RAJIV GANDHI PROUDYOGIKI VISHWAVIDYALAYA, BHOPAL

New Scheme Based On AICTE Flexible Curricula

Civil Engineering, V-Semester

CE502 - Transportation Engineering- II

Unit - I

High way planning, Alignment & Geometric Design: Principles of highway planning, road planning in India and financing of roads, classification patterns. Requirements, Engg. Surveys for highway location.

Cross sectional elements- width, camber, super-elevation, sight distances, extra widening at curves, horizontal and vertical curves, numerical problems.

Unit – II

Bituminous & Cement Concrete Payments: Design of flexible pavements, design of mixes and stability, WBM, WMM, BM, IBM, surface dressing, interfacial treatment- seal coat, tack coat, prime coat, wearing coats, grouted macadam, bituminous concrete specification, construction and maintenance. Advantages and disadvantages of rigid pavements, general principles of design, types, construction, maintenance and joints, dowel bars, tie bars. Brief study of recent developments in cements concrete pavement design, fatigue and reliability.

Unit – III

Low Cost Roads, Drainage of Roads, Traffic Engg. & Transportation Planning: Principles of stabilization, mechanical stabilization, requirements, advantages, disadvantages and uses, quality control, macadam roads-types, specifications, construction, maintenance and causes of failures.

Surface and sub-surface drainage, highway materials: properties and testing etc. Channelised and unchannelised intersections, at grade & grade separated intersections, description, rotary-design elements, advantages and disadvantages, marking, signs and signals, street lighting. Principles of planning, inventories, trip generation, trip distribution, model split, traffic assignment, plan preparation.

Unit - IV

Airport Plaaning, Runway & Taxiway: Airport site selection. air craft characteristic and their effects on runway alignments, windrose diagrams, basic runway length and corrections, classification of airports.

Geometrical elements: taxi ways and runways, pattern of runway capacity**.**

Unit - V

Airport, Obstructions, Lightning & Traffic control: Zoning regulations, approach area, approach surface-imaginary, conical, and horizontal. Rotating beacon, boundary lights, approach lights, runway and taxiway lighting etc. instrumental lending system, precision approach radar, VOR enroute traffic control.

List of Experiments:

1. Aggregate Crushing Value Test
2. Determination of aggregate impact value
3. Determination of Los Angeles Abrasion value
4. Determination of California Bearing Ratio values
5. Determination of penetration value of Bitumen
6. Determination of Viscosity of Bituminous Material
7. Determination of softening point of bituminous material
8. Determination of ductility of the bitumen
9. Determination of flash point and fire point of bituminous material
10. Determination of Bitumen content by centrifuge extractor
11. Determination of stripping value of road aggregate
12. Determination of Marshall stability value for Bituminous mix
13. Determination of shape tests on aggregate

Reference Books:

1. Highway Engineering by Gurucharan Singh
2. Principles of Pavement Design by E.J. Yoder & M.W. Witzech
3. Highway Engineering by O'Fleherty
4. Highway Engineering by S.K. Khanna & C.E.G. Justo
5. Airport Planning & Design by S.K. Khanna & M. G. arora
6. Foresch, Charles "Airport Planning"
7. Horonjeff Robert "The Planning & Design of Airports"
8. Sharma & Sharma, Principles and Practice of Highway Engg.
9. Haung, Analysis and Design of Pavements
10. Relevant IRC & IS codes
11. Laboratory Mannual by Dr. S.K. Khanna
12. Highway Engg. By Hews & Oglesby
13. Highway Material by Walker

Unit I

Highway planning, Alignment & Geometric Design

Principles of highway planning, road planning in India and financing of roads, classification patterns. Requirements, engineering Surveys for highway location.

Cross sectional elements- width, camber, super-elevation, sight distances, extra widening at curves, horizontal and vertical curves and numerical problems.

Introduction to Highway Planning:

Planning is a prerequisite for any engineering activity or project; this is particularly true for the development of a highway network or system in a country.

Role of transportation in society

Transportation is a non-separable part of any society. It exhibits a very close relation to the style of life, the range and location of activities and the goods and services which will be available for consumption. Advances in transportation has made possible changes in the way of living and the way in which societies are organized and therefore have a great influence in the development of civilizations. This chapter conveys an understanding of the importance of transportation in the modern society by presenting selected characteristics of existing transportation systems, their use and relationships to other human activities.

Transportation is responsible for the development of civilizations from very old times by meeting travel requirement of people and transport requirement of goods. Such movement has changed the way people live and travel. In developed and developing nations, a large fraction of people travel daily for work, shopping and social reasons. But transport also consumes a lot of resources like time, fuel, materials and land.

The objectives of highway planning are:

i. **Planning a highway network for safe, efficient and fast movement of people and goods.**
ii. **Keeping the overall cost of construction and maintenance of the roads in the network to a minimum.**
iii. **Planning for future development and anticipated traffic needs for a specific design period.**
iv. **Phasing road development programmes from considerations of utility and importance as also of financial resources.**
v. **Evolving a financing system compatible with the cost and benefits.**

To fulfill these objectives, the following principles have to be borne in mind:

i. **The proposed road links should be a part of the planned road network for the state/nation.**

ii. **The importance of the road shall be based on the traffic demand, and hence its type should fall under the standard classification.**

iii. **The maintenance needs of the roads should receive prompt attention by setting aside funds for this purpose.**

iv. **Statutory provisions for traffic regulation should be in place.**

From the beginning of history, human sensitivity has revealed an urge for mobility leading to a measure of Society's progress. The history of this mobility or transport is the history of civilization. For any country to develop with right momentum modern and efficient Transportation basic infrastructure is a must.

Modes of Transportation:

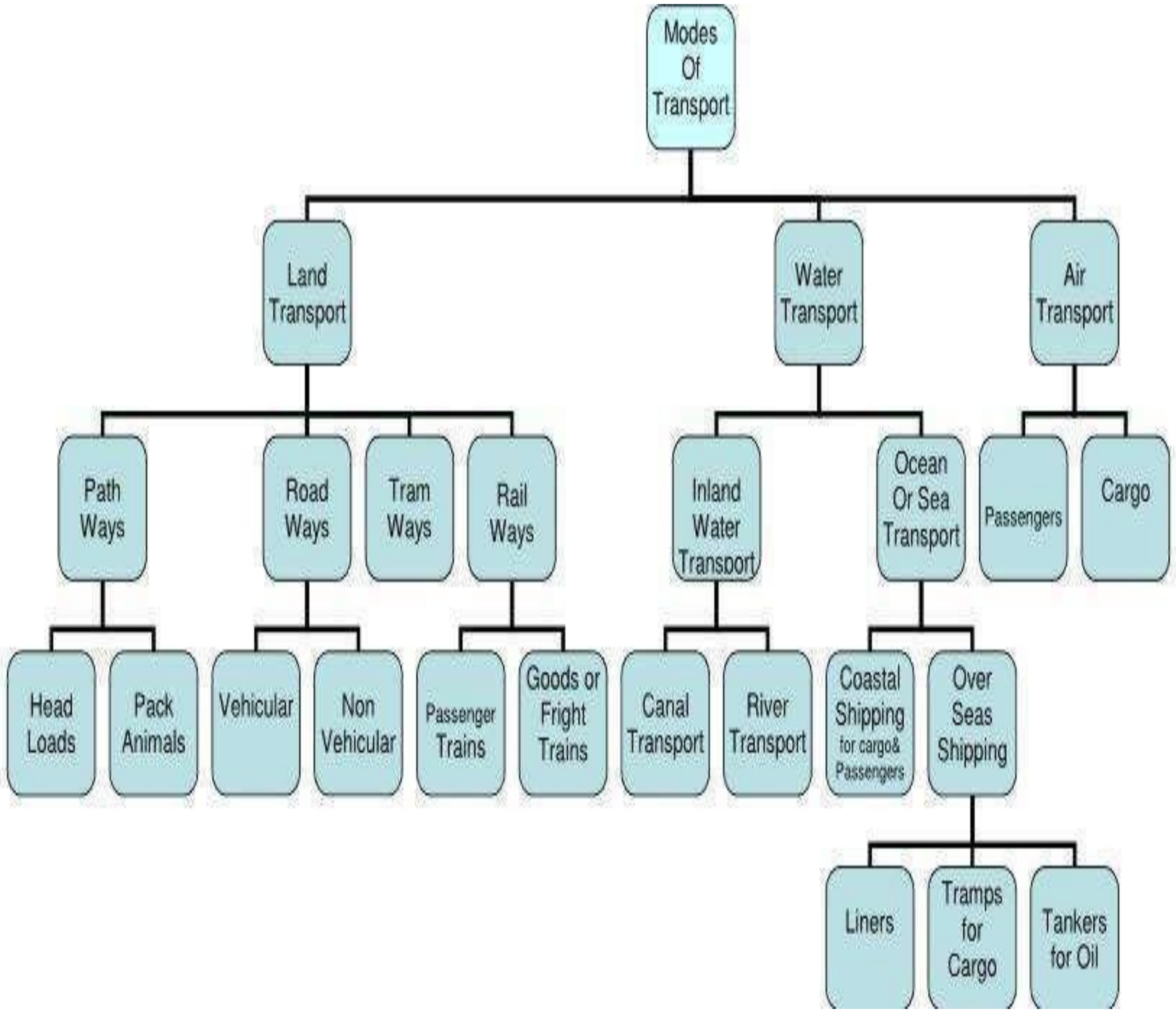

Fig:1 Modes of transportation

Advantage and Disadvantage Road Transportation:

Table:1 Advantage and disadvantages of road transportation

Advantages	Disadvantages
1. Less Capital Outlay	1. Seasonal Nature
2. Door to Door Service	2. Accidents and Breakdowns
3. Service in Rural Areas	3. Unsuitable for Long Distance and Bulky Traffic
4. Flexible Service	4. Slow Speed
5. Suitable for Short Distance	5. Lack of Organization
6. Lesser Risk of Damage in Transit	
7. Saving in Packing Cost	
8. Rapid Speed	

History of Highway Engineering

The history of highway engineering gives us an idea about the roads of ancient times. Roads in Rome were constructed in a large scale and it radiated in many directions helping them in military operations. Thus they are considered to be pioneers in road construction. Here we will see in detail about Ancient roads, Roman roads, British roads, French roads etc.

Ancient Roads

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

Roman roads

The earliest large scale road construction is attributed to Romans who constructed an extensive system of roads radiating in many directions from Rome. Romans recognized that the fundamentals of good road construction were to provide good drainage, good material and good workmanship. Their roads were very durable and some still exist. The roads were bordered on both sides by longitudinal drains. A typical cross section is shown in Fig below. This was a raised formation up to a 1 meter high and 15 m wide and was constructed with materials excavated during the side drain construction. This was then

topped with a sand leveling course. In the case of heavy traffic, a surface course of large 250 mm thick hexagonal stones were provided. They mixed lime and volcanic puzzolana to make mortar and they added gravel to this mortar to make concrete. Thus concrete was a major Roman road making innovation.

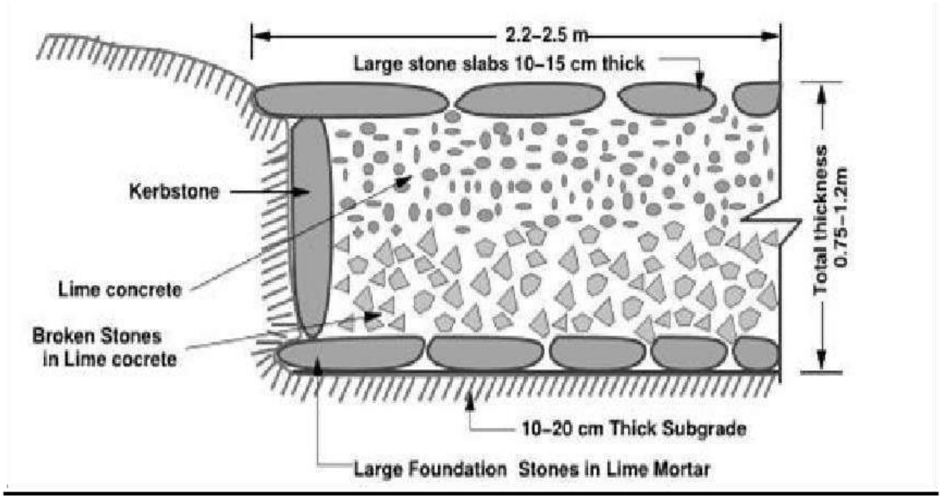

Fig:2 Roman roads

French roads

The significant contributions were given by Tresaguetin 1764 and a typical cross section of this road is given in Figure below. He developed a cheaper method of construction than the lavish and locally unsuccessful revival of Roman practice. The pavement used 200mm pieces of quarried stone of a more compact form and shaped such that they had at least one at side which was placed on a compact formation. Smaller pieces of broken stones were then compacted into the spaces between larger stones to provide a level surface. Finally the running layer was made with a layer of 25 mm sized broken stone. All this structure was placed in a trench in order to keep the running surface level with the surrounding countryside. This created major drainage problems which were counteracted by making the surface as impervious as possible, cambering the surface and providing deep side ditches.

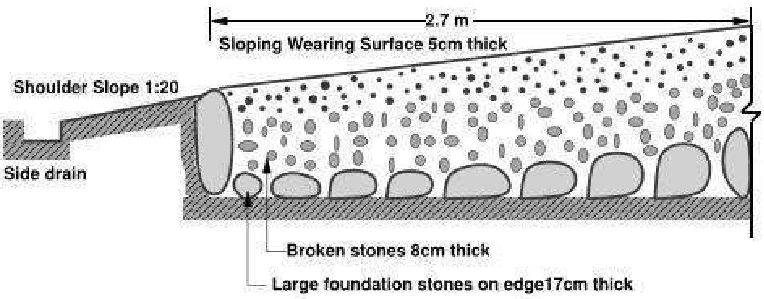

Fig3: French roads

British roads

The British government also gave importance to road construction. The British engineer John Macadam introduced what can be considered as the first scientific road construction method. Stone size was an important element of Macadam recipe. By empirical observation of many roads, he came to realize that 250mm layers of well compacted broken angular stone would provide the same strength a better

running surface than an expensive pavement founded on large stone blocks. Thus he introduced an economical method of road construction.

Modern roads

The modern roads by and large follow Macadam's construction method. Use of bituminous concrete and cement concrete are the most important developments. Development of new equipments helps in the faster construction of roads. Many easily and locally available materials are tested in the laboratories and then implemented on roads for making economical and durable pavements.

Road Development in India

Excavations in the sites of Indus valley revealed the existence of planned roads in India as old as 2500-3500BC.TheMauryan kings also built very good roads. During the time of Mughal period, roads in India were greatly improved. Roads linking North-West and the Eastern areas through gangetic plains were built during this time. The construction of Grand-Trunk road connecting North and South is a major contribution of the British.

Modern developments

The First World War period and that immediately following it found a rapid growth in motor transport. So need for better roads became a necessity. For that, the Government of India appointed a committee called Road development Committee with Mr.M.R. Jayakar as the chairman. This committee came to be known as Jayakar committee.

Jayakar Committee

In 1927 Jayakar committee for Indian road development was appointed. The major recommendations and the resulting implementations were:

- Committee found that the road development of the country has become beyond the capacity of local governments and suggested that Central government should take the proper charge considering it as a matter of national interest.
- They gave more stress on long term planning program, for a period of 20years (hence called twenty year plan) that is to formulate plans and implement those plans within the next 20years.
- One of the recommendations was the holding of periodic road conferences to discuss about road construction and development. This paved the way for the establishment of a semi-official technical body called Indian Road Congress(IRC) in1934
- The committee suggested imposition of additional taxation on motor transport which includes duty on motor spirit, vehicle taxation and license fees for vehicles plying for hire. This led to the introduction of a development fund called Central road fund in 1929. This fund was intended for road development.

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Nagpur road congress (1943-1963)

A twenty year development programme for the period (1943-1963) was finalized. It was the first attempt to prepare a co-ordinate road development programme in a planned manner.

The roads were divided into four classes:

- National highways which would pass through states, and places having national importance for strategic, administrative and other purposes.
- State highways which would be the other main roads of a state.
- District roads which would take traffic from the main roads to the interior of the district. According to the importance, some are considered as major district roads and the remaining as other district roads.
- Village roads which would link the villages to the road system.

The committee planned to construct 2 lakh kilometers of road across the country within 20 years. They recommended the construction of star and grid pattern of roads throughout the country. One of the objective was that the road length should be increased so as to give a road density of 16kmsper 100sq.km

Bombay road congress (1961-1981)

The length of roads envisaged under the Nagpur plan was achieved by the end of it, but the road system was deficient in many respects. Accordingly a 20-yearplan was drafted by the Road swing of Government of India, which is popularly known as the Bombay plan. The highlights of the plan were:

- It was the second 20 year road plan(1961-1981)
- The total road length targeted to construct was about 10lakhs.
- Rural roads were given specific attention.
- They suggested that the length of the road should be increased so as to give a road density of 32kms/100sq.km

The construction of 1600 km of expressways was also then included in the plan.

Lucknow road congress (1981-2001)

Some of the salient features of this plan are as given below:

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

- It aims at improving the transportation facilities in villages, towns etc. such that no part of country is farther than 50 km from NH.
- One of the goals contained in the plan was that expressways should be constructed on major traffic corridors to provide speedy travel.
- Energy conservation, environmental quality of roads and road safety measures were also given due importance in this plan.

Current Scenario:

About 60 % of freight and 87 % passenger traffic is carried by road. Although National Highways constitute only about 2 % of the road network, it carries 40 % of the total road traffic. Easy availability, adaptability to individual needs and cost savings are some of the factors which go in favor of road transport. Road transport also acts as a feeder service to railway, shipping and air traffic. The number of vehicles has been growing at an average pace of around 10 % per annum. The share of road traffic in total traffic has grown from 13.8 per cent of freight traffic and 15.4 percent of passenger traffic in 1950-51 to an estimated 62.9 per cent of freight traffic and 90.2 percent of passenger traffic by the end of 2009-10.Therapid expansion and strengthening of the road network, therefore, is imperative, to provide for both present and future traffic and for improved accessibility to the hinterland.

Highway Planning:

Highway design is only one element in the overall highway development process. Historically, detailed design occurs in the middle of the process, linking the preceding phases of planning and project development with the subsequent phases of right-of-way acquisition, construction and maintenance. It is during the first three stages, planning, project development and design, that designers and communities, working together, can have the greatest impact on the final design features of the project. In fact the flexibility available for highway design during the detailed design phase is limited a great deal by the decisions made at the earliest ages of planning and project development.

Stages of highway development:

- Planning
- Project development
- Final design
- Right of way
- Construction

Planning

The initial definition of the need for any highway or bridge improvement project takes place during the planning stage. This problem definition occurs at the State, regional, or local level, depending on the scale of the proposed improvement. This is the key time to get the public involved and provide input into the decision making process. The problems identified usually fall into one or more of the following four categories:

1. The existing physical structure needs major repair/replacement (structure repair).

2. Existing or projected future travel demands exceed available capacity, and access to transportation and mobility need to be increased (capacity).
3. Therouteisexperiencinganinordinatenumberofsafetyandaccidentproblemsthatcan only be resolved through physical, geometric changes (safety).
4. Developmentalpressuresalongtheroutemakeareexaminationofthenumber, location, and physical design of access points necessary (access).

Factors to Consider During Planning

It is important to look ahead during the planning stage and consider the potential impact that a proposed facility or improvement may have while the project is still in the conceptual phase. During planning, key decisions are made that will affect and limit the design options in subsequent phases.

Project Development

After a project has been planned and programmed for implementation, it moves into the project development phase. At this stage, the environmental analysis intensifies. The level of environmental review varies widely, depending on the scale and impact of the project. It can range from a multiyear effort to prepare an Environmental Impact Statement (a comprehensive document that analyzes the potential impact of proposed alternatives) to a modest environmental review completed in a matter of weeks. Regardless of the level of detail or duration, the product of the project development process generally includes a description of the location and major design features of the recommended project that is to be further designed and constructed, while continually trying to avoid, minimize, and mitigate environmental impact.

Final Design

After a preferred alternative has been selected and the project description agreed upon as stated in the environmental document, a project can move into the final design stage. The product of this stage is a complete set of plans, specifications, and estimates (PS&Es) of required quantities of materials ready for the solicitation of construction bids and subsequent construction. Depending on the scale and complexity of the project, the final design process may take from a few months to several years.

Right-of-way, Construction and Maintenance

Once the final designs have been prepared and needed right-of-way is purchased, construction bid packages are made available, a contractor is selected and construction is initiated. During the right-of-way acquisition and construction stages, minor adjustments in the design may be necessary; therefore, there should be continuous involvement of the design team throughout these stages. Construction may be simple or complex and may require a few months to several years. Once construction has been completed, the facility is ready to begin its normal sequence of operations and maintenance.

Even after the completion of construction, the character of a road can be changed by inappropriate maintenance actions. For example, the replacement of sections of guardrail damaged or destroyed in crashes commonly utilizes whatever spare guardrail sections maybe available to the local highway maintenance personnel at the time.

Stages of Highway Development

Summaries of the five basic stages in highway planning and development.

Table: 2Stages of the highway design

Stages	Description of Activity
Planning	Identification of transportation needs and program project to be built Within financial constraints.
Project Development	The transportation project is more clearly defined. Alternative locations and design features are developed and an alternative is selected.
Design	The design team develops detailed design and specification.
Right-of-way	Land needed for the project is acquired.
construction	Selection of contractor, who then builds the project.

Geometric Design:

Geometric design for transportation facilities includes the design of geometric cross sections, horizontal alignment, vertical alignment, intersections, and various design details. These basic elements are common to all linear facilities, such as roadways, railways, and airport runway sand taxiways. Although the details of design standards vary with the mode and the class of facility, most of the issues involved in geometric design are similar for all modes. In all cases, the goals of geometric design are to maximize the comfort, safety, and economy of facilities, while minimizing their environ-mental impacts. This chapter focuses on the fundamentals of geometric design, and presents standards and examples from different modes.

The geometric design of highways deals with the dimensions and layout of visible features of the highway. The features normally considered are the cross section elements, sight distance consideration, horizontal curvature, gradients, and intersection. The design of these features is to a great extend influenced by driver behavior and psychology, vehicle characteristics, traffic characteristics such as speed and volume. Proper geometric design will help in the reduction of accidents and their severity. Therefore, the objective of geometric design is to provide optimum efficiency in traffic operation and maximum safety at reasonable cost.

The planning cannot be done stage wise like that of a pavement, but has to be done well in advance. The main components that will be discussed are:

1. Highway alignment
2. Road classification,
3. Pavement surface characteristics,

4. Cross-section elements including cross slope, various widths of roads and features in the road margins.
5. Sight distance elements including cross slope, various widths and features in the road margins.
6. Horizontal alignment which includes features like super elevation, transition curve, extra widening and set back distance.
7. Vertical alignment and its components like gradient, sight distance and design of length of curves. Intersection features like layout, capacity, etc

Factors affecting geometric design:

- 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.

Road classification

The roads can be classified in many ways. The classification based on speed and accessibility is the most generic one. Note that as the accessibility of road increases, the speed reduces. Accordingly, the roads can classify as follows in the order of increased accessibility and reduced speeds.

- Freeways: Freeways are access controlled divided highways. Most freeways are four lanes, two lanes each direction, but many freeways widen to incorporate more lanes as they enter urban areas. Access is controlled through the use of interchanges, and the type of interchange depends upon the kind of intersecting road way (rural roads, another freeway etc.)
- Expressways: They are superior type of highways and are designed for high speeds (120km/hr is common), high traffic volume and safety. They are generally provided with grade separations at intersections. Parking, loading and unloading of goods and pedestrian traffic is not allowed on expressways.
- Highways: They represent the superior type of roads in the country. Highways are of two types - rural highways and urban highways. Rural highways are those passing through rural areas (villages) and urban highways are those passing through large cities and towns, i.e. urban areas.
- Arterials: It is a general term denoting a street primarily meant for through traffic usually on a

continuous route. They are generally divided highways with fully or partially controlled access. Parking, loading and unloading activities are usually restricted and regulated. Pedestrians are allowed to cross only at intersections/designated pedestrian crossings.

- Local streets: A local street is the one which is primarily intended for access to residence, business or abutting property. It does not normally carry large volume of traffic and also it allows unrestricted parking and pedestrian movements.
- Collector streets: These are streets intended for collecting and distributing traffic to and from local streets and also for providing access to arterial streets. Normally full access is provided on these streets. There are few parking restrictions except during peak hours.

Based on usage

This classified is based on whether the roads can be used during different seasons of the year.

- All-weather roads: Those roads which are negotiable during all weathers, except at major river crossings where interruption of traffic is permissible up to a certain extent are called all weather roads.

- Fair-weather roads: Roads which are negotiable only during fair weather are called fair weather roads.

Based on carriageway

This classification is based on the type of the carriage way or the road pavement.

- Paved roads with hard surface: If they are provided with a hard pavement course such roads are called paved roads.(eg: stones, Water bound macadam(WBM),Bituminous macadam (BM), concrete roads)

- Unpaved roads: Roads which are not provided with a hard course of at least a WBM layer is called unpaved roads. Thus earth and gravel roads come under this category.

Based on pavement surface

Based on the type of pavement surfacing provided, they are classified as surfaced and un-surfaced roads.

- Surfaced roads (BM, concrete): Roads which are provided with a bituminous or cement concreting surface are called surfaced roads.

- Un-surfaced roads (soil/gravel): Roads which are not provided with a bituminous or cement concreting surface are called un-surfaced roads.

Highway alignment

Once the necessity of the highway is assessed, the next process is deciding the alignment. The highway alignment can be either horizontal or vertical and they are described in detail in the following sections.

