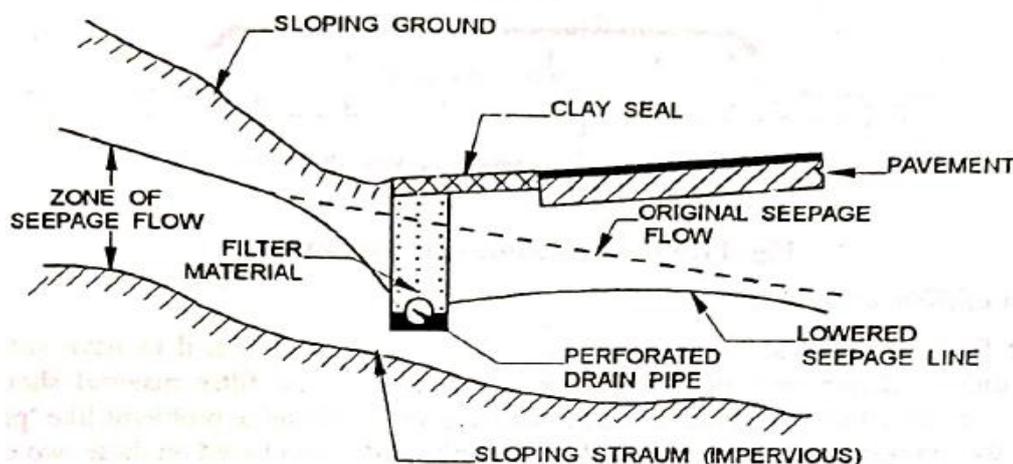


If the soil is relatively less permeable, the lowering of the ground water level may not be adequate at the centre of pavement or in between the two longitudinal drainage trenches. Hence in addition transverse drains may have to be provided in order to effectively drain off the water and thus to lower water table up to the level of transverse drains.



Control of seepage flow:

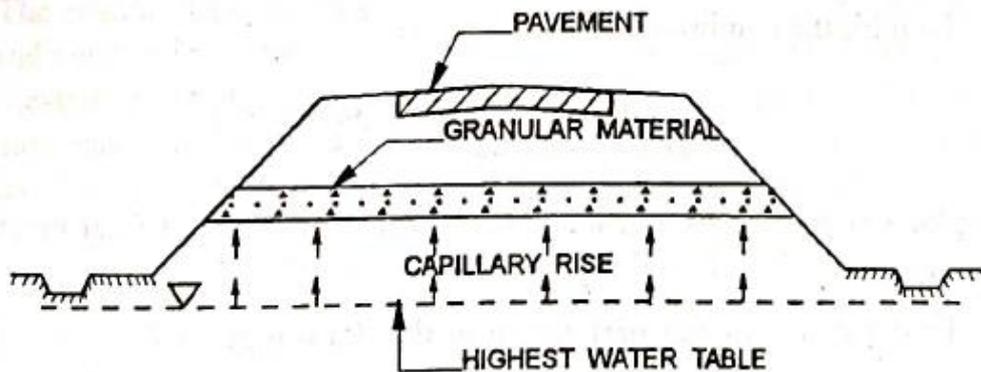
When the general ground is having impervious strata below the sloping, seepage flow is likely to exist. If the seepage zone is at depth less than 0.6 t 0.9 m from the sub-grade level, longitudinal pipe drain in trench filled with filter material and clay seal may be constructed to intercept the seepage flow.



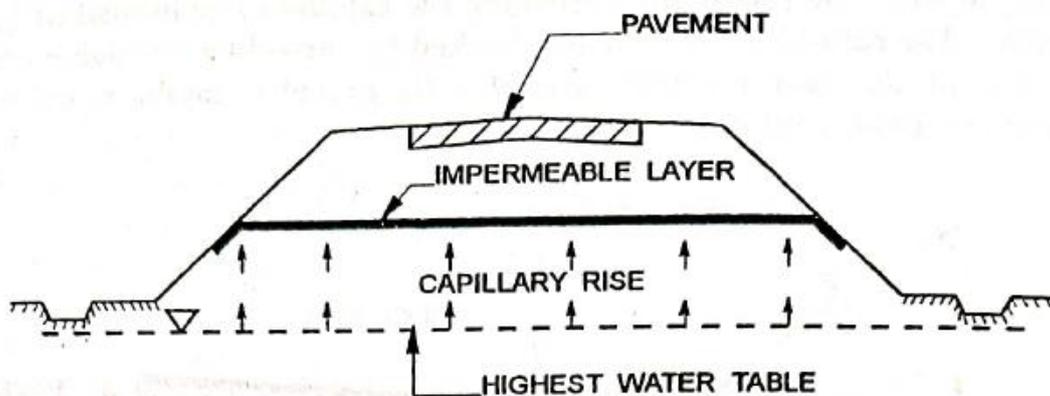
Control of capillary rise:

If the water reaching the sub-grade due to capillary rise is likely to be detrimental, it is possible to solve the problem by arresting the capillary rise instead of lowering the water table. The capillary rise may be checked either by a capillary cut-off of any of the following two types:

- i. A layer of granular material of suitable thickness is provided during the construction of embankment, between the sub-grade and the highest level of subsurface water table.



- ii. Another method of providing capillary cut-off is by inserting an impermeable or a bituminous layer in the place of granular blanket.



2.4.5 Types of cross drainage structures, their choice and location

Whenever streams have to cross the roadway, facility for cross drainage is to be provided. Also often the water from the side drain is taken across by these cross drains in order to divert the water away from the road side drain to a water course or valley. The cross drainage structures commonly in use are culverts and small bridges. When a small stream crosses a road with a linear water way less than about 6m, the cross drainage structure provided is called culvert; for higher values of linear waterway, the structure is called a bridge.

The common types of culverts in use are: slab culvert, box culvert, arch culvert and pipe culvert.

In slab culvert RCC slab is placed over abutments made of masonry and the span is generally limited to 3m. Box culverts of square or rectangular shapes are made of RCC. Arch culvert is generally built using brick or stone masonry or plain cement concrete. A pipe

culverts of minimum diameter 75 cm and made of steel or prefabricated RCC used when the discharge is low.

Various types of bridges are in use; the choice is based on several considerations including the span. RCC and pre-stressed concrete bridges are commonly constructed these days.

On less important roads in order to reduce the construction cost of cross drainage structures, sometimes submersible bridges or cause-ways are constructed. During the floods the water will flow over the road at the locations of the cause-ways. The total period interruption to traffic has however to be kept as low as possible, not exceeding about 15 days in a year. Such roads interruption to traffic occurs during floods are called fair weather roads.

2.5 Recommended questions

1. What are the types of pavement? What are the component parts of flexible pavement and mention their functions
2. Explain the desirable properties of road aggregates.
3. Explain the desirable properties of subgrade soil.
4. Write a note on carriage way, right of way and camber with sketches.
5. Write a note on surface drainage system
6. What are the requirements of highway drainage system?

2.6 Outcomes

Design road geometrics, structural components of pavement and drainage

2.7 Further Reading

1. <https://www.aboutcivil.org/types-of-pavements.html>
2. <http://nptel.ac.in/courses/105101087/downloads/Lec-13.pdf>
3. <http://transportationengineering2012onwards.blogspot.in/2013/09/engineering-surveys-and-location-of.html>
4. <http://www.pavementinteractive.org/subsurface-drainage/>
5. <http://agriculture.vic.gov.au/agriculture/dairy/managing-wet-soils/types-of-subsurface-drainage-systems>

Module – 3

Traffic Engineering

Structure

- 3.0 Introduction
- 3.1 Objectives
- 3.2 Traffic Characteristics
- 3.3 Reaction time of the driver
- 3.4 Traffic Surveys
- 3.5 Concept of PCU value
- 3.6 Traffic Signs
- 3.7 Recommended questions
- 3.8 Outcomes
- 3.9 Further Reading

3.0 Introduction

Traffic engineering is a sub-discipline of civil engineering that deals with the safe, efficient, and economical movement of people and goods on roadways. It involves the planning, design, and operation of streets and highways, as well as the application of scientific principles, tools, and techniques to achieve these goals. This includes addressing issues such as traffic flow, geometric design, and traffic operations, with the ultimate aim of optimizing transportation performance and efficiency. In essence, traffic engineering is a critical component of transportation engineering, which seeks to ensure the safe and efficient movement of people and goods on a global scale.

3.1 Objectives

Realize the significance of road safety by incorporating the concepts of Traffic Engineering.

3.2 Traffic Characteristics

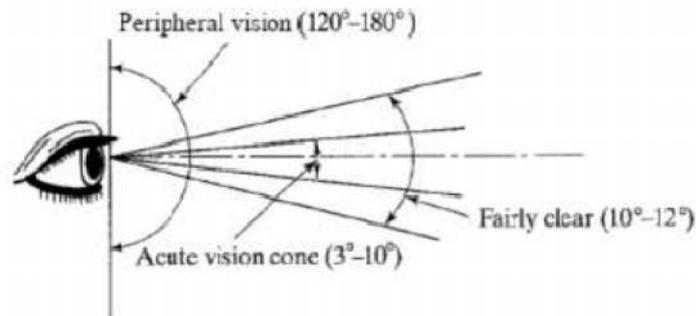
3.2.1 Road User Characteristics

It is important to study the characteristics and limitations of road users because the physical, mental and emotional characteristics of human beings affect their ability significantly.

Several factors influence road user characteristics:

Physical characteristics: Physical characteristics of road users may be either permanent or temporary. The permanent physical characteristics of the driver are vision, hearing, strength and the general reaction to the traffic situations.

Vision: Vision plays the most important role. These include the acuity of vision, peripheral vision and eye movement; glare vision, glare recovery and depth judgment. Field of accurate, clear vision is about a 3 degrees cone. However, the vision is fairly satisfactory up to 10 degrees in general and 20 degrees in horizontal plane. In vertical plane the vision may be limited to 2/3 of that in horizontal plane. These factors are particularly taken care of while designing and installing traffic control devices.



Hearing: Hearing plays an important role when the vision gets affected at horizontal curves and also at vertical curves. At this situation hearing plays an important role in alerting driver about danger, and more important for the pedestrians and cyclists.

Strength: Strength is not an important factor in general; lack of strength may make parking manoeuvres difficult, particularly for heavy vehicles.

Mental Characteristics: Knowledge, skill, intelligence, experience and literacy can affect the road user characteristics. Knowledge of vehicle characteristics, traffic behaviour, driving practice, rules of roads and psychology of road users will be quite useful for safe traffic operations.

Psychological factors: These affect reaction to traffic situations of road users to a great extent. Attentiveness, anger, fear, anxiety, phobias, superstition, and impatience may affect the traffic performance to great extent.

Environmental factors: Facilities to the traffic, atmospheric condition and locality.

3.2.2 Vehicular characteristics

It is important to know about the vehicle characteristics because we can design road for any vehicle but not for an indefinite one. The road should be such that it should cater to the needs of existing and anticipated vehicles. Some of the vehicle factors that affect transportation is discussed below. Vehicular characteristics consist of

Static Characteristics

Static characteristics of vehicles affecting road design are:

- Dimensions
- Weight
- Maximum turning angle
- The height of vehicle affects the clearance of the overhead structures.
- The height of driver seat affects the visibility distance and the height of head light affects the head light sight distance (HLSD) at valley curves.
- The length of vehicles affects the capacity, overtaking distance and maneuverability of vehicles.
- The minimum turning radius depends on the length of wheel base.
- The features of the steering system may affect design of sharp curves for the maneuver of vehicles at slow speeds.

- Gross weight, axle load and wheel load of vehicle govern the structural design of pavements and cross drainage structures.

Dynamic Characteristics

Dynamic characteristics of vehicles affecting road design are:

- Speed
- Acceleration
- Braking characteristics

Speed of Vehicle: The vehicle speed affects:

- Sight distances.
- Super elevation, length of transition curve and limiting radius on horizontal curve.
- Capacity of traffic lane.
- Design and control measures on intersections

The speed depends upon the power of the engine.

Acceleration: Acceleration rate is governed by the vehicle transmission system, weight and horse-power. It is necessary to understand acceleration characteristics when designing the intersection elements (acceleration lane, etc.) and overtaking sight distance.

Braking Characteristics: The deceleration and braking characteristics of vehicles depend on the design and type of braking system (such as mechanical, fluid or air brake) and its efficiency.

3.3 Reaction time of the driver:

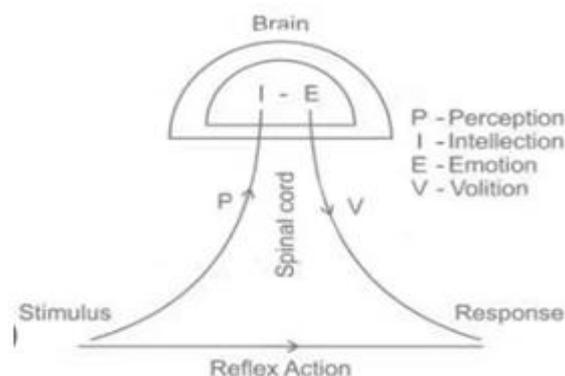
Reaction time of a driver is the time taken from the instant the object is visible to the driver to the instant when the brakes are applied. The total reaction time may be split up into four components based on PIEV theory.

Perception time is the time required for the sensations received by eyes or ears to be transmitted to the brain through nervous system and the spinal cord.

Intellection time is the time required for understanding the situation. It is also the time required for comparing the different thoughts, regrouping and registering new sensations.

Emotion time is the time elapsed during emotional sensations and disturbance such as fear, anger or any other emotional feelings such as superstition etc.

Volition time is the time taken for the final action.



In practice, all these times are usually combined into a total perception- reaction time suitable for design purposes as well as for easy measurement. Many of the studies show that drivers require about 1.5 to 2 sec under normal conditions. However taking into consideration the variability of driver characteristics, a higher value is normally used in design. For example, IRC suggests a reaction time of 2.5 sec.

3.4 Traffic Surveys

3.4.1 Speed Studies

Spot Speed

It is the instantaneous speed of a vehicle at a specified location.

Objectives of Spot Speed Studies

Following are the objectives of spot speed studies:

- 1) To establish the trends in operating speeds by periodic collection of data.
- 2) To check the speed at problem locations whether the speeds are too high or not.
- 3) In accidents analysis, to obtain the relationship of speed to accidents.
- 4) To evaluate the capacity of a road w.r.t. speed.
- 5) In before-and-after studies, to evaluate the effect of changes in conditions.
- 6) In enforcement to find out the effectiveness of traffic control.
- 7) For geometric design features these are helpful in following ways:
 - a) To find out the design speed.
 - b) To design curvature, sight distance, super elevation, etc.
- 8) Data collected in these studies is helpful in traffic regulation and control in the following ways:
 - a) To establish speed limits
 - b) To locate traffic signs
 - c) To located and designing of traffic signals
 - d) Establishing speed zones.
 - e) Safe speeds on curves and at intersections.

Methods of Measuring Spot Speeds

The methods available for measuring spot speed can be grouped as below:

- 1) Those that require observation of the time taken by vehicle to cover a known distance.
 - a) Those in which vehicles are timed over a long distance (long distance)
 - Direct timing procedure
 - Enoscope
 - Pressure contact tubes
 - b) Those in which vehicles are timed over a short distance (short base)
 - Use of vehicle detectors over a short distance
- 2) Radar speedmeter
Automatically records the instantaneous speed
- 3) Photographic method and video camera method

Direct-Timing Procedure for Spot Speed Determination

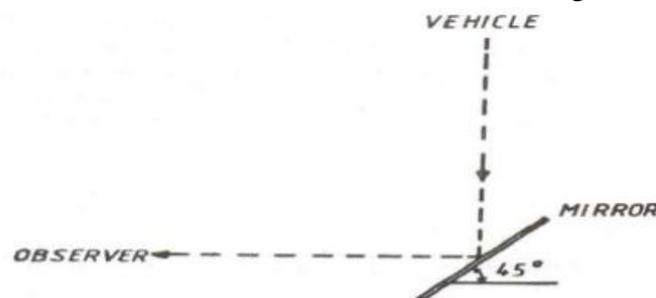
It is one of the simplest method for spot speed determination.

Procedure

- Two reference points are marked on the pavement at a suitable distance apart and an observer starts and stops the stop-watch as a vehicle crosses these two marks.
- From the known distance and by the measured time intervals speed can be calculated.
- Skilled observers can read a stop-watch to an accuracy of 0.2 second.
- The disadvantage with this method is that large errors are likely to be introduced because of the parallax effect.
- A simple variation of this method is to station two observers, one at each reference point. The observer standing at the reference point which the vehicle passes first, signals that a vehicle to be timed is passing the point and the second observer then starts watch. The second observer stops the stop watch when he observes the same vehicle passing the reference point. The disadvantage with this method is that it involves the reaction time of two individual observers.

Enoscope

It is also known as the mirror-box. It is an L-shaped box, open at both ends, with a mirror set at a 45-degree angle to the arms of the instrument as shown in figure.

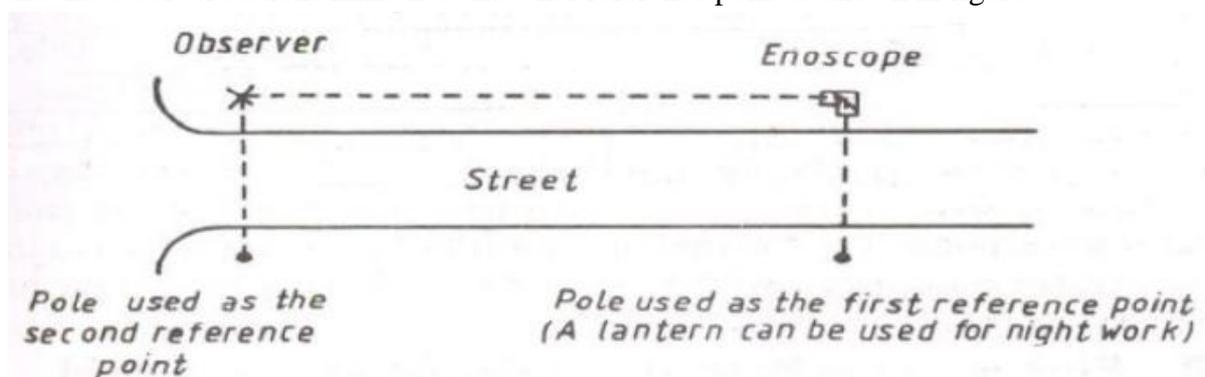


Enoscope eliminates the parallax effect that creeps in when the direct readings are taken by one observer.

Working Principle/Procedure

The instrument bends the Line of Sight (LoS) of the observer so that it is perpendicular to the path of the vehicle. The method can be used with one enoscope or with two enoscopes.

If one enoscope is used, the instrument is placed directly opposite to the first reference point and the observer stations himself at the other reference point as shown in figure.



The stop-watch is started as soon as the vehicle passes the first reference point and is stopped as soon as it passes the second reference point (observer). If two enoscopes are used, the observer stations himself mid-way between the two reference points and starts the stop-watch as soon as a vehicle crosses the first reference point and stops the stop-watch when it crosses the second reference point.

Advantages of Enoscope

- 1) It eliminates parallax errors
- 2) It is very easy, flexible and fairly reliable
- 3) Lesser cost involved
- 4) It provides extra time in judging the vehicle, when it crosses the course length.

Disadvantages of Enoscope

- 1) Progress of work is very slow
- 2) It is not advisable for heavy multi-lane traffic and lesser number of samples are observed.

Pressure Contact Tubes

- In this method, detectors (usually pneumatic tubes) are used to indicate the time of entering and leaving the base length.
- When a vehicle passes over the tube laid at the first reference point, an air impulse is sent, which activates an electromagnetically controlled stop-watch in the hands of the observer.
- When the vehicle passes over the second tube, the stop-watch automatically stops.
- The reading is noted by the observer. Alternatively, the readings can be recorded by automatic data recorders.

Short-Base Methods

Use of Vehicle Detectors over a Short Distance

In short-base methods, the base length for measuring the speeds is very short, say about 2m.

The instruments are electronic and are used in conjunction with pneumatic tubes or electric detectors laid across the pavement.

Recording can be manual i.e., the instantaneous speeds being noted by the observer or can be automatic with an electronic system.

2) Radar Speedmeter

These meters work on the Doppler principle that the speed of a moving body is proportional to the change in the frequency between the radio wave transmitted to the moving body and the radio wave received back.

The instrument directly measures the speed at an accuracy of at least ± 1.5 to 3 kmph. The instrument is battery operated and is portable.

The speed meter is so kept that the angle between the direction of travel of the vehicle and the axis of transmission of the radio wave is as low as possible, within 20° . The

instrument is set up near the edge of the carriage way at a height of about 1m, above the ground level. The speeds of vehicles in both directions can be observed by this method.

This method has been extensively used for traffic engineering studies as well as for enforcement by traffic police.

3) Photographic Method and Video Camera Method

This method is adopted in crowded streets to determine the speeds of vehicles. According to this method, photographs are taken at fixed intervals of time on a special camera. By projecting the film on a screen, the passage of any vehicle can be traced with reference to time. Images by video cameras can also be used.

3.4.2 Journey Time and Delay Surveys

Running Speed and Journey Speed

Running speed is the average speed maintained by a vehicle over a given course while the vehicle is in motion. Running speed excludes that part of the journey time when the vehicle suffers delay.

$$\text{Running speed} = (\text{Length of the course}) / (\text{Running time})$$

$$\text{Running speed} = (\text{Length of the course}) / (\text{Journey time} - \text{delay})$$

Journey speed (overall travel speed) is the effective speed of a vehicle between two points and is the distance between two points divided by the total time taken by the vehicle to complete the journey, including all delays incurred en-route.

$$\text{Journey speed} = (\text{Distance}) / (\text{Total journey time (including delays)})$$

Use of Journey Time and Delay Studies

- 1) The cost of a journey depends upon the speed at which it is made. In all highway economic studies, journey speeds and delay are highly important.
- 2) Journey-time studies on a road network in a town are useful to evaluate congestion, capacity, level of service and the need for improvements.
- 3) In transportation planning studies, the determination of the travel time is necessary for carrying out the trip assignment. Also travel time and delays are some of the factors affecting modal choice.
- 4) Before-and-after studies pertaining to journey time are useful for assessing the effectiveness of improvement measures.
- 5) Delay studies at intersections provide data for the design and installation of the appropriate traffic control device.

Methods for Measurement of Running Speed and Journey Speed

The methods commonly used for measuring running speed and journey speed are:

1) Floating Car Method

In this method, a test vehicle is driven over a given course of travel at an average speed of the traffic stream, thus trying to float with the traffic stream.

A number of test runs are made along the study stretch and a group of observers record the various details.

First observer is seated in the floating car with two stop watches. One of the stop watches is used to record the time at various control points like intersections, bridges or any other fixed points in each trip. The other stop watch is used to find the duration of individual delays.

The **second observer** records the time, location and cause of these delays on suitable tabular forms or by voice recording equipment.

The number of vehicle overtaking the test vehicle and that overtaken by the test vehicles are noted in each trip by a **third observer**.

The number of vehicles travelling in the opposite direction in each trip is noted by a **fourth observer**.

But in mixed traffic flow, more number of observers is required to count the vehicles of different classes. In this method the detailed information is obtained concerning all phases of speed and delay including location, duration and causes of delay.

2) Vehicle Number Method

In this method, synchronized stop-watches or voice recording equipment are used. Observers are stationed at the entrance and exit of a test section where information of travel time is required. The timings and the vehicle numbers are noted by the observers of the observers of the selected sample. From the office computations, travel time of each vehicle could be found. But the method does not give important details such as causes of delays and the duration and number of delays within the test section.

3) Elevated Observation and Photographic Technique

These methods are useful for studying short test sections like intersections, etc.,

Studies at each intersection will help in evaluating the efficiency and effectiveness of the control device like signal system, remedial measures for accidents, etc.

4) Interview Technique

In this method, 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.

Delay Studies

It is done by the moving observer method. The delays occurring due to stopping can be recorded by separate stop-watch. The delays which are measured may be of stopped delays or fixed delays which occur at intersections, railway crossing and stop signs.

