UNIT IV
AIRPORT PLANNING AND DESIGN

AIRFIELD : It is an area where an aircraft can land and take off, which may or may not be equipped with any navigational aids or markings. Many grass strips are also designated as airfields.

AERODROMES A defined area on land or water (including any buildings, installations and equipment) intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft.

Airport Master Plan: An Airport Master Plan is a study used to determine the long-term development plans for an airport. Because air transportation is a vital community industry, it is important that the requirements for new or improved airports be anticipated. The master planning process considers the needs and demands of airport tenants, users, and the general public. The guiding principle of the airport master planning process is the development of a safe and efficient airport. It must also be responsive to area-wide comprehensive transportation planning.

The draft plan includes the following elements:

- Background and Inventory of Facilities
- Aviation Activity Forecasts
- Airfield Design
- Building and Development
- Finance and Implementations

Objectives given by FAA:

- To provide and effective graphical map representation of ultimate development of the airport
- To establish a schedule of various phases for various important improvements in proposed plant
- To present the relevant backup information and data which is essential to the development of master plan.
- To describe the various concepts and alternatives which are considered in the establishment of proposed plan.

Recommendation for airport master plan :

The FAA recommended four different phases to develop airport master plan.

Phase I: AIRPORT REQUIREMENTS: the first phase is essential and examination of these scale and timing of new facilities with respect to expect demand and the status of existing facilities in the context of expected environment suggestions.

PHASE II: SITE SELECTION: for the construction of new airports or the major expansion of existing facilities has been established by evaluation of the surrounding site, environment impact, development, access and availability of utilities, land cost, site development cost and political aspects.

PHASE III: AIRPORT PLANS : the proposed facilities is represented by the following points.

Airport layout plan: it indicates the configuration location and the size of all physical facilities.

Land use plan: the details of land used within the proposed airport boundary and the land use of areas outside the boundaries that are affected by the sitting airport.

Terminal area plan: it shows the size and location of the various buildings and activities within the terminal area.

Airport axis plan: it shows the proposed routing for the various axis modes to the transportation information of that particulate region.

PHASE IV: FINAL PLAN: the final phase involves collection of the data in the four principle areas of financial importance.

Schedules of proposed development: it indicates the short term, intermediate and long term planning's of development for time-time with the demands and estimations.

Estimation of development cost : to plan the schedule and conform the development stages.

Economy feasibility analysis: it examines whether the expected revenue generation will be covered the expected cost.

Financial feasibility analysis : it undertake to determine whether the scale of facilities considered can be finalized by authority involved.

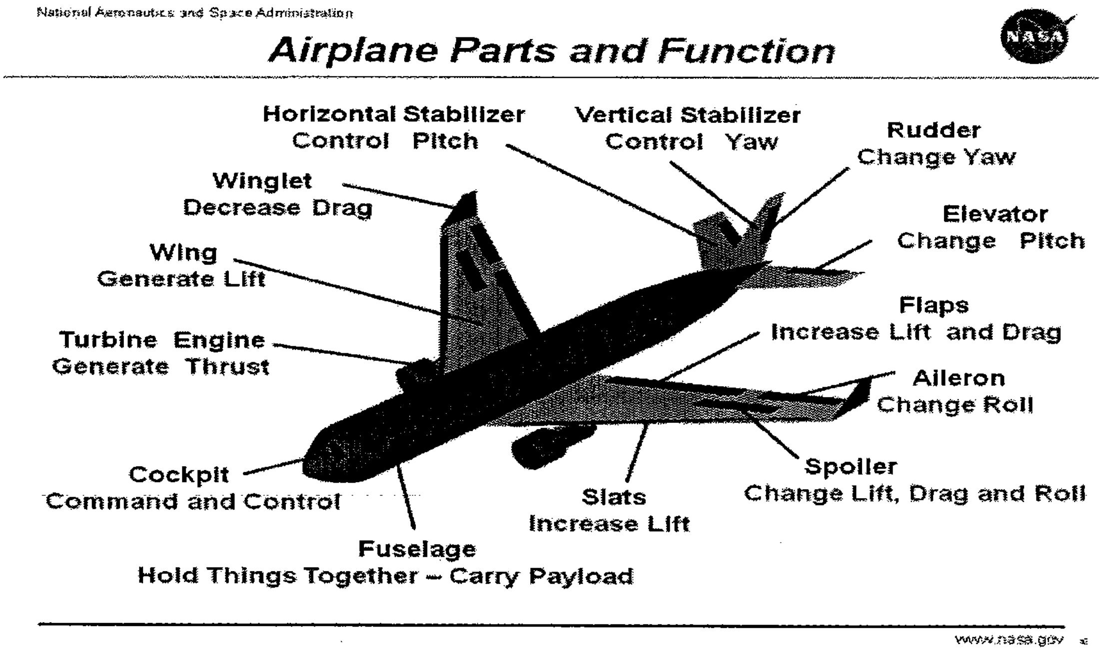
Factors affecting selection of site for Airport

- Regional plan
- Airport use
- Proximity to other airports
- Ground accessibility
- Topography
- obstructions
- visibility
- wind
- noise, nuisance
- grading, drainage and soil characteristics
- future development
- availability of utility for towns

- economic considerations

Airport Layout Plan (ALP) : The Airport Layout Plan (ALP) serves as a critical planning tool that depicts both existing facilities and planned development for an airport. ... By definition, the ALP is a plan for an airport that shows: • Boundaries and proposed additions to all areas owned or controlled by the sponsor for airport purposes.

AIRCRAFT PARTS:



Aircraft Characteristics

- Type of propeller or propulsion
- Size of aircraft
- Minimum turning radius
- Minimum circling radius
- Speed of aircraft
- Capacity of aircraft
- Weight and wheel configuration
- Jet blast
- Fuel spillage
- Noise

Type of propeller or propulsion : The size of aircraft, its circling radius, speed characteristics, weight carrying capacity, noise nuisance etc. depend upon the type of propulsion of the aircraft. the basic runway length also depends on the type of propulsion used in aircraft.

Size of aircraft: The Size of aircraft involves following important dimensions,

(i) wing span

(ii) height

(iii) distance b/w main gears i.e. gear tread

(iv) wheel base & tail width.

Minimum Turning radius: In order to decide the radius of taxiway, its very essential to study the geometry of turning movement of aircraft

• While taking a turn, the nose gear is steered and therefore, makes an angle with the axis of the main gear, called angle of rotation. The point of intersection of main gear and line through axis of steered nose gear is called point of rotation.

• The maximum angle of rotation is 50° - 60°

• The line joining the center of rotation and the tip of the farthest wing of the aircraft is known minimum turning radius

Minimum Circling Radius: There is certain minimum radius with which the aircraft can take turn in space. Its radius depends upon the type of aircraft, air traffic volume & weather conditions. The radii recommended for different types of aircraft are as follows.

Small general aviation aircraft = 1.6 km

- Bigger aircraft = 3.2 km
- Piston engine aircraft = 13 km
- Jet engine aircraft = 80 km

Speed of Aircrafts: The speed of aircraft can be defined in two ways. i.e. Cruising speed or air speed. Cruising speed is the speed of aircrafts with respect to the ground, when the aircrafts is flying in air at its maximum speed. Air speed is the speed of aircraft relative to the wind. If the aircraft is flying at a speed of 500 kmph & there is a head wind of 50 kmph, air speed will be 450 kmph.

Aircraft capacity: The number of passengers, baggage & fuel that can be accommodated in the aircrafts depends upon the capacity of aircraft.

Weight of aircraft & wheel configuration: Weight of the aircraft directly influence the length of the runway as well as the structural requirements i.e. the thickness of the runway, taxiway, apron & hangars.

Jet Blast: This is the blast that comes out of the jet engine at the rear of the aircraft and provides the force movement of the aircraft. But, if we consider it in case where the aircraft is standing and the jet blast is coming from the rear, that is so hot and it creates a severe condition for the things on which it will be falling. So the severity is going to depend on two things; one is the

• height of the tail pipe from the round
• angle of the tail pipe through which this jet blast will be coming out at the tail end.
So if it is in the upward direction then it will go up if it is in the downward direction it will create a pro effect on the pavement on which the aircraft is standing and therefore there is a need to erect the blast fences which can control the damage to the building or damage to the pavement.

Fuel spillage: At loading aprons & shelter it is difficult to avoid spillage completely, but effort should be made to bring it within minimum limit. The flexible pavements are seriously affected by the fuel spillage

Airport Classification :

1)Based on Take-off & Landing

→Conventional Take off & Landing Airport
Runway length > 1500 m
→Reduced Take-Off & Landing Airport
Runway length 1000 to 1500 m
→ Short Take-Off) & Landing Airport
Runway length 500 to 1000 m
→Vertical Take-Off) & Landing Airport
Operational area 25 to 50 sq.m

2) ICAO Classification: Based on Geometric Design

The classification has been done by using code letters viz.) A to E in which the A type of airport has the longest runway length and E type has the shortest length

ICAO Classification: Based on Length of Runway.

Code No	Basic Runway Length (L) in meter
1	<800
2	800 m up to but not including 1200 m
3	1200 m up to but not including 1800 m
4	1800 m & over

FAA Classification: Based on Aircraft Approach Speed.

Approach Category	Approach Speed Knots (1 knots = 1.9 km/hr)
A	< 91
B	91 - 120
C	121 - 140
D	141 - 165
E	165 or greater

Based on Function

Civil Aviation:

International & Domestic

Military Aviation

Classification Based on Pavement Strength

Code	Single Isolated Wheel Load in kg	Wheel Pressure kg/m2
1	45360	8.4
2	34020	7.0
3	27220	7.0
4	20410	7.0
5	13610	6.0
6	6800	4.90
7	2270	2.90

Runway Orientation : The orientation of a runway depends upon the direction of wind & to some extent on the area available for development. Runway are always orientated in the direction of prevailing wind. Determination of a runway orientation is a critical task in the planning & design of an airport. The direction of the runway controls the layout of the other airport facilities, such as passengers terminals, taxiways/apron configurations, circulation roads & parking facilities.

Cross wind component: It is not possible to obtain the direction of wind along the direction of the centre line of runway throughout the year, On some day of the year or hour of the day, the wind may blow making certain angle with the centre line of runway. If the direction of wind is at an angle to the runway will be $V\cos\alpha$ & that normal to the runway centre line will be $V\sin\alpha$ where V is the wind velocity. The normal component of the wind is called cross wind components

The maximum permissible cross wind component : It depends upon the size of the aircraft and the wind configuration.Θ FAA - 15 kmph for small aircrafts - 25 kmph for mixed traffic ICAO – 35 kmph for big aircrafts

Wind Coverage: Wind coverage or usability factor of airport is the percentage of time in a year during which the cross wind component remains within the limits as specified above is wind coverage

Calm Period: This is the period for which the wind intensity remains below 6.4 km/hr This is common to all direction & hence can be added to wind coverage for that direction Calm period = 100 – Total wind coverage

Wind Rose: The wind data i.e direction, duration & intensity are graphically represented by a diagram called wind rose diagram. Application of Wind Rose diagram is for finding the orientation of the runway to achieve wind coverage. The area is divided in to 16 parts using an angle of 22.5^0 . Average wind data of 5 to 10 years is used for preparing wind rose diagram

Wind Rose – Methods;

Type – I: Showing directionΘ & duration of wind.

Type –II: Showing direction, durationΘ & intensity of wind.

Type – I : Showing direction& duration of wind.

- The radial lines indicate the wind direction and each circle represents the duration of wind.
- From the wind data it is observed that the total % of time in a year during which the wind blows from north direction is 10.3%.
- This value is plotted along the north direction in figure. Similarly other values are also plotted along the respective directions.
- All plotted points are then joined by straight lines.
- The best direction of runway usually along the direction of the longest line on wind rose diagram.
- In the figure the best orientation of runway is NS direction.

Type –II ;Showing direction, durationΘ & intensity of wind.

- Each circle represents the wind intensity to some scale.
- The values entered in each segment represents the % of time in a year during which the wind having a particular intensity.
- Procedure: draw 3 equi-spaced parallel lines on a transparent paper strip.
- Place the transport paper strip over the wind rose diagram in such a way that the central line passes through the centre of the diagram.
- With the centre of wind rose, rotate the tracing paper & place it in such a position that the sum of all the values indicating the duration of wind, within the two outer parallel lines, oriented is the maximum.

- The runway should be thus oriented along the direction indicated by the centre line.
- The wind coverage con be calculated by summing up all the % shown in segment.
- Read the bearing of the runway on the outer scale of the wind rose where the central line on the paper.
- That is the best orientation of runway.

Terminal area: An airport terminal is a building at an airport where passengers transfer between ground transportation and the facilities that allow them to board and disembark from aircraft. Within the terminal, passengers purchase tickets, transfer their luggage, and go through security.

Design:

Due to the rapid rise in popularity of passenger flight, many early terminals were built in the 1930s–1940s and reflected the popular art decostyle architecture of the time. One such surviving example from 1940 is the Houston Municipal Airport Terminal. Early airport terminals opened directly onto the tarmac: passengers would walk or take a bus to their aircraft. This design is still common among smaller airports, and even many larger airports have "bus gates" to accommodate aircraft beyond the main terminal.

Pier : A pier design uses a small, narrow building with aircraft parked on both sides. One end connects to a ticketing and baggage claim area. Piers offer high aircraft capacity and simplicity of design, but often result in a long distance from the check-in counter to the gate

Satellite terminals: A satellite terminal is a building detached from other airport buildings, so that aircraft can park around its entire circumference. The first airport to use a satellite terminal was London Gatwick Airport. It used an underground pedestrian tunnel to connect the satellite to the main terminal. This was also the first setup at Los Angeles International Airport, but it has since been converted to a pier layout.

Semicircular terminals:

Some airports use a semicircular terminal, with aircraft parked on one side and cars on the other. This design results in long walks for connecting passengers, but greatly reduces travel times between check-in and the aircraft

Zones

Pre-Security

- Check-in counters
- Retail stores and restaurants
- Baggage claim

Post Security

- Duty-free shops
- Retail stores and restaurants
- Airport lounges
- Airport customs

Important Components of An Airport Layout

1. Runway
2. Terminal Building
3. Apron
4. Taxiway
5. Aircraft Stand
6. Hanger
7. Control Tower
8. Parking

1.Runways: A runway is the area where an aircraft lands or takes off. It can be grass, or packed dirt, or a hard surface such as asphalt or concrete. Runways have special markings on them to help a pilot in the air to tell that it is a runway (and not a road) and to help them when they are landing or taking off. Runway markings are white. Most runways have numbers on the end. The number is the runway's compass direction. (For example, runway numbered 36 would be pointing north or 360 degrees). Some airports have more than one runway going in the same direction, so they add letters to the end of the number R for right, C for center, and L for left.