Alignment:

The position or the layout of the central line of the highway on the ground is called the alignment. Horizontal alignment includes straight and curved paths. Vertical alignment includes level and gradients. Alignment decision is important because a bad alignment will enhance the construction, maintenance and vehicle operating cost. Once an alignment is fixed and constructed, it is not easy to change it due to increase in cost of adjoining land and construction of costly structures by the roadside.

Requirements

The requirements of an ideal alignment are:

- **The alignment between two terminal stations should be short and as far as possible be straight, but due to some practical considerations deviations may be needed.**
- **The alignment should be easy to construct and maintain. It should be easy for the operation of vehicles. So to the maximum extend easy gradients and curves should be provided.**
- **It should be safe both from the construction and operating point of view especially at slopes, embankments, and cutting. It should have safe geometric features.**
- **The alignment should be economical and it can be considered so only when the initial cost, maintenance cost, and operating cost is minimum.**

Factors controlling alignment:

We have seen the requirements of an alignment. But it is not always possible to satisfy all these requirements. Hence we have to make a judicial choice considering all the factors.

The various factors that control the alignment are as follows:

- **Obligatory points: These are the control points governing the highway alignment. These points are classified into two categories. Points through which it should pass and points through which it should not pass. Some of the examples are:**
- **Bridge site: The Bridge can be located only where the river has straight and permanent path and also where the abutment and pier can be strongly founded. The road approach to the bridge should not be curved and skew crossing should be avoided as possible. Thus to locate a bridge the highway alignment may be changed.**
- **Mountain: While the alignment passes through a mountain, the various alternatives are to either construct a tunnel or to go round the hills. The suitability of the alternative depends on factors like topography, site conditions and construction and operation cost.**
- **Intermediate town: The alignment may be slightly deviated to connect an intermediate town or village nearby.**

These were some of the obligatory points through which the alignment should pass. Coming to the second category that is the points through which the alignment should not pass are:

- **Religious places: These have been protected by the law from being acquired for any purpose.**

Therefore, these points should be avoided while aligning.

- Very costly structures: Acquiring such structures means heavy compensation which would result in an increase in initial cost. So the alignment may be deviated not to pass through that point.
- Lakes/ponds etc: The presence of a lake or pond on the alignment path would also necessitate deviation of the alignment.

- Traffic: The alignment should suit the traffic requirements. Based on the origin- destination data of the area, the desire lines should be drawn. The new alignment should be drawn keeping in view the desire lines, traffic flow pattern etc.

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

Cross sectional elements:

The primary consideration in the design of geometric cross sections for highways, run-ways and taxiways is drainage. Details vary depending on the type of facility Highway cross sections consist of traveled way, shoulders (or parking lanes) and drainage channels. Shoulders are intended primarily as a safety feature. They provide for accommodation of stopped vehicles, emergency use and lateral support of the pavement. Shoulders may be either paved or unpaved. Drainage channels may consist of ditches (usually grassed swales) or of paved shoulders with berms or curbs and gutters. Cross sections of various roads are given below.

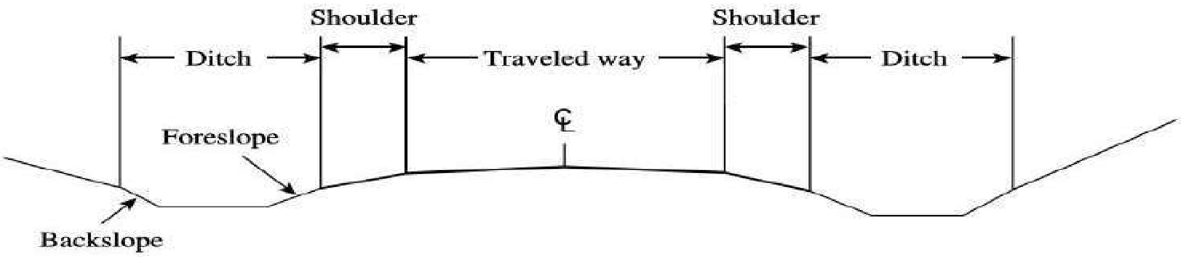


Fig:4 Two-lane highway cross section

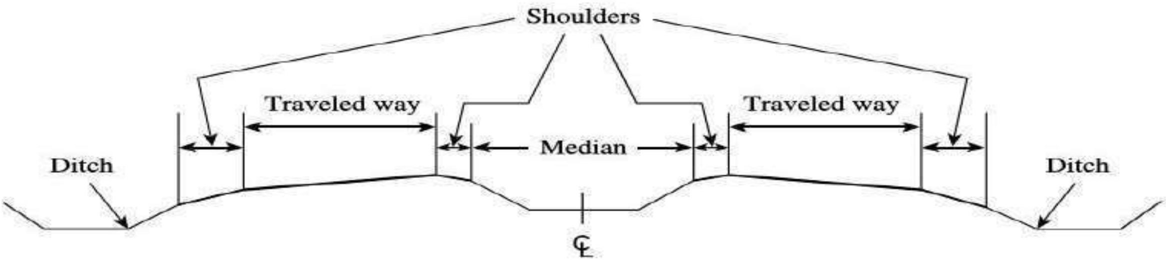


Fig:5 Divided highway cross section, depressed median, with ditches

Pavement surface characteristics:

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.

Skidding happens when the path traveled along the road surface is more than the circumferential movement of the wheels due to friction

Slip occurs when the wheel revolves more than the corresponding longitudinal movement along the road. Various factors that affect friction are:

The frictional force that develops between the wheel and the pavement is the load acting multiplied by a factor called the coefficient of friction and denoted as f. The choice of the value of f is a very complicated issues it depends on many variables. IRC suggests the coefficient of longitudinal friction as 0.35-0.4 depending on the speed and coefficient of lateral friction as 0.15. The former is useful in sight distance calculation and the latter in horizontal curve design.

Unevenness

It is always desirable to have an even surface, but it is seldom possible to have such one. Even if a road is constructed with high quality pavers, it is possible to develop unevenness due to pavement failures. Unevenness 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 1500 mm/km is considered as good, a value less than2500 mm.km is satisfactory up to speed of 100 Kmph and values greater than 3200 mm/km is considered as uncomfortable even for 55kmph.

Drainage

The pavement surface should be absolutely impermeable to prevent seepage of water into the pavement layers. Further, both the geometry and texture of pavement surface should help in draining out the water from the surface in less time.

Camber
Camber or cant is the cross slope provided to raise middle of the road surface in the transverse direction to drain o rain water from road surface.

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

Width of carriageway

Width of the carriage way or the width of the pavement depends on the width of the traffic lane and number of lanes. Width of a traffic lane depends on the width of the vehicle and the clearance. Side clearance improves operating speed and safety.

Kerbs

Kerbs indicate the boundary between the carriage way and the shoulder or islands or foot paths.
Types:

- **Low or mountable kerbs:**

- **Semi-barrier type kerbs:**

- **Barrier type kerbs:**

Road margins
The portion of the road beyond the carriageway and on the roadway can be generally called road margin. Various elements that form the road margins are
Shoulders, parking lanes, bus-bays, service roads, cycle track, footpath and guard rails.

Sight Distances:

Sight Distance is a length of road surface which a particular driver can see with an acceptable level of clarity. Sight distance plays an important role in geometric highway design because it establishes an acceptable design speed, based on a driver's ability to visually identify and stop for aparticular, unforeseen roadway hazard or pass as lower vehicle without being in conflict with opposing traffic. As velocities on a roadway are increased, the design must be catered to allowing additional viewing distances to allow for adequate time to stop.

Types of sight distance

- **Stopping sight distance (SSD) or the absolute minimum sight distance**

- **Intermediate sight distance (ISD) or is the as twice SSD**

- **Overtaking sight distance (OSD) for safe overtaking operation**

The computation of sight distance depends on:

1. **Reaction time of the driver**
2. **Speed of the vehicle**
3. **Efficiency of brakes**

PIEV Process

The perception-reaction time for a driver is often broken down into the four components that are assumed to make up the perception reaction time. These are referred to as the PIEV time or process.

- **Perception** — **the time to see or discern an object or event**
- **Intellection** — **the time to understand the implications of the object's presence or event**
- **Emotion** — **the time to decide how to react**
- **Volition** — **the time to initiate the action, for example, the time to engage the brakes**

Stopping sight distance

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

The stopping sight distance is comprised of the distance to perceive and react to a condition plus the distance to stop:

$$SSD = 0.278\,Vt + \frac{V2}{254\,f} \quad \text{(V is in Kmph)}$$

$$SSD = Vt + \frac{V^2}{2gf} \quad \text{(V is in m/sec)}$$

Where, SSD = Required stopping sight distance, (m)
V = Speed vehicle ()
t = Reaction time of driver (seconds)
f = coefficient of friction
g = acceleration due to gravity ($9.8 m/s^2$)

Overtaking sight distance

The overtaking sight distance is the minimum distance open to the vision of the driver of a vehicle intending to overtake the slow vehicle ahead safely against the traffic in the opposite direction. The overtaking sight distance or passing sight distance is measured along the center line of the road over which a driver with high sea level 1.2m above the road surface can see the top of an object 1.2 m above the road surface.

The factors that affect the OSD are:

- **Velocities of the overtaking vehicle, overtaken vehicle and of the vehicle coming in the opposite direction.**
- **Spacing between vehicles, which in-turn depends on the speed**
- **Skill and reaction time of the driver**
- **Rate of acceleration of overtaking vehicle**

Horizontal curves

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

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

Where,

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

Super elevations

Super elevation is the transverse slope provided to counteract the effect of centrifugal force and reduce the tendency of vehicle to overturn and to skid laterally outwards by raising the pavement outer edge with respect to inner edge. super elevation is represented by “ e ”.

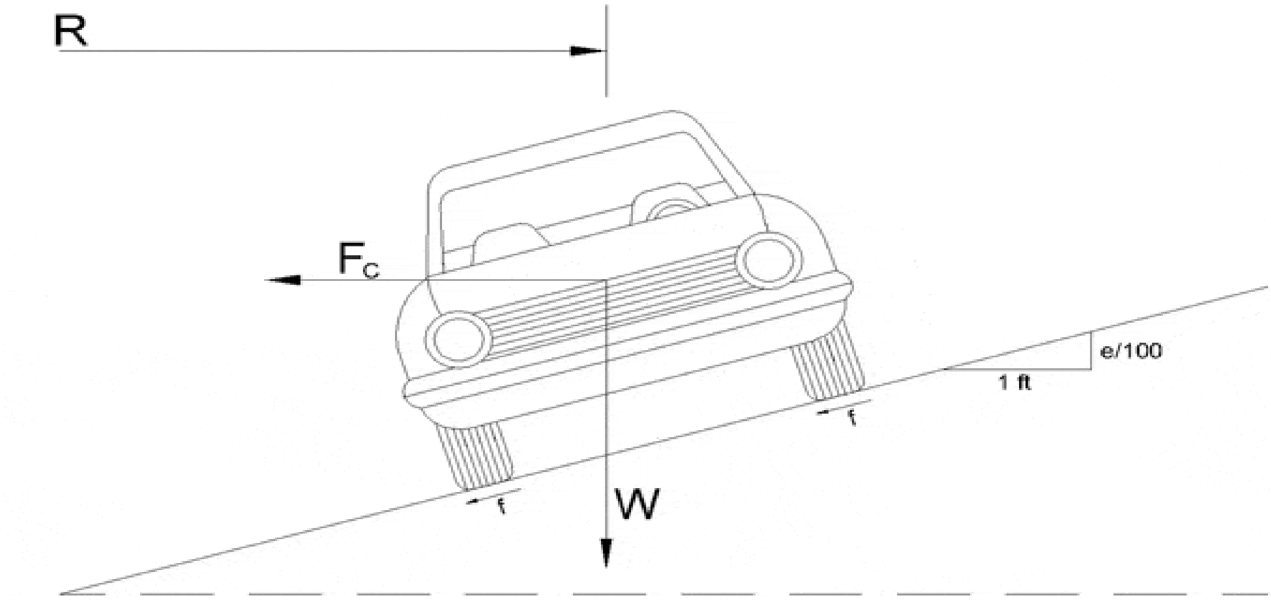
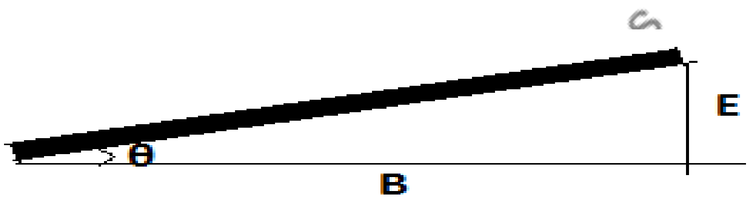


Fig6 :Super elevation in Highway Engineering

Analysis of super elevation



From above fig: $\tan\theta = e = E/B$ .... (1)

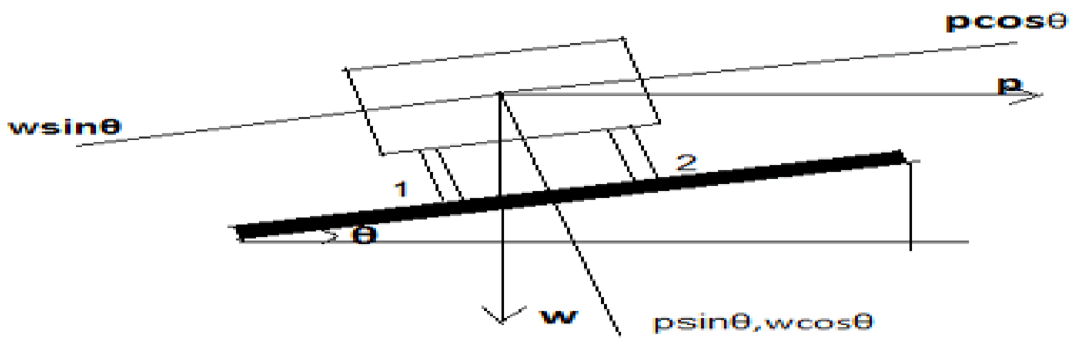


Fig 7:- Super elevation in Highway Engineering

Let us say Design speed = V m/s

Radius = R m

Various forces acting on the vehicle:

IRC Recommendations for Camber

Type of pavement	Light rainfall intensity	Heavy rainfall intensity
C.C pavements and thick bituminous pavements	1 in 60	1 in 50
Thin Bituminous Pavements	1 in 50	1 in 40
W.B.M and Gravel Pavements	1 in 40	1 in 33
Earthen Pavements	1 in 33	1 in25

Widening of Pavement on Horizontal Curves

On horizontal corves, especially when they are not of very large radii, it is common to widen the pavement slightly more than the normal width,

Widening is needed for the following reasons :-

The driver experience difficulties in steering around the curve.

The vehicle occupies a greater width as the rear wheel don't track the front wheel. known as 'Off tracking'

For greater visibility at curve, the driver have tendency not to follow the central path of the lane, but to use the outer side at the beginning of the curve.

While two vehicle cross or overtake at horizontal curve there is psychological tendency to maintain a greater clearance between the vehicle for safety.

Offtracking

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

Mechanical widening (Wm): the widening required to account for the off tracking due to the rigidity of wheel base is called mechanical widening

Psychological widening (Wps): extra width of the pavement is also provided for psychological reasons such as , to provide for greater maneuverability of steering at high speed, to allow for the extra space for overhangs of vehicles and to provide greater clearance for crossing and overturning vehicles on curve.

Total widening $W = W_{ps} + W_m$

$W_m = R_2 - R_1$

From Δ OAB, $OA^2 = OB^2 - BA^2$ $R_1^2 = R_2^2 - l^2$

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

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

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

$W_m = l^2 / 2 R$ (Approx.) or $W_m = nl^2/2R$

Method of introducing extra widening

- With transition curve: increase the width at an approximately uniform rate along the transition curve - the extra width should be continued over the full length of circular curve
- Without transition curves: provide two-third widening on tangent and the remainin one-third on the circular curve beyond the tangent point
- With transition curve: Widening is generally applied equally on both sides of the carriageway
- Without transition curve: the entire widening should be done on inner side
- On sharp curves of hill roads: the entire widening should be done on inner side

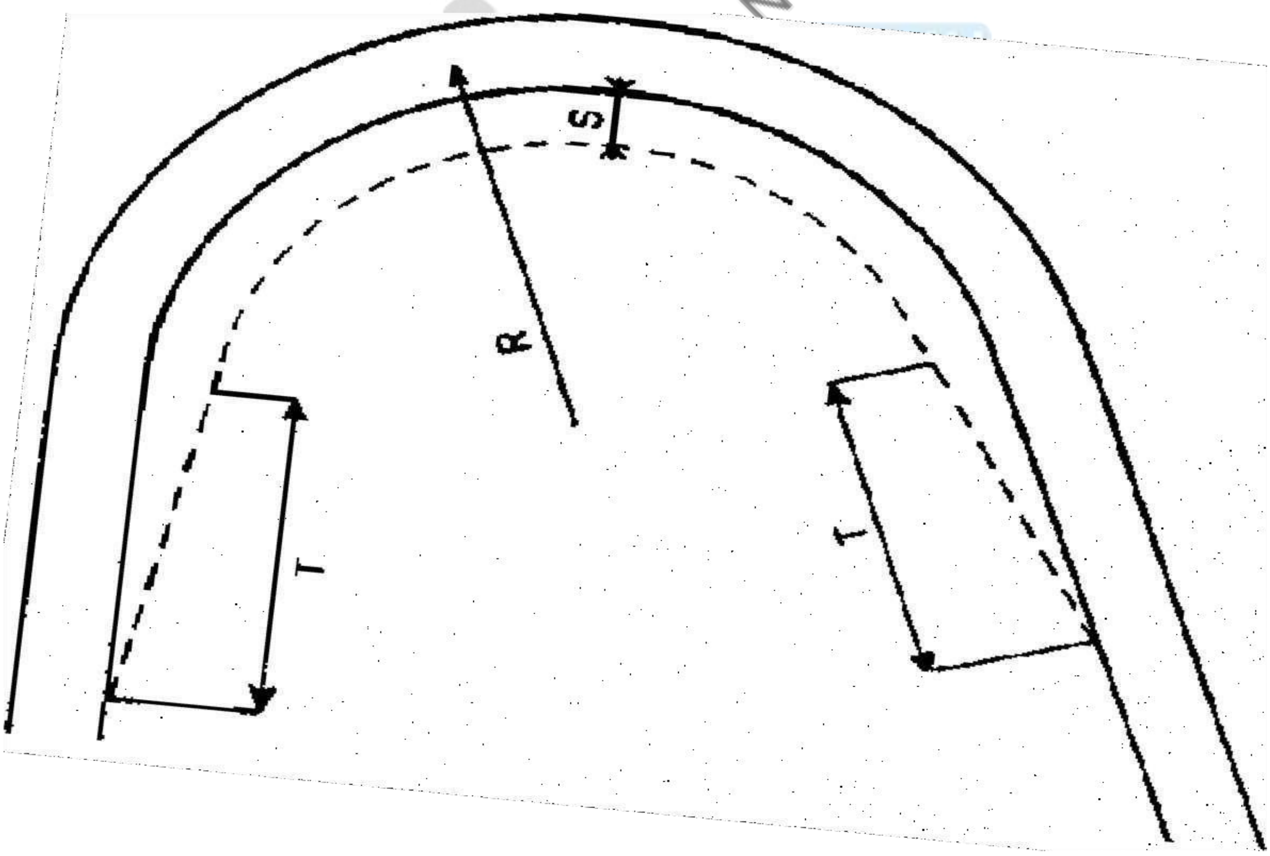


Fig7:- widening of curves

Horizontal transition curves

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

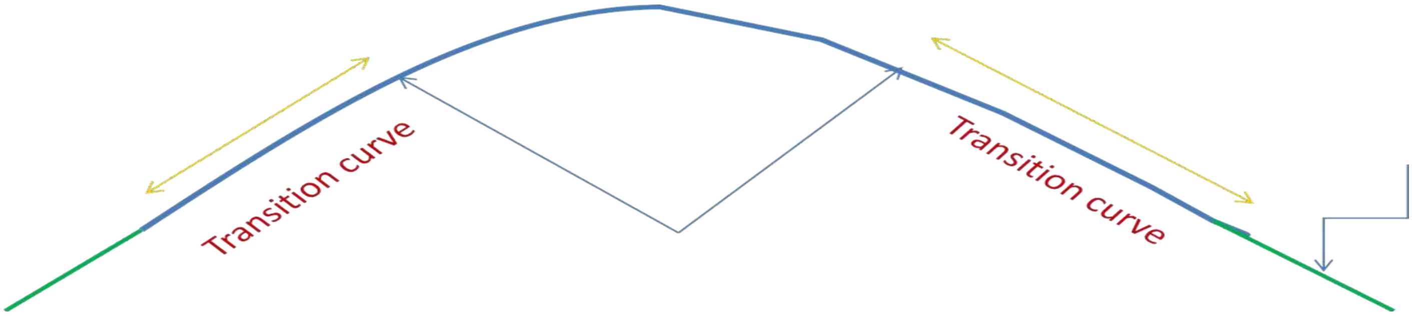


Fig:-8 Horizontal transition curve

Objectives for providing transition curve

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

Shift of the transition curve 'S'

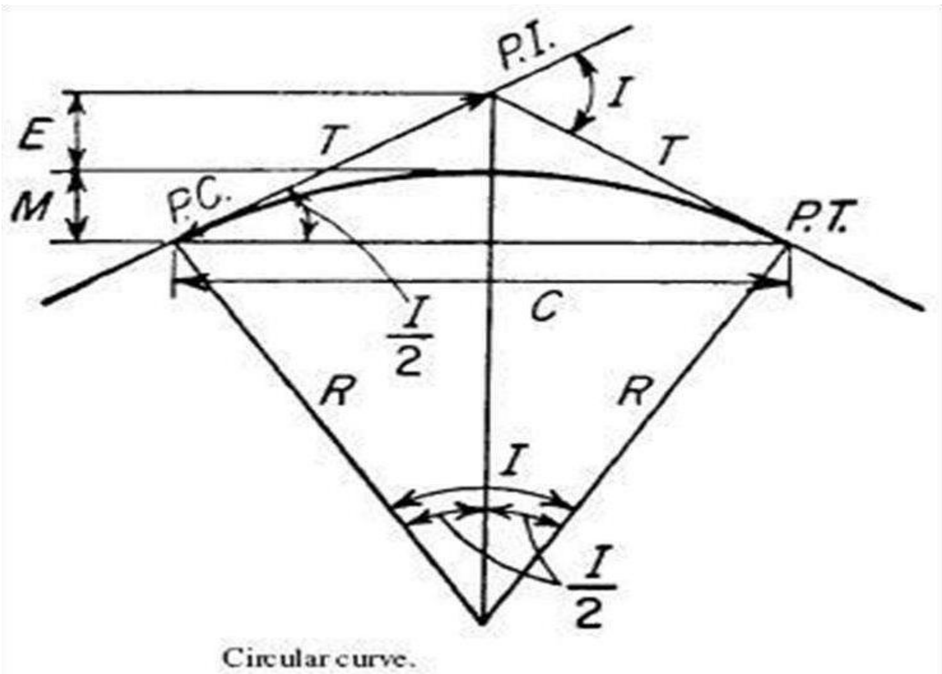


Fig 9:- Shift of Transition curves

Vertical curves:-

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

Represented by:

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

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

Typical Gradients (IRC)

- Ruling Gradient
- Limiting Gradient
- Exceptional gradient
- Minimum Gradient
- Ruling gradient (design gradient):

  It is the maximum gradient within which the designer attempts to design the vertical profile of road, it depends on

  - Type of terrain
  - Length of grade
  - Speed
  - Pulling power of vehicles
  - Presence of horizontal curves
  - Mixed traffic

Limiting Gradient Steeper than ruling gradient. In hilly roads, it may be frequently necessary to exceed ruling gradient and adopt limiting gradient, it depends on

- Topography
- Cost in constructing the road

Exceptional Gradient:

- Exceptional gradient are very steeper gradients given at unavoidable situations. They should be limited for short stretches not exceeding about 100 m at a stretch.

critical length of the grade:

- The maximum length of the ascending gradient which a loaded truck can operate without undue reduction in speed is called critical length of the grade. A speed of 25 kmph is a reasonable value. This value depends on the size, power, load, initial speed.

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 require 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

Terrain	Ruling gradient	Limiting gradient	Exceptional gradient
Plain and Rolling	3.3% (1 in 30)	5%	6.70%
Mountainous terrain	5% (1 in 20)	6%	7%

Table 3:- Terrain and various gradient

Steep terrain up to 3000m (MSL)	**5% (1 in 20)**	**6%**	**7%**
Steep terrain (>3000m)	**6% (1 in 16.7)**	**7%**	**8%**

Grade compensation:-

At the horizontal curve ,due to the turning angle α of the vehicle, the curve resistance develop is equal to T(1-Cos α). When there is a horizontal curve in addition to the gradient, there will be a increase in resistance to fraction due to both gradient and curve. It is necessary that in such cases the total resistance due to grade and the curve should not exceeded the resistance due to maximum value of the gradient specified.

Maximum value generally taken as ruling gradient

- **Thus grade compensation can be defined as the reduction in gradient at the horizontal curve because of the additional tractive force required due to curve resistance (T−Tcosα), which is intended to offset the extra tractive force involved at the curve.**
- **IRC gave the following specification for the grade compensation.**
  1. **Grade compensation is not required for grades flatter than 4% because the loss of tractive force is negligible.**
  2. **Grade compensation is (30+R)/R %, where 'R' is the radius of**

the horizontal curve in meters.