In addition to **stopped delays**, there are delays which are caused by the interaction of various factors such as congestion, inadequacy of carriage widths, mixed traffic conditions, parked cars and heavy pedestrian flow. This kind of delay is called **congestion delay or operational delay** and it is difficult to be measured precisely.

One method of measuring congestion delay is to determine the average running speed when the traffic conditions are free-moving and vehicles are free to move without any hindrance. The difference between this speed and the actual speed under congested conditions gives an idea of the congestion delay.

Design Speed: It is the maximum safe speed selected which can be maintained over a particular section of highway under favourable conditions of weather, traffic and road geometrics.

Median Speed: It is the speed represented by a middle value when all the speeds are arranged in ascending order. It is known as 50th percentile speed.

50th Percentile Speed: Out of total observations half the speed values will be above and half will be below the speed.

85th Percentile Speed: It is the speed below which 85% of the vehicles will travel. It is the speed at which motorists are tempting the safety conditions of highway and should not be exceeded. It is often used as criteria in establishing the upper limit of speed for traffic management purpose.

98th Percentile Speed (or) Speed Limit for Geometric Design: It is the speed at which 98% of observed vehicles are travelling at or below that particular speed.

Modal Speed: It is the speed at which more number of vehicles travel. It is the peak of a frequency distribution curve. It is the speed value which occurs frequently and this speed is having highest frequency of observations.

Average Speed: It is the average of spot speeds of all the vehicles passing a given point on the highway.

This is of two types:

- a) Space-Mean Speed: It is the speed corresponding to average of overall travel time to cover a particular section of highway.
- b) Time-Mean Speed: It is also known as arithmetic mean speed. It is obtained by adding all the journey speeds at different observations and is divided by the number of observations.

3.4.3 Vehicles Volume Survey

Traffic Volume

It is the number of vehicles crossing or passing a section of road per unit time at any selected period. It is generally expressed as number of vehicles per day or number of vehicles per hour.

Objects and Uses of Traffic Volume Studies

- 1) Traffic volume is generally accepted as a true measure of the relative importance of roads and in deciding the priority for improvement and expansion.
- 2) Traffic volume study is used in planning, traffic operation and control of existing facilities and also for planning and designing the new facilities.
- 3) This study is used in the analysis of traffic patterns and trends.
- 4) Classified volume study is useful in structural design of pavements, in geometric design and in computing roadway capacity.

- 5) Volume distribution study is used in planning one-way streets and other regulatory measures.
- 6) Turning movements study is used in the design of intersections, in planning signal timings, channelization and other control devices.
- 7) Pedestrian traffic volume study is used for planning sidewalks, cross walks, subways and pedestrian signals.

By conducting traffic volume studies following details are obtained:

- 1) Direction and volume of traffic
- 2) Hourly, daily, yearly and seasonal traffic volume variations
- 3) Proportion of cars, heavy and slow vehicles on roads
- 4) Variation of vehicle flow on different parts of the road system.

Objectives

- 1) To establish relative importance of any route or road facility.
- 2) To plan one-way streets and other regulatory measures.
- 3) To analyse the traffic patterns and trends.
- 4) For economic studies.
- 5) To plan and design new streets and facilities.
- 6) For research, regulation of traffic.
- 7) To design intersections, in planning signal cycles, for channelization and for controlled devices
- 8) To plan sidewalks, cross walks, subways and pedestrian signals
- 9) To establish priorities and schedules of traffic improvements.
- 10) To measure and establish trends in traffic volume.

Methods of Traffic Volume Studies

- 1) Manual counts/methods
- 2) Mechanical counts/methods

These include:

- a) Pneumatic counter
- b) Photoelectric cells
- c) Radar detector
- d) Ultrasonic device
- e) Magnetic detector
- f) Infrared device, etc

Manual Counts

This method employs a field team to record traffic volume on the prescribed record sheets. By this method it is possible to obtain data which cannot be collected by mechanical counters, such as vehicle classification, turning movements and counts where the loading conditions or number of occupants are required.

Advantages of Manual Methods

- 1) These are simple and quick
- 2) These are flexible and no requirement of setting up of instruments at field or special skills
- 3) Turning movements and direction of movements are recorded
- 4) Traffic classification is cheaper for specific purpose and for short counts
- 5) These are mainly suitable for short term and non-continuous counts.
- 6) Data collected gives information about break-down of traffic in each direction
- 7) In rural areas, this is more suitable due to vandalism
- 8) In developing and under developed countries sophisticated automatic devices are not available.

Disadvantages of Manual Methods

- 1) For longer counts these are expensive.
- 2) It is unsuitable in bad weather condition
- 3) Mainly depends on accuracy and efficiency of the observer
- 4) It is very difficult to conduct manual counts for 24hours in a day for all 365 days

Mechanical Counters

These may be either fixed (permanent) type or portable type. The mechanical counter can automatically record the total number of vehicles crossing a section of the road in a desired period. The working may be by the effect of impulses or stimuli caused by traffic movements on a pneumatic hose placed across the roadway or by using any other type of sensor. Traffic count is recorded by electrically operated counters and recorders capable of recording the impulses. The impulses caused by vehicles of light weight may not be enough in some cases to actuate the counter. Also it is not possible to easily record pedestrian traffic by this method.

Advantages of Mechanical Methods

- 1) This can be used in all weather conditions and at all times
- 2) If maintained properly these gives accurate information
- 3) It gives punched data which is easy to analyse by computers
- 4) For long duration counts these are cheaper
- 5) Where continuous and regular flow of traffic is these are widely used, in developed countries and in remote areas.

Disadvantages of Mechanical Methods

- 1) Need of trained and skilled operator/personnel
- 2) Not possible to do classified counts
- 3) Costly equipments requires proper maintenance and safety
- 4) Costly equipments therefore not advisable for shorter duration counts

3.4.4 Pedestrian Volume Studies**Objects**

- 1) To minimise the vehicular delay
- 2) To plan and design traffic control devices

- 3) To increase safety of pedestrians
- 4) To provide a design this minimises pedestrian-vehicle conflicts
- 5) To find the utility of sidewalks.
- 6) To properly design signal timings at intersections.

Non-motorized Transports

The non-motorized transport is promoted by the following two ways:

1) Pedestrianisation

Complete banning of the motor vehicle from certain areas and declaring the same as pedestrian boundaries has a beneficial effect on the traffic situation. It increases the safety of the pedestrians. It gives them the freedom to move about and shop leisurely. It frees the area from the noise, fumes and smell. Contrary to the belief that it may affect adversely the shopping turn-over, it has led to an increase in business. By and large, the motorists, the pedestrians and the commercial interests are all agreed about the beneficial results of pedestrianisation in selected locations.

2) Promotion of Bicycle Traffic

Bicycles are an important mode of personal transport, particularly for the poor sections of society in India. Because of their many advantages, they must be favoured and patronized. Some of the advantages are:

- 1) They are only human energy, and thus avoid the use of scarce oil-based energy resources.
- 2) They do not let out emissions.
- 3) They are noiseless.
- 4) They require very small parking space
- 5) They are cheap to own and operate
- 6) They offer door-to-door mobility
- 7) They can keep the rider in good health
- 8) They are safe, when they are segregated from fast traffic.

3.4.5 Origin-Destination Survey

Origin: Place where trip begins

Destination: Place where trip ends.

Need for O-D Survey

It is necessary to know the exact origin and destination of the trips, how many trips are made and also to group these trips with reference to the zones of their O and D.

Other information yielded by the O-D survey are:

- a) Land use of the zones of O and D.
- b) Household characteristics of the trip making family
- c) Time of the day when the journeys are made
- d) Trip purpose
- e) Mode of travel

Specific Uses

- a) To determine the amount of by-passable traffic that enters a town, and thus establishes the need for a by-pass.
- b) To develop trip generation and trip distribution models in transport planning process.
- c) To determine the extent to which the present highway system is adequate and to plan for new facilities.
- d) To assess the adequacy of parking facilities and to plan for future.

If the survey is needed for urban transportation planning process for a large town. It is necessary to define the study area and sub-divide it into zones.

In the study of transportation problems of towns (big or small) it is necessary to define the external cordon lines.

In big towns, it may be necessary to select some internal cordon lines, which may be concentric rings arranged in a grid pattern.

For checking the accuracy of survey data, it may be necessary to have screen-lines, which are imaginary lines dividing the area into parts.

Methods of O-D Survey

Following are some of the methods available for conducting an O-D survey:

1) Home Interview Survey

It is one of the most reliable types of surveys for collection of origin and destination data. This survey is intended to yield data on the travel pattern of the residents of the house hold and the general characteristics of the house hold influencing trip-making.

The information on travel pattern includes number of trips made, their origin and destination, purpose of trip, travel mode, time of departure from origin and time of arrival at destination and so on.

The information on household characteristics includes type of dwelling unit, no. of residents, age, sex, race, vehicle ownership, no. of drivers, family income and so on.

Based on these data it is possible to relate the amount of travel to household and zonal characteristics and develop equations for trip generation rates.

A number of techniques are available for the home-interview survey they are:

a) Full interview technique: Full interview technique involves interviewing as many members of the household as possible and directly recording all the information, whereas in home questionnaire technique, the interviewer collects only details of the household characteristics, leaving forms for household residents to complete in regard to travel information. The completed forms are collected after one day or two day by the interviewer.

The Full interview technique is more expensive and it may be possible to collect the needed information only at the rate of 8 interviews per 8 hour day per interviewer. The home-questionnaire technique is speedier and it may be possible to cover about 20 households per day.

Full interview technique yields very accurate data, the same cannot be said for the home-questionnaire method.

b) Home questionnaire technique: The information collected from the home-interview survey is classified under two groups:

a) Household information: Household information contains information such as address, size of household, age and gender structure of household, earning members, occupation, place of work, number of motor vehicles owned, household income, etc.

b) Journey data: Journey data contains information on all journeys made during the previous 24 hour period, including the origin and destination of journeys, purpose of trip, mode of travel, etc.

2) Road Side Interview Survey

It is one of the methods of carrying out a screen-line or cordon- survey. The road side interview survey can be done either by directly interviewing drivers of the vehicles at selected survey points or by issuing prepaid cards containing the questionnaire to all the drivers.

The survey points are selected along the junction of the cordon-line or screen-line with the roads. The cordons may be in the form of circular rings, radial lines or rectangular grids.

For small towns (population <5000), single circular cordon at the periphery of the town should suffice. The internal travel being light, the external cordon survey in this case will give the O-D data.

In case of medium sized cities (population range 5000-75,000). Two cordon lines are necessary, the external cordon at the edge of the urban development and the internal cordon at the limits of the central business district. Road side interviews at the intersection of roads with these two cordon lines should be able, to fairly assess the patterns of travel in such cities.

For large cities, the cordon lines and screen lines may be more complicated. The home-interview technique cannot be dispensed. Cordon line and screen line surveys by the road side interview technique serve to check the accuracy of the home interview survey data.

For dual carriageways or roads with very little traffic, traffic in both directions is dealt simultaneously. In other cases the traffic in two directions will be interviewed at different times.

If the survey covers most of the day it may be sufficient to interview traffic in one direction only and to assume that the journeys in the opposite direction are the same as in the direction interviewed.

It is impractical to stop and interview all the vehicles. Hence sampling is necessary which depends on the number of interviewers and traffic using the road.

3) Post Card Questionnaire Survey

In this method, reply paid questionnaires are handed over to each of the drivers at the survey points and requesting them to complete the information and return by post. The method avoids delay caused to the drivers by the direct roadside interview method but suffer from the disadvantage that the response may not be good. It is possible to get a good amount of information from this method. The method is simpler and cheaper than other methods.

4) Registration Number Plate Survey

This consists of noting the registration numbers of vehicles entering or leaving an area at survey points located on the cordon line. By matching the registration numbers of vehicles at the points of entry and exit from the area, one is enabled to identify two points on the paths of the vehicle

5) Tags on Vehicles

In this method, at each point where the roads cross the cordon line, vehicles are stopped and a tag is affixed, usually under a windscreen wiper.

The tags for different survey stations have different shapes and/or colour to identify the survey station. The vehicles are stopped again at the exit points where the tags are removed. The times of entering and leaving the area may be marked on the tags in order to enable the journey times to be determined.

3.4.6 Road accidents

Definition of Accident: An accident (collision, overturning or slipping) which occurred or originated on a road open to public traffic resulting in either injury or loss, or damage to property, in which at least one moving vehicle was involved.

Causes

There are four basic elements in a traffic accident:

- 1) Road users
- 2) Vehicles
- 3) Road and its condition
- 4) Environmental factors- traffic, weather, etc.

1) Road Users:

- a) Drivers of one or more vehicles involved
- b) Pedestrians
- c) Passenger

a) Driver

- Excessive speed and rash driving
- Carelessness
- Violation of rules and regulations
- Failure to see or understand the traffic situation, sign or signal.
- Temporary effects due to fatigue, sleep or alcohol

b) Pedestrians

- Violating regulations
- Carelessness in using the carriage way meant for vehicular traffic.

c) Passenger

- Alighting from or getting into moving vehicles

2) Vehicle

- Failure of brakes
- Steering system failure
- Tyre burst
- Failure in lighting system

3) Road Condition

- Slippery or skidding road surface
- Pot holes, ruts
- Other damaged conditions of the road surface

Road Design

- Defective geometric design like inadequate sight distance
- Inadequate width of shoulders
- Improper curve design
- Improper lighting
- Improper traffic control devices

Environmental Factors

- The favourable weather condition like mist, fog, snow, dust, smoke or heavy rainfall which restricts normal visibility and render unsafe.

Animals

- Stray animals on the road

Other Causes

- Incorrect signs or signals
- Gate of level crossing not closed when required
- Ribbon development
- Badly located advertisement boards, etc.

Effect of Accidents

The various effects of accidents are grouped as:

- 1) Effects on individual
- 2) Effects on national
- 3) Effects on community

Individual Effects of Accidents**Physical Effects**

- 1) Death
- 2) Permanent loss of mobility/functioning
- 3) Fractures
- 4) Bruising
- 5) Burns

Psychological Effects

- 1) Feelings of guilt
- 2) Post-traumatic stress
- 3) Depression
- 4) Anxiety/ fear

Economic Effects

- 1) Loss of earnings
- 2) Medical bills
- 3) Damage to property

Community Effects of Accidents

- 1) Damages to the vehicles
- 2) Other property damages
- 3) Major consequences of the accident, including dislocation and delay to other traffic

Prevention

These are done by “3-Es”:

- a) **Engineering Measures:** Geometric design of roads, preventive maintenance of vehicles, before-and –after studies, road lighting.
- b) **Enforcement Measures:** Speed control, traffic control devices, medical check, training and super vision, law and regulation.
- c) **Educational Measures:** Educating the road users and pedestrians, education on road safety.

3.4.7 Accident Cost

The study conducted by the Central Road Research Institute (CRRI), made an attempt to determine the economic cost of road accidents in India.

Data collected on different types of accidents such as fatal, severe injury, slight injury and property damages. The data on medical expenditure, legal fees, damages to property etc. will be collected. The data from the insurance companies on the road accident claims is collected and the accidents will be classified according to severity, age and sex and type of vehicles involved.

The details of claims made to the insurance companies and the average compensation awarded will also be collected. To account for the loss of output due to death, the future income of the deceased minus the future consumption were evaluated. The future consumption was taken to be one-third of his income.

The future output will be calculated till the age of 55 years, which is between the average national life expectancy and the retirement age.

Cost estimation of injuries and fatalities of individuals in a complex problem, however some standardized norms may be worked out based on the age and earning capacity of the individual involved, severity of injury and probable loss of time, etc.

The cost of each accident may be estimated by working out the cost involved for the following items:

- 1) Injuries and fatalities of persons involved in the accident
- 2) Damages to the vehicles
- 3) Other property damages
- 4) Major consequences of the accident, including dislocation and delay to other traffic
- 5) Investigations and legal proceeding
- 6) Compensations

3.5 Concept of PCU value

The PCU may be considered as a measure of the relative space requirement of a vehicle class compared to that of a passenger car under a specified set of roadway, traffic and other conditions. If the addition of one vehicle of a particular class in the traffic stream produces the same effect as that due to the addition of one passenger car, then that vehicle class is considered equivalent to the passenger car with a PCU value equal to 1.0. The PCU value of a particular vehicle class may be considered as the ratio of the capacity of a roadway when there are passenger cars only to the capacity of the same roadway when there are vehicles of that class only.

Factors affecting PCU values

The PCU values of different vehicle classes depend upon several factors. Some of these factors are listed below:

- (a) Dimensions of vehicles such as width and length,
- (b) Dynamic characteristics of vehicles such as, power, speed, acceleration and braking.
- (c) Transverse and longitudinal gaps or clearances between moving vehicles which depends upon the speeds, driver characteristics and the vehicle classes at the adjoining spaces.
- (d) Traffic stream characteristics such as composition of different vehicle classes, mean speed and speed distribution of the mixed traffic stream and volume to capacity ratio
- (e) Roadway characteristics such as road geometrics including gradient and Roads, access controls, rural or urban road, presence of intersections and the type of intersections.
- (f) Regulation and control of traffic such as speed limit, one way traffic, presence of different traffic control devices, etc.
- (g) Environmental and climatic conditions

Applications of PCU

Traffic Flow Analysis: PCU allows engineers to convert different types of vehicles into a common unit for analysis.

Capacity and Level of Service (LOS) Calculations: When designing or evaluating roadways, engineers use PCU to estimate the maximum capacity of a road segment or intersection.

Traffic Signal Timing: Traffic signals are timed based on the expected flow of PCUs through an intersection.

Highway Design: PCU plays a role in designing highways and intersections to handle expected traffic volumes.

Traffic Impact Studies: When planning new developments or infrastructure projects, traffic impact studies use PCU to predict how changes in traffic patterns will affect existing roads and intersections.

Public Transit Planning: PCU values also influence public transit planning by considering how buses and other transit vehicles affect traffic flow compared to passenger cars.

Traffic Simulation Models: PCU is a fundamental input parameter in traffic simulation models.

Environmental Impact Assessment: PCU values are used to estimate emissions and fuel consumption associated with different vehicle types.

3.6 Traffic Signs

Importance of Traffic Signs:

Traffic signs perform a number of functions:

- 1) They give timely warning of hazardous situations when they are not self evident.
- 2) They are of great help in regulating traffic by imparting messages to the drivers about the need to stop, give way and limit their speeds.
- 3) They give information as to highway routes, directions and point of interest.

According to Indian Motor Vehicles Act, the traffic signs have been divided into three categories, they are:

- 1) Regulatory signs
- 2) Warning signs
- 3) Informatory signs

The signs should be placed such that they could be seen and recognized by the road users easily and in time. The transverse location of the signs may be such that in the case of roads with kerbs, the edge of the sign adjacent to the road is not less than 0.6m away from the edge of the kerb; on roads without kerbs (as on rural highways with shoulders) the nearest edge may be 2.0 m to 3.0 m from the edge of the carriageway. The signs should be mounted on sign posts painted alternately with 25 cm black and white bands, the size, shape, colour code and the symbols used and the location of the signs should be as specified under each category. The reverse side of all the sign plates should be painted gray.

Regulatory Signs

Regulatory or mandatory signs are meant to inform the road users of certain laws, regulations and prohibitions; the violation of these signs is a legal offence.

The regulatory signs are classified under the following sub-heads:

- a) Stop and Give-way signs
- b) Prohibitory signs
- c) No parking and No Stopping signs
- d) Speed Limit and Vehicle Control signs
- e) Restriction Ends sign
- f) Compulsory Direction Control and other signs

The stop sign is intended to stop the vehicles on a roadway. The give way sign is used to control the vehicles on a road so as to assign right of way to traffic on other roadways

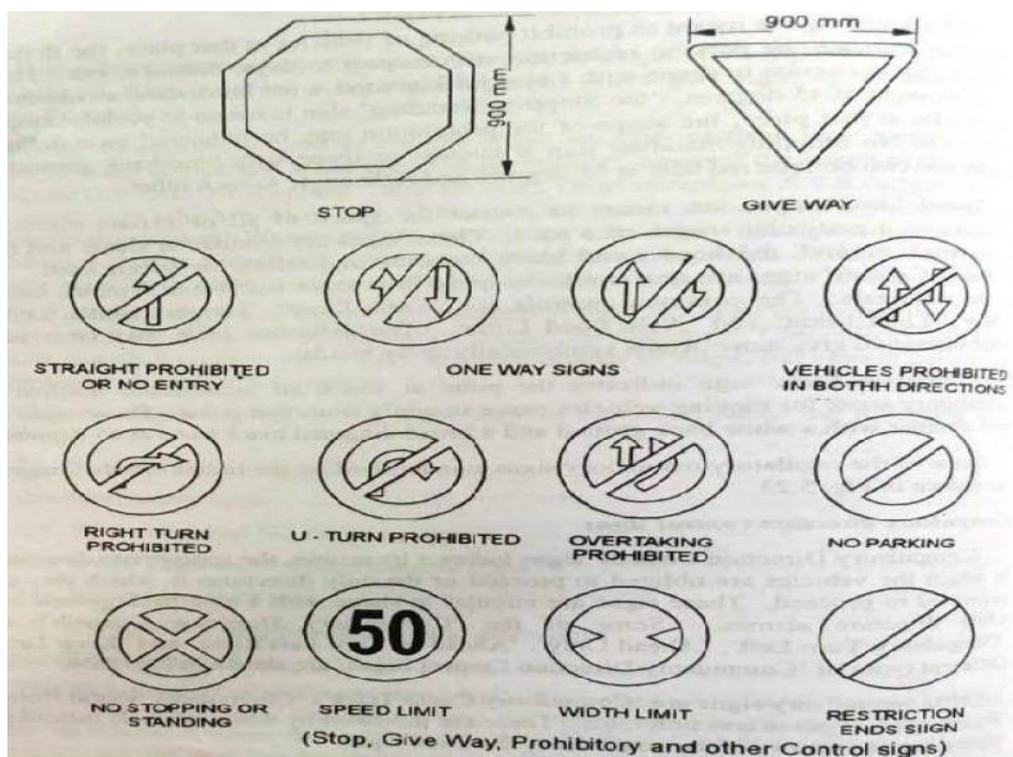
Prohibitory signs are meant to prohibit certain traffic movements, use of horns or entry of certain vehicle class. The common prohibitory signs are: Straight Prohibited, No Entry, One-Way, Vehicles Prohibited in both directions, All Motor Vehicles Prohibited, Truck Prohibited, Bullock Cart and Hand Cart Prohibited, Tonga Prohibited, Cycle Prohibited, Pedestrian Prohibited, Right/ Left Turn Prohibited, U-Turn Prohibited, Overtaking Prohibited and Horn Prohibited.

No parking sign is meant to prohibit parking of vehicles at that place, the definition plate may indicate the parking restriction with respect to days, distance, etc.

Speed limit signs are meant to restrict the speed of all or certain classes of vehicles on a particular stretch of a road. The vehicle control signs are also similar to speed limit signs with black symbols instead of the numerals. The common controls are Width Limit, Height Limit, Length Limit, Load Limit and Axle Load Limit.

Restriction ends sign indicates the point at which all prohibitions notified by prohibitory signs for moving vehicles cease to apply.

Compulsory direction control signs indicate by arrows, the appropriate directions in which the vehicles are obliged to proceed, or the only directions in which they are permitted to proceed.