2. **Terminal Building:** An airport terminal is a building at an airport. It is where passengers are able to get on and off aircraft. Inside the terminal, passengers can buy tickets, leave or pick up their luggage, and be checked by security staff. The buildings that provide access to the airplanes through gates are usually called concourses.

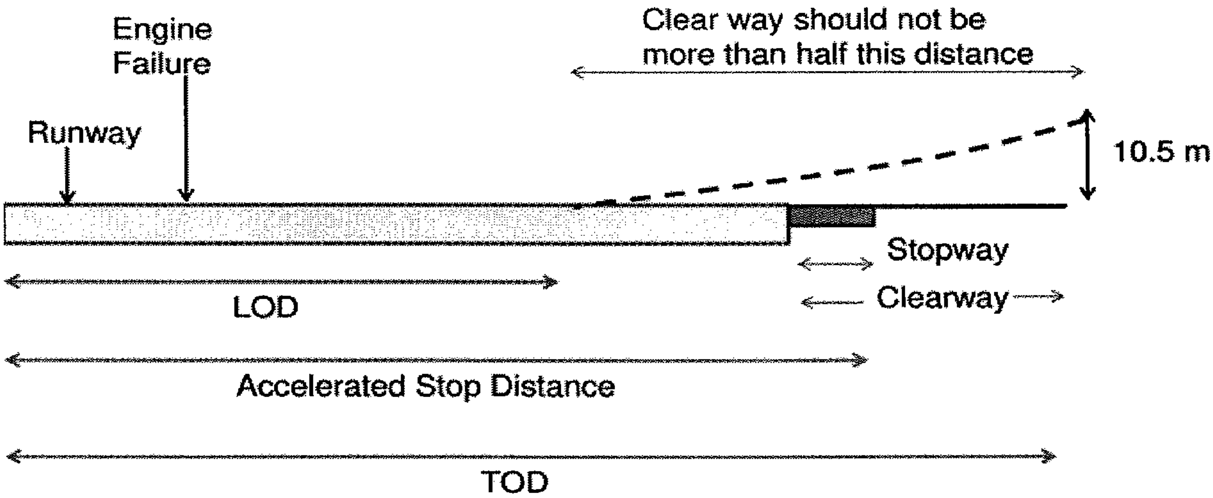
3.APRON : The airport apron or apron, also known as tarmac, is the area of an airport where aircraft are parked, unloaded or loaded, refueled, or boarded. Although the use of the apron is covered by regulations, such as lighting on vehicles, it is typically more accessible to users than the runway or taxiway.

4.taxiway : A taxiway is a path for aircraft at an airportconnecting runways with aprons, hangars, terminals and other facilities. They mostly have a hard surface such as asphalt or concrete, although smaller general aviation airports sometimes use gravel or grass.

5. Aircraft Stand : A stand guidance system is a system which gives information to a pilot attempting to park an aircraft at an airport stand, usually via visual methods, leading to the term *Visual Docking Guidance System* (VDGS) and also *A-VDGS* (the A standing for advanced) This allows them to remain clear of obstructions and ensures that jetways can reach the aircraft.

6. Hanger: A hangar is a closed building structure to hold aircraft, or spacecraft. .Hangars are used for protection from the weather, direct sunlight, maintenance, repair, manufacture, assembly and storage of aircraft, aircraft carriers and ships.
7.control tower : A control tower is a building at an airport from which instructions are given to aircraft when they are taking off or landing. You can also refer to the people who work in a control tower as the control tower.
8.parking : there should be adequate parking for passenger vehicles and the parking place designed by demand of the airport and average population of the day.

Runway design :



Change in direction of runway : It may not be always possible to orient the runway exactly along the direction as determined from the wind rose. Slight adjustment in the directions may be imperative because of the following reasons.

1. **Obstructions**
2. **Excessive grading**
3. **Noise nuisance**

Basic runway length

It is the length of the runway under the following assumed conditions at the airport

1) Airport altitude is at sea level
2) Temperature at the Airport is standard (15'C)
3) Runway is levelled in the longitudinal direction
4) No wind is blowing on runway
5) Aircraft is loaded to its full loading capacity
6) There is no wind blowing enroot to the destination
7) Enroot temperature is standard

The basic runway length is determined from the performance characteristics of the aircrafts using the airport. The following cases are usually considered

- ✓ Normal landing case
- ✓ Normal take-off case
- ✓ Engine failure case
- ❖ For jet engine aircrafts all 3 cases are considered
- ❖ For the piston engine aircraft only 1st and 3rd cases are considered
- ❑ The case which works out the longest runway length is finally adopted.

1) Normal landing case The landing case requires that aircraft should come to stop within 60% of the landing distance. The runway of full strength pavement is provided for the entire landing distance.

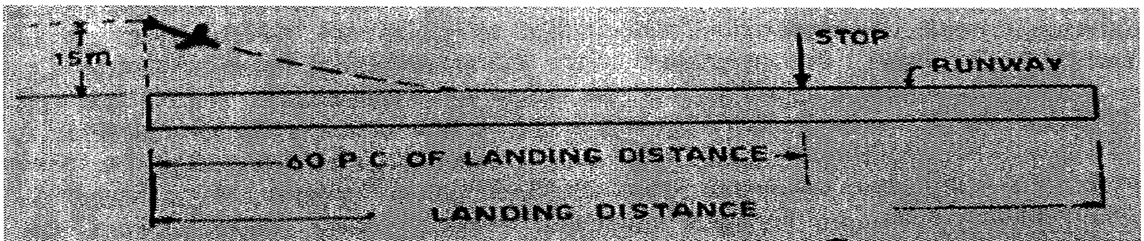


Figure 6.5 Normal Landing Case

2) Normal take-off case : The normal take-off case requires a clearway which is an area beyond the runway and is in alignment with the centre of runway. The width of clearway should not be less than 150 m and is also kept free from obstructions.

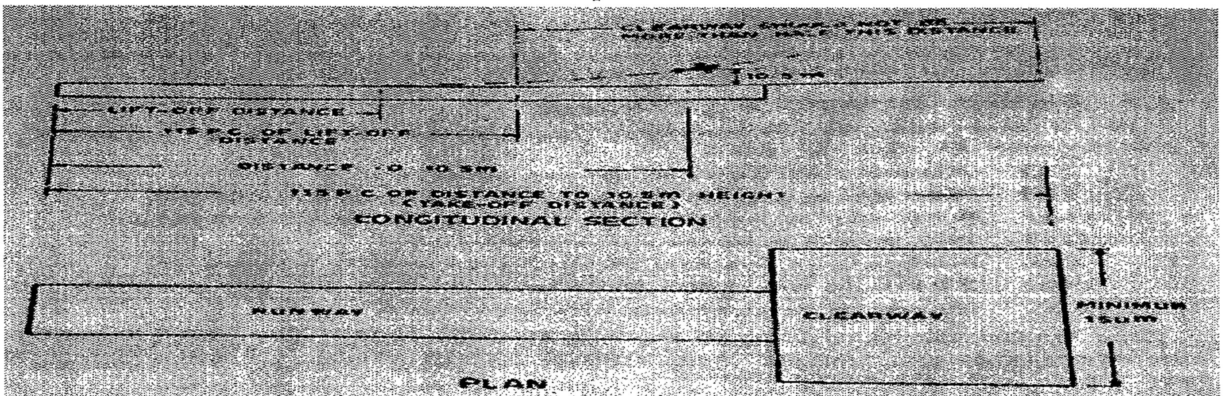


Figure 6.6 Normal Take-off Case

3) Engine failure case The engine failure case may require either a clearway or a stop way, or both. Stop way is described as an area beyond the runway and centrally located in alignment with the centre of runway. It is used for decelerating during an aborted (terminated) take-off.

The strength of stop way pavement should be just sufficient to carry the weight of aircraft without causing any structural damage to the designated engine failure speed, the pilot decelerate the aircraft and makes use of the stop way.

Runway length design procedure:

Correction for Elevation, Temperature & Gradient

1) Correction for elevation:-

As the elevation increases, the air density reduces. This in turn reduces the lift on the wings of the aircraft and the aircraft requires greater ground speed before it can rise into the air.

To achieve greater speed, longer length of runway is required.

ICAO recommends that the basic runway length should be increased at the rate of 7% per 300 m rise in elevation above the mean sea level.

2)Correction for temperature:-

Airport reference temperature

Where Ta- Average daily temperature

Tm- Maximum daily temperature

ICAO recommends that the basic runway length after having been corrected for elevation should be further increased at the rate 1% for every $1^{o}c$ rise of airport reference temperature above the standard atmospheric temperature at the elevation.

3) Check for the total correction: for the elevation plus temperature: ICAO further recommends that's, if total corrections exceeds 35% of the basic runway length, these corrections should be further checked up by conducting specific studies at the site by model tests.

4) Corrections for gradients:-

$$\frac{maximum\ difference\ in\ elevation\ between\ the\ highest\ \&\ lowest\ point}{total\ length\ of\ runway}$$

- ✓ Steeper gradient results in greater consumption of energy & as such longer length of runway is required to attain the desired ground speed.
- ✓ **ICAO** does not recommends any specification for the correction of gradients.
- ✓ **FAA** recommends that the runway length after having been corrected for elevation & temperature should be further increased at the rate of 20% for every 1% of effective gradients.

Runway Geometric Design

ICAO gives various geometric standards for the airport design.

1) Runway length
2) Runway width
3) Width & length of safety area

4) Transverse gradients
5) Longitudinal & effective gradient
6) Sight distance
1) **Runway length**

The basic runway length as recommended by ICAO for different types of airport are there. To obtain the actual length of runway, corrections for elevation, temperature & gradient are applied to the basic runway length.

2) **Runway width**

✓ **ICAO** recommends the pavement width varying from **45 m - 18 m** for different types of aircraft.

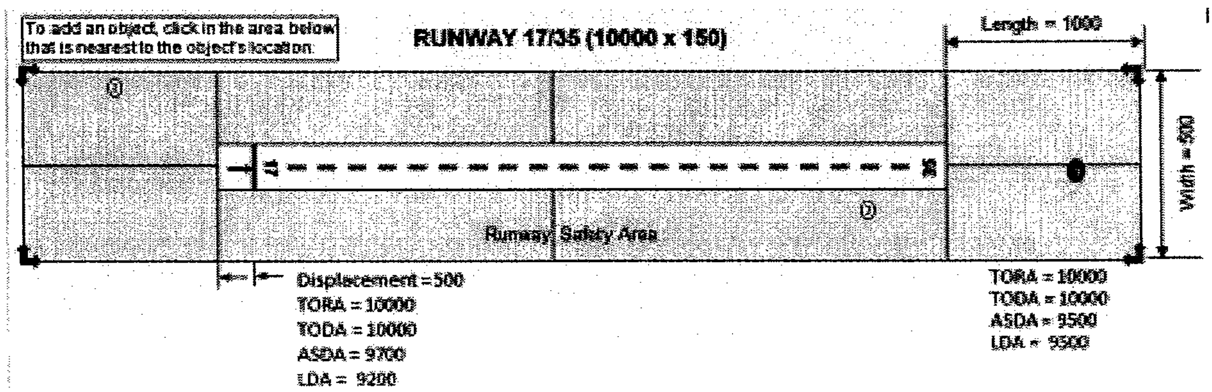
✓ The aircraft traffic is more concentrated in the central 24m width of the runway pavement.

✓ 3) Width & Length Of Safety Area safety area consists of the runway, which is paved area plus the shoulder on either side of runway plus the area is cleared, graded & drained as shown in fig.

✓ The shoulder are usually unpaved as they are used during emergency.

✓ ICAO recommends.

	Types of airport	Width of safety area
Non-instrumental runway	**A,B&C**	**150 m**
	D&E	**78 m**
Instrumental runway	**A,B,C,D&E**	**Mini. 300 m**



4) Transverse gradient :Transverse gradient is essential for quick drainage of surface water. If surface water is allowed to pond on the runway, the aircraft can meet severe hazards. ICAO recommends that the transverse gradient of runway pavement should not

exceed 1.5% for A,B, C & D 2 % for D & E types. ICAO does not recommends that the minimum transverse gradient of runway pavement but it should not greater then 0.5 %.
5) Longitudinal & Effective Gradients The longitudinal gradient of runway increases the required runway length. ICAO recommendation as follows

Types of airport	Longitudinal gradient	Effective gradient
A,B & C	1.5 %	1 %
D & E	2 %	2 %

6) Sight distance (is the length of roadway visible to a driver) :
Two runways or a runway & taxiway intersect each other, there are chances of collision of aircraft, if sufficient sight distance are not available.
ICAO recommends that for A,B & C types of airports, any two points 3 m above the surface of runway should be mutually visible from a distance equal to ½ the runway length.
For D & E types of runway there should be unobstructed line of sight from any point 3 m above runway and to all other point 2.1 m above runway within a distance of at least ½ the length of runway.

TAXIWAY: The main function of the taxiway is the inter connection between runway and loading apron or service hanger
Following consideration decide the layout of taxiway.

- Not interfere with the landing and take-off aircrafts
- At busy airports, taxiway should be located at various points along the runway so that the landing aircraft leaves the runway as early as possible and keeps it clear for use by other aircrafts. Such taxiway are called exit taxiways
- The route for taxiway should be so selected that it provides the shortest distance from the apron to the runway end.
- As for as possible the intersection of taxiway and runway should be avoided.
- Exit taxiways should be designed for high turn-off speed.

Taxiway Geometric Design:
ICAO gives various geometric standards for the airport design.

1) Taxiway length
2) Taxiway width
3) Width & length of safety area
4) Transverse gradients
5) Longitudinal & effective gradient

6) Sight distance
7) Turning radius

Length of taxiway: As short as possible.
Increased number of taxiways have to be provided along the runway.

Width of taxiway:
It is observed that the width of a taxiway is much lower than the runway width, as aircraft is not airborne and speeds are small.
Varies between 22.5 m & 7.5 m

Width of taxiway:

Airport Code	Taxiway width
A	22.5 m
B	22.5 m
C	15.0 m
D	9.9 m
E	7.5m

Longitudinal gradient:
Level taxiway are operationally more desirable.
If gradient is steep, it affects fuel consumption.
As per ICAO, maximum longitudinal gradient is 1.5% for A&B type of airports & 3.0% for C,D&E type of airports.