1. **The maximum grade compensation is limited to 75/R%.**

Velly carve:-

Sag vertical curves are curves that connect descending grades, forming a bowl or a sag. Designing them is is very similar to the design of crest vertical curves. Once again, the sight distance is the parameter that is normally employed to find the length of the curve. When designing a sag vertical curve, however, the engineer must pay special attention to the comfort of the drivers. Sag vertical curves are characterized by a positive change in grade, which means that vehicles traveling over sag vertical curves are

accelerated upward. Because of the inertia of the driver's body, this upward acceleration feels like a downward thrust. When this perceived thrust and gravity combine, drivers can experience discomfort.

The length of sag vertical curves, which is the only parameter that we need for design, is determined by considering drainage, driver comfort, aesthetics, and sight distance. Once again, the aesthetics and driver comfort concerns are normally automatically resolved when the curve is designed with adequate sight distance in mind. Driver comfort, for example, requires a curve length that is approximately 50% of the curve length required for the sight distance. Drainage may be a problem if the curve is quite long and flat, or if the sag is within a cut. For more information on these secondary concerns, see your local design manuals.

The theory behind the sight distance calculations for sag vertical curves is only slightly different from that for crest vertical curves. Sag vertical curves normally present drivers with a commanding view of the roadway during the daylight hours, but unfortunately, they truncate the forward spread of the driver's headlights at night. Because the sight distance is restricted after dark, the headlight beams are the focus of the sight distance calculations. For sight distance calculations, a 1° upward divergence of the beam is normally assumed.

In addition, the headlights of the vehicle are assumed to reside 2 ft above the roadway surface. As with crest vertical curves, these assumptions lead to two possible configurations, one in which the sight distance is greater than the curve length, and one in which the opposite is true. The figure below illustrates these possibilities.

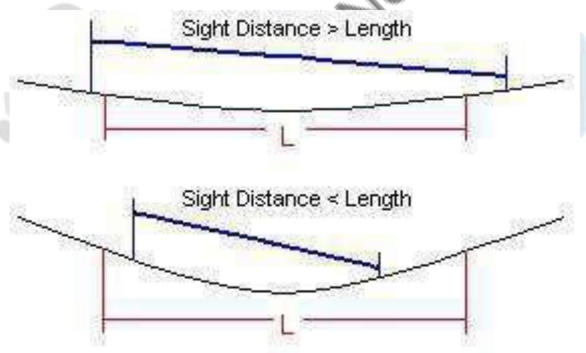


Fig-10 Velly curves

As with crest vertical curves, each possibility has a different design equation. All that you need to do, therefore, is make sure that the results from the equation that you use are consistent with that equation's assumptions. For example, if you employ the equation that assumes the sight distance is greater than the curve length, you should make sure that the resulting curve length is less than the sight distance. The equations for each possibility are given below.

If S > L then

$$L = 2S - \frac{200(H + S*\tan(B))}{A}$$

If S < L then

$$L = \frac{AS^2}{200(H + S*\tan(B))}$$

Where:

L = Curve length (ft)

S = Sight distance (ft) (normally the stopping sight distance)
B = Beam upward divergence (°) (normally assumed as 1°)
H = Height of the headlights (ft) (normally assumed as 2 ft)
A = Change in grade (|G2-G1| as a percent)
The stopping sight distance is normally the controlling sight distance for sag vertical curves. At decision points, the roadway should be illuminated by other means so that the sight distance of the driver is extended. Where possible, increased curve length may also be provided.
Highway overpasses or other obstacles can occasionally reduce the sight distance on sag vertical curves. In these instances, separate equations should be used to determine the correct curve length. These equations are readily available in design manuals.
At this point, you have all of the information that you need to develop the precise layout of your vertical curve. The parabolic curve calculations are identical for sag and crest vertical curves. Just remember to use the appropriate positive or negative values for the participating grades.

Summit curve:-
Crest vertical curves are curves which, when viewed from the side, are convex upwards. This includes vertical curves at hill crests, but it also includes locations where an uphill grade becomes less steep, or a downhill grade becomes steeper.
The most important design criterion for these curves is stopping sight distance. This is the distance a driver can see over the crest of the curve. If the driver cannot see an obstruction in the roadway, such as a stalled vehicle or an animal, the driver may not be able to stop the vehicle in time to avoid a crash. The desired stopping sight distance (S) is determined by the speed of traffic on a road. By first finding the stopping sight distance (S) and then solving for the curve length (L) in each of the equations below, the correct curve length can be determined. The proper equation depends on whether the vertical curve is shorter or longer than the available sight distance. Normally, both equations are solved, then the results are compared to the curve length.

Length of summit curve greater than sight distance($L > S$)

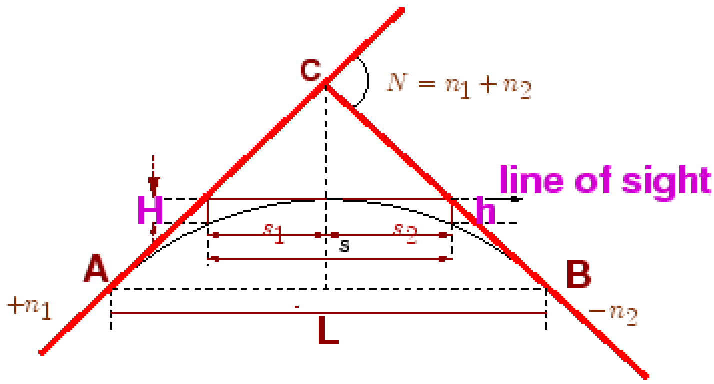


Figure 11: Length of summit curve ($L > S$)

$$
\begin{aligned}
y &= ax^2 \\
a &= \frac{N}{2L} \\
h_1 &= aS_1^2 \\
h_2 &= aS_2^2 \\
S_1 &= \sqrt{\frac{h_1}{a}} \\
S_2 &= \sqrt{\frac{h_2}{a}} \\
S_1 + S_2 &= \sqrt{\frac{h_1}{a}} + \sqrt{\frac{h_2}{a}} \\
S^2 &= \left(\frac{1}{\sqrt{a}}\right)^2 \left(\sqrt{h_1} + \sqrt{h_2}\right)^2 \\
S^2 &= \frac{2L}{N} \left(\sqrt{h_1} + \sqrt{h_2}\right)^2 \\
L &= \frac{NS^2}{2\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}
\end{aligned}
$$

The second case is illustrated in fig 12

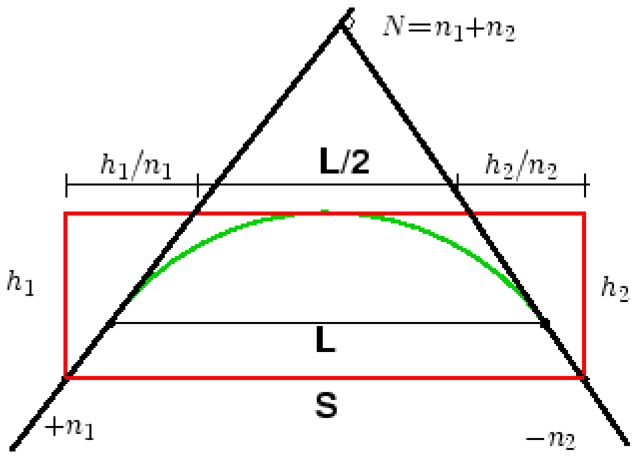


Figure 12: Length of summit curve ($L < S$)

From the basic geometry, one can write

$$S = \frac{L}{2} + \frac{h_1}{n_1} + \frac{h_2}{n_2} = \frac{L}{2} + \frac{h_1}{n_1} + \frac{h_2}{N - n_2} \quad \textbf{(1)}$$

Therefore for a given L, h_1 and h_2 to get minimum S, differentiate the above equation with respect to h_1 and equate it to zero. Therefore,

$$\frac{dS}{dh_1} = \frac{-h_1}{n_1^2} + \frac{h_2}{N - n_1{}^2} = 0 h_1 \left(N - n_1\right)^2 = \qquad h_2 n_1^2$$

$$h_1 \left(N^2 + n_1^2 - 2Nn_1\right) = \qquad h_2 n_1^2$$

$$h_1 N^2 + h_1 n_1^2 - 2Nn_1 h_1 = h_2 n_1^2$$

$$\left(h_2 - h_1\right) n_1^2 + 2Nh_1 n_1 - h_1 N^2 = 0$$

Solving the quadratic equation for n_1,

$$n_1 = \frac{-2Nh_1 \pm \sqrt{\left(2Nh_1\right)^2 - 4\left(h_2 - h_1\right)\left(-h_1 N^2\right)}}{2\left(h_2 - h_1\right)}$$

$$= \frac{-2Nh_1 + \sqrt{4N^2 h_1^2 + 4h_1 N^2 h_2 - 4h_1^2 N^2}}{2\left(h_2 - h_1\right)}$$

$$= \frac{-2Nh_1 + 2N\sqrt{h_1 h_2}}{2\left(h_2 - h_1\right)}$$

$$n_1 = \frac{N\sqrt{h_1 h_2} - h_1 N}{h_2 - h_1} \qquad \textbf{(2)}$$

Now we can substitute n back to get the value of minimum value of L for a given n_1, n_2, h_1 and h_2. Therefore,

$$S = \frac{L}{2} + \frac{h_1}{\frac{N\sqrt{h_1 h_2} - N h_1}{h_2 - h_1}} + \frac{h_2}{N - \frac{N\sqrt{h_1 h_2} - N h_1}{h_2 - h_1}}$$

Solving for L,

$$= \frac{L}{2} + \frac{h_1 (h_2 - h_1)}{N\left(\sqrt{h_1 h_2} - h_1\right)} + \frac{h_2 (h_2 - h_1)}{N h_2 - N h_1 - N\sqrt{h_1 h_2} + N h_1}$$

$$= \frac{L}{2} + \frac{h_1 (h_2 - h_1)}{N\left(\sqrt{h_1 h_2} - h_1\right)} + \frac{h_2 (h_2 - h_1)}{N\left(h_2 - \sqrt{h_1 h_2}\right)}$$

$$= \frac{L}{2} + \frac{h_1 (h_2 - h_1)\left(h_2 - \sqrt{h_1 h_2}\right) + (h_2 - h_1) h_2 \left(\sqrt{h_1 h_2} - h_1\right)}{N\left(\sqrt{h_1 h_2} - h_1\right)\left(h_2 - \sqrt{h_1 h_2}\right)}$$

$$= \frac{L}{2} + \frac{(h_2 - h_1)\left(h_1 h_2 - h_1\sqrt{h_1 h_2} + h_2\sqrt{h_1 h_2} - h_1 h_2\right)}{N\left(\sqrt{h_1 h_2} - h_1\right)\left(h_2 - \sqrt{h_1 h_2}\right)}$$

$$= \frac{L}{2} + \frac{(h_2 - h_1)\left(\sqrt{h_1 h_2}\,(h_2 - h_1)\right)}{N\left(h_2\sqrt{h_1 h_2} - h_1 h_2 + h_1\sqrt{h_1 h_2} - h_1 h_2\right)}$$

$$= \frac{L}{2} + \frac{(h_2 - h_1)\sqrt{h_1 h_2}\left(\sqrt{h_2} + \sqrt{h_1}\right)\left(\sqrt{h_2} - \sqrt{h_1}\right)}{N\sqrt{h_1 h_2}\left(h_2 - 2\sqrt{h_1 h_2} + h_2\right)}$$

$$= \frac{L}{2} + \frac{(h_2 - h_1)\left(\sqrt{h_2} + \sqrt{h_1}\right)\left(\sqrt{h_2} - \sqrt{h_1}\right)}{N\left(\sqrt{h_2} - \sqrt{h_1}\right)^2}$$

$$= \frac{L}{2} + \frac{(h_2 - h_1)\left(\sqrt{h_2} + \sqrt{h_1}\right)}{N\left(\sqrt{h_2} - \sqrt{h_1}\right)}$$

$$= \frac{L}{2} + \frac{\left(\sqrt{h_2} + \sqrt{h_1}\right)\left(\sqrt{h_2} - \sqrt{h_1}\right)\left(\sqrt{h_2} + \sqrt{h_1}\right)}{N\left(\sqrt{h_2} - \sqrt{h_1}\right)}$$

$$= \frac{L}{2} + \frac{\left(\sqrt{h_2} + \sqrt{h_1}\right)^2}{N}$$

$$L = 2S - \frac{2\left(\sqrt{h_2} + \sqrt{h_1}\right)^2}{N}$$

$$L = 2S - \frac{\left(\sqrt{2h_1} + \sqrt{2h_2}\right)^2}{N}$$

When stopping sight distance is considered the height of driver's eye above the road surface (h_1) is taken as 1.2 metres, and height of object above the pavement surface (h_2) is taken as 0.15 metres. If overtaking sight distance is considered, then the value of driver's eye height (h_1) and the height of the obstruction (h_2) are taken equal as 1.2 metres.

Unit II

Bituminous & Cement Concrete Pavements

Design of flexible pavements, design of mixes and stability, WBM, WMM, BM, IBM, surface dressing, interfacial treatment- seal coat, tack coat, prime coat, wearing coats, grouted macadam, bituminous concrete specification, construction and maintenance. Advantages and disadvantages of rigid pavements, general Principles of design, types, construction, maintenance and joints, dowel bars, tie bars. Brief study of recent developments in cement concrete pavement design, fatigue and reliability.

Requirements of Bituminous Mixes The aim of mix design is to obtain an economical blend or mix using proper gradation of coarse aggregates, fine aggregates, filler and adequate amount of bituminous binder to fulfill the desirable properties of mix. Mechanical/Desirable Properties Desirable properties of a good bituminous mix are:

a) Stability

b) Durability

c) Flexibility

d) Skid resistance

e) Workability

a) Stability: Stability is the resistance of the paving mix to deformation under the load. It is the stress to which specified strain is produced (load at which specified deformation). Depending upon the specification or field condition, it is influenced by density of the mix or percentage voids in the compacted mix or viscosity of bituminous binder. If the voids are less, stability will be more and strength will be more. But there must be minimum voids which would provide space on necessary densification which takes place under the traffic movement and expansion of bitumen at high temperature in the atmosphere. If there are no sufficient voids, the bituminous binder bleeds over the surface and causes skidding.

b) Durability It is the resistance of the mix against weathering and abrasive actions. Due to weathering bituminous mix gets harden which is due to loss of volatiles and oxidation. The tensile strain is induced due to heavy wheel loads and excessive strain may be developed which may cause cracks or plastic failure.

c) Flexibility It is the property of the mix that measures the level bending strength.

d) Skid Resistance It is the resistance of the finished pavement against skidding which depends upon the surface texture and bitumen content of mix. If the bitumen content is more, the surface of the pavement is smoothen or slippery. Therefore the bitumen content must be optimum to have better skid resistance.

e) Workability It is the ease with which the mix can be laid and compacted to maximum density. It is the function of gradation of aggregates, their shape and texture, bitumen content and its type.

Requirements of Bituminous mixes

Stability: Stability is defined as the resistance of the paving mix to deformation under traffic load. Two examples of failure are (i) shoving - a transverse rigid deformation which occurs at areas subject to severe acceleration and (ii) grooving - longitudinal ridging due to channelization of traffic. Stability depends on the inter-particle friction, primarily of the aggregates and the cohesion offered by the bitumen. Sufficient binder must be available to coat all the particles at the same time should offer enough liquid friction. However, the stability decreases when the binder content is high and when the particles are kept apart.

Durability: Durability is defined as the resistance of the mix against weathering and abrasive actions. Weathering causes hardening due to loss of volatiles in the bitumen. Abrasion is due to wheel loads which causes tensile strains. Typical examples of failure are (i) pot-holes, - deterioration of pavements locally and (ii) stripping, lost of binder from the aggregates and aggregates are exposed. Disintegration is minimized by high binder content since they cause the mix to be air and waterproof and the bitumen film is more resistant to hardening.

Flexibility: Flexibility is a measure of the level of bending strength needed to counteract traffic load and prevent cracking of surface. Fracture is the cracks formed on the surface (hairline-cracks, alligator cracks), main reasons are shrinkage and brittleness of the binder. Shrinkage cracks are due to volume change in the binder due to aging. Brittleness is due to repeated bending of the surface due to traffic loads. Higher bitumen content will give better flexibility and less fracture.

Skid Resistance: It is the resistance of the finished pavement against skidding which depends on the surface texture and bitumen content. It is an important factor in high speed traffic. Normally, an open graded coarse surface texture is desirable.

Workability: Workability is the ease with which the mix can be laid and compacted, and formed to the required condition and shape. This depends on the gradation of aggregates, their shape and texture, bitumen content and its type. Angular, flaky and elongated aggregates workability. On the other hand, rounded aggregates improve workability.

Desirable Properties:

The desirable properties of a bituminous mix can be summarized as follows:

- Bitumen content to ensure proper binding and water proofing
- Voids to accommodate compaction due to traffic
- Flexibility to meet traffic loads, especially in cold season
- Sufficient workability for construction
- Economical mix
- Stability to meet traffic demand and economical mix.

Aim of Mix Design Method:

Any mix design methods should aim at determining the properties of aggregates and bituminous material and combination of both which would give a mix having the following properties:

a) Sufficient stability to satisfy the service requirements of the pavement and the traffic conditions, without undue displacements.

b) Sufficient bitumen to ensure a durable pavement by coating the aggregate and bonding them together and also by water-proofing the mix.

c) Sufficient voids in the compacted mix as to provide a reservoir space for a slight amount of additional compaction due to traffic and to avoid flushing, bleeding and loss of stability.

d) Sufficient flexibility even in the coldest season to prevent cracking due to repeated application of traffic loads.

e) Sufficient workability while placing and compacting the mix.

f) The mix should be the most economical one that would produce a stable, durable and skid resistant pavement.

Objectives of Mix Design:

The objective of the mix design is to produce a bituminous mix by proportionate various components so as to have:

- Sufficient strength to resist shear deformation under traffic at higher temperature
- Sufficient air voids in the compacted bitumen to allow for additional compaction by traffic
- Sufficient workability to permit easy placement without segregation
- Sufficient flexibility to avoid premature cracking due to repeated bending by traffic, and
- Sufficient flexibility at low temperature to prevent shrinkage cracks.
- Sufficient bitumen to ensure a durable pavement

Constituents of a Mix:

Coarse aggregates: offer compressive and shear strength and shows good interlocking properties. E.g.: Granite

Fine aggregates: Fills the voids in the coarse aggregate and stiffens the binder. E.g. Sand, Rock dust

Filler: Fills the voids, stiffens the binder and offers permeability. E.g. Rock dust, cement, lime.

Binder: Fills the voids, cause particle adhesion and offers impermeability. E.g. Bitumen, Asphalt, Tar

Types of Mix:

Well-graded mix: Dense mix, bituminous concrete has good proportion of all constituents and are called dense bituminous macadam, offers good compressive strength and some tensile strength .

Gap-graded mix: Some large coarse aggregates are missing and has good fatigue and tensile strength.

Open-graded mix: Fine aggregate and filler are missing, it is porous and offers good friction, low strength and for high speed.

Unbounded: Binder is absent and behaves under loads as if its components were not linked together, though good interlocking exists. Very low tensile strength and needs kerb protection.

Design of Bituminous Mixes/ Steps in Mix Design Method: The following steps may be followed for a rational design of a bituminous mix.

a) Selection of Aggregate Aggregates having sufficient strength, hardness, toughness, soundness are selected. Crushed aggregates and sharp sands produce a mix of higher stability compare to natural gravel and rounded sands.

b) Selection of Aggregate Grading:-The density and stability of the mix depend on the gradation or grain size distribution of aggregate. Generally densely textured aggregate (well graded) is specified instead of open texture (poorly graded or gap graded). To attain higher stability, higher maximum size aggregate is selected. However the max size of aggregate used depends on compacted thickness of particular layer. Therefore gradation or max size is specified by the designer or user such as IRC. For a proposed 40 mm thick bituminous concrete layer or bituminous concrete coarse. The specified gradation of aggregate mix is shown in following table:

Table 1: Grading of aggregates

Sieve size, mm	Percent passing, by weight	
	Grade 1	Grade 2
20	-	100
12.5	100	80-100
10.0	80-100	70-90
4.75	55-75	50-70
2.36	35-50	35-50
0.6	18-29	18-29
0.3	13-23	13-23
0.15	8-16	8-16
0.075	4-10	4-10
Binder content, percent by weight of mix	5-7.5	5-7.5

If the available gradation is not satisfying the specification or specified gradation proper blending of different grades is to be adopted for this purpose, either by the method of trials or Rothfuch's method.

c) Determination of Specific Gravity

The specific gravity of aggregate mix is represented as bulk specific gravity or apparent specific gravity or effective specific gravity of mix. If the overall volume of the aggregate mix is considered, the bulk specific gravity is obtained in the apparent or effective specific gravity. The volume of capillary which are filled by the water on 21 hours of soaking or immersion is excluded. When the different aggregate are mixed to obtain required gradation, the specific gravity of combined mixture denoted as 'Ga' is determined using equation:

$$G_a = \frac{100}{W_1/G_1 + W_2/G_2 + W_3/G_3 + W_4/G_4 + \ldots}$$

Where,

W_1, W_2, W_3, W_4 = percent by weight of aggregates

G_1, G_2, G_3, G_4 = specific gravity of each material used in mix

In the above equation, the total weight of aggregate mix is considered which will be in the numerator then this equation gets modified.

$$G_a = \frac{W_1 + W_2 + W_3 + \ldots}{W_1/a_1 + W_2/a_2 + W_3/a_3 + \ldots}$$

Where,

W_1, W_2, W_3 = actual weight of component used in the mix.

d) Proportioning of Aggregates

As a first step the design grading is selected based on the type of construction, thickness of the layer and its specification if any. Then the available aggregate are analysed for gradation. Using the graphical method suggested by Rothfuch's or method of trial. The required method of each component is to be determined to satisfy the design gradation.

e) Preparation of Specimen or Sample

The preparation of specimen depends on the stability test method employed. Hence the size of the specimen, compaction and other specification should be followed as specified in the stability test method. The stability test methods which are in common use for the design mix are Marshall, Hubbard-Field and Hveem. Hence after deciding the test methods, the specimens are molded as per specification.

f) Determination of Specific Gravity of Compacted Specimen

Knowing specific gravity of aggregate mix 'Ga' and that of bituminous binder 'Gb', the theoretical maximum specific gravity of the sample or specimen is determined using the equation:

$$G_t = \frac{100}{(100 - W_b)/G_a + W_b/G_b}$$

g) Stability Tests on Compacted Specimens:

One of the stability tests is carried out based on the design method selected.

h) Selection of Optimum Bitumen Content

The optimum bitumen content is selected based on the test method adopted and the design requirements considered.

Marshall Stability Test

Bruce Marshall, formerly Bituminous Engineer with Mississippi State Highway Department formulated Marshall Method for designing bituminous mixes.

In the Marshall test, the resistance to plastic deformation of cylindrical specimen of bituminous mixture is measured when the specimen is loaded at the periphery at a rate of 5cm per minute. This test procedure is used in designing and evaluating bituminous mixes. There two major features of the Marshall method of designing the mixes namely,

i. **Density – voids analysis**

ii. **Stability – flow tests**

The Marshall stability of the mix is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60° C. The flow is measured as the deformation in units of 0.25 mm between no load and maximum load carried by the specimen during stability test. In this test an attempt is made to obtain Optimum Bitumen Content (OBC) for the type of aggregate mix and traffic intensity.

Apparatus:

a) **Mould assembly: cylindrical mould of 10.16cm diameter and 6.35 cm height, with a base plate and collar.**
b) **Sample extractor**
c) **Compaction pedestal and hammer, weight 4.54 kg with 45.7 cm height of fall.**
d) **Proving ring**
e) **Breaking head, to apply a load on its periphery perpendicular to its axis in a loading machine of 5 ton capacity at a rate of 5 cm per minute.**
f) **Loading machine**
g) **Flow meter (dial gauge)**

Procedure:

a) **Select the aggregate gradation from the specified ranges in the table. (IRC or MOST)**
b) **Take approximately 1200g of aggregate and filler, if any, and heat to a temperature of 175 to 190°C.**
c) **Heat the compaction mould assembly and the rammer to a temperature of 138 to 149° C.**
d) **Heat the given bitumen to a temperature of 121 to 145°C.**
e) **Add the required quantity of trial bitumen content (say 3.5 % by weight of mineral aggregate) and thoroughly mix using a trowel, maintaining a mixing temperature of 154 to 160° C.**
f) **Keep the pre-heated mould and collar on the compaction pedestal.**
g) **Transfer the mix in the pre-heated mould and compact it 75 times using the specified rammer.**
h) **Invert the specimen and again compact 75 times.**
i) **Repeat the procedure with specimens having other trial bitumen contents.**
j) **Allow the specimens to cool in air for a few hours.**

k) Now extract the specimens from the moulds using the sample extractor.
l) Measure the mean diameter and height of the specimens.
m) Find the weight of specimens in air and then in water.
n) Keep the specimens in a water bath maintained at a temperature of 60° C for about 40 minutes.
o) Keep the specimen in the breaking head assembly in the Marshall apparatus.
p) Set the proving ring dial and flow dial to zero
q) Load the specimen until it fails and record the load applied and flow readings at failure.
r) Repeat the process for other specimens.