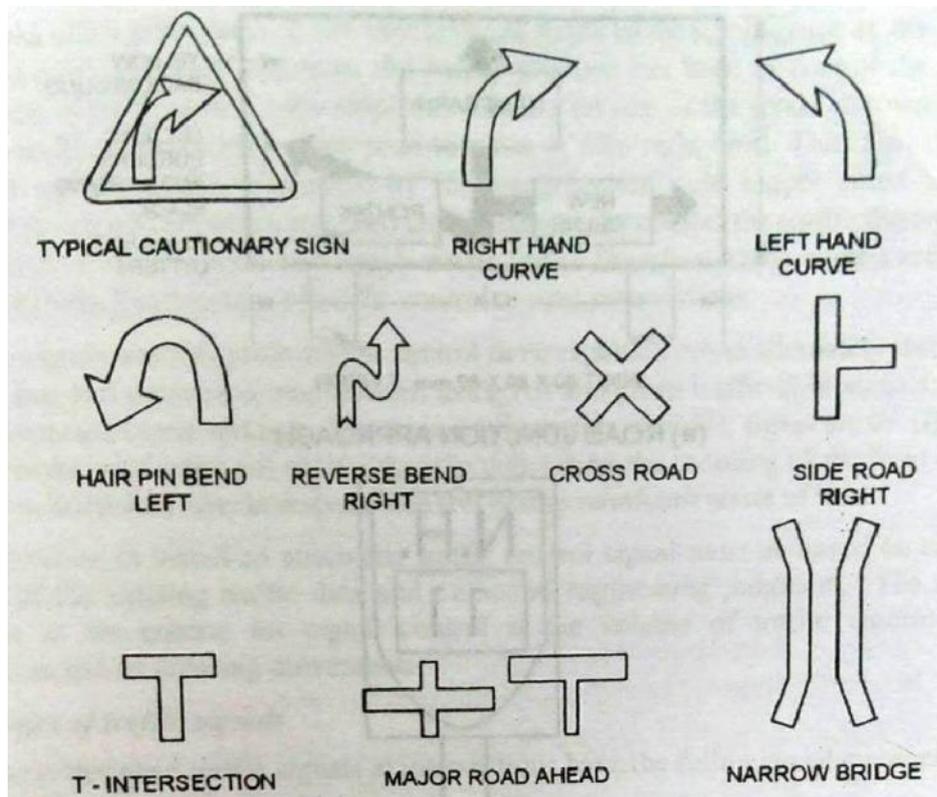


Warning Signs

Warning or cautionary signs are used to warn the road users of certain hazardous conditions that exist on adjacent to the roadway. The warning signs are in the shape of equilateral triangle with its apex pointing upwards. They have a white back ground, red border and black symbols. The warning signs are to be located at sufficient distance in advance of the hazard warned against; these distances are 120, 90 60 and 40 metre

respectively on National/State Highways, Major District Roads, Other District Roads and Village Roads; on urban roads this distance is 50 metre.

The commonly used warning signs are: Right Hand/Left Hand Curve, Right /Left Hair Pin Bend, Right/Left Reverse Bend, Steep Ascent/Descent, Men at work, Cross Road, Side Road, T-Intersection, Y-intersection, etc.



Informatory Signs

The informatory signs are rectangular in shape. These signs are used to guide the road users along routes, inform them of destination and distance, thus providing with information to make travel easier, safe and pleasant.

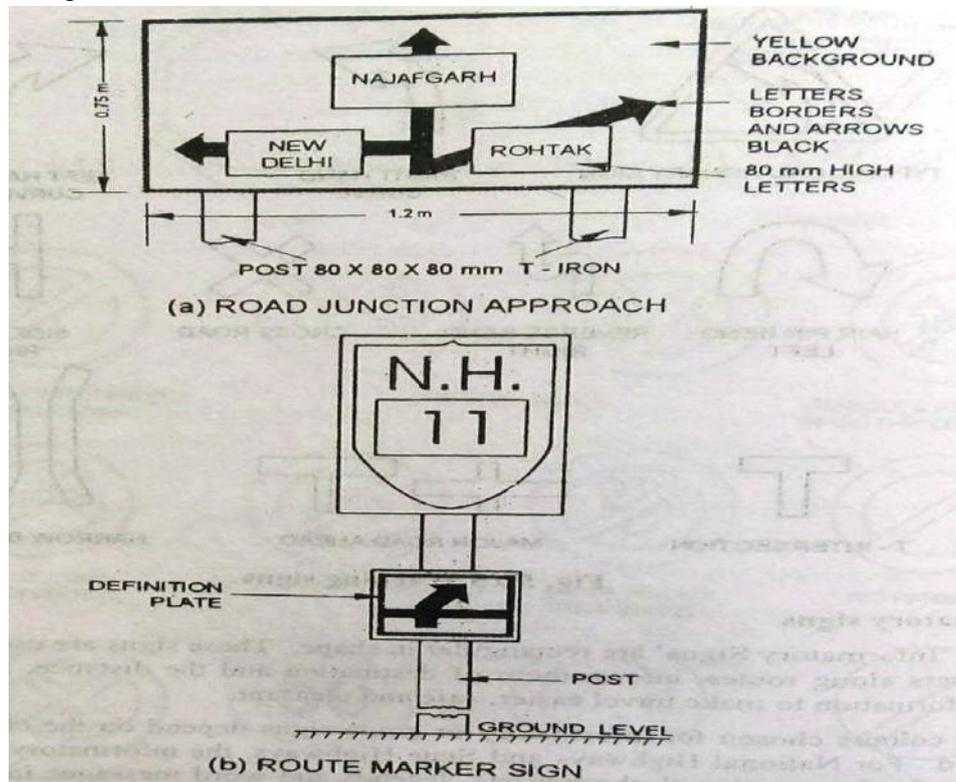
The colours chosen for informatory or guide signs depend on the classification of the road. For National Highways and State Highways, the informatory signs shall be of green back-ground with the borders, legends and the word messages in white colour. For all other categories of road such as MDR, ODR and VR these signs shall have white back-ground with borders, legends and word messages in black colour.

The information signs are grouped under the following sub-heads:

- a) Direction and Place Identification signs
- b) Facility Information signs
- c) Other useful Information signs
- d) Parking signs
- e) Flood Gauge

The 'Direction Signs' and 'Place Identification Signs' are rectangular in shape with the longer side horizontal. The colour of the back-ground of the sign boards and the colour of

the arrows and letters depend on the class of the road where the signs are installed, as mentioned above. The inscriptions should be in English and other language as necessary. The signs of this group include 'Destination Signs', 'Direction Signs', 'Re-assurance Sign', 'Route Marker Signs' and 'Place Identification Signs'. Figure below shows a typical information sign



The Facility information signs are rectangular with blue back ground and white/black letters/symbols. Some of these signs indicate public telephone, petrol pump, hospital, first aid post, eating place and resting place. Other useful information signs include no through road, no through side road, etc. parking signs are set up parallel to the road using square sign board with blue back ground and white coloured letter 'P'. Additional definition plate may be used to indicate category of vehicle for which parking space is reserved, direction of parking space etc.

Flood gauge sign should be installed at all cause ways and submersible bridges or culverts to indicate to the road users the height of the flood above road level.

3.7 Intersection

Intersection is where two or more roads meet and or are the points of potential vehicle conflict. They are critical element of a road section. They are normally a major bottleneck to smooth flow of traffic and a major accident spot. This area is designated for the vehicles to turn to different directions to reach their desired destinations. Its main function is to guide vehicles to their respective directions. Traffic intersections are complex locations on any highway. This is because vehicles moving in different direction wan to occupy same space at the same time.

In addition, the pedestrians also seek same space for crossing. Drivers have to make split second decision at an intersection by considering his route, intersection geometry, speed and

direction of other vehicles etc. A small error in judgment can cause severe accidents. It also causes delay and it depends on type, geometry, and type of control. Overall traffic flow depends on the performance of the intersections. It also affects the capacity of the road. Therefore, both from the accident perspective and the capacity perspective, the study of intersections very important for the traffic engineers especially in the case of urban scenario.

Principles to be considered for a good intersection design:

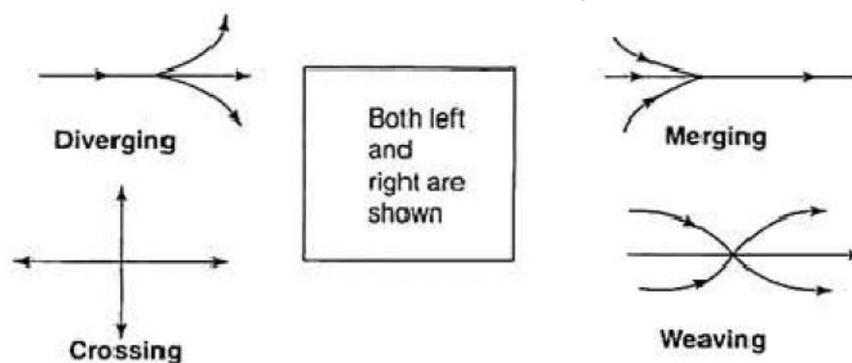
- The number of intersections should be minimum. If necessary minor roads should be connected to major roads.
- The geometric layout should be so selected that hazardous movements by drivers are eliminated.
- The layout should follow the natural vehicle path. Smooth flow of traffic is recommended instead of abrupt and sharp corners.
- The number of conflict points should be minimized.

Types of intersection:

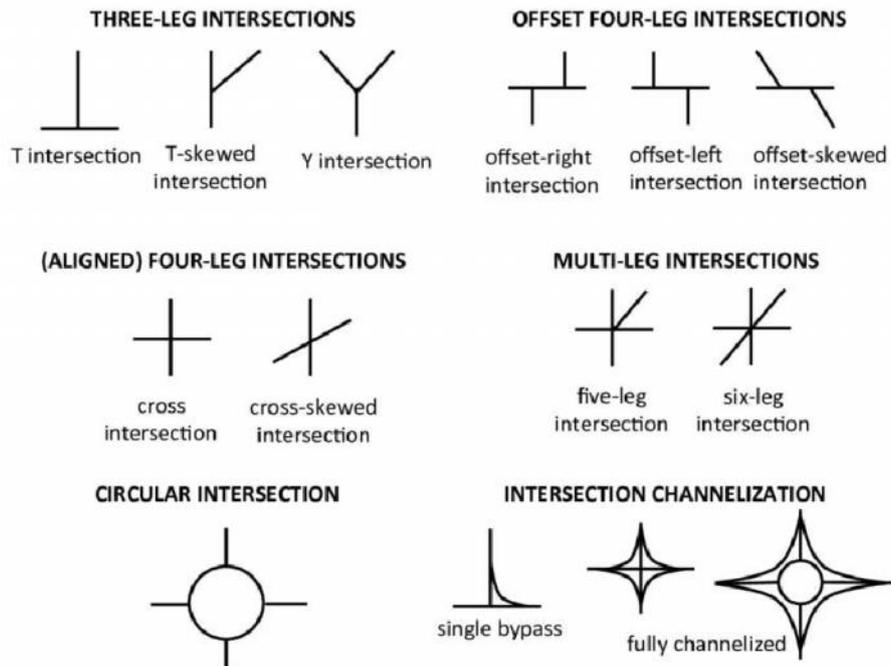
The intersections are of two types. They are at-grade intersections and grade-separated intersections. In at-grade intersections, all roadways join or cross at the same vertical level. Grade separated intersections allows the traffic to cross at different vertical levels. Sometimes the topography itself may be helpful in constructing such intersections. Otherwise, the initial construction cost required will be very high. Therefore, they are usually constructed on high speed facilities like expressways, freeways etc. These type of intersection increases the road capacity because vehicles can flow with high speed and accident potential is also reduced due to vertical separation of traffic.

At-grade intersections:

All the road intersections which meet at about the same level allowing movement of traffic like merging, diverging, crossing and weaving are called at-grade intersection. It is further classified as unchannelized, channelized and rotary intersections.

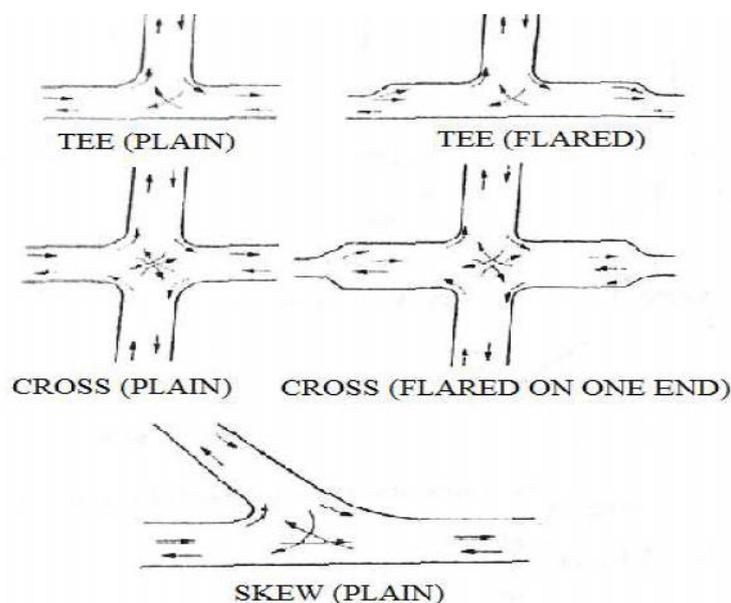


Forms of Intersection:



A) Unchannelized intersection:

- The intersection area is paved and there is no restriction to vehicles to use any part of intersection area. It is easiest in design but most complex in traffic operations resulting in maximum conflict area and more number of accidents unless controlled by traffic signals or police.
- When there is no additional pavement width for turning movement is provided, it is called plain intersection.
- When the pavement width is widened at the intersection area, it is known as flared intersection.
- The arrows indicate the path of traffic flow, turning, crossing and through movements. In this type of intersection conflict area is large
- Path of the turning vehicle is not restricted or controlled.

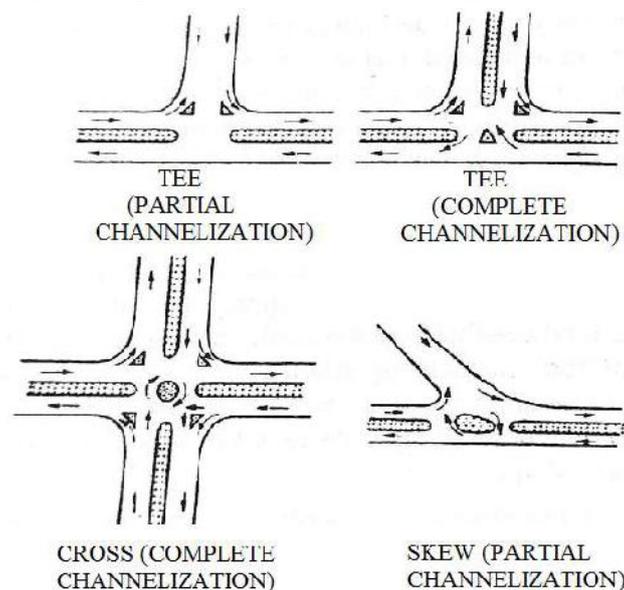


B) Channelized intersection:

Channelized intersection is achieved by introducing islands into intersection areas thus reducing the total conflict area available in the unchannelized intersection. The radius of the entrance and exit curves and the area are suitably designed to accommodate the Channelizing islands of proper size and shape. These islands help to channelize turning traffic, to control their speed and angle of approach and to decrease the conflict area at the intersection. These islands can be either partial or complete divisional and directional islands.

Advantages of channelized intersection:

- By channelizing vehicles can be confined to definite path.
- Conflicts areas can be reduced.
- Speed control can be established over vehicles entering the intersection.
- Points of conflicts can be separated.
- Channelizing islands provide place for installation of signs and control devices.



C) Rotary intersection:

Rotary intersections or roundabouts are special form of at-grade intersections laid out for the movement of traffic in one direction around a central traffic island. Essentially all the major conflicts at an intersection namely the collision between through and right-turn movements are converted into milder conflicts namely merging and diverging. The vehicles entering the rotary are gently forced to move in a clockwise direction. They then weave out of the rotary to the desired direction.

Advantages of Rotary Intersection:

- Traffic flow is regulated to only one direction of movement, thus eliminating severe conflicts between crossing movements.
- Rotaries are self-governing and do not need practically any control by police or traffic signals.
- Because of lower speed of negotiation and elimination of severe conflicts, accidents and their severity are much less in rotaries.

- All the vehicles entering the rotary are gently forced to reduce the speed and continue to move at slower speed. Thus, none of the vehicles need to be stopped, unlike in a signalized intersection.
- They are ideally suited for moderate traffic, especially with irregular geometry, or intersections with more than three or four approaches.

Disadvantages:

- Even when there is relatively low traffic, the vehicles are forced to reduce their speed.
- Rotaries require large area of relatively flat land making them costly at urban areas.
- Where the pedestrian traffic is large, the rotary by itself cannot control the traffic and needs control by traffic police. If the vehicular traffic has to stop to allow pedestrian to cross, the main purpose of rotary is defected.
- At the places of mixed traffic, the design of rotary becomes too elaborate and the operation and control of traffic become complex.
- Where the angle of intersection of two roads is too acute or when there are more than seven intersecting roads, rotaries are unsuitable.
- Where the traffic volume is very low, construction of a rotary cannot be justified.
- It is difficult operate when the intersecting legs are more than five or six.
- It is not desirable to provide rotaries at close intervals on important highways.
- The central island, the entrances and exits need good lighting for safe operation during nights; warning and directional signs needed. These requirements tend to make rotaries expensive.

3.7 Recommended questions

1. Discuss briefly the various factors which affect the road user characteristics.
2. Explain the vehicular characteristics.
3. Outline the different methods of conducting O & D studies.
4. Explain the concept of PCU. Mention the factors affecting PCU values.
5. Discuss the different types of traffic signs used in urban area.
6. Discuss the methods of measuring Spot speeds using direct timing procedure and enoscope
7. Explain the types of intersections.

3.8 Outcomes

1. Conduct traffic studies and analyse traffic data for practical applications.

3.9 Further Reading

1. https://www.civil.iitb.ac.in/~vmtom/nptel/567_Grade/web/web.html
2. <https://www.kittelsohn.com/ideas/pros-and-cons-of-signal-coordination/>
3. https://www.civil.iitb.ac.in/tvm/nptel/563_RdMark/web/web.html
4. <https://archive.nptel.ac.in/courses/105/101/105101008/>
5. https://www.civil.iitb.ac.in/~vmtom/nptel/577_ATC_A/web/web.html

Module - 4

Railway Engineering

Structure

- 4.0 Introduction
- 4.1 Objectives
- 4.2 Permanent way
- 4.3 Gauges and types
- 4.4 Railway track cross sections
- 4.5 Coning of wheels and tilting of rails
- 4.6 Rails
- 4.7 Sleepers and Ballast
- 4.8 Track fittings and fastenings
- 4.9 Point and Crossing
- 4.10 Railway Stations and Yards
- 4.11 Recommended questions
- 4.12 Outcomes
- 4.13 Further Reading

4.0 Introduction:

Railways are a clean and efficient way to transport people and freight across countries and continents. They can also promote economic growth while reducing greenhouse gas emissions. In India, railways are the primary mode of transportation for passengers and freight. They also allow people to participate in a variety of activities, such as sightseeing, business, pilgrimage, and transporting goods over long distances

4.1 Objectives

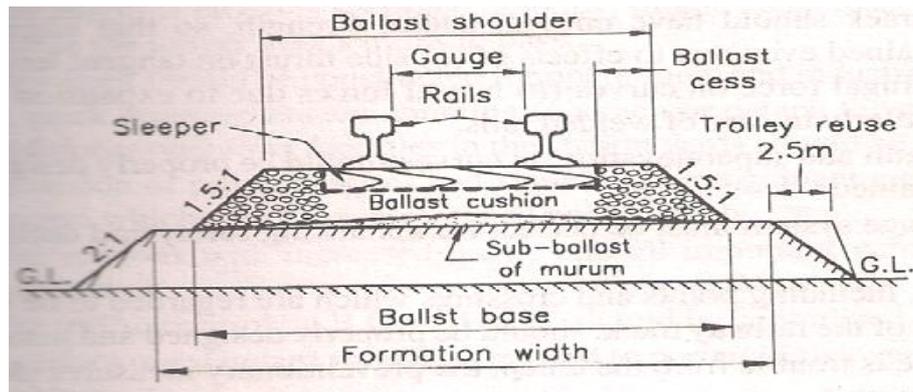
Understand to different aspects of geometric elements of railway system and evaluate the material quantity required for track laying

4.2 Permanent way

The combination of rails, fitted on sleepers and resting on ballast and subgrade is called the railway track or permanent way

Elements of permanent way

- Sub-grade
- Ballast
- Sleepers
- Rails
- Fixture and Fastening
- The track or permanent way is the rail road on which trains run.
- In a permanent way, the rails are joined in series by fish plates and bolts and then they are to sleepers by different types of fastenings.
- The sleepers properly spaced, resting on ballast, are suitably packed and boxed with ballast.



- The layer of ballast rests on the prepared subgrade called the formation.
- The rails act as girders to transmit the wheel load to the sleepers.
- The sleepers hold the rails in proper position with respect to the proper tilt, gauge and level, and transmit the load from rails to the ballast.
- The ballast distributes the load over the formation and holds the sleepers in position.
- On curved tracks, super elevation is maintained by ballast and the formation is levelled. Minimum cushion is maintained at the inner rail, while the outer rail gets kept more ballast cushion.
- Permanent track is regarded to be semi-elastic in nature.
- There is possibility of track getting disturbed by the moving wheel loads.
- The track should be therefore be constructed and maintained keeping the requirements of a permanent way, in view, so as to achieve higher speed and better riding qualities with less future maintenance.

Following are some of the basic requirements of a permanent way:

- The gauge should be correct and uniform.
- The rails should be in proper level. In a straight track, two rails must be at the same level. On curves, the outer rail should have proper super elevation and there should be proper transition at the junction of a straight and a curve.
- The alignment should be correct i.e., it should be free from irregularities.
- The gradient should be uniform and as gentle as possible. Any change of gradient should be followed by a smooth vertical curve, to give smooth riding quality.
- The track should be resilient and elastic in order to adsorb shocks and vibrations of running tracks.
- The radii and super elevation on curves should be properly designed and maintained.
- Drainage system must be perfect for enhancing safety and durability of track.
- Joints, including points and crossings which are regarded to be weakest points of the railway track, should be properly designed and maintained.
- There should be adequate provision for easy renewals and replacements.
- The track structure should be strong, low in initial cost as well as maintenance cost.
- The various components of track i.e., rails, fittings, sleepers, ballast and formation must fully satisfy the requirements for which they have been provided. If any component is lacking in fulfilling its requirements then either it should be improved or replaced.

4.3 Gauges and types

Different gauges on Indian railways: The East India Company intended to adopt the standard gauge of 1435 mm in India also. This proposal was, however, challenged by W. Simms, Consulting Engineer to the Government of India, who recommended a wider gauge of 1676 mm (5'6"). The Court of Directors of the East India Company decided to adopt Simms's recommendation and 5'6" finally became the Indian standard gauge. In 1871, the Government of India wanted to construct cheaper railways for the development of the country and 1000 mm metre gauge was introduced. In due course of time, two more gauges of widths 762 mm (2'6") and 610 mm (2'0") were introduced for thinly populated areas, mountain railways, and other miscellaneous purposes.

Various gauges on Indian Railways

Name of gauge	Width, m
Broad / Standard gauge	1.676
Metre gauge	1.000
Narrow gauge	0.762
	0.610

1. Broad Gauge: When the clear horizontal distance between the inner faces of two parallel rails forming a track is 1676 mm the gauge is called Broad Gauge (B.G). This gauge is also known as standard gauge of India and is the broadest gauge of the world. The Other countries using the Broad Gauge are Pakistan, Bangladesh, Sri Lanka, Brazil, Argentine, etc.

Suitability: Broad gauge is suitable under the following Conditions:- (i) When sufficient funds are available for the railway project. (ii) When the prospects of revenue are very bright. This gauge is, therefore, used for tracks in plain areas which are densely populated i.e. for routes of maximum traffic, intensities and at places which are centres of industry and commerce.

2. Metre Gauge: - When the clear horizontal distance between the inner faces of two parallel rails forming a track is 1000 mm, the gauge is known as Metre Gauge (M.G) The other countries using Metre gauge are France, Switzerland, Argentine, etc.