Rate of change of longitudinal gradient:
Available sight distance on the pavements is affected by the rate of change of longitudinal gradient.
As per ICAO, the maximum change in pavement longitudinal gradient is 4% for A&B category of airport & 3.33% for C,D&E category of airports.

Sight distance:
As speed of aircraft on taxiway is lower than the speed on runway, the smaller value of sight distance will be sufficient on the taxiway.

Sight distance:

Airport Code	Y	X
A	1.5 m	150 m

B	2.0 m	200 m
C,D&E	3.0 m	300 m

Transverse gradient: Adopted same as recommended for runway. Transverse gradient is essential for quick drainage of surface water. ICAO recommended that the transverse gradient of pavement should not exceed 1.5% for A,B&C & 2% for D&E types. Shoulder are usually provided with steeper gradients .

Width of safety area: Safety area is made up to partially paved shoulders on pavement plus the area which is graded & drained.

Turning radius: The design should be such that the aircraft can negotiate the curve without significantly reducing the speed.

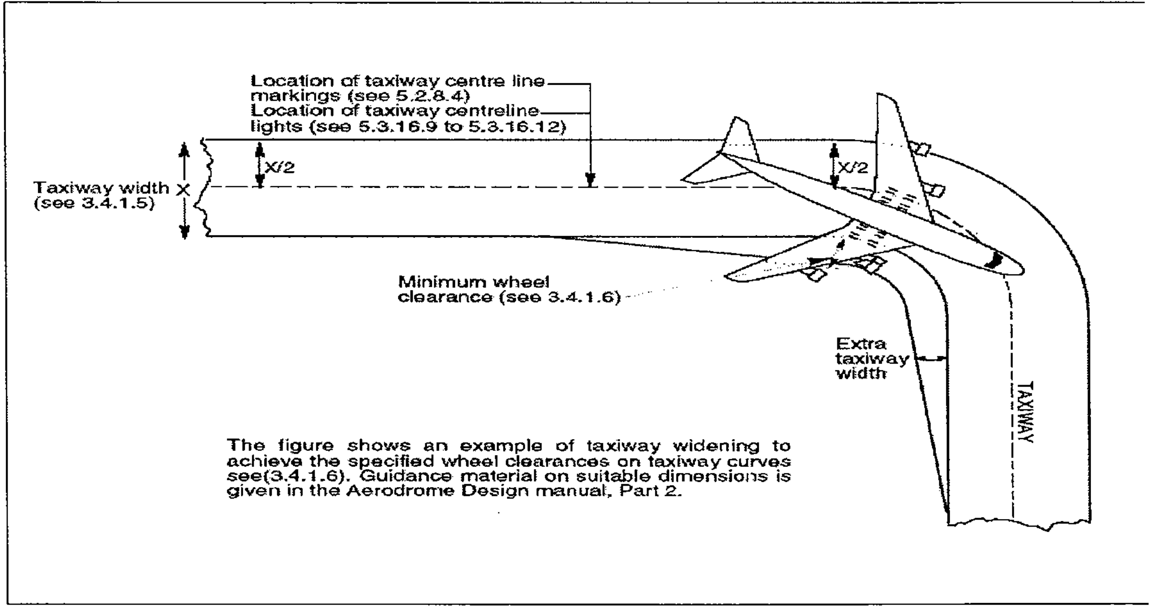
Circular curve of large radius is provided.

Recommended radii corresponding of taxing speeds of small,

Subsonic & supersonic airplanes is 60 m,135 m & 240 m respectively.

$R^2= V^2/125f$,

Where, R=radius in meter, V=speed in KMPhr F=Friction btw tire and pavement

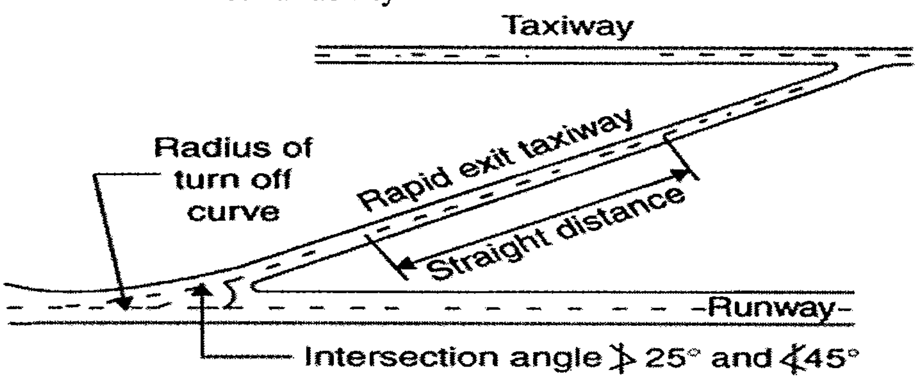


Exit Taxiways

Location of exit taxiway

- This depends upon several factors
  - Number of exit taxiways
  - Exit speed
  - Types of aircrafts

- Weather conditions
- Topographical features
- Pilot variability



Location of exit taxiway

- This depends upon several factors
  - **Number of exit taxiways**: the number of taxiways to be provided decides their location. If there are only two exit taxiways they should be provided at the runway ends. If there are more than it should be ditributed along the runway length.
  - **Exit speed:** the maximum speed with which an aircraft can take a turn and enter the exit taxiway is limited for each aircraft. The aircraft requires certain length of runway to reduce its speed from the landing speed to the turnoff speed. Thus this affects the location of taxiway.
  - **Types of aircrafts:** different types of aircraft lands at different speed. Therefore the distance required by different aircrafts, to reduce their speed to the exit speed value, varies with the type of the aircraft, Thus in turn affects the location of taxiway.
  - Weather conditions
  - Topographical features
  - Pilot variability

DESIGN OF EXIT TAXIWAY CONNECTING RUNWAY & PARALLEL TAXIWAY

1) The most significant factor is the exit speed of aircraft.
2) Slightly widened entrance of 30 m will be provide.
3) Total angle of turn is $^3{}_3{}^3 0_0{}^{00}$-$^0 4^c 5^{-0}$
4) The turning radius should be calculated by the following formula

$$R = \frac{v2}{125\ X f}$$

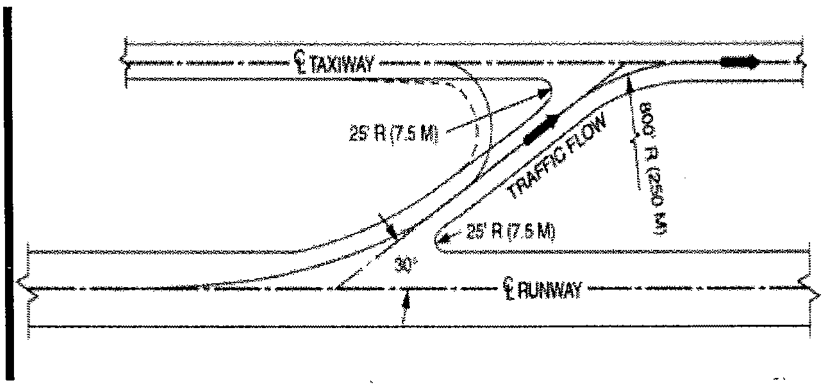
5) A high turn-off speeds of 65-95 kmph a compound curve is necessary to minimize the tire wear on the nose gear.
6) The length of longer radius curve can be roughly obtained by
7) valve of C=0.39

$$L1 = \frac{v3}{45.5\ X\ C\ X\ R2}$$

8.Stopping distance (SD)
Where d- deceleration distance

$$SD = \frac{v2}{25.5\ X\ d}$$

Design of exit taxi way



Zoning laws: Zoning is the way the governments control the physical development of land and the kinds of uses to which each individual property may be put. Zoning lawstypically specify the areas in which residential, industrial, recreational or commercial activities may take place.

- Airport zoning regulations (AZR) restrict the heights of buildings, structures and objects (including natural growth, such as trees) on regulated land. ... ensure that future development near an airport stays compatible with the safe operation of aircraft and of the airport itself.
- The basic purpose and function of zoning is to divide a municipality into residential, commercial, and industrial districts (or zones), that are for the most part separate from one another, with the use of property within each district being reasonably uniform.

- The purpose of zoning is "to promote the health, safety, morals, and general welfare of the community, to protect and conserve the value of buildings, and encourage the most appropriate use of the land."
- Zoning is the term used for designating permitted uses of certain parcels of land by local governments. The word is largely self-explanatory: the local government will designate various zones for different uses of land, such as industrial, agricultural, commercial, and residential
    - Recreational - fun, non-essentials like parks.
    - Transport - roads, railways, and airports.
    - Agricultural - farmland.
    - Residential - housing.
    - Commercial - businesses and factories.

REGIONAL PLANNING :

An overall planning of airports for all the regions of a country is called "regional planning". The planning of an airport should be done considering the traffic needs of the nation as a whole rather than an individual locality. the regional planning airport system plan is a representation of the aviation facilities required to meet the immediate and future transportation needs of the country and their timely and orderly development. Regional planning recommands the general location and characteristics of new airports and nature of expansion for existing airports. It relates the airport system planning to the policy and coordinate transportation planning for the area, land use planning and urban development, to establish a viable integrated network of airports ar the national level.

Objectives of regional planning:

1. To develop a balanced regional multimodal transportation system plan, with coordinated airport facilities.
2. To provide a framework for individual airport development programme consistent with short, intermediate and long term airport system requirements.
3. To implement zoning laws in the areas where new airports are needed in future
4. To develop fiscal plans and establish appropriate priorities for airport financing in short and long term government budgeting.
5. To optimize the use of land and airspace and preserve the existing airport facilities which are consistent with overall objectives of the long term planning.
6. To protect and enhance the environment through the location and expansion of aviation facilities.

Advantages of regional planning :

- It enables to implement the zoning laws in the areas where the new airports are coming up in future.
- There is proper coordination of airports.
- The efficiency of airports in handling the air traffic is greatlyϖ increased.
- It avoids close spacing of airports.
- It helps in preservation of environment.
- Intrusion of acceptable noise levels and air pollution into the community area are avoided.
- It is possible to optimise land use and air space through regional planning

INFORMATION REQUIRED FOR THE REGIONAL PLANNING

- The planning period
- Population
- Geography and topography of the area
- Existing airports in the vicinity
- Air traffic characteristics
- Development of new airports
- Ownership and operation of airports

FACTORS AFFECTING AIRPORT SITE SELECTION :

1. Regional plan
2. Airport use
3. Presence of other airports
4. Topography of the area'
5. Ground accessibility
6. Obstructions
7. Visibility
8. Wind
9. Noise nuisance
10. Geological factors
11. Environmental factors
12. Future development
13. Availability of construction material
14. Availability of utilities
15. Social considerations
16. Economic considerations
17. Avoiding hazards

Visual aids:

- Land marks which are required so as to provide an aid to the pilots Ensures the smooth operating of the air craft
- Required both in good weather and bad weather as well as during day and night
- The runways of the conventional aircraft appears as long and narrow strip with straight sides and free of obstacle

These are available in different forms of markings in the airport and airfield

1.Airport markings

2. Airport lighting

3. Signage

Markings are provided on any of the component of airport in different forms mentioned below

- Strips
- Patches
- Solid lines
- Hollow lines
- Cart lines

Airport markings can be divided into following groups

- Apron marking
- Landing direction indicator
- Runway marking
- Shoulder marking
- Taxiway marking
- Wind direction indicator

Certain guidelines are marked on the apron to help the pilots in maneuvering the most critical aircrafts.

Generally they are related to the path to be traversed during parking in or out operation near terminal location or nose etc.

Yellow colour is used at such locations

It should be fuel resistant as aprons are likely to be subjected to fuel spillage.

AIRPORT LIGHTING :

A line of lights on an airfield to guide aircraft in taking off or landing during night

As a guide to pilot

Emergency power supplies

General Airport Lighting

- Includes Beacon Lights on top of tower, buildings
- The Airport Beacon : large, powerful rotating light highly visible from miles away
- Rotate green and white
- Steady red beacon on top of airport building to aid in collision avoidance for low-flying aircraft

Taxiway Lighting :

- Taxiway Edge Lights: Blue, Lines taxiway
- Taxiway Center Light: Green Light
- Clearance Bar Lights: Steady yellow, visibility of hold line
- Stop Bar Lights: Steady red, ATC in low visibility situation, across taxiway at hold short line
- Runway Guard Lights: A pair of two steady yellow light at hold short line, may be flashing

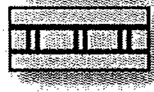
Runway Lighting:

- Runway End Identifier Lights: white flashing light one on each side of approach end of runway
- Runway Edge Light Systems (HIRL/MIRL/LIRL):steady white light on edges of runway Runway Centerline Lighting System (RCLS)
- Touchdown Zone Lights (TDZL) :
- Define landing portion of runway, Up to midpoint Land and
- Hold Short Lights (LAHSO)
- Runway status light or Runway entry light(REL)

Factors Affecting Airport Lighting

- Airport classification
- Availability of power
- Amount of traffic
- Nature of aircraft
- Type of night operation plan
- Type of landing surface provided
- Weather condition

Type of Sign	Action or Purpose
4-22	**Taxiway/Runway Hold Position:** Hold short of runway on taxiway
26-8	**Runway/Runway Hold Position:** Hold short of intersecting runway
8-APCH	**Runway Approach Hold Position:** Hold short of aircraft on approach
ILS	**ILS Critical Area Hold Position:** Hold short of ILS approach critical area
⊖	**No Entry:** Identifies paved areas where aircraft entry is prohibited
B	**Taxiway Location:** Identifies taxiway on which aircraft is located
22	**Runway Location:** Identifies runway on which aircraft is located
4	**Runway Distance Remaining:** Provides remaining runway length in 1,000 feet increments

Type of Sign	Action or Purpose
	**Runway Safety Area/Obstacle Free Zone Boundary:** Exit boundary of runway protected areas
	**ILS Critical Area Boundary:** Exit boundary of ILS critical area
J→	**Taxiway Direction:** Defines direction & designation of intersecting taxiway(s)
↙L	**Runway Exit:** Defines direction & designation of exit taxiway from runway
22↑	**Outbound Destination:** Defines directions to takeoff runways
↖MIL	**Inbound Destination:** Defines directions for arriving aircraft
	**Taxiway Ending Marker:** Indicates taxiway does not continue
↙A G L→	**Direction Sign Array:** Identifies location in conjunction with multiple intersecting taxiways

UNIT V RUNWAY DESIGN

Various design factors :

1. Design wheel load

2. Strength characteristics of materials used in pavements

3. sub grade supporting capacity

1. Design wheel load : the part of the **load** of a vehicle that is carried by a single **wheel** and transmitted by it to a road surface or a track.
But to carry large loads multiple axles are provided. Since the design of flexible pavements is by layered theory, only the wheels on one side needed to be considered. ... Standard axle load: It is a single axle load with dual wheel carrying 80 KN load and the design of pavement is based on the standard axle load.