Results

Marshall Stability of given mix at bitumen content --------% = --------------

Optimum bitumen content for the given mix = ---------------%

Observations

The Marshall Test properties of any specimen can be calculated using the following formulae:

1) Bulk Density of Compacted Specimen (Gb)

$$Gb = \frac{\text{Wt. in air}}{\text{Wt. in air - Wt. in water}}$$

2) Theoretical Density of Specimen (Gt)

$$Gt = \frac{100}{W1/G1 + W2/G2 + W3/G3 + W4/G4} \text{ in gm/cc}$$

3) Volume of Air Voids (Vv)

$$Vv = \frac{Gt - Gb}{Gt} \times 100 \quad \%$$

4) Volume of Bitumen (Vb)

$$Vb = Gb \times \frac{W4}{G4} \%$$

Where, W4 = % wt of bitumen

G4 = Sp. Gravity of bitumen

5) Voids in Mineral Aggregate (VMA)

$$VMA = Vv + Vb \quad \%$$

6) Voids Filled with Bitumen (VFB)

$$VFB = \frac{100\ Vb}{VMA} \times 100 \%$$

7) Determination of Marshall Stability

Marshall Stability = Proving ring dial gauge reading x Correction factor for thickness of specimen x Proving ring dial gauge constant.

Pavement engineering is a branch of civil engineering that uses engineering techniques to design and maintain flexible (asphalt) and rigid (concrete) pavements. This includes streets and highways and involves knowledge of soils, hydraulics, and material properties. Pavement engineering involves new construction as well as rehabilitation and maintenance of existing pavements. Maintenance often involves using engineering judgment to make maintenance repairs with the highest long-term benefit and lowest cost. The Pavement Condition Index (PCI) is an example of an engineering approach applied to existing pavements. Another example is the use of a falling weight deflecto-meter (FWD) to non-destructively test existing pavements. Calculation of pavement layer strengths can be performed from the resulting deflection data. The two methods - empirical or mechanistic is used to determine pavement layer thicknesses.

Types of Highway Construction

The highway types are classified as below:

(i) Earth road and gravel roads

(ii) Soil stabilized roads

(iii) Water bound macadam (WBM) road

(iv) Bituminous or black-top roads

(v) Cement concrete roads

The roads in India are classified based on location and functions. All the roads do not cater for the same amount of traffic volume or intensity. Since the funds available at hand for financing the construction projects are also meager, it is necessary to have roads which cost less. The adoption of low cost roads is now preferred in developing countries like India where large lengths of roads are to be constructed in the rural areas with the limited finances available in the country. Earth roads and stabilized roads are typical examples of low cost roads. Stabilised soil roads are gaining importance in the form of low cost roads.

Earthworks are engineering works created through the moving or processing of parts of the earth's surface involving quantities of soil or unformed rock. The earth may be moved to another location and formed into a desired shape for a purpose. Much of earthworks involves machine excavation and fill or backfill.

Excavation is the process of cutting or loosening and removing earth including rock form its original position. Transporting and dumping it as a fill or spoil bank. The excavation or cutting mat be needed in soil, soft rock or even in hard rock, before preparing the subgrade.

Excavation may be classified by type of material:

1. Topsoil excavation
2. Earth excavation
3. Rock excavation
4. Muck excavation – this usually contains excess water and unsuitable soil
5. Unclassified excavation – this is any combination of material types

Excavation may be classified by the purpose:

1. Stripping
2. Roadway excavation
3. Drainage or structure excavation
4. Bridge excavation
5. Channel excavation
6. Footing excavation
7. Borrow excavation
8. Dredge excavation
9. Underground excavation.

COMPOSITION AND STRUCTURE OF FLEXIBLE PAVEMENT

Flexible pavements support loads through bearing rather than flexural action. They comprise several layers of carefully selected materials designed to gradually distribute loads from the pavement surface to the layers underneath. The design ensures the load transmitted to each successive layer does not exceed the layer's load-bearing capacity. A typical flexible pavement section is shown in Figure 1. Figure 2 depicts the distribution of the imposed load to the subgrade. The various layers composing a flexible pavement and the functions they perform are described below:

a) Bituminous Surface (Wearing Course). The bituminous surface, or wearing course, is made up of a mixture of various selected aggregates bound together with asphalt cement or other bituminous binders. This surface prevents the penetration of surface water to the base course; provides a smooth, well-bonded surface free from loose particles, which might endanger aircraft or people; resists the stresses caused by aircraft loads; and supplies a skid-resistant surface without causing undue wear on tires.

Base Course. The base course serves as the principal structural component of the flexible pavement. It distributes the imposed wheel load to the pavement foundation, the sub base, and/or the subgrade. The base course must have sufficient quality and thickness to prevent failure in the subgrade and/or sub base, withstand the stresses produced in the base itself, resist vertical pressures that tend to produce consolidation and result in distortion of the surface course, and resist volume changes caused by fluctuations in its moisture content. The materials composing the base course are select hard and durable aggregates, which generally fall into two main classes: stabilized and granular. The stabilized bases normally consist of crushed or uncrushed aggregate bound with a stabilizer, such as Portland cement or bitumen. The quality of the base course is a function of its composition, physical properties, and compaction of the material.

c) Sub base. This layer is used in areas where frost action is severe or the subgrade soil is extremely weak. The sub base course functions like the base course. The material requirements for the sub base are not as strict as those for the base course since the sub base is subjected to lower load stresses. The sub base consists of stabilized or properly compacted granular material.

d) Frost Protection Layer. Some flexible pavements require a frost protection layer. This layer functions the same way in either a flexible or a rigid pavement.

e) Subgrade. The subgrade is the compacted soil layer that forms the foundation of the pavement system. Subgrade soils are subjected to lower stresses than the surface, base, and sub base courses. Since load stresses decrease with depth, the controlling subgrade stress usually lies at the top of the subgrade. The combined thickness of sub base, base, and wearing surface must be great enough to reduce the stresses occurring in the subgrade to values that will not cause excessive distortion or displacement of the subgrade soil layer.

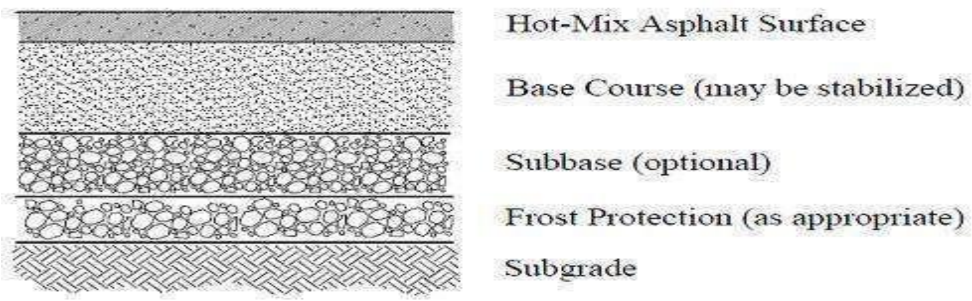


Fig1 Typical flexible pavement structure

Granular sub base layer:

Aggregates are used in granular base and sub-base layers below the driving surface layer(s) in both asphalt concrete and Portland cement concrete pavement structures. The aggregate base layers serve a variety of purposes, including reducing the stress applied to the subgrade layer and providing drainage for the pavement structure. The granular base layer is directly below the pavement surface and acts as the load bearing and strengthening component of the pavement structure. The granular sub-base forms the lowest (bottom) layer of the pavement structure, and acts as the principal foundation for the subsequent road profile, provides drainage for the pavement structure, and protects the structure from frost.

Granular bases are typically constructed by spreading the materials in thin layers of 150 mm (6 in) to 200 mm (8 in) and compacting each layer by rolling over it with heavy compaction equipment.

MATERIALS

Aggregates used in granular base and sub base applications generally consist of sand and gravel, crushed stone or quarry rock, slag, or other hard, durable material of mineral origin. The gradation requirements vary with type (base or sub-base).

Granular base materials typically contain a crushed stone content in excess of 50 percent of the coarse aggregate particles. Cubical particles are desirable, with a limited amount of flat or thin and elongated particles. The granular base is typically dense graded, with the amount of fines limited to promote drainage. Granular sub-base is also dense graded, but tends to be somewhat more coarse than granular base. The requirement for crushed content for granular sub-base is not required by many agencies, although provision of 100 percent crushed aggregates for base and sub-base use is increasing in premium pavement structures to promote rutting resistance.

Specification of material –

1. The materials to be used for the work shall be natural sand, moorum, gravel, crushed stone or combination depending on grading requirement.
2. The materials shall be free from organic or deleterious constituents & should conform to one of the three grading given in table A.
3. The grading in Table A are in respect of close graded granular sub base materials, & Table B for coarse graded materials.

Table 2: – Grading for close graded granular sub – base materials.

IS Sieve degignation	Percentage by weight passing the IS sieve		
	Grading 1	Grading 2	Grading 3
75mm	100	-	-
53.5mm	80-100	100	-
26.5mm	55-90	70-100	100
9.5mm	35-65	50-80	65-95
4.75mm	25-55	40-65	50- 60
2.36mm	20-40	30-50	40-65
.425mm	10-25	15-25	20-53
0.075mm	3-10	3-10	3-10
BR Value	30	25	20

MATERIAL PROPERTIES AND TESTING METHODS

The granular base and sub-base generally make up the greatest thickness of the pavement structure, and provide both bearing strength and drainage for the pavement structure. Hence, proper size, grading, shape, and durability are important attributes to the overall performance of the pavement structure. Granular base and sub-base aggregates may consist of durable particles of crushed stone, gravel or slag capable of withstanding the effects of handling, spreading, and compacting without generation of deleterious fines.

Some of the more important properties of aggregates for granular base and sub-base include:

Gradation – a wide range of aggregate sizes and gradations are used depending on the pavement type and the conditions to which the granular base and sub-base will be subjected. The aggregate grading markedly influences the base stability, drainage (permeability) and frost susceptibility. Aggregates for use as granular base tend to be dense-graded with a maximum size of 50 mm (2 in) or less, while granular sub-base can have a nominal maximum size commonly up to 100 mm (4 in). The percentage of fines (minus 0.075 mm (No. 200 sieve)) in the granular base is limited, for drainage and frost-susceptibility purposes, to a maximum of 8 percent, with up to 12 percent permitted in granular sub-base.

Particle Shape – the use of angular, nearly equidimensional aggregate with rough surface texture is preferred over rounded, smooth aggregate particles. Thin or flat and elongated particles have reduced strength when load is applied to the flat side of the aggregate or across its shortest dimension and are also prone to segregation and breakdown during compaction, creating additional fines.

Base Stability – granular base should have high stability, particularly in a flexible asphalt pavement structure. Large, angular aggregate, dense-graded and consisting of hard, durable particles, is preferred for stability. For maximum base stability, the granular base should have sufficient fines to just fill the voids and the entire gradation should be close to its maximum density. However, while base density is maximized at fines content between 6 and 20 percent, load-carrying capacity decreases when the fines content exceeds about 9 percent. Stability also increases with the percentage of crushed particles and increasing coarse aggregate size.

Permeability – since the granular sub-base provides drainage for the pavement structure, its grading and hydraulic conductivity are important. The fines content is usually limited to a maximum of 10 percent for normal pavement construction, and 6 percent where free-draining sub-base is required.

Plasticity – the presence of plastic fines can significantly reduce the load-carrying strength of the granular base and sub-base.

Abrasion Resistance – particles should have sufficient strength to resist degradation or breakdown during construction, under compaction or under traffic.

Resilient Modulus – can assist in providing design coefficients for multi-layered pavements by defining the relationship between stress and the deformation of granular base and sub-base layers.

Physical requirements –

a) The material shall have 10% finer value of 50KN or more.
b) If the water absorption value for coarse aggregates exceeds 2%, soundness test is carried out.

c) The material passing 425 micron sieve for all 3 grading shall have liquid limit & plasticity Index not more than 25 & 6%.

d) Construction Operations –

a) Preparation of sub grade – Before laying sub base, the sub grade should be prepared by removing vegetation & extraneous matter, lightly sprinkled with water if necessary & rolled with two passes of 80 – 100KN smooth wheeler roller.

b) Spreading & Compacting – The sub base material should be spread on prepared sub grade with help of motor grader, its blades having controls for maintaining the required slope & grade.

1. base material have combination of materials, mixing is done mechanically. Manual mixing is permitted where the width of laying is small for mechanical operations. The equipment used for min – in place construction is rotavator.

2. Moisture control of loose material shall be checked with IS – 2720 & suitably adjusted by sprinkling water from truck mounted or trailer mounted water tank.

3. At the time of compaction, water content should be from 1% above to 2% below the optimum moisture content.

4. After adding water it is processed by horrows, rotavators until the layer is uniformly wet.

5. Immediately rolling will start, if the thickness of compacted layer does not exceed 100mm, a smooth wheeled roller is used. For a compacted single layer up to 225mm, vibratory roller or heavy pneumatic tyred roller of min 200 to 300KN wt is used.

6. Rolling will start from lower edge & proceed towards upper edge longitudinally to achieve super elevation & unidirectional cross fall & should start at both edges & progress towards centre for portions having cross fall on both sides.

7. Each pas of roller shall uniformly overlap not less than one third of track made in preceding pass. The speed of roller shall not exceed 5km per hour.

8. Rolling is continued till the density is achieved at least 98% of MDD for the material determined.

9. The surface of any layer of material on completion of compaction shall be will closed, free from movement under compaction equipment & from compaction planes, ridges, cracks or loose materials. If so happens it should be re – compacted.

Surface Finish & Quality control of work – The surface finish of construction & control on the quality of materials & works shall be in accordance with section 900, the tests to be conducted are as below -

Table 3: Quality control tests on granular sub – base

SN	Type of Test	Frequency (Min)
1	Gradation	One per 200 m3
2	Atterberg limits	One test per 200m3
3	Moisture content prior to compaction	One test per 500 m3
4	Density of compacted layer	One test per 500 m3
5	Deleterious Constituents	As required
6	CBR	As required

Water Bound Macadam:

WBM Stands for Water Bound Macadam which is the most commonly used road construction procedure for over more than 190 years. Pioneered by Scottish Engineer John Loudon McAdam around 1820 Macadam is a type of Road Construction. The broken stones of base and surface course, if any are bound by the stone dust is presence of moisture is called WBM Roads. Macadam means the pavement base course made of crushed or broken aggregate mechanically interlocked by rolling and the voids filled with screening and binding material with the assistance of water.WBM may be used as a sub-base, base or a surface course. The thickness of each compacted layer of WBM ranges from 10cm to 7.5cm depending on size and the gradation of aggregate used.

Materials:

The coarse aggregates used for WBM construction shall be anyone of the following:

- **a) Crushed or broken rock,**
- **b) Crushed or broken slag,**
- **c) Broken brick aggregate.**

Specification of materials –

- **a) Coarse aggregates – It can be either crushed or broken stone, crushed slag, over burnt rick aggregates or naturally occurring aggregates such as Kankar & Laterite. The aggregates shall conform the physical requirements said in table 400 – 6. If the water absorption is greater than 2% the soundness test shall be carried out.**

Table4: Physical requirements of coarse aggregates for water bound Macadam for sub base / base courses.

Sn	**Types of test**	**Test Methods**	**Requirements**
1	**Loss angels abrasion test**	**IS-2386**	**40% Max**
2	**Combine flakiness and elongation test**	**IS-2386**	**30% Max**

Crushed Slag – It is made from air cooled blast furnace slag. It should be angular shape, reasonably uniform in quality & density. The weight of crushed slag shall not be less than 11.2 KN/m^3 & percentage of glossy material shall not be more than 20 water absorption should not be more than 10% sulphur content should not exceed 2%.

Crushed or Broken Stone – It should be hard, durable & free from excess flat, elongated, soft & disintegrated particles, dirt & other deleterious material.

Over burnt (Jhama) bick aggregates – It should be made from over burnt bricks or brick bats & be free from dust & deleterious materials.

i. **Grading requirement of coarse aggregates – The coarse aggregates shall conform to one of the gradings given in table below D, the use of Grading No – 1 shall be restricted to sub – base courses only.**

The compacted thickness for a layer with Grading – I shall be 100mm while for layer with other grading 2 & 3 should be 75mm.

v. Screenings – It is used to fill voids in coarse aggregates which consists of same material as the coarse aggregate. Such as non plastic materials like moorum or gravel is used provided liquid limit & plasticity Index are below 20 & 6 respectively & fraction passing 75 micron sieve does not exceed 10%. Screenings should conform to the grading serial in table 400 – 8. It should be omitted in case of soft aggregates such as brick metal, kankar, laterites etc as they get crushed under rollers. Table below E – Grading for Screenings –

Table:- 5 Classification of Grading

Grading classification	Size of screenings	IS SIEVE Designation	Percentage by weight passing the IS sieve
A	13.2mm	13.2mm	100
		11.2	95-100
		5.6mm	15-35
		180micron	0-10
B	11.2mm	11.2mm	100
		5.6mm	90-100
		180micron	15-35

Vi Binding Material – It is used as a filler material for WBM having PI value less than 6, the quantity of binding material to be used depend on type of screening. Generally, the quantity required for 75mm compacted thickness will be 0.06 – 0.09m3/10m2 & for 100mm compacted thickness it will be around 0.08 – 0.10m3/10m^2.

II. Construction Operations –

a) **Preparation of Base –**

The surface of subgrade / sub base to receive WBM coarse shall be prepared to specified lines & cross fall & made free of dust & other materials. Levelling course is used to correct the irregularities in the profile. Laying of WBM over thick bituminous layer is avoided due to the internal drainage of the pavement at the interface of 2 courses. Where the intensity of rain is low & the interface drainage facility is efficient WBM can be laid over the existing thin bituminous surface by cutting 50mm X 50mm furrows at an angle of 45o to the centre line at one meter interval.

b) Invented Choke –

If WBM is to be land directly over subgrade, a 25mm coarse of screening B or coarse sand is spread before application of aggregates. In case of find sand or silty or clayey subgrade, it is advisable to lay 100mm of screening or coarse sand on top of fine grained soil. As an alternative to inverted choke, geo synthesis are used for separation & drainage over the prepared subgrade.

c) **Spreading Coarse Aggregates –**

The coarse aggregates shall be spread uniformly & evenly upon the prepared subgrade in thickness not more than 100mm for Grading – I & 75mm for Grading – II & III. The spreading shall be done from stockpiles along the side of road way ro directly from vehicles. No segregation between aggregates is allowed & it must be of uniform gradation with no fine material. The surface of the aggregates shall be checked carefully by removing or adding aggregates at high or low spots & it is checked with a straight edge. The coarse aggregates should not normally be spread more than 3 days.

d) **Rolling –**

Rolling is started immediately after spreading by three wheeled power rollers, or tandem or vibratory rollers 80 to 100KN static weight. Except on super elevated portions where the rolling will proceed from inner edge to outer & it begins from edges gradually progressing towards centre. During rolling, slight sprinkling of water may be done if necessary. Rolling is not done when subgrade is soft or yielding or when it causes a wave like motion in the subgrade or sub base course. The rolled surface shall be checked transversely & longitudinally with templates & corrected or re – rolled to derived camber & grade. Materials getting crushed during compaction should be removed & replaced. Shoulders are built up simultaneously along with WBM courses.

e) **Application of Screenings –**

After the coarse aggregate has been rolled, screenings are applied to fill the voids. There shall not be damp or wet at the time of application. Dry rolling shall be done while the screenings are being spread so that it will settle into voids. The screenings are spread uniformly in thin layers by hand shovels or by mechanical spreaders or from dipper.

The screening is applied at a slow & uniform rate so as to ensure filling of voids accompanied by dry rolling & brooming with mechanical or hand brooms or both.These operations shall continue until no more screenings fills voids of aggregates. The spreading, rolling & brooming of screenings could be completed in one day.

f) **Sprinkling of water and grouting –**

After the screenings are applied, the surface should be sprinkled with water, swept & rolled. Hand brooms are used to sweep & distribute wet screenings evenly. It is continued until coarse Spreading Coarse Aggregates –

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g) Sprinkling of water and grouting –

After the screenings are applied, the surface should be sprinkled with water, swept & rolled. Hand brooms are used to sweep & distribute wet screenings evenly. It is continued until coarse aggregate has been thoroughly keyed, well bonded & firmly set in full depth & a grout has been formed of screenings.

g) Application of Binding Material –

After application of screening, binding material is applied in 2 or more thin layers at a slow & uniform rate. After each application water is sprinkled & swept with brooms to fill the voids & rolled. This is continued till a wave head of the wheels of the moving roller is formed on slurry.

h) Setting & drying –

After final compaction of WBM course, the pavement is allowed to dry overnight Next morning spots be filled with screenings or binding materials & lightly sprinkled with water & rolled.

No traffic shall be allowed on the load until the macadam has set. The compacted WBM course should be allowed to completely dry & set before the next pavement course is laid over it.

III. Quality control tests on Water Bound Macadam Course –

Table:- 6 Quality control for BMC

SN	Type of Test	Frequency
1	Aggregates Impact value	1 Test per 200m3
2	Grading	One test per 100m3
3	Flakiness Index & Elongation index	One test per 200m3 aggregates
4`	Atterbergs Limits of Binding Material	One test per 325 m3 of binding material

Wet Mix Macadam layer:

Specification of Materials –

a) Physical requirements of aggregates – Coarse aggregates shall be crushed stone & it should conform to the physical requirements said in Table – 400 – 10.

Table 7: Quality control for Wet Mix Macadam Layer

Sn	Types of test	Test Methods	Requirements
1	Loss angels abrasion test	IS-2386	40% Max
2	Combine flakiness and elongation test	IS-2386	30% Max

If the water absorption value of aggregates is greater than 2%, soundness test is carried out.

b) Grading requirements for WMM is given in table below 400 – II.

Table 8: Grading of Aggregates

IS Sieve degignation	Percentage by weight passing the IS sieve
75mm	100
53.5mm	95-100
26.5mm	-
9.5mm	60-80
4.75mm	40-60
2.36mm	25-40
.425mm	15-30
0.075mm	8-2
BR Value	3

Materials finer than 425micron shall have plasticity Index not more than 6.

II. Construction Operations –

a) Preparation of base – It is done us the same as WBM layer as we have discussed earlier.

b) Provision of lateral confinement of aggregates – while constructing WMM, arrangement shall be made for lateral confinement of wet mix. This shall be done by laying in adjoining shoulders along with WMM.

c) Preparation of mix – WMM is prepared in mixing plant where pug mill or pan type mixer of concrete batching plant is used. Optimum moisture for mixing is determined at the time of compaction; water in the WMM should not vary from optimum value. The mixed material should be uniformly wet & no segregation is permitted.

d) Spreading of mix –

1. Immediately after mixing it is spread uniformly & evenly on prepared subgrade / sub-base / base. In no case it should be dumped in heaps.

2. The mix may be spread by paver finisher or motor grader.

3. The motor grader is cable of spreading the material uniformly so as to achieve the specified slope & grade.
4. No segregation of large & fine particles should be allowed.
e) Compaction –
1. After the mix has been laid to required thickness, grade & cross fall the same shall be compacted uniformly to the full depth by roller.

2. **If the thickness is 100mm single layer, smooth wheel roller is used. For compacted single layer up to 200mm vibratory roller is used.**
3. **Same kind off rolling as in WBM is done as we discussed before.**
4. **Along forms, kerbs, walls or other inaccessible places for rollers, mechanical tampers or plate compactor is used.**
5. **Rolling should not be done when the subgrade in soft.**
6. **If irregularities develop during rolling which exceed 12mm when tested with 3m straight edge, the surface should be loosened & premixed material added or removed.**
7. **Rolling shall be continued till the density achieved is atleast 98% of the max dry density for the material.**
8. **After completion, the surface of any finished layer is well closed, free from movement under compaction equipment or any compaction planes, ridges, cracks & loose material.**
9. **All loose, segregated area shall be made good to the full thickness of layer & recompacted.**
10. **Setting & Drying – After final compaction of wet mix macadam course, the rolad shall be allowed to dry for 24 hours.**

Opening to traffic – Preferably no vehicular traffic or any kind should be allowed on finished WMM surface till it has dried & the wearing course is laid.

Penetration Macadam and Built up Spray Grout:
Penetration Macadam – Bituminous penetration macadam is used as base or binder course. The course aggregates are first spread & compacted well. The hot bitumen is sprayed at top, it penetrates in voids & binding some stone aggregates together. Depending on quantity of bitumen spread & extent of penetration, it is called „full grout" & semi grout" when depth is full or half & is adopted in heavy & moderate rain fall regions respectively.
Built up spray grout [BSG] – it consists of 2 layer composite construction of compacted crushed aggregates with application of bituminous binder after each layer with key aggregates at top to provide a total thickness, 75mm. It is used for strengthing of existing bituminous pavement. A suitable wearing course is invariably provided over this & opened to traffic.
Bituminous Concrete –
Indian code Specification of Materials –
1) Bitumen – Same as DBM
Bitumen, Fine aggregates, Filler, Coarse aggregate are all same as DBM but Grading changes.
Table 9: Grading of aggregates

IS Sieve degignation	Percentage by weight passing the IS sieve
26.5mm	100
19mm	95-100
9.5mm	56-80
4.75mm	35-65
2.36mm	23-49
0.3mm	5-19
.075mm	2-8

Mix Design –

1) Marshall Stability 820Kg (Min)
2) Marshall Flow 2 – 4
3) Air voids 3 – 5
4) VMA 11 – 13%
5) VFB 65 – 75
6) Binder Content Min 45
7) Water Sensitivity Min 75%
8) Swell Test 1.5% Max

II. Construction Operations –

1. Preparation of Base – The base on which bituminous concrete is to be laid shall be prepared, shaped & conditioned to the specified levels, grade and crossfall (Camber).

2. The surface shall be thoroughly swept clean free from dust and other matter using mechanical broom and dust removed by mechanical means or blown off by compressed air. In portions where mechanical means cannot reach, other approved method is used.

3. Applying tack coat, preparation of mix, spreading, rolling are same as DBM layer as we have discussed earlier.

4. Opening to Traffic – Traffic may be allowed immediately after completion of final rolling when the mix has cooled down to surrounding temperature.

