Introduction to Basic Civil Engineering

Lecture 1 - Introduction

Sreejith Krishnan, *PhD*

Class Policies – Important!!!

- Please mute the microphones during the lecture
- Join 5 minutes before the start of the lecture
- Questions and clarifications – Last 5 minutes.
- Course Language – Primarily in English
- Please refer to the syllabus/references from the KTU website for the exam pattern/sample questions
- Feel free to contact me via email in case of additional clarifications – sreejith@mec.ac.in

Course Objectives

- To provide an introduction to the civil engineering to students
    - Civil engineering is everywhere – building, dams, roads…….

- To learn about fundamental aspects of civil engineering
    - Different sub-branches
    - Different types of building materials
    - Different building types

- To highlight the role of a civil engineer in the modern society

- Ultimately, you should be able to understand the basic civil engineering terms!!!

Introduction

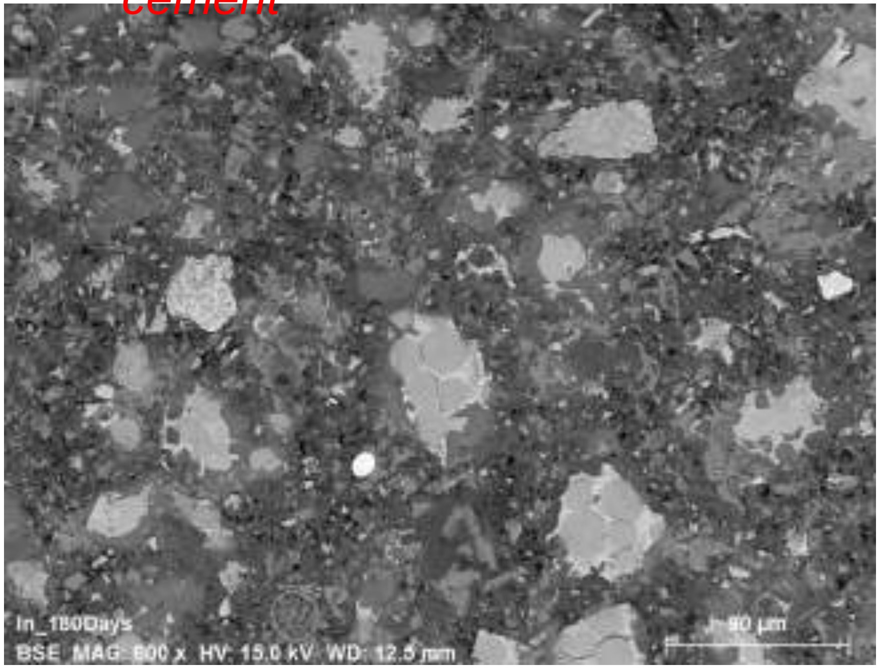
- Oldest branch of engineering
  - Deals with civilian infrastructure – design, construction, and maintenance
  - Historical evidence of engineering in ancient civilisations.
- First engineering school in France opened in 1747!!
- Thomson College of Engineering in India at Roorkee. Now an IIT.
- Cement and concrete are not new materials!!
  - Stone, lime mortar, mud etc also used
  - Newer modifications for a newer age

Scale of Civil Engineering

- From mega-structures to nano-materials..
- Complex structures also means complex science!!!

Hoover Dam

Microstructure of hydrated cement



Why should you care???

- Because when everything goes well, we get →


Why should you care???

- But when something goes really bad, it will be catastrophic
  - Loss of lives, money and resources

Why should you care???

- Even failures can lead to something positive!!!

Importance of Civil Engineering in Society

- A significant section of the society does not have a home
  - Requires the construction of buildings and houses.
  - Housing for all by 2022 scheme – PMAY
- Schools, hospital and factories
- Dams/nuclear power plants are required for generating electricity
- Roads/Railways are required for transportation of the goods and people
- Maintenance of critical infrastructure!!

Investment in Infrastructure leads to Economic Development!!!

Sub-Branches of Civil Engineering

- Civil Engineering is not a monolith and contains several sub-branches
  - Structural Engineering
  - Geotechnical Engineering
  - Environmental Engineering
  - Transportation Engineering
  - Hydraulics and Water Resources Engineering
  - Remote Sensing and GIS
  - Building Technology and Construction Management

Structural Engineering

- Deals with design, plan and analyse structural elements of the buildings like beams and column
- Design the skeleton of the building
  - Building must with stand different load combinations – wind loads, live loads, earthquake loads etc.
  - Design the reinforcement/steel in the cement
  - Bad design example near us – A bridge

Geotechnical Engineering

- Deals with engineering aspects of soil and rocks
  - Calculate the bearing capacity of the soil
  - Design of the foundations of the soil

Environmental Engineering

- Deals the environmental implications of civil engineering
- Sewage and waste water management
- Design of structures to reduce air pollution air pollution etc.


Transportation Engineering

- Deals with the design of transportation related infrastructure
  - Roads
  - Railways
  - Airports and Seaport

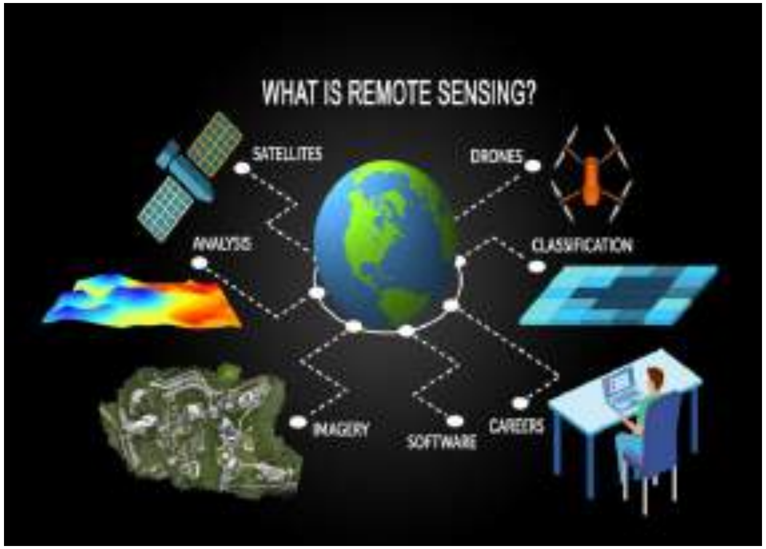
- Design of traffic signals, roundabouts, railway lines etc.

Hydraulics and Water Resources Engineering

- Design of structures and systems for managing the water resources
  - Flow and transportation of fluids – water and sewage
  - Design systems for irrigation
  - Managing hydrological cycle and ground water management

Remote Sensing and GIS

- Mapping and analysing features of earth
- Remote sensing means detecting from a distance
- Sensors detect energy reflecting from earth
  - Generally mounted on satellites
  - Light is the most common source of energy
- Useful for disaster management
  - Floods, fire etc.
- Monitoring farm land, predict weather etc.



Building Technology & Construction Management

- Deals with civil engineering materials and functional design of buildings

- Understanding the science behind building materials

- Durability of the structures, corrosion resistance etc.

- Construction management deals with organising labour, timely completion of construction projects etc.

A combination of all the branches is required in reality

Summary

- In this lecture, we had an introduction to basic civil engineering and its history
- We tried to understand the role of civil engineering in the development of the society
- We looked into the different sub-sections of civil engineering and their area of study
- In the next lecture, we will be discussing the different types of structures encountered in Civil Engineering

Thank You!

- Any doubts..???

Introduction to Basic Civil Engineering

Lecture 2 – Introduction to Buildings/Structures

Sreejith Krishnan, *PhD*

Recap

- In the previous lecture, we looked into –
  - A brief history of civil engineering
  - The importance of civil engineering in the modern society
    - Housing for all
    - Safe disposal of industrial and residential waste
    - Safe industrial and domestic water supply
    - Transportation of goods and people
    - Economic development leading to improvement in standard of living
  - Different branches of civil engineering like structural engineering, geotechnical engineering and their specific roles

Introduction

- Many types of construction are possible –
  - Residential and commercial buildings – Houses and apartments, Factories etc.
  - Roads and bridges
  - Dams
  - Towers
  - Water tanks
  - Airports
  - Seaports
  - Railways

Classification of Buildings

- As per National Building Code – 2005
  - A – Residential Buildings
  - B – Educational Buildings
  - C – Institutional Buildings
  - D – Assembly Buildings
  - E – Business Buildings
  - F – Mercantile Buildings
  - G – Industrial Buildings
  - H – Storage Buildings
  - J – Hazardous Buildings

A. Residential Buildings

- These shall include any building in which sleeping accommodation is provided for normal residential purposes with or without cooking or dining or both facilities, except any building classified under Group C

- Further sub-divisions
  - Lodging or rooming houses
  - One or two-family private dwellings
  - Dormitories
  - Apartment houses (flats)
  - Hotels

B. Educational Buildings

- These shall include any building used for school, college, other training institutions for day-care purposes involving assembly for instruction, education or recreation

C. Institutional Buildings

- These shall include any building or part thereof, which is used for purposes, such as medical or other treatment or care of persons suffering from physical or mental illness, disease or infirmity.

- Sub-divisions
  - Hospitals
  - Custodial Institutions
  - Prisons

D. Assembly Buildings

- These shall include any building or part of a building, where number of persons not less than 50 congregate or gather for amusement, recreation, social, religious, patriotic, civil, travel and similar purposes

  - D-1 Buildings having a theatrical stage and fixed seats for over 1000 persons
  - D-2 Buildings having a theatrical stage and fixed seats for less than 1000 persons
  - D-3 Buildings without a stage having accommodation for 300 or more persons but no permanent seating arrangement
  - D-4 Buildings without a stage having accommodation for less than 300 persons
  - D-5 All other structures designed for assembly of people not covered by subdivisions D-1 -to D-4

E. Business Buildings

- These shall include any building or part of a building which is used for transaction of business (other than that covered by Group F)

- Business types of building are further sub divided as per following
  - Offices, banks, professional establishments, like offices of architects, engineers, doctors, lawyers, etc.
  - Laboratories, research establishments and test houses.
  - Computer installations.

F – Mercantile Buildings

- These shall include any building or part of a building, which is used as shops, stores, market, for display and sale of merchandise, either wholesale or retail.

- Further classified as
  - Shops, stores, departmental stores markets with area up to 500 m2.
  - Shops, stores, departmental stores markets with area more than 500 m2.
  - Underground shopping centres.

G – Industrial Buildings

- These shall include any building or part of a building or structure, in which products or materials of all kinds and properties are fabricated, assembled, manufactured or processed

- Examples - Assembly plants, industrial laboratories, dry cleaning plants, power plants, generating units, pumping stations

- Buildings under Group G shall be further sub-divided as follows:
  - Buildings used for low hazard industries.
  - Buildings used for moderate hazard industries.
  - Buildings used for high hazard industries.

H – Storage Buildings

- These shall include any building or part of a building used primarily for the storage or sheltering of goods, ware or merchandise vehicles or animals

- Warehouses, cold storage, freight depots, transit sheds, storehouses, truck and marine terminals, garages, hangers, grain elevators, barns and stables

- Few numbers of people with respect to the area of the building

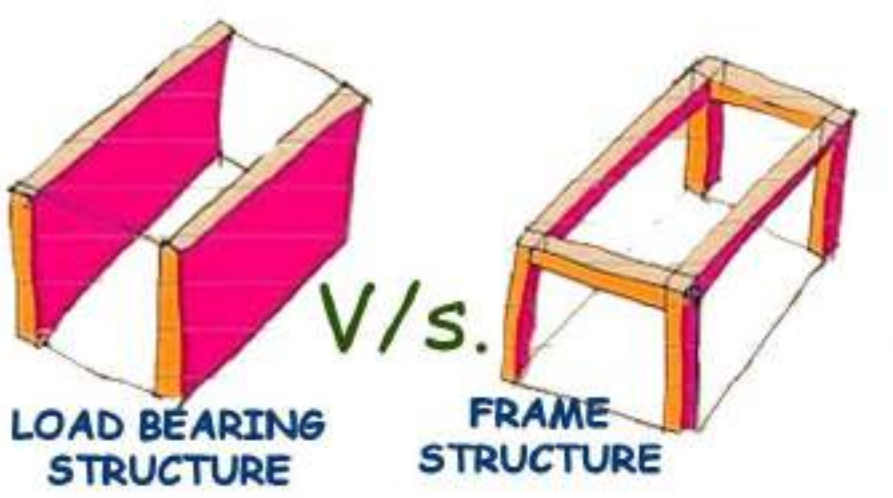
J – Hazardous Buildings

- These shall include any building or part of a building which is used for the storage, handling, manufacture or processing of highly combustible or explosive materials or products which are liable to burn with extreme rapidity and or which may produce poisonous fumes or explosions

- Storage of petroleum products, ammonia etc.

Other classifications

- Load bearing structures and framed structures
- In load bearing structures, the loads are transferred to the foundation by thick walls
- In framed structures, the loads are transferred to the foundation by columns and footings
  - The walls are do not transfer any loads and serves as partition walls



Other classifications

- Based on the type of construction material used
  - RCC structures
  - Steel structures
  - Wood structures

Site Selection for a building

- Selection of an ideal site is important for the planning, design and construction of a building

- Site selection also depends upon the requirement of the building/other factors
  - You do not want to build a hospital in an heavily industrial area – Noise and other types of pollution
  - High rise buildings near airports not possible due to zoning

- In reality, a certain level of compromises are required!!!

Site Selection

- Level of the site – Should be higher than the surrounding areas for good drainage

- Climatic Conditions – Low rainfall and ground water level to prevent dampness in the building

- Sub-soil conditions – Hard sub soil within reasonable depth from the ground level

- Amenities - Must be within the city limits for getting water, electricity and sanitation facilities. Other facilities like schools, hospitals and shopping malls should be available

Some precautions

- Should avoid recently land filled sites
  - Settling of the soil leading to cracks
  - At least 2 to 3 years before construction

- Should avoid sites close to coastal areas, water bodies
  - Flooding

- Residential buildings must be away from industrial area for avoiding pollution

- Be aware of the potential legal issues
  - Flat demolition
  - Third party legal rights to the property

Thank You!

- Any doubts..???

Introduction to Basic Civil Engineering

Lecture 3 – Components of a building

Sreejith Krishnan, *PhD*

Recap

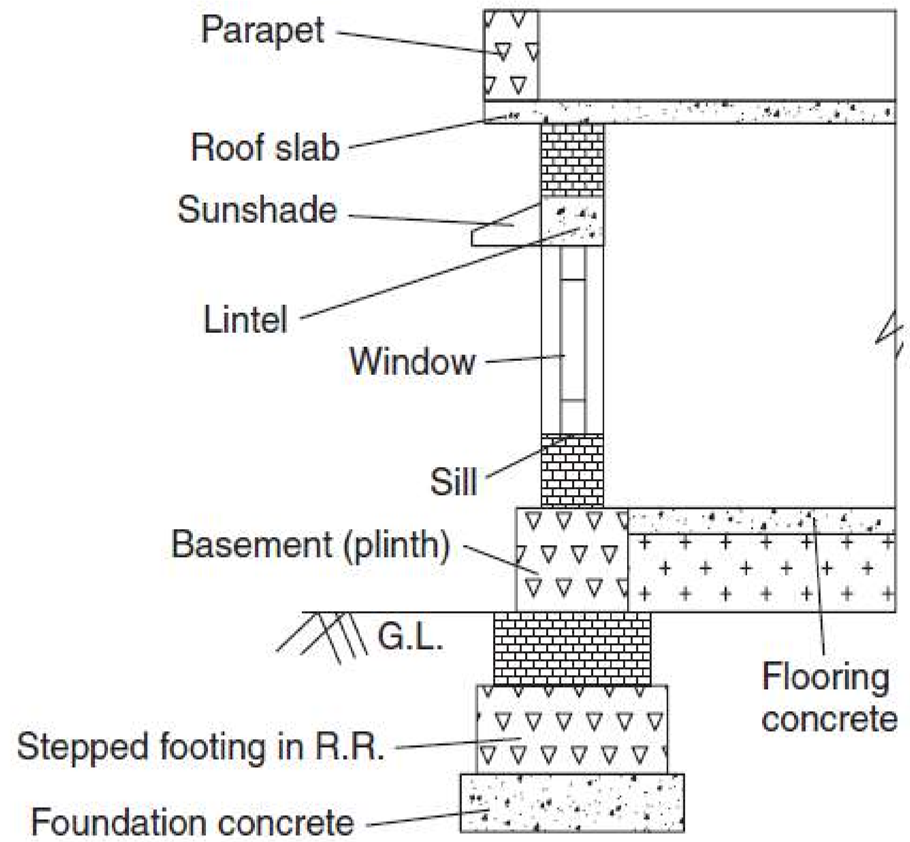
- In the previous lecture, we looked into –
  - Different types of buildings and their classification based on the National Building Code
  - Other possible classifications
    - Load bearing vs framed structures
    - RCC vs Steel Structures
  - Importance of site selection and ideal characteristics for a site

Introduction

- Basic requirements from a building
  - Strong enough to withstand the different loads
  - It should not deflect under the loads – Serviceability
  - It must give comfort and convenience to its occupants

Component of a building

- Generally consists of three parts
  - Foundation
  - Plinth
  - Superstructure



Components of a building

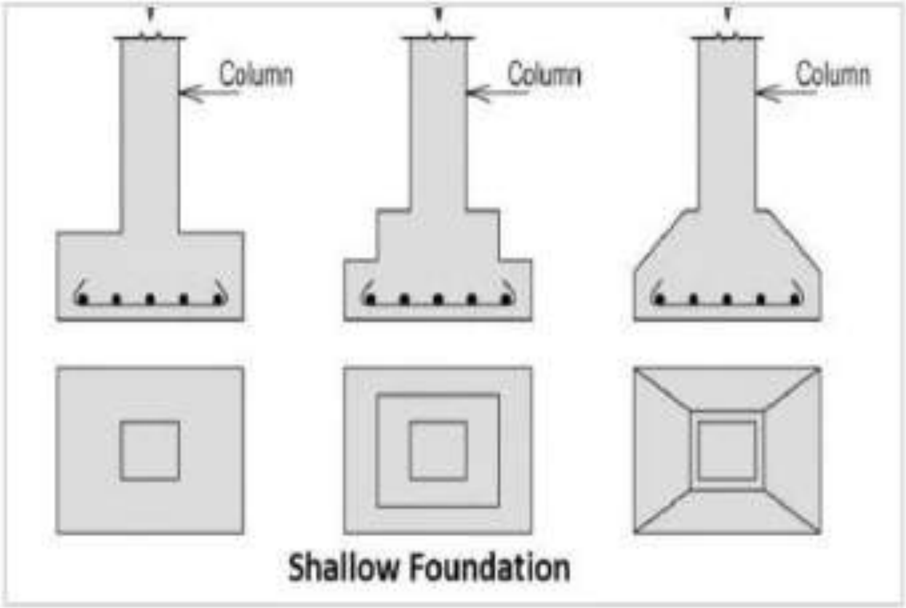
- Foundations
- Plinth
- Walls
- Doors
- Windows
- Floors
- Windows and Beams
- Staircase and lift
- Building finishes – such as plaster
- Building services – Plumbing, electrical, water supply, sewage etc.

Foundation

- The part of the structure below the ground level.
- To safely distribute the loads coming from the super structure safely to the soil below.
- To give stability to the structure against various disturbing forces such as wind and rain.
- To prepare a level surface for concreting and masonry work

Foundation

- Can be of two types
  - Shallow Foundation
  - Deep Foundation



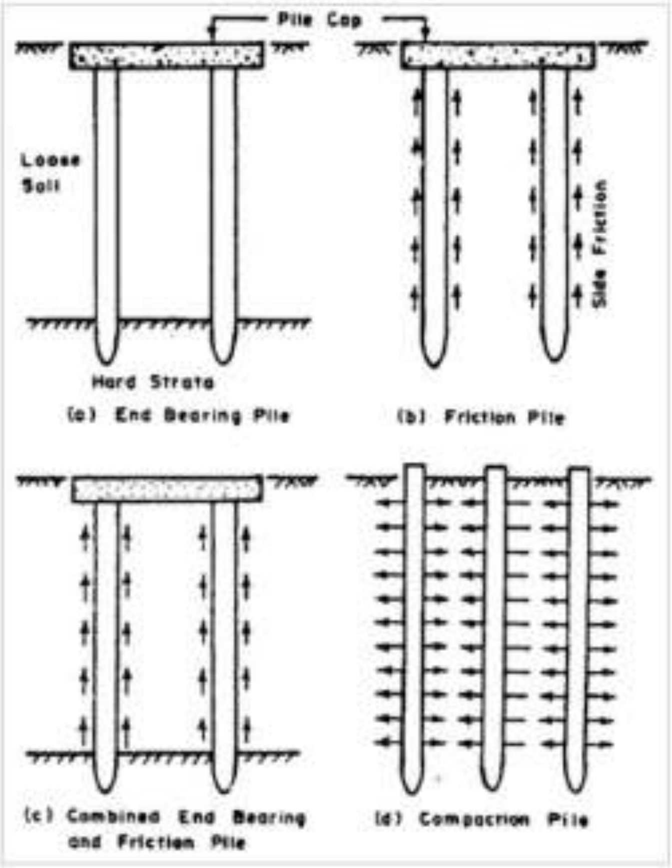
- Shallow Foundation - a foundation that transfers building loads to the earth very near to the surface

- The depth of the foundation is less than its width

- When soil at shallow depth can support the loads of the structure

Foundation

- Deep foundation – a foundation which transfers to the loads farther down the surface of the earth
- Pile foundation is an example
- Expensive but can take very high loads
- Can be up to 65m in depth



Foundation

Plinth

- This is the portion of the structure between the surface of the surrounding ground and the surface of the floor immediately above the ground.

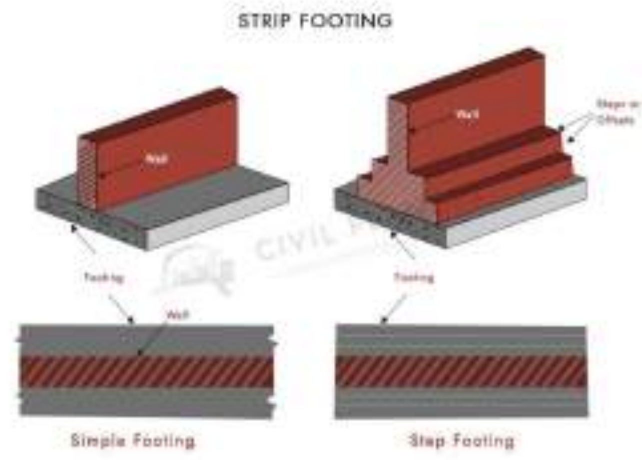
  - To transmit the load of the superstructure to the foundation.
  - To act as a retaining wall so as to keep the filling in position below the raised floor or the building.
  - To protect the building from dampness or moisture.
  - To enhance the architectural appearance of the building.

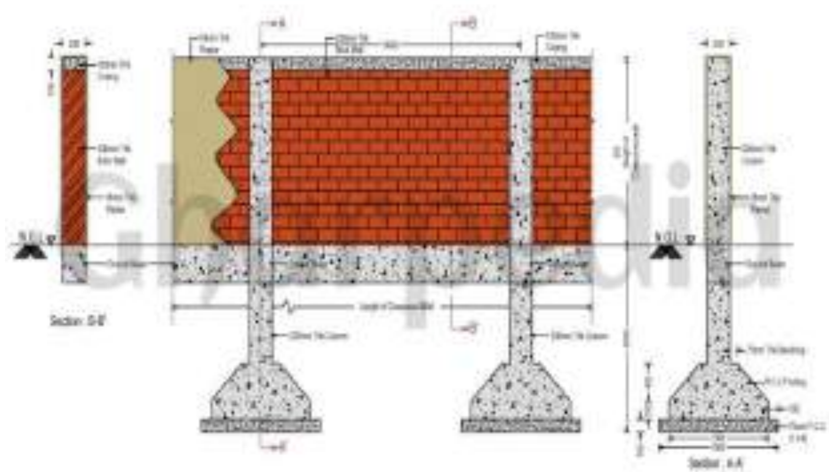
- 30 to 75 cm.

Plinth

Walls

- A masonry structure provided above plinth
- The primary function of the wall is to enclose or divide space.
- To provide privacy and security
- Two types – Partitioning and load-bearing





Floors

- The main function of a floor is to provide support for occupants, furniture and equipment of a building
- To separate the building into different floors
- Strong, stable, durable, sound resistant and fire resistant
- Timber, mosaic, marble, granite etc.

Doors and windows

- The main function of doors in a building is to serve as a connecting link between internal parts and to allow free movement to the outside of the building.

- Windows are generally provided for proper ventilation and lighting

- Weather resistance, sound and thermal insulation, fire resistance, privacy and security

Lintels

- Structural element provided on top of windows and doors for carrying the load of walls from the above
- Wood, stone, RCC, Steel etc. can be used
- A continuous lintel is advantageous from the view of earthquake resistance

Stairs

- A stair is a structure consisting of a number of steps leading from one floor to another.
- Act as an escape route during building fire
- Durable, strong, fire resistance, comfortable

Roofs

- A roof is the uppermost part of a building whose main function is to enclose the space and to protect the same from the effects of weather elements.

Finishing

- Finishes of several types such as pointing, plastering, painting and distempering and decorative colour washing are applied on the walls

- Protect walls from exposure

- Provide smooth surface to the walls, improved aesthetics

Thank You!

- Any doubts..???

Introduction to Basic Civil Engineering

Lecture 4 – Types and classification of structure

Sreejith Krishnan, *PhD*

Recap

- In the previous lecture, we looked into –
  - Basic requirements from a building – safety and serviceability
  - Different components of a residential building – foundation, plinth and superstructure
  - The role of different building components in a construction – beams, columns, lintel etc.

Buildings

- We had a detailed discussion on the types of buildings
- Single and double storey buildings were the most common
- Nowadays, due to cost of construction, land, family structure etc., multi-storey buildings are gaining more and more popularity

Tower

- Tower is a tall structure with a specific purpose (other than living/residential)

  - Electricity transmission tower- for distribution of electric power

  - Communication tower- for transmission of communication signals like microwave

  - Radio tower - for transmission of radio signals

  - Bell tower – for hanging bells in churches

  - Tourist tower – As a tourist attraction for the tourists to see (Eiffel tower in Paris, Leaning tower of Pisa, Italy etc)

Tower

- The towers are normally constructed with steel sections like angle, I section, Channel, square section etc.
- Connected at the junctions through welding or bolt and nut.

Chimneys

- A **chimney** (flue) is a structure intended for the passing off smoke, hot flue gases from furnace or fireplace to the outside atmosphere

- Chimneys can be found in buildings, steam locomotives, ships, brick kilns, factories etc.

- The dispersion of pollutants at higher altitudes can reduce their impact on the immediate surroundings.

Chimneys

- Chimneys can be circular, square or rectangular

- Some considerations while building chimneys
  - Refractory lining to be provided where higher temperatures are expected

  - Wind pressure to be considered during the design

Dams

- **Dams** are structures constructed across rivers to store water

- The water may be used for drinking, irrigation or hydro electric power generation

Dams - Classification

- Storage dam – Constructed to store water. The stored water may be used for irrigation, drinking or hydro electric power generation

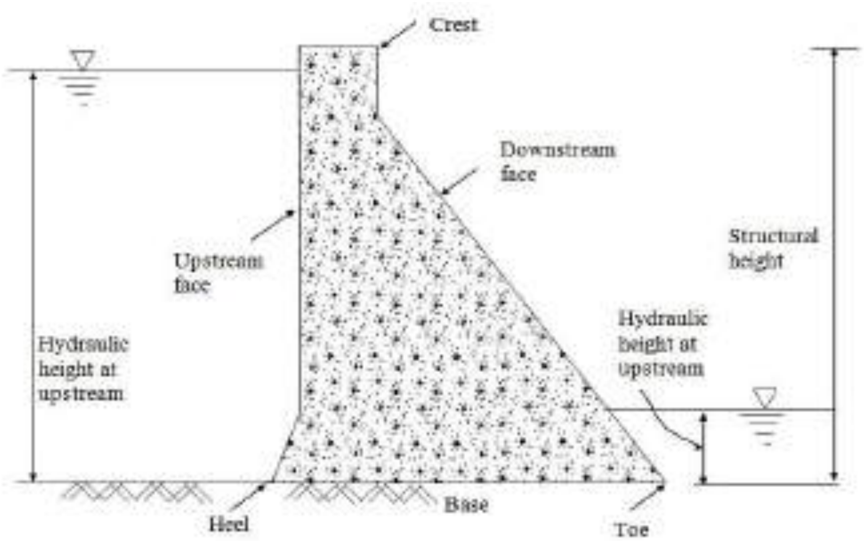
- Flood control dam – To store the flood water and release it slowly so that the down- stream side is safeguarded against the damaging effects of floods

- Diversion dam - To divert the water from the river to a channel.

- Coffer dam – A temporary structure constructed to divert water so that the new dam or bridge can be constructed.

Dams - Classification

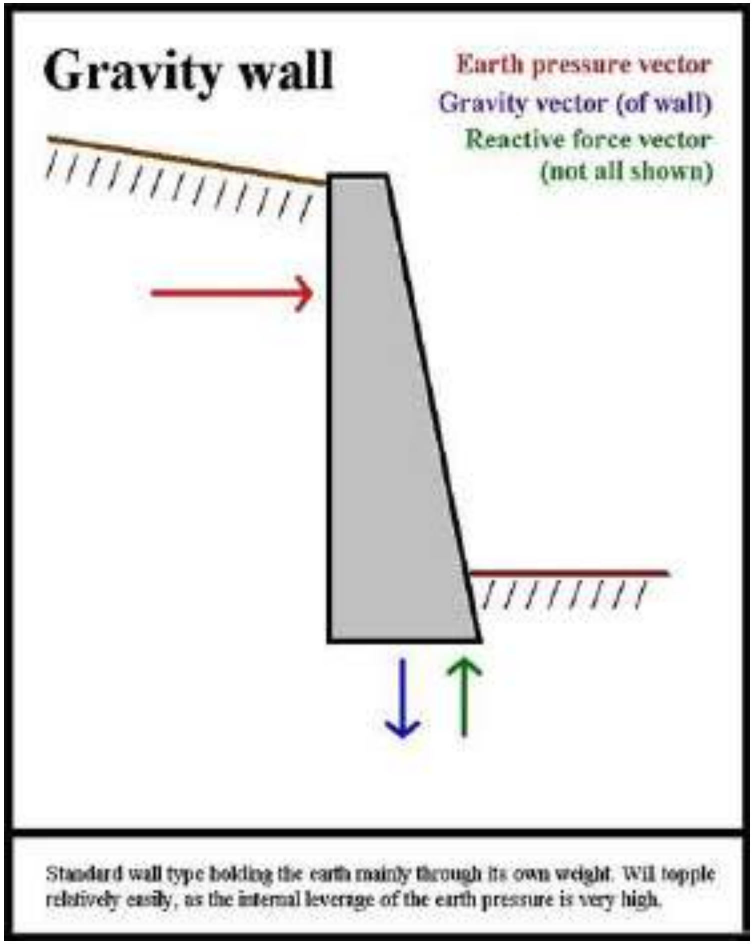
- Based on materials used for construction – Earthen dam, masonry dam, concrete dam, wooden dam
- Arch dams, gravity dams and arch-gravity dams



Retaining Walls

- **Retaining walls** are walls made of concrete or masonry to retain soil**.**

- Protect soil from erosion, stabilise slops



Water tanks

- A **water tank** is a container to store and distribute water

- Can be an overhead water tank, underground sumps

- Can be constructed using steel, concrete or plastic

- Useful distributing water, irrigation, rain water harvesting

Silos

- **Silo** is a structure, typically cylindrical in shape in which grain, cement or other materials are stored

- Can be constructed from concrete, steel etc.

Pipelines

- **Pipeline** transport is the transportation of goods through a pipe.

- Fuel, water, sewage etc.

- Can be made of concrete, plastic, or steel

- Several advantages – large scale transportation of hazardous goods, cost effective, easy transportatiom

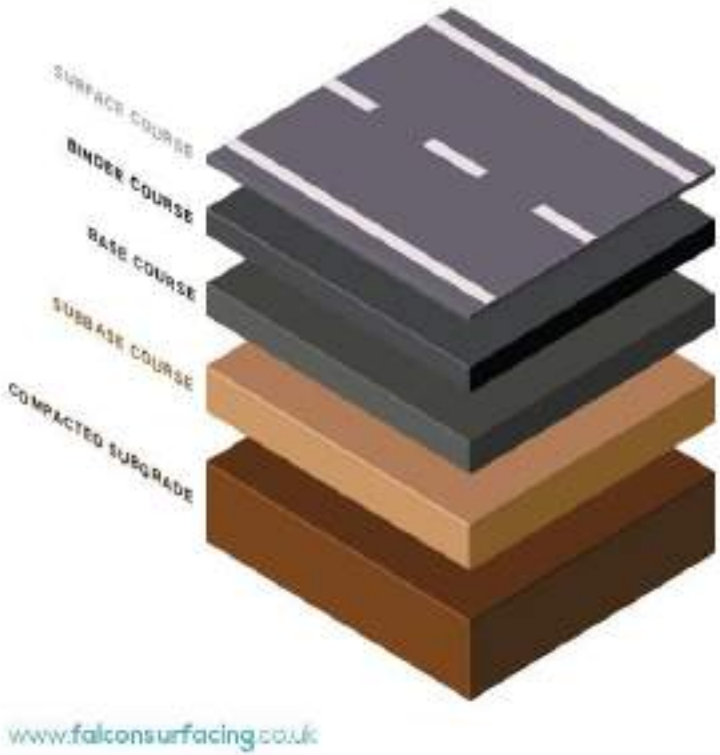
Roads

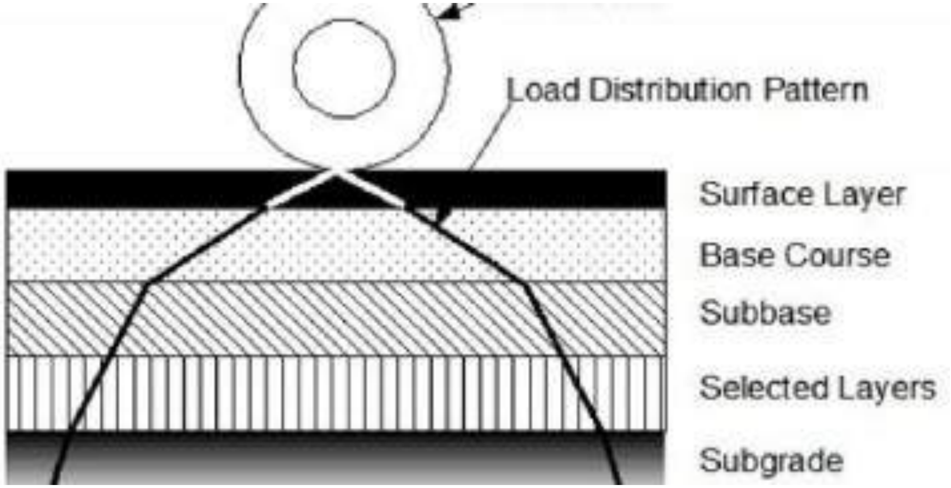
- Road is an identifiable pathway between two locations

- Allows easy movement of goods, people etc.

- Vital for economic development

Roads - Section





Roads - Classification

- Based on size – Single lane, double lane, four lane etc.

- Based on Nagpur road plan
  - National Highways
  - State Highways
  - Major district roads
  - Minor district roads
  - Village roads

- Based on road surface
  - Rigid pavement (Concrete pavement)
  - Flexible pavement (Asphalt pavement)

Runways

- **Runway** is a rectangular area of land in an airport prepared for the landing and take-off of aircraft.

- Runways may be a man-made surface (asphalt, concrete, or a mixture of both) or a natural surface.

- Airport types - Civilian airport, military airport

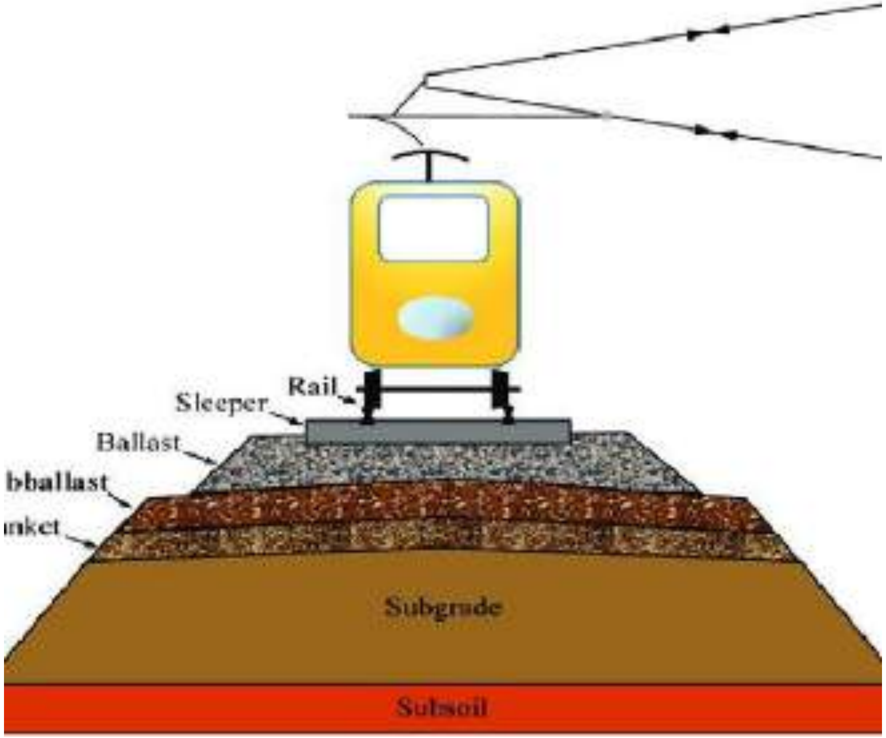
- The capacity of an airport is defined as the number of aircraft operations during a specified interval of time corresponding to a tolerable level of delay

- The selection of a site for an airport depends on – Economic factors, Commercial factors, Meteorological factors, Physical and Engineering factors.