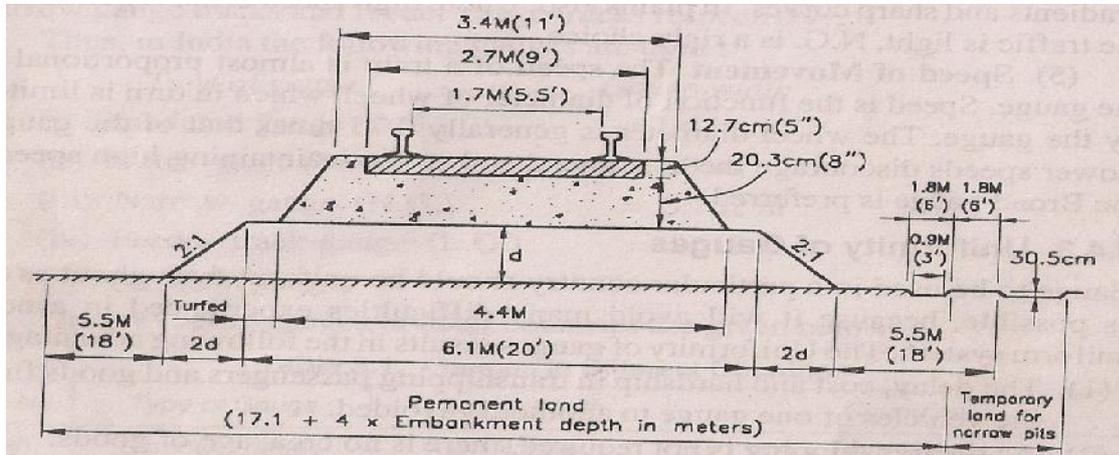
Suitability: Metre Gauge is suitable under the following conditions: (i) When the funds available for the railway project are inadequate. (ii) When the prospects of revenue are not very bright. This gauge is, therefore, used for tracks in under-developed areas and in interior areas, where traffic intensity is small and prospects for future development are not very bright.

3. Narrow Gauge:- When the clear horizontal distance between the inner faces of two parallel rails forming a track is either 762 mm or 610 mm, the gauge is known as Narrow gauge (N.G) The other countries using narrow gauge are Britain, South Africa, etc.

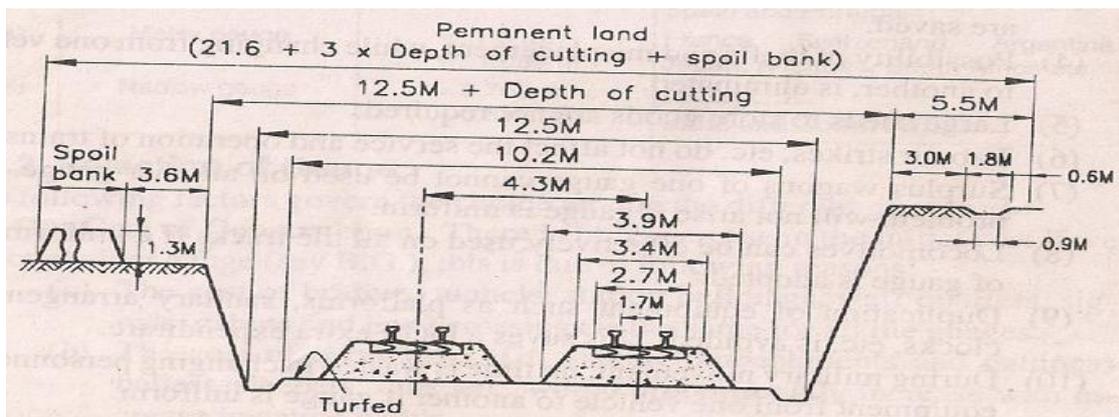
Suitability: Narrow gauge is suitable under the following conditions:- (i) When the construction of a track with wider gauge is prohibited due to the provision of sharp curves,

steep gradients, narrow bridges and tunnels etc. (ii) When the prospects of revenue are not very bright. This gauge is, therefore, used in hilly and very thinly populated areas. The feeder gauge is commonly used for feeding raw materials to big government manufacturing concerns as well as to private factories such as steel plants, oil refineries, sugar factories, etc

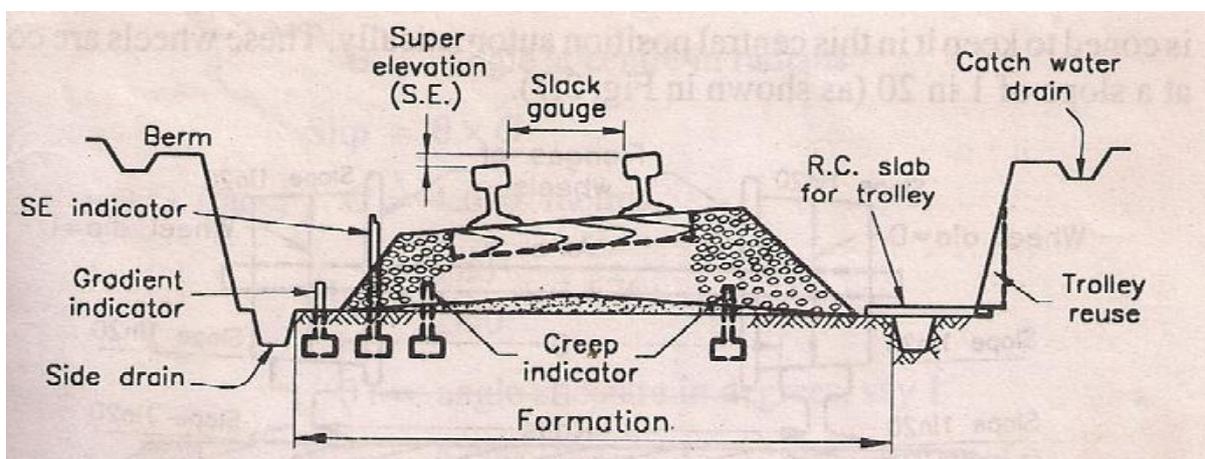
4.4 Railway track cross sections



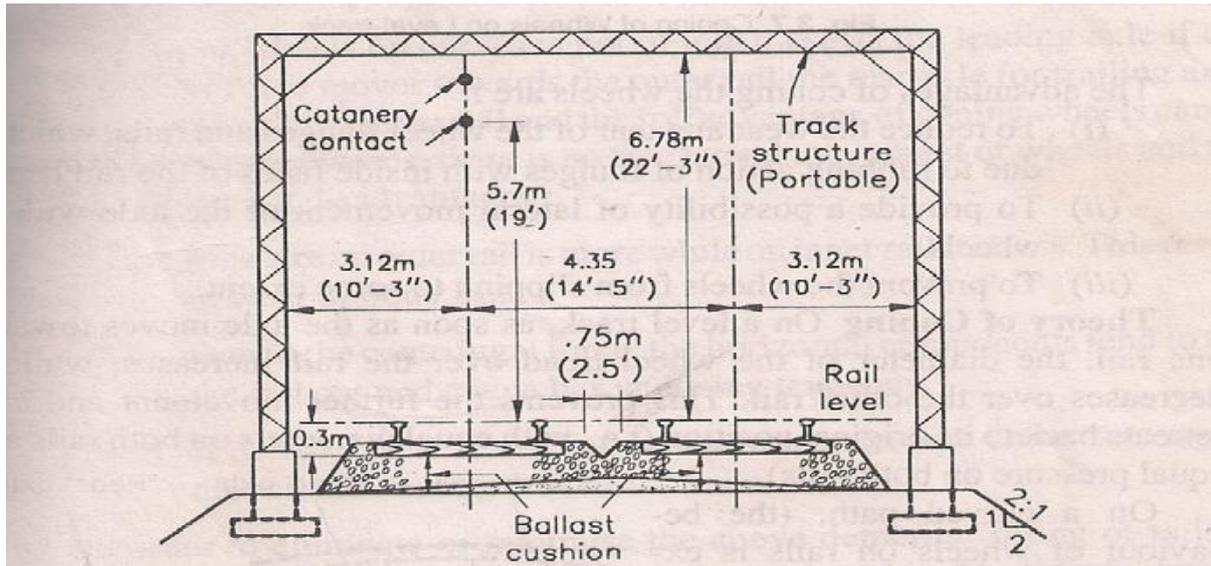
Cross section of a B.G track in embankment



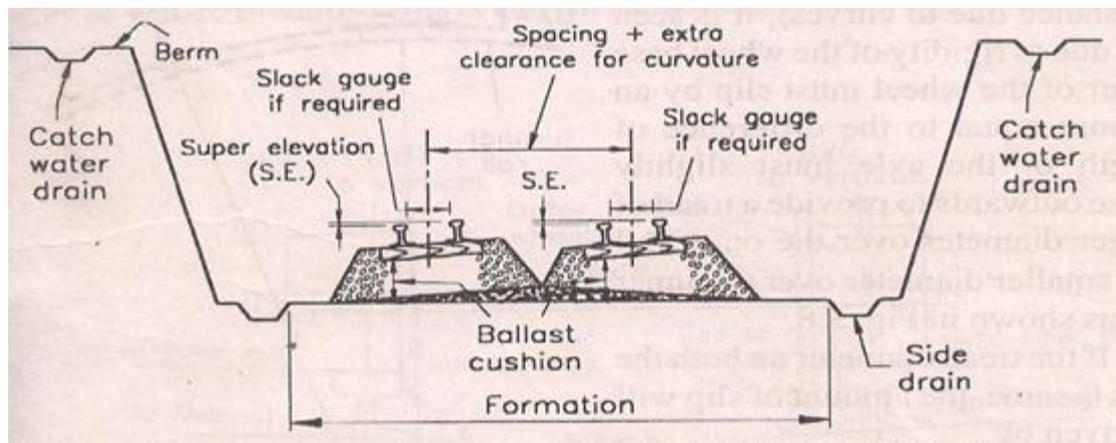
Cross section of a B.G track in cutting of a double line



Cross section of a B.G track for a single line (on Curved track)



Cross section of a B.G track for double line with electric traction

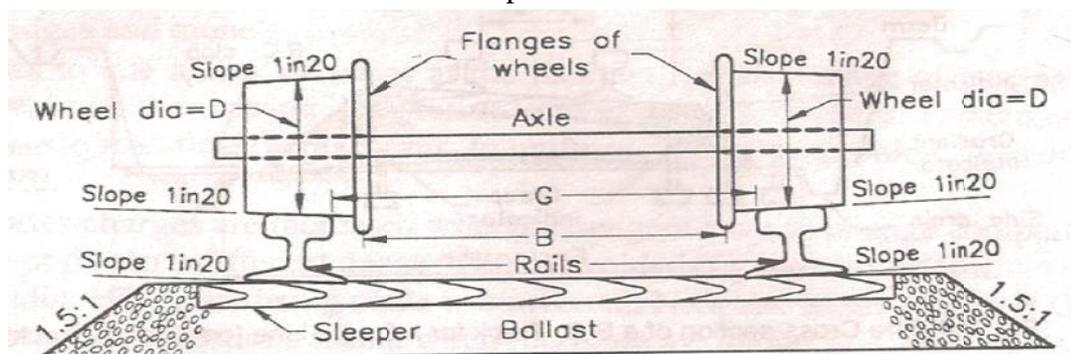


Cross section of a B.G track of double line in cutting (on curved track)

4.5 Coning of wheels and tilting of rails

Coning of wheels

- The distance between the inside edges of wheel flanges is generally kept less than the gauge of the track.
- So there is a gap between the wheel flanges and running edges of the rails, nearly equal to 1cm on either side.
- These wheels are coned at a slope of 1 in 20.

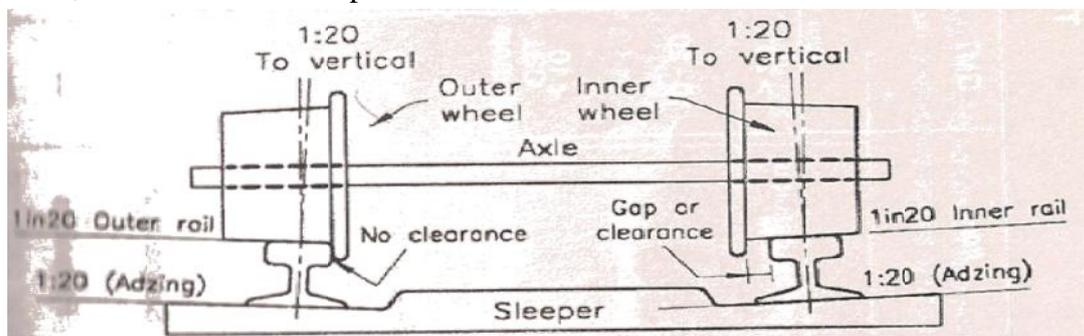


The advantages of coning of the wheels are

- To reduce the wear and tear of the wheel flanges and rails.
- To provide a possibility of lateral movement of the axle with its wheels.
- To prevent the wheels from slipping to some extent.
- It provides a smooth ride.
- It helps the train to negotiate a curve smoothly.

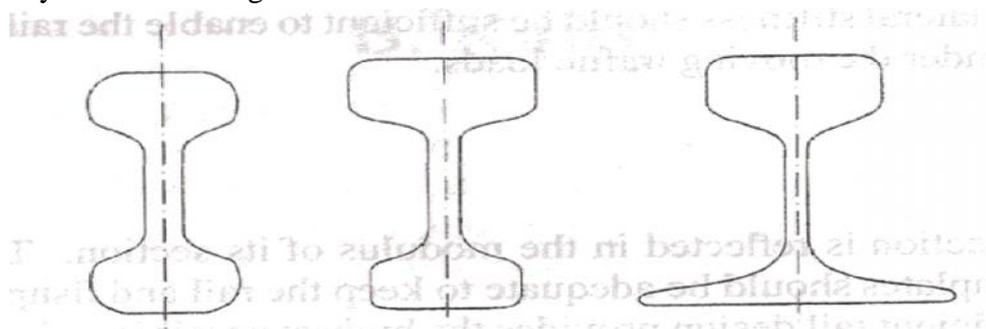
Tilting of rails

- Rails are tilted inward at an angle of 1 in 20 to reduce wear and tear on the rails as well as on the tread of the wheels.
- As the pressure of the wheel acts near the inner edge of the rail, there is heavy wear and tear of the rail.
- Lateral bending stresses are also created due to eccentric loading of rails.
- To reduce the wear and tear as well as lateral stresses, rails are tilted at a slope of 1 in 20, which is also the slope of wheel cone.



4.6 Rails

- Rails on the track can be considered as steel girders for the purpose of carrying axle loads.
- They are made of high carbon steel to withstand wear and tear.



Types of Rails

The rails used in the construction of railway track are of following types:

1. Double headed rails (D.H Rails)
2. Bull headed rails (B.H Rails)
3. Flat footed rails (F.F Rails)

Double headed rails

The rail sections, whose foot and head are of same dimensions, are called Double headed or Dumb-bell rails. In the beginning, these rails were widely used in the railway track. The idea behind using these rails was that when the head had worn out due to rubbing action of wheels, the rails could be inverted and reused. But by experience it was found that their foot could not be used as running surface because it also got corrugated under the impact of wheel loads. This type of rail is not in use in Indian Railways now-a day.

Bull headed rails

The rail section whose head dimensions are more than that of their foot are called bull headed rails. In this type of rail the head is made little thicker and stronger than the lower part by adding more metal to it. These rails also require chairs for holding them in position. Bull headed rails are especially used for making points and crossings.

Merits

- (i) B.H. Rails keep better alignment and provide smoother and stronger track.
- (ii) These rails provide longer life to wooden sleepers and greater stability to the track.
- (iii) These rails are easily removed from sleepers and hence renewal of track is easy.

Demerits

- (i) B.H. rails require additional cost of iron chairs.
- (ii) These rails require heavy maintenance cost.
- (iii) B.H. rails are of less strength and stiffness.

Flat footed rails

The rail sections having their foot rolled to flat are called flat footed or vignole's rails. This type of rail was invented by Charles Vignole in 1836. It was initially thought that the flat footed rails could be fixed directly to wooden sleepers and would eliminate chairs and keys required for the B.H. rails. But later on, it was observed that heavy train loads caused the foot of the rail to sink into the sleepers and making the spikes loose. To remove this defect, steel bearing plates were used in between flat footed rails and the wooden sleeper. These rails are most commonly used in India.

Merits

- (i) F.F. rails have more strength and stiffness.
- (ii) No chairs are required for holding them in position.
- (iii) These rails require less number of fastenings.
- (iv) The maintenance cost of track formed with F.F. rails is less.

Demerits

- (i) The fittings get loosened more frequently.
- (ii) These rails are not easily removed and hence renewal of track becomes difficult.
- (iii) It is difficult to manufacture points and crossings by using these rails.

Functions of rails

1. Rails provide a hard, smooth and unchanging surface for passage of heavy moving loads with a maximum friction between the steel rails and steel wheels.
2. Rails bear the stresses developed due to heavy vertical loads, lateral and braking forces and thermal stresses.
3. The rail material used is such that it gives minimum wear to avoid replacement charges and failures of rails due to wear.
4. Rails transmit the loads to sleepers and consequently reduce pressure on ballast and formation below.

Composition of rail steel

- For ordinary rails: high carbon steel
- For rails on points and crossing: medium carbon steel

Requirements of Rails

1. They should be of proper composition of steel and should be manufactured by open fireplace or duplex process.
2. The vertical stiffness should be high enough to transmit the load to several sleepers underneath. The height of rail should therefore adequate.
3. Rails should be capable of withstanding lateral forces. Large width of head and foot endows the rails with high lateral stiffness.
4. The head must be sufficiently deep to allow for an adequate margin of vertical wear. The wearing surface should be hard.
5. Web of rails should be sufficiently thick to bear the load coming on it and should provide adequate flexural rigidity.
6. Foot should be wide enough so that rails are stable against overturning especially on curves.
7. Bottom of the head and top of the foot of rails should be so shaped as to enable the fish plates to transmit the vertical load efficiently from the head to the foot at rail joints.
8. Relative distribution of material of rail in head, web and foot must be balanced for smooth transmission of loads.
9. The centre of gravity of the rail section must lie approximately at mid height so that maximum tensile and compressive stresses are equal.
10. The tensile strength of the rail piece should not be less than 72kg/m^2 .

Wear on rails

Wear is one of the prominent defects of rails.

When the axle loads are abnormally heavy and the train moves with very fast speed then the concentrated stresses exceed the elastic limit resulting in metal flow, on the gap or joint the ends are battered and at the curves the occurrence of skidding, slipping and striking of wheel flanges with rails results in wear and tear of rails.

- Classification of wear
 - On the basis of location.

- On the basis of position of wear on rails.
- On the basis of location
 - On sharp curves
 - On gradients
 - On approaches to stations, where brakes are frequently applied.
 - In tunnels
 - Coastal areas(sea breeze)
 - Weak foundations
- On the basis of position of wear
 - Wear on the top or head of rail
 - Wear at the ends of rails
 - Wear on the sides of the head.

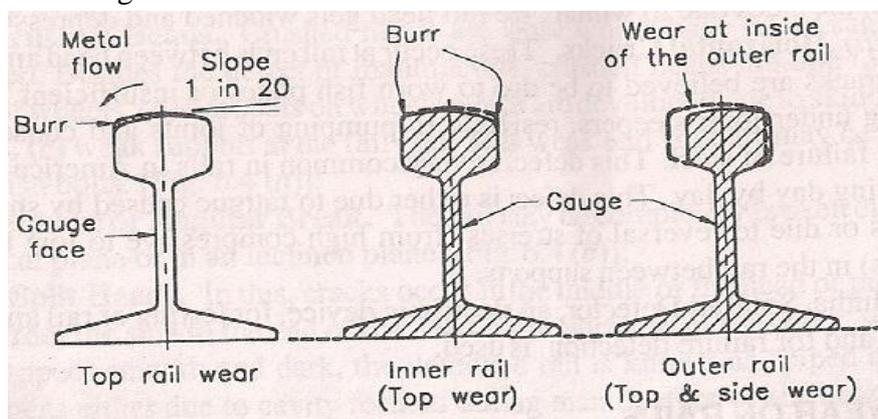
Wear on the top or head of rail: This type of wear occurs on straight i.e., tangent tracks and at curves.

On tangent tracks: the following are the factors which cause or encourage the wear on the top of rails on tangent lengths:

- Due to flow of metal- this is because the heavy loads concentrated on small area produce the stresses which exceed the elastic limit and hence plastic flow of the metal takes place and burrs are formed which later get chipped off by moving wheel flanges
- Heavy axle load and its recurring impact cause the wear at the top of rails.
- Due to abrasion of rolling wheels, the rails generally get worn out at the top of rails.
- Due to constant brake application, which results in skidding and burning of the rail head? This finally results in excessive wear and abrasion.
- Due to use of sand which is spread to produce friction in case of dampness in tunnels. The grinding action of sand particles with rails gives rise to wear.
- Due to fluctuations in gradients.
- Due to corrosion of rails by the action of sea breeze, this also gives rise to wear on top of rails.

On curves: the wear on top of rails at curves is due to the following causes:

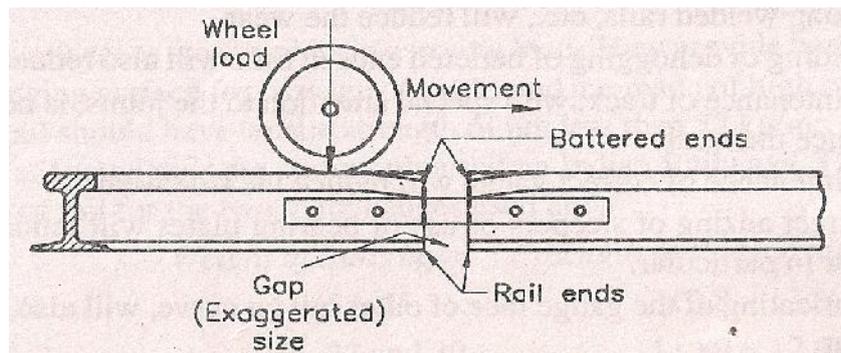
- i. Due to slipping or skidding of wheels
- ii. Due to effect of centrifugal force and improper super elevation, load on one rail is greater than the other.



Wear on the ends of the rails:

This type of wear occurs, when a wheel jumps over the gap, giving blow to the end of the rail, as rough riding in the track, loosens the ballast under the joints and even disturbs the sleeper.

- This type of wear is occurs due to following factors:
 - Due to lose fish plates and fish bolts
 - Due to heavy loads and large joint openings
 - Difference in levels at joints
 - Bad conditions of the vehicle springs
 - Poor maintenance of the track



Wear on sides of the rail head

- This type of wear is only prominent when the rails are laid at curves.
- This wear is more than first two types of wear and is most destructive in nature.
- This wear occurs due to following causes
 - At curves, there is greater thrust on inner rail, when trains run at lesser speed than equilibrium speed.
 - Due to the rigidity of the wheel base.
 - Slipping and skidding of wheel at curves.
 - Allowable limits of wear: in India prescribed limit of wear is 5% of rail weight.

Wear Prevention

- Better maintenance of track
- Reducing number of joints
- Use of special alloy steel
- Interchanging inner and outer rails
- Regular maintenance of rail joints
- Maintenance of correct gauge
- Application of heavy mineral oil-corrosion
- Lubricating gauge face
- Using check rails in sharp curves

4.7 Sleepers and Ballast

Sleepers:

Sleepers are members generally laid transverse to the rails on which the rails are supported and fixed, to transfer the loads from rails to the ballast and subgrade below.

Functions of sleepers

1. To hold the rails to correct gauge.
2. To hold the rails in proper level or transverse tilt so as to provide a firm and even supports to rails.
3. To act as an elastic medium in between the ballast and rails to absorb the blows and vibrations of moving loads.
4. To distribute the load from the rails to the index area of ballast underlying it or to the girders in case of bridges.
5. Sleepers also add to the longitudinal and lateral stability of the permanent track on the whole.
6. They also provide means to rectify track geometry during service life.

Requirements of sleepers

1. The sleepers to be used should be economical i.e., they should have minimum possible initial and maintenance costs.
2. The fittings of the sleepers should be such that they can be easily adjusted during maintenance operations such as easy lifting, packing, removal and replacement.
3. The weight of sleepers should not be too heavy or excessively light i.e., they should have moderate weight for ease of handling.
4. The design of sleepers should be such that the gauge, alignment of track and levels of the rails can be easily adjusted and maintained.
5. The bearing area of sleepers below the rail seat and over the ballast should be enough to resist the crushing due to rail seat and crushing of the ballast underneath the sleeper.
6. The sleeper design and spacing should be such as to facilitate easy removal and replacement of ballast.
7. The sleepers should be capable of resisting shocks and vibrations due to passing of heavy loads of high speed trains.
8. The design of the sleepers should be such that they are not damaged during packing processes.
9. The design of sleepers should be such that they are not pushed out easily due to moving trains especially with steel sleepers.