Semi Dense Bituminous Concrete –

1. Specification of Materials –

a) Bitumen – Same as BM (30/40 to 80/100) grade materials are almost same as BM & DGBM course layers which we have discussed earlier.

b) Coarse aggregates, fine aggregates, filler same specification as dense grade bituminous macadam.

c) Mix Design

1) Marshall Stability 820Kg
2) Marshall flow 2 – 4
3) Air voids in mix 3 – 5

4) VMA 13 – 15
5) VFB 65 – 75
6) Binder Content 44%

Table 10: Grading of aggregates

IS Sieve degignation	Percentage by weight passing the IS sieve		
	Grading 1	Grading 2	Grading 3
22.4mm	-	100	100-
13.2mm	100	85-100	79-100
11.2mm	88-100	7092	68-90
5.6mm	42-64	42-64	33-55
2.8mm	22-38	22-38	22-38
710micron	11-24	11-24	6-22
355micron	7-18	7-18	4-14
180micron	5-13	5-13	2-9
90micron	3-9	3-9	3-9

II. Construction Operation –

Construction is similar to Dense BM as discussed earlier.

a) Preparation of Base – The base on which SDBC is to be laid shall be prepared, shaped & conditioned to the specified lines, grades and cross sections. Tack Coat, prepration of mix, rolling is same as DBM.

Opening to traffic – Traffic may be allowed after completion of final rolling when the mix has cooled down to surrounding temperature.

Seal Coat

a) Scope – This work shall consist of application of seal coat for sealing the voids in bituminous surface.

b) Specification of Materials –

1. Binder – Suitable grade appropriate to region, traffic, rain fall & other environmental conditions.
2. Stone chippings for type (A) & type (B) seal coat – It should consists of angular fragments of clean, hard, durable, tough and free from dust, soft or flaky elongated material, organic matter. It should be 6.7mm size and 0.18mm size respectively.

c) Purpose – a) To seal the surfacing against the ingress of water. b) To develop skid resistance texture. c) To enliven an existing dry or weathered bituminous surface.

DIFFERENTIATE BETWEEN SEAL COAT AND PRIME COAT

Seal coat is usually recommended as a top coat over certain bituminous pavements which are not impervious, such as open graded bituminous constructions like premixed carpet and grouted Macadam. Seal coat is also provided over an existing bituminous pavement which is worn out.

(a) To seal the surfacing against the ingress of water

(b) To develop skid resistant texture

(c) To enliven an existing dry or weathered bituminous surface.

<u>Prime coat</u>: Bituminous prime coat is the first application of a low viscosity liquid bituminous material over an existing porous or absorbent pavement surface like the WBM base course.

Surface Dressing –

a) Scope – This work shall consists of the application of one coat or 2 coats of surface dressing, each coat consisting of a layer of bituminous binder sprayed on base followed by cover of chippings rolled to form wearing course.

b) Specification of Materials -

Binder – It should be of suitable grade appropriate to region, traffic, rainfall.

Stone Chipping – The stone polishing value should not be less than 55 & water absorption restricted to 1%.

Quantities of Materials – For single coat or the first coat of 2 coat surface dressing, 13.2mm size where it passes 100% 22.4mm & retained on 11.2mm IS Sieve. For second coat, 11.2mm passing 100% 13.2mm Sieve & retained on 5.6mm Sieve. c) Purpose –

1. To serve as a thin wearing course of pavement & to protect the base course.

2. To water proof the pavement surface and to prevent infiltration of water.

3. To provide dust – free pavement surface in dry weather & mud – free pavement in wet weather.

Mastic Asphalt –

It is a mixture of bitumen, fine aggregates & filler in suitable proportions which yields a void less & impermeable mass. Though the ingredients in mastic asphalt when cooled results in hard, stable & durable layer suitable to withstand heavy traffic. This material also can absorb vibrations and has a property of self – healing of cracks without bleeding. It is suitable surfacing materials for bridge deck slap. The filler, bitumen binder & aggregate are taken in suitable proportion & to make the mix.

Bituminous Macadam

Bituminous Macadam (BM) or Bitumen Bound Macadam is a premixed construction method consisting of one or more courses of compacted crushed aggregates premixed with bituminous binder, laid immediately after mixing. The BM is laid in compact thicknesses of 75 mm or 50mm and three different gradations of aggregates have been suggested for each thickness to provide open graded and semi-dense constructions.

1. Bituminous Premixed Carpet

Premixed Carpet (PC) consists of coarse aggregates of 12.5 and 10.0 mm sizes, premixed with bitumen or tar binder are compacted to a thickness of 20 mm to serve as a surface course of the pavement. Being a open graded construction, the PC is to be invariably covered by a suitable seal coat such as premixed sand-bitumen seal coat before opening to traffic. The PC consists of all aggregates passing 20 mm and

retained on 6.3mm sieve. When a fairly well graded material as per specification is used for the construction of the bituminous carpet of thickness 20 o 25 mm, the construction method is called semi-dense carpet.

2. Bituminous Concrete or Asphalt Concrete

Bituminous Concrete or Asphaltic Concrete (AC) is a dense graded premixed bituminous mix which is well compacted to form a high quality pavement surface Course. The AC consists of a carefully proportioned mixture of coarse aggregates fine aggregates, mineral filler and bitumen and the mix is designed by an appropriate method such as the Marshall method to fulfill the requirements of stability, density, flexibility and voids. The thickness of bituminous concrete surface course layer usually ranges from 40 to 75 mm. The IRC has provided specification for 40mm thick AC surface course for highway pavements.

3. Sheet Asphalt

Sheet asphalt or rolled asphalt is a dense sand-bitumen premix of compacted thickness 25 mm, used as a wearing course. The sheet asphalt consists of well graded coarse to fine sand (without coarse aggregates) and a suitable penetration grade bitumen to from a dense and impervious layer. This is usually laid over cement concrete pavement to provide an excellent riding surface. The sheet asphalt also protects the joints in cement concrete pavements and could cause a reduction in warping stresses due to a decrease in the temperature variations between top and bottom of the concrete slab.

4. Mastic Asphalt

Mastic asphalt is a mixture of bitumen, fine aggregates and filler in suitable proportions which yields a void less and impermeable mass. Though the ingredients in mastic asphalt are similar to those in bituminous concrete, properties of mastic asphalts are quite different. The mastic asphalts when cooled results in a hard, stable and durable layer suitable to withstand heavy traffic. This material also can absorb vibrations and has property f self-healing of cracks without bleeding. It is a suitable surfacing material for bridge deck slabs.

Construction Procedure for Bituminous Macadam

The Bituminous Macadam (BM) bitumen bound macadam is a premix laid immediately after mixing and then compacted. It is an open graded construction suitable only as a base or binder course. When this layer is exposed as a surface course, at least a seal coat is necessary.

Specifications of Materials: The grades of bitumen used are 30/40, 60/70 and 80/100 penetration. Road tar RT-4, cutback and emulsion can also be used in cold mix construction technique. The binder content used varies from 3.0 to 4.5 percent by weight of the mix). Aggregates used are of low porosity fulfilling the following requirements for the base Course.

Los Angle abrasion value 50 percent max.

Aggregate impact value 35 percent max.

Flakiness index 15 percent max.

Stripping at 40°C after 24 hours immersion (CRRI test) 25 percent max.

Loss with sodium sulphate, 5 cycles 12 percent max.

For binder course the specified maximum abrasion and impact values are 40 and 30 percent respectively. The grading of the aggregates for 75 mm and 50 mm thickness for base and binder course instruction as specified by Indian Roads Congress are given in Table 8.4 (a) & respectively. The quantity of aggregates required for 10 m2 of bitumen bound macadam are 0.60 to 0.75 m3 and 0.90 to 1.0 m3 respectively, for 50 and 75 mm compacted thickness. The bitumen quantity would be determined based on the grading adopted as specified above.

Constructions Steps

1. Preparation of existing layer: The existing layer is prepared to a proper profile. Pot holes are patched and irregularities are made even. The surface is properly cleaned.
2. Tack coat or prime coat application: A track coat is applied of thin layer of bitumen binder on the existing layer either using the sprayer or a pouring can. the quantity of application is 40 to 7.5 kg per 10 m2 for black top layer and 7.5 to 10kg per 10 m^2 for untreated WBM layer.
3. Premix preparation: The bitumen binder and aggregates as per recommended gradings are separately heated to the specified temperatures and are then placed in the mixer chosen for the job. The mixing temperature for each grading and the bitumen binder is also specified based on. The laboratory results. A tolerance of ± 10°C is allowed. The mixing is done till a homogeneous mixture is obtained. The mixture is then carried to the site for its placement through a transporter or a wheel barrow.
4. Placement. The bituminous paving mixture is then immediately placed on the desired location and is spread with rakes to a pre-determined thickness. The camber profile is checked with a template. It may be stated here that a compacting temperature also influences the strength characteristic of the resulting pavement structure. It is therefore required that the minimum time is spent between the placement of the mix and the rolling operations.
5. Rolling and finishing The paving mix. The rolling is done with 8 to 10 tones tandem roller. The rolling is commenced from the edges of the pavement construction towards the centre, and uniform overlapping is provided. The finished surface should not show separate lines of markings due to defective or improper rolling. The roller wheels are kept damp, otherwise the paving mix may partly stick to the wheels and the finishing may not be good. A variation of 6mm over 3 m length is allowed in the cross profile. The number of undulations exceeding 10 should be less than 30 in 300 m length of pavement.

Construction Procedure for Bituminous Concrete

The bituminous concrete is the highest quality of construction in the group of black top surface. Being of high cost specifications, the bituminous mixes are properly designed to satisfy the design requirements of the stability and durabi1ity. The mixture contains dense grading of coarse aggregate, fine aggregate and mineral filler coated with bitumen binder.

The mix is prepared in a hot-mix plant. The thickness of the bituminous concrete layer depends upon the traffic and quality of base course. The specifications of materials and the construction steps for bituminous concrete or asphaltic concrete (AC) surface course are given below:

Specification of Materials:

a) Binder: Bitumen of grade 3 0/40,60/70 or 80/100 may be chosen depending Upon tic condition of the locality.
b) Aggregates and Filler: The coarse aggregates should fulfill the following requirements:

Aggregate impact value, maximum percent: 30
Loss Angeles abrasion value, max percent: 40
Flakiness index, max percent: 25
Stripping at 40°C after 24 hours, max percent: 25

Soundness:
Loss with sodium sulphate in 5 cycles, max. Percent: 12
Loss with magnesium sulphate in 5 cycles, max. Percent: 18

Design of joints Joints-

Joints are purposefully placed discontinuities in a rigid pavement surface course All types of joints are used in rigid pavement construction methods for all P`CC pavement types. CRCP uses longitudinal reinforcing steel in order to limit the number of transverse contraction joints, but it still uses longitudinal joints and periodic transverse joints.
Joints can be formed in two ways. Contraction joints are most often sawed in after PCC placement. Others such as expansion, isolation and construction joints, are created by formwork before the PCC is placed. Each one of these methods of joint construction has its own method and set of considerations.
Types

Isolation Joints-

An isolation joint is used to lessen compressive stresses that develop at T- and unsymmetrical intersections, ramps, bridges, building foundations, drainage inlets, manholes, and anywhere differential movement between the pavement and a structure (or another existing pavement) may take place (ACPA, 2001). They are typically filled with a joint filler material to prevent water and dirt infiltration.

Construction Joints-

A construction joint (see Figure 6) is a joint between slabs that results when concrete is placed at different times. This type of joint can be further broken down into transverse and longitudinal construction joints. Longitudinal construction joints also allow slab warping without appreciable separation or cracking of the slabs. Workers manually insert dowel bars into the construction joint at the end of the work day. Construction joints should be planned so that they coincide with contraction joint spacing to eliminate extra joints.

- Expansion joints

The purpose of the expansion joint is to allow the expansion of the pavement due to rise in temperature with respect to construction temperature. The design consideration are:

- Provided along the longitudinal direction,
- design involves finding the joint spacing for a given expansion joint thickness (say 2.5 cm specified by IRC) subjected to some maximum spacing (say 140 as per IRC)

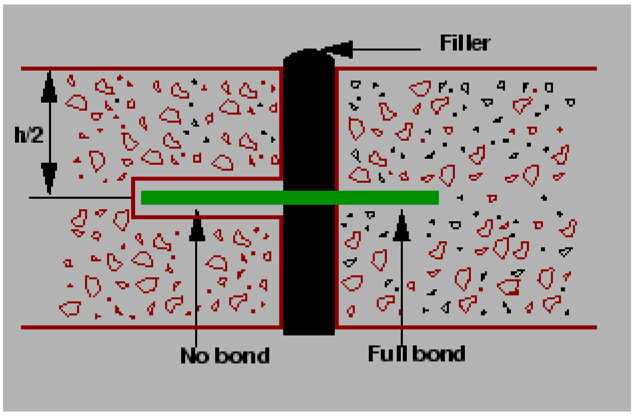


Figure2: Expansion joint

- Contraction joints

The purpose of the contraction joint is to allow the contraction of the slab due to fall in slab temperature below the construction temperature. The design considerations are:

- The movement is restricted by the sub-grade friction
- Design involves the length of the slab given by:

$$L_c = \frac{2 \times 10^4 S_c}{W.f}$$

- where, S_c is the allowable stress in tension in cement concrete and is taken as 0.8 kg/cm ^{2} , W is the unit weight of the concrete which can be taken as 2400 kg/cm ^{3} and f is the coefficient of sub-grade friction which can be taken as 1.5.
- Steel reinforcements can be use, however with a maximum spacing of 4.5 m as per IRC.

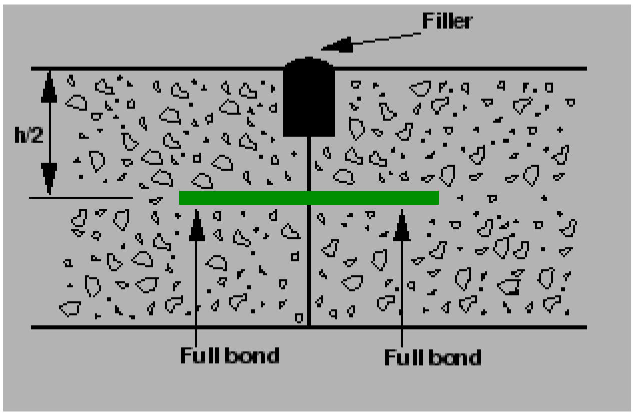


Figure3: Contraction joint

Dowel bars

The purpose of the dowel bar is to effectively transfer the load between two concrete slabs and to keep the two slabs in same height. The dowel bars are provided in the direction of the traffic (longitudinal). The design considerations are:

- **Mild steel rounded bars,**
- **bonded on one side and free on other side**

Bradbury's analysis

Bradbury's analysis gives load transfer capacity of single dowel bar in shear, bending and bearing as follows:

$$P_s = 0.785\ d^2\ F_s$$

$$P_f = \frac{2\ d^3\ F_f}{L_d + 8.8\delta}$$

$$P_b = \frac{F_b\ L_d^2\ d}{12.5\ (L_d + 1.5\delta)}$$

where, P is the load transfer capacity of a single dowel bar in shear s, bending f and bearing b , d is the diameter of the bar in cm, L_d is the length of the embedment of dowel bar in cm, δ is the joint width in cm, $F_s,\ Ff,\ F_b$ are the permissible stress in shear, bending and bearing for the dowel bar in kg/cm ^{2}.

Design procedure

Step Find the length of the dowel bar embedded in slab L_d by equating Eq.

=Eq. , i.e.

$$L_d = 5d\sqrt{\frac{F_f}{F_b}\frac{(L_d + 1.5\delta)}{(L_d + 8.8\delta)}}$$

Step Find the load transfer capacities P_s , P_f , and P_b of single dowel bar with the L_d

Step Assume load capacity of dowel bar is 40 percent wheel load, find the load capacity factor f as

$$\max\left\{\frac{0.4P}{P_s},\ \frac{0.4P}{P_f},\ \frac{0.4P}{P_b}\right\}$$

Step Spacing of the dowel bars.

- **Effective distance upto which effective load transfer take place is given by $1.8\ l$, where l is the radius of relative stiffness.**
- **Assume a linear variation of capacity factor of 1.0 under load to 0 at $1.8\ l$.**
- **Assume a dowel spacing and find the capacity factor of the above spacing.**
- **Actual capacity factor should be greater than the required capacity factor.**
- **If not, do one more iteration with new spacing.**

Difference between Flexible Pavements and Rigid Pavements:

	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.**

Typical layers of a flexible pavement

Typical layers of a conventional flexible pavement includes seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural sub-grade.

Seal Coat: Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance.

Tack Coat: Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water. It provides proper bonding between two layer of binder course and must be thin, uniformly cover the entire surface, and set very fast.

Prime Coat: Prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed. It provides bonding between two layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, and forms a water tight surface.

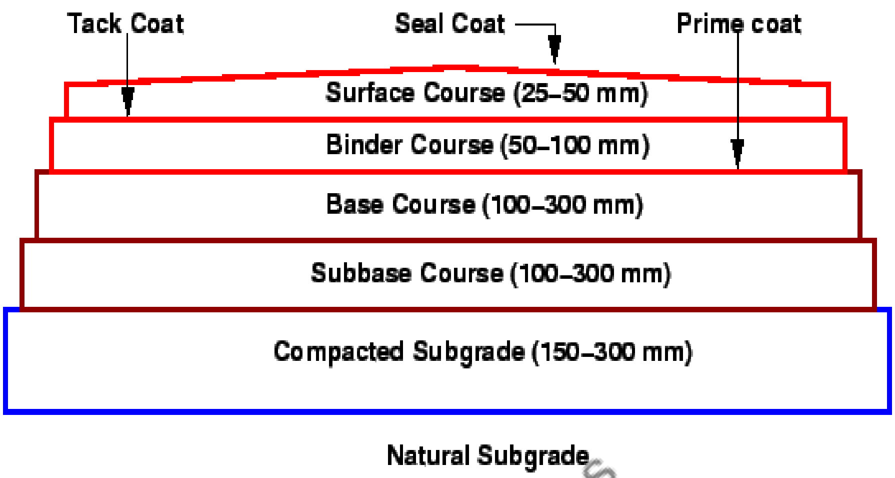


Fig4: cross section of road

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. It's 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.

Flexible pavements are so named because the total pavement structure deflects, or flexes, under loading. A flexible pavement structure is typically composed of several layers of materials. Each layer receives loads from the above layer, spreads them out, and passes on these loads to the next layer below. Thus the stresses will be reduced, which are maximum at the top layer and minimum on the top of subgrade. In order to take maximum advantage of this property, layers are usually arranged in the order of descending load bearing capacity with the highest load bearing capacity material (and most expensive) on the top and the lowest load bearing capacity material (and least expensive) on the bottom.

Unit III

Low Cost Roads, Drainage of Roads, Traffic Engineering & Transportation Planning:

Principles of stabilization, mechanical stabilization, requirements, advantages ,Dis-advantages and uses, quality control, macadam roads-types, specifications, construction, Maintenance and causes of failures. Surface and sub-surface drainage, highway materials: properties and testing etc. Channelized and un-channelized intersections, at grade & grade separated intersections, Description, rotary-design elements, advantages and disadvantages, marking, signs, Signals & street lighting. Principles of planning, inventories, trip generation, trip distribution, Model split, traffic assignment, plan preparation.

Introduction:

Low cost roads:- Surfacing is not always necessary to provide an adequate or "good-enough" road. Sometimes the soil already in place along the road line may be sufficiently strong to support small numbers of light vehicles in areas with modest rainfall (up to about 1,000mm/year). The soil must be shaped into a camber to shed rainwater to each side and then consolidated, as a minimum, with hand rammers. The passage of vehicles will also help. Compaction is always necessary to ensure its durability, and it must be maintained with regular reshaping or grading. Such a road is referred to as an 'Engineered Earth Road' or 'Engineered Natural Surface'. Soils with California Bearing Ratio (CBR) strength of about 15 or more can usually be used in this way. Strength may be gauged by using simple low cost apparatus such as the Dynamic Cone Penetrometer (DCP).

However, it is often necessary to stabilize or improve the in-situ soils mechanically, either with other selected soils/aggregates or with cement, bitumen or chemicals, or else construct a stronger pavement on top to support heavier vehicles or higher traffic flows. This will help spread vehicle loads so that they can be carried on the alignment soils without causing deformation.

There is also a range of surfacing or paving options that can be used. Natural gravel surfacing is generally used as the principal low cost solution in many developing countries. This material provides an intermediate surface between basic engineered earth and higher cost, often bituminous, paving. Gravel can be appropriate where suitable material is available and laid to strict surfacing specifications and procedures, gravel haul distances are short (usually less than 10 km), road gradients are less than about 6%, rainfall is low or moderate (less than 2,000mm/year), traffic is relatively low (usually less than about 100 motor vehicles/day), finance and resources are available for periodic regravelling, and dry season dust generation is not severe.

Unfortunately, these requirements are not met in many locations. Naturally occurring lateritic and other suitable gravels tend to be rare with good quality deposits often far from the roads. Transport can become very expensive. Furthermore, gradients can be steep on low volume roads to minimise overall construction costs. When rainfall is intense and concentrated within relatively short periods of the year as is frequently the case, the gravel surface will be quickly washed away. Dry season dust loss leads to the surface disintegrating, to be again washed away during the rainy season, particularly on steep sections. Maintenance of gravel roads is expensive, especially for periodic regravelling, typically required at three to five year intervals, Therefore gravel roads are rarely maintained systematically and many revert eventually to earth standard roads.

There are also environmental problems. Unrestored borrow pits, which fill with water, form loci for erosion and disease while the clouds of dust thrown up by motor vehicles during the dry season are a health and safety hazard, as well as affecting nearby crops and property. In many countries, gravel roads are meeting increasing resistance because of this.
Fortunately, there are alternative surfacing and paving options already tried in various countries that could provide appropriate, economical and sustainable alternatives. Suitability will depend on local circumstances. These alternatives, involving the appropriate use of available materials, may be cheaper in whole-life-cost terms (covering all construction and maintenance costs and vehicle operating cost savings). Many can be carried out by small local enterprises using labour-based methods and light equipment. They could have lower maintenance requirements than gravel, not only in terms of cost but also by reducing the need for heavy equipment to transport and compact, and the resulting damage to haul routes. The many considerations influencing the choice of surface are discussed in this page.

In summary, the window of opportunity for gravel surfaces in developing countries is being squeezed from below by low cost if fragile earth roads, and from above by the increasing awareness of low-cost surfacing alternatives. Gravel surfaces have proved to be relatively costly, taking account of their need for regular replenishment, their low durability, especially in many less-developed countries, and the rapidly declining level of service it provides to users as it deteriorates. As countries, especially in Asia, get richer, dust becomes more unpopular, to the point where communities finance street paving on their own even if the roads leading to their town remain unpaved. Alternative surfaces, many perfected years ago, can now be justified at lower traffic levels than hitherto thought. These include water-bound macadam, hand-laid stone, fired brick paving, simple concrete paving on steep slopes, and low-cost seals. These surfaces are more durable and allow year-round mobility to all types of vehicle.

In developing countries like India the biggest handicap to provide a complete network of road system is the limited finances available to build road by the conventional methods. Therefore there is a need to resort to one of the suitable methods of low cost road construction. The construction cost can be considerably decreased by selecting local materials including local soils for the construction of the lower layers of the pavement such as the sub-base course. If the stability of the local soil is not adequate for supporting wheel loads, the properties are improved by soil stabilization techniques. Thus the principle of soil stabilized road construction involves the effective utilization of local soils & other suitable stabilizining agents.

Highway drainage:
Highway drainage is the process of removing and controlling excess surface and sub-surface water within the right way. This includes interception and diversion of water from the road surface and sub-grade. The installation of suitable surface and sub-surface drainage system is an essential part of highway design and construction. During rain, part of the rain water flow on surface and part of it percolates through the soil mass as gravitational water until it reaches the ground water below the water table. Removal and diversion of surface water from the roadway and adjoining land is termed as surface drainage, while the removal of excess soil-water from the sub-grade is termed as sub-surface water,

some water is retained in the pores of the soil mass and drained off by the normal gravitational method and this water is termed as held water. Culvert of minimum diameter 75 cm and made of steel or prefabricated RCC is 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 steel bridges are commonly constructed these days. On less important roads, in order to reduce the construction cost of cross drainage structures, sometime submersible bridges or cause ways are constructed. During the floods the water will flow over the road. The total period interruption to traffic has however to be as low as possible, not exceeding about 15 days in a year.

SUB-SURFACE DRAIN

Change 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. In sub-surface drainage of highways, it is attempted to keep the variation of moisture in sub-grade soil to a minimum. However only the gravitational water is drained by the usual drainage systems.

LOWERING OF WATER TABLE

The highest level of water table should be fairly below the level of sub grade, in order that the sub grade and pavements layers are not subjected to excessive moisture. From practical considerations it is suggested that the water table should be kept at least 1.0 to 1.2 meter below the sub grade. In place where water table is high (almost at ground level at times) the best remedy is to take the road formation on embankment of height not less than 1.0 to 1.2 meter. When the formation is to be at or below the general ground level, it would be necessary to lower the water table.

If the soil is relatively permeable, it may be possible to lower the high water table merely construction of longitudinal drainage trenches with drain pipe and filter sand. The depth of the trench would on the required lowering of water table, distance between the drainage trenches and soil type. If the soil is relatively less permeable, the lowering of ground water level may not be adequate at the center of the pavement or in between the two longitudinal drainage trenches. Hence in addition, transverse drainage may have to provide in order to effectively drain off the water and thus lower the water table up to the level of transverse drains.