2. Strength characteristics of materials used in pavements : the strength and deformation properties of Florida base course materials have been evaluated in laboratory experiments. The project involved the development of laboratory test techniques, the evaluation of base course materials according to these techniques, and the review of present state laboratory procedures in light of the new tests. The conclusions will be used to examine and revise present Florida base course specifications where necessary

3. subgrade supporting capacity : The overall strength and performance of a pavement is dependent not only upon its design (including both mix design and structural design) but also on the load-bearing capacity of the sub grade soil. ... Increasing sub grade support by alternative means. Sub grade elevation. Prime coats for HMA pavements.

Flexible pavements design methods :

1. Burmister method of pavement design

2. CBR method of pavement design

3. McLeod Design Method for flexible pavements

4. Group Index Method of Flexible Pavement Design

1.Burmister method of pavement design

Burmister introduced a semi empirical method for the design of flexible pavements. In this method, he considered pavement as number of layers. And some assumptions are considered which are as follows:

- The material in each layer is homogeneous
- The material is isotropic
- The material is elastic in nature
- Contact between the layers is continuous
- Unloaded top layer is free from normal and shearing stresses
- The surface layer is infinite in length (horizontal direction) and finite in depth (vertical

- direction).
- The underlying layers are infinite in both directions
  Burmister given the deformation equations for both flexible and rigid pavements by considering the poisons ratio of soil and pavement material to 0.5

For flexible pavements

$$\Delta = 1.5 \frac{paF_2}{E_s}$$

For rigid pavements

$$\Delta = 1.18 \frac{paF_2}{E_s}$$

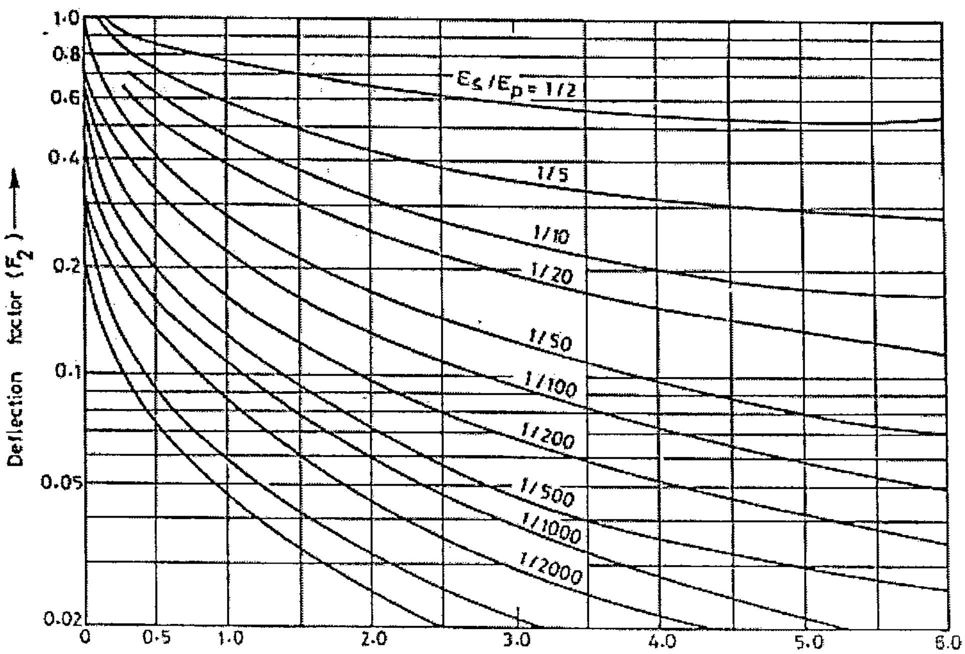
Where, p = uniform pressure

a = radius of plates

F_2 = deflection factor

E_s = modulus of the subgrade soil.

Deflection factor is dependent of ratio of modulus of subgrade soil to the modulus of pavement material. So, from the below graph we can select the value of deflection factor corresponding to the ratio of base layer thickness to the radius of load that is h/a.



Procedure of Flexible Pavement Design by Burmister's Method

In the Burmister's design process, firstly conduct plate bearing test on the soil. The diameter of plate used is 30cm. now determine the modulus of subgrade soil. In the next step, determine the deflection factor from the below formula

$$F_2 = \frac{\Delta . E_S}{1.18\, p\, a}$$

After obtaining the deflection factor from above formula, now select the value of ratio of modulus of subgrade soil to the modulus of pavement material (E_s/E_p) for the given value of (h/a ratio from the graph. Now for the design load (P) and tire pressure (p) determine the contact radius (a) from the below formula.

$$a = \sqrt{\frac{P}{\pi p}}$$

And again, find the new value of deflection factor F2 for the design deflection value

$$F_2 = \frac{\Delta . E_S}{1.18\, p\, a}$$

Where Δ = 0.25cm or 0.5cm.

For the obtained values of new deflection factor and E_s/E_p ratio, select the appropriate h/a ratio from the above graph. And finally, by substituting contact radius (a) in h/a ratio we can get the value of base layer thickness (h).

CBR method of pavement design :

Flexible pavement design by CBR method is used to determine the total thickness of pavement. Generally there are two methods to design the pavement from CBR (California bearing ratio) value.

They are

1. CBR method recommended by California state of highways
2. CBR method recommended by IRC

CBR method recommended by California state of highways:

Data required for flexible pavement design:

a. CBR value of soil subgrade

b. CBR value of sub base course

c. CBR value of base course

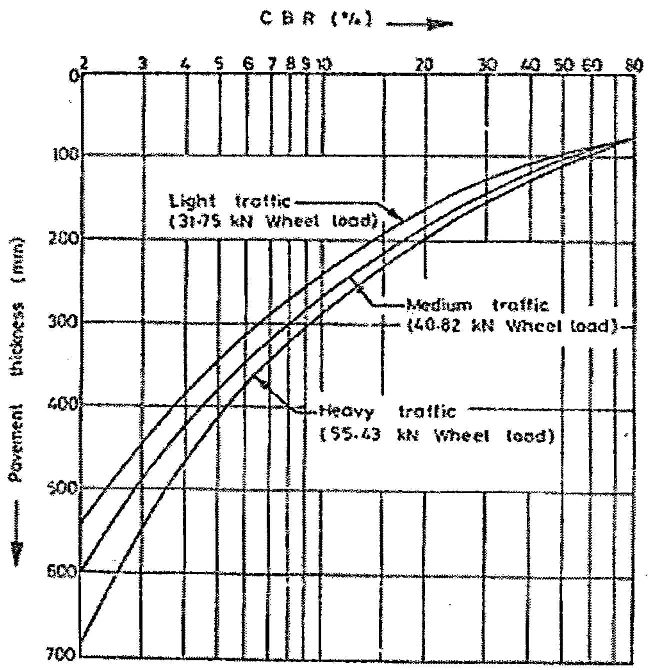
d. Wheel load in KG or KN

Wheel load is classified into three groups based on traffic conditions.

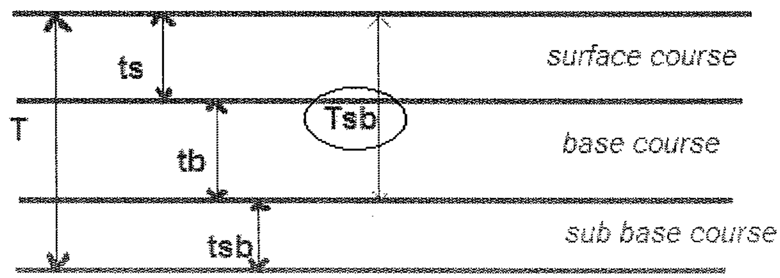
- Light traffic(3175 KG)

- Medium traffic(4082 KG)
- Heavy traffic (5443 KG)

Flexible Pavement Design Procedure:
Calculation of total thickness (T):From the below chart for given CBR value of soil subgrade and Wheel load value select appropriate thick curve value of "combined thickness of surface, base and sub-base line" which will give the total thickness of pavement.

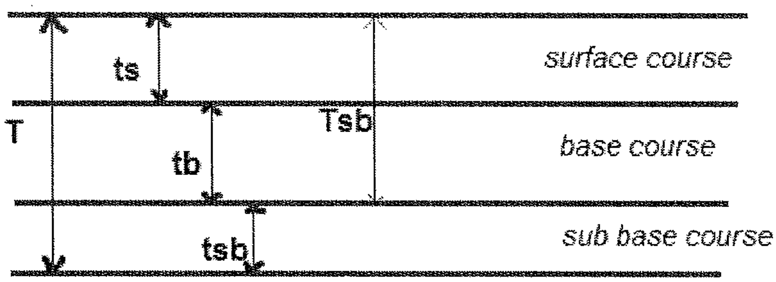


Calculation of sub base course thickness (t_{sb}): By using the above chart, forgive CBR value of sub base course material and for wheel load read the thickness of pavement which is above the soil sub base. It is denoted as (Tsb). Which is highlighted by circle in the below fig. but here we have to find t_{sb}.Therefore, thickness of sub base course t_{sb} =T – Tsb



Calculation of base course thickness (t_b): Similar to the above procedure, from the CBR value of base course and wheel load read the value of thickness of pavement which is above the base

course (t_s). From this we can find out the value of t_b. $t_b = T_{sb} - t_s$
Therefore all the values of pavement are known and cross section



CBR method recommended by IRC (Indian road congress): In this method, the chart contains several curves (A, B, C, D, E, F, and G) which represents the different levels of traffic intensities. Based on this we will find out the layers thicknesses.

Data required for design:

a. CBR value of soil subgrade

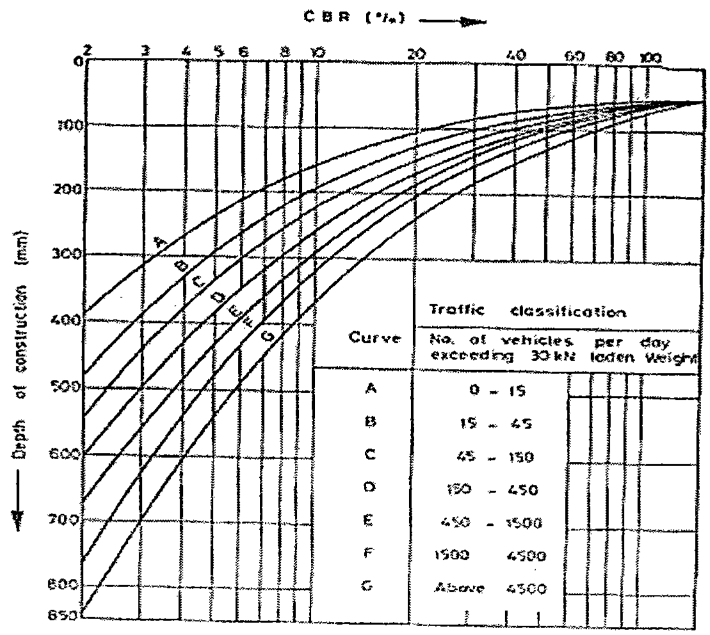
b. CBR value of sub base course

c. CBR value of base course

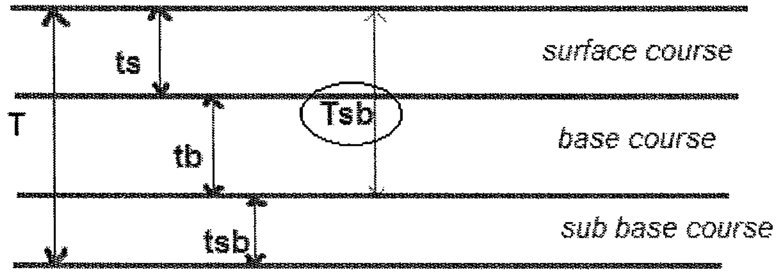
d. Traffic intensity

Flexible Pavement Design Procedure:

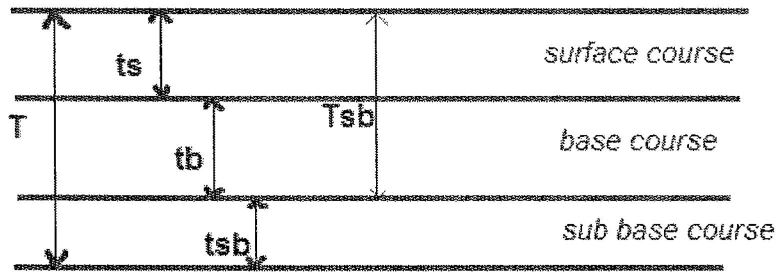
Calculation of total thickness (T): In this step, firstly for the given value of traffic intensity select appropriate curve from classification table which is shown in the below chart. Now, from the given CBR value of subgrade soil read the total thickness (T) with respect to selected curve.



Calculation of sub base course thickness (t_{sb}): By using the above chart, for give CBR value of sub base course material and for traffic intensity value read the thickness of pavement which is above the soil sub base. It is denoted as (Tsb). Which is highlighted by circle in the below fig. but here we have to find $t_{sb.}$ Therefore, thickness of sub base course t_{sb} =T – Tsb



Calculation of base course thickness (t_b): Repeat the above procedure again, from the CBR value of base course and from traffic intensity value read the value of thickness of pavement which is above the base course (t_s). From this we can find out the value of $t_{b.}$ $t_b = T_{sb} - t_s$
Therefore all the values of pavement are known and cross section of pavement is as follows.



3. McLeod Design Method for flexible pavements

The McLeod method is based on two basic principles:

1. The application rate of a given aggregate should be determined such that the resulting seal coat will be one-stone thick. This amount of aggregate will remain constant, regardless of the binder type or pavement condition.
2. The voids in the aggregate layer need to be 70 percent filled with asphalt for good performance on pavements with moderate levels of traffic.

Design Procedure Components

Median Particle Size. The Median Particle Size (M) is determined from the aggregate gradation chart. It is the theoretical sieve size through which 50 percent of the material **Flakiness Index.** The flakiness index (FI) is a measure of the percent, by weight, of flat particles. It is determined by testing a sample of the aggregate particles for their ability to fit through a slotted plate (TxDOT Test Method Tex-224-F).