Classification of sleepers

Wooden/Timber Sleepers

- Wooden sleepers are regarded to be best as they fulfill almost all the requirements of ideal sleeper.
- Their life depends upon their ability to resist wear, decay, attack by vermin (white ants) and quality of timber used.

Advantages:

- Timber is easily available in all the parts of India.

- Fittings for wooden sleepers are few and simple in design.
- These sleepers are able to resist shocks and vibrations due to heavy moving loads and also give less noisy track.
- These are easy to lay, relay, pack, lift and maintain.
- These are suitable for all types of ballast.
- Wooden sleepers are over-all economical.

Disadvantages:

- These sleepers are subjected to wear, decay, attack by white ants, warping, cracking, end splitting, rail cutting etc.
- It is difficult to maintain gauge in the case of wooden sleepers.
- Track is easily disturbed.
- Wooden sleepers have got minimum service life (12-15 years) as compared to other types.
- Maintenance cost of wooden sleepers is highest as compared to other types.

Metal Sleepers

- Due to growing scarcity of wooden sleepers, high cost and short life metal sleepers were being used.
- Metal sleepers are either of cast-iron or steel. Cast-iron is in greater use because of its resistance to corrosion.

Advantages:

- Metal sleepers are uniform in strength and durability.
- In metal sleepers, the performance of fittings is better and hence lesser creep occurs.
- Metal sleepers are economical as life is longer and maintenance is easier.
- Gauge can be easily adjusted and maintained.
- Frequent renewal is not required.
- Have good scrap value, easy to manufacture and not susceptible to fire hazards.

Disadvantages:

- More ballast is required than other types of sleepers.
- Fittings required are greater in number and difficult to maintain/inspect.
- They are liable to rusting/corrosion.
- Metal being good conductor of electricity interferes with track circuiting.
- They are unsuitable for bridges, level crossings and in case of points and crossings.
- These are only suitable for stone ballast and for rails which they are manufactured.

Concrete Sleepers

These are made of strong homogenous material, impervious to effects of moisture, and is unaffected by the chemical attack of atmospheric gases or subsoil salts.

These can easily moulded to size and shape required to withstand stresses produced by fast and heavy traffic.

Advantages:

- These are free from natural decay and attack by vermin etc.
- They have maximum life as compared to others (40-60 years)
- These are not affected by moisture, chemical action of ballast and subsoil salts.

- There is no difficulty in track circuiting of electrified tracks.
- Increased weight helps to reduce joint maintenance, greater stability of track and better resistance against temperature variation.
- These have higher elastic modulus and hence can withstand the stresses induced by fast and heavy traffic.
- They offer an ideal track in respect of gauge, cross-level and alignment.

Disadvantages:

- The weight of concrete sleeper is as high as 2.5 to 3 times of wooden sleeper, requiring the mechanical appliances for handling.
- These require pads and plugs for spikes.
- They damage the bottom edge during packing.
- The scrap value is almost nil.
- The damages to the concrete sleepers are very heavy in case of derailment.

Spacing of sleepers and sleeper density

- The space between two adjacent sleepers determines the effective span of the rail over the sleepers.
- The spacing of sleepers, therefore in a track depends on the axle load which the track is expected to carry and lateral thrust of locomotives to which it is subjected.
- The number of sleepers in a track is indicated by the number per rail length.
- Since sleeper also provides lateral stability to the track, so more the number of sleepers more is the lateral stability.
- The number of sleepers however cannot be increased indefinitely as certain minimum space between sleepers is required for packing of ballast.
- In India, this minimum distance for manual packing of ballast is kept 30.5cm to 35.5cm
- The number of sleepers per rail varies in India from $M+4$ to $M+7$ for main tracks, where M = length of rail in metres.
- Sleeper density is the number of sleepers per rail length and it is specified as $M+x$ or $N+x$, where M is the length of the rail in metres (N is the length of rail in yards) and x is a number, varying according to the factors.
- Factors governing the sleeper density are: axle load, speed, type and section of the rails, type of ballast and ballast cushion, type and strength of sleepers and nature of foundation.

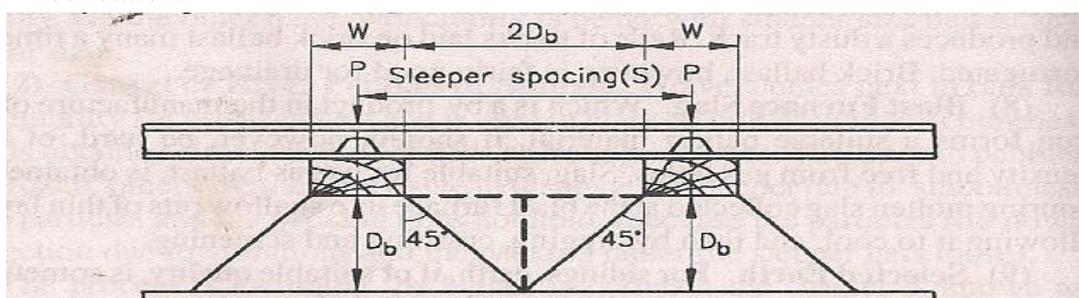


Fig. 11.1. Minimum Depth of Ballast

$$\text{Sleeper Spacing (S)} = \text{width of sleeper (w)} + 2 \times \text{depth of ballast (Db)}$$

Ballast

- It is the granular material usually broken stone or brick, shingle or kankar, gravel or sand placed and packed below and around the sleepers to transmit load from sleepers, to formation and at the same time allowing drainage of the track.
- It provides a suitable foundation for the sleepers and also hold the sleepers in their correct level and position, preventing their displacement by lateral or longitudinal thrusts.
- The lateral stability of track depends on the ballast.

Functions of ballast

- It provides levelled bed or support for the railway sleepers.
- It transfers the load from sleepers to subgrade and distributes the load uniformly on subgrade.
- It holds the sleepers in a firm position while the trains pass by.
- It prevents the longitudinal and lateral movement of sleepers.
- It offers good drainage to the track

Requirements of the good ballast

- It should be tough and wear resistant.
- It should be hard so that it does not get crushed under the moving loads.
- It should be generally cubical with sharp edges.
- It should be non-porous and should not absorb water.
- It should resist both attrition and abrasion.
- It should be durable and should not get pulverized or disintegrated under adverse weather conditions.
- It should allow for good drainage of water.
- It should be cheap and economical.
- It should not make the track dusty or muddy due powder under dynamic wheel loads but should be capable of being cleaned to provide good drainage.
- It should not produce any chemical action in rail and metal sleepers
- The size of stone ballast should be 5cm for wooden sleepers, 4cm for metal sleepers and 2.5cm for turnouts and crossovers.

Types of Ballast

1. Broken stone Ballast: Broken stone is widely used ballast in railways. It is obtained by crushing hard stones like granite, hard trap, quartzite etc. In lieu of broken stones, limestone and sandstone can also be used. It is suitable for high-speed railway tracks. The broken stone selected as ballast should be hard, tough and non-porous. It should stay strong against inclement weather conditions.

Benefits of Broken Stone Ballast

- Broken stones are hard, tough and durable.
- Hold the sleepers in a strong position and provide stability to the track.

- Suitable for heavy traffic tracks and for high-speed tracks.

Drawbacks of Broken Stone Ballast

- Since broken stones are not easily available, their initial cost is a little high.
- Produce noise when the train is moving on the track.

2. Sand Ballast: Sand can also be used as a ballast material. It is well suitable under cast iron sleepers and can be seen in desert railway tracks where plenty of sand gets accrued on the track. Coarse sand is best suitable as ballast than fine sand.

Benefits of Sand Ballast

- It provides excellent drainage facilities to the track.
- Cheap and abundantly available material.

Drawbacks of Sand Ballast

- Sand may blow off easily due to vibrations produced by train or due to high winds. So, a frequent renewal is required.
- Excessive wear of sleepers and moving parts can occur due to friction developed by sand.

3. Gravel Ballast: Gravel is a naturally occurring material formed by the erosion of rocks. They are suitable for all types of sleepers and are usually round and smooth and can be obtained from river beds, gravel pits etc.

Benefits of Gravel Ballast

- It occurs naturally and hence is cheap and easily available.
- Properly cleaned gravel offers excellent drainage facilities to the track.
- Well packed gravel requires less maintenance and has high durability.

Drawbacks of Gravel Ballast

- Because of their smoothness and roundness, they may get separated from the bed under vibrations.
- Produce noise when the train is moving on the track.

4. Moorum Ballast: Moorum is formed by the decomposition of laterite. It is available mostly in red colour and, sometimes, in yellow. If the track is to be laid on black cotton soil, moorum can be used as a blanketing material or sub-ballast since it prevents permeability of water into the subgrade or formation.

Benefits of Moorum Ballast

- Moorum is good as sub-ballast especially in the case of weak soil sub-grades.
- Provides good aesthetics to the track.

Drawbacks of Moorum Ballast

- It is very soft and when subjected to vibrations gets converted into a powdered form and blows away.
- It requires frequent maintenance.

5. Coal Ash or Cinder Ballast: Coal ash also called cinder is the by-product of coal-fired power plants and railway locomotives. It can be used as a ballast material since it is cheaply

available and also possesses good drainage properties. It is used as ballast especially for station yards and as initial ballast for newly constructed tracks.

Benefits of Coal Ash Ballast

- It is economical and abundantly available.
- It has excellent drainage properties.
- It can be handled with ease and is light in weight.

Drawbacks of Coal Ash Ballast

- Turns into dust when subjected to loads.
- Makes the track dirty and complicates the maintenance procedure.

6. Brickbat Ballast: Brickbats are nothing but crushed pieces of bricks which are generally over-burnt. Under-burnt brickbats are not suitable since they are not as porous as over-burnt brickbats.

Benefits of Brickbat Ballast

- Porous brickbats have good drainage properties.
- Brickbats are useless products of brick industries and hence can be bought at cheap prices.

Drawbacks of Brickbat Ballast

- When subjected to loads they turn into a powder which can be easily blown away by the wind.
- The brick dust makes the track dirty and demands frequent maintenance

Size and section of ballast

- The size of the ballast varies from 1.9cm to 5.1cm
- Stones of larger size are not desirable and the maximum size as 5.1cm is preferable as interlocking of stones of this size is better than that of stone of larger sizes.
- The size of stone ballast should be 5cm for wooden sleepers, 4cm for metal sleepers and 2.5cm for turnouts and crossovers.
- The section of ballast layer consists of depth of ballast under the sleepers and the width of the ballast layer.
- The depth of the ballast under the sleepers is an important factor in the load bearing capacity and uniformity of distribution of load.
- In India, this recommendation will give unnecessarily thicker layer of ballast due to large spacing of sleepers being used.
- The lateral strength increases with increase in width of ballast layer but there is a limit beyond which no useful purpose is served by widening.
- This width limit is at 38cm to 43cm from the end of these sleepers as computed.
- Although the lines of equal pressure in ballast through wheel loads are in the shape of a bulb yet simplicity purpose, the load dispersion can be assumed at 45° to the vertical.

4.8 Track fittings and fastenings

Track fittings and fastenings are fittings requires for joining of rails end to end and also for fixing the rails to sleepers in a track.

Functions of track fittings and fastenings

Rail fixtures and fastenings have the following functions:

- (i) To join the rails end to end to form full length of track.
- (ii) To fix the rails to sleepers.
- (iii) To maintain the correct alignment of the track.
- (iv) To provide proper expansion gap between rails.
- (v) To maintain the required tilt of rails.
- (vi) To set the points and crossings in proper position.

Fish plates

Fish plates are used in rail joints to maintain the continuity of the rails.

Two types of fish plates are commonly used on Indian Railways for joining F.F. and B.H. rails, each fish plate is 457 mm long and provided with four holes 32 mm at a spacing of 114 mm c/c.

These are manufactured of steel and are so designed that they fit in between the head and foot of the rail.

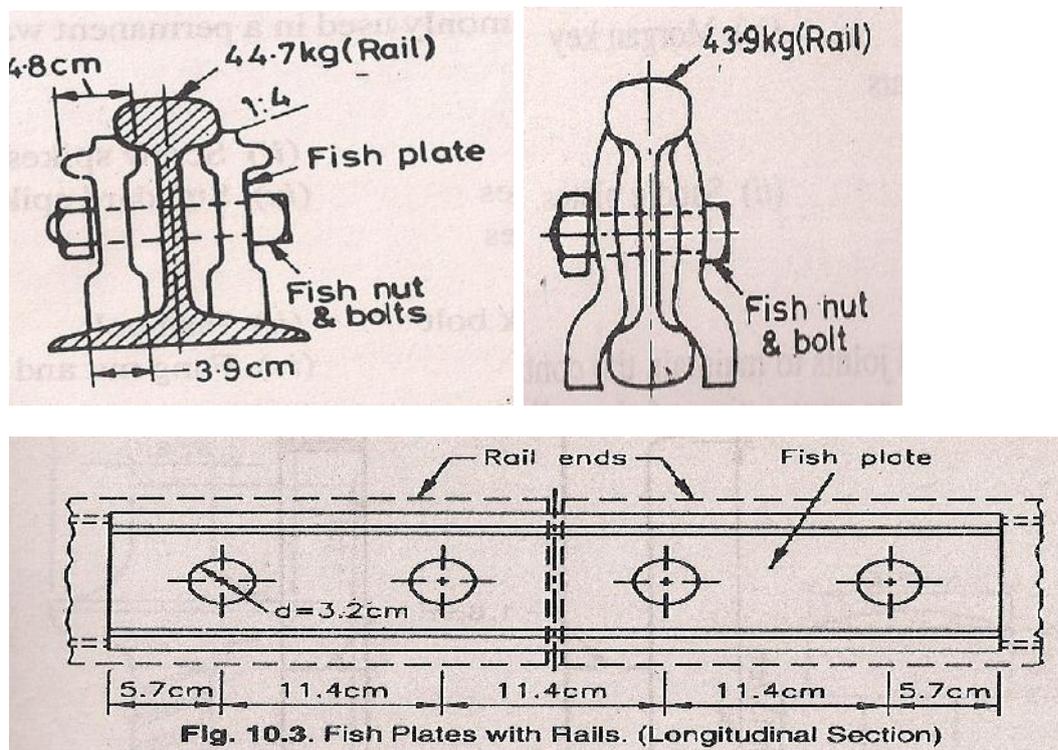


Fig. 10.3. Fish Plates with Rails. (Longitudinal Section)

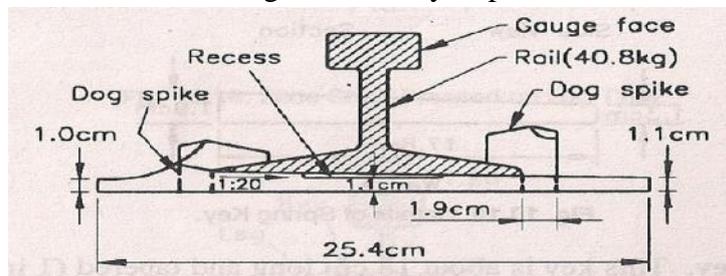
Requirements of fish plates

- (i) They should hold the adjoining ends of rails in correct horizontal and vertical plane.
- (ii) They should allow free longitudinal movements of rails due to temperature variation.
- (iii) They should be able to resist all types of wear.
- (iv) They should allow easy renewal and replacement of rails in case of wear and damage.

Bearing plates

- Bearing plates are cast iron or steel plates placed in between the F.F rail and wooden sleepers of a railway track.

- F.F. rails if fixed directly on wooden sleepers sink in the sleeper due to the heavy loads of trains and thus loosen the spikes.
- To overcome this difficulty bearing plates are used under F.F. rails to distribute the load over a wider area and bring the intensity of pressure within limit.



Advantages

- They distribute the loads to wider area and prevent sinking of the rail to the sleeper.
- They enable the spikes to remain tight and require less maintenance.
- Bearing plates prevent the widening of gauge on curves.
- Bearing plates increase the overall stability of the track.
- They prevent the destruction of the sleeper due to rubbing action of the rail.

Disadvantages

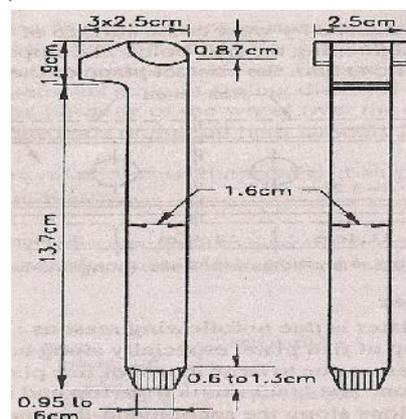
- When the bearing plates become loose due to settlement of ballast, moisture is likely to enter between the sleepers and plates, causing sleepers to wear.
- If spike is damaged and it is required to be redriven at another place, all other spikes of the bearing plates have to be removed, which reduce the holding power of the spikes.

Spikes

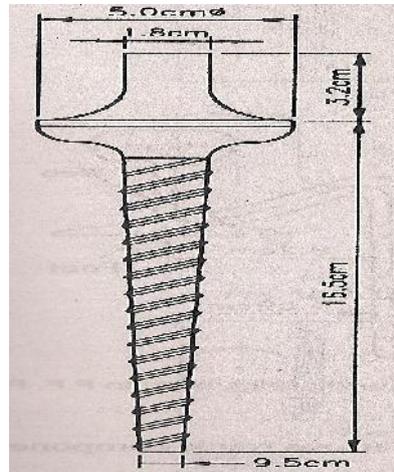
Requirements of a good spike

- It should be easy in fixing or removing from the sleepers.
- It should hold the rails and bearing plates in proper position.
- It should be cheap.
- It should require minimum maintenance.
- It should not come out of the sleepers under vibrations.

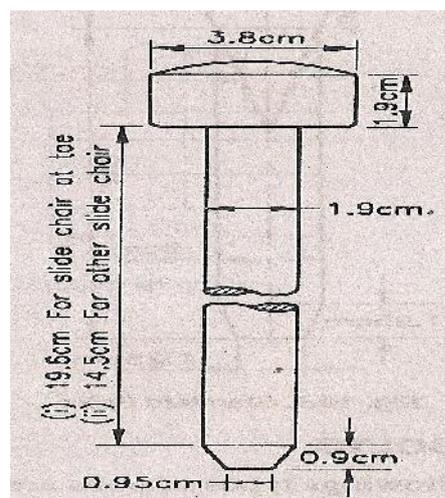
Dog spikes: Dog spikes are the cheaper type of spikes which hold the rails at correct gauge and can be easily fixed and removed. These are commonly used for holding F.F. rails. Four dog spikes are used per sleeper, two on either side of the rail.



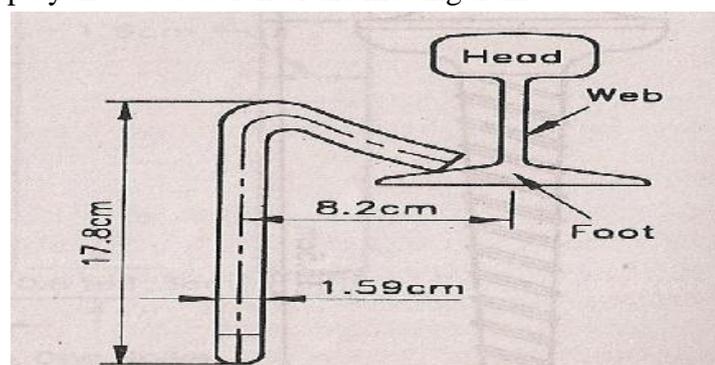
Screw spikes: Screw spikes are tapered screws with V-threads. Their head is circular with a square projection and are used to fasten rails with wooden sleepers. The holding power of these spikes is more than double to that of dog spikes and can resist the lateral thrust better than the dog spikes.



Round spikes: Round spikes are used for fixing chairs of B.H. rails to wooden sleepers and also for fixing slide chairs of points and crossings. These have both cylindrical or hemispherical head and blunt end.



Elastic spikes: Elastic spikes are used for fixing F.F. rails to wooden sleepers. These give better grip and result in reduction of wear and tear of rail. The advantage of this type of spike is that it is not pulled up by the wave action of the moving train.



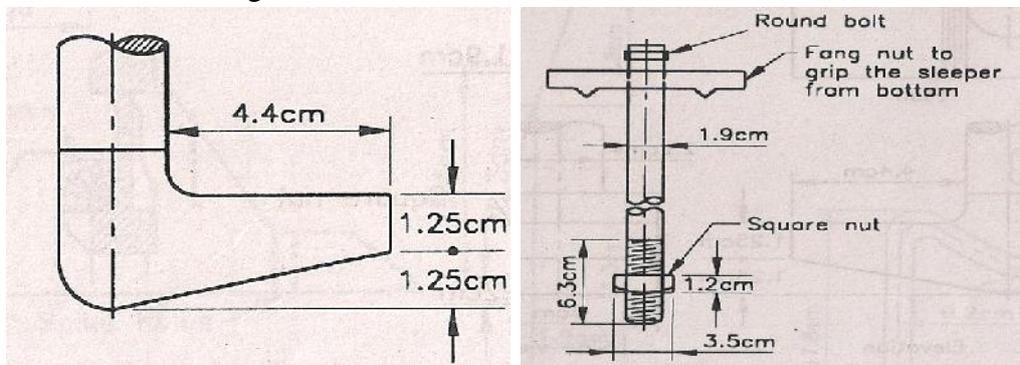
Bolts

Fish bolts: Fish bolts are used for connecting fish plates with the rails. Four bolts are required for each pair of fish plates. These bolts are inserted from outside the track and bolted on the inside of the track.

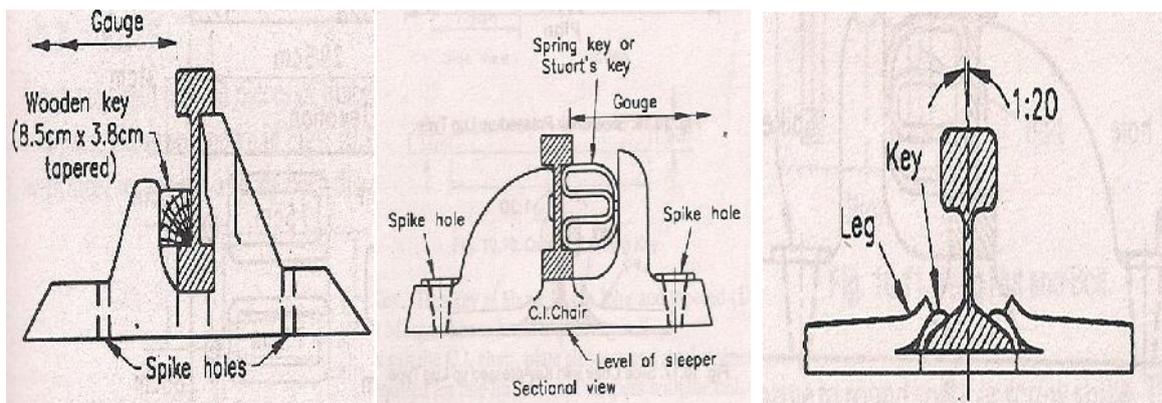
Hook bolts: Hook bolts are also known as dog bolts due to the shape of their heads. These bolts are used to fix sleepers which rest directly on a girder. Two bolts per sleeper are used. Dog bolts are of two types.

- (i) Sloping lips- for fixing sleepers to plate girder spans.
- (ii) Straight lips- for fixing sleepers to joint spans.

Fang bolts: Fang bolts are used for fixing side chairs to sleepers. These are alternative to screw or round spikes. The fang bolts are found to be more effective but are not generally used, because fixing and removal of these bolts are difficult.



Chairs



Keys: These are small tapered pieces of timber or steel used to fix rails to chairs on metal sleepers.