CONTROL OF SEEPAGE FLOW

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

CONTROL OF CAPILLARY RISE

If the water reaches 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 capillary cut-off of any one of the following two types:-

A layer of granular material of suitable thickness is provided during the construction of embankment, between the sub grade and the highest level of sub surface water table.
The thickness of the granular capillary cut-off layer should be sufficiently higher than the anticipated capillary rise with in the granular layer so that the capillary water cannot rise above the cutoff layer.

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

DESIGN OF SUBSURFACE DRAINAGE SYSTEM

The size of spacing of subsurface drainage system would depend on the quantity of water to be drained off, the type of soil and type drains. Mostly this is decided based on experience and other practical considerations. However, proper filter material should be used for back filling the drainage trenches and also for use in all subsurface drainage system.

DESIGN OF FILTER MATERIAL

The filter material used in subsurface drain should be designed to have sufficient permeability offering negligible resistance to the flow. The filter material should also be designed to resist the flowing of the fine foundation soil resulting in problem like piping. Hence the grain size distribution of filter material is decided based on these two criteria of permeability and piping. The procedure for design of filter is briefly discussed below:-

On a grain size distribution chart plot the grain size distribution curve for the foundation soil.

Find the value of D15 size of foundation material and plot a point of particle size 5D15 of foundation to represent the lower limit of D15 size of filter. This to fulfill the permeability condition given by:- (D15 of filter / D15 of foundation) should be > 5.

To fulfill the condition to prevent piping :- (D15 of filter / D85 of foundation) should be less than (<) 5, hence plot a point to represent the upper limits of D15 size of filter given by 5D85 of foundation.

Find the size of perforation in the drain pipe or the gap in the open joints pipes and let this be = Dp. Plot a point to represent D85 size of filter given by the size 2Dp.

DRAINAGE OF SLOPES AND EROSION CONTROL

Drainage of slopes and embankment, cutting and hill side are of utmost important to prevent instability of slopes and slides. Soaking of the slope causes stress and reduction in strength. Hence an efficient network of surface drainage system consisting of interception drains and sloping drains to keep the slopes properly drained is very useful for stability. The sloping drains may be provided with lining or pitching or may be filled with gravel. The water from the sloping drains is collected in the catch pits ant diverted across through the culverts at suitable intervals

Mechanics of Soil Stabilization:

The term soil stabilization means the improvement of the stability or bearing power of the soil by the use of controlled compaction, proportioning or the addition of suitable admixture or stabilizers. Soil stabilization deals with physical, physic-chemical & chemical methods to make the stabilized soil serve its purpose as pavement component material. The basic principles in soil stabilization are:

- **Evaluating the properties of given soil**
- **Deciding the economical method of stabilization**
- **Designing the stabilized soil mix**
- **Compacting the stabilized layers.**

Soil stabilization may result in any one or more of the following changes:

- **Increase in stability, change in properties like density or welling, change in physical characteristics.**
- **Change in chemical properties**
- **Retaining and desired minimum strength by water proofing.**

Soil stabilization Methods:

- **Mechanical soil stabilization**
- **Soil cement stabilization**
- **Soil lime stabilization**
- **Soil bitumen stabilization**

Mechanical Soil stabilization:

Correctly proportioned materials (Aggregate & Soil) when adequately compacted to get a mechanically stable layer, the method is called Mechanical Soil Stabilization. The two basic principles in this method are:

- **Proportioning**
- **Compaction**

If a granular soil containing negligible fines is mixed with a certain proportion of binder soil, it is possible to increase the stability. Similarly the stability of a fine grained soil could be considerably improved by mixing a suitable proportion of granular materials to get a suitable gradation.

Mechanical stabilization has been successfully applied for sub-base & base course constructions. It has also been used as surface course for low cost roads such as village roads when the traffic & rainfall are low.

Factors affecting Mechanical stability:

- **Mechanical strength of aggregates**
- **Gradation**
- **Properties of soil**
- **Presence of salts, mica etc.**
- **Compaction**

Mix design in Mechanical Stabilization:

The factors to be considered in the design of mix are gradation, density, index properties & stability.

Gradation: The particle size distribution that gives maximum density is generally aimed at. The theoretical gradation for maximum dry density is generally

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

Where, p= percent finer than diameter'd' (mm) in the material

D= diameter of largest particle (mm)

n= gradation index

Proportioning: When a few materials are available in the near vicinity, it is necessary to mix then in such a proportion which would produce mix with highest density. For example, coarse aggregates, sand & fine soils are available from three deposits, it is first essential to decide the best proportion of these component materials. Two graphical methods are in common use for proportioning are the triangular chart method & Rothfutch's method.

Density: Standard dry density is obtained in the laboratory compaction test.

Index properties: Following are recommended values of liquid limit & plasticity index for the material passing 0.425mm sieve

	Base course	Surface course
Liquid limit	25% maximum	35% maximum
Plasticity Index	6% maximum	5 to 10%

Stability: CBR test is commonly adopted for stability.

Construction procedure:

Materials: The constructions materials are collected from the selected borrow pits & are stacked along the sides of the road in the desired proportion

Equipment: Machinery or manual labor may be used for excavation & haulage. For compaction- rollers of suitable type & weight are used.

Construction steps:

The sub-grade is prepared

Materials are mixed to the desired proportions as per design

The existing moisture content is checked by a rapid method & additional water required is spread & the material is re-mixed

The wet mix is spread to the desired grade & compacted by the rollers. Rolling is started from edges & with adequate longitudinal over-lap; it is continued up to center.

Field control test: two field test are necessary:

Determination of moisture content of the mix before compaction

Determination of density during & just after compaction

Stabilized road is opened to traffic after the compacted layer hardness by drying.

Soil Cement Stabilization:

Soil cement is an intimate mix of soil, cement & water which is well compacted to form a strong base course.

In granular soil, the mechanism of stabilization is due to the development of bond between the hydrated cement & the compacted soil particles at the points of contact.

In fine grained soil, the stabilization is due to reduction in plasticity & formation of matrix enclosing small clay lumps.

Degree of stabilization depends on nature of soil, proportion of cement, compacting moisture cement & the dry density of the compacted mix.

Soil cement can be used as a sub-base or base course of all types of pavements.

Factor influencing the properties of soil cement:

- Soil
- Cement
- Pulverizing & Mixing
- Compaction
- Curing
- Additives

Soil: Physical properties of soil like particle size distribution, clay content, specific surface, liquid limit & plasticity index affects the properties of soil cement

Cement: An increase in cement content generally causes increase in strength & durability. Both normal & air entraining cement give almost the same results of stabilization.

Pulverizing & Mixing: Better the pulverization &degree of mixing, higher is the strength. Presence of un-pulverized dry lumps of soil reduces strength & durability of soil-cement.

Compaction: There is optimum moisture content corresponding to maximum value of dry density or strength of a soil-cement mix

Curing: During curing adequate moisture is to be retained. Higher temperature of curing accelerates the rate of gain in strength; the strength also increases with age.

Additives: Various activities to soil-cement which improves the properties, Lime are a useful additive when clayey soil or an organic soil is to be stabilized. Sodium hydroxide, sodium carbonate & calcium chloride are some of the useful chemical additives to soil-cement.

Constructions of soil cement Base Course:

Materials:

The soils to be stabilized, either from site or near-by borrow pits are collected and pulverized. From practical consideration, the following properties are recommended for the soils to be selected:

Passing 4.75mm sieve	>50%
Passing 0.075mm sieve	<50%
Liquid limit	<40%
Plasticity index	<18%

Plants & equipments:

There are two methods of construction:

- Mix-in-place method
- Plant mix method

Construction steps for Mix-in-place method:

- Preparation of sub-grade or sub-base

Pulverization of soil
Application of cement & dry mixing
Addition or spraying water & remixing
Spreading & grading
Compaction
Curing the soil-cement layer
Joint with old work
Field control tests

In plant-mix method, large mixing plants are used which can batch the materials (soil, cement & water) mix them & deliver for spreading. Compacting equipments are also needed.

Soil-Lime Stabilization:

Soil-lime has been widely used either as a modifier for clayey soil or as a binder.

When clayey soils with high plasticity are treated with lime, the plasticity index is decreased and the soil becomes friable & easy to be pulverized, having less affinity with water.

Lime also imparts some binding action even in granular soils. In fine grained soils there can also be pozzolonic action resulting in added strength.

When clay is treated with lime, the various possible reactions are Base Exchange, coagulation or flocculation, reduction in thickness of water film around clay particles, cementing action & carbonation.

The fine clay particles react with lime & get flocculated or aggregated into larger particle groups which are fairly stable even under subsequent soaking.

The maximum dry density of soil-lime mix is decreased by 2-3 % in terms of untreated soil however this decrease in dry density with the addition of small proportion of lime does not cause reduction in strength.

Soil-lime is quite suitable as sub-base course for high types of pavement & base course for pavements with low traffic.

Factors affecting soil-lime stabilization:

Soil type
Lime content
Types of lime
Compaction
Curing
Additives

Stabilization of soil using Bituminous Materials:

The basic principles in bituminous stabilization are water proofing & binding.

By water proofing the inherent strength & other properties of soil could be retained. In case of cohesion-less soils, binding action is also important.

In granular soil the coarser grains may be individually coated & stuck together by a thin film of bituminous materials.

But in fine grained soils the bituminous material plugs up the voids between small soil clods, thus water proofing the compacted soil-bitumen.

Most commonly used materials are cutback bitumen & emulsion.

After the soil-bitumen is compacted, the layer is cured during which the water & volatiles evaporate & the mix hardens.

Factors affecting the properties of soil-bitumen:

- Soil
- Types of bituminous material
- Amount of bitumen
- Mixing
- Compaction
- Curing
- Additives

Traffic islands:

Traffic islands are raised areas constructed within the roadway to establish physical channels through which the vehicular the vehicular traffic may be guided. Traffic island may be classified based on the function as:

- Divisional islands
- Channelizing islands
- Pedestrian loading islands
- Rotary

Divisional islands are intended to separate opposing flow of traffic on a highway with four or more lanes. By thus dividing the highway into two one way roadways, the head-on collisions are eliminated and in general other accidents are also reduced.

Channelizing islands are used to guide the traffic into proper channel through the intersection area. Channelizing islands are very useful as traffic control devices for intersection at grade, particularly when the area is large. The size & shape of the channelizing islands will very much depend upon the layout and dimensions of the intersections. The various uses of properly designed channelizing islands are listed below:

- The area possible conflicts between traffic stream is reduced.
- They established the desired angles of crossing & merging of traffic streams.
- They are useful when the traffic of the flow is to be changed.
- They serve as convenient locations for other traffic control devices.

Pedestrian loading islands are provided at regular bus stops & similar places for the protection of passengers. For crossing multi lane highways, pedestrian refuge island after two or three lanes would be desirable.

Rotary Island is the large central island of a rotary intersection; this island is much larger than the central island of channelized intersection.

Design of intersection: At the intersection there are through, turning & crossing traffic and these traffic movements may be handled in different ways depending on the type of intersection and its design.

Intersection at grade: These include all roads which meet at more or less the same level. The traffic maneuvers like merging, diverging & crossing are involved in the intersections at the grade.

Grade separated intersection: The intersecting roads are separated by difference in level, thus eliminating the crossing maneuvers.

Un-channelized intersections:

The intersection area is paved & there is absolutely no restriction to vehicles to use any part of intersection area.

Hence the un-channelized intersections are the lowest class of intersection, easiest in the 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 no additional pavement width for turning movement Is provided, it is called plain intersection.

But when the pavement is widened at the intersection area, by a traffic lane or more, it is known as flared intersection.

Channelized intersections:

Channelized intersection is achieved by introducing islands into the intersectional area, thus reducing the total conflict area available in the un-channelized intersection.

The radius of the entrance & exit curves and the area are suitably designed to accommodate the channelizing islands of proper size & shape.

These islands help to channelized turning traffic, to control their speed & angle of approach and to decrease the conflict area at the intersection.

The advantages of the channelized intersections are:

By canalization vehicles can be confined to definite paths.

Angle of merging streams can be forced to be at flat angles so as to cause minimum disruption.

Angle between intersecting streams of traffic may be kept as desired in a favorable way.

Speed control can be established over vehicles entering the intersections.

Point of conflicts can be separated.

Rotary intersection: Rotary:-

Rotary intersections or round abouts 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 in orderly fashion. They then weave out of the rotary to the desired direction. The benefits, design principles, capacity of rotary etc.

Advantages and disadvantages of rotary

The key advantages of a rotary intersection are listed below:

1. Traffic flow is regulated to only one direction of movement, thus eliminating severe conflicts between crossing movements.

2. 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.

3. Because of lower speed of negotiation and elimination of severe conflicts, accidents and their severity are much less in rotaries.

4. Rotaries are self-governing and do not need practically any control by police or traffic signals.

5. They are ideally suited for moderate traffic, especially with irregular geometry, or intersections with more than three or four approaches.

Although rotaries offer some distinct advantages, there are few specific limitations for rotaries which are listed below.

1. All the vehicles are forced to slow down and negotiate the intersection. Therefore, the cumulative delay will be much higher than channelized intersection.
2. Even when there is relatively low traffic, the vehicles are forced to reduce their speed.
3. Rotaries require large area of relatively flat land making them costly at urban areas.
4. The vehicles do not usually stop at a rotary. They accelerate and exit the rotary at relatively high speed. Therefore, they are not suitable when there is high pedestrian movements.

Guidelines for the selection of rotaries

Because of the above limitation, rotaries are not suitable for every location. There are few guidelines that help in deciding the suitability of a rotary. They are listed below. 1. Rotaries are suitable when the traffic entering from all the four approaches are relatively equal. 2. A total volume of about 3000 vehicles per hour can be considered as the upper limiting case and a volume of 500 vehicles per hour is the lower limit. 3. A rotary is very beneficial when the proportion of the right-turn traffic is very high; typically if it is more than 30 percent. 4. Rotaries are suitable when there are more than four approaches or if there is no separate lanes available for right-turn traffic. Rotaries are ideally suited if the intersection geometry is complex.

Traffic operations in a rotary

As noted earlier, the traffic operations at a rotary are three; diverging, merging and weaving. All the other conflicts are converted into these three less severe conflicts.

1. Diverging: It is a traffic operation when the vehicles moving in one direction is separated into different streams according to their destinations.
2. Merging: Merging is the opposite of diverging. Merging is referred to as the process of joining the traffic coming from different approaches and going to a common destination into a single stream.
3. Weaving: Weaving is the combined movement of both merging and diverging movements in the same direction.

Design elements The design elements include design speed, radius at entry, exit and the central island, weaving length and width, entry and exit widths. In addition the capacity of the rotary can also be determined by using some empirical formula.

Design speed:- All the vehicles are required to reduce their speed at a rotary. Therefore, the design speed of a rotary will be much lower than the roads leading to it. Although it is possible to design roundabout without much speed reduction, the geometry may lead to very large size incurring huge cost of construction. The normal practice is to keep the design speed as 30 and 40 kmph for urban and rural areas respectively.

Entry, exit and island radius:- The radius at the entry depends on various factors like design speed, super-elevation, and coefficient of friction. The entry to the rotary is not straight, but a small curvature is introduced. This will force the driver to reduce the speed. The entry radius of about 20 and 25 metres is ideal for an urban and rural design respectively. The exit radius should be higher than the entry radius and the radius of the rotary island so that the vehicles will discharge from the rotary at a higher rate. A general practice is to keep the exit radius as 1.5 to 2 times the entry radius. However, if pedestrian movement is higher at the exit approach, then the exit radius could be set as same as that of the entry radius. The radius of the central island is governed by the design speed, and the radius of the entry curve. The radius of the central island, in practice, is given a slightly higher radius so that the movement of the traffic already in the rotary will have priority. The radius of the central island which is about 1.3 times that of the entry curve is adequate for all practical purposes.

Weaving operation in a rotary

Width of the rotary The entry width and exit width of the rotary is governed by the traffic entering and leaving the intersection and the width of the approaching road. The width of the carriageway at entry and exit will be lower than the width of the carriageway at the approaches to enable reduction of speed. IRC suggests that a two lane road of 7 m width should be kept as 7 m for urban roads and 6.5 m for rural roads. Further, a three lane road of 10.5 m is to be reduced to 7 m and 7.5 m respectively for urban and rural roads. The width of the weaving section should be higher than the width at entry and exit. Normally this will be one lane more than the average entry and exit width. Thus weaving width is given as, w

weaving = e1 + e2 2 + 3.5m

where e_1 is the width of the carriageway at the entry and e_2 is the carriageway width at exit.

Weaving length determines how smoothly the traffic can merge and diverge. It is decided based on many factors such as weaving width, proportion of weaving traffic to the non-weaving traffic etc. This can be best achieved by making the ratio of weaving length to the weaving width very high. A ratio of 4 is the minimum value suggested by IRC. Very large weaving length is also dangerous, as it may encourage over-speeding.

Capacity The capacity of rotary is determined by the capacity of each weaving section. Transportation road research lab (TRL) proposed the following empirical formula to find the capacity of the weaving section. Qw = 280w[1 + e w][1 − p 3] 1 + w l

where e is the average entry and exit width, i.e, (e1+e2) 2 , w is the weaving width, l is the length of weaving, and p is the proportion of weaving traffic to the non-weaving traffic. types of movements at a weaving section, a and d are the non-weaving traffic and b and c are the weaving traffic. Therefore, p = b + c a + b + c + d

This capacity formula is valid only if the following conditions are satisfied.

Weaving width at the rotary is in between 6 and 18 metres.

Traffic approaching the rotary 2. The ratio of average width of the carriage way at entry and exit to the weaving width is in the range of 0.4 to 1. 3.

The ratio of weaving width to weaving length of the roundabout is in between 0.12 and 0.4. 4.

The proportion of weaving traffic to non-weaving traffic in the rotary is in the range of 0.4 and 1. 5.

The weaving length available at the intersection is in between 18 and 90 m.

Fig 1 Rotary intersection

Highway lightening:

The rate of highway accidents & fatalities that occur during night driving is several times higher in terms of vehicle-kilometer, than that during day driving. One of the various causes of increased accident rate during night may be attributed to poor night visibility. Highway lighting is particularly more important at intersections, bridge site, level crossings & in places where is restriction of traffic to movements. On urban roads where the density of population is also high, road lighting has other advantages like feeling of security & protection.

During night driving the manner in which the objects are visible varies with both the absolute level of brightness and the relative brightness of the road surface and the object. A light colored, rough textured pavement surface can reflect back is considered more desirable. When the pavement surface is very dark like black top surface, the objects which are relatively brighter in color are seen by this process.

Thus the various factors that influence night visibility are:

- Amount & distribution of light flux from the lamps
- Size of object
- Brightness of object
- Brightness of background
- Reflecting characteristics of the pavement surface
- Glare on the eyes of the driver
- Time available to see an object

Design factors of Highway lighting:

- Lamps
- Luminaries distribution of light
- Spacing of lighting units
- Height & over-hang of mounting
- Lateral placement
- Lighting layouts

Lamps: The choice of the lamp, its type, size & color depends upon several considerations in addition to distribution of light flux on the pavement surface. The various types of lamps in use for highway lighting are filament, fluorescent & sodium or mercury vapor lamps. The cheapest among these is the filament lamp.

Luminaire distribution of light: To have the best utility or source of light, it is necessary to have proper distribution of light. The distribution should be downward so that high percentage of lamp light is utilized for illuminating the pavement and adjacent area. The distribution from the Luminaire should cover the pavement between the kerbs & provide adequate lighting on adjacent area i.e 3m to 5m beyond the pavement edge.

Spacing of lighting units: It is often influenced by the electrical distribution poles, property lines, road layout & type of side features & their illumination. Large lamps with high mountings & wide spacing’s should be preferred from economy point of view.

Height & over-hang of mounting: The distribution of light, shadow & the glare effect from street lamps depends also on the mounting height. The glare on eyes from the mounted lights increases with the power of the lamp directed towards the eye & decreases with increase in height of mounting. Usual mounting heights range from 6m to 10m.

Traffic & Transportation planning:

Traffic planning:

The problem of traffic accidents & congestion in urban roads is being viewed with grave concern in the recent years. The main causes for this problem are improper planning of road network & other road way facilities and poor traffic planning. Hence traffic functions now occupy a good position in corporation & municipalities. In municipal organizations a fully-fledged traffic engineering unit can be entrusted to look after public safety. Such a traffic engineering unit may have several divisions such as:

- Field studies
- Accident analysis
- Traffic control devices
- Design & planning
- Special investigations
- Economic analysis & decision theory in engineering design and
- Administration

Urban transportation planning process:

The transportation planning process is developed in a series of stages:

- Inventories
- Trip generation
- Trip distribution
- Model split
- Traffic assignment
- Plan preparation and evaluation

Inventories: information related to land use, economic activity, population; travel characteristics and transportation facilities are collected through a series of surveys. For this purpose the metro Politian area under study is sub-divided into number of smaller zones:

- Zones should be homogeneous in land use
- Zones should be homogeneous traffic generating characteristics
- Zones should conform to enumeration districts, natural and physical barriers.
- Zones should not be large enough to produce errors resulting from the assumption that all activities occur at zonal centroid.
- Zones should preferably have geometrical shape for easy determination of centroid.

Trip Generation: This is the first stage of the travel demand forecasting process. Trip generation concerns with the estimation of number of trips produced In or attracted to a given zone. The trip is defined as "One-way movement having single purpose & mode of travel between a point of origin & a point of destination". Two popular methods of trip generation estimation are:

- Multiple regression analysis
- Category analysis

Trip distribution: It is the stage where the trips generated and attracted from ach zone are distributed to any other zone. The most important method for this procedure is the gravity model. This method is based on the principle that the trips between any two zones say I & j are directly proportional to the number of trips generated in the zone I, the number of trips attracted to zone j and are inversely proportional to some function of distance or separation between the zones. The model is as follows:

$T_{ij} = G_i \ A_j F_{ij} / \sum A_i F_{ij}$

Here,

T_{ij}= number of trips from zone I to j

G_i = trips generated in zone i

A_j = trips attracted to zone j

F_{ij} = empirically derived 'friction factor' calculated on area wise basis

n = number of zones in the urban area

Grade intersection:-

Grade separation is a method of aligning a junction of two or more surface transport axes at different heights (grades) so that they will not disrupt the traffic flow on other transit routes when they cross each other. The composition of such transport axes does not have to be uniform; it can consist of a mixture of roads, footpaths, railways, canals, or airport runways. Bridges (or overpasses or flyovers), tunnels (or underpasses), or a combination of both can be built at a junction to achieve the needed grade separation.

Advantages

Roads with grade separation generally allow traffic to move freely, with fewer interruptions, and at higher overall speeds; this is why speed limits are typically higher for grade-separated roads. In addition, less trouble between traffic movements reduces the risk of accidents.

Disadvantages

Grade-separated road junctions are typically space-intensive, complicated, and costly, due to the need for large physical structures such as tunnels, ramps, and bridges.

Their height can be obtrusive, and this combined with the large traffic volumes that grade-separated roads attract, tend to make them unpopular to nearby landowners and residents. For these reasons, proposals for new grade-separated roads can receive significant public opposition.

Rail-over-rail grade separations take up less space than road grade separations: because shoulders are not needed, there are generally fewer branches and side road connections to accommodate (because a partial grade separation will accomplish more improvement than for a road), and because at-grade railway connections often take up significant space on their own. However, they require significant engineering effort, and are very expensive and time-consuming to construct.

Grade-separated pedestrian and cycling routes often require modest space since they do not typically intersect with the facility (such as a highway) that they cross.

Grade-separation can create accessibility problems for people with disabilities due to the vertical gradient required to pass or to reach rail platforms.

Grade-separated roads that permit for higher speed limits can actually reduce safety due to 'weaving' (see below) as well as a perceived sense of safety.

The term is most widely applied to describe a road junction in which the direct flow of traffic on one or more of the roads is not disrupted. Instead of a direct connection, traffic must use on and off ramps or slip roads to access the other roads at the junction. The road which carries on through the junction can also be referred to as grade separated.

Typically, large freeways, highways, motorways, or dual carriageways are chosen to be grade separated, through their entire length or for part of it. Grade separation drastically increases the capacity of a road compared to an identical road with at-grade junctions. For instance, it is extremely uncommon to find an at-grade junction on a British motorway; it is all but impossible on a U.S. Interstate Highway, though a few do exist.

If traffic can traverse the junction from any direction without being forced to come to a halt, then the junction is described as fully grade separated or free-flowing.

Fully separated

Stack interchange (two-level, three-level, or four-level stack, depending on how many levels cross at the central point)

Cloverleaf interchange

4. Partially separated

5. Diamond interchange

6. Partial cloverleaf interchange

7. Single-point urban interchange

8. Roundabout interchange

9. Compact grade-separation,

Whereby the two roads are linked by a compact "connector road", with major-minor priority junctions at each of its ends; usually a variant of the cloverleaf type interchange, but only involving two quadrants rather than four

Unit IV

Airport planning, Runway & Taxiway: Airport site selection, aircraft characteristics and their effects on runway alignments, wind-rose diagrams, basic runway length and corrections, classification airports. Geometrical elements: Taxiways & Runways, pattern of runway capacity.

Introduction:

The primary modes by which transportation takes place are:

- **On land**
- **Through water**
- **Through air**

Transportation on land primary consists of movement by road & on rail. Transportation through water mainly consists of movement using ships, which requires docks & harbors or ports. Transportation through air consist is effected by using different types of aircraft such as airplanes & helicopters.

Airport engineering is associated with the engineering aspects of air transport. An airport is defined as a place where aircraft can takeoff & land for operating commercial services.