Average Least Dimension. The Average Least Dimension, or ALD (H), is determined from the Median Particle Size and the Flakiness Index. It is a reduction of the Median Particle Size after accounting for flat particles. It represents the expected seal coat thickness in the wheel paths where traffic forces the aggregate particles to lie on their flattest side. The ALD is calculated as follows:

$$H = \frac{M}{1.139285 + (0.011506)FI}$$

Equation 4-6.
where:

- H = Average Least Dimension, inches
- M = Median Particle Size, inches
- FI = Flakiness Index, percent.

Loose Unit Weight of the Cover Aggregate. The dry loose unit weight (W) is determined according to TxDOT Test Method Tex-404-A and is needed to calculate the voids in the aggregate in a loose condition. The loose unit weight is used to calculate the air voids expected between the stones after initial rolling. It depends on the gradation, shape, and specific gravity of the aggregate.

Voids in the Loose Aggregate. The voids in the loose aggregate (V) approximate the voids present when the stones are dropped from the spreader onto the pavement. Generally, this value will be near 50 percent for one size of aggregate, less for graded aggregate. After initial rolling, the voids are assumed to be reduced to 30 percent and will reach a low of about 20 percent after sufficient traffic has oriented the stones on their flattest side. However, if there is very little traffic, the voids will remain 30 percent, and the seal will require more binder to ensure good aggregate retention. The following equation is used to calculate the voids in the loose aggregate:

$$V = 1 - W/62.4G$$

Equation 4-7.
where:

- V = Voids in the loose aggregate, in percent expressed as a decimal
- W = Loose unit weight of the cover aggregate, lbs/ft^3
- G = Bulk specific gravity of the aggregate (Tex-403-A for natural aggregates and Tex-433-A for lightweight aggregates).

Aggregate Absorption. Most aggregates absorb some of the binder applied to the roadway. The design procedure should be able to correct for this condition to ensure enough binder will remain on the pavement surface. McLeod suggests an absorption correction factor, A, of 0.02 gal/SY if the aggregate absorption is around 2 percent (as determined from Tex-403-A). In the

Minnesota Seal Coat Handbook, it is recommended that a correction factor of 2 percent be used if the absorption is 1.5 percent or higher.

Traffic Volume. The traffic volume, in terms of vehicles per day, plays a role in determining the amount of asphalt binder needed to sufficiently embed the aggregate. Typically, the higher the traffic volume, the lower the binder application rate. At first glance, this may not seem correct. However, remember that traffic forces the aggregate particles to lie on their flattest side. If a roadway had no traffic, the particles would be lying in the same orientation as when they were first rolled during construction. As a result, they would stand taller and need more asphalt binder to achieve the ultimate 70 percent embedment. With enough traffic, the aggregate particles will be laying as flat as possible causing the seal coat to be as thin as possible. If this is not taken into account, the wheel paths will likely bleed. The McLeod procedure uses Table 4-3 to estimate the required embedment, based on the number of vehicles per day on the roadway.

Traffic Factor*				
Traffic – Vehicles per day				
Under 100	100 to 500	500 to 1000	1000 to 2000	Over 2000
0.85	0.75	0.70	0.65	0.60
* The percentage, expressed as a decimal, of the ultimate 20 percent void space in the aggregate to be filled with asphalt.				

Traffic Whip-Off. The McLeod method also recognizes that some of the aggregate will get thrown to the side of the roadway by passing vehicles as the seal coat is curing. This loss is related to the speed and number of vehicles on the new seal coat. To account for this, a traffic whip-off factor (E) is included in the aggregate design equation. A reasonable value is to assume 5 percent for low volume, residential type traffic and 10 percent for higher speed roadways Existing Pavement Condition. The condition of the existing pavement plays a major role in the amount of binder required to obtain proper embedment. A new smooth pavement with low air voids will not absorb much of the binder applied to it. Conversely, a dry, porous and pocked pavement surface can absorb much of the applied binder. Failure to recognize when to increase or decrease binder application rate to account for the pavement condition can lead to excessive stone loss or bleeding. The McLeod method uses the descriptions and factors in Table 4-5 to add or reduce the amount of binder to apply in the field.

Table 4-5. Surface Correction Factor, S.

Existing Pavement Texture	Correction, S
Black, flushed asphalt surface	– 0.01 to – 0.06
Smooth, nonporous surface	0.00
Slightly porous, oxidized surface	+ 0.03
Slightly pocked, porous, oxidized surface	+ 0.06
Badly pocked, porous, oxidized surface	+ 0.09

McLeod Seal Coat Design Equations

The following equations are used to determine the aggregate and binder application rates. While the results may need adjustment in the field, especially the binder application rate, they have been shown to provide a close approximation of the correct material quantities.
Aggregate Design Equation. The aggregate application rate is determined from the following equation:

$$C = 46.8\langle 1 - 0.4V\rangle HGE$$

Equation 4-8.
where:

- C = Aggregate application rate, lbs/SY
- V = Voids in the loose aggregate, in percent expressed as a decimal (Eq. 7)
- H = Average least dimension, inches
- G = Bulk specific gravity of the aggregate
- E = Wastage factor for traffic whip-off (Table 4-4).

Binder Design Equation .The binder application rate is determined as follows:

$$B = \frac{2.244HTV + S + A}{R}$$

Equation 4-9.
where:

- B = Binder application rate, gal/SY
- H = Average least dimension, inches
- T = Traffic Correction Factor (based on vehicles per day, Table 4-3)
- V = Voids in loose aggregate, percent expressed as decimal (Eq. 7)
- S = Surface condition factor, gal/SY (based on existing surface, Table 4-5)
- A = Aggregate absorption factor, gal/SY
- R = Percent residual asphalt in the emulsion expressed as a decimal. Check with supplier to determine percent residual asphalt content of emulsion. For asphalt cement, R = 1.

Design of Flexible Pavement by Group Index Method :
Determination of Group Index Value of Soil Subgrade Group Index is a number assigned to the soil based on its physical properties like particle size, Liquid limit and plastic limit. It varies from a value of 0 to 20, lower the value higher is the quality of the sub-grade and greater the value, poor is the sub-grade. By sieve analysis test we can determine Group index value of soil subgrade from below equation

$$\mathbf{GI = 0.2a + 0.005\,ac + 0.01bd}$$

Where,
a= percentage of soil passing 0.074 mm sieve in excess of 35 per cent, not exceeding 75.
b= percentage of soil passing 0.074 mm sieve in excess of 15 per cent, not exceeding 55.
c= Liquid limit in per cent in excess of 40.
d= Plasticity index in excess of 10.

4.Group Index Method of Flexible Pavement Design

Data Required for Flexible Pavement Design

1. Group index of soil subgrade

Group index value range of different soils is given below

- For good soil – 0 to 1
- For fair soil – 2 to 4
- For poor soil – 5 to 9
- For very poor soil – 10 to 20

2. Traffic volume It is the measure of Annual average daily traffic, peak-hour traffic. It is denominated by commercial vehicles/day or CVPD.

It is classified in three categories. Based on number of vehicles per day.

If no. of vehicles per days is

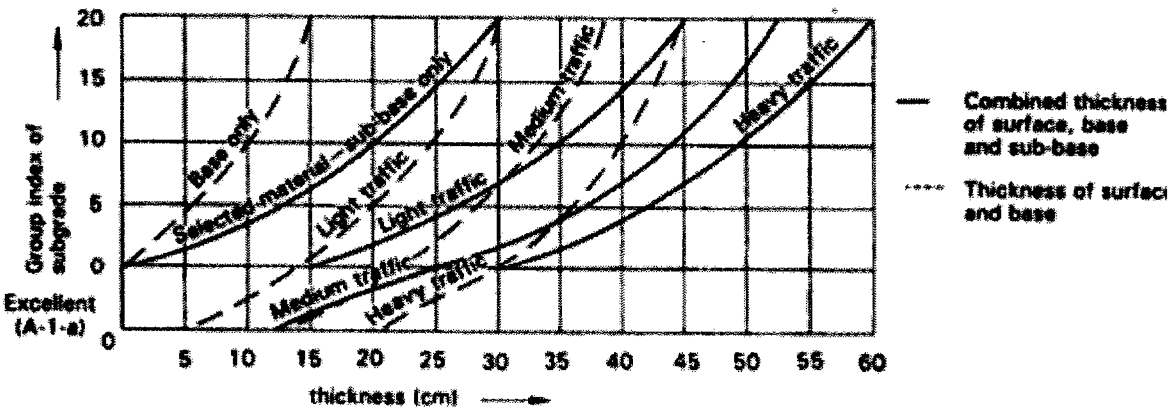
- <50 – light traffic
- 50-300 – medium traffic
- >300 – Heavy traffic

Flexible Pavement Design Procedure:

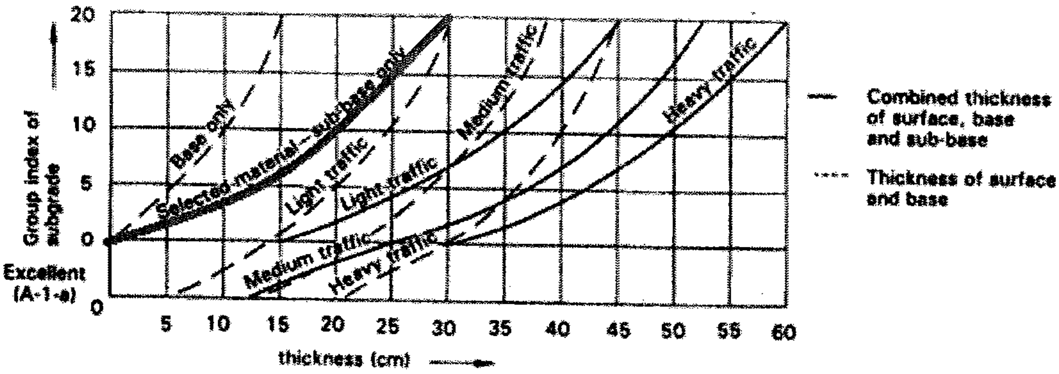
Before going to design the pavement we must know the structure of flexible pavement

Calculation total thickness (T):

From the below chart for given group index of soil subgrade and traffic volume value select appropriate thick curve value of "combined thickness of surface, base and sub-base line" which will give the total thickness of pavement.



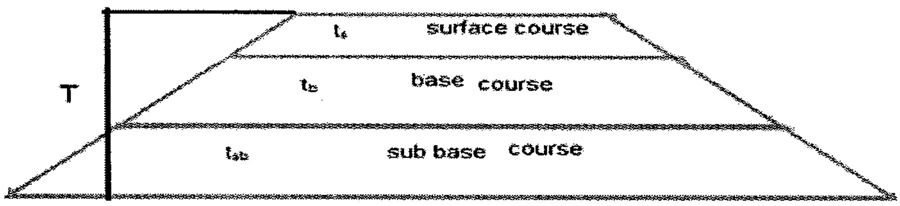
Calculation thickness of sub-base course (t_{sb}): From the below chart for given group index of soil subgrade select appropriate curve value of "thickness of sub base only" which will give the thickness of the sub-base course. The curve highlighted in below diagram



Calculation of thickness of base and surface course (t_b & t_s): Thickness of surface and base course = total thickness – sub-base thickness = **T – t_{sb}** The combined value of thickness of base and surface course can be found out from above chart form dotted curve with the help of group index value and traffic volume. Or otherwise assume the thickness of surface course (t_s) = 5 cm Then we can easily calculate the value of thickness of the base course,

$$T_b = T - t_{sb} - t_s$$

Cross section of flexible pavement:



The group index method is essentially an empirical method based on the physical properties of the subgrade soil and it does not consider the strength characteristics of soil and is therefore open to question regarding its reliability.

The pavement is designed as a flexible pavement upon a black cotton soil sub grade, the CBR method as per IRC 37-2001 is most appropriate method than available methods. The pavement is designed as a flexible method from which each method is designed on the basis of their design thickness from which each method has different cost analysis of a section, from which CBR as per IRC is most appropriate in terms of cost analysis.

Design Of Rigid Pavement

Data: Width of expansion joint gap=2.5cm

Maximum variation in temperature between summer and winter=13.10c

Thermal coefficient of concrete=10*100C

Allowable tensile stress in CC during curing=0.8Kg/cm2

Coefficient of friction=1.5

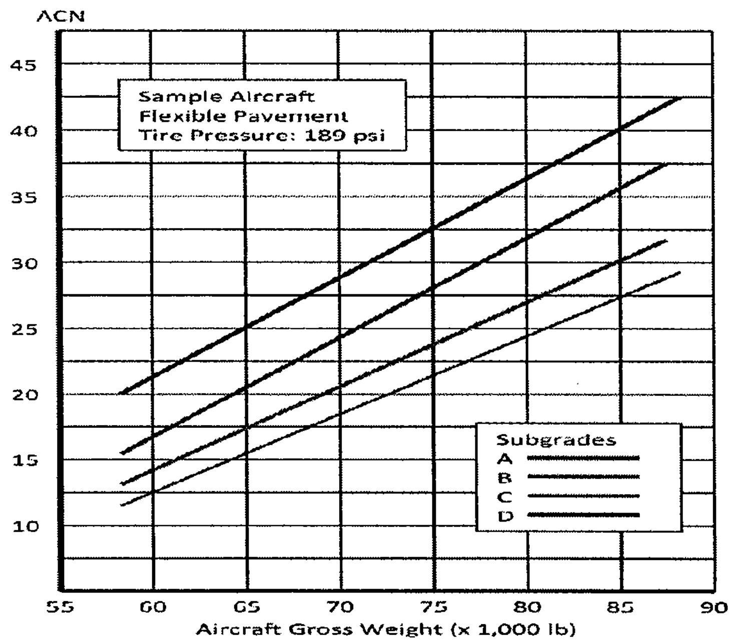
Unit weight of CC=2400kg/cm3
Design wheel load=5100Kg
Radius of contact area=15Cm
Modulus of reaction of sub base course=14.5Kg/cm3
Flexural strength of concrete =45Kg/cm2+
E value of concrete=3*105Kg/cm2
Value =0.15Δ Design load transfer through dowel system=40%
Permissible flexural stress in dowel bar=1400Kg/cm2
Permissible shear stress in dowel bar=1000Kg/cm2
Permissible bearing stress in concrete =100Kg/cm2
Permissible tensile stress in steel=1400Kg/cm2
Permissible bond stress in deformed tie bars=24.6Kg/cm2
Present traffic intensity=4100
commercial vehicles/day (Data collected by traffic survey)
(Note: The data assumed based on IRC-58:2002) SLAB THICKNESS
Assume trial thickness of slab=20cm
Radius of relative stiffness, Eh3[I= μ/12K(1- 2]) 1/4 =[3*105*203/12*14.5(1-0.152)]1/4
L=61.28 Lx/I=445/95.41 =4.66 Ly/I = 350/95.41 =3.66(according to I.R.C.Chart)
Adjustment for traffic intensity Ad =P' (1+r)(n+30)
Assuming growth rate =75 %
Number of year after the last count before new pavement is opened to traffic n =3 Ad =4100 (1+(7.5/100))(3+30) =44592.6 CV/day
So traffic intensity being in the range >4500, Fall in group and the adjustment factor =+2cm
So revised design thickness of the slab =20+2 =22 cm

The pavement is designed as a rigid pavement, the method suggested by IRC is most suitable. It is observed that flexible pavements are more economical for lesser volume of traffic. The life of flexible pavement is near about 15 years whose initial cost is low needs a periodic maintenance after a certain period and maintenance costs very high. The life of rigid pavement is much more than the flexible pavement of about 40 years approx 2.5 times life of flexible pavement whose initial cost is much more then the flexible pavement but maintenance cost is very less.