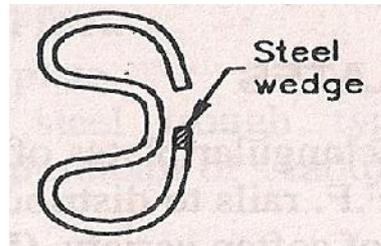
Keys are of two types

- (i) Wooden keys
- (ii) Metal keys

Wooden keys are small straight or tapered pieces of timber. These are cheap and easily prepared. These are not strong and become loose under vibrations. These require frequent maintenance. Wooden keys are not used now-a day in Indian Railways.

Metal keys are small tapered or spring like pieces of steel. These keys are much more durable than wooden keys. Metal keys are of two types.

- (i) Stuart's key and
- (ii) Morgan key



4.9 Point and Crossing

Points and crossings are provided facilitates the change of railway vehicles from one track to another. The tracks may be parallel, diverging, or converging to each other. Points and crossings are necessary due to the inside flanges of wheels of railway vehicles and, therefore require special arrangement to navigate their way on the rails. The points or switches aid in diverting the vehicles and the crossings provide gaps in the rails so as to help the flanged wheels to roll over them. A complete set of points and crossings, along with lead rails, is called a turnout.

Important terms: The following terms are often used in the design of points and crossings.

Turnout It is an arrangement of points and crossings with lead rails by means of which the rolling stock may be diverted from one track to another. Figure (a) shows the various constituents of a turnout. The details of these constituents are given in Table below. Table:
Parts of a turnout

Name of the main assembly	Various constituents of the assembly	Set of switches
A pair of stock rails, a pair of tongue rails, a pair of heel blocks, several stretcher bars, and a gauge tie plate	Two or more slide chairs, two or more	
Crossing	A nose consisting of a point rail and splice rails, two wing rails, and two check rails	Lead rails
		Four sets of lead rails

Direction of a turnout A turnout is designated as a right-hand or a left-hand turnout depending on whether it diverts the traffic to the right or to the left. Figure (a) shows a left-hand turnout. In Fig. (b), the turnout is a right-hand turnout because it diverts the traffic towards the right side.

The direction of a point (or turnout) is known as the facing direction if a vehicle approaching the turnout or a point has to first face the thin end of the switch. The direction is trailing direction if the vehicle has to negotiate a switch in the trailing direction, that is, the vehicle first negotiates the crossing and then finally traverses on the switch from its thick end to its thin end. Therefore, when standing at the toe of a switch, if one looks in the direction of the crossing, it is called the facing direction and the opposite direction is called the trailing direction.

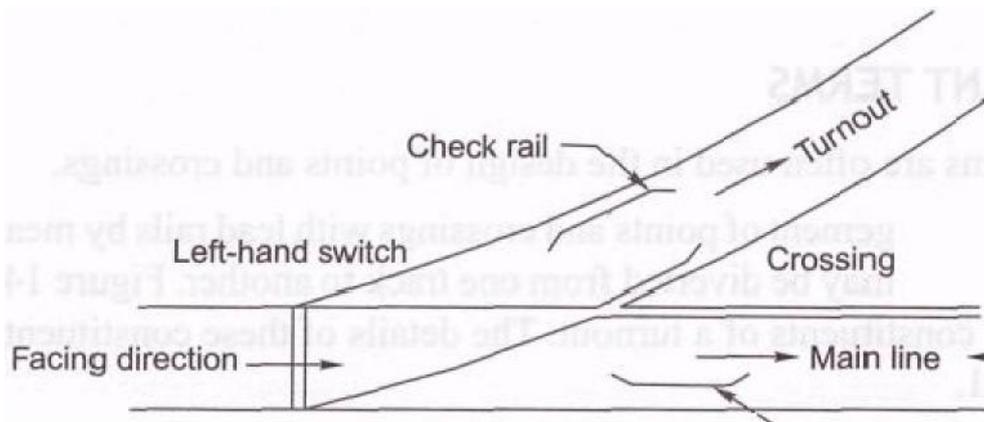


Fig. (a) Left-hand turnout

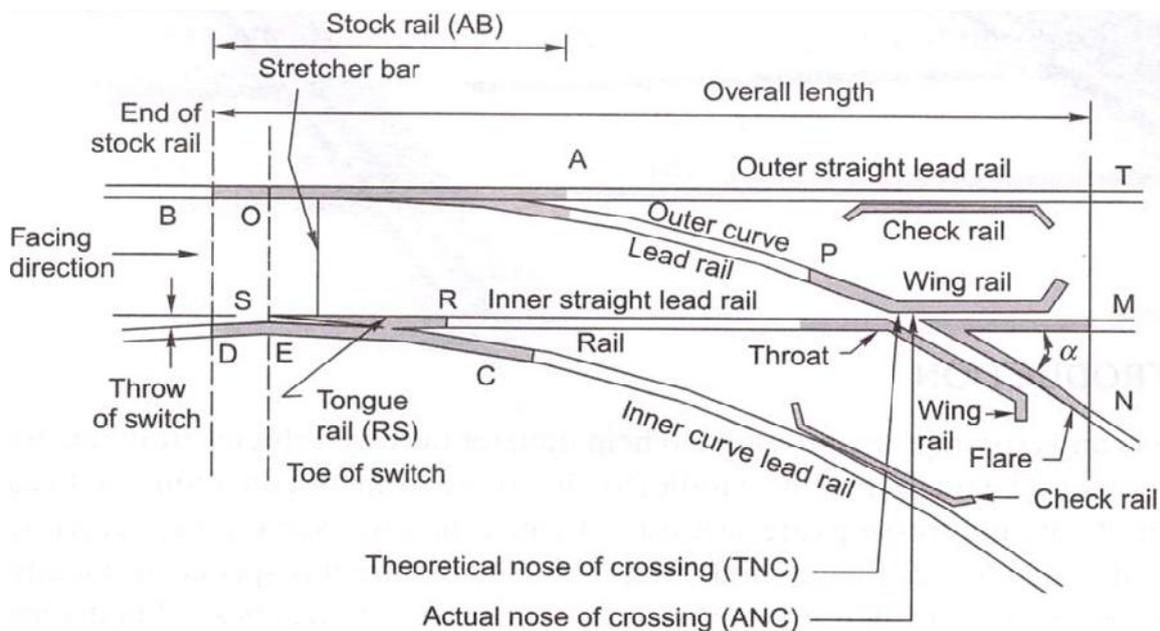


Fig. (b) Constituents of a turnout

Tongue rail: It is a tapered movable rail, made of high-carbon or -manganese steel to withstand wear. At its thicker end, it is attached to a running rail. A tongue rail is also called a switch rail.

Stock rail: It is the running rail against which a tongue rail operates.

Points or switch: A pair of tongue and stock rails with the necessary connections and fittings forms a switch.

Crossing: It is a device introduced at the junction where two rails cross each other to permit the wheel flange.

4.10 Railway Stations and Yards

4.10.1 Railway Stations

A railway station or a railroad station and often shortened to just station, is a railway facility where trains regularly stop to load or unload passengers and/or freight

A railway station is that place on a railway line where traffic is booked and dealt with and where trains are given the authority to proceed forward. Sometimes only one of these functions is carried out at a station and accordingly it is classified as a flag station or a block station. In the case of a flag station, there are arrangements for dealing with traffic but none for controlling the movement of the trains.

Requirements of a Passenger Station

The main requirements of a passenger yard are the following.

- (a) It should be possible to lower the signals for the reception of trains from different directions at the same time. This facility is particularly necessary at junction stations so that all the trains what are to be connected with each other may be received at the same time.
- (b) Unless all trains are booked to stop at the station, it should be possible to run a train through the station at a prescribed speed.
- (c) In the case of an engine changing station, an engine coming from or going to a shed should cause minimum interference in the arrival and departure of trains.
- (d) An adequate number of platforms should be provided so that all trains can be dealt with at the same time.
- (e) There should be convenient sidings where extra carriages can be stabled after having been detached from trains or before their attachment to trains.
- (f) There should be provision of facilities for dealing with special traffic such as pilgrim and tourist traffic, parcels in wagon loads, livestock, and motor cars.
- (g) Stabling lines, washing lines, sick lines, etc., should be provided as per requirement.

Purpose / Requirements of a Railway Station

A railway station is provided for one or more of the following purposes.

- (a) To entrain or detrain passengers
- (b) To load or unload goods or parcels
- (c) To control the movement of trains
- (d) To enable trains to cross each other in the case of a single-line section
- (e) To enable faster trains to overtake slower ones
- (f) To enable locomotives to refuel, whether it be diesel, water, or coal
- (g) To attach or detach coaches or wagons to trains
- (h) To collect food and water for passengers
- (i) To provide facilities for change of engines and crew/staff
- (j) To enable sorting out of wagons and bogies to form new trains
- (k) To provide facilities and give shelter to passengers in the case of emergencies such as floods and accidents, which disrupt traffic

Selection of Site for a Railway Station

The following factors are considered when selecting a site for a railway station.

Adequate land: There should be adequate land available for the station building, not only for the proposed line but also for any future expansion. The proposed area should also be without any religious buildings.

Level area with good drainage: The proposed site should preferably be on a fairly level ground with good drainage arrangements. It should be possible to provide the maximum permissible gradient in the yard. In India, the maximum permissible gradient adopted is 1 in 400, but a gradient of 1 in 1000 is desirable.

Alignment: The station site should preferably have a straight alignment so that the various signals are clearly visible. The proximity of the station site to a curve presents a number of operational problems.

Easy accessibility: The station site should be easily accessible. The site should be near villages and towns. Nearby villages should be connected to the station by means of approach roads for the convenience of passengers.

Water supply arrangement: When selecting the site, it should be verified that adequate water supply is available for passengers and operational needs.

Classification of Stations

Stations can be classified on the basis of their operation as

1. Block stations-Class A, Class B and Class C
2. Non Block Stations-Class D stations or Flag stations
3. Special class stations.

Block Stations:

The stations at the end the block sections are called Block stations

A class station: A class stations are normally provided on double-line sections. At such stations a 'line clear' signal cannot be granted at the rear of a station unless the line on which a train is to be received is clear and the facing points set and locked. No shunting can be done after line clear has been granted.

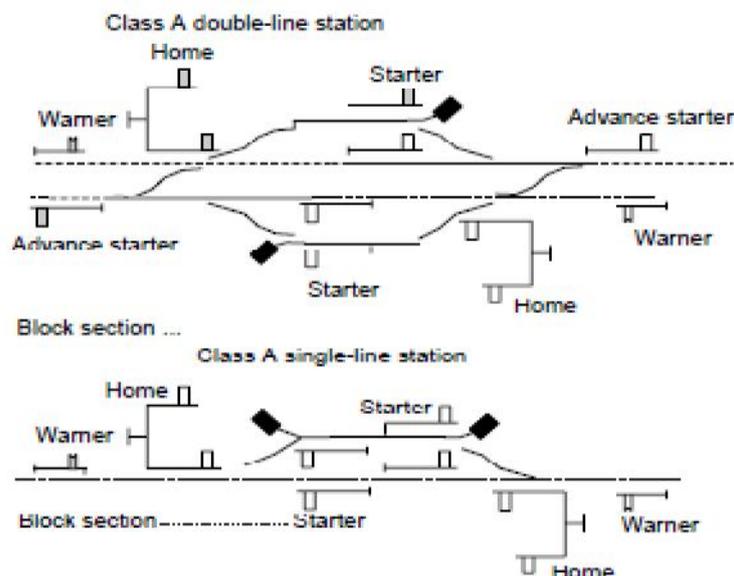


Fig. 26.1 A class station

B class station: This is the most common type of station and is provided on single-line as well as double-line sections. At a B class station, the line has to be clear up to an adequate distance beyond the outer signal before 'permission to approach' can be given to a train. The minimum signals required at a B class station are as follows.

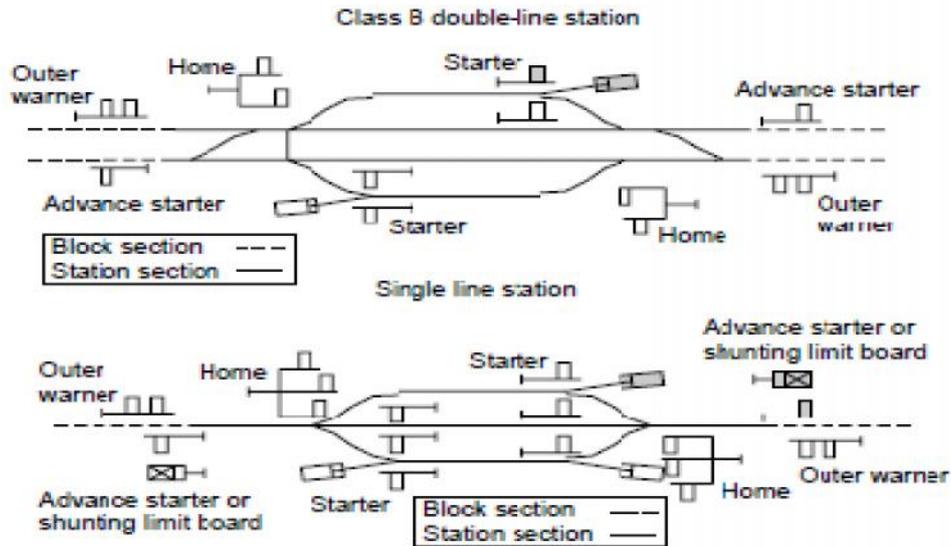


Fig. 26.2 B class station

C class station: The C class station is only a block hut where no booking of passengers is done. It is basically provided to split a long block section so that the interval between successive trains is reduced. No train normally stops at these stations.

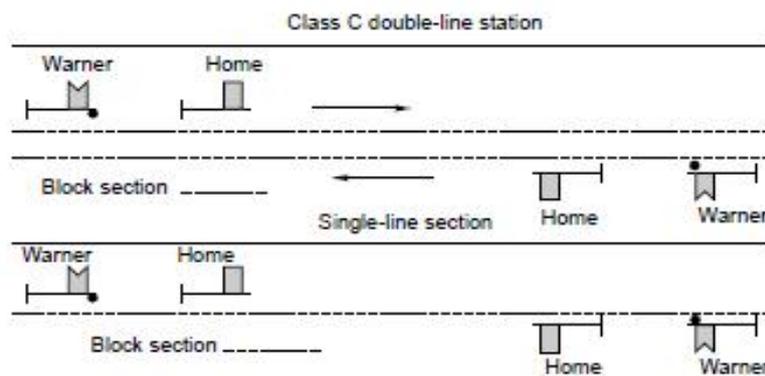


Fig. 26.3 C class station

Non-block Stations or D Class Stations: D class or non-block stations are located between two block stations and do not form the boundary of any block section. No signals are provided at D class stations.

4.10.2 Types of Yards

A yard is a system of tracks laid out to deal with the passenger as well as goods traffic being handled by the railways. This includes receipt and dispatch of trains apart from stabling, sorting, marshalling, and other such functions. Yards are normally classified into the following categories.

Coaching yard

The main function of a coaching yard is to deal with the reception and dispatch of passenger trains. Depending upon the volume of traffic, this yard provides facilities such as watering

and fuelling of engines, washing of rakes, examination of coaches, charging of batteries, and trans-shipment of passengers.

Goods yard

A goods yard provides facilities for the reception, stabling, loading, unloading, and dispatch of goods wagons. Most goods yards deal with a full train load of wagons. No sorting, marshalling, and reforming is done at goods yards except in the case of ‘sick’ wagons or a few wagons booked for that particular station. Separate goods sidings are provided with the platforms for the loading and unloading of the goods being handled at that station.

Marshalling yard

A goods yard which deals with the sorting of goods wagons to form new goods trains is called a marshalling yard. This is discussed in detail in Section 26.8.1.

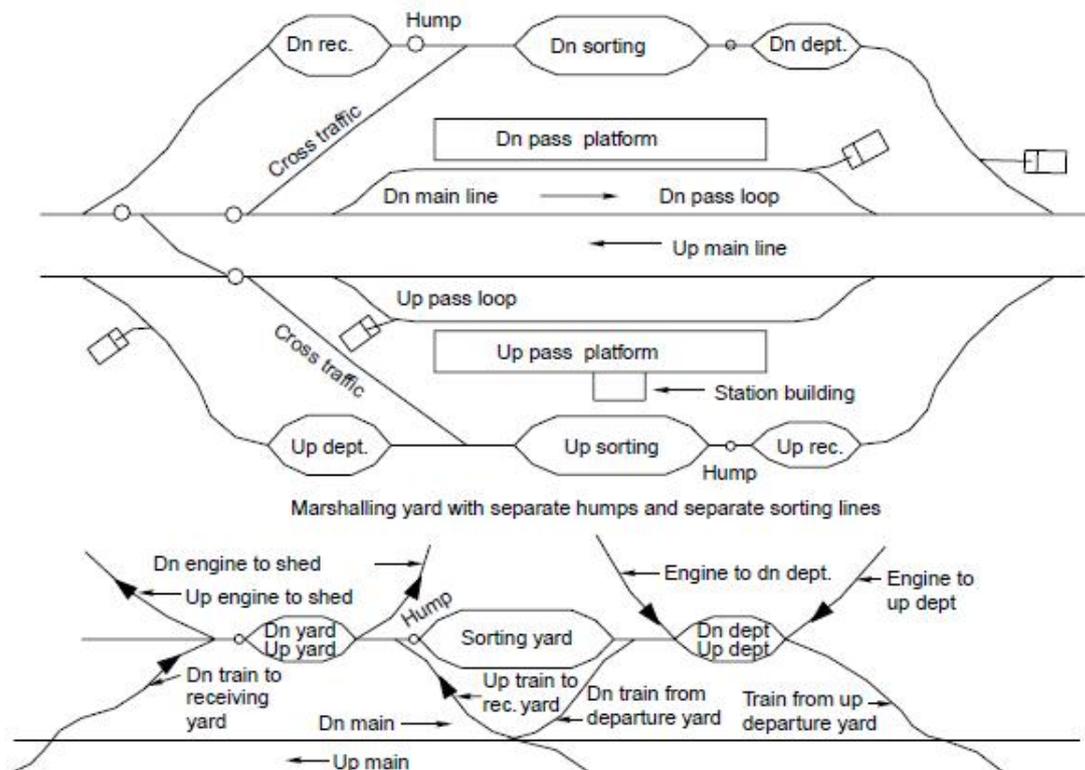


Fig. 26.14 Marshalling yard with a common hump and common sorting yard

Locomotive yard

This is the yard which houses the locomotive. Facilities for watering, fuelling, examining locomotives, repairing, etc., are provided in this yard. The yard layout is designed depending upon the number of locomotives required to be housed in the locomotive shed. The facilities are so arranged that a requisite number of locomotives are serviced simultaneously and are readily available for hauling the trains. Such yards should have adequate space for storing fuel. The water supply should be adequate for washing the locomotives and servicing them.

Sick line yard

Whenever a wagon or coach becomes defective, it is marked 'sick' and taken to sick lines. This yard deals with such sick wagons. Adequate facilities are provided for the repair of coaches and wagons, which include examination pits, crane arrangements, train examiner's office and workshop, etc. A good stock of spare parts should also be available with the TXR (train examiner) for repairing defective rolling stock.

4.11 Recommended questions

1. Define permanent way. Mention the elements of permanent way with sketch.
2. Explain the concept of coning of wheels and tilting of rails
3. Enumerate the functions and requirements of sleepers used in railway.
4. Explain left-hand turn out with typical sketch
5. Explain classifications of stations
6. Define yards. Explain the types of yards.
7. Evaluate the quantity of materials required to construct 1.5 km long BG track. Take Sleeper Density = $(m + 6)$, Length of Rail = 13 m.

4.12 Outcomes

Identify the Components parts of Railway Track and design the suitable runway for an Airport.

4.13 Further Reading

- a) <http://www.pavementinteractive.org/subsurface-drainage/>
- b) <http://agriculture.vic.gov.au/agriculture/dairy/managing-wet-soils/types-of-subsurface-drainage-systems>
- c) <http://nptel.ac.in/courses/105104098/45>
- d) <https://www.ijedr.org/papers/IJEDR1603152.pdf>

Module – 5

Airport Engineering

Structure

- 5.0 Introduction
- 5.1 Objectives
- 5.2 Component parts of Airport
- 5.3 Criteria for airport site selection and ICAO stipulations
- 5.4 Aircraft Characteristics Affecting Airport Design
- 5.5 Airport classification
- 5.6 Runway Orientation
- 5.7 Runway Length
- 5.8 Runway Geometric Design
- 5.9 Taxiway Planning
- 5.10 Comparison between Runway and Highway
- 5.11 Design of exit taxiway
- 5.12 Recommended Questions
- 5.13 Outcomes
- 5.14 Further Reading

5.0 Introduction

The planning of an airport is such a complex process that the analysis of one activity without regard to the effect on other activities will not provide acceptable solutions. An airport encompasses a wide range of activities which have different and often conflicting requirements. Yet they are interdependent so that a single activity may limit the capacity of the entire complex. In the past airport master plans were developed on the basis of local aviation needs. In more recent times these plans have been integrated into an airport system plan which assessed not only the needs at a specific airport site but also the overall needs of the system of airports which service an area, region, state, or country. If future airport planning efforts are to be successful, they must be founded on guidelines established on the basis of comprehensive airport system and master plans.

The elements of a large airport, It is divided into two major components, the airside and the landside. The aircraft gates at the terminal buildings form the division between the two components. Within the system, the characteristics of the vehicles, both ground and air, have a large influence on planning. The passenger and shipper of goods are interested primarily in the overall door to-door travel time and not just the duration of the air journey. For this reason access to airports is an essential consideration in planning.

5.1 Objectives

- Gain knowledge about various components of an Airport and its runway design.

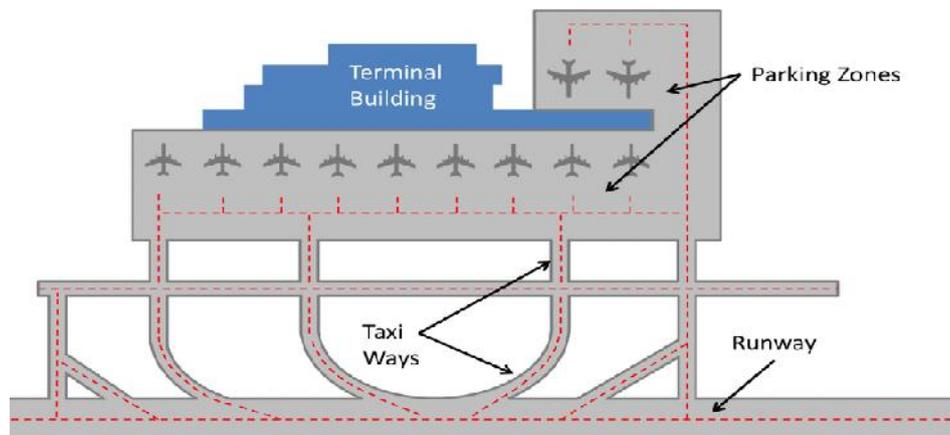
5.2 Component parts of Airport

Therefore, the main components of airport are

1. Runway
2. Terminal Building

3. Apron
4. Taxiway
5. Aircraft Stand
6. Hanger
7. Control Tower
8. Parking

Runways: It is the most important part of an airport in the form of paved, long and narrow rectangular strip which actually used for landing and takeoff operations. It has turfed (grassy) shoulders on both sides. The width of runway and area of shoulders is called the landing strip. The runway is located in the centre of landing strip. The length of landing strip is somewhat larger than the runway strip in order to accommodate the stop way to stop the aircraft in case of abandoned takeoff.



The length and width of runway should be sufficient to accommodate the aircraft which is likely to be served by it. The length of runway should be sufficient to accelerate the aircraft to the point of takeoff and should be enough such that the aircraft clearing the threshold of runway by 15m should be brought to stop within the 60% of available runway length. The length of runway depends on various meteorological and topographical conditions. Transverse gradients should not be less than 0.5% but should always be greater than 0.5%.

Terminal Buildings: Also known as airport terminal, these buildings are the spaces where passengers board or alight from flights. These buildings house all the necessary facilities for passengers to check-in their luggage, clear the customs and have lounges to wait before disembarking.

The terminals can house cafes, lounges and bars to serve as waiting areas for passengers. Ticket counters, luggage check-in or transfer, security checks and customs are the basics of all airport terminals.