Railways

- For the movement of trains
- Transport of goods and passenger over long distance
- Two rails are kept at a fixed distance over a sleeper
- The distance between two rails is called a gauge
  - Broad gauge (1676mm)
  - Meter gauge (1000mm)
  - Narrow gauge (762mm or 610mm)

Railways



Bridges

- A **bridge** is a structure built to cross an obstacle

Bridges

- Based on the material of construction
  - RCC Bridges
  - Steel Bridges
  - Wooden bridges

- Based on the function
  - Railway bridge
  - Road bridge
  - Pedestrian over-bridge
  - Aqueduct
  - Viaduct

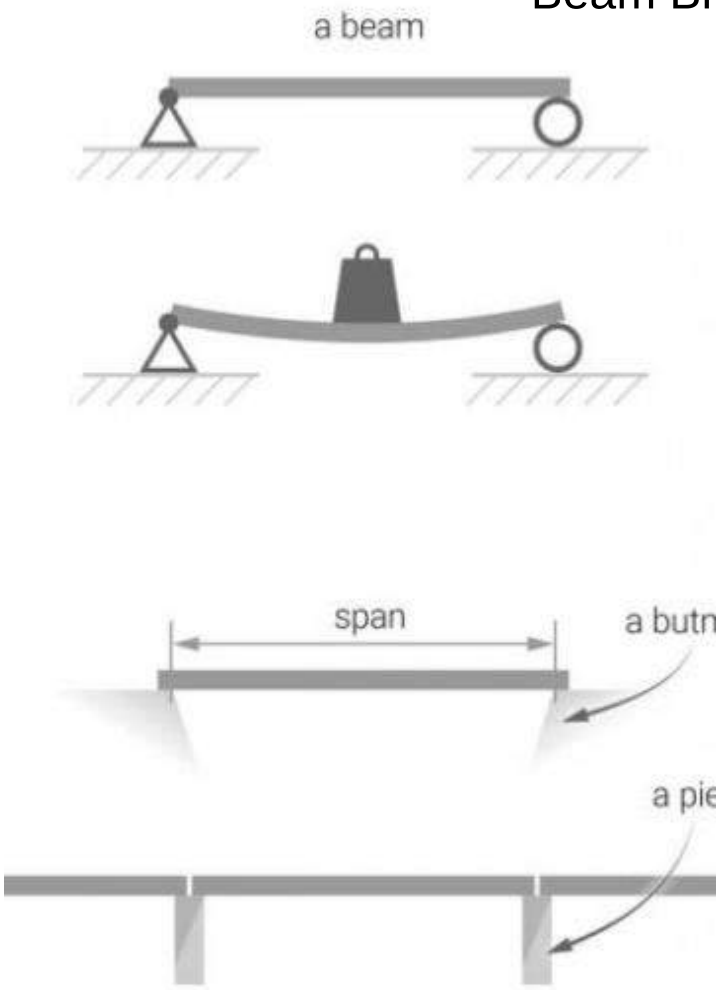
Bridges

- There are different types of bridges
  - Beam bridges
  - Truss bridges
  - Cantilever bridges
  - Arch bridges
  - Suspension bridges
  - Cable stayed bridges

- The site should be easily approachable, width of the river should be minimum, firm and stable banks, suitable foundation,

Beam Bridges

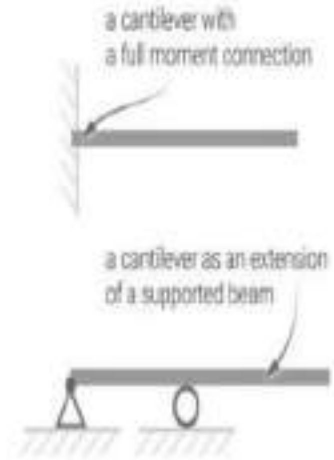
Beam Bridges



- Simplest bridge, easy to build, inexpensive
- Limited span, transportation underneath can be difficult

Cantilever Bridges

- Support is required only on one side of each cantilever
- Cantilever bridges do not require false work
  - Temporary structure for support during construction
- Longer spans, easy navigation
- Very expensive and requires high levels of maintenance
- May not be suitable in extreme weather conditions



Cantilever Bridges

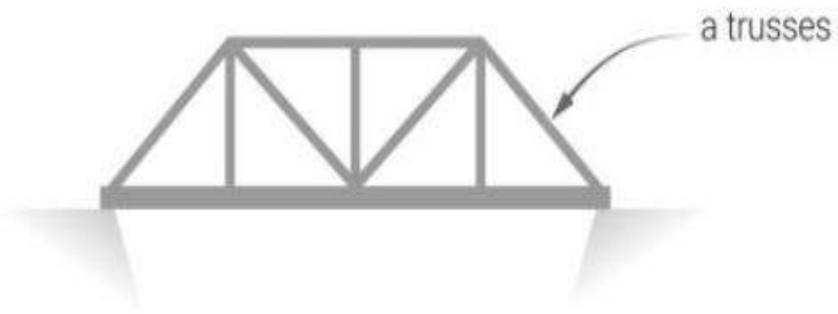
Truss Bridges

- The loads are shared by a network of trusses (interconnecting triangles)

- Extremely strong

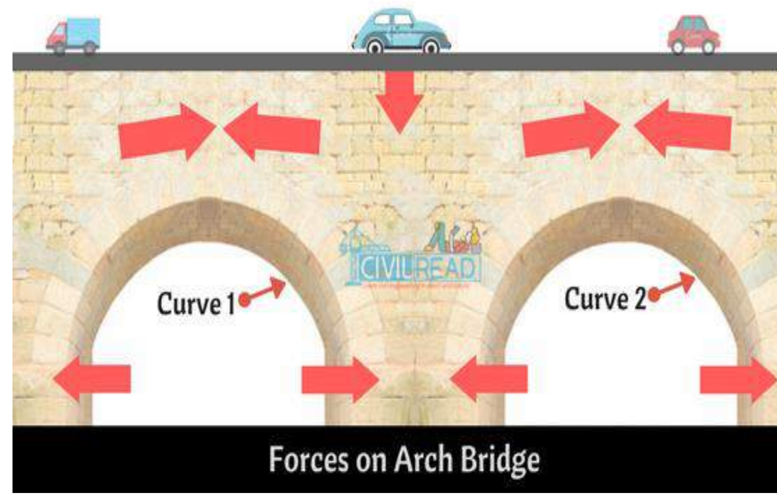
- Deck can be on top or bottom

- High maintenance levels, expensive



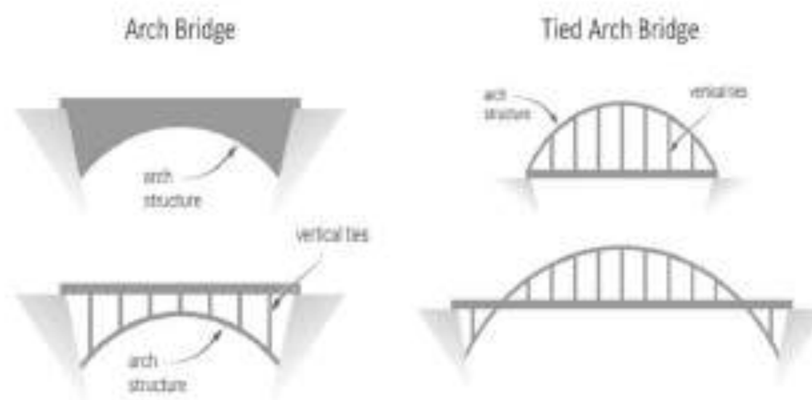
Arch bridges

- The weight of the bridge is thrust into the abutments at either side



- Very strong, can be constructed from locally available materials

- Small spans for economy



Suspension Bridges

- This type of bridges are constructed by suspending the deck slab using suspension cables.

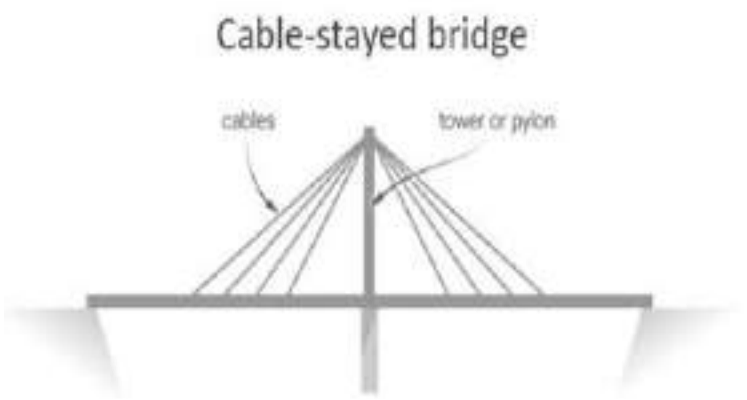
- The roadway is hanged using steel cables which are connected to two towers and secured by anchors on both ends of the bridge

- Strong and can span long distances such as across rivers.

- Expensive and complex to build.

Cable-Stayed bridge

- In this type of bridge, the cables are directly connected to the roadway at different points radially, and towers alone bear the compression forces



- It is more economical when compared with the suspension bridge

- Longer spans are possible

- High levels of maintenance required

Bridge

- Lets watch a video of a bridge failure

- Learning from failures is important

Classification of Buildings

- We discussed the classification based on NBC norms
- Load bearing vs. framed structure
- Based on materials of construction – RCC, Steel, wood, composite
- Based on fire resistance – Type 1, Type 2, Type 3 and Type 4

Thank You!

- Any doubts..???

Introduction to Basic Civil Engineering

Lecture 5 – Building Rules and Regulations

Sreejith Krishnan, *PhD*

Recap

- In the previous lecture, we looked into –
  - The different type of structures other than buildings
  - Towers, dams, retaining wall, bridges etc.
  - Different classifications and functions
  - Fire resistant buildings

National Building Code

- It is the premier building code of India
- Published by the Bureau of Indian Standards
- Provides the regulation and guidelines for the construction activities across the country
  - Adopted by Government agencies, PWD and private companies
- Administrative regulations, development control rules, general building requirements
  - Fire safety, structural design, construction materials etc.
- Violation of the NBC norms can lead to heavy penalties, cancellation of building permits, or even demolition of the structure

KMBR and KPBR

- Kerala Municipal Building Rules (1999) and Kerala Panchayat Building Rules (2011) regulates the construction activities in Kerala
- Kerala Building Rules (1984) was used prior to the enactment of these rules
- KMBR for municipalities and corporations, KPBR for Panchayats
- Objective of KMBR and KPBR
  - Planned development of an area
  - Safety and well being of the occupants and public

KMBR and KPBR

- A person planning a building construction has to submit an application along with the site plan, ground plan, elevation and sections on the building to the secretary of the respective Panchayat/Municipality/Corporation for approval

- Applicant also has to prove the ownership of the land

- Secretary has to inspect the site and the building drawings to ensure that the construction will comply the regulations
  - Work permit is issued if everything is satisfactory
  - Necessary changes can be made if there are any violations

- Not required for government projects such as railways, highways etc.

- Not required for minor works such as repair, painting etc.

- Separate norms for the requirements of parking spaces, fire escape, open spaces etc. for different buildings based on the occupancy

CRZ

- Coastal zones are ecologically sensitive
- Human activities like construction, waste disposal fishing etc. has resulted in the degradation of the coastal ecosystem
  - Role of mangroves in Tsunami
- Coastal Regulatory Zones have been implemented in the Environmental Protection Act 1986
  - Objective is sustainable development and conservation of Coastal ecosystems
  - Local community (for e.g. fishermen) to play an important role in the conservation process

CRZ – Classifications

- CRZ-1: These are ecologically sensitive areas these are essential in maintaining the ecosystem of the coast. They lie between low and high tide line. Exploration of natural gas and extraction of salt are permitted

- CRZ-2:The areas that have already developed up till the shoreline of the coast are included in this zone. Construction of unauthorised structures is prohibited in this zone.

- CRZ-3: Rural and urban localities which fall outside the 1 and 2. Only certain activities related to agriculture even some public facilities are allowed in this zone

- CRZ-4: This lies in the aquatic area up to territorial limits. Fishing and allied activities are permitted in this zone. No Solid waste should be let off in this zone.

CRZ

Coastal Regulation Zone Notification, 2011

Index

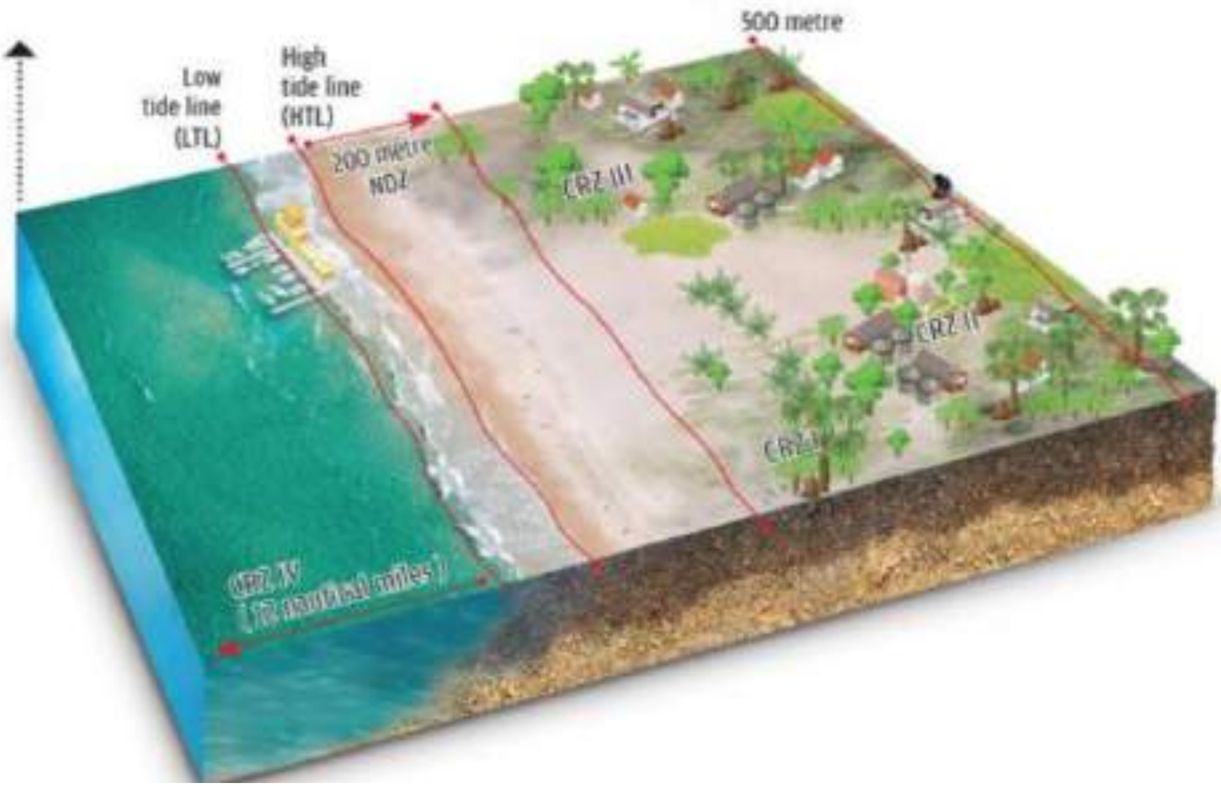
CRZ I: Eco-sensitive and intertidal areas

CRZ II: Areas which have been developed up to or close to the shore

CRZ III: Areas that are relatively undisturbed and do not fall under CRZ-I or CRZ-II

CRZ IV: Area between Low Tide Line and 12 nautical miles into the sea/ tidal influenced waterbodies

NDZ: No development zone that extends up to 200 m from High Tide Line towards land in CRZ-III area



Selection of site

- We had a small discussion on this in previous lecture
- Extent of site investigation depends on the complexity of the work
  - Minor studies for small construction like houses
  - Detailed investigation for large structures such as bridges
- Helpful in economical and safe development of the site
- Small part of the total construction cost but can potentially save huge amount at later stages

Factors considered for site selection

- Level of the land
- A plot with normal water table level
    - Can affect the quality of water
    - Can affect the foundation design
- Shape of the plot – should facilitate easy construction
- Quality of the soil – To check the bearing capacity of the soil for designing the foundations
- Easy access to amenities, located away from polluting areas

Requirements from a residential building

- Strength and Stability – Should withstand the different loads coming on to the structure
- Serviceability – Structural members should not deflect too much
- Comfort and Convenience
- Prevent dampness in the structure
- Safety against fires – Resist fire as much as possible

Requirements from a residential building

- Day lighting – Sufficient day light should be available with the help of windows

- Heat and sound insulation –
  - Should be able to maintain a constant temperature irrespective of the outside temperature variations
  - Should be able to reduce the outside noise as much as possible
  - Can be achieved using AAC blocks, thicker walls etc.

- Durability – Should last for a long time

Requirements from a residential building

- Doors and windows placement – Should be placed to ensure sufficient sunlight
- Aesthetics – The elevation of the building should be pleasing
- Privacy – Sufficient privacy has be to available
- Placement and grouping of the rooms –
  - Kitchen in the east side, bedrooms in south/south-west direction for air circulation
  - Dining hall to be placed next to kitchen, living room near verandah etc.
- Spaciousness –
  - Plan for maximum utilisation of available space

Requirements from a residential building

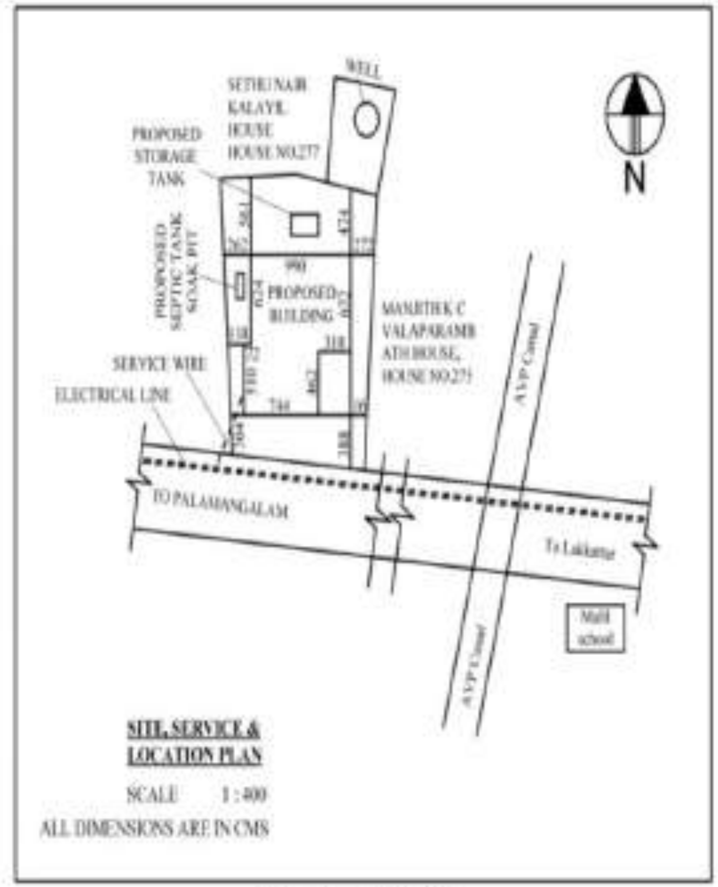
- Circulation – Simple and straightforward path should be provided between room for easy circulation
  - Don't provide entry to a room from another room
  - Ideal placement of furniture for easy circulation

- Sanitation –
  - Well designed drainage facilities to remove waste from kitchen, bathroom etc.

- Flexibility
  - Some flexibility should be available for future modifications

Site Plan of the building

- Site plan is a detailed sketch of the plot with all the required details
- Should be prepared according to the building rules
- Should contain
    - Boundary of the plot and its details
    - Position of the site from neighbouring roads
    - Details of the road with name etc.
    - Existing structures in the plot
    - North direction should be marked
    - Proposed layout of the planned building
    - Other details – agricultural land, any subdivisions of the plot, requests by the authority
- Minimum scale of 1:400 on paper of size 24cm * 33 cm



Site plan of a building

Orientation of the building

- The method of fixing the direction of the plan of building so as to derive the maximum benefits from the nature elements – sun, wind and rain

- Well oriented building can also help to provide privacy and dust free environment

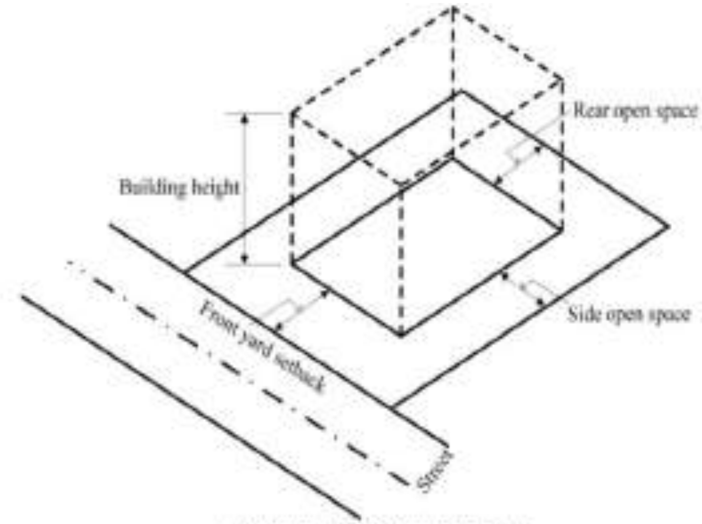
- Orientation of the building has to be first decided after the plot for construction has been identified

Factors affecting orientation

- Relative path of the sun
  - Building tends to absorb the sun rays during the day time and release the heat during the night time
  - Longer walls on the north and south side, shorter walls on the west and east side
  - Shading can be provided in by planting trees etc.
- Prevailing wind conditions
  - Windows of bedrooms provided perpendicular to the prevailing wind conditions for coolness
- Rainfall
- Site conditions

Open Space

- Open space needed around a residential building is dependent on the air and light requirements
- For public buildings, other factors must also be considered
- Open spaces are also known as setbacks
- Every building with a road in the front should definitely have a front open space



Exterior and interior open air spaces

Front Setback, m	Road Width, m
1.5	<7.5
3	7.5 to 18
4.5	18 to 30
6	>30

Rear Open Space

- Average width of 3m, but no less than 1.8m
- For back to back plots, it has to be constant 3m
- For buildings up to 7m high, rear space can be reduced to 1.5m
- Rear open space shall have to be provided along the back wall
- For corner plots less than 300m^2 in area, the rear open space should be min 2.4m

Room Sizes - Bedroom

- The room size can depend on lots of factors – purpose, flexibility of the usage, finances involved etc.

- The height of a room designed for human occupation shall not be less than 2.75 m
- Bedrooms – Should have min. 9.5m^2 net area, also used for storing materials
- Minimum width is 2.9m, one wall external for ventilation
- Rectangle preferred, air circulation is important so should be located on the side of prevailing wind

Room Sizes -

- Kitchen – Oriented towards east or north-east for maximum sunlight

- Should be of appropriate size – not too big and not too small

- Can be combined with a dining room

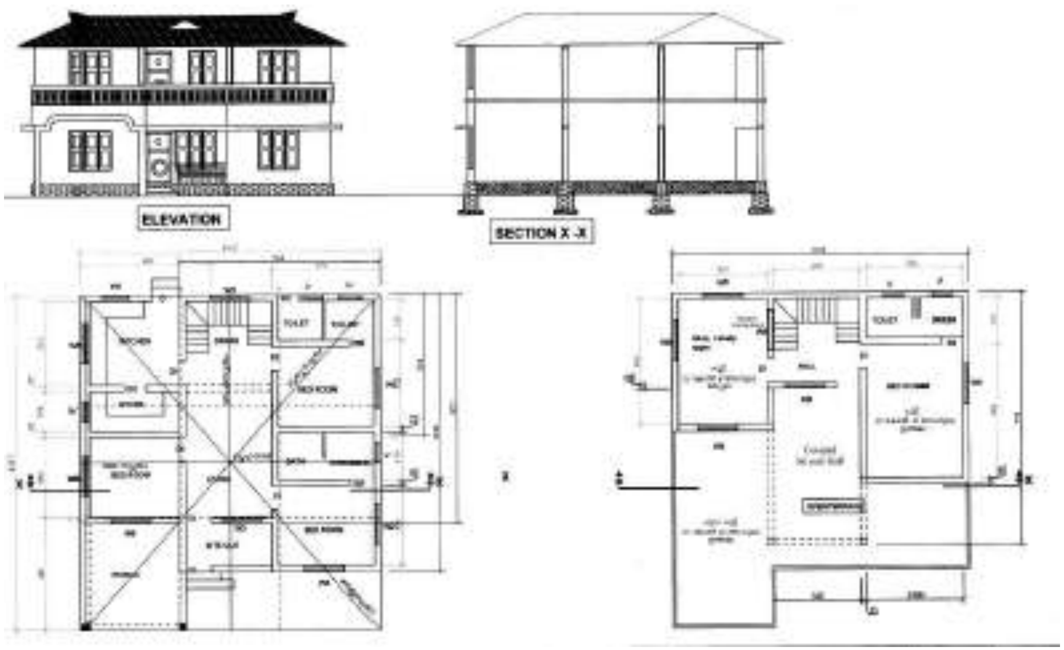
- Min 5 m^2 area, with a width of 1.8m

Room sizes

- Bathroom – Bathing and washing cloths
- Sufficient space for the activities
- Area should not be less than $1.8m^2$, with a minimum width of 1.2m
- Floor area of a water closed shall be $1.1m^2$

Residential plan

- It is planned drawing of the proposed construction in the paper
- Graphical representation of a building projected on to the paper
  - Scale of 1:100 on paper, should show all the details like windows, doors, stairs etc.



Residential plan

- Floor plans of all the floors, indicating size of all the rooms and members
- Show the use an occupancy of the different rooms
- Should show exactly all essential services – bathroom, kitchen etc.
- At least one elevation
- At least one section through staircase
- Show the arrangement of structural members such as beams, columns etc.
- North should be clearly marked
- Terrace plan to show the drainage and shape of the roof

Building Terms

- Plinth area/ built up area – measured at floor level of basement or individual floors including wall thickness
  - Should exclude plinth offsets

- So this is the entire area occupied by the outer walls

- Floor area – Plinth area – area of the walls

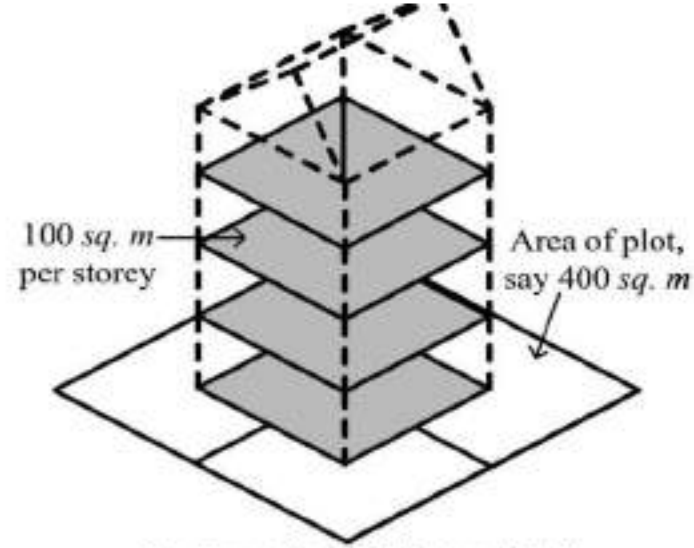
- Carpet area – floor area of the usable rooms at any floor levels

- Verandah, corridor, passageways, staircase, kitchen, lavatory not included

Building Terms

- KMBR states that 20% of the floor area shall be reduced to calculate the carpet area

- Floor area ratio – is the ratio of total built up area or the total floor area to the total area of the plot
  - Maximum allowed value is 3
  - Ranges from 1 to 2 for residential building



An example of FAR equal to 1

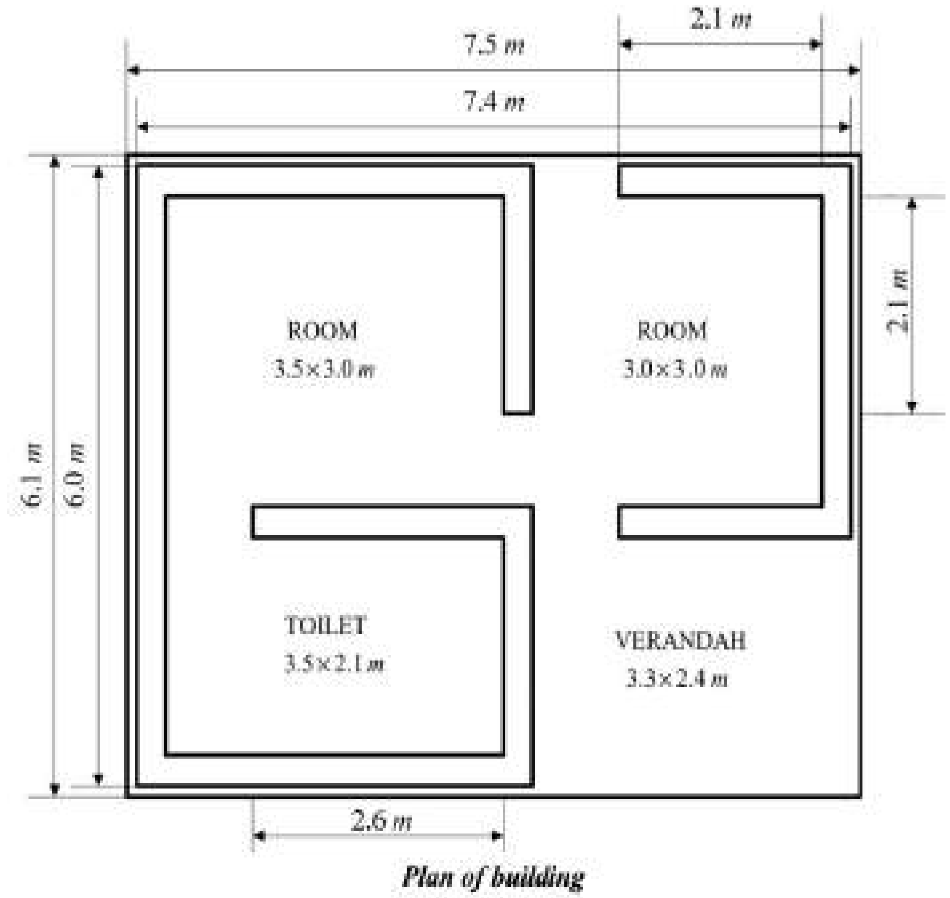
$$FAR = \frac{\text{Total covered area (plinth) on all floors}}{\text{Area of the plot}}$$

Problems

- Calculate plinth area, floor area, and carpet area of the following plan

- Walls area 30 cm thick

- Assume door as 0.9m * 2.1m



Thank You

- Any doubts???

Introduction to Basic Civil Engineering

Module 2- Building Materials

Civil Engineering Materials

- Cement
- Concrete
- Bricks
- Timber
- Asphalt
- Stone
- Mud
- Metal
- Ceramics
- Glass
- Stone
- Paintings and coatings

The life of materials

- Availability
- Extraction or/and production
- Usability – workability
- Predictability
- Strength
- Durability
- Disposability

Availability

Extraction/Production

Usability

Predictability in Laboratory

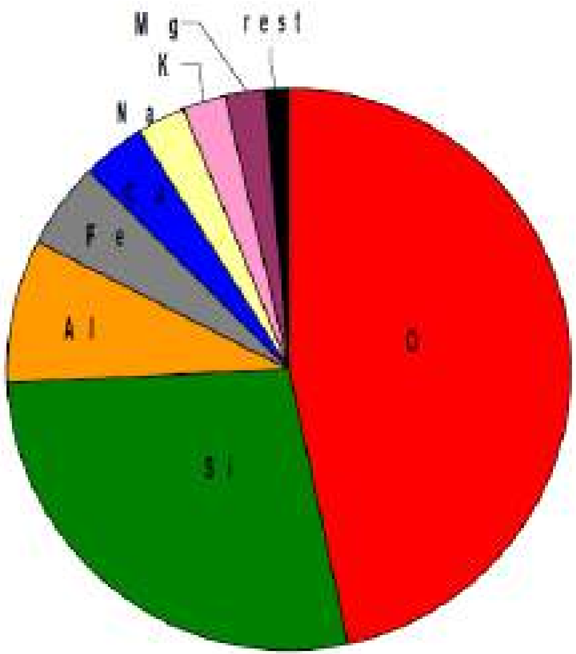
Predictability in Field

Strength

Durability

Disposability

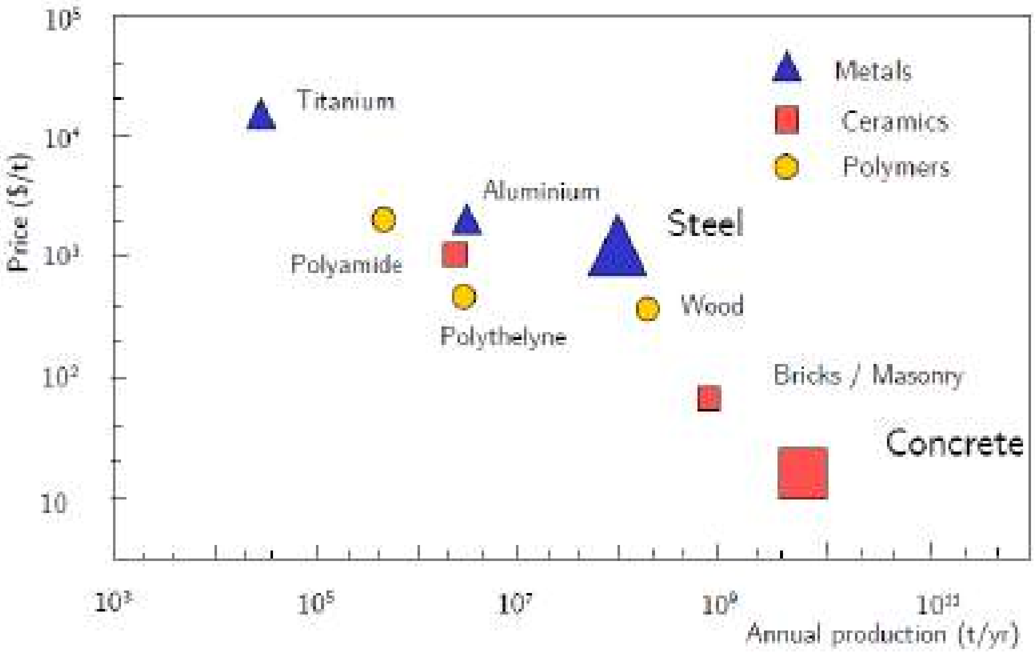
Let’s understand materials



Earth's crust

Source of all the materials

What materials do we use now?



Source: *INTRODUCTION à LA SCIENCE DES MATÉRIAUX*, Kurz,Mercier, Zambelli,. PPUR , 2002

Defects and Flaws

- All materials have flaws
  - Cracks
  - Crystal defects
  - Substitutions
  - Non-uniformities

- Flaws make important contribution to properties
  - True material properties make limited contribution

Some interesting facts

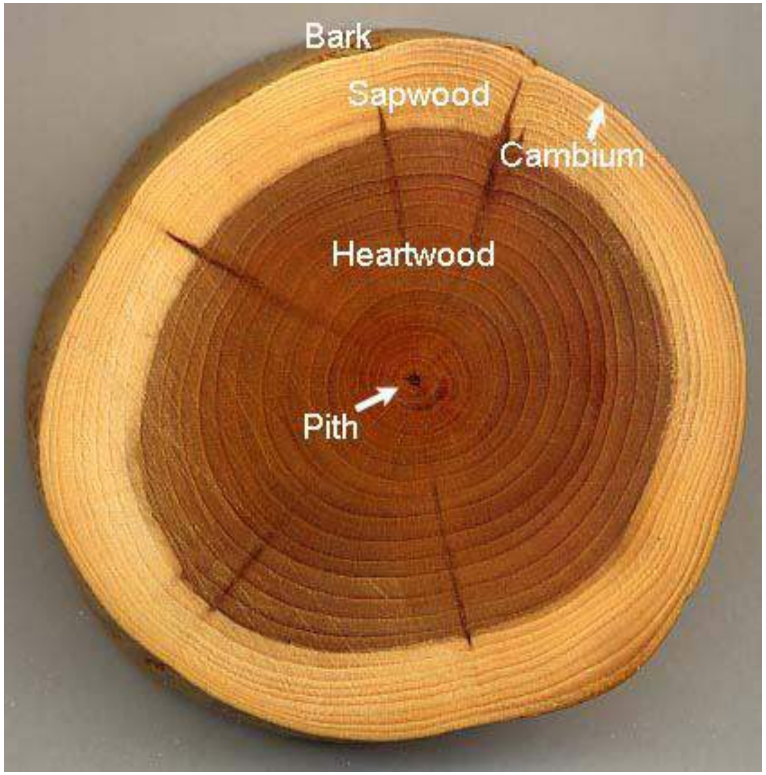
- Cement and concrete are not new materials... they have existed for thousands of years!

Some interesting facts

- Fired clay bricks are the most long lasting construction material

Some interesting facts

- Delignifed cellulose fibres can have strengths from 500 MPa to 2000 MPa



Some interesting facts

- Bitumen is one of the few massively used organic construction materials
- Obtained from petroleum!!!!