Characteristics of Air transport:

The positive attributes of air transport are:

- **Rapidity or high speeds**
- **Continuous travel for long distances**
- **Accessibility- even to remote locations, which are normally inaccessible by other modes of transport.**

The dis-advantages are:

- **Need for high skill & sophisticated equipment for ensuring safety in operation.**
- **Difficulty in operating under un-favorable weather conditions.**
- **Prohibitive cost of flying.**

Development of National Organizations for Civil Aviation:

The following is the sequence of development of national organizations for controlling civil aviation in India:

- **International Airport authority of India (IAAI)**
- **Civil aviation development & National Airport Authority (NAA)**
- **Airport Authority of India (AAI)**
- **Open sky policy**

Components of Airports & their functions:

- **Terminal area**
- **Landing area**

Terminal Area: this is the focal point of an airport, with several elements, each of which has its own functions. They are:

Apron: paved area parking of the aircraft for passengers to emplane & deplane & for cargo to be loaded & unloaded.

Terminal building: This building houses all facilities for the passengers, operational staff & control towers.

Motor vehicle parking & circulation area: this is meant to provide the facility of parking for the motor vehicles by which passengers arrive at end & depart from the airport.

Hangars: These are large sheds which house aircraft for servicing, fuelling & repairs. Machine shops & spare parts are necessary adjuncts for hangers.

Landing Area: This is very critical for operation of an aircraft. Landing as well as takeoff operations are performed in this area with the aid of runways & taxiways. This area includes the approach zone & clear zone & is governed by zoning laws & restrictions.

Aircraft characteristics & their influence on Airport planning & Design:

- **Type of propulsion**
- **Size of aircraft**
- **Aircraft weight & wheel configuration**
- **Tyre pressure & wheel configuration**
- **Speed of aircraft**
- **Minimum circling radius**
- **Minimum turning radius**
- **Takeoff & landing distances**
- **Range of aircraft**
- **Noise of Aircraft**
- **Fuel spilling & Jet blast**
- **Aircraft capacity**

Type of propulsion: reciprocating engine running with gasoline as fuel & a shaft connected to a propeller or a turbo jet or turbo propulsion- governs the size, weight-carrying capacity, speed, circling radius & noise created by airplane.

Size of aircraft: length of fuselage, height, wingspan, tail width, gear treads & wheel base are the important constituents that determines the size of the aircraft.

Weight of aircraft & wheel configuration: It plays an important role in deciding the runway design, range of aircraft, fuel requirements & so on.

Minimum circling radius this is the radius of the imaginary circle in space which should be free of any obstruction if the aircraft has to take a smooth & safe turn when required. It depends upon the type of aircraft & weather conditions.

Minimum turning radius: This governs the design of taxiways & helps to ascertain the positioning of aircraft on the aprons & in the hangars.

Take off & landing distances: these will govern the minimum length of runway required. These distances depend on the altitude of the airport, wind speed & direction, gradient of the runway, weight of aircraft at takeoff & landing & temperature.

Range of Aircraft: the maximum distance that an aircraft can fly without refueling is called the range, this is inversely related to pay load.

Noise of Aircraft: this is also crucial to minimize noise pollution. The noise level during takeoff is more severe than that during landing.

Aircraft capacity: this refers to the number of passengers (along with baggage & cargo) that can be accommodated.

Civil & Military aircraft: Military aircraft includes fighter planes during emergencies & wars. They are designed to travel at supersonic speeds & for heavier payloads.

Classification of Airports:

In general it is classified as:

- Military airports: these are meant to operate military aircraft for emergencies & natural calamities at time of peace & for defence purposes during war time.
- Civil or Commercial aircrafts: these are meant for civil aviation for ferrying passengers & cargo/mail, both within the country & abroad.

ICAO Classification of Airports:

The most popular classification of airports is given by the ICAO, following are the two criteria

A. Code letter A to E are used to indicate the basic length of the runway, width of runway & the maximum longitudinal gradient (%) as given below:

B.

Table 1:- Basic length of Runway length

Code letter	Basic length of runway (m)		Width of runway (m)	Max. 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
E	749	600	18	2

C. **The numbers 1 to 7 are used to indicate the isolated wheel load & tyre pressure, as shown below:**

Table 2 Wheel load and Code of Airport

Code number	Isolated wheel load (kg)	Tyre pressure (kg.cm)
1	45000	8.5
2	34000	7
3	27000	7
4	20000	7
5	13000	6
6	7000	5
7	2000	2.5

Airport Planning:

- **Justification of the need for the airport**
- **Formulation of the layout plan based on the assessed requirements**
- **Integration of the planning with regional needs & national needs**

Steps in airport planning:

- **Estimation of traffic potential**
- **Site selection**
- **Layout plan**
- **Design of various components**
- **Preparation of working drawings**
- **Cost estimation**
- **Proposals for financing & institutional arrangements**

- Environmental impact assessment.

Master plan: A master plan may be made for the development of airport in the entire country on the basis of needs as well as priorities, bearing in mind national interests.

Regional planning: This aims at the formation of an effective network of airports in a zone or region & ultimately in a country, in such a way that the planning of an individual airport smoothly merges into the regional plan of other airports & the regional plan, in turn, merges into the national plan.

Improvement of an existing airport: It is essential to consider making improvements to an existing airport to cater to the needs of increased air traffic before deciding to construct an entirely new facility. For this, an appropriate traffic forecast for a reasonable design period say 20 years, is the first step.
Next, the capacity of the existing airport should be assessed in respect of the facilities such as aprons, hangars, baggage & cargo handling facilities & so on.

Site selection for an Airport:
It is an important element in airport planning. Factor affecting the site selection for an airport are:

- Atmospheric & climatic conditions
- Topography
- Location of other airports in the vicinity
- Accessibility
- Availability of land for future needs
- Availability of utility services
- Land use pattern of the surrounding area
- Regional plan
- Soil characteristics
- Obstructions surrounding the site
- Economy of construction
- Purpose of the airport

Atmospheric & climatic conditions: Visibility is affected by fog, haze & smoke, which hamper flight operations & impair its capacity.

Topography: Topographical features like ground contours, streams, trees & vegetation should be studied with the aid of topo-sheets for the area. A raised ground with good drainage & good visibility will be an ideal site.

Location of other airports in the vicinity: According to the recommendations of the ICAO, a certain minimum distances is necessary between adjacent airports to prevent obstructions in the operation of the aircraft.

Accessibility: It is an important criterion, not only for airline users, but also for the other section of the public. Proper accessibility reduces the overall travel time & hence it is an attractive feature for selecting an airport site.

Availability of land for future needs: This is necessary for future expansion needs.

Availability of utility services: Utility services like water supply, electricity & telephones are essential for an airport.
Regional plan: The site should fit appropriately into the overall regional plan & ultimately into the national plan of development.

Soil characteristics: Good pervious soil is desirable for effective drainage; a soil with good bearing capacity is desirable for construction of buildings & runways.

Deign of runway:

Runway design is concerned with planning the pattern and configuration of runways at an airport; it further includes the geometric elements of runways and their design. The number of runways at an airport depends on the volume of air traffic expected to use the facility. Orientation of a runway is its direction along its length and its positioning with respect to the direction of the wind prevailing at the airport site.

Geometrics of Runway:

- Length
- Width
- Longitudinal gradient
- Rate of change of gradient
- Transverse gradient
- Sight distance
- Runway shoulders
- Safety area

Orientation of a Runway:
The orientation of a runway is its direction at an airport; this is an important aspect in runway design & is primarily dependent on the wind characteristics at the airport site.

Head Wind: A runway is usually oriented in the direction of the prevailing winds; head wind means wind against & direction of the head or nose of the aircraft, while it is landing or taking off. The advantages of head wind are:

- Braking effect during landing helps the aircraft to come to a stop in a relatively short length of the runway.

- **Greater lift on aircraft wings during takeoff makes the aircraft to rise above the ground using relatively the shorter length of the runway.**

Cross wind components: it is not possible to obtain the head wind along the centre line of the runway on all the days of the year, thus for some period of the year, the wind blows at a certain angle with respect to the center line of the runway.
In such a case, while a component parallel to the center line of the runway is helpful in the operations, the component perpendicular to it, which is called the cross-wind component, is considered to be undesirable beyond a certain limit, this is because it can affect the safety of landing & takeoff of light & medium-weight aircraft. In general, cross-wind component should not exceed 25km/hour.

Wind coverage: This is defined as the percentage of time in a year during which the cross wind component is within the stipulated permissible limit.
For the purpose of calculating the wind coverage in any particular direction, a deviation up to +/- 11.25˚ is considered permissible.

Calm period: this is the period, expressed as percentage in a year, during which velocity is less than a stipulated minimum. This value is considered to be velocity of 6km/hour, which will have negligible effect.

Wind Rose: The average wind data of a design period (5 to 10 years) are represented in a graphical form by means of a chart, known as wind-rose. (it is so called because the plotted chart appears in the form of rose petals)

Wind rose diagrams may be plotted in two different ways:

- **Type-I shows the direction & duration of the wind in percent in a year**
- **Type-II shows the direction, percent duration in a year & wind velocity or intensity.**

Type-I Wind Rose:
A typical set of wind data (an average of say 5 years) for a site of an airport is given below
:

Table3: Wind forecast

Wind direction	Duration of wind (%)			Total in each direction (%)
	6-25km/hour	25-50km/hour	50-75km/hour	
N	7.2	2.8	0.2	10.2
NNE	5.4	2.4	0.2	8
NE	2.7	0.7	0.6	4
ENE	1.2	0.5	0.1	1.8
E	0.7	0.3	0	1

ESE	**0.4**	**0.2**	**0**	**0.6**
SE	**4.2**	**2.8**	**0.2**	**7.2**
SSE	**5.6**	**3.6**	**0**	**9.2**
S	**9.6**	**4.8**	**0**	**14.4**
SSW	**6.3**	**3.6**	**0.6**	**10.5**
SW	**3.6**	**1.9**	**0.5**	**6**
WSW	**1.2**	**0.6**	**0.2**	**2**
W	**0.5**	**0.1**	**0**	**0.6**
WNW	**0.3**	**0.1**	**0**	**0.4**
NW	**5.4**	**2**	**0**	**7.4**
NNW	**5**	**1.4**	**0.3**	**6.7**
			Total:	**90**

Type I Wind Rose

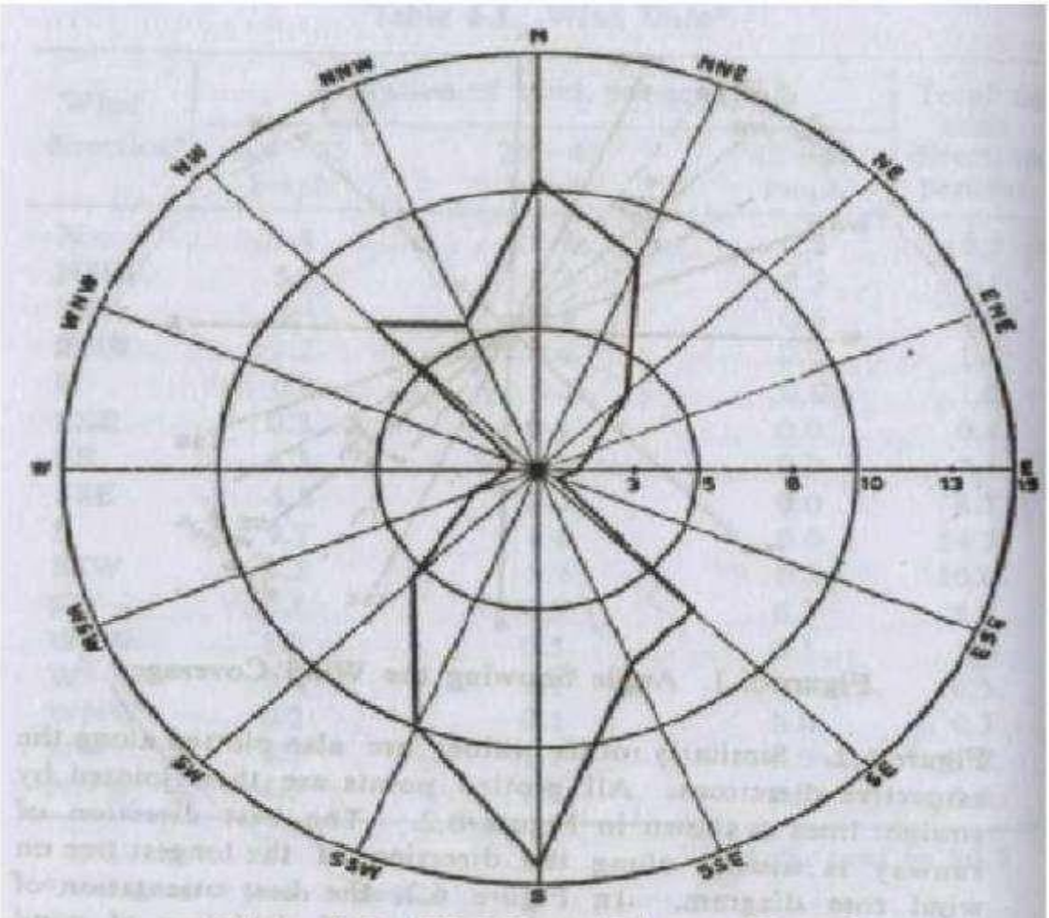


Figure 6.2 Wind Rose Diagram Type I

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 which the wind blows from north direction is X percent. This value is plotted along the north direction.
- Similarly other values are also plotted along the respective directions,
- All plotted points are then jointed by straight lines as shown in Figure.
- 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.

Figure1: Wind rose diagram: Type I

Type-II Wind- Rose:

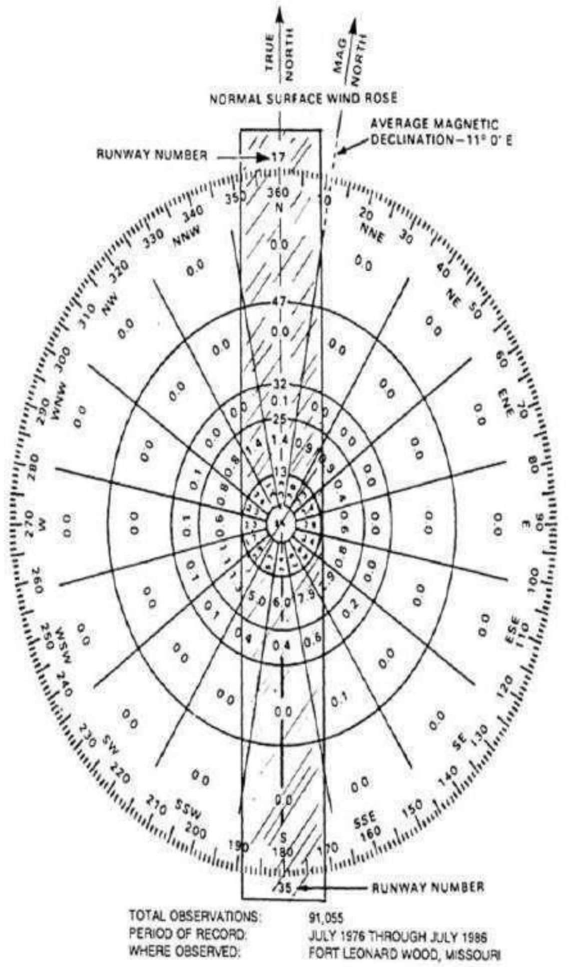


Figure 11-10. Determination of runway alignment by wind-rose analysis

Figure 2:-Wind-rose diagram- Type II

For the same data, type-II wind-rose is obtained as follows:

- **Concentric circles corresponding to 6, 25, 50 & 75km/hour of wind velocity are drawn to a convenient scale.**
- **The 16 radial directions are shown on the outermost circle as shown**
- **The respective wind durations for each direction are marked in the corresponding sector or part of it.**

The following manner to obtain the best orientation of the runway for these conditions:

- **A transparent paper template, rectangular in shape, is taken such that its length is a little more than the diameter of the outer most circles. The center line parallel to the length is drawn to represent the runway.**
- **Two more parallel lines are drawn to this line such that they are at a distance of 25km/hour on either side of the centerline, to the same scale used on the wind rose.**
- **This template is placed on the wind rose such that their centers coincide**
- **The template is now turned & orientated in such a way that the sum of all the values of wind duration between the two outer parallel lines is the maximum value.**

- The center of the template in this orientation is the best orientation of the runway
- The wind coverage percentage is obtained by summing up the percentages marked in the segments encompassed by the template.

Length of runway:
The length of runway has to be carefully determined for safe & efficient landing & takeoff of the various aircraft expected to use the airport.

Basic runway length: The length of the runway under standard prevalent conditions is known as the basic runway length. These conditions are:

- The airport is situated at sea-level
- The temperature at the airport is the standard value of 15˚C.
- The temperature along the way to the destination is also the standard value.
- The runway is level along its longitudinal direction
- No wind blows on the runway
- No wind blows even on the way to the destination
- The aircraft is loaded to its full capacity

The basic length of the runway is determined based on the performance characteristics of the aircraft during landing & takeoff. The following three cases are considered:

- Normal landing
- Normal takeoff
- Engine failure or emergency.

Correction in basic runway length

1. Correction for elevation:

As per the recommendation of ICAO (International Civil Aviation Organization), the basic runway length should be increased at the rate of 7 per center 300 m rise in elevation of airport above the mean sea level. This correction is required because the air density reduces as the elevation increases which in turn reduces the lift on the wings of the aircraft. Thus, the aircraft will require more ground speed to rise to the air and for achieving more speed; the longer length of runway will be required.

2. Correction for temperature:

The rise in airport reference temperature has the same effect as that of the increase in its elevation above mean sea-level. After the basic length is corrected for the elevation of airport, it is further increased at the rate of1% for every 1°C rise in airport reference temperature above the standard atmospheric temperature at that elevation.
Where T
1 = monthly mean of the average daily temperature for the hottest month of the year
2= monthly mean of the maximum daily temperature for the same month.
The standard temperature at the airport site can be determined by reducing the standard mean sea-level temperature of 15 0C at rate of 6.5°C per thousand meter rise in elevation.

Note:

The ICAO recommends that if the total correction for elevation plus temperature exceeds 35% of the basic runway length, the
Specific studies at the site by model tests should be carried out.

Correction for gradient:

The maximum difference in elevation between the highest and the lowest points of runway divided by the total length of runway is known as the
Effective gradient:

According to FAA (Federal Aviation Administration) of U.S.A., the runway length after being corrected for elevation and temperature should further be increased at the rate of 20% for every 1% of the effective gradient.

Taxiway design:-

Taxiway A taxiway is a path for aircraft at an airport connecting runways with aprons hangars terminals and other facilities.

Geometric Design Standards

a. Length of taxiway
b. Width of safety area
c. Longitudinal gradient
d. Transverse gradient
e. Rate of change of longitudinal gradient
f. Sight distance
g. Turning Width of taxiway
h. Radius

Length of Taxiway

- It should be as short as practicable.
- No specifications are recommended by any organization.

Width of taxiway

- Width of taxiway is lower than the runway width.
- The speed of an aircraft on a taxiway is also less than the runway.

Width of safety area

- This area includes taxiway pavement on either side that may be partially paved plus the area that is graded and drained.
- A width of 7.5 m of shoulders adjacent to the pavement edges should be paved with light strength material.

Longitudinal Gradient

- ICAO recommends that the longitudinal gradient should not exceed 1.5% for A and B types and 3% for C D and E types.

Transverse Gradient

- **This is essential for quick drainage of water.**
- **ICAO has recommended that the transverse gradient should not exceed 1.5% for A,B and C and C types and 2% for D and E types of airports. Rate of change of longitudinal gradient**
- **ICAO recommends that the rate of change of slope in longitudinal direction should not exceed 1% per 30 m length of vertical curve for A,B and C types and 1.2% for D and E types of airports.**

Sight distance

- **ICAO has recommended that the surface of taxiway must be visible from 3m height for a distance of 300m for A,B and C types and distance of 250 m be visible for 2.1m height for D and E types of airports. Turning radius**
- **Whenever there is a change in the direction of taxiway a horizontal curve is provided .**
- **The radius of horizontal curve is obtained by : R=V^2/125f V =speed in kmph coefficient of friction f =.13**

Horonjeff equation

R=.388w^2/T/2-S

- **W=wheel base of taxiway in meter**
- **T=width of taxiway pavement in meter S=distance between midway point of main gears and the edge of the taxiway pavement in meter for**
- **supersonic planes it is taken as 180m and for sub sonic it is taken as 120m.**

Unit V

Airport, Obstructions, Lightning & Traffic control: Zoning regulations, approach area, approach surface-imaginary, conical and horizontal. Rotating beacon, boundary lights, approach lights, runway and taxiway lighting etc. Instrumental landing system, precision approach radar & VOR en-route traffic control.

These airport obstructions basically are those obstructions which are provided on the sites of the airports which are related to the type of the development which has taken place on the sites of the airport and are related mostly with not only with the nature of the development but also with the height of that development.

Airport obstructions are divided into following categories:

- Imaginary surfaces
- Objects with actual heights

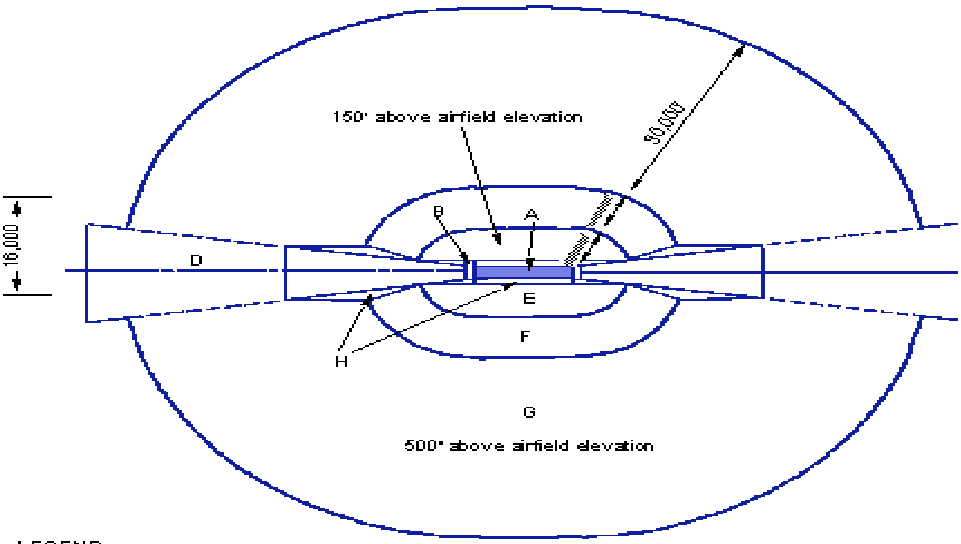
In imaginary surfaces where we assume that there can be any surface which may come up to this level and therefore we have just marked some surfaces on any airport by which the aircrafts should move above of that particular surface only and if it is coming below of that surface then it may be hazardous whereas the other cases with the actual conditions where the type of the development is going in the vertical direction then what is the height of that development and what can be the height in the light of the operation of the aircrafts on any airport.
In the case of imaginary surfaces again there are different types of surfaces which we will be looking at and these imaginary surfaces are basically established surfaces in relation to airport and to each runway above which no obstruction should project and for each and every runway on which the aircraft is going to land or from where it is going to take off with respect to that one then we start looking at some of the imaginary locations in space which are assumed to be surfaces and the aircraft follows those surfaces so that there is no obstruction projecting within that much area of navigation and this size of imaginary surface depends upon the category of each runway and the type of approach planned for that runway. So these are the factors basically the creating an effect on what type of imaginary surface of what magnitude of that imaginary surface is to be provided or assumed or any of the runway strips on any airport

Airport obstructions:

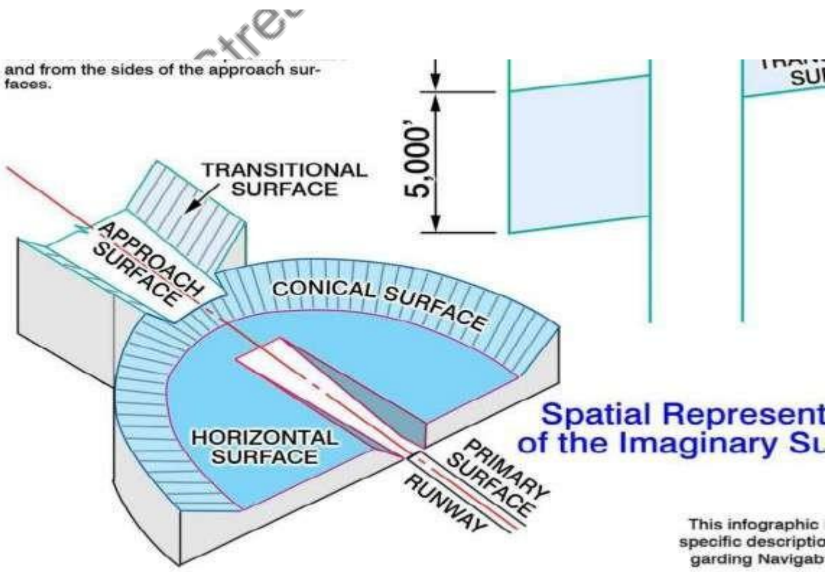
- Approach surface
- Conical surface
- Horizontal surface
- Take off climb surface
- Transitional surface

Approach surface:

- **Provided at the end of the landing side of runway**
- **Trapezoidal in shape**
- **Diverging away with upgrade**
- **Longitudinally centered o the extended center line of runway**