LCN SYSSTEM OF PAVEMENT DESIGN :

Load Classification Number LCN A number expressing the relative effect of an aircraft on a pavement or the bearing strength of a pavement. The original LCNclassification system was developed in the UK in the late 1940s but in 1971 the method of calculating LCNs was altered and the LCN/LCG system introduced.

Contact area = load / tire pressure



system of classification of the supporting capacity of pavements,indicating their ability to sup port loads without cracking or becoming permanently deformed.

The number is obtained by making plate bearing tests on the pavement. Likewise, the equivalent ingle wheel load of any aircraft can be expressed in terms of LCN.

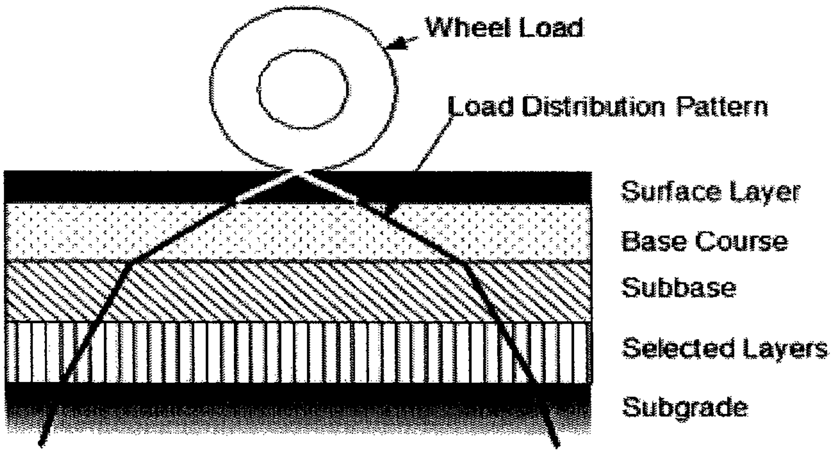
LCN isdependent on the gear geometry, tire pressure, and the compositionand thickness of th e pavement. Thus, if the LCN of an airfield pavementis larger than the LCN of the aircraft, th e aircraft can safely use thepavement. To express the capacity of pavement as a single number , thestandard load classification was introduced (shown in the table).

Wheel loading		Tire pressure		LCN
(Lbs)	(kg)	(psi)	(kg/cm^2)	
10,000	4,500	75	5.27	10
20,000	9,100	80	5.62	20
30,000	13,600	85	5.98	30
40,000	18,600	90	6.33	40
50,000	22,700	95	6.68	50
60,000	27,200	100	7.03	60
70,000	31,800	105	7.38	70
80,000	36,300	110	7.74	80
90,000	40,800	115	8.09	90
1,00,000	45,400	120	8.44	100

Pavement failures:

Introduction

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable light reacting characteristics, and low noise pollution. The major Flexible pavement failures are fatigue cracking, rutting, and thermal cracking. The fatigue cracking of flexible pavement is due to horizontal tensile strain at the bottom of the asphaltic concrete. The failure criterion relates allowable number of load repetitions to tensile strain and this relation can be determined in the laboratory fatigue test on asphaltic concrete specimens. Rutting occurs only on flexible pavements as indicated by permanent deformation or rut depth along wheel load path. Two design methods have been used to control rutting: one to limit the vertical compressive strain on the top of sub-grade and other to limit rutting to a tolerable amount (12 mm normally. Thermal cracking includes both low temperature cracking and thermal fatigue cracking.



Failures may be:

Failure in sub grade

- Inadequate Stability
- excessive application of stresses
- plastic deformation

Failures in sub base or Base course

- Inadequate stability
- Loss of binding action
- Loss of bearing course materials
- Inadequate wearing course

Causes of Premature Failures

- Rutting due to high variation in ambient temperature
- Uncontrolled heavy axle loads
- Limitation of pavement design procedures to meet local environmental conditions

Common Flexible Pavement Failure/ Distresses

- Cracking
- Deformation
- Deterioration
- Mat problems
- Problems associated with seal coats

Category	Distress type
1. Cracking	Longitudinal, Fatigue,Transverse,reflective,block,edge
2.Deformation	Rutting,Corrugation,Shoving,depression,overlay bumps
3. Deterioration	Delamination,Potholes,Patching,raveling,stripping,Polished aggregate, Pumping
4. .Mat Problems	Segregation,Checking,Bleeding
5. Seal coats	Rock loss,Segregation,bleeding/fat spots,Delamination

Types of Distresses/Failures and Definitions :

Longitudinal Cracking: Cracks that are approximately parallel to pavement centerline and are not in the wheel path. Longitudinal cracks are non-load associated cracks. Location within the lane (wheel path versus non-wheel path) is significant. Longitudinal cracks in the wheel path are normally rated as Alligator 'A 'cracking

Fatigue Cracking: Cracks in asphalt layers that are caused by repeated traffic loadings. The cracks indicate fatigue failure of the asphalt layer. When cracking is characterized by interconnected cracks, the cracking pattern resembles that of an alligator's skin or chicken wire. Therefore, it is also referred to as alligator cracking

Transverse Cracking: Cracks that are predominately perpendicular to pavement centerline and are not located over Portland cement concrete joints. Thermal cracking is typically in this category

Reflection Cracking: Cracks in HMA overlay surfaces that occur over joints in concrete or over cracks in HMA pavements.

Block Cracking: Pattern of cracks that divides the pavement into approximately rectangular pieces. Rectangular blocks range in size from approximately 0.1 square yard to 12 square yards

Edge Cracking: Crescent-shaped cracks or fairly continuous cracks that intersect the pavement edge and are located within 2 feet of the pavement edge, adjacent to the unpaved shoulder. Includes longitudinal cracks outside of the wheel path and within 2 feet of the pavement edge.

Rutting: Longitudinal surface depression that develops in the wheel paths of flexible pavement under traffic. It may have associated transverse displacement.
Corrugation: Transverse undulations appear at regular intervals due to the unstable surface course caused by stop-and-go traffic
Shoving: A longitudinal displacement of a localized area of the pavement surface. It is generally caused by braking or accelerating vehicles, and is usually located on hills or curves, or at intersections. It also may have vertical displacement
Depression: Small, localized surface settlement that can cause a rough, even hazardous ride to motorists
Overlay Bumps: In newly overlaid pavements, bumps occur
Delaminating: Loss of a large area of pavement surface. Usually there is a clear separation of the pavement surface from the layer below. Slippage cracking may often occur as a result of poor bonding or adhesion between layers.
Pot holes: Bowl-shaped holes of various sizes in the pavement surface. Minimum plan dimension is 150 mm.
Patching: Portion of pavement surface, greater than 0.1 sq. meter, that has been removed and replaced or additional material applied to the pavement after original construction.
Raveling: Wearing away of the pavement surface in high-quality hot mix asphalt concrete that may be caused by the dislodging of aggregate particles and loss of asphalt binder.
Stripping: The loss of the adhesive bond between asphalt cement and aggregate, most often caused by the presence of water in asphalt concrete, which may result in raveling, loss of stability, and load carrying capacity of the HMA pavement or treated base
Polished aggregate: Surface binder worn away to expose coarse aggregate
Pumping: Seeping or ejection of water and fines from beneath the pavement through cracks.
Segregation: Separation of coarse aggregate from fine aggregate as a result of mishandling of the mix at several points during mix production, hauling, and placing operations. Segregation leads to non-uniform surface texture and non-uniform density
Checking: Short transverse cracks, usually 1 to 3 inches in length and 1 to 3 inches apart, which occur in the surface of the HMA mat at some time during the compaction process. The cracks do not extend completely through the depth of the course, but are only about ½inch deep
Bleeding/Flushing: Excess bituminous binder occurring on the pavement surface. May create a shiny, glass-like, reflective surface that may be tacky to the touch. Usually found in the wheel paths
Segregation: Separation of coarse aggregate from fine aggregate as a result of mishandling of the mix at several points during mix production and placing operations. Segregation leads to nonuniform surface texture
Bleeding/Fat Spots: Excess binder occurring on the surface treated pavements. May create a shiny, glass-like, reflective appearance. Fat spots are localized bleeding

Common Rigid Pavement Distresses

- **Spalling Faulting**
- **Cracking**
- **Longitudinal cracks**
- **Slab cracking**
- **Durability**
- **"D" cracking**
- **Polished Aggregates**
- **Pop-out**
- **Blow Ups**
- **Pumping and**
- **water bleeding**
- **Shrinkage**
- **Cracking**

Spalling at the Joint :

- Cracking, breaking or chipping of joint/crack edges. Usually occurs within about 0.6 m (2 ft.) of joint/crack edge.
- Loose debris on the pavement, roughness, generally an indicator of advanced joint/crack deterioration.
- Excessive stresses at the joint/crack caused by infiltration of incompressible materials and subsequent expansion (can also cause blowups).

Faulting :

- A difference in elevation across a joint or crack usually associated with undoweled JPCP.
- Usually the approach slab is higher than the leave slab due to pumping, the most common faulting mechanism.
- Faulting is noticeable when the average faulting in the pavement section reaches about 2.5 mm (0.1 inch).
- When the average faulting reaches 4 mm (0.15 in), diamond grinding or other rehabilitation measures should be considered.

Longitudinal Cracking :

- Longitudinal cracks not associated with corner breaks or blowups that extend across the entire slab.
- Typically, these cracks divide an individual slab into two to four pieces.
- Often referred to as "panel cracking".

Corner Cracking :

- A crack that intersects the PCC slab joints near the corner. "Near the corner" is typically defined as within about 2 m (6 ft) or so.
- A corner break extends through the entire slab and is caused by high corner stresses.

- Severe corner stresses caused by load repetitions combined with a loss of support, poor load transfer across the joint, curling stresses and warping stresses.

Durability:

- Cracking Series of closely spaced, crescent-shaped cracks near a joint, corner or crack.
- It is caused by freeze-thaw expansion of the large aggregate within the PCC slab.
- Durability cracking is a general PCC distress and is not unique to pavement PCC.
- Some roughness leads to spalling and eventual slab disintegration.

Polished Aggregate :

- Areas of pavement (either PCC or HMA) where the portion of aggregate extending above the asphalt binder (in the case of HMA) or cement paste (in the case of PCC) is either very small or there are no rough or angular aggregate particles. Repeated traffic applications.
- Generally, as a pavement ages the protruding rough, angular particles become polished.
- This can occur quicker if the aggregate is susceptible to abrasion or subject to excessive studded wear and tear.

Popouts:

- Small pieces of PCC that break loose from the surface leaving small divots or pock marks.
- Pop outs range from 25 – 100 mm (1 – 4 inches) in diameter and from 25 – 50 mm (1 – 2 inches) deep.
- Pop outs usually occur as a result of poor aggregate durability.
- Poor durability can be a result of a number of items
  such as:
    - Poor aggregate freeze-thaw
    - resistance.
    - Expansive aggregates
    - Alkali-aggregate reactions

Blow-ups

- A localized upward slab movement and shattering at a joint or crack.
- Usually occurs in spring or summer and is the result of insufficient room for slab expansion during hot weather.
- During cold periods (e.g., winter) PCC slabs contract leaving wider joint openings. If these openings become filled with incompressible material (such as rocks or soil), subsequent PCC slab expansion during hot periods (e.g., spring, summer) may cause high compressive stresses.
- If these stresses are great enough, the slabs may buckle and shatter to relieve the stresses.
- **Blowup can be accelerated by:**
    - Joint Spalling (reduces slab contact area and provides incompressible material to fill the joint/crack).

- D-Cracking (weakens the slab near the joint/crack area).
- Freeze-thaw damage (weakens the slab near the joint/crack area).

Pumping and Water Bleeding :

- Movement of material underneath the slab or ejection of material from underneath the slab as a result of water pressure.
- Water accumulated underneath a PCC slab will pressurize when the slab deflects under load.
- This pressurized water can do one of the following:
  - Move about under the slab.
  - Move from underneath one slab to underneath an adjacent slab.
  - This type of movement leads to faulting.
  - Move out from underneath the slab to the pavement surface.
  - This results in a slow removal of base, sub-base and/or sub grade material from underneath the slab resulting in decreased structural support.