Some interesting facts

- Pure metals are too soft to use in construction
  - Contamination is important!
  - Alloys like steels

Bricks

Red clay brick

Hollow clay brick

Fly ash brick

Hollow concrete block

AAC block

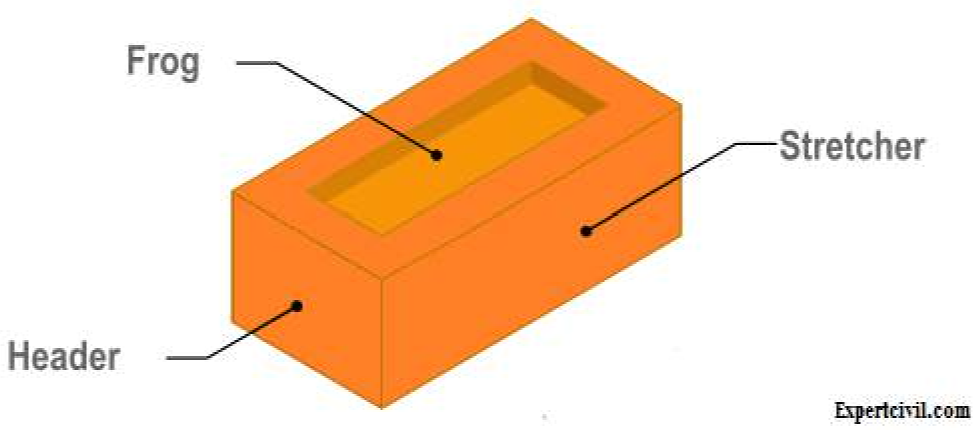
CLC block

Characteristics of bricks

- Strength
- Hardness
- Impact resistance
- Weight
- Bond
- Insulation: sound and heat
- Water absorption and permeability
- Colour
- Texture
- Shape and size

Clay bricks

- Clay is the most important material used to make bricks
  - Size of modular brick: 19x9x9 cm
  - Additional 1 cm for mortar
  - Field bricks are usually 9”x4.5”x3”
  - Bricks contain a 10x4x1 cm frog as a shear key
  - Prepared by firing at high temperature



Composition of brick

- Silica: 50% - 60%
  - Gives durability and stability
- Alumina 20% - 30%
  - Makes clay plastic, increases refractory nature
- Lime 10%
  - Helps in melting of silica, reduces drying shrinkage
  - Excess lime can cause brick to lose shape

Composition of brick

- Magnesia < 1%
  - Makes brick yellow
  - Softens clay

- Ferric oxide < 7%
  - Gives red colour: oxygen condition
  - Improved durability
  - Gives strength

- Alkalis < 10%
  - Help in fluxing
  - Cause efflorescence

Brick manufacturing

- Unsoiling – removal of top soil for clay mining
- Digging – extraction and spreading of clay on a level land
- Cleaning – removal of impurities/lumps/stones/pebbles
- Weathering – softening of clay by exposing to atmosphere
- Blending – mixing of other ingredients
- Tempering or pugging - Water in the required quantity is added and the whole mass is mixed so as to form a mass of uniform character.
- Moulding – shaping the clay mix to required shape
- Drying – drying the bricks in atmosphere
- Burning – dried bricks are placed in kiln and fired

Brick Manufacturing

Brick Manufacturing

Classes of bricks: First class

- Thoroughly burnt – deep red in colour
- Smooth, rectangular, free of flaws
- Uniform texture
- No lumps of lime
- Cannot be scratched
- Metallic ringing sound
- 12-15% water absorption
- Strength > 10 MPa

Classes of bricks: Second class

- Small cracks and distortions permitted
- 16-20% water absorption
- Strength > 7.0 MPa

Classes of bricks: Third class

- Under-burnt
- Soft and light coloured
- Dull sound
- Used for temporary structures

Classes of bricks: Fourth class

- Over-burnt
- Badly distorted
- Brittle
- Used for mettle work in floors, foundation and roads

Strength classes of bricks

Table 1 Classes of Common Burnt Clay Bricks
(*Clause* 4.1)

Class Designation	Average Compressive Strength not Less Than N/mm²	(kgf/cm²) (approx)
35	35·0	(350)
30	30·0	(300)
25	25·0	(250)
20	20·0	(200)
17·5	17·5	(175)
15	15·0	(150)
12·5	12·5	(125)
10	10·0	(100)
7·5	7·5	(75)
5	5·0	(50)
3·5	3·5	(35)

Tests of bricks

- Crushing strength
- Absorption
- Shape and size
- Field Tests

Crushing Strength

- Bricks are placed in a compressive strength testing machine and crushed
- Frog is filled with mortar, stored in a damp jute bag for 24 hours, followed by immersion in water for 24 hours
- Load applied uniformly over the brick
- The failure load noted to calculate the compressive strength
- Average value of 5 bricks is reported

Absorption

- Brick specimen are weighed dry
- Then they are immersed in water for a period of 24 hours.
- The specimen are taken out and wiped with cloth. The weight of each specimen in wet condition is determined.
- The difference in weight indicate the water absorbed
- Should not be more than 20%

Shape and Size

- Bricks should be of standard size and edges should be truly rectangular with sharp edges
- 20 bricks placed along length, breadth and height
- Following tolerance levels are allowed
  - Length wise: 3680 to 3920 mm
  - Width wise: 1740 to 1860 mm
  - Height wise: 1740 to 1860 m

Field Tests/ Desirable Bricks Properties

- Uniformity in shape – A good brick should have rectangular plane surface and uniform in size.

- Uniformity in colour **-** A good brick will be having uniform colour throughout.

- Structure - A few bricks may be broken in the field and their cross-section observed. The section should be homogeneous, compact and free from defects such as holes and lumps.

Field Tests/ Desirable Bricks Properties

- Sound Test - If two bricks are struck with each other they should produce clear ringing sound
- Hardness Test: For this a simple field test is scratch the brick with a nail. If no impression is marked on the surface, the brick is sufficiently hard.
- Toughness Test – Drop the brick from 1m height. It should not crack

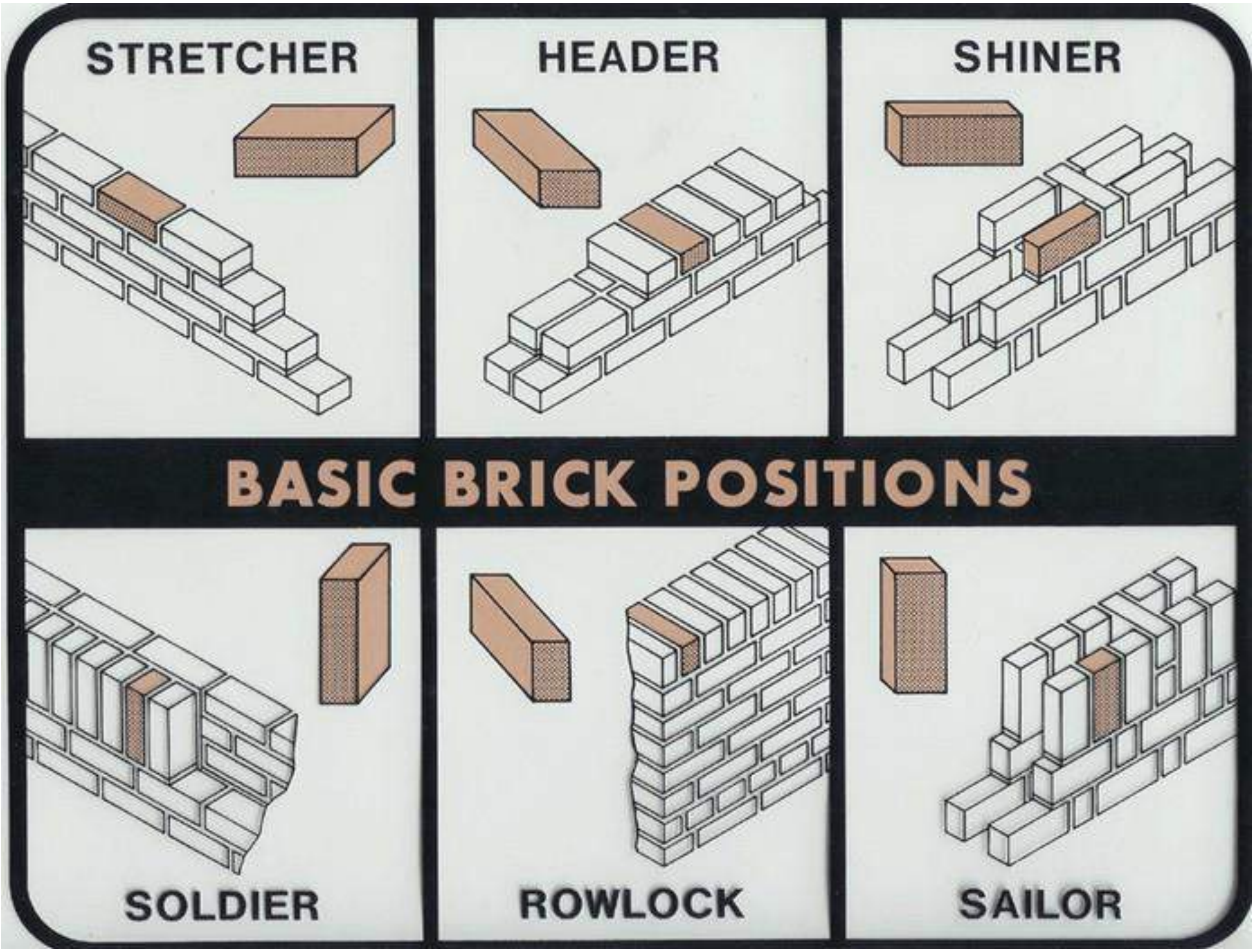
Field Test - Efflorescence

- Place the brick specimen in a glass dish containing water to a depth of 25 mm in a well ventilated room.

- After all the water is absorbed or evaporated again add water for a depth of 25 mm.

- After second evaporation observe the bricks for white/grey patches.

Position of bricks



Thank You!

- Any doubts..???

Introduction to Basic Civil Engineering
Module 2- Stones and Cement

Stones

- One of the most commonly used building material during early ages

- Obtained from rocks in the earths crust

- Usually, a combination of minerals such as quartz, calcite, etc.

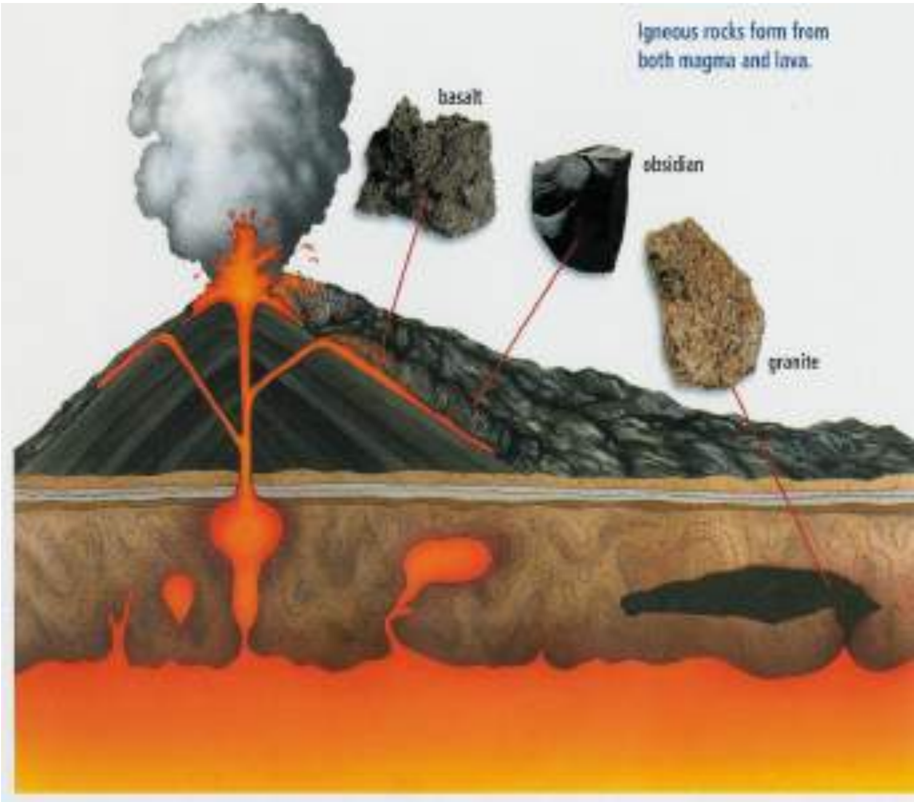
Use of stones

- Construction of foundation, walls, arches, abutments etc.
- For making stone masonry
- Coarse aggregate in concrete
- Ballast in railways, preparation of base course and sub base course in roads
- Flooring materials
- Roofing materials
- Industrial application such as production of cement

Stones - Classification

Based on origin –

- Igneous rocks - formed by the cooling of magma are called igneous rocks.
  - Strong and durable



- The portion of lava which comes outside the surface cools quickly and forms a rock of non-crystalline nature called as trap or basalt

- The rest which remains inside the earth undergoes cooling at a slow rate and results in the formation of a rock of crystalline variety known as granite.

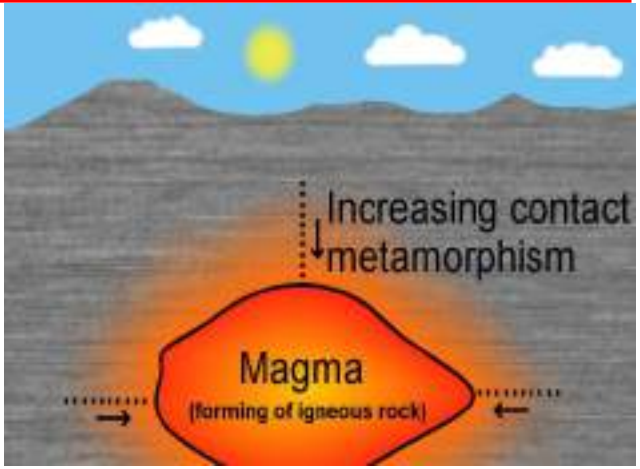
Stones - Classification

- Sedimentary Rocks - formed by the weathering action on the original rock and subsequent transportation by air, river, glacier and sea and deposition at a different localities

- The deposits gets consolidated by the pressure and heat forming rocks
  - Uniform, fine grained and compact
  - Stratified in appearance
- Eg. limestone, sand stones etc.
- Further classified into
  - Residual deposit, sedimentary deposit, chemical deposit and organic deposits

Stones - Classification

- Metamorphic stones - rocks are formed by the change in character of the pre-existing rocks
  - High pressure and temperature, chemical agents



- Eg. Limestone to Marble, sandstone to quartzite, granite to gneiss

Stones - Classification

Based on chemical composition

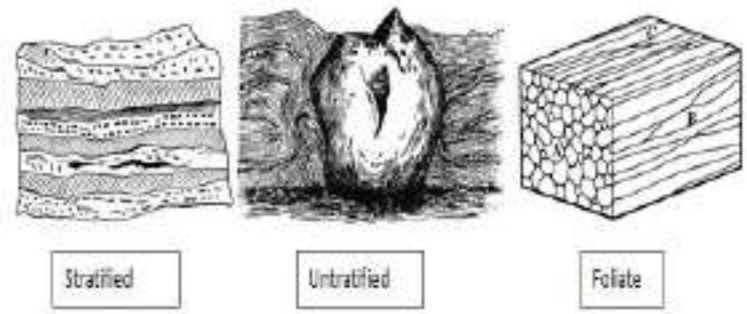
- Siliceous rocks – Silica is the major mineral
  - Hard and durable
  - Not easily affected by weathering
  - Granite, Sandstones etc

- Argillaceous rocks – Clays are the main mineral
  - Can be dense, compact
  - Can be soft and brittle
  - Laterites, slate etc.

- Calcareous rocks – Calcium carbonate is the predominant mineral
  - Durability will depend on the atmosphere
  - Limestone, marble, dolomite

Stones - Classification

Based on the structure of the rock



- Stratified rocks - possess planes of stratification or cleavage
- Can be easily split along the layers of stratification

- Unstratified rocks – No layers or stratifications.
- Structure may be crystalline granular or compact granular
- Cannot be split into thin slabs
- Granite,

- Foliated rocks – typically seen in metamorphic rocks were grains are oriented along a particular direction due to heat and pressure
- These rocks have a tendency to be split up in a definite direction only

Identify

Dressing of stones

- A place where exposed surfaces of good quality natural rocks are abundantly available is known as ‘quarry’
- The process of taking out stones from the natural bed is known as ‘quarrying
- The stones after being quarried are to be cut into suitable sizes and with suitable surfaces which is called dressing of stones
  - To make the transport from the quarry easy and economical.
  - To suit the requirements of stone masonry.
  - To get the desired appearance for the stonework

Characteristics of a good stone

- Crushing strength – Should have sufficient strength to withstand loads.

- Hardness – Should be sufficiently hard, especially for flooring and pavement applications.

- Appearance – important from an architectural point of view. Colour is dependent on the type of mineral present.

- Resistance to fire – clay stones are resistant to fire but softer

- Texture - good building stone should have a compact fine crystalline structure, free from cavities, cracks or patches of soft or loose material.

Characteristics of a good stone

- Durability -It denotes the period in years for which a stone may stand practically unaltered after being used in construction.

- *Water absorption:* Moisture reduces the strength of the rocks and as such rocks that contain or absorb great amounts of moisture show lower strength values. For a good stone, percentage absorption by weight after 24 hours should not exceed 0.60

- *Weathering:* A good building stone should possess better weathering qualities. It should be capable of withstanding adverse effects of various atmospheric and external agencies such as rain, frost, wind, etc.

- Ease of dressing - Should be capable of being dressed easily. Important from the economic point of view

Common Stones in India

- *Granite:* Granite is an igneous rock and is hard and durable. Possess excellent building properties, like high strength, very low abrasion value, good resistance to frost and other weathering agencies, and are available in different appealing colours

Common Stones in India

- *Limestone:* They are sedimentary rocks composed mainly of calcium carbonate. They show great variation in their properties and, hence, all types are not useful as building stones.

- Useful for paving and flooring

- Useful for the production of cement

- Can be used for road construction etc.

Common Stones in India

- *Marble:* These are metamorphic rocks and have been formed from limestone under high temperatures. Marbles vary greatly in colour, structure and texture and most of them are suitable both as an ornamental stone and as a construction material.

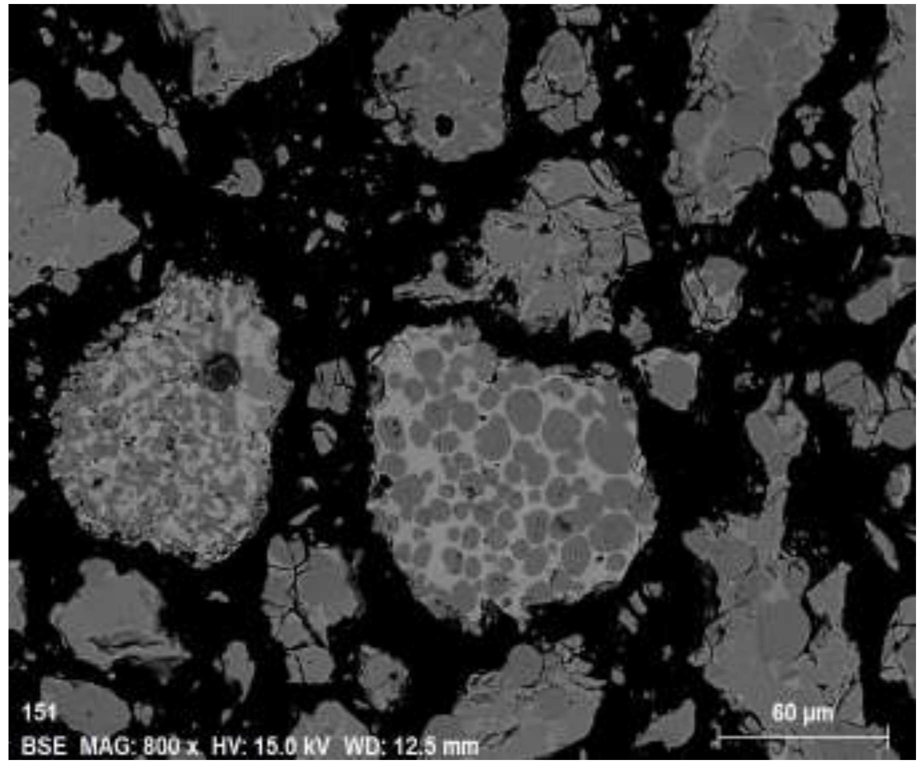
- *Laterite:* It is a sedimentary rock composed mainly of oxides of iron and aluminium. Laterites are of dull red or brown colour and their important property is that they are quite soft and plastic when cut from the natural bed rock but become hard on exposure.

Common Stones in India

- Other kind of stones are sand stone, basalt, kankar, gneiss, etc.

Cement

- In construction, cements are usually fine powders (100nm to 300µm) that harden on reacting with water



Cements

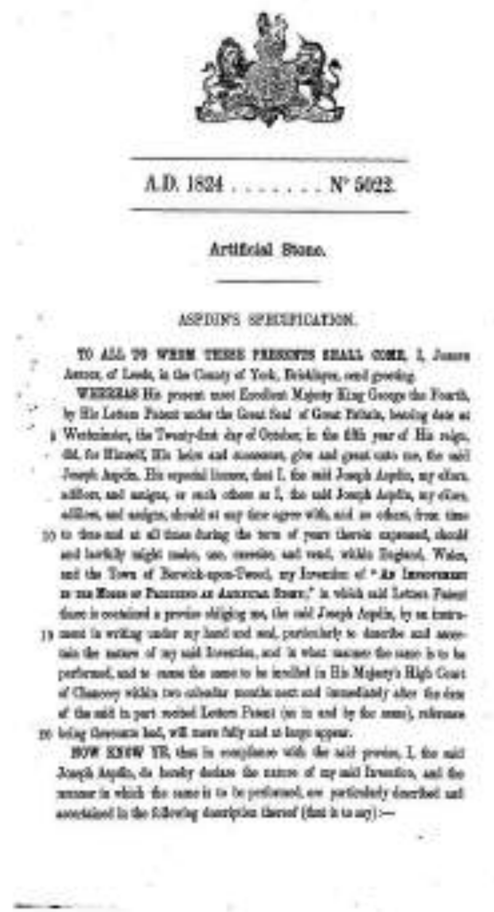
- There are many types of cements, e.g.:
  - Portland cements,
  - Calcium aluminate cements (High alumina cements),
  - Calcium sulpho-aluminate cements
  - Blended cements, etc.

Portland Cement

- The most commonly used cement is Ordinary Portland Cement or simply OPC

- OPC is so called as it bears similarity to the Portland Stone found in England

- Joseph Aspdin, a British brick-layer got a patent to Portland cements in 1824



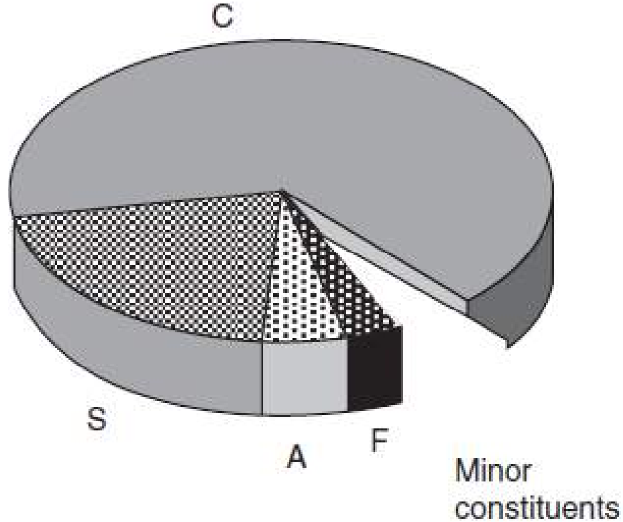
A.D. 1824 . . . . N° 5022.

Artificial Stone.

ASPDIN'S SPECIFICATION.

Cement Composition

Main constituents	Cement chemist's shorthand	%
SiO_2	S	21.1
Al_2O_3	A	5.6
Fe_2O_3	F	3.0
CaO	C	65.5
		95.2



Minor constituents	%
Mn_2O_3	0.05
P_2O_5	0.15
TiO_2	0.30
MgO	1.50
SO_3(S)	1.20
Loss on ignition	0.50
K_2O	0.72
Na_2O	0.18
Fluorine	0.04
Chloride	0.02
Trace elements	0.01
	4.67

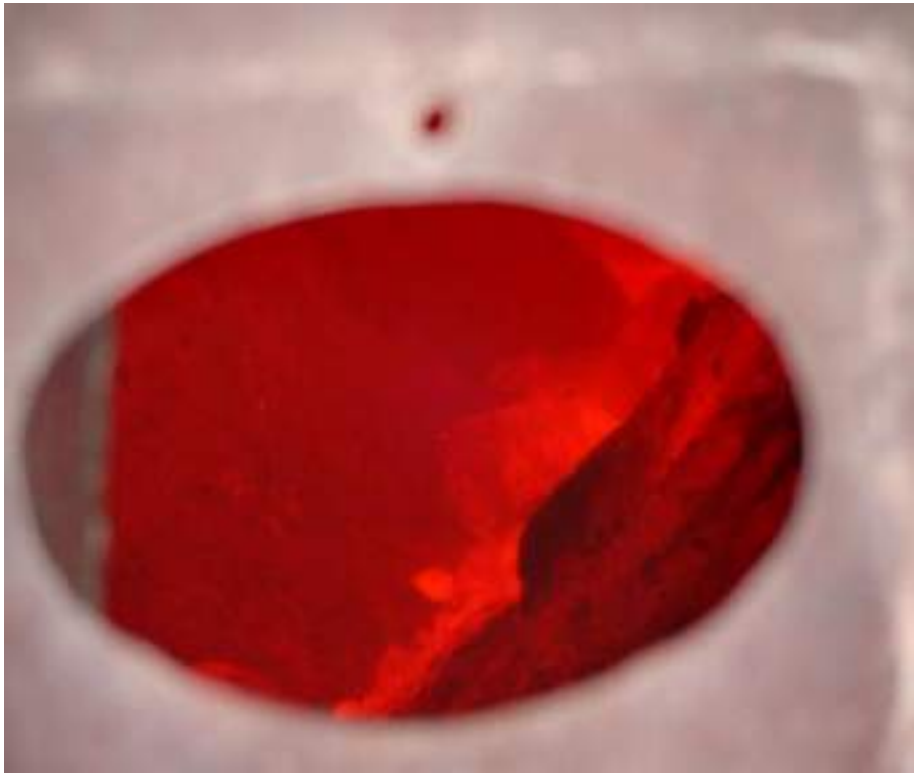
Cement Production

- By heating a well homogenised mixture of clay and limestone in a rotary kiln up to 1450° C

- Limestone
  - Production of $CaO + CO_2$

- Clay
  - Production of $SiO_2 + Al_2O_3 + Fe_2O_3$

Cement Production



Cement production

- Clinker is formed in the rotary kiln
  - Ground with gypsum to regulate the setting time of cement

Cement Composition

Major phases in Portland Cement

- 3CaO.SiO2 – Alite – C_3S (45-65%)
- 2CaO.SiO2 – Belite – C_2S (10 – 30%)
- 3CaO.Al2O3 – Aluminate – C_3A (5-12%)
- 4CaO.Al2O3.Fe2O3 – Ferrite - C_4AF (6 – 12%)

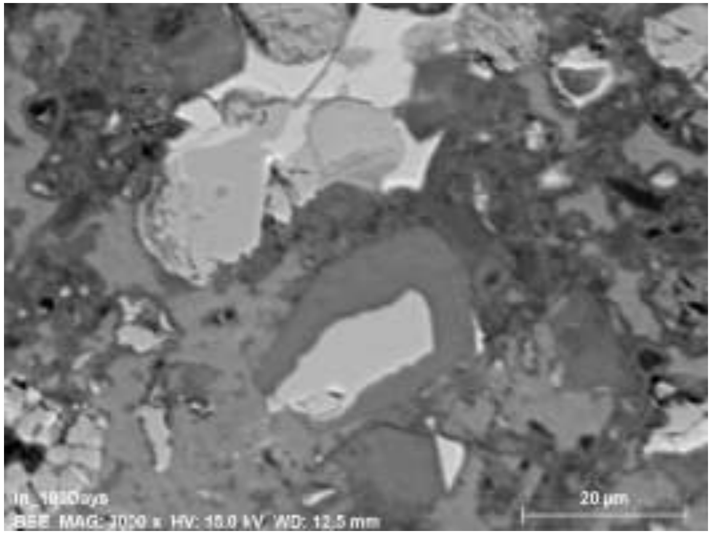
Cement chemistry notations are used

Alite and belite are the main strength providers

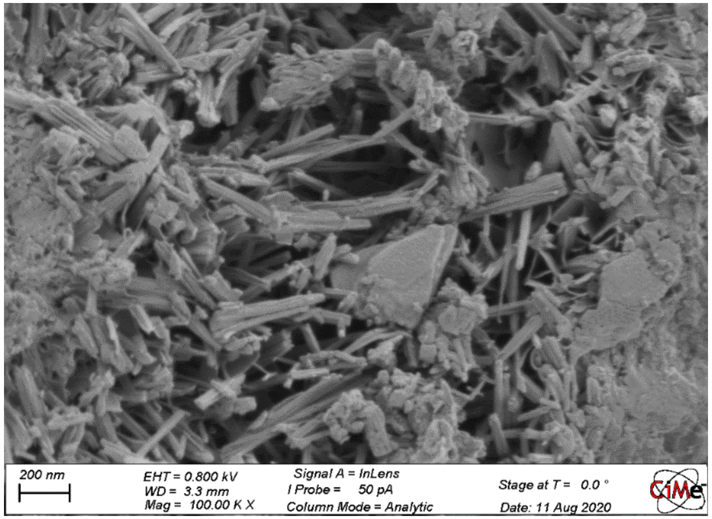
We add 5% gypsum to prevent very fast reaction of cement

Why does cement harden?

- Alite and belite react with water to form amorphous calcium silicate hydrate gel
  - $C_3S + H \rightarrow C\text{-}S\text{-}H + CH$
  - $C_2S + H \rightarrow C\text{-}S\text{-}H + CH$



- C-S-H is the binding "glue" of concrete

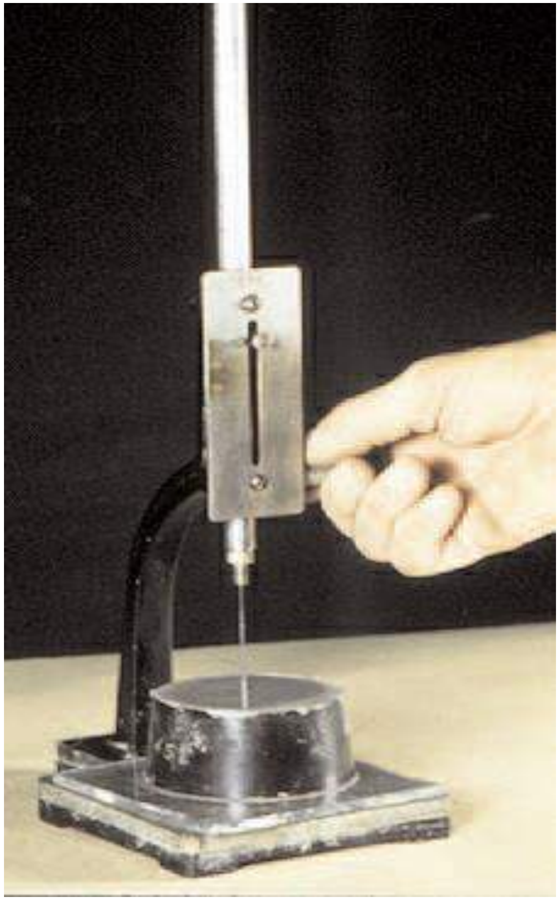


Setting Times

- Initial setting time – the time that elapses from the moment water is added until the paste ceases to be fluid and plastic
  - Minimum 30 minutes suggested in the code
  - Typically more than 3 hours

- Final setting time – the time that elapses from the moment water is added until the cement paste achieved a certain degree of hardness

- A certain given penetration into fresh paste using a standard needle – IS 4031 (Part 5)



Strength

- Strength measured on mortar (1:3) cubes (7.07 cm on side – IS4031 (Part 6)
- Demoulded after 24 hours
- Tested at 3, 7 and 28 days

Grades of Cement – BIS Specifications

33 Grade cement

- 16 MPa in 72 hours, 22 MPa in 168 hours,33 MPa in 672 hours

43 Grade cement

- 23 MPa in 72 hours, 33 MPa in 168 hours, 43 MPa in 672 hours

53 Grade cement

- 27 MPa in 72 hours, 37 MPa in 168 hours, 53 MPa in 672 hours

Qualities of Cement

- Fineness – should not be too fine or too coarse
- Setting time – must conform to specifications
- Soundness – ability of a hardened **cement** paste to retain its volume after setting without delayed destructive expansion
  - This destructive expansion is caused by excessive amounts of free lime (CaO) or magnesia (MgO)
- Strength development – should achieve the specified compressive strength

Storage of Cement

- Cement needs to be carefully stored
- Absorbs moisture from atmosphere
- Stacked and covered using waterproof sheets
- Do not store more than 1.5 to 2 years

Types of cement

- Ordinary portland cement – discussed previously

- Rapid hardening cement: The rapid hardening property is imparted to the cement primarily by burning at a higher temperature and secondly by finer grinding of the particles
  - Gains strength rapidly compared to OPC, very high early strengths
  - It can be used when the construction has to be carried out fast
  - Emergency repair and maintenance

- Low heat cement: It is a type of Portland cement which sets and hardens with the evolution of very low heat of hydration
  - It contains low percentage of tricalcium aluminate, of about 5 per cent, and higher percentage of dicalcium silicate, of about 45 per cent.

  - Ideal for construction of mass structures

Types of cement

- *Quick setting cement:* It is produced by adding a small percentage of aluminium sulphate and by finely grinding the cement
  - It contains very little or no retarding substances like gypsum. The setting action of the cement starts within 5 minutes after addition of water and it becomes hard in less than 30 minutes.

- *Portland Pozzolanic cement –* Produced by replacing a part of cement with pozzolanic materials such as fly ash or calcined clay
  - Lower heat of hydration compared to OPC
  - More durable in conditions high sulphates and chlorides

Self-Reading

- High alumina cements
- Sulphate resisting cements
- Portland slag cements
- Hydrophobic cements
- Expanding cements

Thank you

- Any doubts????

Introduction to Basic Civil Engineering
Module 2- Sand, Mortar and Concrete

Sand

- Sand is an important building material
- Sand particles consist of small grains of silica (SiO_2)
- Formed by the weathering of rocks
- Major ingredient in concrete, mortar etc.

Sand

- Based on the natural sources from which sand is obtained, it is classified as follows:
  - Pit sand
  - River sand
  - Sea sand

- *Pit Sand* - obtained by forming pits in soils. It is excavated from a depth of about 1-2 m from the ground level

- This sand is found as deposits in soil and it consists of sharp angular grains, which are free from salts.

- Pit sand must be made free from clay and other organic materials before it can be used in mortar.

- Extremely good for construction

Sand

- River Sand - It is obtained from the banks or beds of rivers and it consists of fine rounded grains.
  - Usually white in colour
  - General purpose sand
  - Good for construction activities

- Sea Sand – Obtained from sea shores
  - Not ideal for engineering purposes
  - Why?

Sand Classification

Based on the grain size distribution, sand is classified as fine, coarse and gravelly.

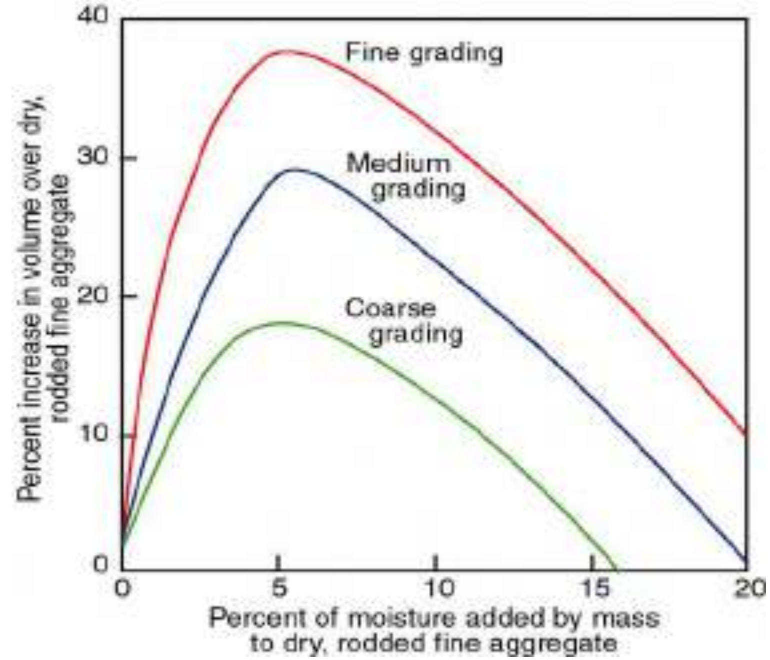
- *Fine sand:* The sand passing through a sieve with clear openings of 1.5875 mm is known as fine sand.
  - Fine sand is mainly used for plastering.

- *Coarse sand:* The sand passing through a sieve with clear openings of 3.175 mm is known as coarse sand.
  - It is generally used for masonry work.

- *Gravelly sand:* The sand passing through a sieve with clear openings of 7.62 mm is known as gravelly sand.
  - It is generally used for concrete work.