Hangers: A hangar is a closed building structure to hold aircraft, spacecraft or tanks in protective storage. Most hangars are built of metal, but other materials such as wood and concrete are also used

Hangars are used for protection from the weather, direct sunlight, maintenance, repair, manufacture, assembly and storage of aircraft on airfields, aircraft carrier.

Aprons: Aircraft aprons are the areas where the aircraft park. Aprons are also sometimes called ramps. They vary in size, from areas that may hold five or ten small planes, to the very large areas that the major airports have.

Taxiway: Taxiway is the paved way rigid or flexible which connects runway with loading apron or service and maintenance hangars or with another runway. They are used for the movement of aircraft on the airfields for various purposes such as exit or landing, exit for takeoff etc. The speed of aircraft on taxiway is less than that during taking off or landing speed.

Aircraft Stand: A portion of an apron designated as a taxiway and intended to provide access to aircraft stands only.

Control Tower: A tower at an airfield from which air traffic is controlled by radio and observed physically and by radar.

Parking: Parking is a specific area of airport at which vehicles park

5.3 Criteria for airport site selection and ICAO stipulations

The selection of a suitable site for an airport depends upon the class of airport under consideration. However if such factors as required for the selection of the largest facility are considered the development of the airport by stages will be made easier and economical. The factors listed below are for the selection of a suitable site for a major airport installation:

Regional plan: The site selected should fit well into the regional plan there by forming it an integral part of the national network of airport.

Airport use: the selection of site depends upon the use of an airport. Whether for civilian or for military operations. However during the emergency civilian airports are taken over by the defence. Therefore the airport site selected should be such that it provides natural protection to the area from air roads. This consideration is of prime importance for the airfields to be located in combat zones. If the site provides thick bushes.

Proximity to other airport: the site should be selected at a considerable distance from the existing airports so that the aircraft landing in one airport does not interfere with the movement of aircraft at other airport. The required separation between the airports mainly depends upon the volume of air traffic.

Ground accessibility: the site should be so selected that it is readily accessible to the users. The airline passenger is more concerned with his door to door time rather than the actual time in air travel. The time to reach the airport is therefore an important consideration especially for short haul operations.

Topography: this includes natural features like ground contours trees streams etc. A raised ground a hill top is usually considered to be an ideal site for an airport.

Obstructions: when aircraft is landing or taking off it loses or gains altitude very slowly as compared to the forward speed. For this reason long clearance areas are provided on either side of runway known as approach areas over which the aircraft can safely gain or lose altitude.

Visibility: poor visibility lowers the traffic capacity of the airport. The site selected should therefore be free from visibility reducing conditions such as fog smoke and haze. Fog generally settles in the area where wind blows minimum in a valley.

Wind: runway is so oriented that landing and takeoff is done by heading into the wind should be collected over a minimum period of about five years.

Noise nuisance: the extent of noise nuisance depends upon the climb out path of aircraft type of engine propulsion and the gross weight of aircraft. The problem becomes more acute with jet engine aircrafts. Therefore the site should be so selected that the landing and takeoff paths of the aircrafts pass over the land which is free from residential or industrial developments.

Grading, drainage and soil characteristics: grading and drainage play an important role in the construction and maintenance of airport which in turn influences the site selection. The original ground profile of a site together with any grading operations determines the shape of an airport area and the general pattern of the drainage system. The possibility of floods at the valley sites should be investigated.

Future development: considering that the air traffic volume will continue to increase in future more member of runways may have to be provided for an increased traffic.

5.4 Aircraft Characteristics Affecting Airport Design

1. Engine and Propulsion
2. Size
3. Aircraft capacity
4. Aircraft speed
5. Minimum turning radius
6. Minimum circling radius
7. Aircraft weight and wheel arrangements
8. Range
9. Noise
10. Take off and landing distances
11. Tire pressure and contact area.

Engine and Propulsion: The size of aircraft, its circling radius, speed characteristics, weight carrying capacity, noise nuisance, etc, depend upon the type of propulsion of the aircraft.

The performance characteristics of aircrafts, which determine the basic runway length and also depend on the type of propulsion.

Size of Aircraft: Size depends upon

1. Wing Span
2. Length (Fuselage length)
3. The maximum height
4. Distance between main gears
5. Wheel base
6. Tail Width

Size decides load carrying capacity

Wing Span decides: The apron size, taxiway clearance, hangar size turning radius – ICAO classification

The length of Aircraft decides: The width of exit taxiway, apron size, length of hanger etc.

The height decides: The height of hangers and its gate.

The gear treads and wheel base affect the minimum turning radius of the aircraft.

Air Craft capacity: Aircraft capacity determines;

- Number of Passengers
- Baggage
- Cargo and Fuel.

Aircraft Speed:

- Speed now a days is measured in mach i.e. the speed of sound
- Piston engines – 500 to 800 km/hr (0.6 to 0.8 mach)
- Jet Engines - 1200 – 2400 km/hr (1 to 2 mach)
- Rocket engines - > 4800 km/hr (4 mach and above)

Speed has nothing to do with planning of airport, it gives an idea of the time of arrival of aircraft. However approach speed decides runway length.

Minimum Turning Radius: It is necessary to know the minimum turning radius of an aircraft to decide the radius of taxiways and to ascertain its position in the landing aprons and hangars.

Minimum Circling radius: A certain minimum circling radius in space is required for the aircraft to take a smooth turn. It is known as the minimum circling radius. It depends upon,

- Type of aircraft
- Air traffic volume
- Weather conditions
- The knowledge of minimum circling radius helps in separating two nearby airports by adequate distance.
- For jet planes its around 80 km
- For other planes its around 8 – 15 km.
- If minimum circling radius is not provided it will reduce the airport capacity and adjustment of timings for landing and take-off of aircrafts between the airports needs to be adjusted.

Aircraft Weight and Wheel Configuration:

- Governs the length and thickness of the runways, taxiways.
- Number of wheels to be provided depends on aircraft weight.
- Structural design of the airport is based on the total load of the aircraft.

The weight of the aircraft may be classified into:

- **Operating empty Weight** – Weight of empty aircraft, including its crew and all equipment needed for flight, but excluding passengers, fuel load and cargo.
- **Pay load** – revenue producing load which consists of passengers, mail and cargo.
- **Fuel Load-** Weight of the fuel carried by the aircraft required for the trip and certain reserve. It may vary from 9% to 40% of the total gross weight.

Wheel Configurations:-

More number of wheels lesser is the load on the runway pavement.

- Depends upon the size and type of aircraft.
- Wheel configuration also decides minimum turning radius.

Fuel Spillage:-

- The spilling of fuels and lubricants occur in loading aprons and hangers.
- It is difficult to avoid spilling completely.
- The bituminous pavements are seriously affected by fuel spillage. Hence the areas of bituminous pavements below the fuel inlets, the engines, and main landing gears are kept under constant watch by the airport authorities.
- Causes skidding of aircrafts.

Range:

- The distance that an aircraft can fly without refueling is called range.
- As range increases pay load decreases and vice versa.

Noise: This is a big problem in the areas where airports are quiet near to the developed areas. Efforts are being made to bring it to minimum possible level.

The major source of noise is:

- Engine
- Machinery prominent during landing
- Primary jet, prominent during take off

It causes Sleep disturbance, deafness, irritability, Loss of Concentration.

5.5 Airport classification**5.5.1 Based on take-off and landing:**

- Conventional Take-Off and Landing Airport (CTOL)
Runway Length > 1500 m
- Reduced Take-Off and Landing Airport (RTOL)
Runway Length 1000 to 1500 m
- Short Take-Off and Landing Airport (STOL)
Runway Length 500 to 1000 m

- Vertical Take-Off and Landing Airport (VTOL)
Operational area 25 to 50 sq m

5.5.2 FAA Classification:

Based on Air Craft Approach speed:

An aircraft approach category is a grouping differentiating aircraft based on the speed at which the aircraft approaches a runway for a landing.

Approach Category	Approach Speed (knots)
A	< 91
B	91 – 120
C	120 – 140
D	141 – 165
E	>165

1 knot = 1.852 kmph

5.5.3 ICAO Classification:

Based on Geometric Design:

- Properly designed airport geometry provides optimum efficiency in traffic operation with maximum safety.
- Geometric design of runway is considered as the major part of the design of runway.

Airport Type	Basic Runway Length (m)		Width of Runway Pavement (m)	Maximum Longitudinal Grade (%)
	Maximum	Minimum		
A	Over 2100	2100	45	1.5
B	2099	1500	45	1.5
C	1499	900	30	1.5
D	899	750	22.5	2.0
E	749	600	18	2.0

5.5.4 Based on Aircraft Wheel Characteristics:

Aircraft wheels are important component of a landing gear system. With tires mounted upon them, they support the entire weight of the aircraft during taxi, takeoff and landing. The typical aircraft wheel is lightweight, strong and made from aluminium alloy. Some magnesium alloy wheels also exist.

Code No.	Single Isolated Wheel Load (kg)	Tyre Pressure (kg/cm ²)
1	45000	8.5
2	34000	7.0
3	27000	7.0
4	20000	7.0
5	13000	6.0
6	7000	5.0
7	2000	2.5

5.5.5 Based on Function:

a) **Civil Aviation:** It is one of two major categories of flying, representing all non-military aviation, both private and commercial.

Domestic: A domestic airport is an airport that handles only flights within the same country. Domestic airports do not have customs and immigration facilities.

International: An international airport is an airport with customs and border control facilities enabling passengers to travel between countries.

b) Military Aviation: Military aviation is the use of military aircraft and other flying machines for the purposes of conducting or enabling aerial warfare, including national airlift capacity to provide logistical supply to forces stationed in a theatre or along a front.

5.5.6 Aerodromes in India:

International Hubs: This category includes airports currently classified as International Airports and having facilities of world standards.

Delhi, Mumbai, Bangalore, Chennai, Kolkata, Hyderabad, Thiruvananthapuram

Regional Hubs: Regional Airports will have to act as operational bases for regional airlines and also have all the facilities currently postulated for model airports, including the capability to handle limited international traffic. (Cochin, Ahmadabad etc)

Domestic Airports:

- Model Airports (Indore, Nagpur, Vadodara, Bhubaneswar)
- Operational (Udaipur, Kota, Kanpur)
- Non Operational (Patna, Mysore)

Custom Airports:

Having National and International tourist potential (Jaipur, Calicut, Agra, Gaya etc.)

Civil Enclaves (At defense airfields):

- Operational (Bagdodara, Leh etc.)
- Non Operational

Air force aerodromes

- Not for civil use

5.6 Runway Orientation

According to the International Civil Aviation Organization (ICAO) a runway is a "defined rectangular area on a land aerodrome prepared for the landing and takeoff of aircraft".

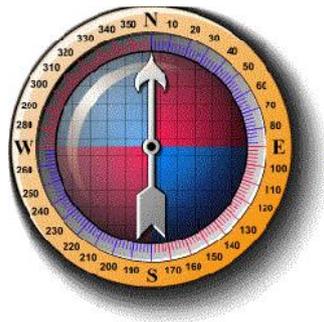
The orientation of the runway is an important consideration in airport planning and design. The correct runway orientation maximizes the possible use of the runway throughout the year accounting for a wide variety of wind conditions. FAA and ICAO regulations establish rules about runway orientation and their expected coverage Runway Location Considerations. FAA mandates identification standards for airport layout that is meant to assist pilots in easily recognizing runways.

Runway is usually oriented in the direction of prevailing winds. The head wind i.e. the wind direction of wind opposite to the direction of landing and taking-off provides greater

lift on the wings of the aircraft when it is taking-off. As such the aircraft rises above the ground much earlier and in a shorter length of runway. During landing, the head wind provides a braking effect and the aircraft comes to a stop in a smaller length of runway. Landing and take-off operations, if done along the wind direction, would require longer runway.

The challenge for the designer is to accommodate all of the aircraft using the facility in a reliable and reasonable manner.

In navigation, all measurement of direction is performed by using the numbers of a compass. A compass is a 360° circle where 0/360° is North, 90° is East, 180° is South, and 270° is West, as shown in figure.



Cross Wind Component

It is not possible to obtain the direction of wind along the direction of the centre line of runway throughout the year. On some day of the year or hour of the day, the wind may blow making certain angle with the centre line of runway. If the direction of wind is at an angle to the runway centre line, its component along the direction of runway will be $V \cos \theta$ and that normal to the runway centre line will be $V \sin \theta$, where V is the wind velocity. The normal component of the wind is called cross wind component and may interrupt the safe landing and take-off of the air-crafts.

Wind Coverage

The maximum permissible cross wind component depends upon the size of aircraft and the wing configuration. FAA recommends that for small aircrafts, the cross wind component should not exceed 15 kmph (10 mph) and for mixed traffic it should not exceed 25 kmph (15 mph). For airports serving big aircrafts, ICAO recommends that the cross wind component should not exceed 35 kmph (23 mph). The percentage of time in a year during which the cross wind component remains within the limits as specified above is called wind coverage. According to FAA, the runway handling mixed air traffic should be so planned that for 95 per cent of time in a year, the permissible cross wind component does not exceed 25 kmph. For busy airports, the wind coverage may be increased to as much as 98 percent to 100 percent

5.6.1 Wind Rose Diagram

Runway orientation using wind rose:

The wind data, i.e., direction, duration and intensity are graphically represented by a diagram called wind rose. The wind data should usually be collected for a period of at least 5 years and preferably of 10 years, so as to obtain an average data with sufficient accuracy. As

far as possible, these observations should be taken at or near site selected, since the wind conditions may vary considerably with location particularly in hilly regions.

A typical wind data is given in Table below. In this table, the duration of wind for any one direction covers an angle of 22.5 degrees as shown in Figure below. It is assumed that the wind may come from any point within the 22.5 degree sector. It is possible the wind for a particular location have not been recorded. In such cases the data from two or more of the nearest wind recording station should be used to fix up the wind characteristics of the site. However, this cannot be done if the intervening terrain is mountainous. In such cases, the observations of the wind at the actual site should be recorded for at least one year and these results should be used in the interpretation of the data of the nearby weather station as applied to site. Wind rose diagram can be plotted from the data of Table below. It helps in analysing the wind data and obtaining the most suitable direction of the runway.

Wind Data *

Wind direction	Duration of wind, Percent **			Total in each direction, percent
	6.4 – 25 kmph	25 – 40 kmph	40 – 60 kmph	
N	7.4	2.7	0.2	10.3
NNE	5.7	2.1	0.3	8.1
NE	2.4	0.9	0.6	3.9
ENE	1.2	0.4	0.2	1.8
E	0.8	0.2	0.0	1.0
ESE	0.3	0.1	0.0	0.4
SE	4.3	2.8	0.0	7.1
SSE	5.5	3.2	0.0	8.7
S	9.7	4.6	0.0	14.3
SSW	6.3	3.2	0.5	10.0
SW	3.6	1.8	0.3	5.7
WSW	1.0	0.5	0.1	1.6
W	0.4	0.1	0.0	0.5
WNW	0.2	0.1	0.0	0.3
NW	5.3	1.9	0.0	7.2
NNW	4.0	1.3	0.3	5.6
Total percent				86.5

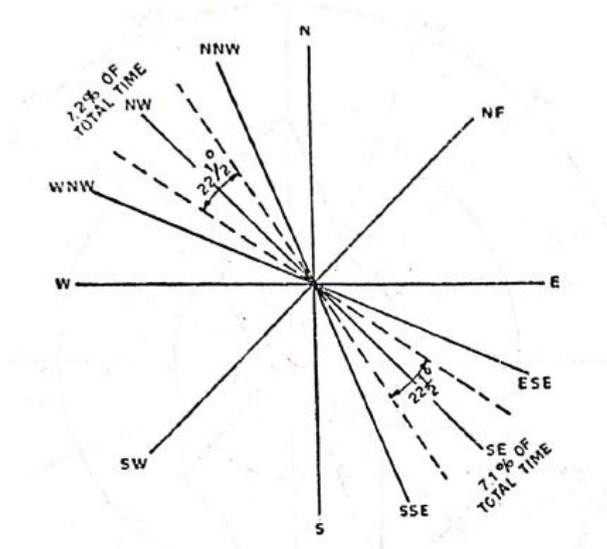
* - Average of 8 years periods

** - Percentage of time during which wind intensity, is less than 6.4 kmph in 100 - 86.5 = 13.5 percent. This period is called calm period and does not influence the operation of landing or take-off because low wind intensity.

Wind rose diagrams can be plotted in two types as follows:

Type I: Showing direction and duration of wind

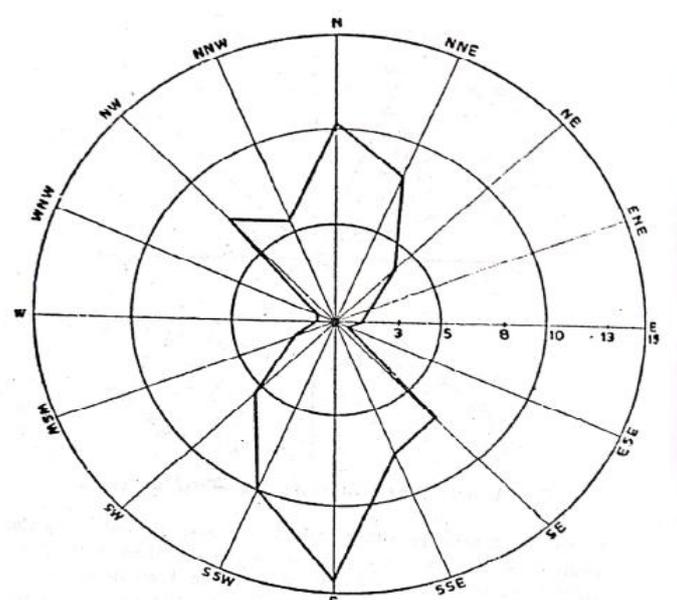
Type II: Showing direction, duration and intensity of wind



5.6.1.1 Type I Wind Rose

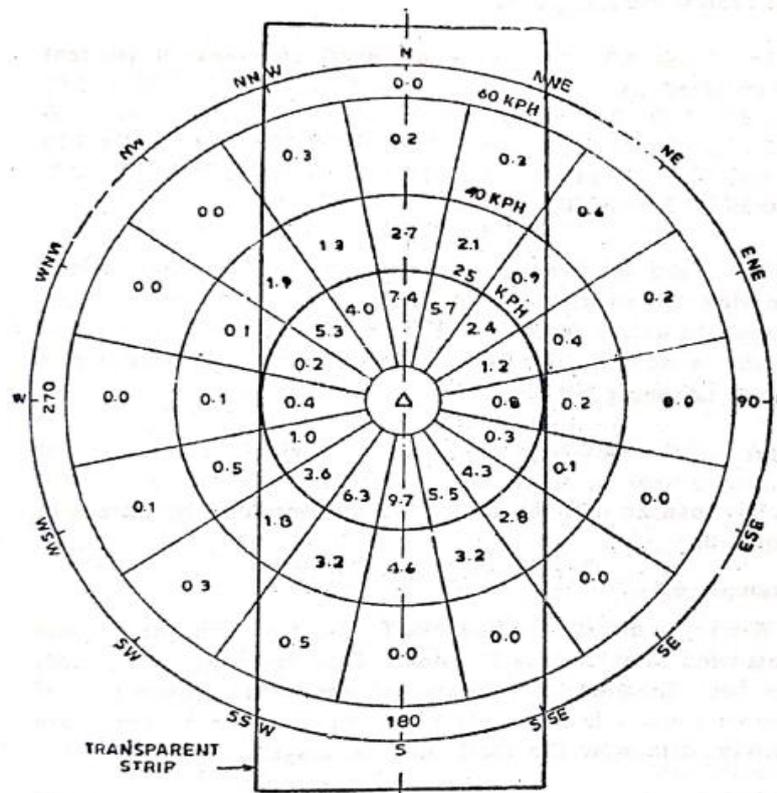
This type of wind rose is illustrated in Figure. The radial lines indicate the wind direction and each circle represents the duration of wind. From the Table, it is observed that the total percentage of time in a year during the wind blows from north direction is 10.3 percent. This value is plotted along the north direction in Figure. Similarly other values are also plotted along the respective directions. All plotted points are then jointed by straight lines as shown in Figure 5.2. The best direction of runway is usually along the direction of the longest line on wind rose diagram. In Figure, the best orientation of runway is thus along NS direction. If deviation of wind direction up to $(22.5^\circ + 11.25^\circ)$ from the direction of landing and take-off is permissible, the percentage of time in a year during which the runway can safely be used for landing and take-off, will be obtained by summing the percentages of time along NNW, N, NNE, SSE, S and SSW directions. This comes to 57.0 percent.

Calm period, i.e., the percentage of time during which wind intensity is less than 6.4 kmph is also added to the above period. The total percentage of the time therefore comes to $57.0 + 13.5 = 70.5$. This type of wind rose does not account for the effect of cross wind component.



5.6.1.2 Type II Wind Rose

This type of wind rose is illustrated in Figure. The wind data as in the previous type, i.e. of Table is used for this case. Each circle represents the wind intensity to some scale. The values entered in each segment represent the percentage of time in a year during which the wind, having particular intensity, blows from the respective direction. The procedure for determining the orientation of runway is described below:



(i) Draw three equi - spaced parallel lines on a transparent paper strip in such a way that the distance between the two nearby parallel lines is equal to the permissible cross wind component. This distance is measured with the same scale with which the wind rose diagram is drawn. In Figure 5.3, the permissible cross wind component is 25 kmph.

(ii) Place the transparent paper strip over the wind rose diagram in such a way that the central line passes through the centre of the diagram.

(iii) With the centre of wind rose, rotate the tracing paper and place it in such a position that the sum of all the values indicating the duration of wind, within the two outer parallel lines, is the maximum. The runway should be thus oriented along the direction indicated by the central line. The wind coverage can be calculated by summing up all the percentages shown in segment. The percentage value is assumed to be equally distributed over the entire area of the segment. When of the outer parallel lines of the transparent strip crosses a segment, a fractional part of the percentage appearing in that segment within the outside lines is also counted in the summation. Fractional areas are determined by judgement to the nearest decimal place.

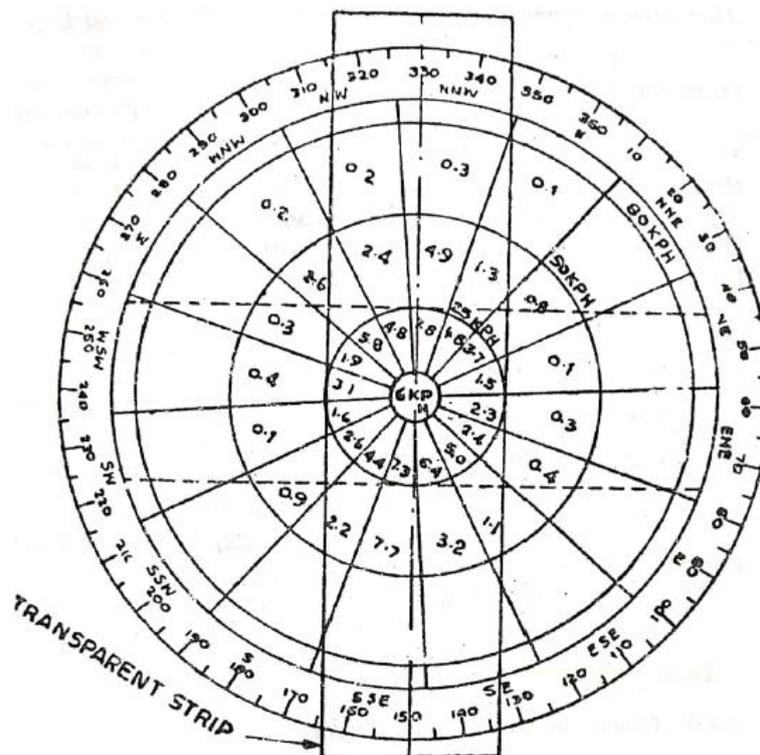
In Figure 5.3, the maximum wind coverage in per cent is obtained as 13.50 (Calm period) + $7.40 + 5.70 + 2.40 + 1.20 + 0.80 + 0.30 + 4.30 + 5.50 + 9.70 + 6.30 + 3.60 + 1.00 + 0.40 + 0.20 + 5.30 + 4.00 + 2.70 + 2.10 + 0.50 + 0.10 + 0.03 + 2.10 + 3.20 + 4.60 + 3.20 + 1.13 + 0.30 + 0.02 + 1.50 + 1.30 + 0.20 + 0.20 + 0.0 + 0.30 + 0.25 = 96.50$.