Shrinkage Cracking :

- Hairline cracks formed during PCC setting and curing that are not located at joints. Usually, they do not extend through the entire depth of the slab.
- Shrinkage cracks are considered a distress if they occur in an uncontrolled manner (e.g., at locations outside of contraction joints in JPCP or too close together in CRCP).
- Possible causes-
  - Contraction joints sawed too late.
  - Poor reinforcing steel design.
  - Improper curing technique.
  - High early strength PCC

Maintenance And Rehabilitation

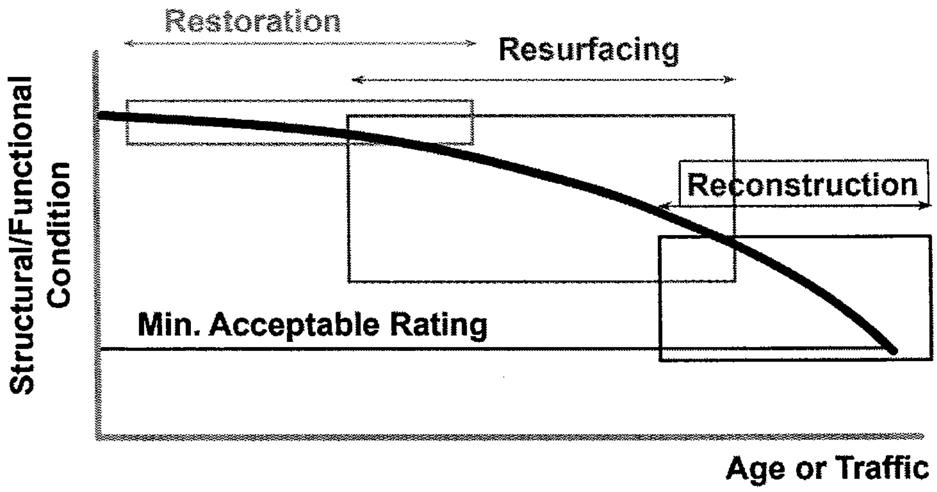
- The combined effects of traffic loading and the environment will cause every pavement, no matter how well-designed/constructed to deteriorate over time. Maintenance and rehabilitation are what we use to slow down or reset this deterioration process.
- Maintenance actions, such as crack sealing, joint sealing, fog seals and patching help slow the rate of deterioration by identifying and addressing specific pavement deficiencies that contribute to overall deterioration.
- Rehabilitation is the act of repairing portions of an existing pavement to reset the deterioration process.
- For instance, removing and replacing the wearing course in a pavement provides new wearing course material on which the deterioration process begins anew.
- This Module discusses the maintenance options for HMA and PCC pavement.

➢ Rigid Pavement Distress is a serious issue all over the world,

➢ The distresses causes some serious problems at wide range.

➢ Prevention of rigid pavement distress is a challenge to the Engineers.
➢ Maintenance and Rehabilitation is to be properly done to prevent the distresses in rigid pavement.

Pavement maintenance :



- Pavement maintenance is treatment of road defects The first step in the maintenance process is collection of information about defects •
- Some defects are environment-related, like silting of drains, clogging of culverts & vegetation growth. These are treated under routine maintenance (say, twice a year).
- Traffic induced defects are assessed by manual and mechanical methods and treated according to the type and intensity of defect.

Pavement Defect: Cracking

Development If neglected, general or local destruction of pavement

Remedies

Surface cracking: local sealing or filling of cracks

Cracks in pavement structure: local sealing, filling of cracks and patching when cracking is severe

Treatment: Local Sealing

• Defects treated: Cracks & Final treatment for local repairs

• Material used

Cutback bitumen, coarse sand up to 5 mm, chippings 6 to 10 mm size for local repairs

Execution steps

a) sweep area (surface must be clean & dry)

b) mark out the area to be sealed, with chalk

c) distribute binder (use water can) 1kg/m2 ; do not overheat bitumen.

d) distribute aggregate by scattering with shovel.. Whole area must be covered.

crack sealing •

Defects treated

Closely spaced cracks

• Materials used

Bituminous slurry

• Execution

a) Sweep the area (surface must be dry and clean)

b) mark out the area to be repaired, with a chalk

c) prepare bitumen slurry by mixing 6 liters of bitumen emulsion with20 liters of coarse sand (< 5mm) –

d) Spread the slurry with squeegee in thin layer 5 mm thick) over marked area. Allow it to dry before allowing traffic

Airport drainage

An adequate drainage system for the removal of surface and subsurface water is vital for the safety of aircraft and for the long service life of the pavements. Improper drainage results in the formation of puddles on the pavement surface which can be hazardous to aircraft taking off and landing poor drainage can also results in the early deterioration of pavements.

Purpose of drainage

The functions of an airport drainage system are as follows;

- Intercepting and diversion of surface and ground water flow originating from lands adjacent to the airport.
- Removal of surface run off from the airport
- Removal of subsurface flow from the airport

Design storm for surface run off

Federal aviation administration recommends that for civil airports the drainage system be designed for a storm whose probability of occurrence is once in 5 years. The designs should, however be checked with a storm of lesser frequency (10 to 15 years). Drainage system for military airfields is based on a 2-years storm frequency. Rainfall intensity is expressed in inches per hour for various durations of a particular storm. The FAA adopts the following formula for the calculation of amount of run off.

$$Q = CIA$$

Q = Run off from the drainage basin (ft/sec)

C = ratio of runoff to rainfall (coefficient of runoff)

I = Rainfall intensity (inch /hour)

A = Drainage area in acres

For drainage basins consisting of several types of surfaces with different infiltration characteristics, the weighted run off coefficient should be computed as

$$C = \frac{A_1C_1+A_2C_2+A_3C_3}{A_1+A_2+A_3}$$

Having calculated the discharge to be handled, the pipes diameter is determined. Pipes used are of perforated metal, concrete on vitrified clay. Pipes are of usually 6" diameter wth a minimum recommended slope of 0.15%. a minimum thickness of 6" of filter material should surround the drain and filter material must be many times more pervious than the protected soil. For cleaning and inspection, manholes and risers are often installed along the drains. The crops of engineers recommend that manhole be placed at intervals not more than 1000 ft with one riser midway between the manholes. Some time one combined drain is provided both for surface and subsurface drainage (combined system).

Surface drainage

Water from a discharge area is collected into the storm drain by means of inlets. The inlets structures consists of a concrete box, whose top is covered with a grating made of cast iron, cast steel or reinforced concrete a cover is designed to takes aircraft wheel loads. The inlets are spaced from 200 – 400 ft. Support locations of inlets depend on the configuration of the airport and on the grading plan.

Normally drains are placed near the edge of the runway pavement or at the toe of the slope of the graded area. The grades of the storm drain should be such as to maintain a minimum velocity of 2.5 ft/sec self cleaning velocity. The diameter of surface drains should not be less than 12". The design should be such that entire quantity of surface run off should be removed in 1 to 2 hours following the rain storm.

Ponding

If the airport area is subjected to high rainfall intensities and calculations gives very large diameter of drains required to remove water from the land area. So ponding of water is done to accumulate water for some time and then allow it to enter the drains, thus reducing size of drains. Water is collected in catch basin and carried away by storm sewer.

Sub surface drainage

Functions of subsurface drainage are to

Remove water from a base course

Remove water from the sub grade beneath a pavement and

Intercept, collect and remove water flowing from springs and previous strata.

Base drainage is usually required;

Where frost action occurs in the sub-grade beneath a pavement

Where the ground water is expected to rise to the level of base course.

Where the pavement is subjected to frequent inundation and the sub-grade is highly impervious and sub surface waters from adjacent areas are seeping towards the airport pavements.

Methods for draining sub-surface water : Base course are usually drained by installing sub-surface drains adjacent to and parallel to the edge of pavement. The pervious material in the trench should extend to the bottom of base course and center line of the drain pipe should be placed a minimum of 1 ft below the bottom of the base course. Sub grade is drained by pipes installed along the edge of the pavement and the center line of the drain should be placed at edge.

UNIT VI PLANNING, LAYOUT, CONSTRUCTION & MAINTENANCE OF DOCKS & HARBORS

Dock: the enclosed area provided for berthing ships to keep them afloat at a uniform level to facilitate loading and unloading is called the dock.

Harbor: The sheltered area of the sea in which vessels could be launched, built or repaired, or could seek refuge during storm time and provide loading and unloading facilities of cargo and passengers is called harbor.

PORT: A port is a location on a coast or shore containing one or more harbors where ships can dock and transfer people or cargo to or from land. ... A port is usually located inside a harbor.

CLASSIFICATION OF PORTS
1.Inland port
2.Fishing port
3.Dry port
4.Warm-water port
5.Seaport
→Cruise home port
→Port of call
→Cargo port

1. Inland port: An inland port is a port on an inland waterway, such as a river, lake, or canal, which may or may not be connected to the ocean. The term "inland port" is also used to refer to a dry port, which is an inland extension of a seaport, usually connected by rail to the docks.

2. Fishing port: A fishing port is a port or harbor for landing and distributing fish. It may be a recreational facility, but it is usually commercial. A fishing port is the only port that depends on an ocean product, and depletion of fish may cause a fishing port to be uneconomical.

3. Dry port: A dry port (sometimes inland port) is an inland intermodal terminal directly connected by road or rail to a seaport and operating as a centre for the transshipment of sea cargo to inland destinations.

4. Warm-water port: A "warm water port" is a port where the water does not freeze in winter. Because they are available year-round, warm water ports can be of great geopolitical or economic interest, with the ports of Saint Petersburg and Valdez being notable examples.

5. Seaport: a port, harbor, or town accessible to seagoing ships

→ **Cruise home port**: A cruise home port is the port where cruise ship passengers board (or embark) to start their cruise and disembark the cruise ship at the end of their cruise.

→**Port of call**: A port where a ship docks in the course of a voyage, especially to load or unload passengers or cargo, to obtain supplies, or to undergo repairs.

→**Cargo port**: A port is a maritime commercial facility which may comprise one or more wharves where ships may dock to load and discharge passengers and cargo. Although usually situated on a sea coast or estuary, some ports, such as Hamburg, Manchester and Duluth, are many miles inland, with access from the sea via river or canal.

REQUIREMENTS OF A GOOD PORT:

1. It should be centrally situated for the hinterland. For a port, the hinterland is that part of the country behind it which can be served with economy and efficiency by the port.
2. It should get good tonnage i .e. charge per ton of cargo handled by it. It should have good communication with the rest of country.
3. It should be populous
4. It should be advance in culture, trade and industry.
5. It should be a place of defense and for resisting the sea-borne invasion it should command valuable and extensive trade.
6. It should be capable of easy, smooth and economic development. It should afford shelter to all ships and at all seasons of the years
7. It should provide the maximum facilities to all the visiting ships including the servicing of ships.

Harbor:
→It is a sheltered area
→Used for loading and unloading of cargo
→Vessels are also built, repair and launch
→It protects ships naturally or artificially from fury of sea
→Ships, boats, and barges can seek shelter from stormy weather, in navigable waters well
→protected naturally or artificially
→Situated along sea shore or river estuary or lake or canal connected to sea

CLASSIFICATION OF HARBORS:

1. **Natural harbors**
2. **Semi-natural harbors**
3. **Artificial harbors.**

1. **Natural harbor:** A natural harbor is a landform where a part of a body of water is protected and deep enough to furnish anchorage. Many such harbors are rias. Natural harbors have long been of great strategic naval and economic importance, and many great cities of the world are located on them.
   →Natural formations affording safe discharge facilities for ships on sea coasts, in the form of creeks and basins, are called natural harbors.
   →With the rapid development of navies engaged either in commerce or war, improved accommodation and facilities for repairs, storage of cargo and connected amenities had to be provided in natural harbors.
   →The size and draft of present day vessels have necessitated the works improvement for natural harbors.
   →The factors such as local geographical features, growth of population, development of the area, etc. have made the natural harbors big and attractive. Bombay and Kendal are, examples of natural harbors
2. **Semi natural:** This type of harbor is protected on sides by headlands protection and it requires man-made protection only at the entrance
3. **Artificial harbor:** An artificial harbor can have deliberately constructed breakwaters, sea walls, or jetties or they can be constructed by dredging, which requires maintenance by further periodic dredging. In contrast, a natural harbor is surrounded on several sides by prominences of land.

Requirements of a good harbor:

→The depth of a harbor should be sufficient for every type of visiting ships.
→The bottom of harbor should provide secured anchorage to hold the ships against high winds.
→To prevent destructive wave action, break water are provided.
The entrance of a harbor should be wide enough to provide the easy passage of ships.

Harborarea required depends uponthe following factors:

→Size and number of ships to be accommodated in the harbor at a time
→Length and width needed for movement of ships to and from berths.
→Type of cargo carried

Classifications of docks: If ship is subjected to a vertical movement by the tides, great inconvenience will be felt in lifting the cargo from the ship and special arrangement will be needed for lifting the cargo
Docks can be classified into following two categories:

- **Wet docks.**
- **Dry docks.**

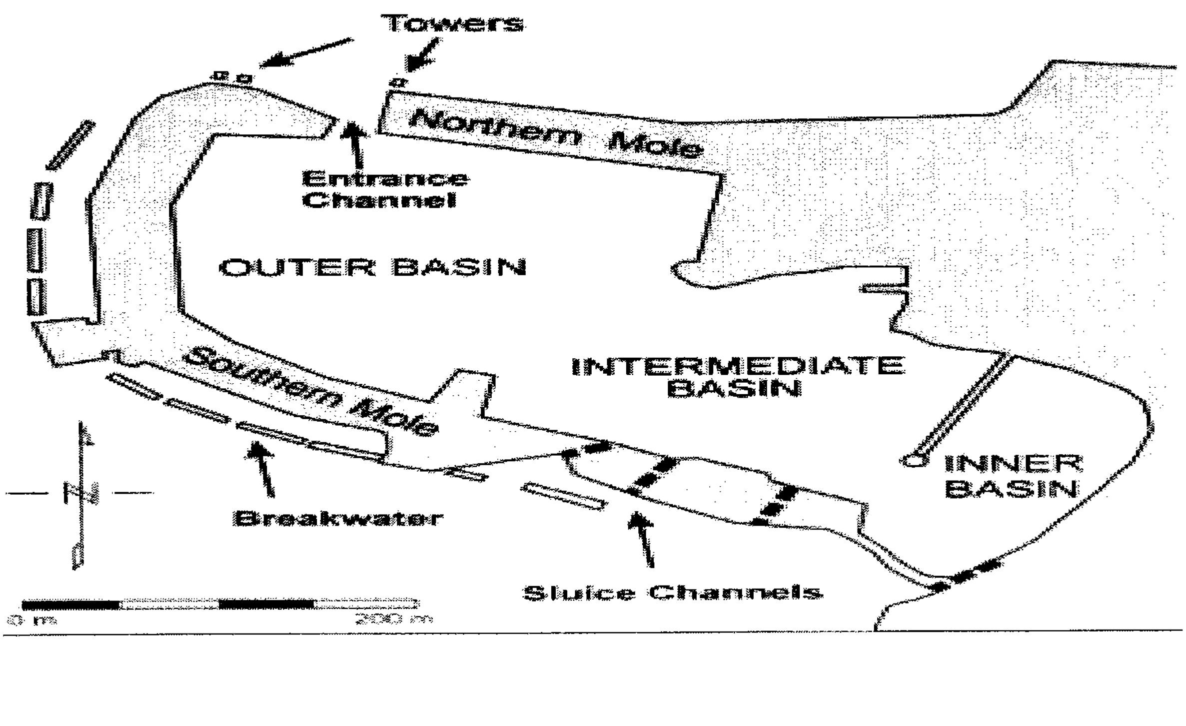
- **Wet docks:** Docks required for berthing of ships or vessels to facilitate the loading and unloading of passengers and cargo are called wet docks.
  These are also known as harbor docks.