BULKING OF SAND

- The increase in the volume of sand due to the presence of moisture is known as bulking of sand.
- Moisture forms a film of water around the sand particles
- Finer sand are more affected by bulking
- Volume increase up to 40% at 5-8% moisture content
- Practical Implications???



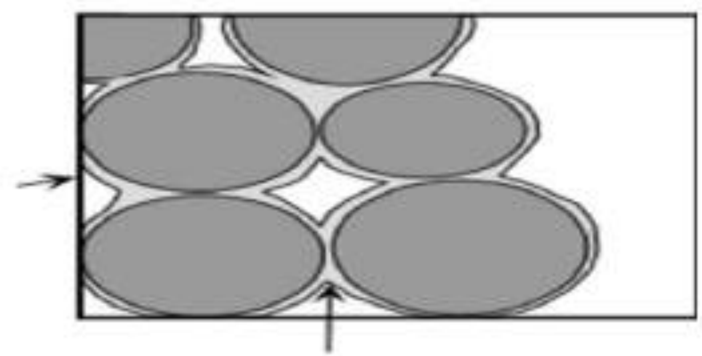


fig 1. Thin water firm

BULKING OF SAND

Ideal Sand

- It should be clean and coarse
- It should be free from any organic or vegetable matter; 3-4% clay is permitted
- It should be chemically inert.
- It should contain sharp, angular, coarse and durable grains
- It should not contain salts which attract moisture from the atmosphere.
- It should be well graded, i.e., it should contain particles of various sizes in suitable proportions.
- It should be strong and durable. It should be clean and free from coatings of clay and silt.

Functions of sand

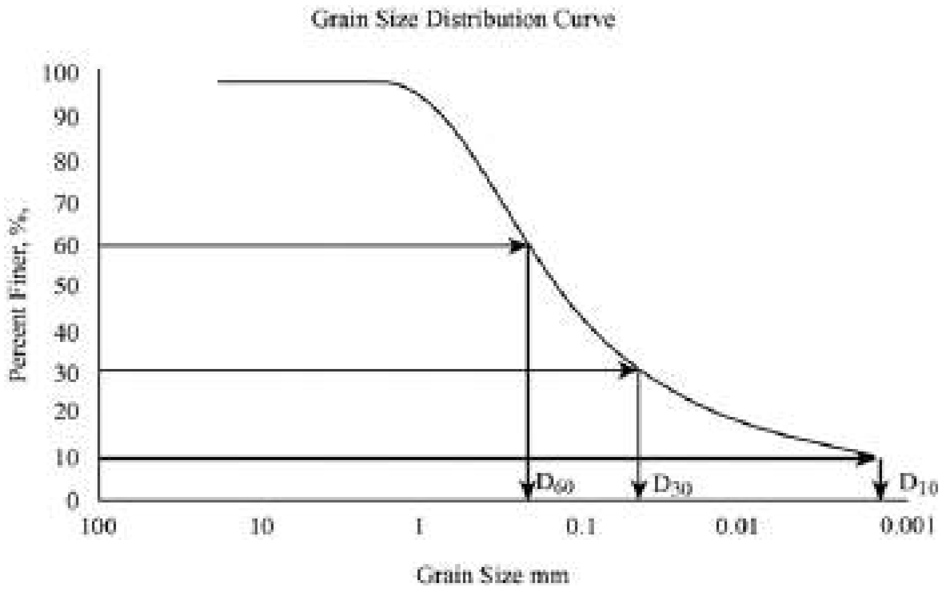
- *Strength:* It helps in the adjustment of the strength of mortar or concrete by variation of its proportion with cement or lime. It also increases the resistance of mortar against crushing.
- *Bulk:* It acts as an adulterant. Hence, the bulk or volume of mortar is increased which results in reduction of cost.
- *Setting:* In the case of fat lime, carbon dioxide (CO_2) is absorbed through the voids of sand and setting of fat lime occurs effectively.
- *Shrinkage:* It prevents excessive shrinkage of mortar in the course of drying and, hence, the cracking of mortar during setting is avoided.
- *Surface area:* It subdivides the paste of the binding material into a thin film and, thus, more surface area is offered for its spreading and adhering.

Grading of Aggregates

- Grading is the particle size distribution of the aggregate as determined by sieve analysis
- Sieves with square openings are used
- Sizes of the squares are defined in standards

Grading of Aggregates

- Several standards exist
- IS383 gives:
  - 7 sieve sizes for fine aggregates – 10mm to 150µm
  - 9 sieve sizes for coarse aggregates from 2.36mm to 80mm



IS383 – F.A. Grading limits

Percent passing for

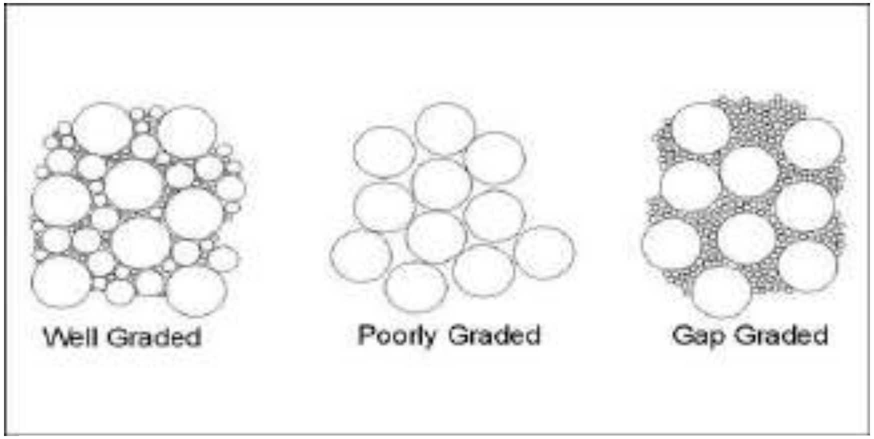
Sieve Size	Zone - I	Zone - II	Zone - III	Zone - IV
10 mm	100	100	100	100
4.75 mm	90-100	90-100	90-100	95-100
2.36 mm	60-95	75-100	85-100	90-100
1.18 mm	30-70	55-90	75-100	90-100
0.6 mm	15-34	35-59	60-79	80-100
0.3 mm	5-20	8-30	12-40	15-50
0.15 mm	0-10	0-10	0-10	0-15

Grading of Aggregates

- Grading is expressed as percentage of material passing each sieve
- Grading affects:
  - Aggregate and cement proportions
  - Water requirements
  - Workability
  - Economy
  - Shrinkage
  - Durability
  - Grading should be uniform

Different gradations of Sand

- *Well Graded* – Contains particles of wide size ranges
  - Ideal for preparation of concrete
  - Well packed structure since fine particles will fill the space between the coarse aggregates



- *Uniformly graded:* Small variation in particle sizes
  - Ineffective packing. Results in large voids
  - Uneconomical
- *Gap graded:* Some particles sizes are missing
  - Stiff and low workability in concrete

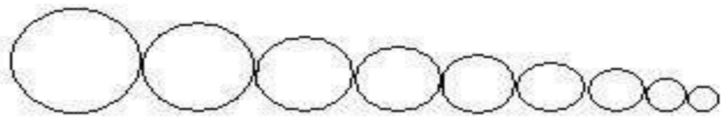


Figure 1. Well Graded

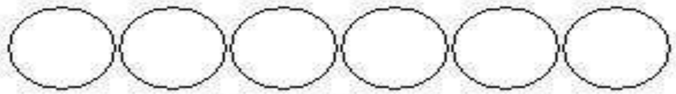
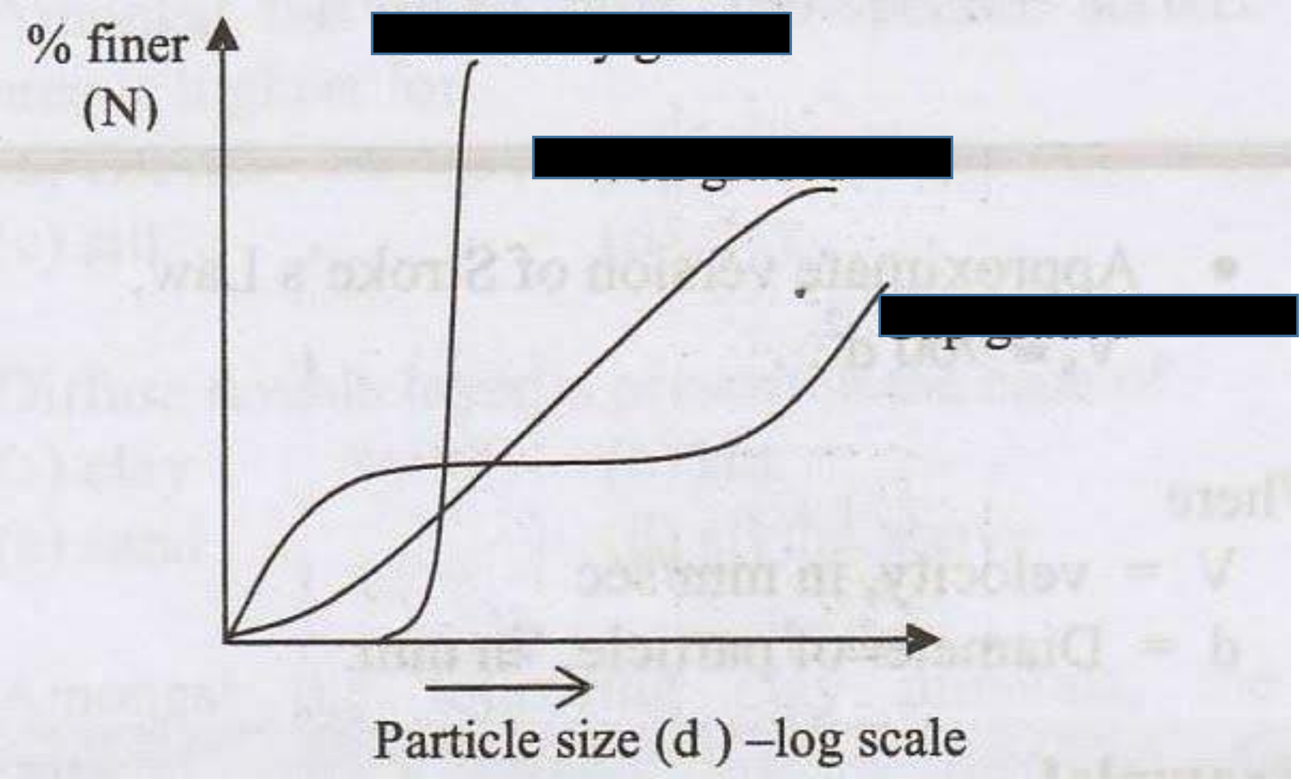


Figure 2. Uniformly-Graded

Figure 3. Gap-Graded

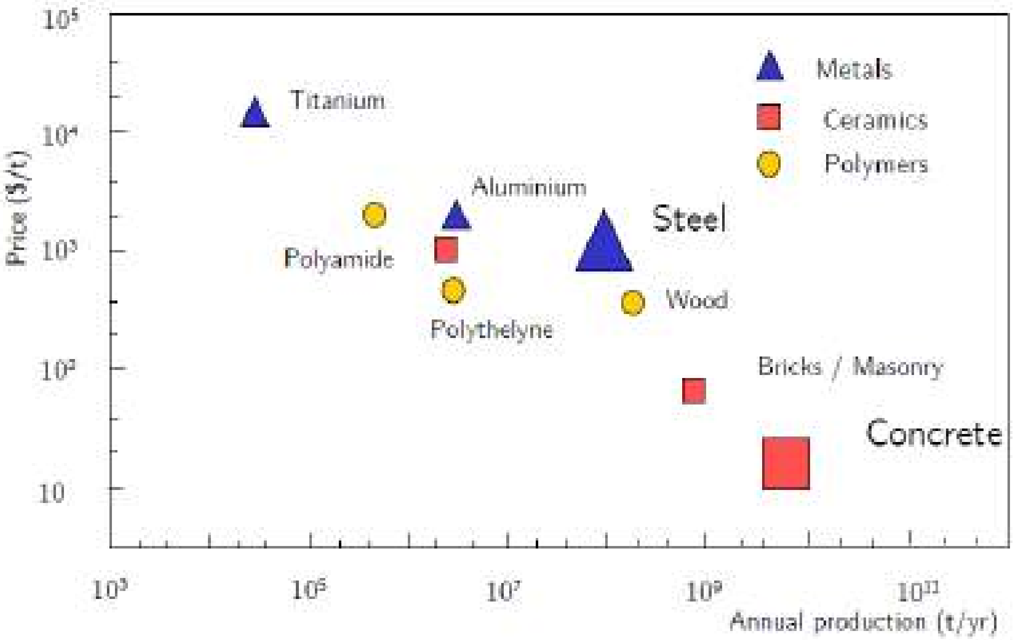
Different gradations of Sand



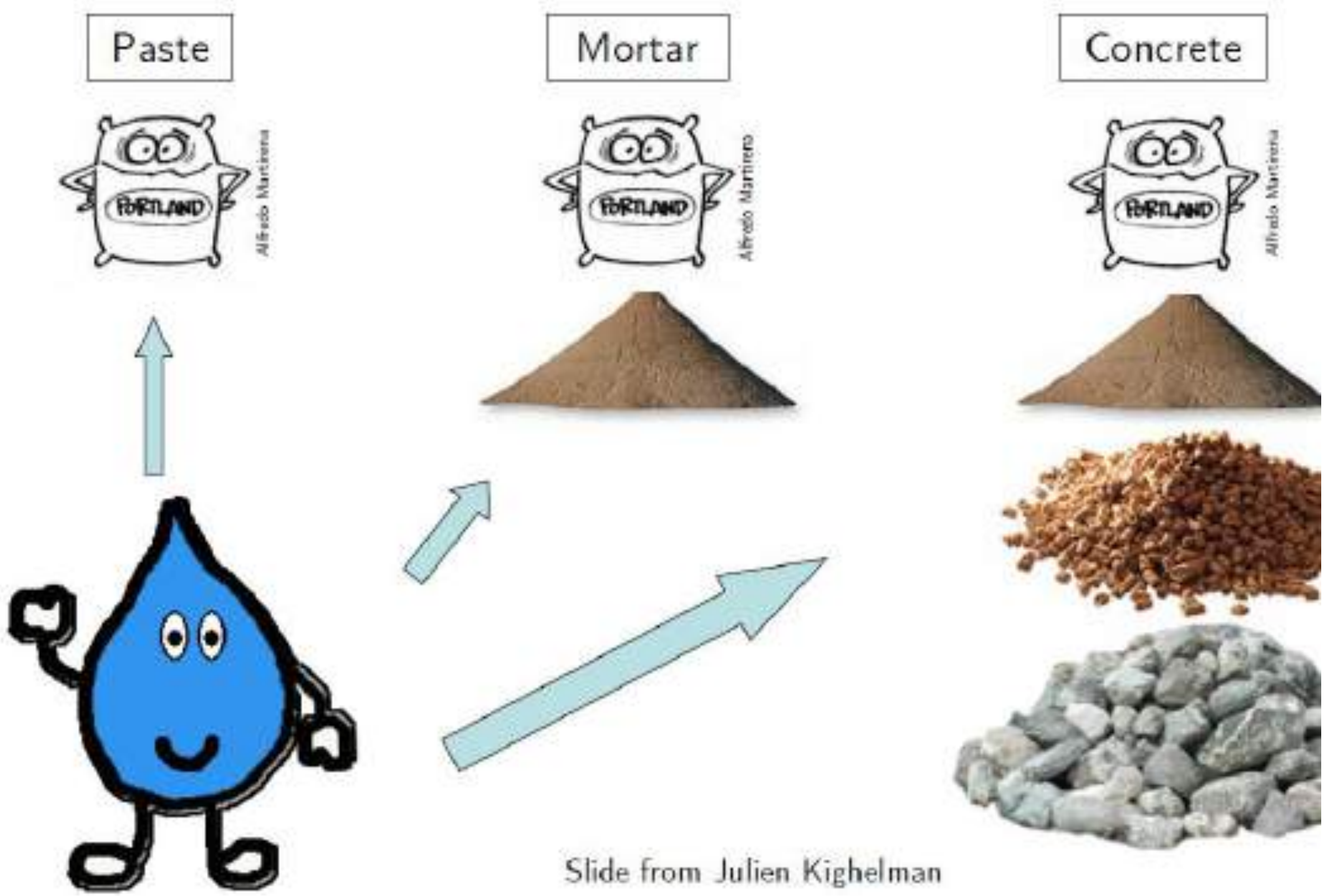
Alternatives

Concrete

- Concrete is the most used construction material in the world



What is concrete?



Why Concrete?

- Concrete is a widely used material because
  - It is cheap
  - It can be made with locally available materials
  - It can be transported to the site or made on site with whatever resources are available
  - It is a viscous mix that can take any form
  - Concrete is a strong and usually a durable material
  - However, it shows brittle failure and has a low tensile strength
  - Comparison with steel and timber – Strength development

Components of concrete

- Cement
- Water
- Aggregates – fine (<4.75mm) and coarse (>4.75mm)
- Chemical admixtures, e.g. Super plasticizers, retarders, accelerators, etc.
- Mineral additions, e.g. fly ash, slag, rice husk ash, etc.

Aggregates

- Aggregates should be graded to minimise voids
  - Fine aggregates fill spaces between coarse aggregates
- Aggregates are usually the strongest and the cheapest solid component of plain concrete, so there is an interest in increasing their fraction
- However, the zone around the aggregates can be weak and can reduce strength

Batching

- The proportioning of the components is called batching
- Batching practices vary throughout the world
- Batching can be based on volume or on weight
- Volumetric batching is less accurate

Concrete Production

Concrete Transportation

Source: cariolawheelbarrow.com

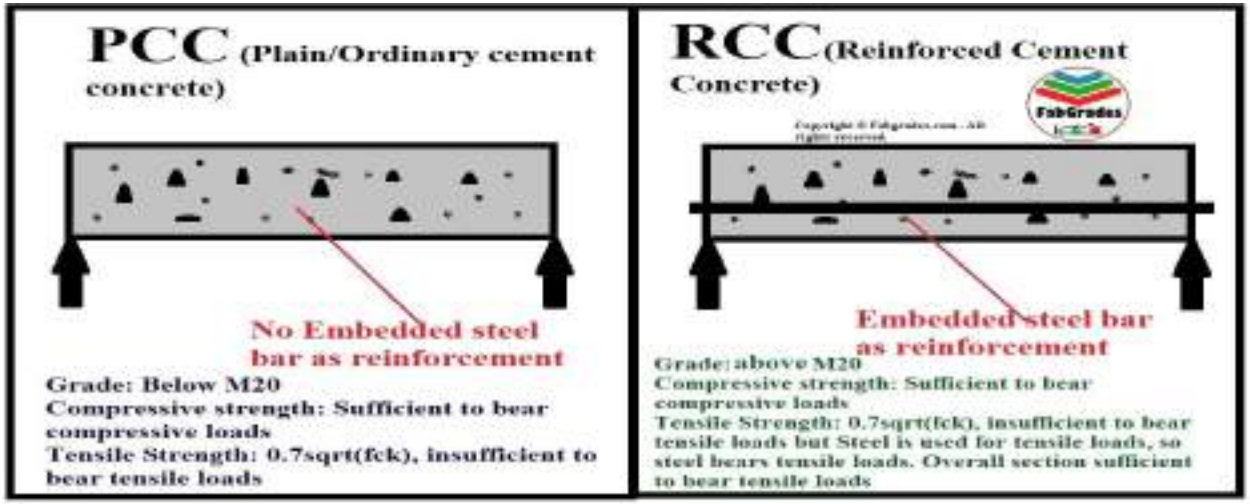
Concrete Transportation

Formwork

Types of Concrete

- Plain cement concrete – without reinforcement
  - Low tensile strength
  - Brittle failure
  - We need to use reinforcement

- Reinforced Cement Concrete – plain concrete plus rebar



Grades of Concrete

- The concrete mixes are designated as M10, M15, M20, M25, M30, M35 and M40.
- The number denotes the ultimate strength of concrete mix in MPa at the end of 28 days.
- Another term is characteristic strength or f_{ck}
- Minimum grade for RCC is M20

Type of work	*Recommended mix*	*Applications*
Ordinary concrete	M 10, M 15, M 20	Mass concrete like heavy wall.
Standard concrete	M 25, M 30, M 35, M 40, M 45, M 50, M 55	Thinner sections.
High strength concrete	M 60, M 65, M 70, M 75, M 80.	Pre-stressed concrete.

1) Proportioning Concrete

- Arbitrary Proportioning – Some standard ratios of cement:FA:CA are given based on the experience

Proportion of concrete mix	Maximum size of aggregate	Nature of work
1:1:2	12–20 mm	Heavily loaded RCC columns and RCC arches of long span
1:2:2	12–20 mm	Small precast members of concrete, such as poles for fencing telegraphs, long piles, watertight constructions and heavily stressed members of the structures.
1:1½ :3	20 mm	Water-retaining structures, piles, precast products, etc.
1:2:3	20 mm	Water tanks, concrete deposited under water, bridge construction and sewers
1:2½:3½	25 mm	Footpaths and roadworks
1:2:4	40 mm	For all general RCC works in building, such as stair, beam, column, weather shed, slab and lintel, machine foundation subjected to vibration and RCC piles.
1:3:6	50 mm	Mass concrete works in culverts, retaining walls, etc.
1:4:8 or 1:5:10 or 1:6:12	60 mm	Mass concrete work for heavy walls, foundation, footings, etc.

1.Proportioning Concrete : Batching

- The proportioning of the components is called batching
- Batching practices vary throughout the world
- Batching can be based on volume or on weight
- Volumetric batching is less accurate

2.Mixing

- Hand Mixing
- Machine Mixing

3.Transportation of Concrete

- Mixed concrete has to be taken to the location as soon as possible
- Special concrete can be designed that can be pumped
- Should not lose uniformity, homogeneity, etc.
- Should not undergo segregation

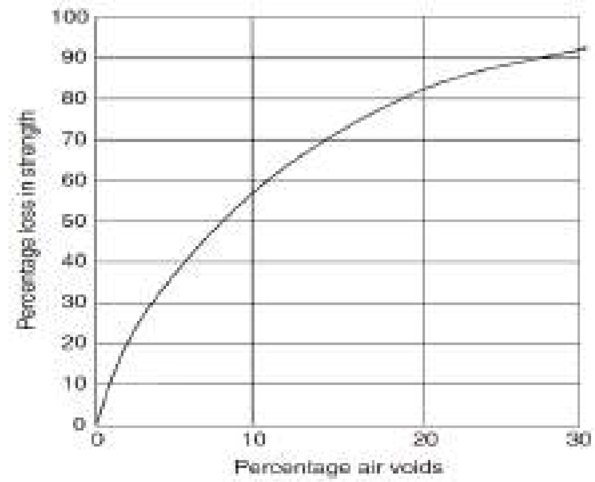
4. Placing concrete

- Well cleaned, adequately supported, oiled formwork has to be placed in the correct position
- Concrete must be laid continuously
- Should not be poured from a height more than 1m

- Concrete should not undergo segregation
- Formwork should not be displaced

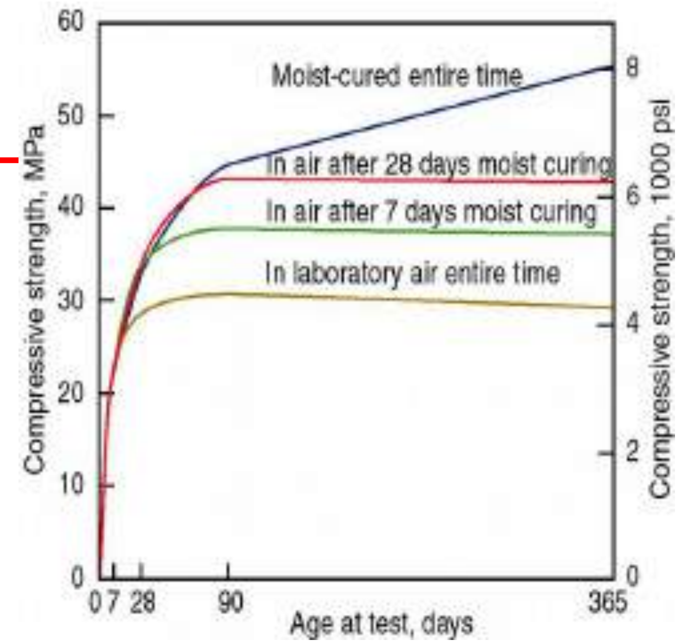
5. Compacting Concrete

- Compaction of concrete is the method adopted for expelling the entrapped air from the concrete.
- If the air is not removed fully, the concrete loses strength considerably.
- Hand compaction or machine compaction possible
- Helps in providing finishing to concrete
- Care should be taken to not over compact

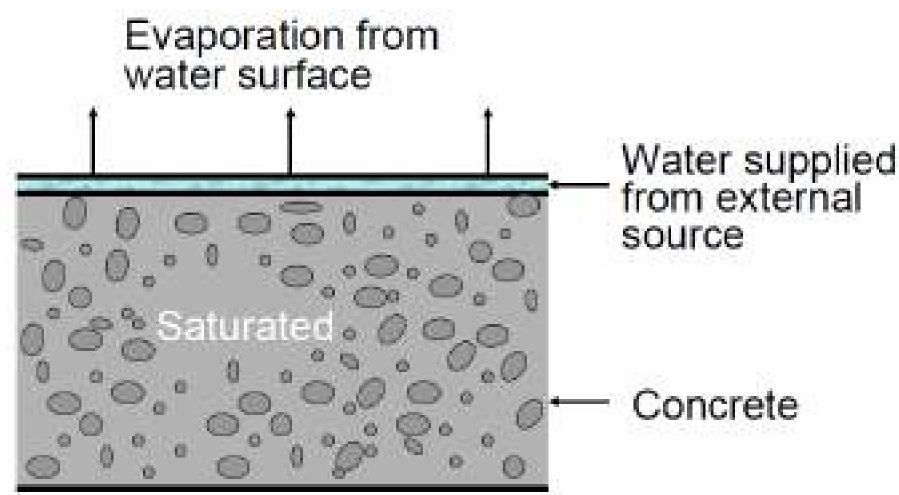


5. Compacting Concrete

6. Curing



- Curing requires adequate
  - Moisture
  - Temperature
  - Time
- Proper curing will improve
  - Strength
  - Abrasion resistance
  - Water tightness
  - Durability
  - Volume-stability



6.Curing


Spraying, fogging,
ponding
Saturated wet covering


Ponding on concrete slab

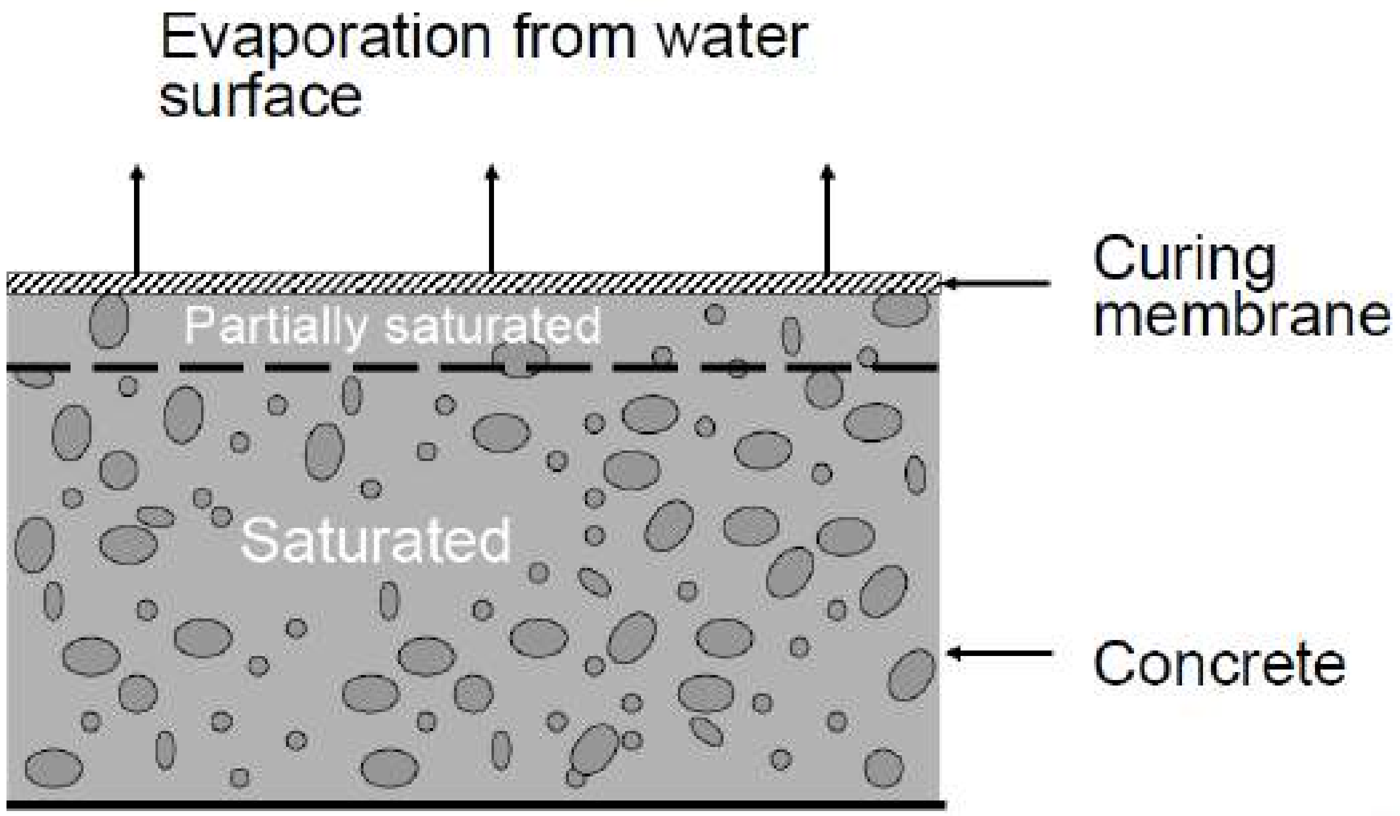
6.Curing

Plastic sheets

6.Curing - Chemicals

Curing compounds

6.Curing - Membrane



Classification of Concrete

- PCC
- RCC
- Fibre Reinforced Concrete
- Self-Compacting Concrete
- Precast Concrete
- Prestressed Concrete
- Light weight concrete

Thank you

- Any doubts???

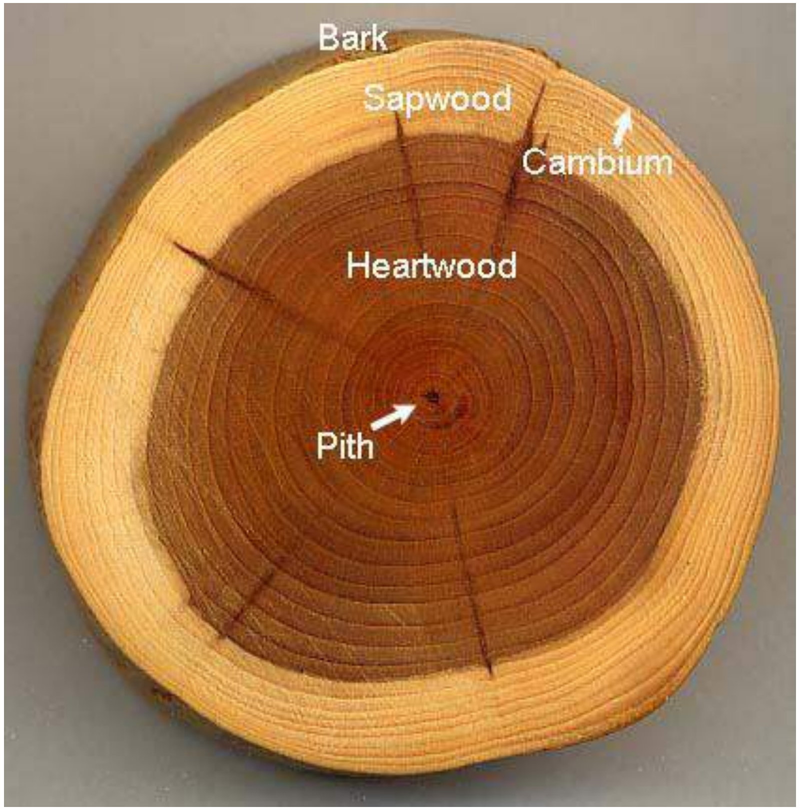
Introduction to Basic Civil Engineering

Lecture 2 – Steel and Timber

Sreejith Krishnan, *PhD*

Timber

- Timber denotes wood which is suitable for building or carpentry and for various engineering and other purposes



Classification of Timber

- Based on mode of growth
  - Exogenous – Grows outwards
    - Further divided to coniferous and deciduous
    - Coniferous trees have cone shape leaves and fruits. Yields softwood. Eg. Cedar, Pine
    - Deciduous trees have broad leaves which regularly falls and get replaced. Yields hardwood. Eg. Teak, Mahagony and oak
    - Useful for structural applications
  - Endogenous – Grows inwards
    - Not suitable for construction
    - Eg. Bamboo, Sugar cane

Classification of Timber

Classification based on modulus of elasticity – *Young's modulus* is determined by conducting ***bending test***. On this basis timber is classified as follows.

a) ***Group A***, $E = 12.5\ kN/mm^2$

b) ***Group B***, $E = 9.8\ kN/mm^2$ to $12.5\ kN/mm^2$

c) ***Group C***, $E = 5.6\ kN/mm^2$ to $9.8\ kN/mm^2$.

Classification based on durability – Durability tests are conducted by the forest research establishment. They bury test specimen of size $600 \times 50 \times 50\ mm$ in the ground to half their length and observe their conditions regularly over several years. Then timbers are classified as follows.

a) ***High durability*** – If average life is more than 10 years.

b) ***Moderate durability***– Average life between 5 to 10 years.

c) ***Low durability*** – Average life less than 5 years.

Classification of Timber

Classification based on availability – The ***IS***: ***339-1963*** has grouped timber into the following three grades based on availability.

a) ***X*** – Most common ; 1415 m^3 or more per year

b) ***Y*** – Common ; 355 m^3 to 1415 m^3 per year

c) ***Z*** – Less common ; less than 355 m^3 per year.

Properties of timber

- *Appearance:* A freshly cut surface of timber should exhibit a hard and shining appearance.
- *Colour:* The colour of the timber should be preferably dark. A light colour indicates low strength.
- *Hardness:* A good timber should be hard, i.e., it should offer resistance when it is being penetrated by another body. The chemical present in heartwood and the density of wood imparts hardness to timber.
- *Durability:* A good timber should be durable. It should be capable of resisting the action of fungi, insects, chemicals, physical agencies and mechanical agencies.
- *Strength:* A good timber should be strong for working as a structural member such as joist, beams and rafter. It should be capable of taking loads slowly or suddenly.
- *Structure:* The structure should be uniform and the medullary rays should be hard and compact. The annual rings should be regular and should be closely located.

Properties of timber

- *Mechanical wear:* A good timber should not deteriorate easily due to mechanical wear or abrasion. This property is essential for places where timber would be subjected to traffic, like wooden floors and pavements.
- *Toughness:* A good timber should be tough. It should be capable of offering resistance to shocks due to vibrations.
- *Elasticity:* This is the property by which the timber returns to the original shape when load causing deformation is removed. This property is essential when timber is used for bows, carriage shaft, etc.
- Fire resistance: Timber is a bad conductor of heat. A dense wood offers good resistance to fire and it requires sufficient heat to cause a flame.
- *Defects:* A good timber should be free from serious defects such as dead knots, flaws and shakes

Seasoning of wood

- Wood is dried by exposure to air to reduce moisture from 30-35% to 12-15%
- Kiln-drying can be carried out at higher temperatures (>80°C) to reduce water to 3.5%
- Other methods such as salt, chemical, boiling seasoning are also used
- Wood shrinks during seasoning
  - Circumferential shrinkage more than radial
  - Can lead to cracking

Use of wood in construction

- Wood can be used for most structural and functional elements of structures
- Can used for building formwork and scaffolding
- Can be used for making ply wood, etc.
- Framework of windows and doors
- Flooring
- Roof members

Advantages of Wood

- Easy to manipulate, shape and transport
- Can be planed, sawed and jointed using simple carpenters tools
- Easily available and transportable
- It is light weight but strong at the same time
- Wood is easily available and cheap
- It provides good insulation
- Is generally weather-resistant and ductile
- Can last hundreds of years if properly seasoned
- Easy to conduct repairs
- Maybe ideal for construction near marine conditions

Disadvantages of Wood

- It is not fire resistant
- Likely to decay if not preserved properly
- Can swell and shrink due to atmospheric moisture
- Requires regular maintenance
- Can crack or warp if not maintained properly

Steel

- Steel is an iron alloy
- It contains iron mixed with 0.2% to 2.1% carbon
- Manganese, chromium, vanadium and tungsten also used
- Steel has been known for thousands of years, earliest known is 4,000 years old from Anatolia
- Wootz steel has been used in India from around 300 B.C.

Steel

- Carbon increases the hardness of iron
- Carbon and other elements prevent dislocations from sliding and harden iron
- Hardness, ductility and tensile strength of steel can be controlled by varying the amount of alloying elements
- There are many types and grades of steel

Uses of steel

- Steel can be used for various purposes in building works.
  - As structural material in trusses, beams, etc.
  - As non-structural material for grills, doors, windows, etc.
  - In steel pipes, tanks, etc.
  - In sanitary and sewer fittings, rainwater goods, etc.
  - Corrugated sheets.
  - As reinforcement for concrete.