LEGEND:
A Primary surface
B Clear-zone surface
C Approach/departure-clearance surface (glide angle)
D Approach/departure-clearance surface (horizontal)
E Inner horizontal surface
F Conical surface
G Outer horizontal surface
H Transitional surface



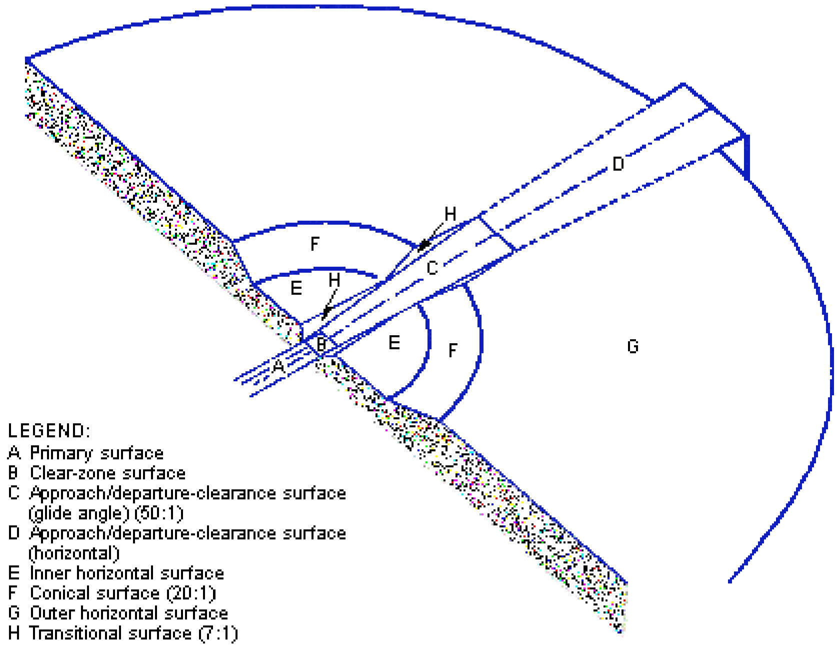


Figure1 : Imaginary surfaces

Take off climb surface:

- **Similar to approach surface**
- **Provided at the take off end of runway**
- **Trapezoidal in shape**

Table 1: Different Runway length, Divergence of side, Length of longitudinal Projection

	A	B	C	D	E
WIDTH NEAR END OF RUNWAY (m)	180	180	180	80	60
DIVERGENCE OF SIDES	12.5%	12.5%	12.5%	10%	10%
LENGTH OF LONGITUDINAL PROJECTION (m)	15000	15000	15000	2500	1600
Longitudinal upgrade	2%	2%	2%	4%	5%

Horizontal surface:

- **Extends from upper edge of transition surface and ends at lower or inner circular edge of conical surface**
- **The height of outer horizontal surface extends from 150m (above the ARP elevation) to 9900m (for airports with length of runway between 900m & 1500m) or to 15000m (for airports having runway length more than 1500m) above elevation of airport reference point.**
- **The shape of horizontal imaginary surface may or may not be circular**

- **The radius of outer limit measured from the ARP**
- **Not provided for the airports having runway length less than 900m**

Transition surface:

- **Trapezoidal in shape**
- **Extends along the landing strip**
- **Slopes upward & outward to the inner horizontal surface**

Conical surface:

- **Extends upward & outward inner horizontal surface to a point which is at some height above the horizontal surface.**
- **Circular in shape**

Table 2: Standard data for design

Runway code	Side slope transitional surface	% of conical surface	Height of outer or upper circular edge of the conical surface above HS (m)	Radius of inner circular edge conical surface with ARP (m)
A	14.3	5	100	4000
B	14.3	5	100	4000
C	14.3	5	75	4000
D	20	5	55	2500
E	20	5	35	2000

Objects with actual heights:

- **Any object which exceeds certain limiting height above the ground is considered to be an obstruction to the air navigation.**
- **An object within 4.5km distance from the runway end is considered is considered as the obstruction if its actual height is more than 30m above the ground or above the level of approach end of runway whichever is higher.**
- **Any object which is located beyond a distance of 4.5km from the runway end is considered as an obstruction if its height is above 30m increases by more than 7.5m for each additional of 1.5km distance from the runway.**
- **When we reach 15km from runway end it should not exceed 75m**
- **Any object which projects above the minimum approach flight altitude or whose height exceeds 150m above the ground is also to be considered as obstruction.**

Airport lighting:

FACTORS AFFECTING AIRPORTLIGHTING:

- **Airport classification**
- **Amount of traffic**
- **Availability of power**
- **Nature of aircraft using the airport**
- **Type of night operation plans**
- **Type of landing surfaces provided**
- **Weather condition**

To achieve uniformity and to guide pilots for unfamiliar airports, colours and general arrangement of airport lights are standardized. Airport lights are kept clean, well-maintained, checked regularly for faulty bulbs and replacement. Tough and laborious job, major airport contains 30,000 lights. Provision of emergency power supplies, which can take over in seconds in case of any power failure.

ELEMENTS OF AIRPORT LIGHTING:

- **Airport beacon**
- **Approach lighting**
- **Apron**
- **Hangar lighting**
- **Boundary lighting**
- **Lighting of landing direction indicator**
- **Lighting of wind direction indicator**
- **Runway lighting**
- **Taxiway lighting**
- **Threshold lighting**

AIRPORT BEACON: Beacon- strong beam of light- used to indicate any geographical location- situated slightly above the horizontal- rotated to produce flashing light to an observer. It gives out white and green flashes in the horizontal directions 180° **apart. Flashes are visible for the pilot from any direction of approach and it indicates the approximate situation of an airport equipped for the night operations. Rotates at six revolutions per minute- mounted at top of terminal building or hangar. Obstruction not cleared yet- then separate tower is provided for installation of rotating beacon.**

APPROACH LIGHTING: Before runway begins- sequence of high-intensity lighting arrangement for a length of 900m. Helps pilots to check if the aircraft is centered correctly or not and gives way to touch down zone lights from threshold of the runway. Normally mounted on pedestals-varying heights-to accommodate any irregularities in ground- ensuring the lights themselves are in level. Arrangements adopted for approach lightings:

- **Calvert system**

- **ICAO system**

APRON AND HANGAR LIGHTING: These areas for are flood lit for the convenience in servicing and loading. Flood-lighting system: constitutes a projector designed to be arranged to illuminate a surface. Mounted such a way that they do not cause a glare in the eyes of the pilots, passengers and service personnel. Recommendation: flood lights should be placed at a height of not less than 12m above the pavement.

BOUNDARY LIGHTING: Entire boundary of the airfield is provided with lights at a c/c distance of about 90m with height of about 75cm from the ground. If fence is provided along the boundary, then these lights should be placed inside the fence at a distance of about 3m. For indicating hazardous approach, the boundary lights are provided with red marker lights.

LIGHTING OF LANDING DIRECTION INDICATOR: The landing direction indicator is illuminated with suitable lighting arrangement so that the airport can be used at night also.

LIGHTING OF WIND DIRECTION INDICATOR: The wind direction indicator is illuminated by four 200 watts angle reflectors placed 1.8m above the top of the cone for providing a continuous lighting at any position of the cone. This arrangement grants the use of wind direction indicator at night and during bad weathers.

RUNWAY LIGHTING: After crossing the threshold, the pilot must complete a touchdown and roll out on the runway. The planning of runway lighting is carried out in such a way that the pilot gets enough information on alignment, lateral displacement, roll and distance. The lights are so arranged so that they form a visual pattern which the pilot can interpret easily. During night landings, flood lights were used in olden days. But now runway edge lights are adopted. Narrow gauge pattern- the most precise runway alignment which is widely used. It makes use of centre-line and touchdown zone lights for operations in very poor visibility.

Black hole effect: As the pilot crosses the threshold, and continues to look along the centre-line, the principal source of guidance, namely, the edge lights has moved far to each side in the peripheral vision. As a result, the central area appears black and the pilot is virtually flying blind for the peripheral reference information. This can be eliminated by adopting the narrow gauge pattern of the runway lighting, the central portion gets illuminated and the black hole effect is partly eliminated. The narrow gauge pattern forms a channel of light of 18m width up to 1140m from the threshold and beyond this distance, the closely spaced lights are placed along the centre-line of the runway extending up to the other end of the runway. All the lights provided on the runway are white in color and of flush type, i.e. they do not protrude more than 1cm above the surface of pavement. The runway edge lights are of elevated type and they are white color except for the last 400m if an instrument runway facing the pilot which are of yellow color to indicate a caution zone.

TAXIWAY LIGHTING: The pilots have to man oeuvre the aircrafts on a system of taxiways to and from the terminal and hangar areas either after landing or on the way to take off. The taxiway system is much complicated on large airports and therefore it is necessary to provide adequate lighting at night and at daytime when the visibility is very poor.
Design considerations to be applied to the visual aids for the taxiways:

- For normal exits- centerline terminated at the edge of the runway
- At taxiway intersections, the lights continue across the intersection. They are placed at a distance of 6m to 7.5m along the straight length and 3m to 3.6m along the curves
- The complete route from the runway to the apron should be easily identified.
- The edge lights should not extend more than 75cm above the pavement surface.
- The exits from the runways should be so lighted that the pilots are able to locate the exits 360m to 400m ahead of the point of turn
- The intersection of taxiways and runways-taxiway crossings should be clearly marked.
- The lights on the tangent portion are placed not more than 60m apart and the distance from the edge along the curves and the intersections to facilitate easy identification. The spacing varies from 6m for curve of radius 4.5m to 60m for a curve of 300m.
- There should be adequate guidance along the taxiway
- The taxiway edge lights are blue and the taxiway centre lights are green.
- The taxiway should be clearly identified so that they are not confused with the runways.

THRESHOLD LIGHTING: Identification of threshold- a major factor for decision of the pilot to land or not to land. For this reason, the region near the threshold is given with special lighting treatment. At large airports: threshold is identified by a complete line of green lights extending across the entire width of the runway. They must be of semi-flash type, i.e. protruding not more than 12cm above the surface.
At small airports, the threshold is identified by four lights on each side of the threshold. They can be of elevated type, i.e. protruding more than 12cm above the surface. The threshold lights in the direction if landing are green and in the opposite direction, they are red to indicate the end of the runway.

INSTRUMENT LANDING SYSTEM (ILS): Radio beam transmitter that provides a direction for approaching aircraft that tune their receiver to the ILS frequency.
The Uses of ILS:
• To guide the pilot during the approach and landing. –Very helpful when visibility is limited
• To provide an aircraft with a precision final approach.
• To provide an aircraft guidance to the runway both in the horizontal and vertical planes.

ILS Components: ILS consists of Ground Installations and Airborne Equipments. There are 3 equipments for Ground Installations, which are:
1. Ground Localizer (LLZ) Antenna – To provide horizontal navigation
2. Ground Glide path (GP) Antenna – To provide vertical navigation
3. Marker Beacons – To enable the pilot cross check the aircraft's height.

There are 2 equipments for Airborne Equipments, which are:
1. LLZ and GP antennas located on the aircraft nose.
2. ILS indicator inside the cockpit

Localizer: Localizer is the horizontal antenna array located at the opposite end of the runway. Localizer operates in VHF band between 108 to 111.975 MHz. Transmit two signals which overlap at the centre. The left side has a 90 Hz & right has a 150 Hz modulation. The overlap area provides the on-track signal. Right Left How Localizer Works. Localizer Needle indicates direction of runway. Centered Needle = Correct Alignment.

Glide Path Antenna Array

• Glide Path is the vertical antenna located on one side of the runway about 300 m to the end of runway.
• Glide Path operates in UHF band between 329.15 and 335 MHz. Glide path produces two signals in the vertical plane. The upper has a 90 Hz modulation and the bottom has a 150 Hz modulation.

Marker Beacons: Marker beacons operating at a carrier frequency of 75 MHz are provided. When the transmission from a marker beacon is received it activates an indicator on the pilot's instrument panel. The correct height the aircraft should be at when the signal is received in an aircraft.

Types of Runway Approach 1.Non-Instrument Runway (NI) – A runway intended for the operation of aircraft using visual approach procedure 2. Instrument Runway – A runway intended for the operation of aircraft using instrument approach procedures a) Non-Precision Runway (NP)
• An instrument runway served by visual aids and a non-visual aid providing at least lateral guidance adequate for a straight-in approach b) Precision Runway (P)
• Allow operations with a decision height and visibility

How ILS works:

Ground localizer antenna transmit VHF signal in direction opposite of runway to horizontally guide aircraft to the runway centre line.
• Ground Glide Path antenna transmit UHF signal in vertical direction to vertically guide aircraft to the touchdown point.
• Localizer and Glide Path antenna located at aircraft nose receives both signals and sends it to ILS indicator in the cockpit.
• These signals activate the vertical and horizontal needles inside the ILS indicator to tell the pilot either go left/right or go up/down.
• By keeping both needles centered, the pilot can guide his aircraft down to end of landing runway aligned with the runway center line and aiming the touchdown.

taxiway lighting and markings

The most important rule to remember is that any sign that has white letters on red is mandatory. Usually they mark points that must not be passed without permission from air traffic control.

Taxiways should have centerline markings and runway holding position markings whenever they intersect a runway. Taxiway edge markings are present whenever there is a need to separate the taxiway from a pavement that is not intended for aircraft use or to delineate the edge of the taxiway. Taxiways may also have shoulder markings and holding position markings for Instrument Landing System/Microwave Landing System (ILS/MLS) critical areas, and taxiway/taxiway intersection markings. The taxiway centerline is a single continuous yellow line, 6 inches (15 cm) to 12 inches (30 cm) in width. This provides a visual cue to permit taxiing along a designated path. Ideally the aircraft should be kept centred over this line during taxi to ensure wing-tip clearance.

Taxiway Edge Markings. Taxiway edge markings are used to define the edge of the taxiway. They are primarily used when the taxiway edge does not correspond with the edge of the pavement. There are two types of markings depending upon whether the aircraft is suppose to cross the taxiway edge:

1. Continuous Markings. These consist of a continuous double yellow line, with each line being at least 6 inches (15 cm) in width spaced 6 inches (15 cm) apart. They are used to define the taxiway edge from the shoulder or some other abutting paved surface not intended for use by aircraft.

2. Dashed Markings. These markings are used when there is an operational need to define the edge of a taxiway or taxi-lane on a paved surface where the adjoining pavement to the taxiway edge is intended for use by aircraft. e.g. an apron. Dashed taxiway edge markings consist of a broken double yellow line, with each line being at least 6 inches (15 cm) in width, spaced 6 inches (15 cm) apart (edge to edge). These lines are 15 feet (4.5 m) in length with 25 foot (7.5 m) gaps.

Taxi Shoulder Markings. Taxiways, holding bays, and aprons are sometimes provided with paved shoulders to prevent blast and water erosion. Although shoulders may have the appearance of full strength pavement they are not intended for use by aircraft, and may be unable to support an aircraft. Usually the taxiway edge marking will define this area. Where conditions exist such as islands or taxiway curves that may cause confusion as to which side of the edge stripe is for use by aircraft, taxiway shoulder markings may be used to indicate the pavement is unusable. Taxiway shoulder markings are yellow.

Surface Painted Taxiway Direction Signs. Surface painted taxiway direction signs have a yellow background with a black inscription, and are provided when it is not possible to provide taxiway direction signs at intersections, or when necessary to supplement such signs. These markings are located adjacent to the centerline with signs indicating turns to the left being on the left side of the taxiway centerline and signs indicating turns to the right being on the right side of the centerline.

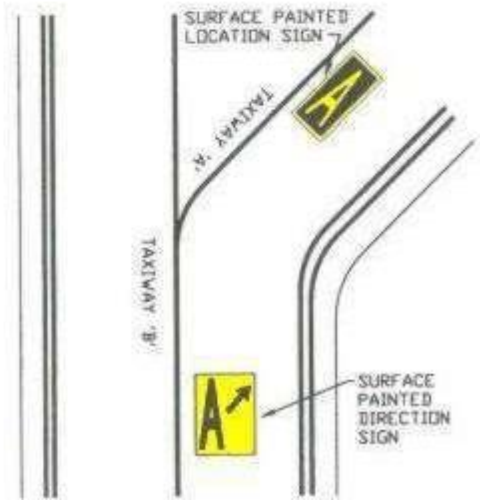


Fig2:-Surface Painted Taxiway Direction Signs

Surface Painted Location Signs: Surface painted location signs have a black background with a yellow inscription. When necessary, these markings are used to supplement location signs located along side the taxiway and assist the pilot in confirming the designation of the taxiway on which the aircraft is located. These markings are located on the right side of the centerline.

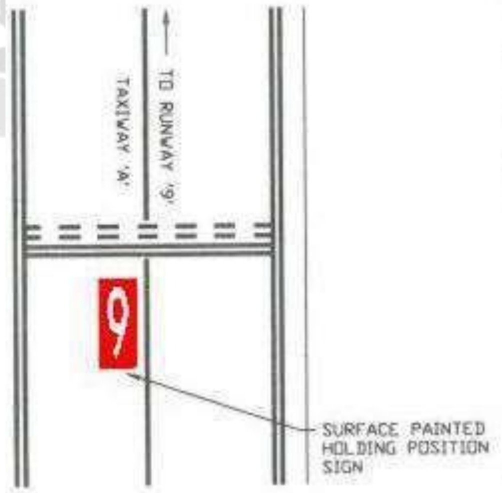


Fig:3-Surface Painted Location Signs

Geographic Position Markings: These markings are located at points along low visibility taxi routes designated in the airport's Surface Movement Guidance Control System (SMGCS) plan. They are used to identify the location of taxiing aircraft during low visibility operations. Low visibility operations are those that occur when the runway visible range (RVR) is below 1200 feet (360m). They are positioned to the left of the taxiway centerline in the direction of taxiing. The geographic position marking is a circle comprised of an outer black ring contiguous to a white ring with a pink circle in the middle. When installed on asphalt or other dark-colored pavements, the white ring and the black ring are reversed, i.e., the white ring becomes the outer ring and the black ring becomes the inner ring. It is designated with either a number or a number and letter. The number corresponds to the consecutive position of the marking on the route.

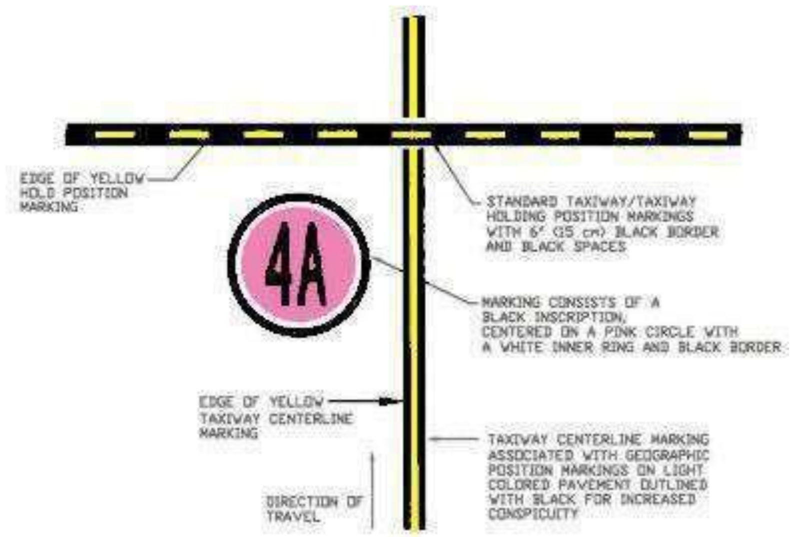


Fig4:-Geographic Position Markings

Holding Position Markings

Runway Holding Position Markings. For runways these markings indicate where an aircraft is supposed to stop. They consist of four yellow lines two solid, and two dashed, spaced six or twelve inches apart and extending across the width of the taxiway or runway. The solid lines are always on the side where the aircraft is to hold. There are three locations where runway holding position markings are encountered.

Runway Holding Position Markings on Taxiways: These markings identify the locations on a taxiway where an aircraft is supposed to stop when it does not have clearance to proceed onto the runway. When instructed by ATC "Hold short of (runway "xx")" the pilot should stop so no part of the aircraft extends beyond the holding position marking. When approaching the holding position marking, a pilot should not cross the marking without ATC clearance at a controlled airport or without making sure of adequate separation from other aircraft at uncontrolled airports. An aircraft exiting a runway is not clear of the runway until all parts of the aircraft have crossed the applicable holding position marking.

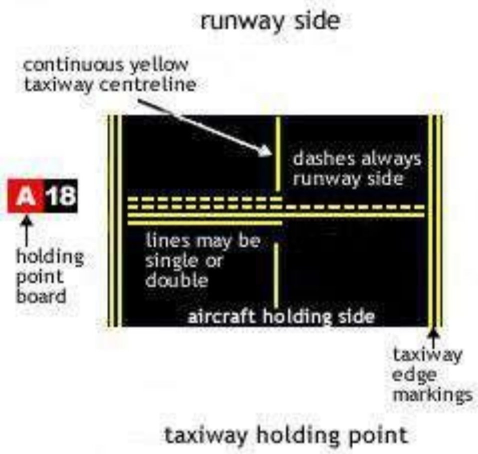


Fig5:- Taxi way holding point

Runway Holding Position Markings on Runways: These markings are installed on runways only if the runway is normally used by air traffic control for "land, hold short" operations or taxiing operations and have operational significance only for those two types of operations. A sign with a white inscription on a

red background is installed adjacent to these holding position markings. (See figure 5) The holding position markings are placed on runways prior to the intersection with another runway, or some designated point. Pilots receiving instructions "cleared to land, runway "xx"" from air traffic control are authorized to use the entire landing length of the runway and should disregard any holding position markings located on the runway. Pilots receiving and accepting instructions "cleared to land runway "xx," hold short of runway "yy"" from air traffic control must either exit runway "xx," or stop at the holding position prior to runway "yy."

Taxiways Located in Runway Approach Areas. These markings are used at some airports where it is necessary to hold an aircraft on a taxiway located in the approach or departure area of a runway so that the aircraft does not interfere with the operations on that runway. This marking is collocated with the runway approach area holding position sign.

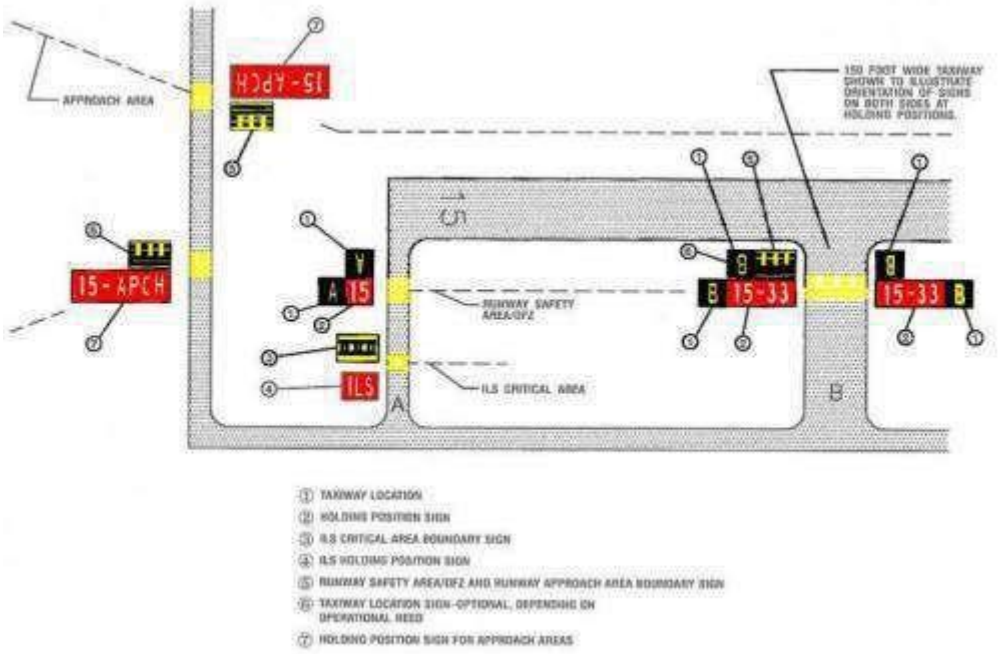


Fig6:-Taxiways Located in Runway Approach Areas

Holding Position Markings for Instrument Landing System (ILS): Holding position markings for ILS/MLS critical areas consist of two yellow solid lines spaced two feet apart connected by pairs of solid lines spaced ten feet apart extending across the width of the taxiway as shown. A sign with an inscription in white on a red background is installed adjacent to these hold position markings. When the ILS critical area is being protected, the pilot should stop so no part of the aircraft extends beyond the holding position marking. When approaching the holding position marking, a pilot should not cross the marking without ATC clearance. ILS critical area is not clear until all parts of the aircraft have crossed the applicable holding position marking.

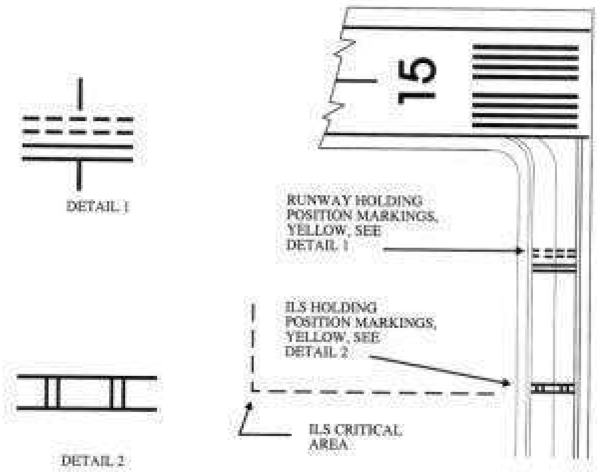


Fig7:- Holding parking marking