- **Dry docks:** The docks used for repairs of ships are known as dry docks.
  It is long excavated chamber, having side walls, a semi circular end wall and a floor. The open end of the chamber is provided with a gate and acts as the entrance to the dock

Transit shed: It is a shed for goods in transit from the vessel to the consignees or from consignors to the vessel. For export cargo, to facilitate the quick loading cargo is first brought to a transit shed and collected there. In case of import cargo, it is not possible to clear all the destinations by railway and trucks. In fact for general cargo, verification of marks, quantity and safe delivery makes it necessary to take this cargo to a temporary covered storage, thus for a temporary storage, a covered arrangement is called a transit shed.

Workhouse: It is a shed for goods in transit from the vessel to the consignees or from consignors to the vessel. For export cargo, to facilitate the quick loading cargo is first brought to a workhouse and collected there. In case of import cargo, it is not possible to clear all the destinations by railway and trucks. In fact for general cargo, verification of marks, quantity and safe delivery makes it necessary to take this cargo to a permanent covered storage, thus for a permanent storage, a covered arrangement is called a workhouse. It means the goods can be stored for years as compared to transition sheds.

Layout of harbor :



Selection of site :

The guiding factors which play a great role in choice of site for a harbor are as follows :

→Availability of cheap land and construction materials Transport and communication facilities

→Natural protection from winds and waves Industrial development of the locality

→Sea-bed subsoil and foundation conditions Traffic potentiality of harbor

→Availability of electrical energy and fresh water Favorable marine conditions

→Defense and strategic aspects

Shape of the harbor: The following principles should be kept in mind:

In order to protect the harbor from the sea waves, one of the pier heads should project a little beyond the other.

Inside the pier heads, the width should widen very rapidly.

The general shape of the harbors should be obtained by a series of straight lengths and no re-entrant angle should be allowed

Harbor planning: The important facts to be studied and scrutinized can be enumerated as follows:

It is necessary to carry out a thorough survey of the neighborhood including the foreshore and the depths of water in the vicinity

The borings on land should also be made so as to know the probable subsurface conditions on land. It will be helpful in locating the harbor works correctly

Features of harbor:

- **Break water**
- **Docks**
- **Entrance channel**
- **Jetty**
- **Light house**
- **Berthing Basin**
- **Turning Basin**
- **Pier Head**
- **Wharves**

Breakwater :

→Breakwater are the structures constructed to enclose the harbors to protect them from the effect of wind generated waves by reflecting and dissipating their force or energy.

→Helps to use the area thus enclosed as a safe anchorage for ships and to facilitate loading and unloading of water by means of wave breakers.

→Height depends upon the its purpose, extent of enclosed water area and nature of existing shipping work.

→Generally the height of breakwater is kept as equivalent to 1.2 to 1.25 times the waves expected.

→It also helps to prevent beach erosion

→The most common breakwater used has a core of small rocks or rubble with a covering of large rocks to keep the core from being washed away

→It may be small structures, placed one to three hundred feet offshore in relatively shallow water

→Breakwater either fixed or floating- choice depend on normal water depth & tidal range Its construction is usually parallel or perpendicular to the coast

Alignment: A good alignment for a breakwater is to have straight converging arms so that the angle of inter section does not exceed 60 degrees. It is desirable to avoid straight parallel or diverging arms running out to sea.

Design of breakwaters: Following information should he collected before the design of a breakwater:

→Character of coastal currents

→Cost and availability of materials of construction

→Directions and force of prevailing winds

→Nature of the bottom or foundation

→Probable maximum height, force and intensity of waves.

The three important rules to be observed in the design of a breakwater are as under:

The design should be based on the extreme phenomena of the wind and waves, and not on the mean or the average.

The height of the wave should he determined by Using the equation

H = 034¥Fand the height of wall should be decided accordingly by making sufficient allowance for freeboard.

It should be seen that the material in the foundation is not subject to scour.

Detrimental forces acting on breakwaters:

Hydrostatic force: This force reduces the apparent weight and hence, the marine structures suffer these losses to a great extent unless the foundations are absolutely impervious.

External forces:
→The intensity of external forces, especially wind and wave action, is enormous.
→The power of wind produces vibrations in the masonry structure and weakens the different courses of masonry.
→In a similar way, the wave when it recedes induces 'suction action and it results in the erosion of the foundation unless it is made safe and secure.

Solvent action of sea water:
This quality of sea water causes damage to the materials of construction Sea insects.
The concentrated action of sea insects results in the undermining of the hardest and the soundest building material and it is for this reason that the marine structures are made specially bulky and strong.

Classification of breakwaters:
Heap or mound breakwater
Mound with superstructure
Upright wall breakwater.

Heap or mound breakwater :
It is a heterogeneous assemblage of natural rubble, undressed stone blocks, rip rap, supplemented in many cases by artificial blocks of huge bulk and weight, the whole being deposited without any regard to bond or bedding.
This is the simplest type and is constructed by tipping or dumping of rubble stones into the sea till the heap or mound emerges out of the water, the mound being consolidated and its side slopes regulated by the action of the waves.
The quantity of rubble depends upon the depth, rise of tides and waves and exposure. On exposed sites, the waves gradually drag down the mound, giving it a flat slope on the sea face. As far as possible, such flattening has to he protected.
The disturbing action of the waves is the most between the high and low water levels.
Consequently, all protective methods are adopted above the low water level.
Protection is also very necessary to the top of the mound and outer or exposed face.

Quay walls: Wharves along and parallel to the' shore, are generally called quays and their protection walls are called quay walls
design of quay walls:
They are built to retain and protect the embankment or filling:
Factors affecting the design are as follows

→Character of foundation
→Pressure due to water that finds its way to the real of the wall
→Effect of buoyancy for the portion of the wall submerged
→Earth pressure at rear
→Weight of the wall itself
→live load of vehicles passing on the platform at the rear
→dead load of the goods stored on the platform
→force of impact of vessels
→Quay wails are designed similar to retaining walls

WHARVES Platforms or landing places are necessary for ships to come, close enough to the shore, for purposes of embarkation, disembarkation, etc. at the same time.

→These platform locations should give sufficient depth of water for the ship to float. Such platforms are, called wharves. They are built out into or on to. the water Thus, a wharf affords a working platform alongside the ship in continuity of the shore.
→A wharf is quay but the term wharf is generally used for an open structure of piles or posts with bracings, jutting from the shore towards the sea.
→A wharf may be a sheet pile wall or it may consist of a piled projection with or without artificial retention of soil some distance behind or it may be a gravity wall.
→Wharves may either be parallel to the shore and abutting against it or they may project into the water either at right angles or oblique to the shore.
→The former type is adopted at places where depth of water is sufficient for the ships to berth, say 10 m to 12 m
→ The latter type is adopted at places where depth of water near the shore is not enough for the ships to enter safely.
→The level of wharf should be above the high water level. But at the same time, it should be economical to load the vessels when the water level is low.
→Wharf should act as a unit when there is an impact from any vessel.
→Hence, it should be properly braced and bolted. It is desirable to provide rounded corners for
→wharves which art likely to be used by large vessels.
→Such a construction will result in a smooth entry of vessels into the slips

JETTIES:

- These are the structures in the form of piled projections and they are built out from the shore to deep water and they may be constructed either for a navigable river or in the sea.
- In rivers, the jetties divert the current away from the river bank and thus, the scouring action is prevented.
- As the current is diverted to deep waters, the navigation is also controlled.
- In the sea, the jetties are pr at places where harbor entrance is affected by littoral drift or the sea is shallow for a long distance.
- Thus, they extend from the shore to the deep sea to receive the ships.

- In a limiting sense, a jetty is defined as a narrow structure projecting from the shore into water with berths on one or both sides and sometimes at the end also.
  Jetties are exposed to severe wave action and their structural design is similar to that of breakwater.
- However, the designed standards may be released to a certain extent due to the fact that the jetties are usually built normal to the most dangerous wave front.
- The impact caused by the berthing ships will depend on the skill of the berthing officer, local condition of currents, wind, etc.
- The berthing velocity depends upon the condition of approach, wind, etc. and it decreases with the increase in the size of the ships

TIDES AND WAVES: Tides are caused by gravitational pull of the moon and the sun. The rise and fall of the tides play an important role in the natural world and can have a marked effect on maritime-related activities. ... The difference in height between the high tide and the low tide is called the tidal range.
They are as follows:
Coastal currents and evidences of sitting, including littoral drift or coast erosion. Tides and tidal range.
Wind, wave and their combined effect on harbor structures.
Tides:
Tides on the coast-line are caused by the sun and moon.
The effect of tides is to artificially raise and lower the mean sea level during certain stated periods.
This apparent variation of mean sea level is known as the tidal range.
Spring tides and Neap tides:
At new and full moon or rather a day or two after (or twice in each lunar month), the tides rise higher and fall lower than at other times and these are called Spring tides.
Also one or two days after the moon is in her quarter i.e. about seven days from new and full moons (twice in a lunar month), the tides rise and fall less than at other times and are then called neap tides.
Waves and wind:
The 'sea wave' is by far the most powerful force acting on harbor barriers and against which the engineer has to contend.
The wave has the impulse of a huge battering ram and equipped with the point of a pick axe and chisel edge".
It is the most in compressible natural phenomena.
The formation of storm waves takes place in the open sea due to the action of wind.
Water waves are of two kinds:
- Waves of oscillation and
- Waves of translation;

The former are stationary, while the latter possess forward motion. But all translator waves originally start as waves of oscillation

TASK (Tidal Analysis Software Kit) is a complete software solution for the harmonic analysis of data from tide gauges right through to the prediction of tides into the future and the production of fully formatted tide tables.
Designed for the professional hydrographic, GeoTide handles each step of tidal analysis and prediction in an intuitive and user-friendly way.
Tidal prediction uses the values of the harmonic constants to predict the tide.
Once the harmonic constants have been determined the tide can be accurately predicted for many decades into the future.
These windows-based programs use the industry standard technique of harmonic analysis to produce accurate tidal predictions from observed tidal height or stream data.

- GeoTide Analyzer converts tide gauge data into the harmonic constants for that place
- GeoTide Predictor converts the harmonic constants into tidal predictions

Dredging: it is the operation of removing material from one part of the water environment and relocating it to another. In all but a few situations the excavation is undertaken by specialist floating plant, known as a dredger. Dredging is carried out in many different locations and for many different purposes, but the main objectives are usually to recover material that has some value or use, or to create a greater depth of water.

Purposes of dredging:

- Maintenance: dredging to deepen or maintain navigable waterways or channels which are threatened to become silted with the passage of time, due to sediment sand and mud, possibly making them too shallow for navigation. This is often carried out with a trailing suction hopper dredge. Most dredging is for this purpose, and it may also be done to maintain the holding capacity of reservoirs or lakes.
- Land reclamation: dredging to mine sand, clay or rock from the seabed and using it to construct new land elsewhere. This is typically performed by a cutter-suction dredge or trailing suction hopper dredge. The material may also be used for flood or erosion control.
- Capital dredging: dredging carried out to create a new harbor, berth or waterway, or to deepen existing facilities in order to allow larger ships access. Because capital works usually involve hard material or high-volume works, the work is usually done using a cutter suction dredge or large trailing suction hopper dredge; but for rock works, drilling and blasting along with mechanical excavation may be used.
- Preparatory: dredging work and excavation for future bridges, piers or docks or wharves, This is often to build the foundations.
- Winning construction materials: dredging sand and gravels from offshore licensed areas for use in construction industry, principally for use in concrete. This very specialist industry is focused in NW Europe, it uses specialized trailing suction hopper dredgers self discharging the dry cargo ashore.
- Contaminant remediation: to reclaim areas affected by chemical spills, storm water surges (with urban runoff), and other soil contaminations, including silt from sewage sludge and from decayed matter, like wilted plants. Disposal becomes a proportionally large factor in these operations.

- Flood prevention: dredging increases the channel depth and therefore increase a channel's capacity for carrying water.
- Fishing dredging is a technique for catching certain species of edible clams and crabs. In Louisiana and other American states, with salt water estuaries that can sustain bottom oyster beds, oysters are raised and harvested. A heavy rectangular metal scoop is towed astern of a moving boat with a chain bridle attached to a cable. This drags along the bottom scooping up oysters. It is periodically winched aboard and the catch is sorted and bagged for shipment

NAVIGATIONAL AIDS

Necessity for signals:

The mariner and his ship have to be guided by proper signals during navigation, especially,
to avoid dangerous zones like hidden rocky outcrop and sand bars,
to follow proper approaches and
to locate ports

Fixed and floating light stations:

The light stations when they are built on land are called fixed as in the case of permanent lighthouse structures.

Such structures are located either in the hinterland close to the shore or in the sea on submerged outcrops and exposed to the fury of the waves.

Alternately, where there are difficulties in establishing proper foundations; floating light rations in the form of a light vessel may be adopted.

Buoys of standard shapes also belong to the 'floating type and are generally used to demarcate boundaries of approach channels in harbor basins.

Lighthouse:

It is a lofty structure popularly built of masonry or reinforced concrete in the shape of a tall tower on a high pedestal.

The tower is divided into convenient number of floors, the topmost floor containing powerful lighting equipment and its operating machinery.

The lower floors are used, as stores and living rooms necessary for the maintenance and working of the light station.

The main parts of a typical lighthouse tower are illustrated in fig.

Lighthouses may be located on shore or on islands away from the mainland as in the case of warning light stations.

Maintenance of ports and harbor:

Ports and harbor facilities should remain in service in good condition for a long time, so as to perform their method functions. Towards this objectives, a high level of precautions is to be taken to maintain the structural performance of the port .

1. Visual inspection of deteriorated structures and deterioration grading , major , minor , and local
2. Measurement and prevention of chloride ion concentration in concrete

3. Diagnosis of structural member surfaces with appropriate NDT tests such as chloride test , half-cell potential survey , carbonation test , sounding hammer test and cover-meter test .
4. Grouting motor/injection of epoxy resin into cracks and restoration of spelled concrete
5. Surface coating of rust stains and their extensions
6. RC deck protective coating
7. Installation of cathodic protection to fender piles
8. Replacement of corrodes steel pipe piles/steel beams
9. Dredging where sediment found under water
10. Re-casing of piles/pile caps
11. Improvements of load bearing capacity under structures which are subjected to wave action
12. Structural steel and concrete repairs
13. Restoration of navigational aids
14. Structural steel and concrete repair