Mild steel

- Mild and low carbon steel
  - 0.05% to 0.15% carbon
  - Cheap and malleable
  - Neither brittle nor ductile
  - Density ~7.85 g/cm3
  - Young's modulus: 210 Gpa
  - Used in structures

Higher carbon steels

- Medium carbon steel
  - 0.3-0.59% carbon content
  - Balances ductility and strength
  - Used for forging, large parts and automotive
  - components
- High carbon steel
  - 0.6-0.99% carbon
  - Very strong, used for springs and high strength wires

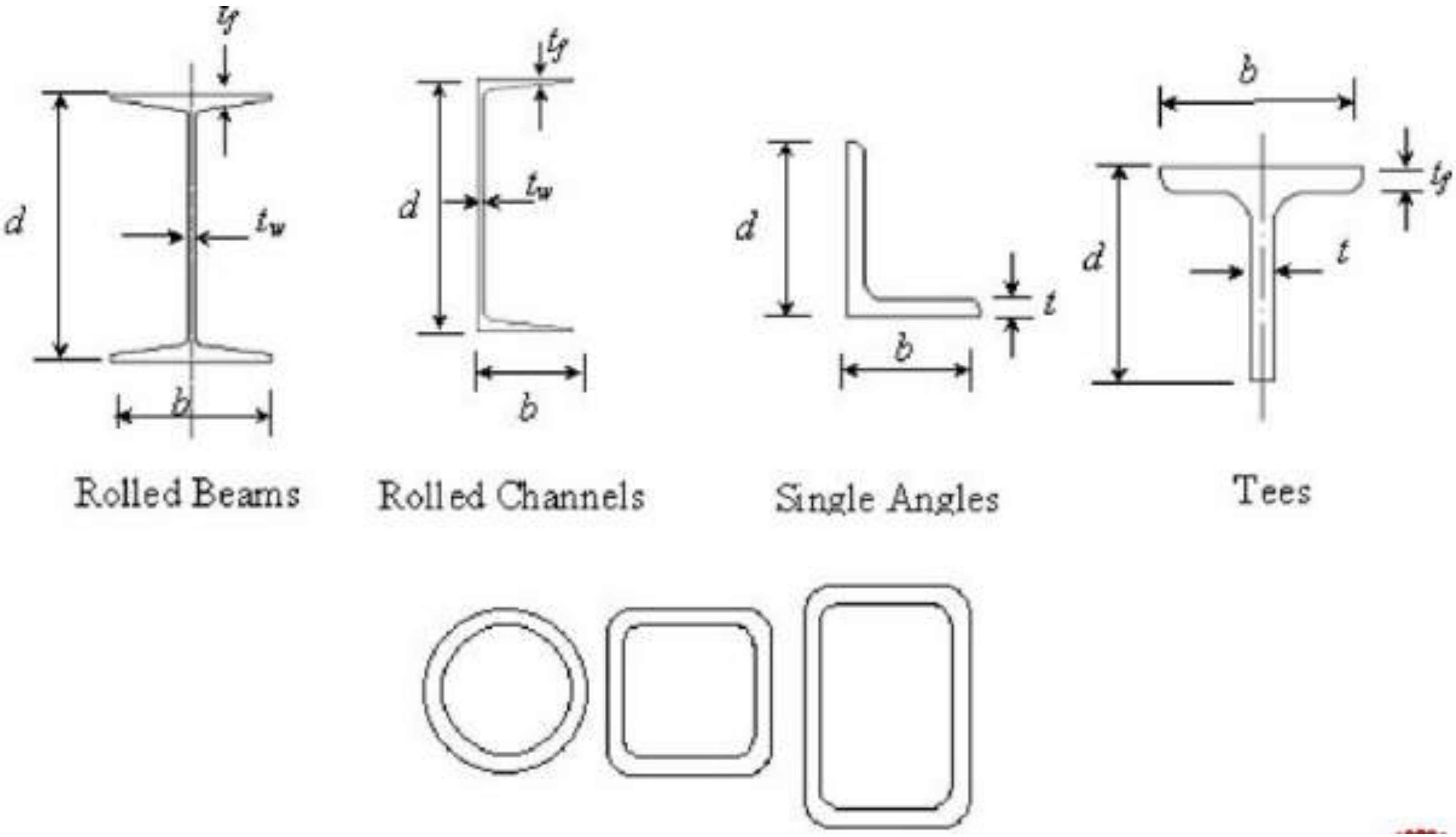
Other Steel types

- High-strength low-alloy steels
  - 0.05-0.25% carbon
  - Up to 2% manganese
  - Small amounts of chromium, nickel, molybdenum, copper, nitrogen, vanadium, niobium, titanium and zirconium
- Stainless steel
  - Minimum 10.5% chromium by mass up to 26%
  - Passivation offered by oxidation of chromium

Other steel types

- High-yield steel
  - Usually cold-rolled twisted bars
  - Deformations improve bond with concrete
  - Higher yield-stress than mild-steel (415-500 MPa)
  - More brittle than mild-steel

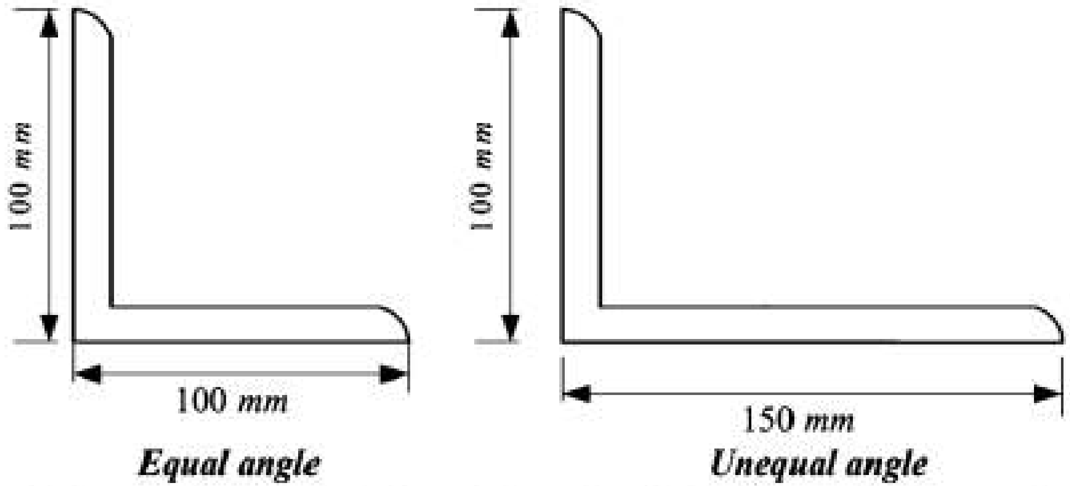
Forms of steels



Forms of Steel

- Angle sections

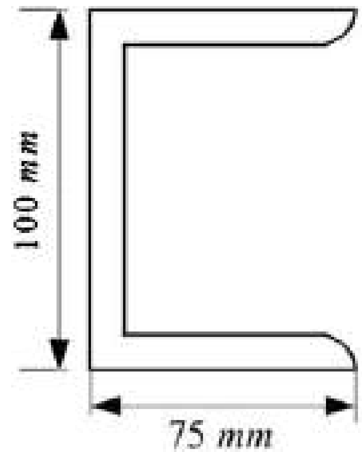
Angle section – Angle section consists of two legs, which can be of equal or unequal size or length. Accordingly they are specified as *ISA* (*Indian Standard Angle*) equal or unequal angles. These are available in sizes varying from 20 × 20 × 3 *mm* to 200 × 200 × 25 *mm*. *Indian Standard bulb angle* is another type of angle with bulged portion at the end of the leg.



Forms of Steel

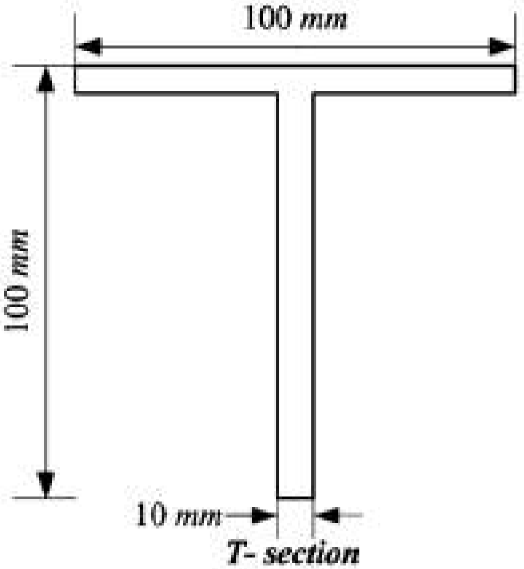
- Channel Section

Channel section – Channel section consists of a web with two equal flanges. Channel section is designated by the height of web and width of flange. These are available in sizes varying from 100 *mm* × 45 *mm* to 400 *mm* × 100 *mm*. BIS designates channel as *ISJC – Indian Standard Junior Channel*, *ISLC – Indian Standard Light Channel*, *ISMC–Indian Standard Medium Channel*, *ISSC–* Indian *Standard Special Channel*, etc.



Channel section

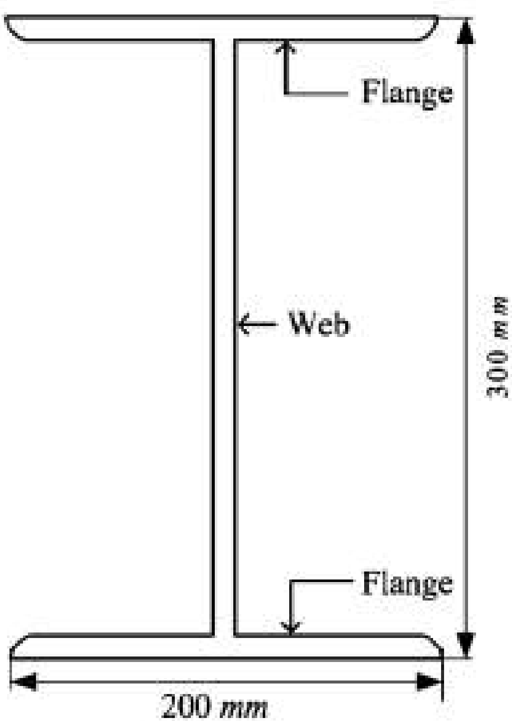
Forms of Steel



T – sections – The shape of this section is like that of letter T and it consists of flange and web. It is designated by overall dimensions and thickness. The specifications are *ISNT – Indian Standard Normal Tee*, *ISHT – Indian Standard Heavy Tee*, *ISWC – Indian Standard Wide Tee*, *ISST - Indian Standard Short Tee*, *ISMT - Indian Standard Medium weight Tee*, etc. T-sections are widely used as member of the steel roof trusses and to form built-up sections. These sections are available in sizes varying from 20 *mm* × 20 *mm* × 3 *mm* to 150 *mm* × 150 *mm* × 10 *mm*. The figure shows a T-section of size 100 *mm* × 100 *mm* × 10 *mm*. Special T-sections with unequal sides, bulbs at bottom edge of web, etc., are also available.

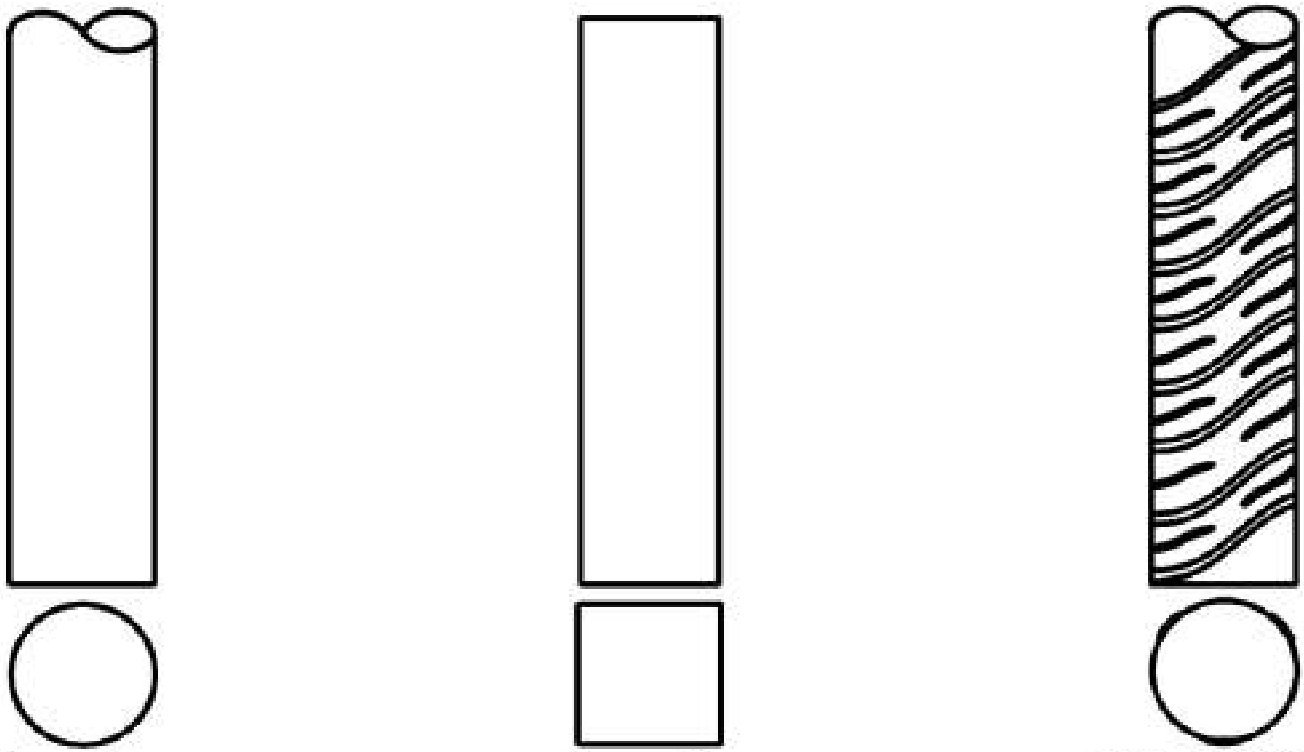
Forms of Steel

I - section – It consists of two flanges connected by a web, are also known as ***Rolled Steel Joists*** (***RSJ***). It is designated by overall depth, width of flange and weight per *metre* length. Available sizes are 75 *mm* × 50 *mm* to 600 *mm* × 210 *mm* of varying thickness. The designated sections are *ISJB – Indian Standard Junior Beam*, *ISLB – Indian Standard Light Beam*, *ISMB - Indian Standard Medium Beam*, *ISWB - Indian Standard Wide flange Beam*, *ISHB - Indian Standard Heavy Beam*, etc. These are used as beams, lintels, columns, members of steel framework, grillage foundations, built up columns for carrying lateral loads, etc. The economy in material is achieved by concentrating the material in two flanges where bending stresses are maximum. Rolled steel I-section is the most ideal section of a beam, wherein the flange resists major portion of the bending moment while the web resists major portion of shear.



I- section

Forms of steel



Round bars　　Square bar　　Ribbed HYSD bar

Thank You

Introduction to Basic Civil Engineering

Other building materials

Sreejith Krishnan, *PhD*

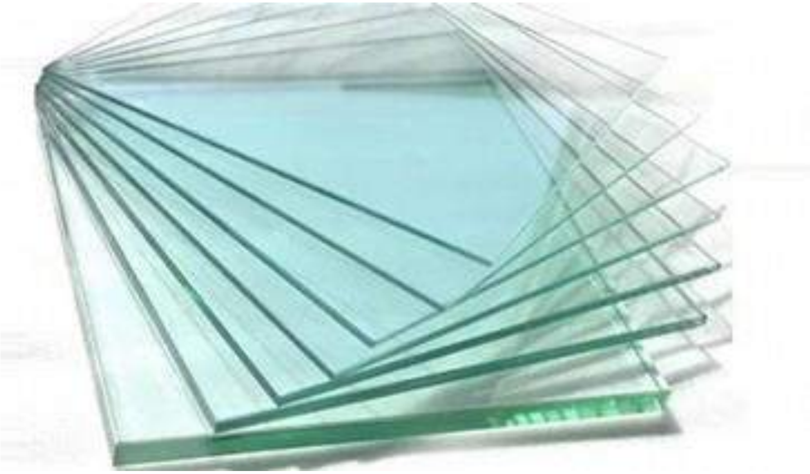
Ceramics

- A **ceramic** is any of the various hard, brittle, heat-resistant and corrosion-resistant materials made by shaping and then firing a nonmetallic mineral, such as clay, at a high temperature.

- Common examples are earthenware, porcelain, and brick.

Ceramics

- High tensile strength in theory
  - Presence of flaws and cracks
- High compressive and shear strength
- Uncertain transverse strength



Glass

- **Glass** is a non-crystalline, often transparent amorphous solid, that has widespread practical, technological, and decorative use.

Glass

- It may also be considered as a solidified super-cooled solution of various metallic silicates having infinite viscosity.

- It is a mixture of metallic silicates, one of which is usually that of an alkali material

- It is difficult to assign a particular composition to glass
  - SiO_2 is the main phase
  - Sodium or potassium carbonate is added to ensure lowering of silica melting point.
  - Easier workability

Glass – Properties

- It absorbs, refracts or transmits light.
- It can take up a high polish.
- t has no definite crystalline structure.
- t has no sharp melting point.
- It is affected by alkalis.
- It is an excellent electrical insulator.
- It is available in beautiful colours.
- Can be cleaned easily
- Some glasses have excellent chemical resistance
- Can be welded by fusion

Uses of glass

- Glass can be used for window panels.
- Glass blocks can be used for partitions up to 6 m for insulation.
- Sheet glass can be used for glazing.
- Structural glass can be used for insulation, panel walls, wall facings, enclosures, etc.
- Potash lead glasses are used for making electric bulbs.
- Tinted glass can be used for decorative glassworks.
- Fibre glass reinforced plastics can be used to construct furniture, lampshades and bathroom fittings.

Types of glass

- Soda lime glass - also known as soda ash glass, soda glass, commercial glass or soft glass which is obtained from the fusion of a mixture of silica, lime, soda and alumina.

- It is the most common type of glass produced in the world.

- It is widely used for glazing of doors, windows, and for making ordinary glassware such as glass bottles, containers, etc.

Types of glass

- Potash lime glass - It is also known as hard glass or Bohemian glass.

- Potash lime glass is similar to soda lime glass, except that soda is replaced by potash.

- Potash lime glass has a high melting point and hence can withstand high thermal stresses.

- Hard glass has good resistance towards acids and alkalis as compared to soda lime glass. It is used for making laboratory apparatus and combustion tubes.

Types of glass

- Potash lead glass: It is also known as flint glass or lead glass. It is obtained from the fusion of a mixture of silica, lead, and potash, in which the content of lead is around 18-40%.

- Due to the presence of lead oxide, this glass has more transparent and shiny look.

- Lead increases the stability of the glass, and thus it is less brittle as compared to other glasses.

- Potash lead glass is used for high-quality glassware, cut glass, bulbs, lenses and prisms.

- Lead is also known to block x-rays and gamma radiations, thus they are used in making shields for personnel working in the nuclear science industry.

Types of glass

- Borosilicate glass: also known as Pyrex glass. It is obtained from the fusion of silica, borax, lime, and feldspar.

- Due to the addition of boron, borosilicate glass has good resistance to thermal and electric shocks.

- They have excellent chemical resistant properties

- Laboratory glassware – burette and pippette

Types of glass

- Common glass - also known as bottle glass is prepared from cheap raw materials like sodium silicate, iron silicate and calcium silicate.

- Bottle glass is available in different colours like green, brown and yellow.

- They have moderate resistance to chemicals. Bottle glass allows less light to enter and thus prevents fading or degradation of products stored in it.

- Common glass is mainly used to manufacture household bottles, medicine bottles, glassware used for drinking, packaging of drugs, etc.

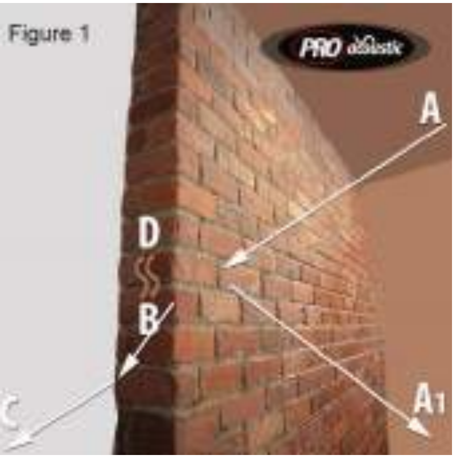
Acoustics insulating materials

- Sound proofing – to prevent the transmission of sound from one section to another.

- Important in case of film studios, laboratories etc.

Acoustics insulating materials

- Non-porous rigid materials – like plastered solid brick masonry wall
  - Insulation depends on weight per unit area
  - Thickness of wall is important but there is a practical limit
  - Weight doubling leads to an additional sound insulation of 4 to 5 dB



Acoustics insulating materials

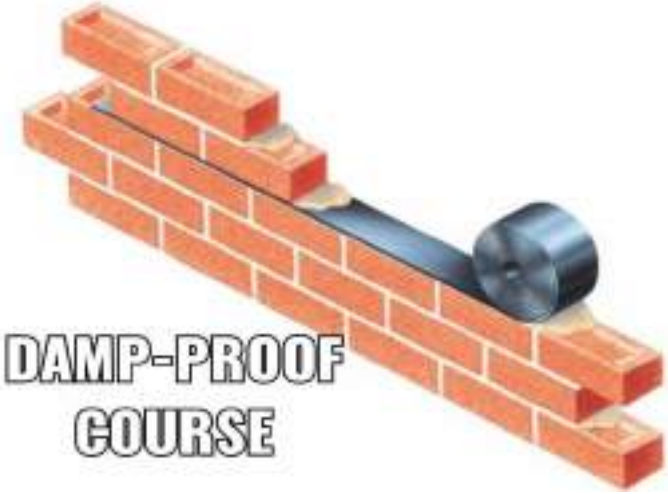
- Porous rigid materials – these materials provide higher sound insulation.
  - 10% higher sound insulation for the same weight
  - Eg. Cinder concrete

Acoustics insulating materials

- Non-rigid flexible porous materials – materials such as glass wool, felt etc.
- Less sound insulation compared to rigid materials
- Can be used in combination with rigid materials

Waterproofing Materials

- Dampness is the ingress of moisture into the building
- Very undesirable since dampness is unhygienic, reduction in the strength, corrosion etc.
- Damp proof course is typically provided to prevent ingress of dampness into the building
- Continuously provided without any breaks



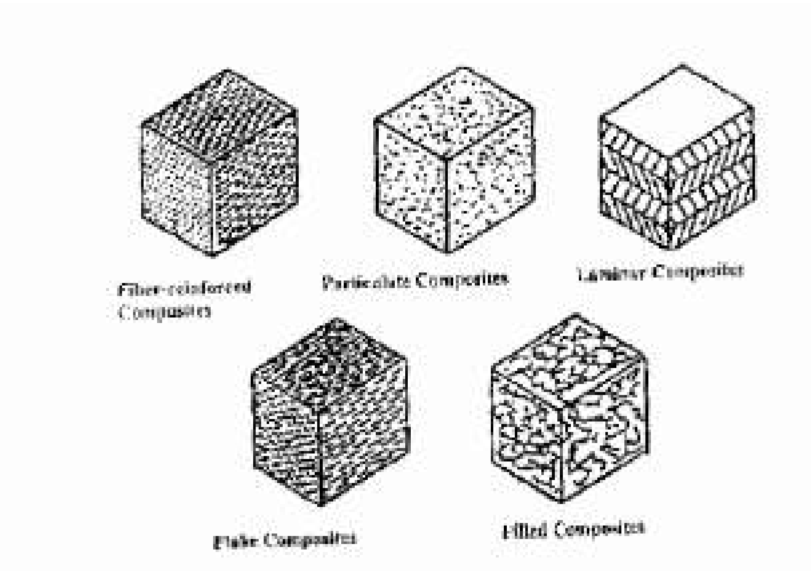
Damp proof course

Waterproofing Materials

- Hot bitumen – A 3mm layer of bitumen can act as a damp proof course
- Mastic Asphalt – Semi rigid materials obtained by heating asphalt with sand and fillers. It is laid on mortar or concrete bed.
- Bituminous Felt – sheet liked material that can be rolled on the flat mortar surface
- Metal Sheet – Sheets of lead, Copper or aluminium
- Combination of sheet and felt
- Different chemical solutions
- Plastic sheets can be used for temporary damp proof course
- Concrete layer over plinth level can act as DPC

Composite Materials

- Composite materials are usually made using two or more phases tha are bonded together to obtain superior properties
  - Eg. Reinforced cement concrete



- Composites can be a combination of metal, ceramics or polymers

- Glass Fibre Reinforced Polymers – Fibreglass : glass fibres in epoxy
  - Glass is strong but brittle
  - Epoxy is flexible

Composite Materials

- Carbon Fibre Reinforced Polymer – carbon fibres are embedded in polymers

- Can be used for reinforcement, for making cycles, aeroplanes etc.

Plastic

- **Thermoplastics** are the plastics that, when heated, do not undergo chemical change in their composition and so can be molded again and again.

- **Thermosets**, or **thermosetting polymers**, can melt and take shape only once: after they have solidified, they stay solid.[12] If heated again, they do not melt; they decompose instead.

Thermoplastics

- PVC – Making water pipes, waste water pipes, window frames, flooring and roofing foils
  - Generally less expensive, light and durable
- Polypropylene – naturally strong and flexible, can stretch and deform without breaking.
  - Packaging industry, automotive industry
- Acrylic – hard and high impact strength.
  - Sanitary wares, sinks, sheeting, roof glass etc

Thermosets

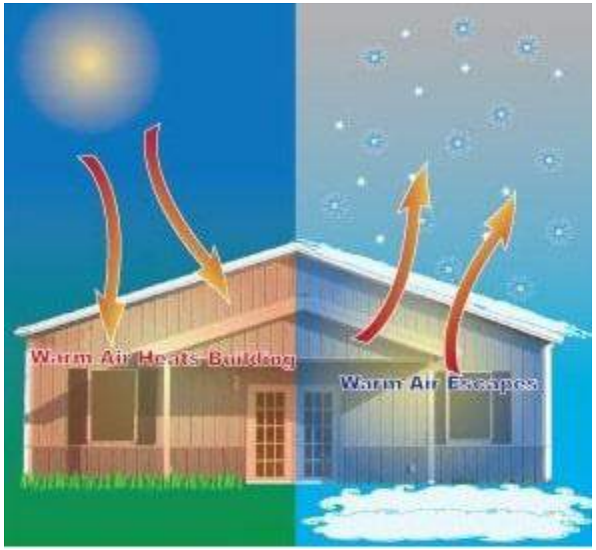
- Epoxy resins – Good resistance for heat and chemicals.
  - Generally used for repair work

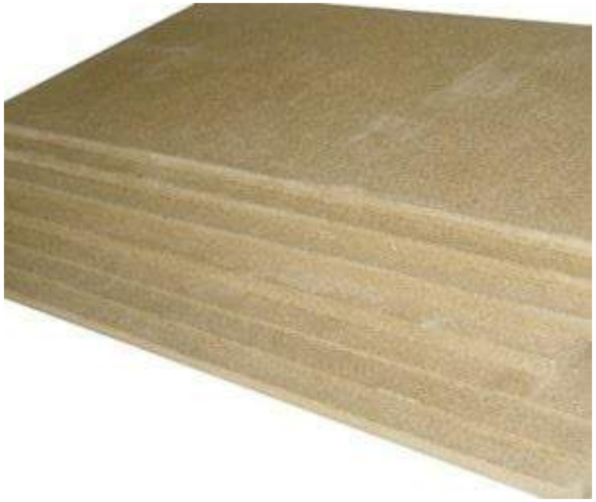
- Bakelite or phenol formaldehyde – Are strong, dimensionally stable and resist heat
  - Electric Panels, Lavatory seats etc,.

Thermal insulators

- To control the rate of heat transmission in the building

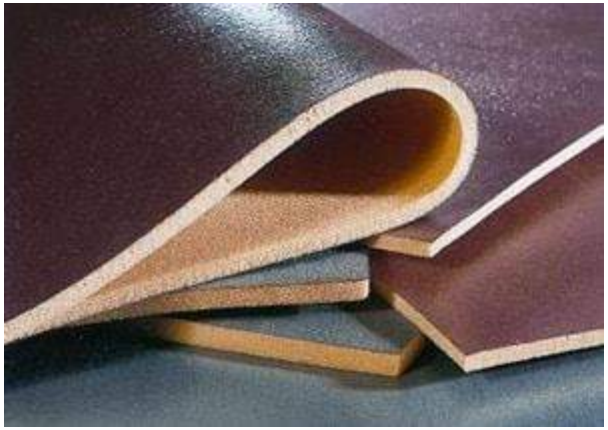
- Slab or Block Insulation
  - The blocks are made of mineral wool, cork board, cellular glass, and cellular rubber or saw dust etc.
  - These are fixed to the walls and roofs to prevent heat loss and maintains required temperature.





Thermal insulators

- Blanket Insulation –
  - Blanket insulation materials are available in blanket shape or like paper rolls which are directly spread over the wall or ceilings.
  - They are flexible and having a thickness about 12 to 80mm.



- Bat Insulating Materials
  - These are also available as blanket rolls but bat insulating rolls are having more thickness than blanket type materials.
  - These are also spread over the walls or ceilings.

Thermal insulators

- Loose Fill Insulation
    - Stud space is provided in wall where windows and doors are to be provided. In that studding space of wall loose fill of some insulating materials is provided. The materials are rock wool, wood fiber wool, cellulose etc.

Thermal insulators

- Reflective materials – can be provided to reflect away sunlight
  - White or black?

- Special building materials – AAC blocks, CLC blocks etc,

Prefabricated Construction

- Precast concrete is a construction product produced by casting concrete in a reusable mold or "form" which is then cured in a controlled environment, transported to the construction site and lifted into place

- In contrast, standard concrete is poured into site-specific forms and cured on site.

Prefabricated Construction

- Cast in a yard.
- Members transported to the location and placed using cranes
- Better quality control, cheap, faster, etc.
- Handling and transportation is a challenge, high initial investment for setting up,

Self Study

- Gypsum

Thank you

Introduction to Basic Civil Engineering

Surveying

Sreejith Krishnan, *PhD*

Surveying

- The art of making measurements of the relative positions of natural and man-made features on the Earth's surface, and the presentation of this information either graphically or numerically.

- The first surveying works date back to the antiquity, the Greek provided the first account of surveying techniques.

Objective of Surveying

- The aim of surveying is to prepare a map to show the relative positions of the objects on the surface of the earth.
- To collect field data.
- To prepare plan or map of the area surveyed.
- To analyse and calculate the field parameters for setting out operation of actual engineering works
- To set out the field parameters at the site for further engineering works.
- Can be over water as well

Importance of Surveying

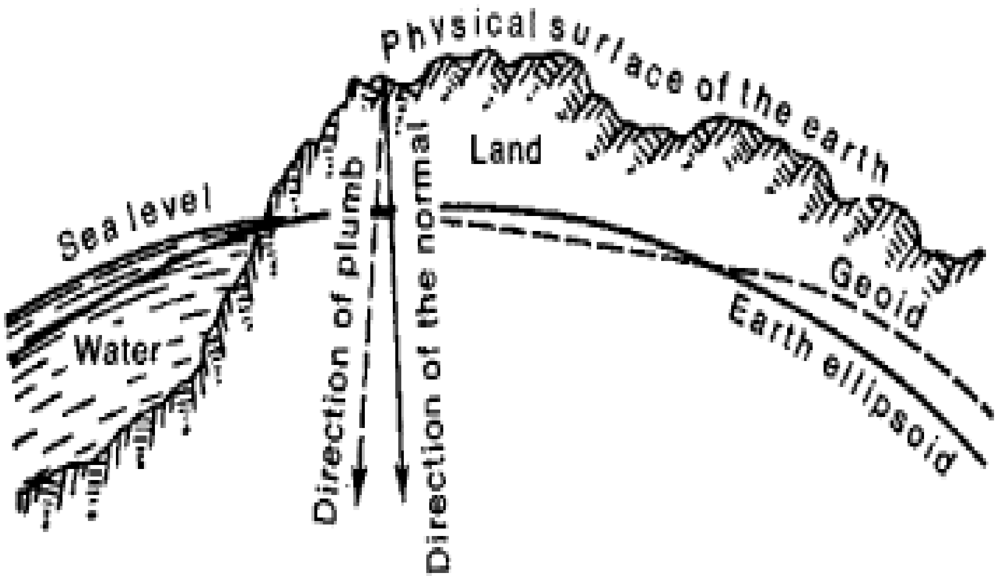
- Preparation of site plan
  - Help to decide alignments, best layouts etc.
  - Surveying is vital in understanding the economic aspects of project
- It helps to prepare topographical maps which show natural and manmade features
- It helps to prepare cadastral maps showing the boundaries of the properties and other land rights
- It helps to prepare an engineering map which shows the details of engineering works such as roads, railways, reservoirs etc.
- It helps to prepare a contour map to determine the steepness or gentleness of slopes

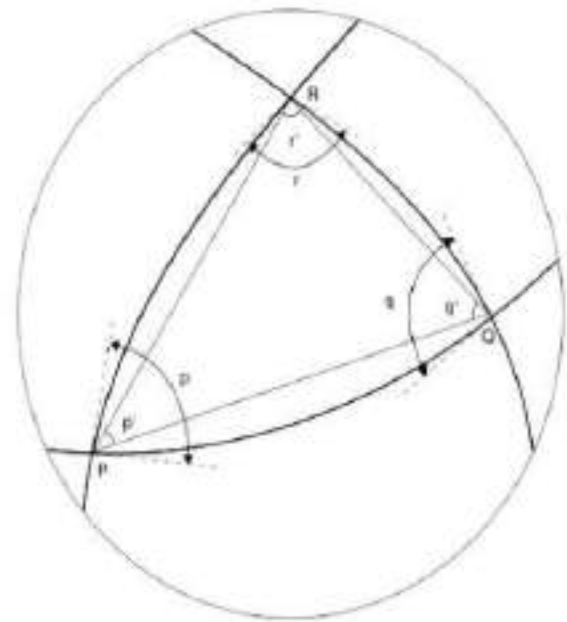
Classification of Surveys

- Plane surveying - Survey in which the mean surface of earth is regarded as plane surface and not curved as it really is
  - Engineering projects on large scale such as factories, bridges, dams, location and construction of canals, highways, railways, etc
  - For establishing boundaries.

- Geodetic surveying - Survey in which the shape (curvature) of the earth's surface is taken into account and a higher degree of precision is exercised in linear and angular measurements
  - A line connecting two points is regarded as an arc. The distance between two points is corrected for the curvature and is then plotted on the plan.
  - The angles between the intersecting lines are spherical angles.