(iv) Read the bearing of the runway on the outer scale of the wind rose where the central line on the transparent paper crosses the angular scale. In Figure 5.3 the best orientation of runway is along the direction whose whole circle bearing is zero degree i.e. along NS direction.

(v) If the coverage provided by a single runway is not sufficient, two or more number of runways is planned in such a manner that the total coverage provided by them is as required.

Example:

Wind rose diagram is shown in Figure. The permissible cross wind component is 25 kmph. Determine the calm period, the best direction of runway and the wind coverage. If another runway is to be placed at right angles to the above runway, determine the total wind coverage.



Solution:

Calm period is the percentage of time during which wind intensity is less than 6 kmph.

If is therefore, equal to $100 - (7.8 + 4.8 + 3.7 + 1.5 + 2.3 + 2.4 + 5.0 + 6.4 + 7.3 + 4.4 + 2.6 + 1.6 + 3.1 + 1.9 + 5.8 + 4.8 + 4.9 + 1.3 + 0.1 + 0.1 + 0.3 + 0.4 + 1.1 + 3.2 + 7.7 + 2.2 + 0.9 + 0.1 + 0.4 + 0.3 + 2.6 + 2.4 + 0.3 + 0.1 + 0.2 + 0.2) = 5.1$ per cent.

Runway oriented along 150° - 340° line (S 33° E) gives the maximum wind coverage as obtained by summing up the data within the two outer parallel lines:

Direction	Percentage within outer parallel lines	Direction	Percentage within outer parallel lines
N	5.67	S	6.00
NNE	3.85	SSW	2.62
NE	1.50	SW	1.60
ENE	2.50	WSW	3.10
E	2.40	W	1.95
ESE	5.80	WNW	7.10
SE	9.60	NW	7.35
SSE	15.0	NNW	13.0

Sum of the above percentages = 89.04
 Add calm period = 5.10
 The required wind coverage is = 89.04 + 5.10 = 94.14 percent

Alternatively summing the percentage outside the parallel lines

Direction	Percentage outside parallel lines	Direction	Percentage outside parallel lines
N	0.38	S	0.44
NNE	0.60	SSW	0.75
NE	0.10	SW	0.10
ENE	0.30	WSW	0.40
E	0.32	W	0.25
ESE	0.30	WNW	1.50
SE	0.00	NW	0.05
SSE	0.00	NNW	0.00

Sum of the above percentage = 5.49 percent
 Required wind coverage = 100 - 5.49 = 94.51 percent.

If another runway is placed at right angles to the previous runway, it would give an additional wind coverage = 0.21 + 0.40 + 0.10 + 0.42 + 0.40 + 0.10 + 0.30 + 0.30 = 2.13 percent.

Total wind coverage = 94.51 + 2.13 = 96.64 percent

5.7 Runway Length

It is the length of runway under the following assumed conditions:

5.7.1 Corrections for elevation, temperature and gradient

The basic runway length as discussed earlier is for mean sea level elevation having standard atmospheric conditions. Necessary corrections are therefore applied for any change in elevation, temperature and gradient for the actual site of construction.

5.7.2 Correction for elevation

- As the elevation increases, the air density reduces. This in turn reduces the lift on the wings of the aircraft and the aircraft requires greater ground speed before it can rise into the air.
- To achieve greater speed, longer length of runway is required.
- ICAO recommends that the basic runway length should be increased at the rate of 7 per cent per 300m rise in elevation above the mean sea level.

5.7.3 Correction for temperature

- The rise in airport reference temperature has the same effect as that of the increase in elevation. Airport reference temperature is defined as the monthly mean of average daily temperature (T_a) for the hottest month of the year plus one third the difference of this temperature (T_a) and the monthly mean of the maximum daily temperature (T_m) for the same month of the year.
- Thus airport reference temperature = $T_a + \frac{(T_m - T_a)}{3}$
- ICAO recommends that the basic runway length after having been corrected for elevation should be further increased at the rate of 1 percent for every 1°C rise of airport reference temperature above the standard atmospheric temperature at that elevation.

5.7.4 Check for total correction for elevation plus temperature

- ICAO further recommends that, if the total correction for elevation plus temperature exceeds 35percent of the basic runway length, these corrections should then be further checked up by conducting specific studies at the site by model tests.

5.7.5 Correction for gradient

- Steeper gradient results in greater consumption of energy and as such longer length of runway is required to attain the desired ground speed.
- ICAO does not recommend any specific correction for the gradient.
- FAA recommends that the runway length after having been corrected for elevation and temperature should be further increased at the rate of 20 % for every 1 percent of effective gradient.
- Effective gradient is defined as the maximum difference in elevation between the highest and lowest points of runway divided by the total length of runway.

Examples

1. The data below refers to the daily temperature for the hottest month of the year 1988 for a given airport site. Determine the airport reference temperature.

Date	Temperature, °C		Date	Temperature, °C	
	Maximum	Average		Maximum	Average
1	42.5	25.5	16	43.7	26.2
2	42.5	25.5	17	43.8	25.8
3	42.7	25.7	18	44.0	26.3
4	43.0	25.9	19	44.8	26.3

5	43.0	25.9	20	44.1	26.3
6	43.0	25.9	21	44.3	26.5
7	42.8	25.8	22	44.3	26.9
8	43.0	25.9	23	44.5	26.5
9	43.0	25.9	24	44.6	26.5
10	43.1	25.0	25	44.6	26.9
11	43.3	26.3	26	44.7	27.0
12	43.5	26.4	27	44.6	27.0
13	43.3	26.3	28	44.7	27.0
14	43.5	26.4	29	44.8	26.2
15	43.6	26.3	30	45.0	27.2

Solution:

Mean of the maximum daily temperatures, $T_m = \frac{1311.6}{30} = 43.72 \text{ }^\circ\text{C}$

Mean of the average daily temperatures, $T_a = \frac{789.7}{30} = 26.32 \text{ }^\circ\text{C}$

Airport Reference Temperature, $ART = T_a + \frac{(T_m - T_a)}{3} = 26.32 + \frac{(43.72 - 26.32)}{3} = 32.12 \text{ }^\circ\text{C}$

2. The monthly mean temperatures of the atmosphere, at a particular site, where an airport has to be developed, are given below. Determine the airport reference temperature. If the site is at mean sea level, determine the actual runway length. The runway is assumed to be level.

Month	Temperature $^\circ\text{C}$	
	Mean value of average daily, (T_a)	Mean value of Maximum daily, (T_m)
January	3	5
February	15	17
March	20	23
April	25	32
May	35	47
June	40	50
July	32	37
August	30	35
September	27	31
October	22	28
November	12	18
December	6	9

Solution:

The above table indicates that the hottest month of the year is the month of June.

Therefore, mean of the maximum daily temperatures, $T_m = 50 \text{ }^\circ\text{C}$

Mean of the average daily temperatures, $T_a = 40 \text{ }^\circ\text{C}$

Airport Reference Temperature, $ART = T_a + \frac{(T_m - T_a)}{3} = 40 + \frac{(50 - 40)}{3} = 43.33 \text{ }^\circ\text{C}$

Suppose the basic runway length = L meters. Since the runway is at the mean sea level, no correction in length is required for the elevation. The correction for the temperature is necessary as the airport reference temperature is above the standard atmospheric temperature at MSL (15 °C).

The rise of temperature = $43.33 - 15 = 28.33$ °C.

The correction is applied at the rate of 1 percent per 1°C rise of temperature

$$\therefore \text{The required correction} = \frac{L}{100} * 28.33$$

The corrected length = $L + 0.2833 L = 1.2833 L$ metre

No correction is required for gradient since; the runway is assumed as level in length direction. Therefore, the actual length of runway to be provided = 1.2833 L metres.

3. The following data refers to the proposed longitudinal section of runway.

End to End of Runway	Gradient
0.0 to 5.0 Chains	+ 1.0 %
5.0 to 15.0 Chains	- 1.0 %
15.0 to 30.0 Chains	+ 0.8 %
30.0 to 40.0 Chains	+ 0.2 %

If one metric chain is of 20 m length, determine the effective gradient of runway.

Solution:

Chainage	0	5	15	30	40
Elevation	100.0	101.0	99.0	101.4	101.8

Maximum difference in elevation = $101.8 - 99.0 = 2.8$ m

Total runway length = $40 * 20 = 800$ m

Therefore, effective gradient of runway = $\frac{2.8}{800} * 100 = 0.35$ percent

4. The length of runway under standard conditions is 1620 m. The airport site has an elevation of 270 m. Its reference temperature is 32.94 °C. If the runway is to be constructed with an effective gradient of 0.20 percent, determine the corrected runway length.

Solution:

(i) Correction for elevation:

$$= \frac{7}{100} * 1620 * \frac{270}{300}$$

$$= 102 \text{ m}$$

Corrected length = $1620 + 102 = 1722$ m

(ii) Determination of standard atmospheric temperature at the given elevation:

$$= 15 - 0.0065 * 270 = 13.18 \text{ °C}$$

(iii) Correction for temperature:

Rise of temperature = $32.90^\circ - 13.18^\circ = 19.72^\circ\text{C}$

$$\text{Correction} = \frac{19.72}{100} * 1722 = 340 \text{ m}$$

Corrected length = $1722 + 340 = 2062$ m

(iv) Check for the total correction for elevation plus temperature:

Total correction in percentage = $\frac{(2062 - 1620)}{1620} * 100 = 27.28$ percent

According to ICAO, this should not exceed 35%

(v) Correction for gradient:

$$= \frac{20}{100} * 2062 * 0.20 = 82.48 \text{ m}$$

Corrected length = $2062 + 82.48 = 2144.48$ m

Rounding the above value to the nearest 10 m, the corrected runway length is 2150 m.

5. The runway length required for landing at sea level in standard atmospheric conditions is 3000 m. Runway length required for take-off at a level site at sea level in standard atmospheric conditions is 2500 m. Aerodrome reference temperature is 24 °C and that of the standard atmosphere at aerodrome elevation of 150 m is 14.025 °C. If the effective runway gradient is 0.5 percent, determine the runway length to be provided.

Solution:

(a) Corrections to runway take-off length

(i) Correction for elevation:

$$= \frac{7}{100} * 2500 * \frac{150}{300}$$

$$= 87 \text{ m}$$

Corrected length = $2500 + 87 = 2587$ m

(ii) Correction for temperature:

Rise of temperature = $24^\circ - 14.025^\circ = 9.975^\circ \text{C}$

Correction = $\frac{9.975}{100} * 2587 = 258$ m

Corrected length = $2587 + 258 = 2845$ m

(iii) Check for the total correction for elevation plus temperature:

Total correction in percentage = $\frac{(2845 - 2500)}{2500} * 100 = 13.8$ percent

According to ICAO, this should not exceed 35%

(iv) Correction for gradient:

$$= \frac{20}{100} * 2854 * 0.50 = 284 \text{ m}$$

Corrected length = $2845 + 284 = 3130$ m

(b) Corrections to runway landing length

(i) Correction for elevation:

$$= \frac{7}{100} * 3000 * \frac{150}{300}$$

$$= 105 \text{ m}$$

Corrected length = $3000 + 105 = 3105$ m

No corrections are needed to landing length for temperature and gradient.

(c) Actual runway length to be provided would be greater of (a) and (b) above 3130 m

6. Calculate the actual length of runway from the following data

Airport elevation : R.L 100
Airport Reference Temperature : 28 °C
Basic length of runway : 600 m
Highest point along the length : R.L 98.2
Lowest point along the length : R.L 95.2

Solution:

(i) Correction for elevation:

$$\begin{aligned}
 &= \frac{7}{100} * 600 * \frac{100}{300} \\
 &= 14 \text{ m}
 \end{aligned}$$

Corrected length = 600 + 14 = 614 m

(ii) Determination of standard atmospheric temperature at the given elevation:

$$= 15 - 0.0065 \times 100 = 14.35 \text{ } ^\circ\text{C}$$

(iii) Correction for temperature:

$$\text{Rise of temperature} = 28^\circ - 14.35^\circ = 13.65^\circ\text{C}$$

$$\text{Correction} = \frac{13.65}{100} * 614 = 84 \text{ m}$$

$$\text{Corrected length} = 614 + 84 = 698 \text{ m}$$

(iv) Check for the total correction for elevation plus temperature:

$$\text{Total correction in percentage} = \frac{(698 - 600)}{600} * 100 = 16.33 \text{ percent}$$

According to ICAO, this should not exceed 35%

(v) Correction for gradient:

$$\text{Effective gradient} = \frac{(98.2 - 95.2)}{600} = 0.5 \%$$

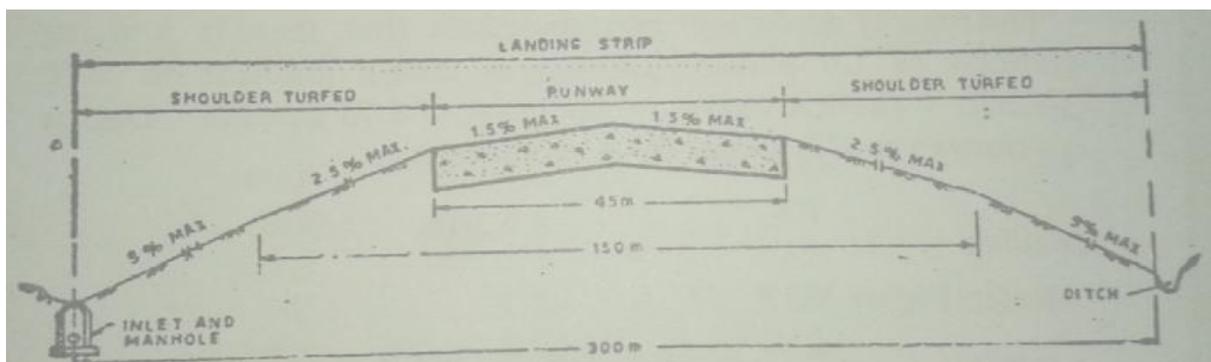
$$\text{Correction} = \frac{20}{100} * 698 * 0.50 = 70 \text{ m}$$

Corrected length = 698 + 70 = 768 m

5.8 Runway Geometric Design

Factors considered in geometric design of runways:

- i. Runway length
- ii. Runway width
- iii. Width and length of safety area
- iv. Transverse gradient
- v. Longitudinal and effective gradient
- vi. Rate of change of longitudinal gradient



Runway length: The basic runway length as recommended by ICAO for different types of airport is given in the table below. To obtain the actual length of runway, corrections for elevation, temperature and gradient are applied to the basic runway length.

Airport Type	Basic Runway Length (m)		Width of Runway Pavement (m)	Maximum Longitudinal Grade (%)
	Maximum	Minimum		
A	Over 2100	2100	45	1.5
B	2099	1500	45	1.5
C	1499	900	30	1.5
D	899	750	22.5	2.0
E	749	600	18	2.0

Runway width

- ICAO recommends the pavement width varying from 45 m to 18m for different types of airport.
- The aircraft traffic is more concentrated in the central 24m width of the runway pavement.
- Another consideration in determining the runway width is that the outermost machine of large jet aircraft using the airport should not extend off the pavement on to the shoulders. This is because the shoulder is usually of loose soil or established soil etc which is likely to get into the engine and damage it.
- The outer engines of a large jet transport are about 13.5m from the longitudinal axis of the aircraft.
- As such a pavement width of 45m will provide adequate protection to the engine from the shoulder material during normal operations.

Width and length of safety area

- Safety area consists of the runway, which is a paved area plus the shoulder on either side of runway plus the area that is cleared, graded and drained.
- The shoulders are usually unpaved as they are used during emergency. They may at the most be prepared of stabilized soil or turf.
- Another advantage of providing shoulders on either side of runway is that they impart a sense of openness to the pilot and improve psychology during landing and take-off.
- ICAO recommends that for non-instrumental runway, the width of safety area should be at least 150m for A, B, C, and 78 m for D and E types and for instrumental runway, it should be minimum 300m.

Transverse gradient

- This is essential for quick drainage of surface water. If surface water is allowed to pond on the runway, the aircraft can meet severe hazards.
- ICAO recommends that the transverse gradient of runway pavement should not exceed 1.50percent for A, B, C and 2 percent for D and E types. It does not specify the minimum limit of the transverse gradient.
- ICAO recommends that the transverse gradient of portion of the shoulder should not exceed 2.50percent.

- Transverse gradient of the remaining portion of the shoulder should not exceed 5 percent.

Longitudinal and effective gradient

- The longitudinal gradient of runway increases the required runway length. ICAO gives the following recommendations for the maximum longitudinal gradient and the maximum effective gradient.
- For longitudinal gradient:
 - A, B and C types: 1.50 percent
 - D and E types: 2.00 percent
 - For effective gradient
 - A, B and C types: 1.00 percent
 - D and E types: 2.00 percent

Rate of change of longitudinal gradient

- The abrupt change of longitudinal gradient restricts the height distance and may also cause premature lift-off of the aircraft during the taking-off operation.
- The premature lift-off of aircraft will affect its performance of aircraft during its take-off and can also develop structural defects in the aircraft.
- Too many changes in the gradients over a small length of runway can also restrict the sight distance and increase the runway length.
- The changes in gradients should be smoothed by vertical curves.
- ICAO recommends that the rate of change of gradient should be limited to a maximum of 0.10 percent per 30m length of vertical curve for A and B types, 0.2 percent for C type and 0.4 percent for D and E types of airports.

5.9 Taxiway Planning

5.9.1 Factors controlling taxiway layout:

- Taxiway should be so arranged that the aircrafts which have just landed and are taxiing towards the apron do not interfere with the aircrafts taxing for take-off.
- At busy airports, taxiways should be so selected at various points along the runway so that the landing aircraft leaves the runway as early as possible and keeps it clear for use by other aircrafts. Such taxiways are called exit taxiways.
- The route for taxiway should be so selected that it provides the shortest practicable distance from the apron to the runway.
- As far as possible the intersection of taxiway and runway should be avoided.
- Exit taxiway should be designed for high turn off speeds. This will reduce the runway occupancy time of aircraft and thus increase the airport capacity.

5.9.2 Geometric design standards:

- Length of taxiway
- Width of taxiway
- Width of safety area
- Longitudinal gradient

- Traverse gradient
- Rate of change of longitudinal gradient
- Sight distance
- Turning radius

Length of taxiway:

- It should be as short as practicable. This will save the fuel consumption.
- No specifications are recommended by any organisation for limiting the length of taxiway.

Width of taxiway:

- The width of taxiway is much lower than the runway width.
- The speed of the aircraft on a taxiway is also lower than the speed on runway.
- The pilot can comfortably manoeuvre the aircraft over a smaller width of taxiway than on a runway.

Width of safety area:

- This area includes taxiway pavement shoulders on either side that may be partially paved plus the area that is graded and drained.
- This may extend up to a point where it intersects a parallel runway, taxiway and apron.
- Bitumen treated shoulders are normally used.
- The shoulders must be thick enough to support the airport petrol vehicles and the sweeping equipment.

Longitudinal gradient:

- If the gradient is steep, there will be greater fuel consumption.
- ICAO recommends that the longitudinal gradient should not exceed 1.5 percent for A and B types and 3 percent for other types of airports.

Transverse gradient:

- This is essential for quick drainage of surface water.
- ICAO recommends that for taxiway pavement like runway, the transverse gradient should not exceed a value of 1.5 percent for A, B and C types and 2 percent for D and E types of airports.
- ICAO does not specify any value for the transverse slope of taxiway shoulders.
- FAA recommends that it should be 5 percent for the first 3 m and 2 percent thereafter for all types of airports.

Rate of change of longitudinal gradient:

- ICAO recommends that rate of change of slope in longitudinal direction should not exceed 1 percent per 30 m length of vertical curve for A, B and C types and 1.2 percent for D and E types of airports.

Sight distance:

- ICAO recommends that the surface of a taxiway must be visible from 3 m height for a distance of 300 m for A, B and C types and distance of 250 m must be visible from 2.1 m height for D and E types of airports.

Turning radius:

Whenever there is a change in the direction of a taxiway, a horizontal curve is provided.

$$R = V^2 / 125 f$$

Where, R – Radius, m
V – Speed, kmph
f – Coefficient of friction, 0.13

- For airport serving subsonic jet transports, minimum value of radius of curvature is 120 m is suggested.
- For airport serving supersonic jet transports, minimum value of radius of curvature is 180 m is suggested.

ICAO classification	Taxiway width	Maximum longitudinal gradient, %	Minimum transverse gradient, %	Maximum rate of change of longitudinal gradient per 30 m, %
A	22.5	1.5	1.5	1.0
B	22.5	1.5	1.5	1.0
C	15	3.0	1.5	1.0
D	9.9	3.0	2.0	1.2
E	7.5	3.0	2.0	1.2

Table: Taxiway geometrics

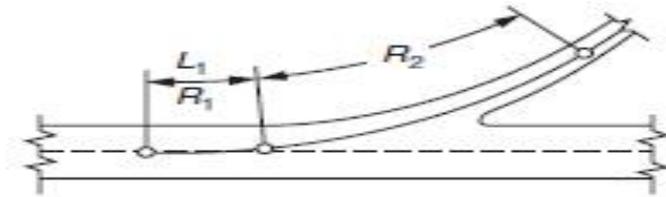
5.10 Comparison between Runway and Highway pavement

Highway pavement	Airfield pavement
Cost is low.	Cost is high.
Less toughness compare to airfield.	High toughness need.
Design load is less.	Design load is very High
Less hardness compare to airfield	Need higher resistant to wear and tear due to aircraft trust.
Compare to airfield, less construction cost and design cost	Design cost and material cost is high due to rigid specifications and high level of construction practice.
Length of Highway payment is very high.	Length of airfield pavement is less compare to Highway pavement.
Low tire pressure	High tire pressure
Serious distress at edge for flexible pavement	No distress at edge for flexible pavement
Pumping action for rigid pavement without base course	No pumping action

5.11 Design of Exit Taxiway connecting runway and parallel taxiway

The following principles govern the design of taxiway:

- i. The most significant factor affecting the turning radius is the exit speed of aircraft.
- ii. Slightly widened entrance of 30m gradually tapering to the normal width of taxiway is preferred. The widened entrance gives to the pilot more latitude in using the exit taxiway.
- iii. Total angle of turn of 30° to 45° can be negotiated satisfactorily.
- iv. For the smooth and comfortable turn, the turning radius should be determined from the equation $V^2/125f$. A high turn-off speed of 65 to 95 kmph, a compound curve is necessary to minimise the tire wear on the nose gear. Therefore, the main curve radius R_2 should be preceded by a larger radius curve of R_1 as shown in figure.



- vi. The length of larger radius curve can be roughly obtained from the following relation:
Value of C is 0.39
- vii. Sufficient distance must be provided to comfortably decelerate an aircraft after it leaves the runway. This distance may be based on an average deceleration rate of 1 m/sec². The stopping distance may be obtained from the following equation :

$$S.D = \frac{V^2}{25.5d}$$

Where, d is the deceleration in m/sec²

The stopping distance should be measured from the edge of the runway pavement along the exit taxiway.

5.12 Recommended Questions

1. Enumerate the various factors which you would keep in view while selecting a suitable site for an airport.
2. Write the classification of airports based on ICAO and FAA?
3. Explain the component parts of airports.
4. Explain the aircraft characteristics which affect the airport design.
5. Explain the geometric design of taxiway.
6. Write the assumptions of basic runway

5.13 Outcomes

- Identify the Components parts of Railway Track and design the suitable runway for an Airport.

5.14 Further Reading

1. <http://textofvideo.nptel.ac.in/105107123/lec14.pdf>
2. <https://nptel.ac.in/courses/105107123/6>
3. <http://science.howstuffworks.com/transport/flight/modern/airport1.htm>