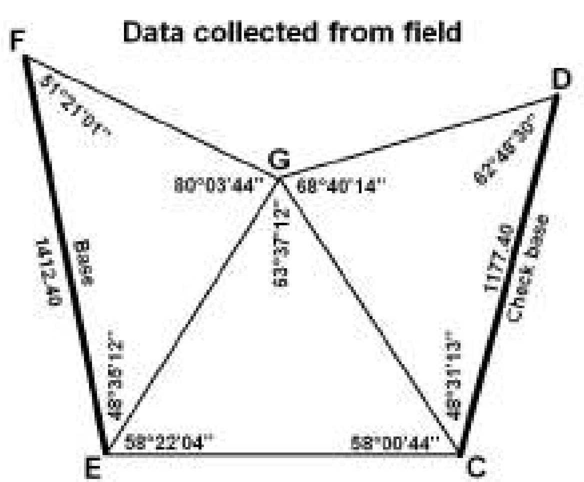
Classification of Surveys

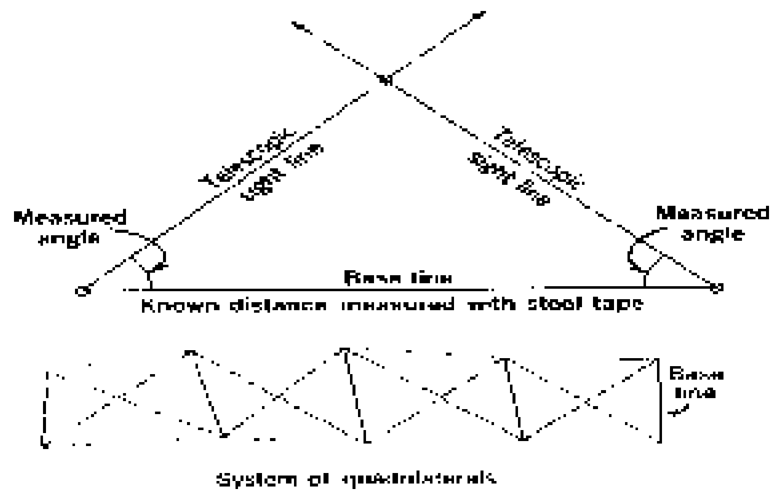




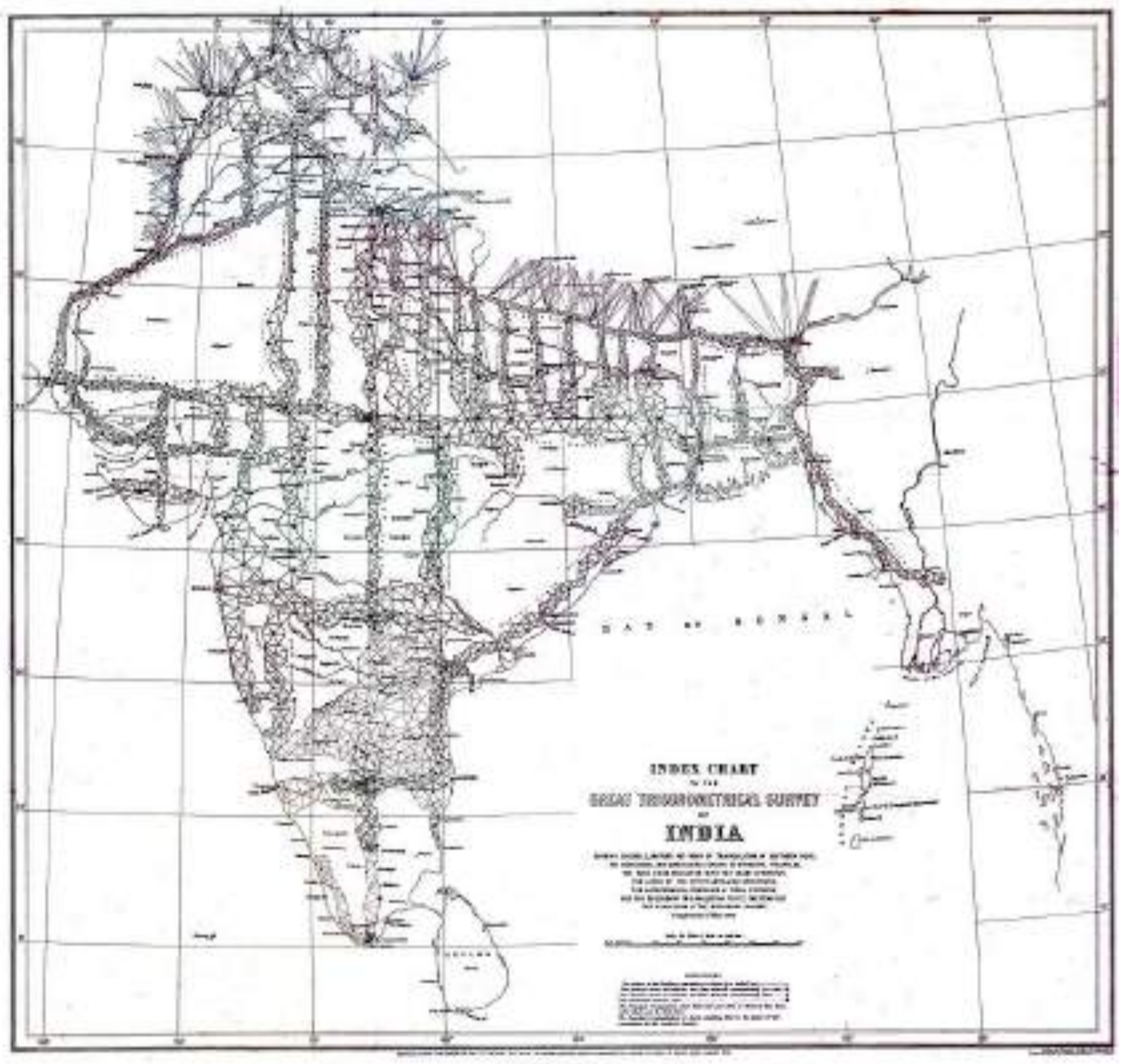
Classification – Based on Method

- Triangulation Survey - When the area to be surveyed is of considerable extent, triangulation is adopted.
  - The entire area is divided into a network of triangles.
  - Any one side of any of the triangles so formed, is selected and is measured precisely.
  - Such a line is called baseline.
  - All the angles in the network are measured with a transit.





Great Trigonometric Survey of India

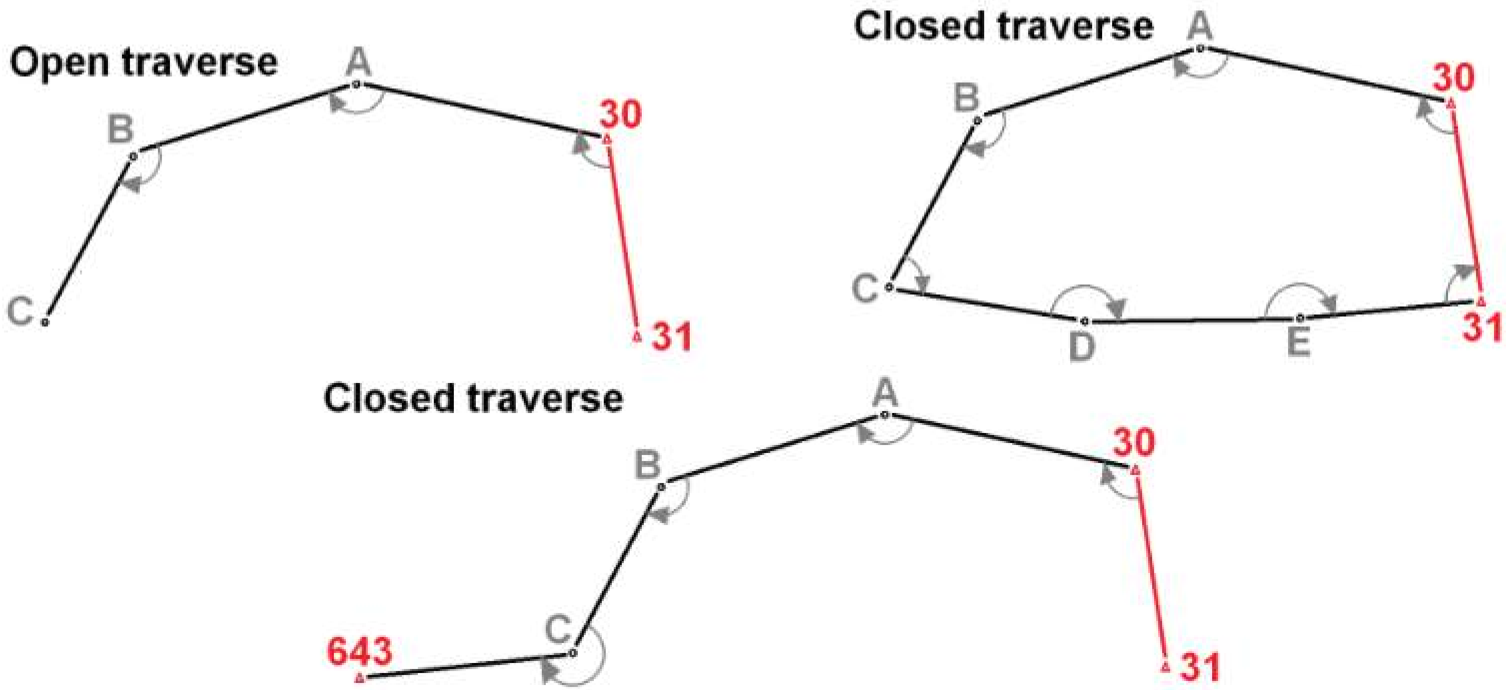


Classification – Based on Method

- Traversing - When the linear measurements are done with chain and tape and the directions or angles are measured with compass or transit respectively, the survey is called traversing.
    - **A traverse survey measures distances and angles (courses) between the points.**
    - These points can serve as control stations. Other, less precise measurements, can be taken from control stations then.
    - **Traversing is used usually for smaller areas or on areas with many obstacles.** The method is appropriate for land and property surveys as well.

Classification – Based on Method

- Open traversing and closed traversing

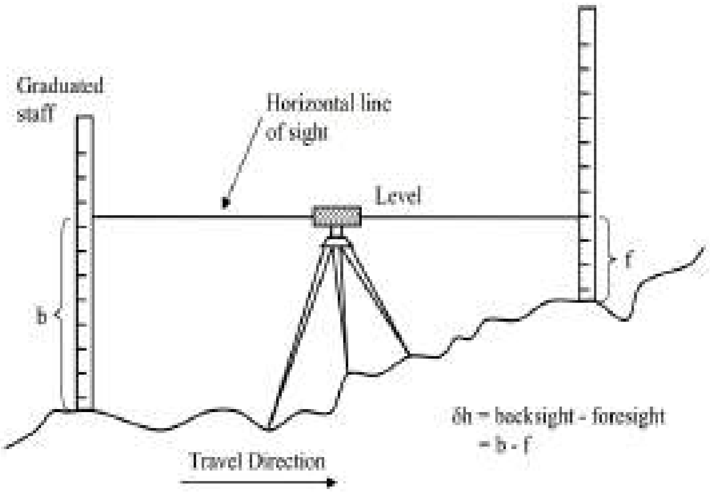


Classification – Based on Method

- Levelling - This is a method of surveying in which the relative vertical heights of the points are determined by employing a level and a graduated staff.

- In planning a constructional project, irrespective of its extent, i.e., from a small building to a dam, it is essential to know the depth of excavation for the foundations, trenches, fillings, etc.

- This can be achieved by collecting complete information regarding the relative heights of the ground by levelling.

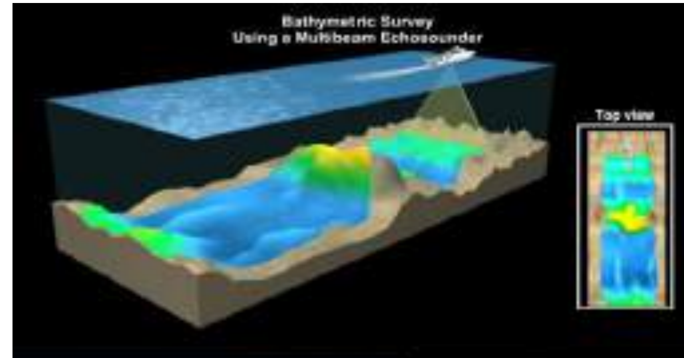


Classification – Based on Method

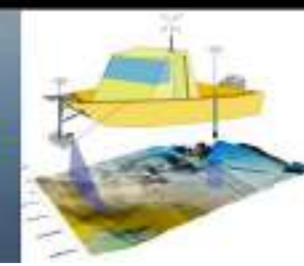
- Chain Surveying - When a plan is to be made for a very small open field, the field work may consist of linear measurements only.
    - All the measurements are done with a chain and tape.
    - However, chain survey is limited in its adaptability because of the obstacles to chain like trees and shrubs.
    - Also, it cannot be resorted to in densely built-up areas.
    - It is recommended for plans involving the development of buildings, roads, water supply and sewerage schemes.

Based on Nature of Field

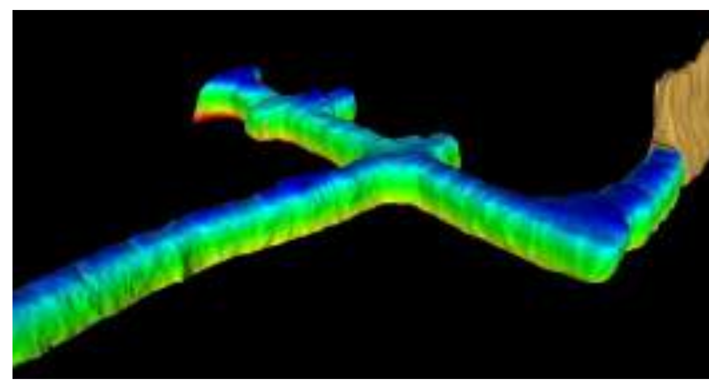
- Land Survey - It consists of re-running old land lines to determine their lengths and directions, subdividing the land into predetermined shapes and sizes and calculating their areas and setting monuments and locating their positions



- Marine Survey - It deals with the survey of water bodies like streams, lakes, coastal waters and consists in acquiring data to chart the shore lines of water bodies

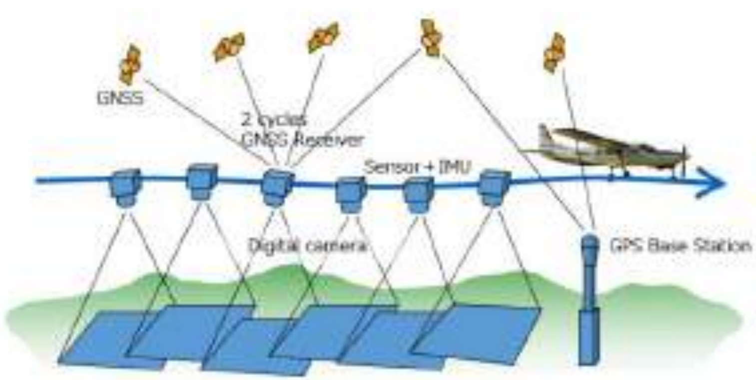


- Underground Survey - This is referred to as the preparation of underground plans, fixing the positions and directions of tunnels, shafts and drifts, etc.



Based on Nature of Field

- Aerial Survey - When the survey is carried out by taking photographs with a camera fitted in an aeroplane, it is called aerial or photogrammetric surveying. It is extremely useful for making large-scale maps of extensive constructional schemes with accuracy. Though expensive, this survey is recommended for the development of projects in places where ground survey will be slow and difficult



Based on Objective

- Geological Survey
- Engineering Survey
- Defence Survey
- Archaeological survey
- Mine survey

Based on instrument used

- Chain Surveying
- Compass Surveying
- Plain Table surveying
- Theodolite Surveying
- Total Station Surveying
- Aerial surveying

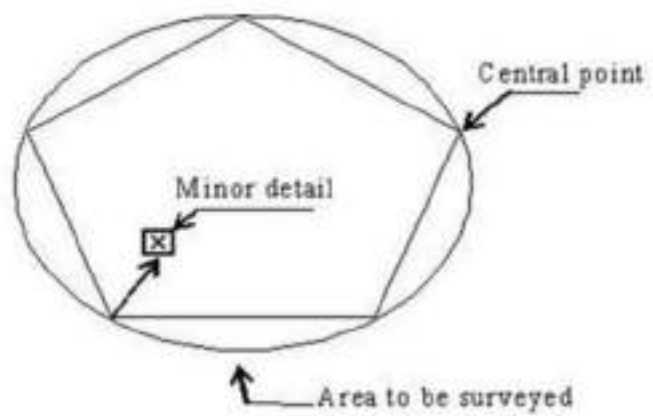
Principles of Surveying

- There are two basic principles of surveying. These find their inherent applications in all the stages of a project, i.e., from initial planning till its completion.
    - To work from whole to part.
    - To locate a point by at least two measurements.

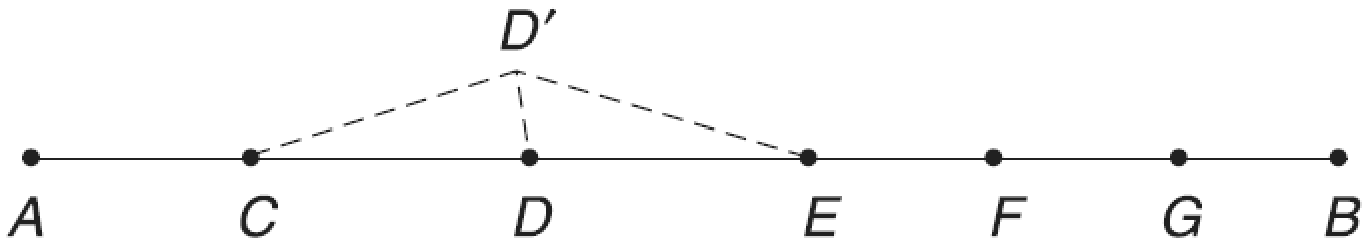
1. To work from whole to part

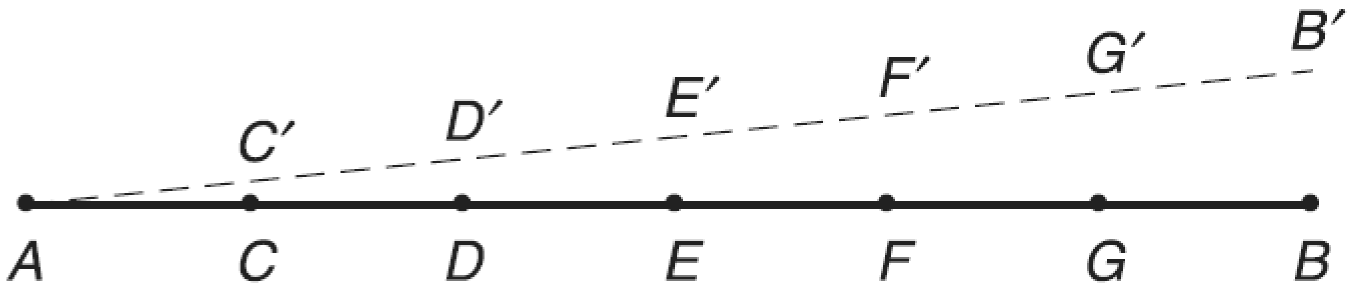
- The main idea of working from whole to part is to localise the errors and prevent their accumulation.

- On the contrary, if we work from part to whole, the errors accumulate and expand to a greater magnitude in the process of expansion of survey, and consequently, the survey becomes uncontrollable at the end.



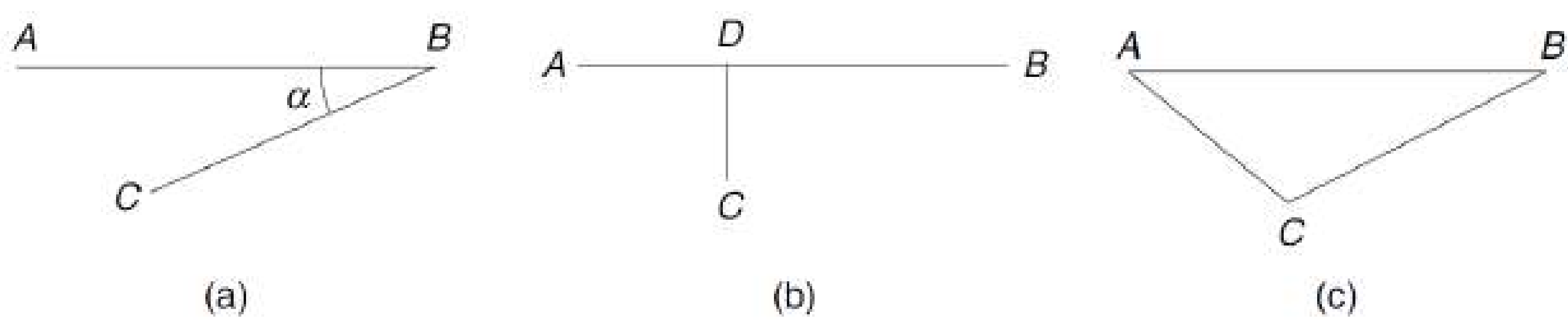
1. To work from whole to part

- 



To locate a point by at least two measurements

- Two control points (any two important features) are selected in the area and the distance between them is measured accurately. The line joining the control points is plotted to the scale on drawing sheet. Now the desired point can be plotted by making two suitable measurements from the given control points.



Thank you

Introduction to Basic Civil Engineering

Module 3

Sreejith Krishnan, *PhD*

Bearing Capacity

- The bearing capacity of soil is the maximum load per unit area which the soil or material in foundation, may be rock or soil, will support without displacement.
- Since soil is usually much weaker than other common materials of construction, such as steel and concrete, a greater area or volume of soil is necessarily involved in order to satisfactorily carry a given loading

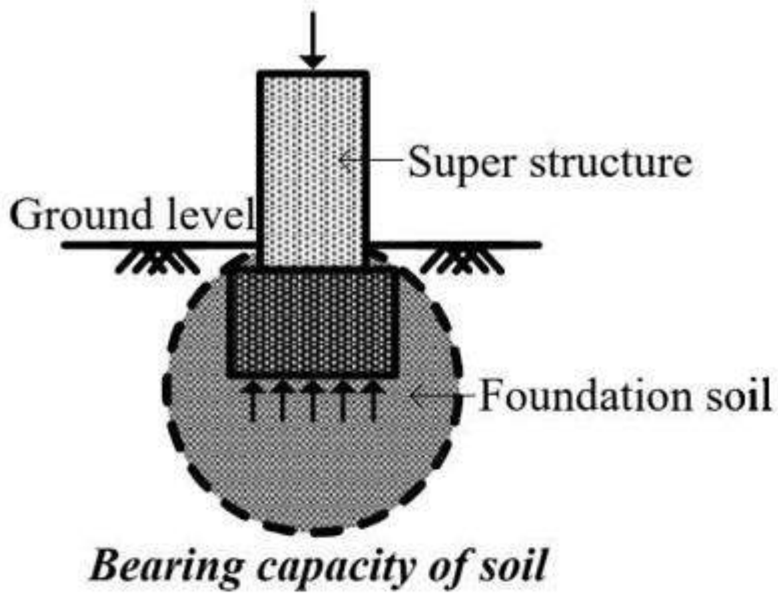
Bearing Capacity

- Ultimate bearing capacity or Gross bearing capacity: It is the least gross pressure which will cause shear failure of the supporting soil immediately below the footing.

- Net ultimate bearing capacity: It is the net pressure that can be applied to the footing by external loads that will just initiate failure in the underlying soil. It is equal to ultimate bearing capacity minus the stress due to the weight of the footing and any soil or surcharge directly above it.

Bearing Capacity

- Safe bearing capacity: It is the bearing capacity after applying the factor of safety (FS).

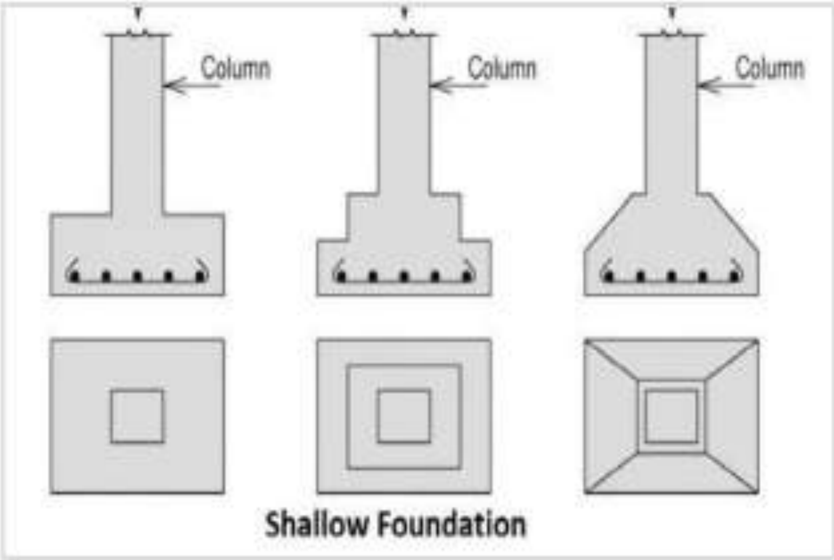


Foundation

- The part of the structure below the ground level.
- .To support the loads of the superstructure
- To give stability to the structure against various disturbing forces such as wind and rain.
- To prepare a level surface for concreting and masonry work
- Should go deep enough to be not affected by swelling and shrinkage
- Should distribute the loads evenly

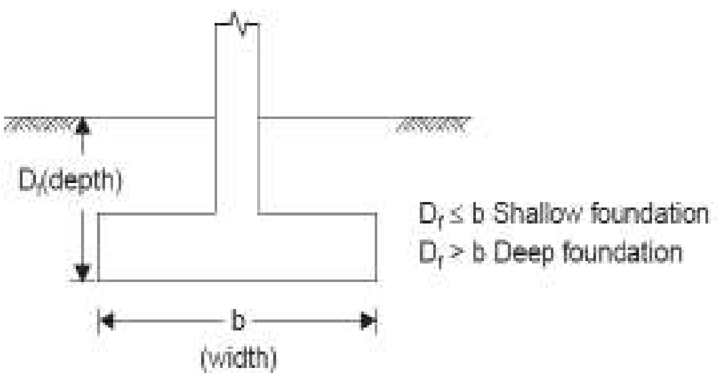
Foundation

- Can be of two types
  - Shallow Foundation
  - Deep Foundation



- Shallow Foundation - a foundation that transfers building loads to the earth very near to the surface

- The depth of the foundation is less than its width

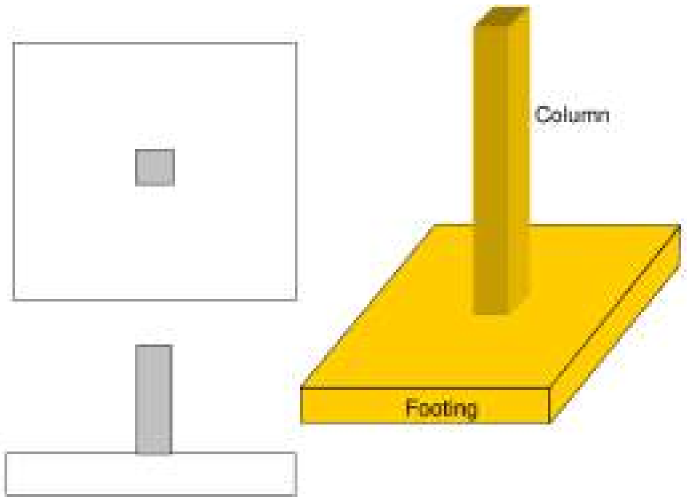


- When soil at shallow depth can support the loads of the structure

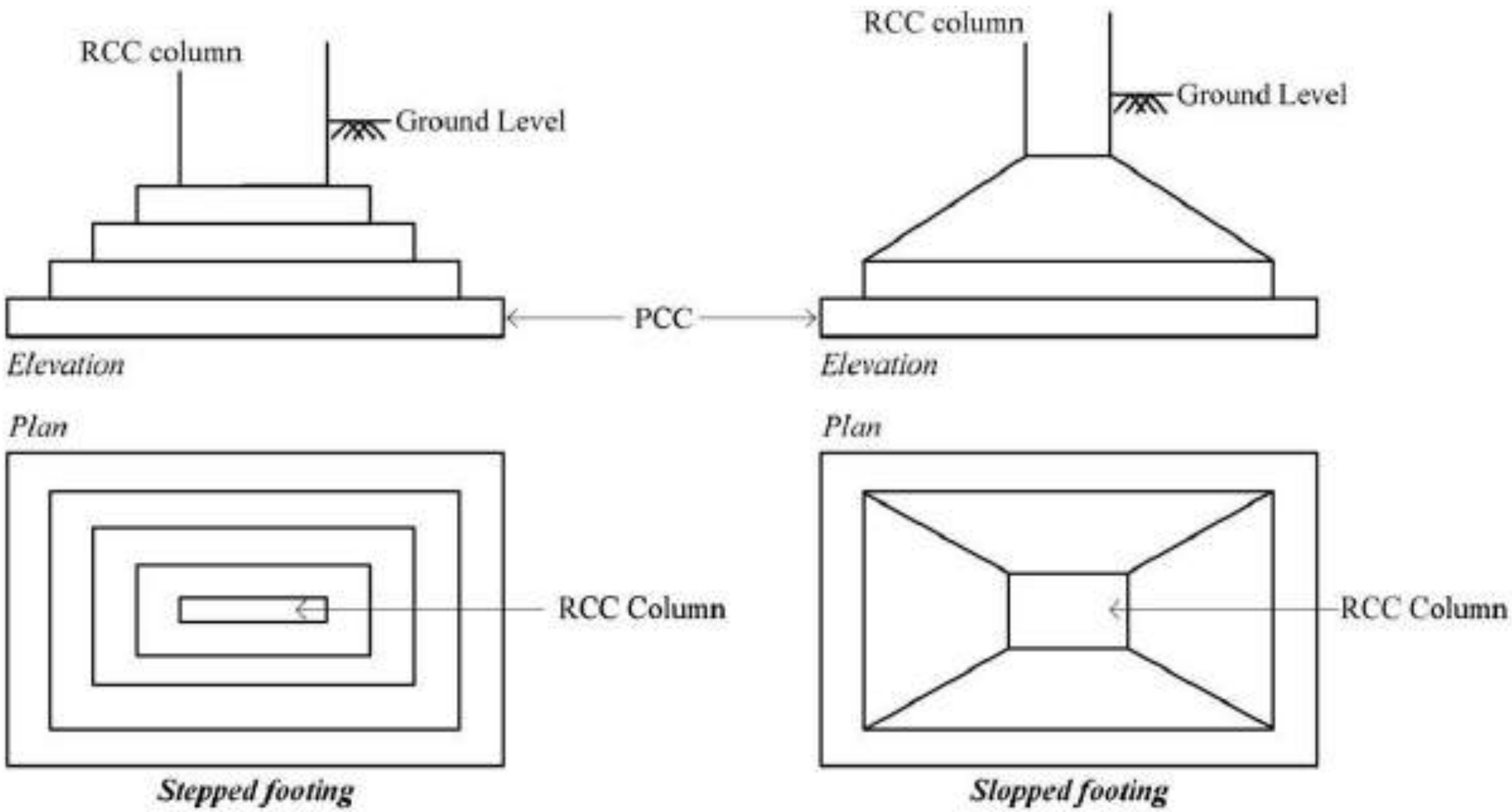
Types of shallow foundation

- Footings are structural elements, which transfer loads to the soil from columns, walls or lateral loads from earth retaining structures

- Isolated spread footings are provided under individual columns. These can be square, rectangular, or circular.

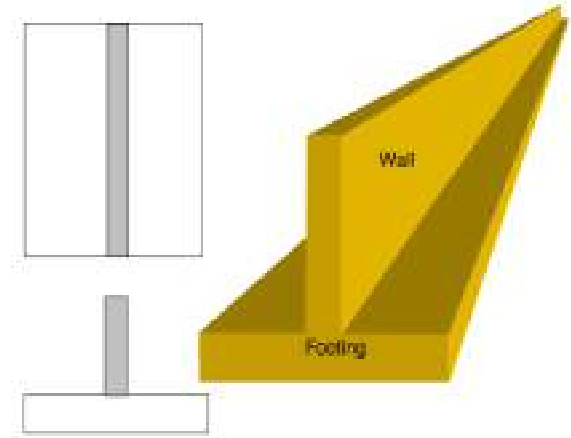


Isolated spread footings



Types of shallow foundation

- Wall footing or strip footing is a continuous slab strip along the length of wall.

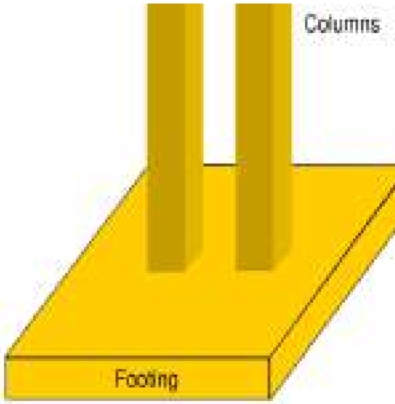


- Can also be provided for closely spaced columns

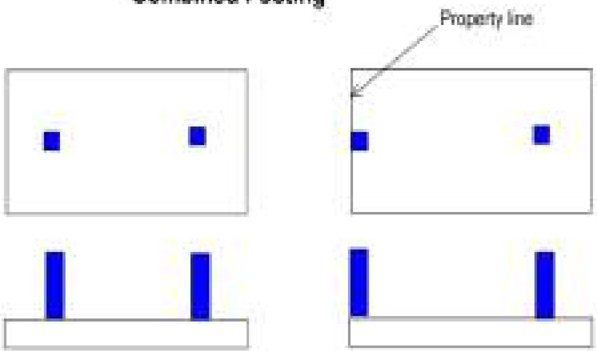
- Used for individual columns, walls and bridge piers where the bearing soil layer is within 3m (10 feet) from the ground surface.

Types of shallow foundation

- Combined footings support two columns.
- Also called continuous footing if it supports more than 3 columns
- Can be economical
  - Single pit
  - No risk of soil collapse between the spread foundations
- These can be rectangular or trapezoidal plan.
  - Uniform vs non uniform loading



Combined Footing

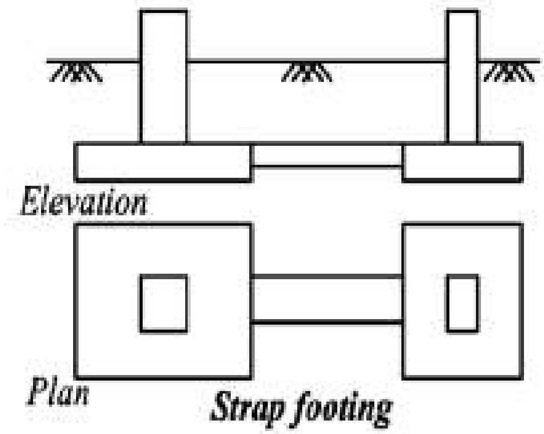


Types of shallow foundation

- Cantilever or strap footings: These are similar to combined footings, except that the footings under columns are built independently, and are joined by strap beam.

- It is used to help distribute the weight of either heavily or eccentrically loaded column footings to adjacent footings

- The strap beam restrains the tendency of the footing to overturn by connecting it to nearby footings



Types of shallow foundation

- Raft or Mat foundation: This is a large continuous footing supporting all the columns of the structure.

- The raft or mat foundation is a combined footing that covers the entire area beneath the structure and supports the columns.

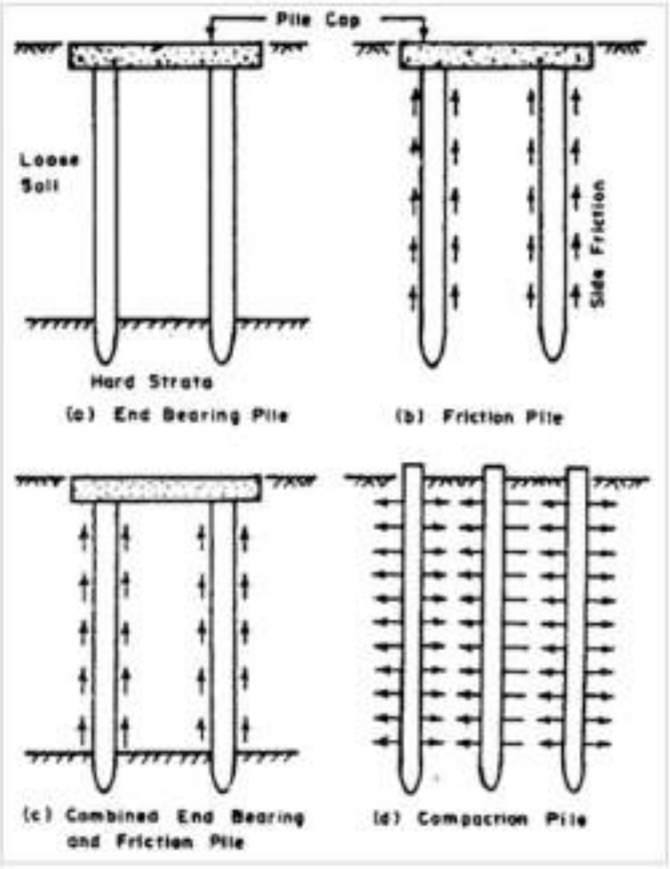
- This is used when soil conditions are poor but piles are not used.

- Usually, when hard soil is not available within 1.5–2.5 m, a raft foundation is adopted.

- Raft foundation is economical when one-half area of the structure is covered with individual footings and wall footings are provided.

Foundation

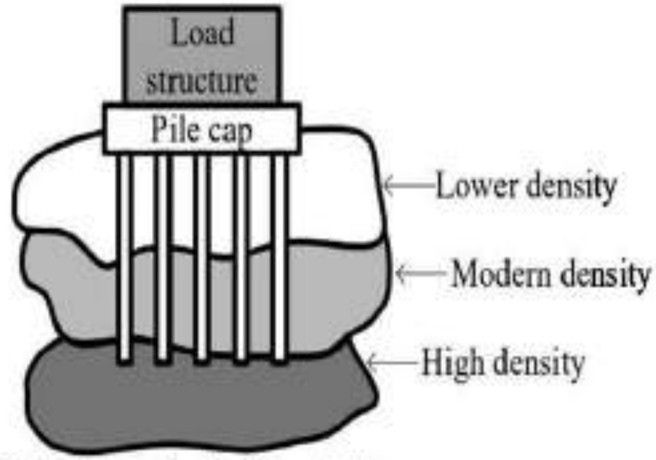
- Deep foundation – a foundation which transfers to the loads farther down the surface of the earth
- Pile foundation is an example
- Expensive but can take very high loads
- Can be up to 65m in depth



Deep Foundation

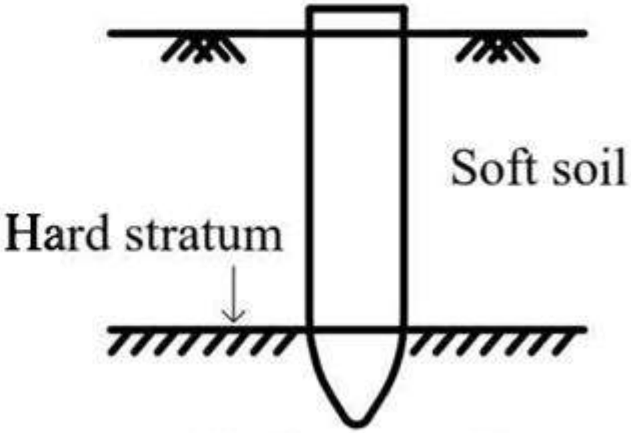
- Pile foundations are intended to transmit structural loads through zones of poor soil to a depth where the soil has the desired capacity to transmit the loads.

- Piles obtain lateral support from the soil in which they are embedded so that there is no concern with regard to buckling

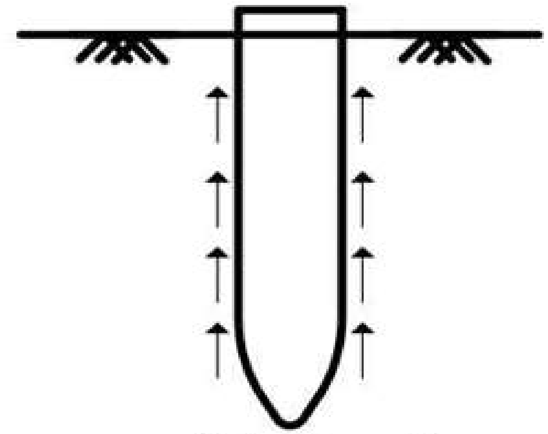


Principle of pile foundation

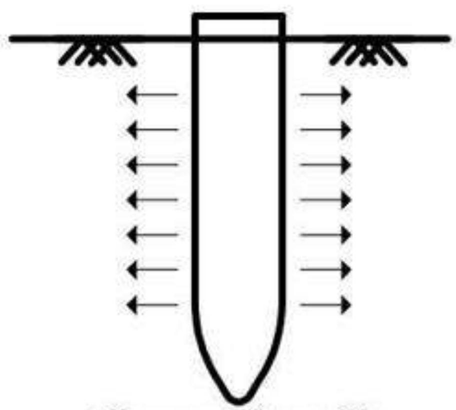
Different Pile Foundations



End bearing pile



Friction pile



Compaction pile

Other piles are also possible – Sheet pile, anchor pile

Different Pile Foundations

- Based on construction materials
  - Steel
  - RCC
  - Timber

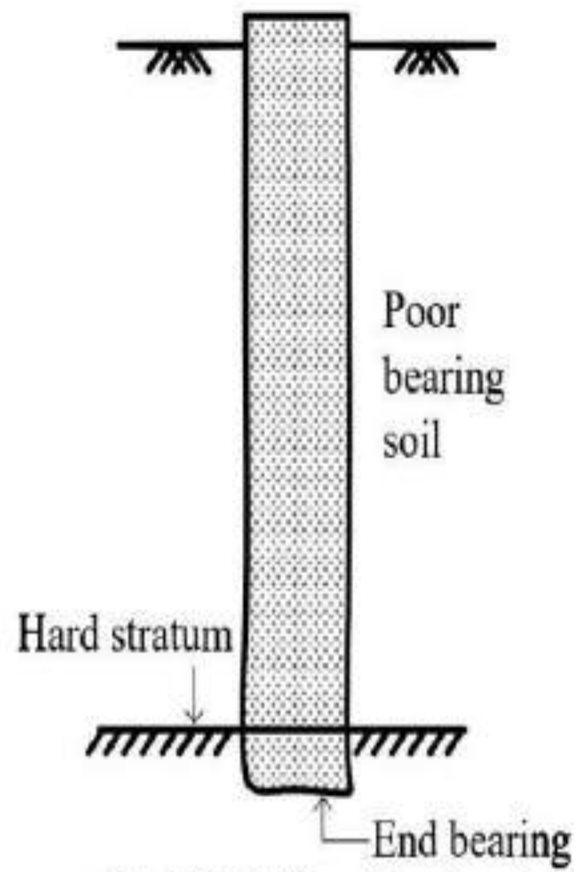
Pier Foundations

- A pier is a vertical column of a relatively larger cross-section than a pile. A pier is installed in an area by excavating a cylindrical hole of a large diameter to the desired depth and then backfilling it with concrete.

- A cast-in-situ pile greater than 0.6 m diameter is generally termed as a pier.

- Shallower in depth than pile foundation

- The difference between the pile foundation and pier foundation lies in the method of construction. Though pile foundations transfer the load through friction and bearing, pier foundations transfer the load only through the bearing.



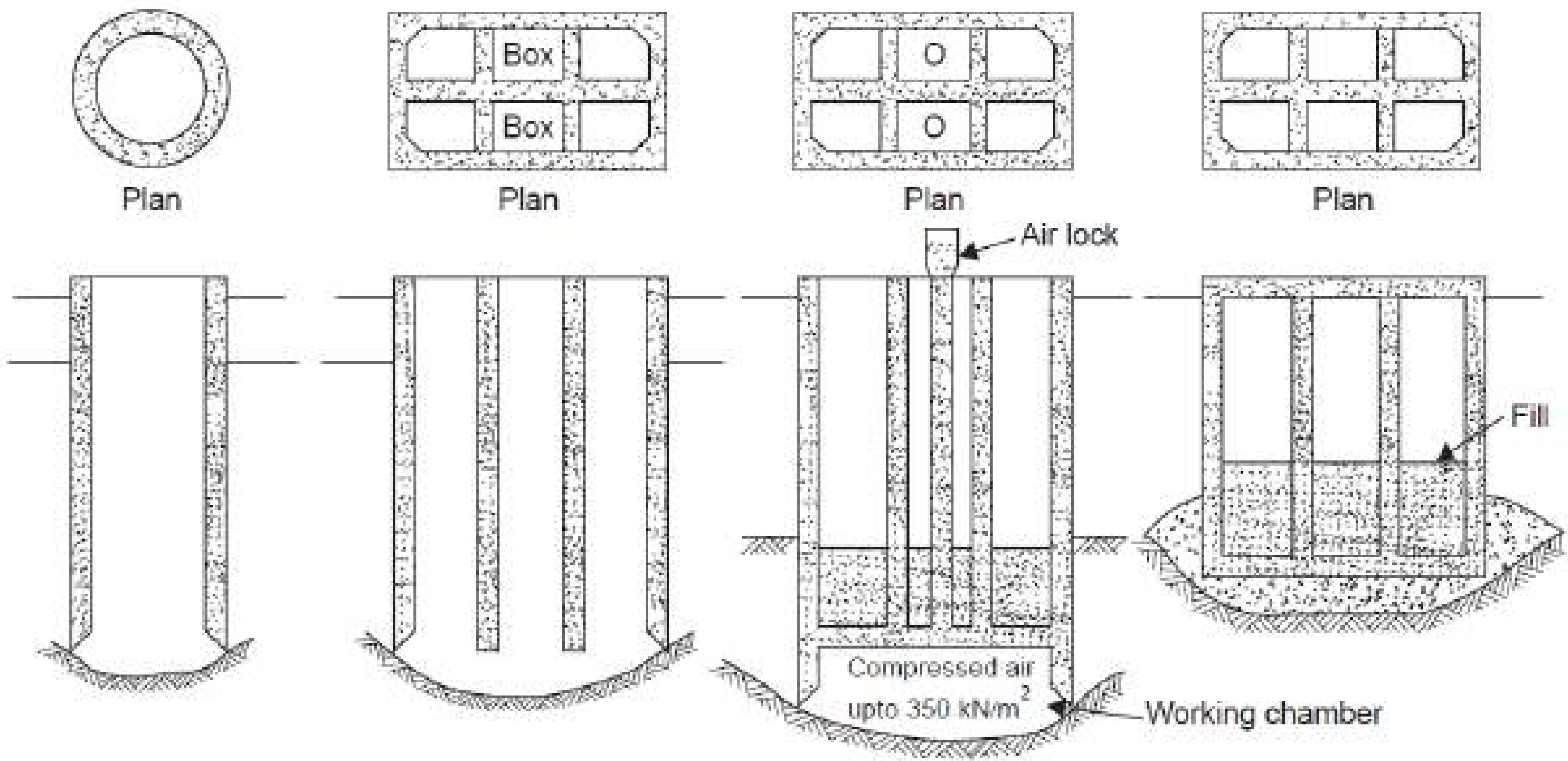
Straight shaft end bearing pier

Caisson Foundation

- A caisson is a structural box or chamber that is sunk into place or built in place by systematic excavation below the bottom.

- Caissons are classified as 'open' caissons, 'pneumatic' caissons, and 'box' or 'floating' caissons.
- Open caissons may be box-type or pile-type.
- Can withstand lateral loads

Caisson Foundation



(a) Pile-type open caisson

(b) Box-type open caisson

(c) Pneumatic caisson

(d) Box (floating) caisson

Thank you

Introduction to Basic Civil Engineering

Module 3

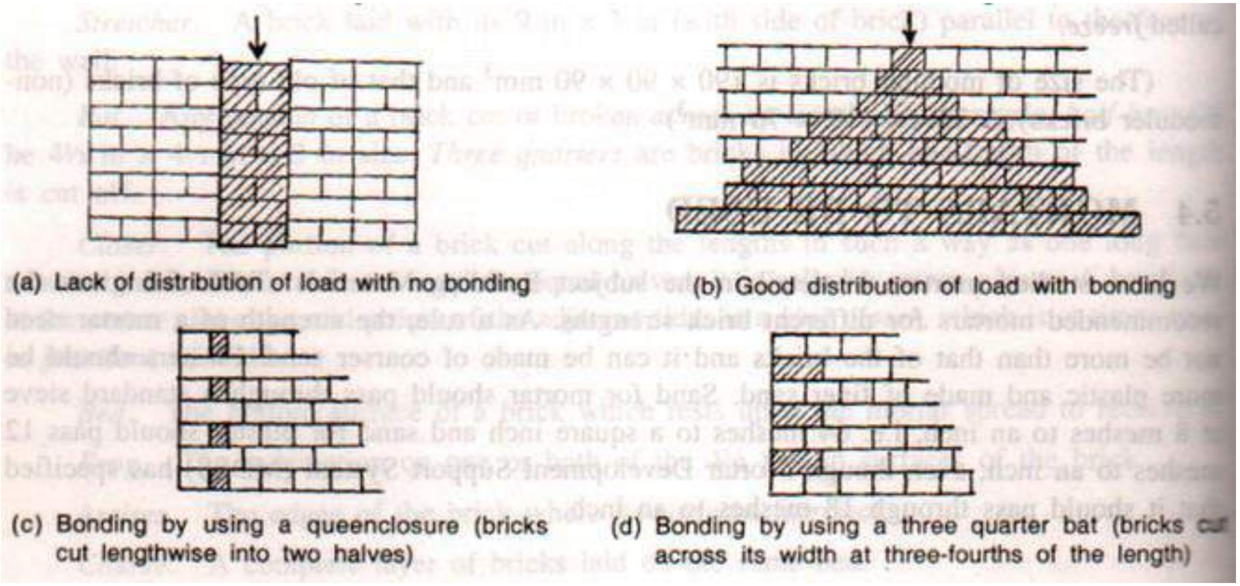
Sreejith Krishnan, *PhD*

Brick Masonry

- The masonry wall is built of individual blocks of materials such as stones, bricks, concrete, hollow blocks, cellular concrete and laterite, usually in horizontal courses cemented together with some form of mortar.

Bonding of Bricks

- Orderly arrangement of bricks
  - Continuous joints are eliminated
  - Good distribution of load takes place
  - Many types of bonds available



(a) Lack of distribution of load with no bonding

(b) Good distribution of load with bonding

(c) Bonding by using a queenclosure (bricks cut lengthwise into two halves)

(d) Bonding by using a three quarter bat (bricks cut across its width at three-fourths of the length)

Common Terms used in Brick Masonry

- *Course:* A course is a horizontal layer of bricks or stones.

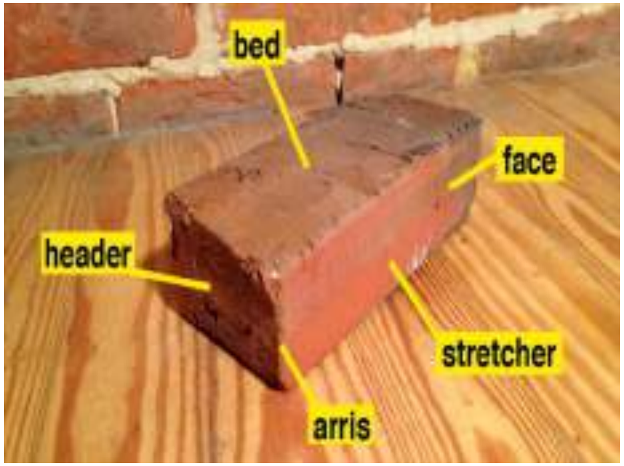
- *Back:* The inner surface of a wall that is not exposed is called a back. The material forming the back is known as backing.

- *Face:* The exterior of a wall exposed to weather is known as face. The material used in the face of a wall is known as facing.

- *Stretcher:* This is a brick laid with its length parallel to the face or front or direction of a wall. The course containing stretchers is known as stretcher course.

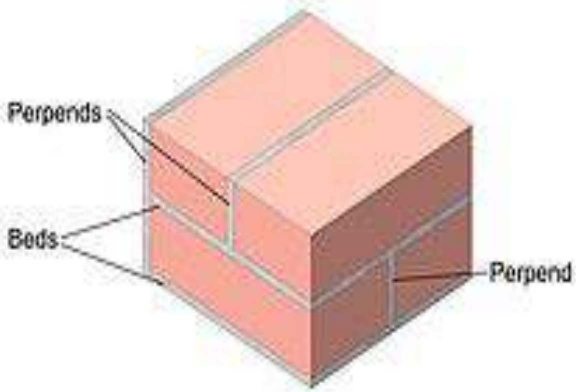
Common Terms used in Brick Masonry

- *Header:* This is a brick laid with its breadth or width parallel to the face or front or direction of a wall.

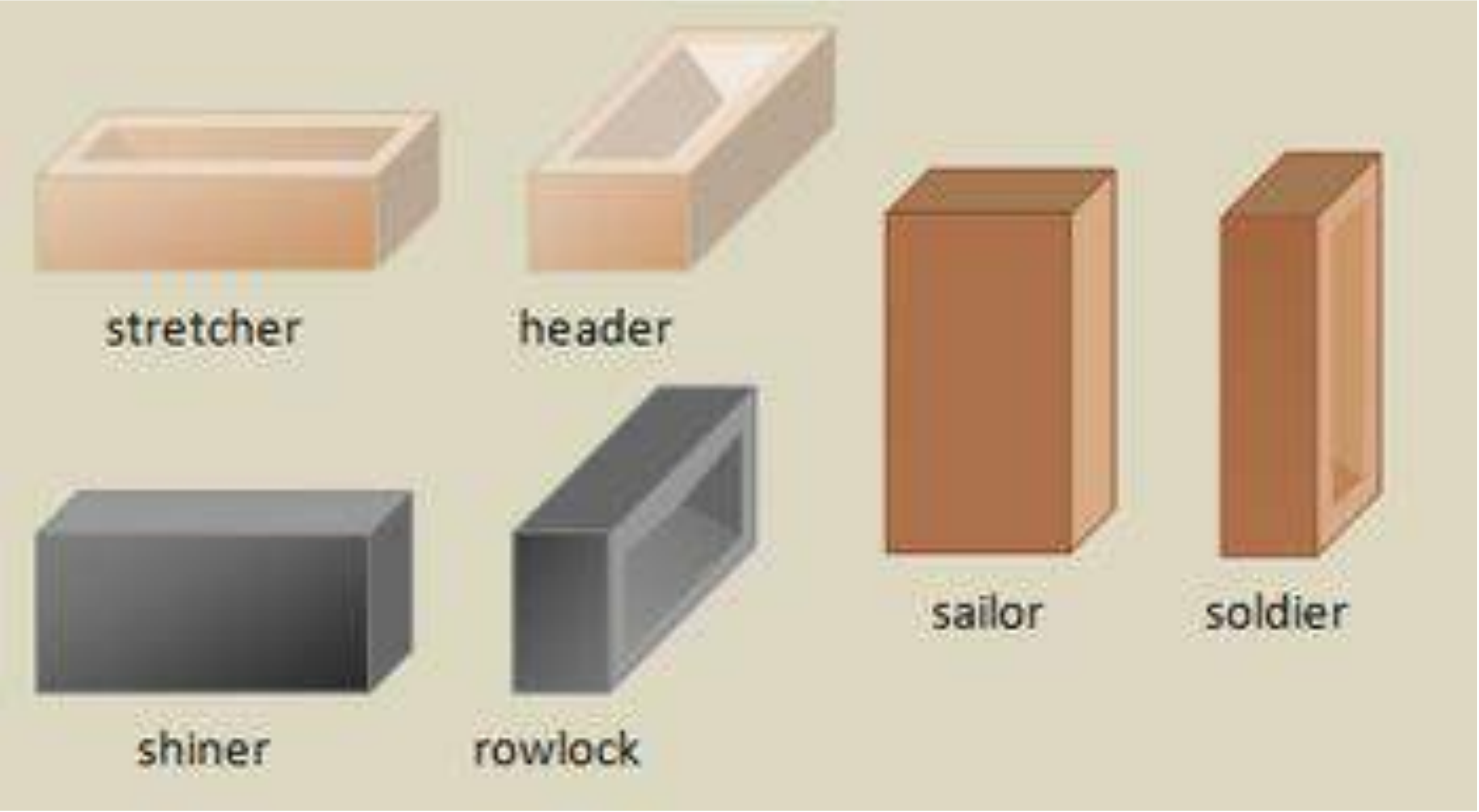


- *Arrises:* The edges formed by the intersection of plane surfaces of a brick are called the arrises and they should be sharp, square and free from damage.

- *Perpends:* The vertical joints separating the bricks in either length or cross direction are known as the perpends; for a good bond the perpends in alternate courses should be vertically one above the other.



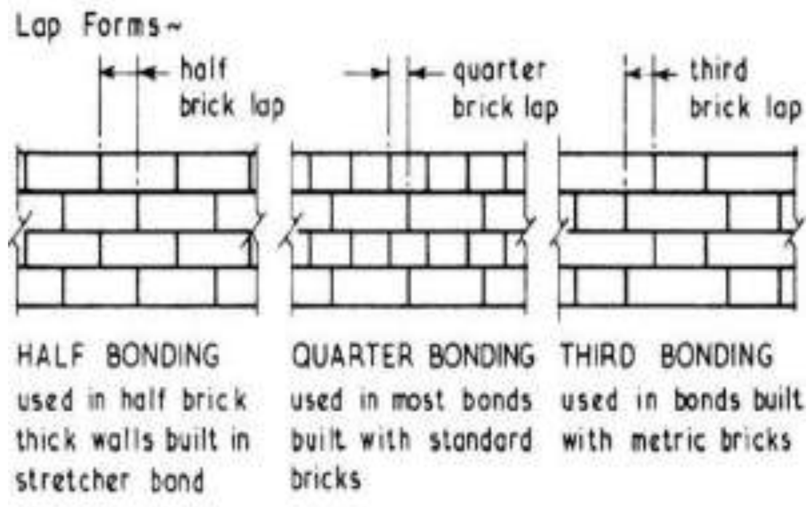
Other laying positions

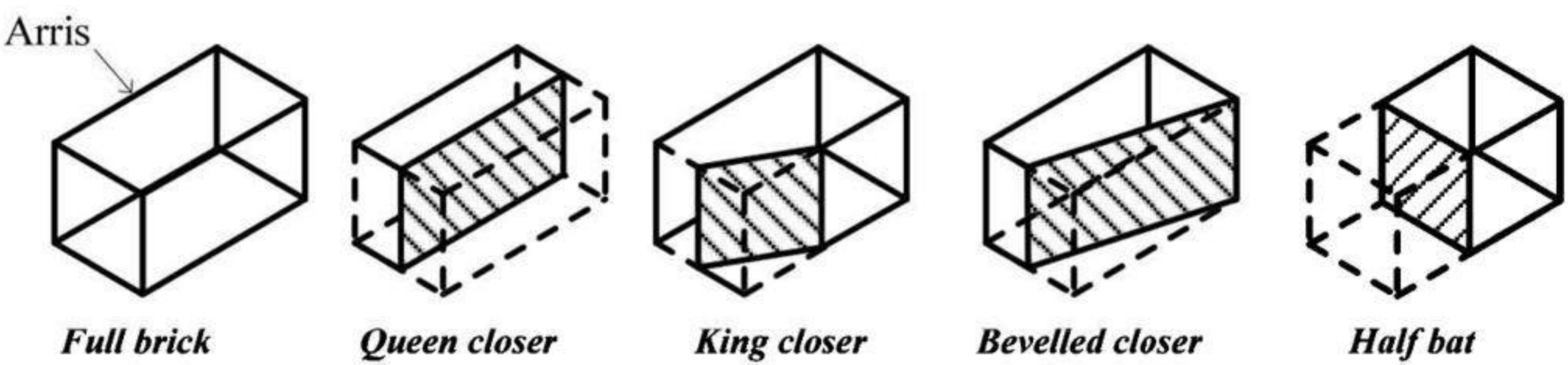


Common Terms used in Brick Masonry

- *Lap:* The horizontal distance between the vertical joints in successive courses is termed as a lap; for a good bond it should be one-fourth of the length of a brick

- *Closer:* A piece of brick which is used to close up the bond at the end of brick courses is known as the closer. It helps in preventing the joint of successive courses to come in a vertical line.





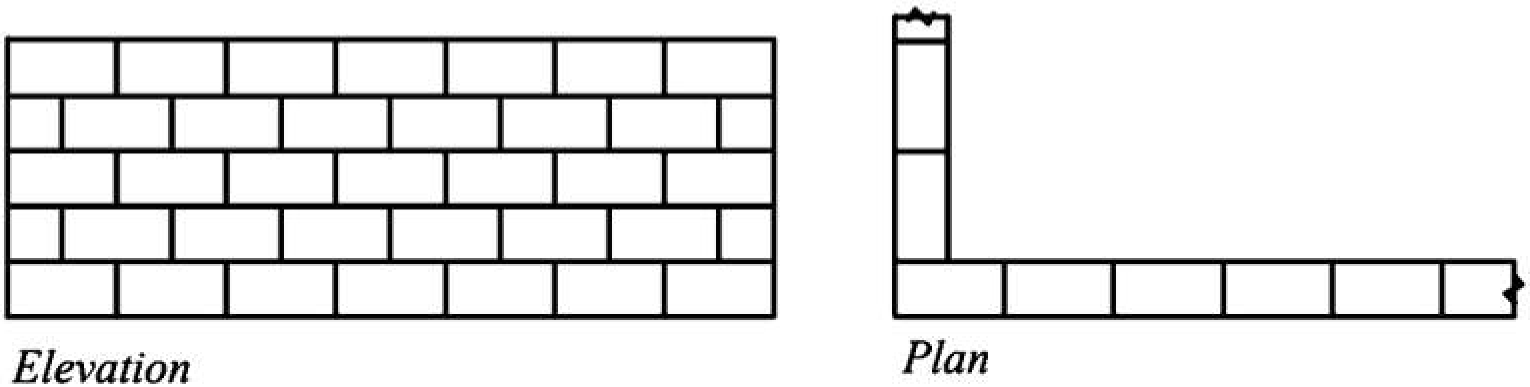
Rules for good bonding

- Bricks should have uniform shape and size
- Minimise the use of bats
- Bricks must be laid in full mortar
- The vertical joints in alternate should lie in the same perpend
- All the joints should be filled with mortar
- The lap distance should be minimum $\frac{1}{4}$ bat along the length of the wall and $\frac{1}{2}$ brick along the width of the wall

Bad Examples...

Bonds

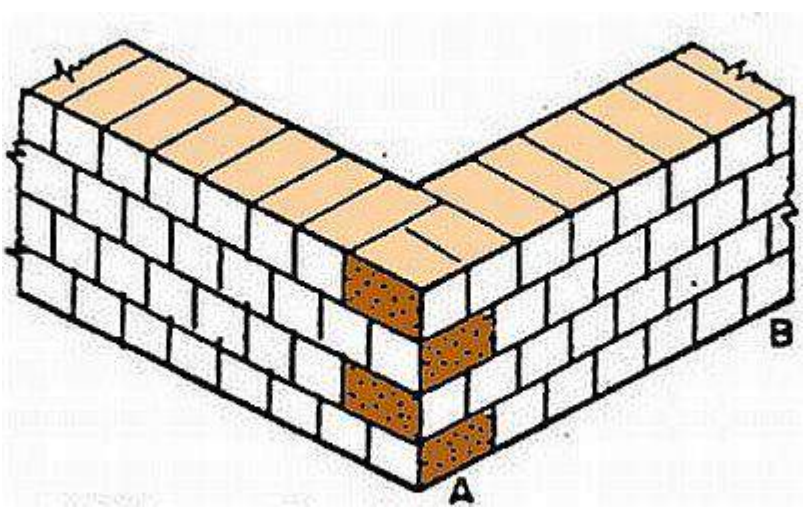
- Stretcher bond - In this type of bond, all the bricks are laid with their length in the direction of the wall. The stretcher bond is useful for one-brick partition walls as there are no headers.
- This bond does not develop proper internal bond and it should not be used for walls having thickness greater than that of one-brick wall.
- To break the vertical continuity $\frac{1}{2}$ brick bat is provided in alternating courses

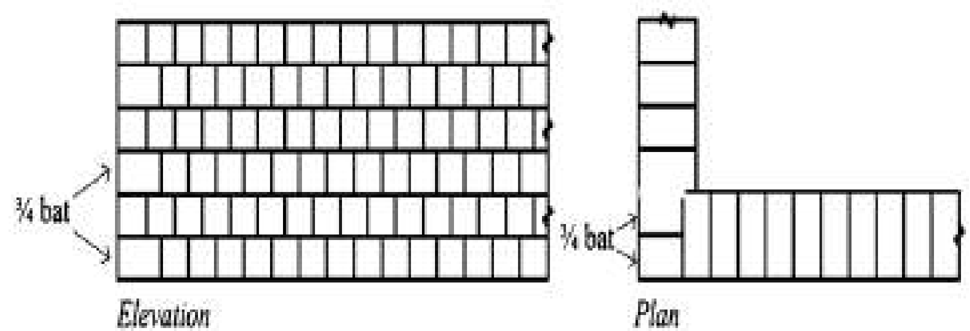


Stretcher bond-one brick wall

Bonds

- Header Bond - In this type of bond, all the bricks are laid with their ends towards the face of the wall.
- Thus, the bond does not have the strength to transmit pressure in the direction of the length of the wall. This bond is used for curved surface
- Not pleasing aesthetically

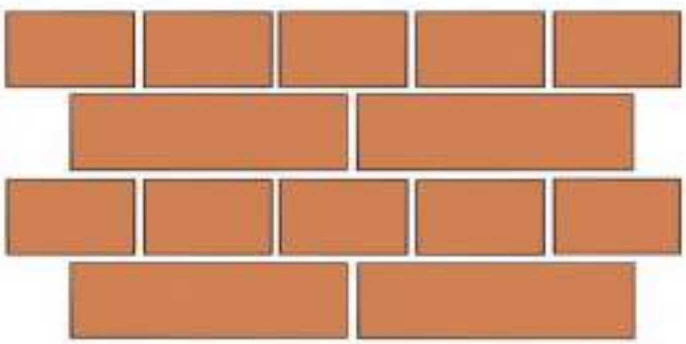


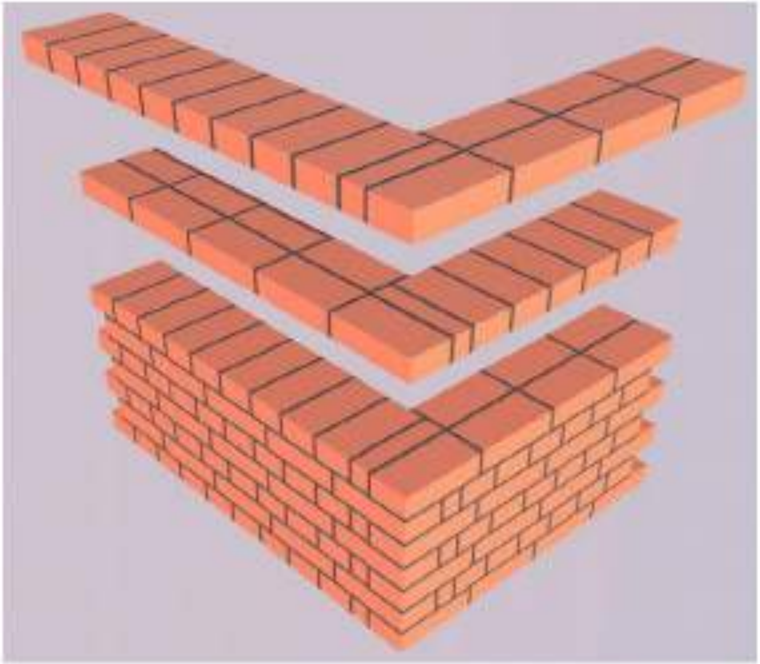


Header bond -one brick wall

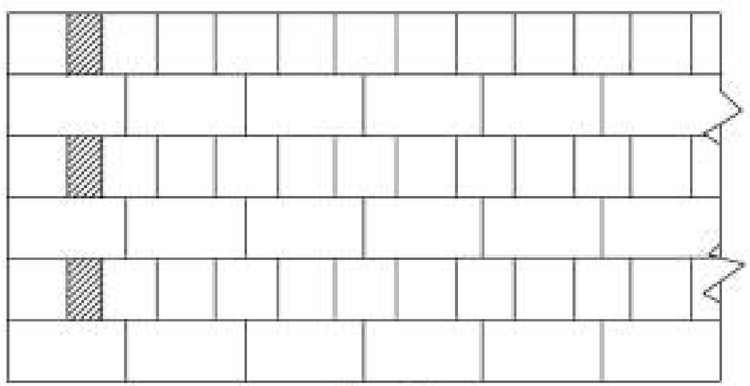
Bonds

- English bond - In this type of bond, alternate courses of headers and stretchers are laid. It is necessary to place queen closers after the first header in the heading course for breaking the joints vertically

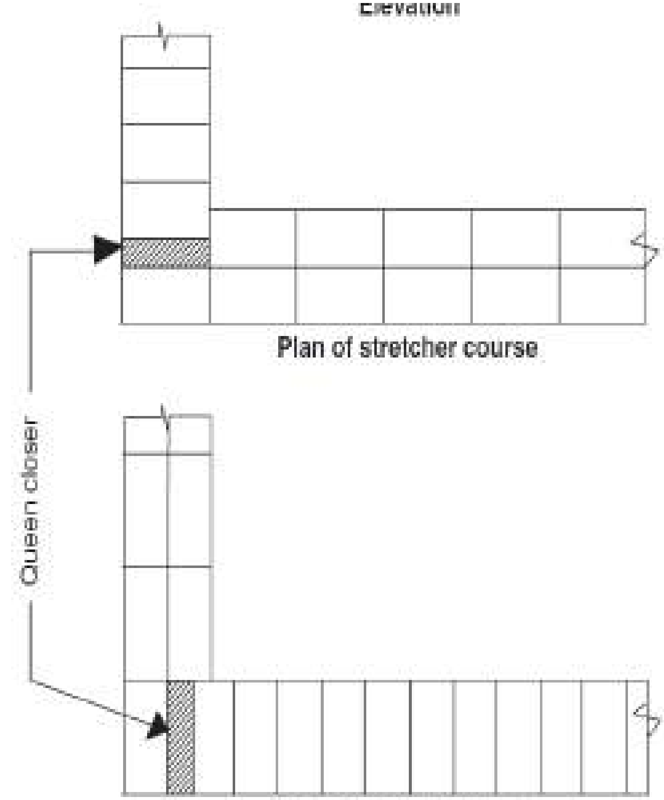




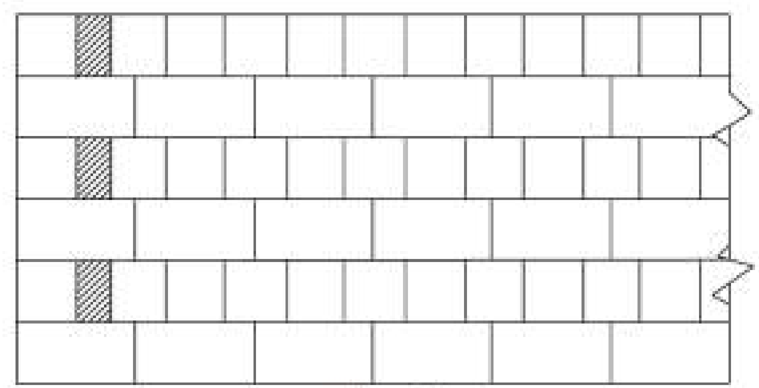
English Bond – 1 Brick Thick



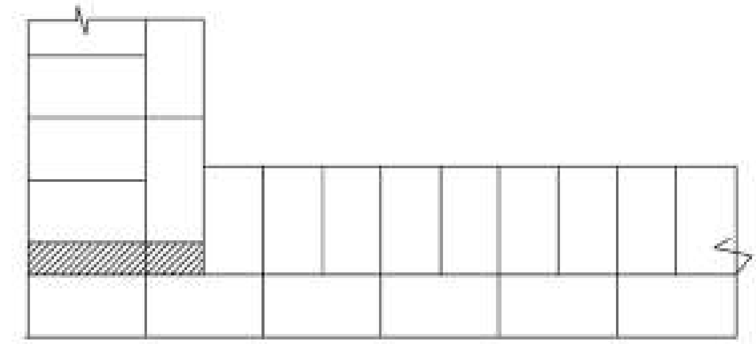
Elevation



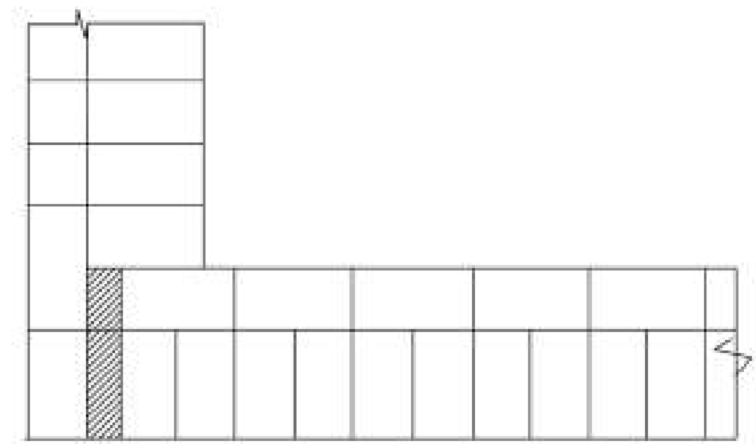
English Bond – 1 and 1/2 Brick Thick



Elevation



Plan of stretcher course



Plan of header course

English Bonds

- A queen closer must be provided after a quoin header or first header. A header course should never start with a queen closer.

- Each alternate header should be centrally placed over a stretcher.

- Continuous vertical joints should not be allowed except at the stopped end.

- In case the wall thickness is equivalent to an even number of half bricks, the wall shall present similar appearance in both faces.

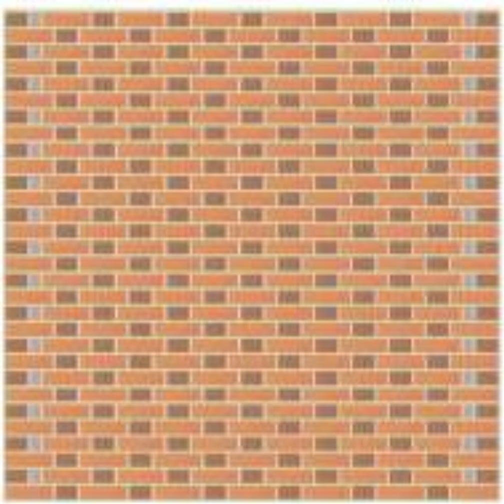
- In case the wall thickness is equivalent to an odd number of half bricks, the same course shall have stretcher on one face and header on the other face.

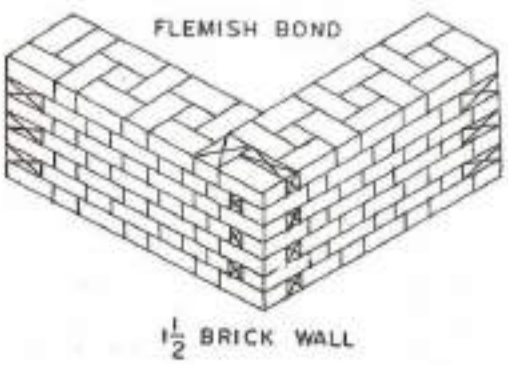
- The joints on the header course should be made thinner than those in the stretcher course. This is because of the fact that the number of vertical joints in the stretcher course is half the number of joints in the header course.

Flemish Bonds

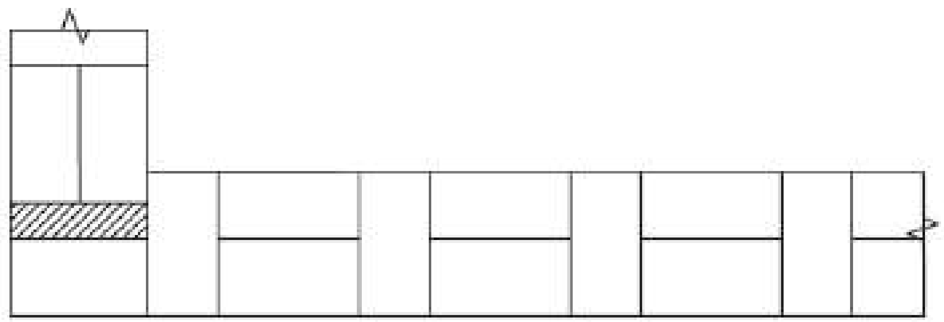
- This type of bond is created by laying alternate headers and stretchers in a single same course. The very next course of brick is laid such a way that header lies in the centered of the stretcher in the course below, i.e. the alternate headers of each course are centered on the stretcher of course below.

- Each and every alternate course of this bond starts with a header at the corner.

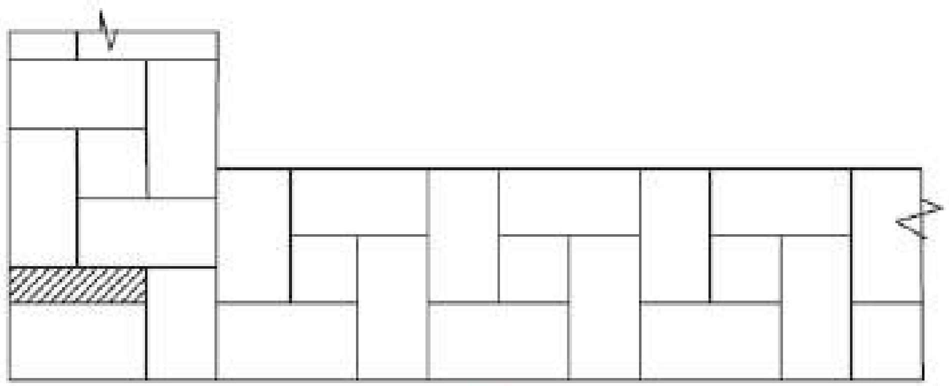




Flemish Bonds



1 brick wall



1½ brick wall

Flemish Bonds

A Comparison Between English and Flemish Bonds

English bond	Flemish bond
More compact and strong for walls having thickness more than 1½ bricks	Less compact and less strength
Less pleasing in appearance from facing	Better appearance in the facing
Strict supervision and skill are not required	Good workmanship and careful supervision required
More in cost	Cheaper in cost

Random Rubble Masonry

- Rubble masonry is rough, uneven building stone set in mortar, but not laid in regular courses.

- In this type of rubble masonry, stones of irregular sizes and shapes are used. The stones are arranged to have a good appearance. It is to be noted that more skill is required to make the masonry structurally stable.

Thank you

Introduction to Basic Civil Engineering

Lecture 14

Sreejith Krishnan, *PhD*

Floors

- Floors are provided to divide a building into different levels for creating more accommodation one above the other within a certain limited space

- Ground floor, basement floor, First floor etc.

- A floor may consist of two main components:
  - A sub-floor that provides proper support to the floor covering and the superimposed loads carried on it.
  - A floor covering which provides a smooth, clean, impervious and durable surface.

- Strength, durability, fire resistance, sound insulation and thermal insulation are some of the requirements from the floor

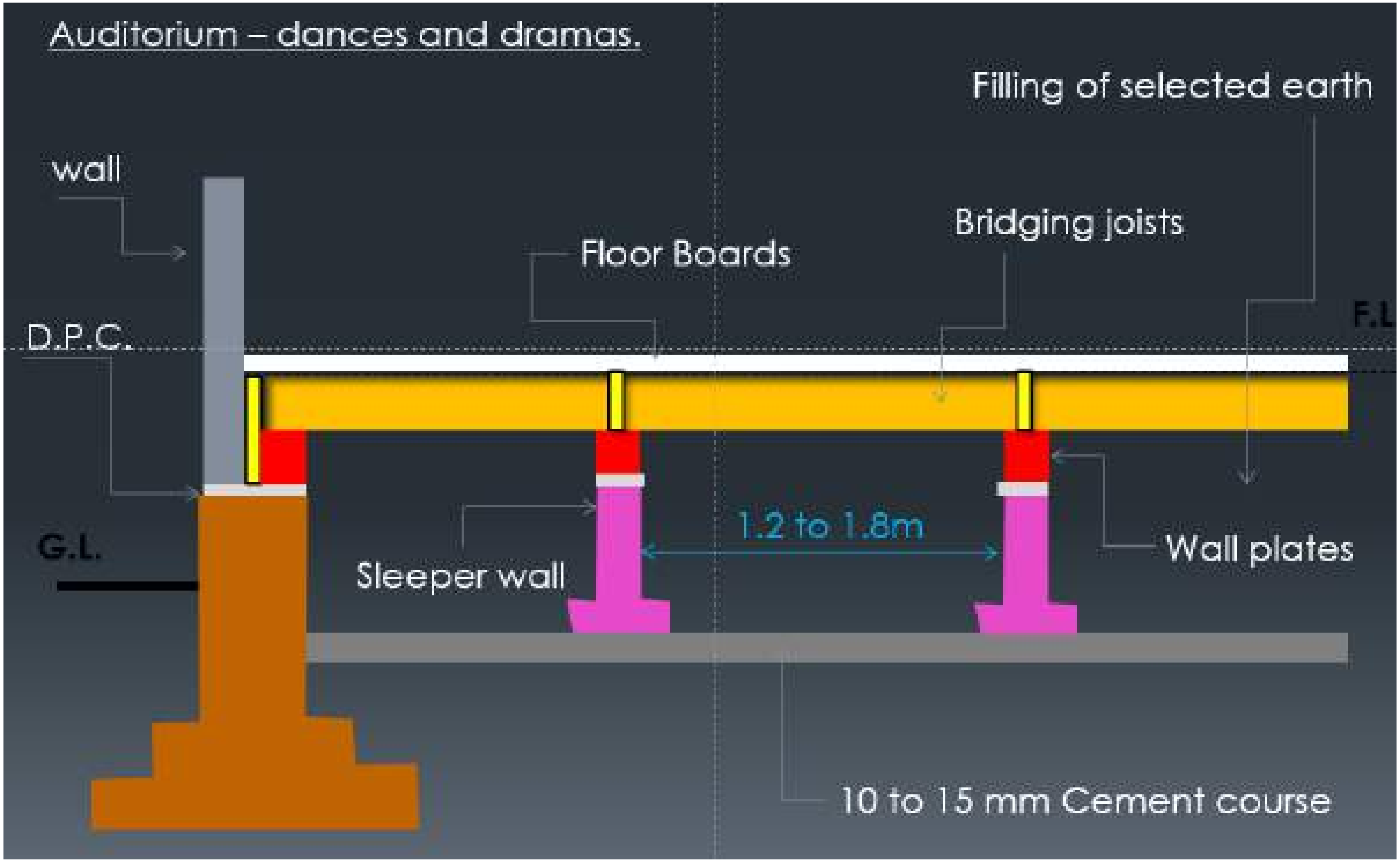
Factors affecting selection

- Initial Cost
- Appearance
- Cleanliness
- Durability
- Damp resistance
- Sound insulation
- Thermal insulation
- Smoothness
- Hardness
- Maintenance

Types of floor

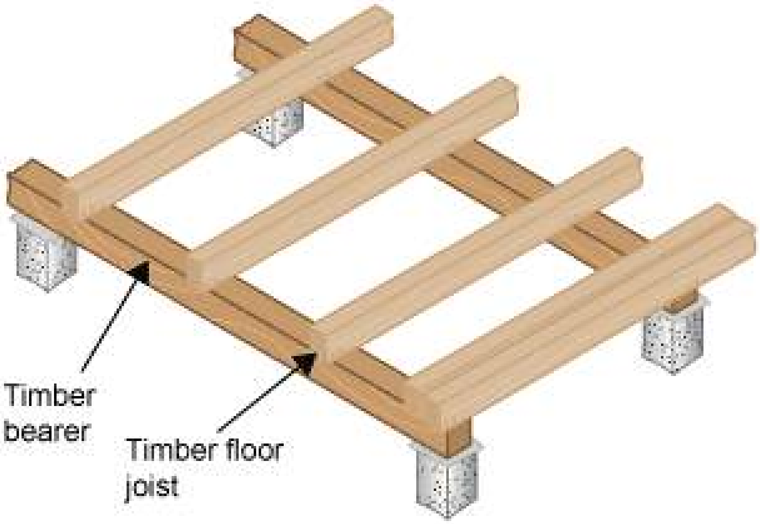
- Basement or ground timber floor
- Single joist timber floor
- Jack arch floor
- Hollow tiled and ribbed floor
- Double flagstone floor
- Flat slab floor
- RCC floor

Basement or ground timber floor



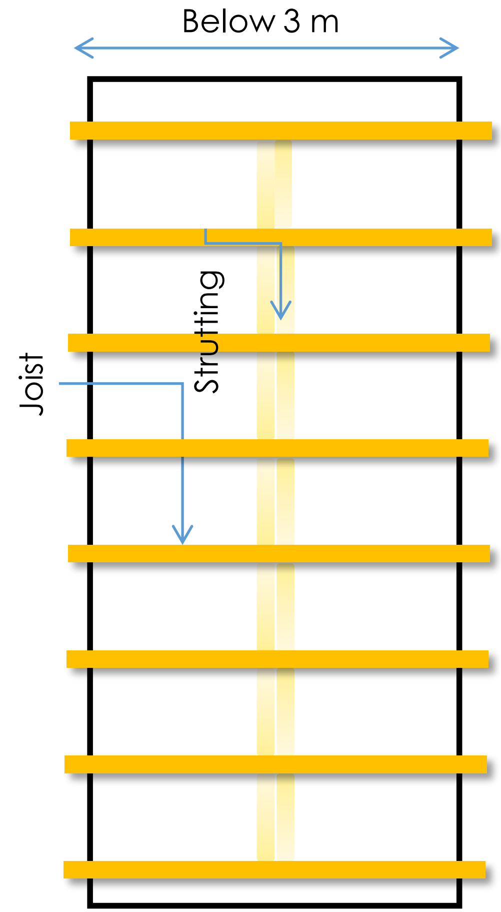
Basement or ground timber floor

- Soil below timber floor – covered with PCC 1:2:4 (100 to 150 mm thick).
- Plain cement concrete- it is used for providing a non porous, firm & level space for laying RCC & also used under flooring .
- DPC – exterior wall + top of the sleeper wall.
- A Sleeper Wall is a short wall used to support floor joists of a ground floor.
- Well seasoned timber is used.
- Hollow space between bottom of concrete and floor level is filled up with selected earth.



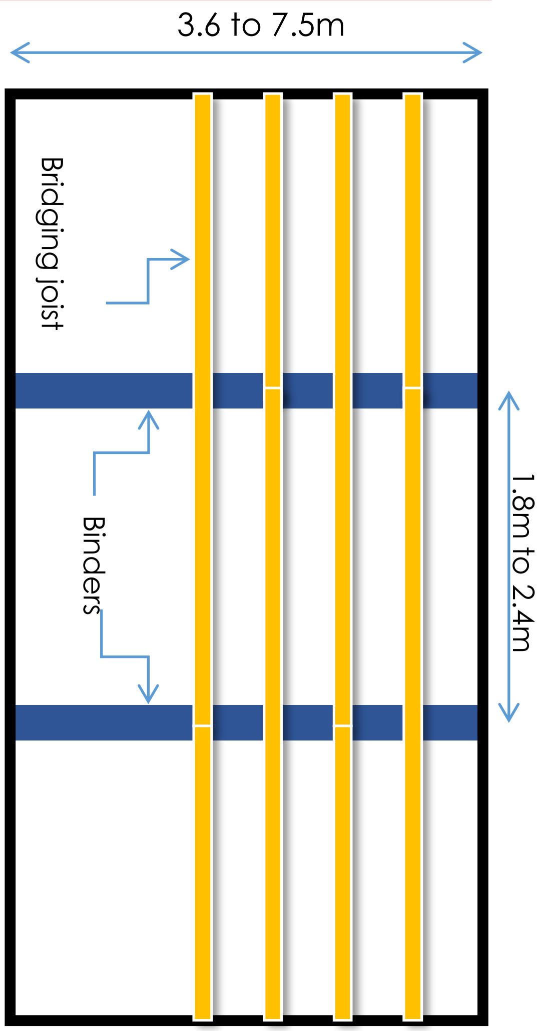
Single Joist Timber Floor

- This type of floor is used for residential buildings where spans are comparatively small and the loads are lighter. The wooden joists are placed at about 30 cm centre to centre, spanning the rooms in the shorter direction.
- Wooden planks are laid over these joists.
- The timber joists are supported on wall plates.
- Joists must be strong enough to withstand the loads and at the same time they should not deflect too much.
- Distribution of loads on the wall is more uniform as the joists are spaced closely.
- Easy construction and cheap

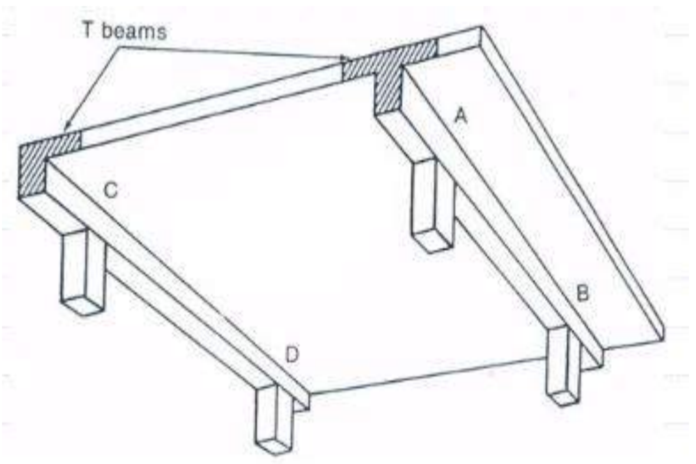


Double Joist Timber Floor

- This type of floor is stronger than the single joist timber floor. They are used for longer spans of 3.6–7.5 m and prevent the travel of sound waves to a great extent.
- Intermediate supports called binders are placed for bridging the joists.
- Binders are spaced at a centre-to-centre distance of about 2 m.
- The depth of the floor is considerably increased and, thus, the head room is reduced
- Loads distributed to few points in the walls



RCC floor



- Reinforced cement concrete (RCC) slab is being more commonly used in the construction of modern buildings.
- For small spans and comparatively lighter loads, a simple RCC slab is suitable.
- If the ratio of the length and width of a room is more than 1.5, the slab is designed to span along the shorter direction. The main reinforcement is provided along this shorter dimension of the room. The thickness of the slab is guided by the superimposed loads, span and type of concrete used.

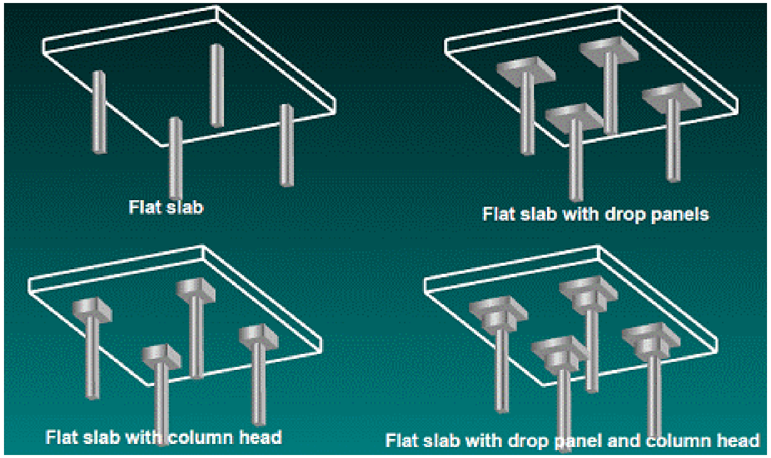
- For larger spans and greater loads, RCC beams and slab construction are adopted in the construction of buildings.
- The slab acts as a flange of the beam and is cast monolithic with the beams. In this case, the size of the beam is greatly reduced.
- Over the RCC floor suitable covering is laid to get the desired finish

Flat slab floor

- It is directly supported on the columns without providing any intermediate beams.
- This type of construction is adopted when the use of beams is forbidden.
- Simple Formwork,
- More clear head room is available for use.

.

- No projecting of beams is to be seen and, therefore, the need of false ceiling is eliminated.



Types of flooring materials

- Brick flooring - It is employed for cheap constructions such as godowns, sheds, stores and barracks and where good bricks are available.

- Over well-compacted and levelled ground a layer of lean cement concrete mix (1:6:18) of 10 cm thickness is laid. Over this bedding, bricks are placed in proper bonds on their edges.

- Durable, hard, fire resistant, cheap etc.

- They are joined with cement or lime mortar. The only drawback of brick floor covering is that it absorbs water.

Stone flooring

- Square or rectangular slabs of stones are used as the floor covering.
- Generally, 20–40 mm thick stone slabs of size 30 cm × 30 cm, 45 cm × 45 cm, 60 cm × 60 cm, 45 cm × 60 cm, etc. are used. The stone should be hard, durable, tough and of good quality.
- Stones must be dressed
- The earthen base is levelled, compacted and watered. On this surface a layer of 10–15 cm thick concrete is laid and properly rammed. Over this concrete bed the stone slabs are fixed with a thin layer of mortar
- The stone surface may be rough or polished. A rough surface is provided in rough works like godowns, sheds, stores, etc. and a polished surface is provided in superior type of works.
- A slope of 1:40 should be provided in such type of floor covering for proper drainage.

Tiled floor covering

- Clay tiles of different sizes, shapes, thickness and colours are prepared and they are used as floor coverings. They are placed in position on a concrete base with a thin layer of mortar. When these tiles are to be fixed on timber floors, special beds of emulsified asphalt and Portland cement are used.

- Non absorbant, decorative, durable
- Quick installation, easy to repair

- Generally costly initially, slippery when wet

- Vitrified tiles vs ceramic tiles

Wooden floor covering

- This type of floor covering is the oldest type, but nowadays it is used for some special-purpose floors such as theatres and hospitals. It possesses natural beauty and has enough resistance to wearing.

  - Strip floor covering: This is made up of narrow and thin strips of timber which are joined to each other by tongue and groove joints.
  - Planked floor covering: In this type of construction, wider planks are employed and these are joined by tongue and groove joints.
  - Wood block floor covering: It consists of wooden blocks which are laid in suitable designs over a concrete base. The thickness of a block is 20–40 mm and its size varies from 20 × 8 to 30 × 8 cm. The blocks are properly joined together with the ends of the grains exposed.

Concrete Floor Covering

- The concrete flooring consists of two layers:
  - A base course or the subgrade and
  - A wearing course
  - The concrete flooring consists of a topping of cement concrete 2.5–4 cm thick laid on a 10–15 cm thick base of either lime or cement concrete

- It is non-absorbent and, hence, offers sufficient resistance to dampness. This is used for water-retaining floors as well as stores.
- It possesses high durability and, hence, is employed for floors in kitchens, bathrooms, schools, hospitals, etc.
- It provides a smooth, hard, even and pleasing surface.
- It can be easily cleaned and overall has proved economical due to less maintenance cost.
- Concrete being a non-combustible material offers a fi re-resistant floor required for fire-hazardous buildings.

Concrete Flooring

- Defects once developed in concrete fl oors, whether due to poor workmanship or materials, cannot be easily rectified.
- The concrete flooring cannot be satisfactorily repaired by patchwork.
- It does not possess very satisfactory insulation properties against sound and heat.

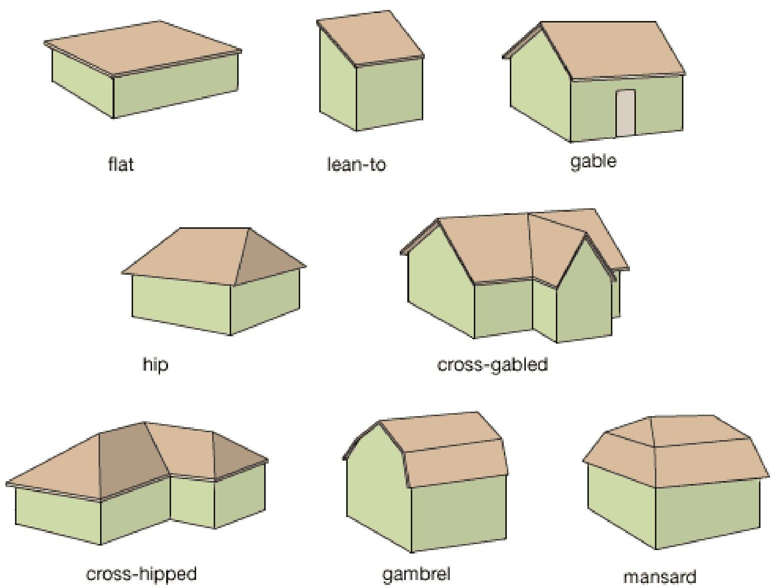
Flooring materials

- Rubber flooring
- Glass flooring
- Mosaic flooring
- Linoleum flooring etc.

Roofs

- A roof is the uppermost part of a building whose main function is to enclose the space and to protect the same from the effects of weather elements such as rain, wind, sun, heat and snow.

- A good roof is just as essential as a safe foundation.



Requirements from a roof

- ***Strength and stability:*** The roof structure should be strong and stable enough to take up the anticipated loads safely.
- ***Weather resistance:*** The roof covering should have adequate resistance to resist the effects of weather elements such as wind, rain, sun and snow.
- ***Heat insulation:*** The roofs should provide adequate insulation against heat, particularly in the case of single-storeyed buildings where the roof area may exceed that of walls with a consequent greater heat loss.
- ***Sound insulation:*** The roof construction for all buildings should provide adequate degree of insulation against sound from external sources.
- ***Fire resistance:*** The roof should offer an adequate degree of fire resistance in order to give protection against the spread of fire from any adjacent building and to prevent early collapse of the roof. The form of construction should also be such that the spread of fi re from its source to other parts of the building by way of roof cannot occur.

Types of roofs

- Pitched or sloping roofs
- Flat roofs
- Shell roofs
- Domes

Flat Roofs

- **Flat Roofs:** These roofs are nearly flat. However slight slope (not more than 10°) is given to drain out the rain water.

- All types of upper storey floors can serve as flat roofs.

- Many times top of these roofs are treated with water proofing materials- like mixing water proofing chemicals in concrete. With advent of reliable water proofing techniques such roofs are constructed even in areas with heavy rain fall.

Flat Roofs - Advantages

(a) The roof can be used as a terrace for playing and celebrating functions.

(*b*) At any latter stage the roof can be converted as a floor by adding another storey.

(*c*) They can suit to any shape of the building.

(*d*) Over-head water tanks and other services can be located easily.

(*e*) They can be made fire proof easily compared to pitched roof.

Flat Roofs - Disadvantages

a) They cannot cover large column free areas.

b) Leakage problem may occur at latter date also due to development of cracks. Once leakage problem starts, it needs costly treatments.

c) The dead weight of flat roofs is more.

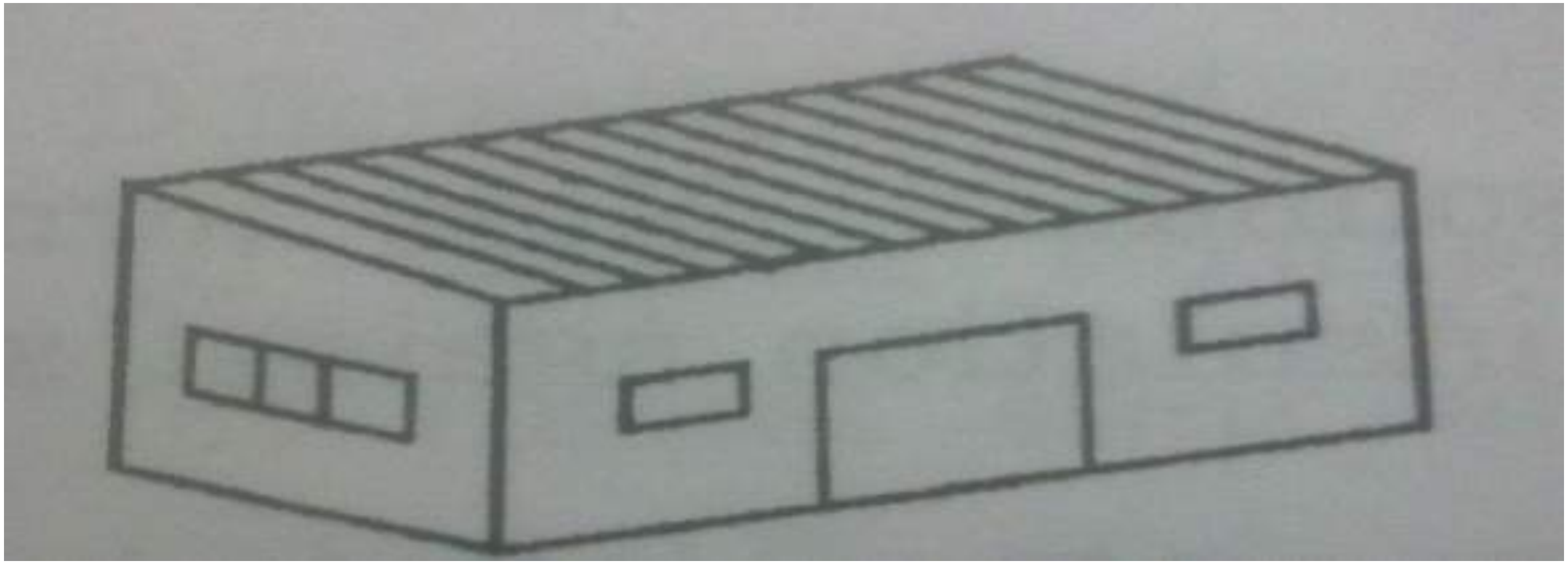
d) In places of snow fall flat roofs are to be avoided to reduce snow load

Pitched or Sloping Roofs

- Sloping top surface
- Suitable in areas with heavy rain and snowfall
- Can be used when the width of the building is small and simple plans
- The slope of roof shall be more than 10 degrees. They may have slopes as much as 45 to 60 degrees.
- The sloping roofs are preferred in large spanned structures like workshops, factory buildings and ware houses.
- In all these roofs covering sheets like A.C. sheet, G.I. sheets, tiles, slates etc.

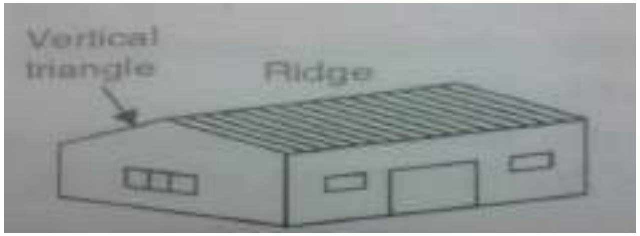
Forms of Pitched Roofs

- **LEAN-TO-ROOF:-**It is the simplest form of a pitched roof and it is known as pent roof. In this type of roof, one wall is carried up sufficiently higher than the other to give necessary slope to the roof.

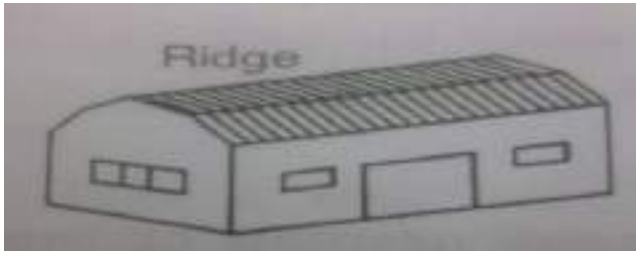


Forms of Pitched Roofs

- **GABLE ROOF:-** This is the common type of sloping roof which slopes in two direction. The two slopes meet at the ridge.



- **GAMBREL ROOF:-** This roof like gable roof, slopes in two directions but there is break in each slope.

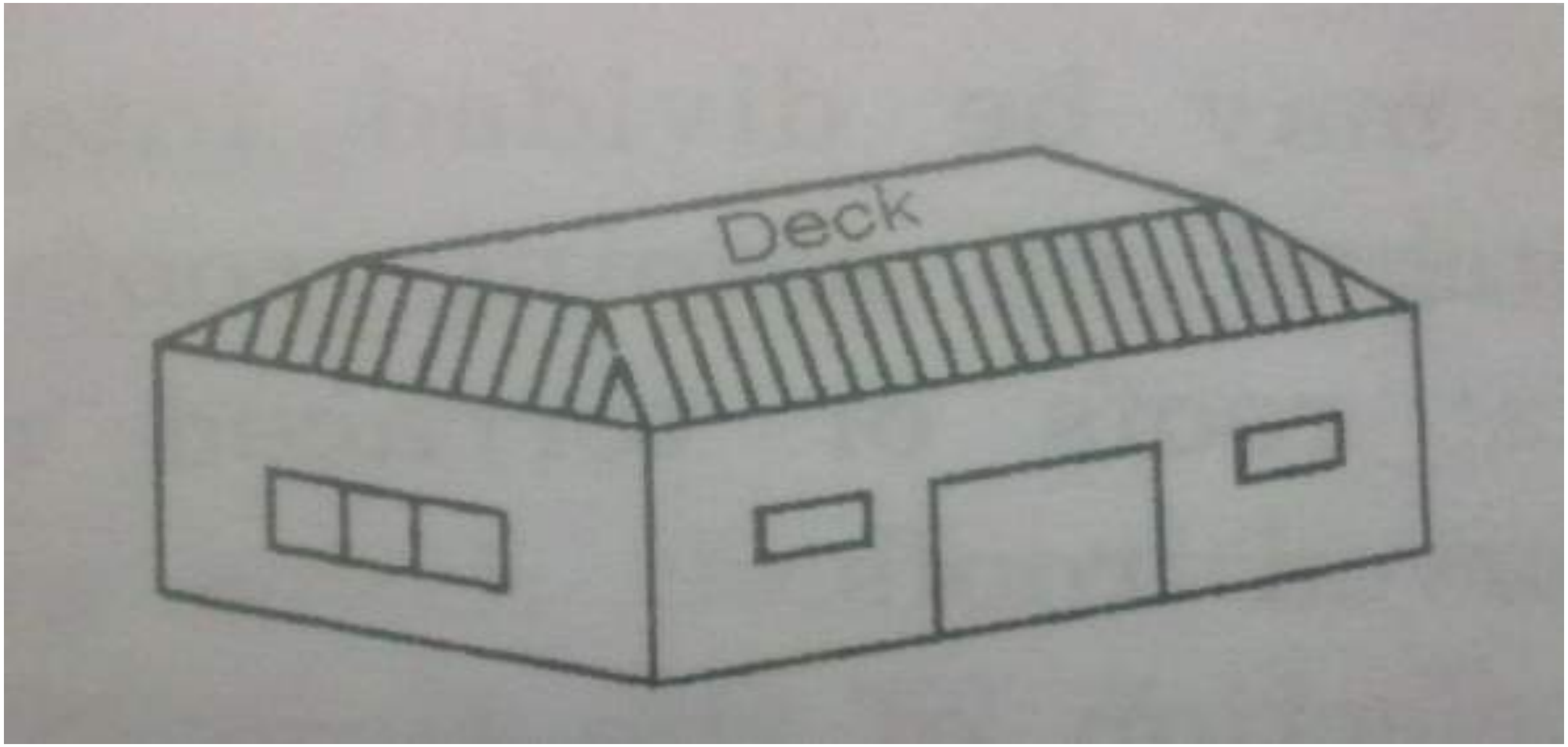


- **HIP ROOF:-** This roof is formed by four sloping surfaces in four directions.

- **MANSARD ROOF:-** This roof like a hip roof, slopes in four directions but each slope has a break.

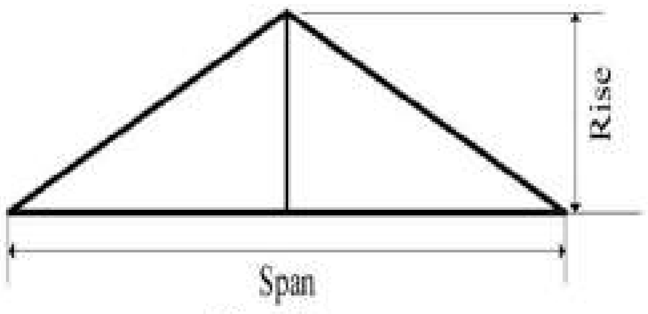
Forms of Pitched Roofs

- **DECK ROOF:-** A deck roof has slopes in all the four directions, like a hip roof but a plane surface is formed at the top.

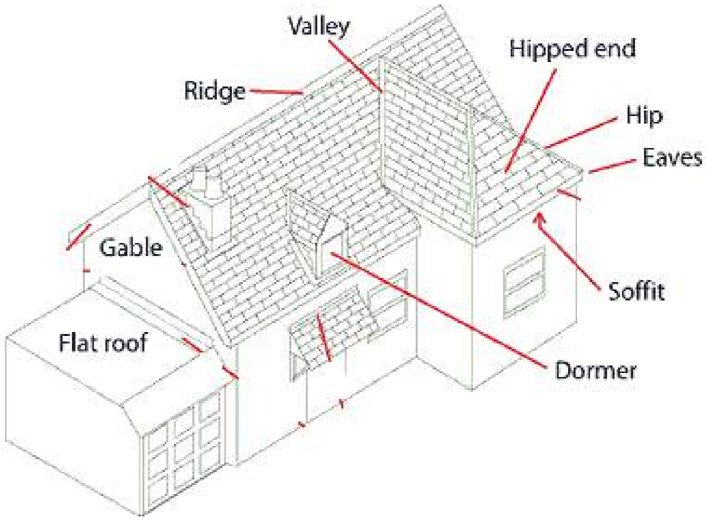


Parts of a Pitched Roofs

- **SPAN:-** The horizontal distance between the internal faces of walls or supports is known as span or clear span.
- **RISE:-** It is the vertical distance between the top of the ridge and wall plate.
- **PITCH:-** It is the inclination of the sides of a roof to the horizontal plane. It is expressed in degrees or as a ratio of rise to span.
- **RIDGE:-**It is defined as the apex line of the sloping roof.
- **EAVES:-**The lower edge of a roof which are resting upon or projecting beyond the supporting walls are known as eave.

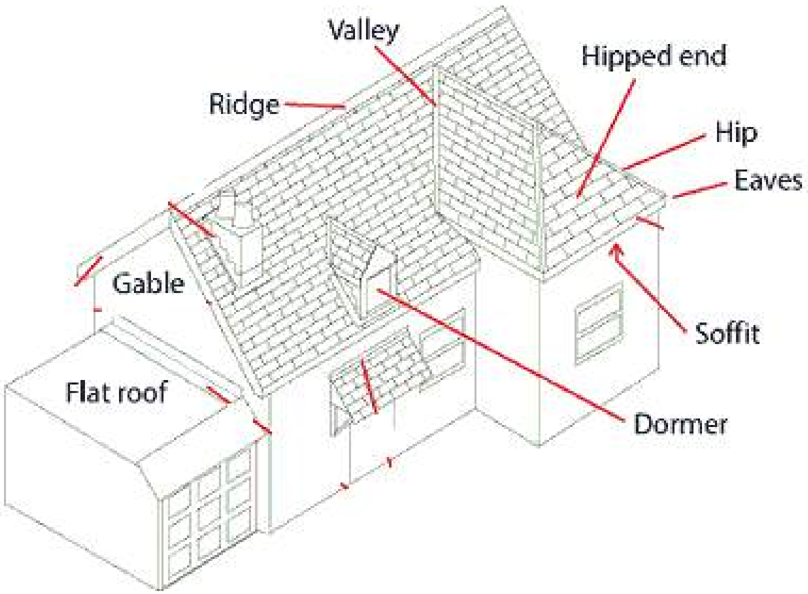


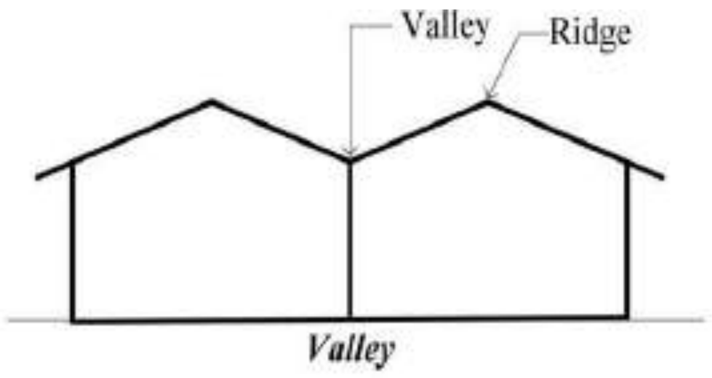
Rise of truss



Parts of a Pitched Roofs

- **HIP:-**The angle formed at the intersection of two roof slopes is known as hip.
- **VALLEY:-**When two roof surfaces meet together and form an internal angle, a valley is formed.
- **VERGE:-** The edge of a gable, running between the eaves and ridge is known as a verge.
- **COMMON RAFTER:-**These are the intermediate rafters, which give support to the roof coverings.
- **PRINCIPAL RAFTER:-** These are the inclined members of a truss.





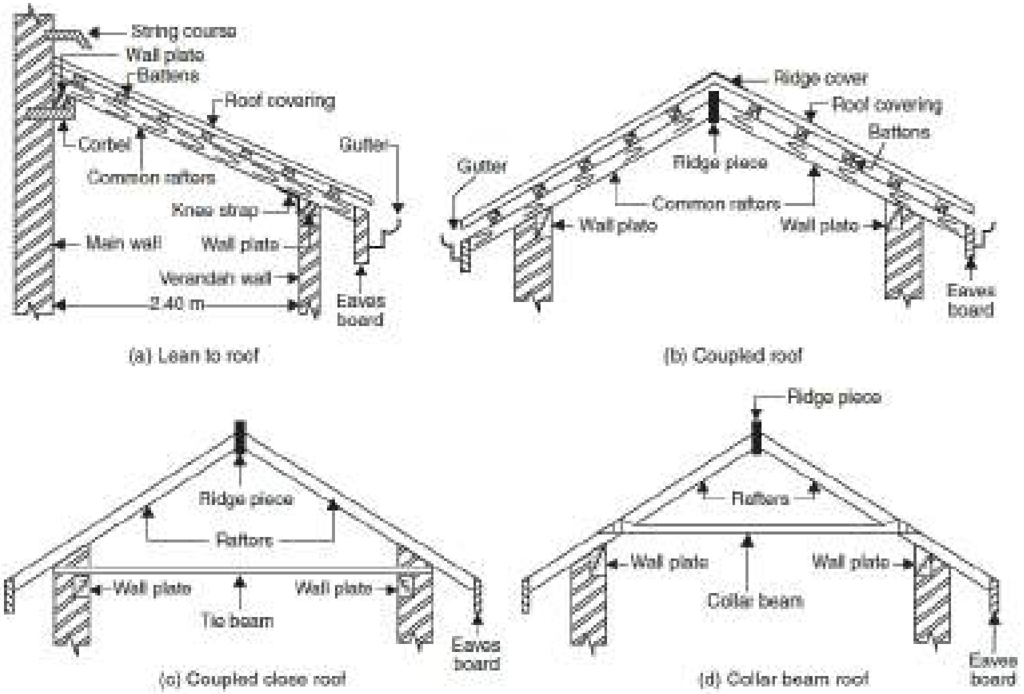
Pitched Roofs

- The pitched roofs are classified into
  - Single roofs
  - Double or purlin roofs
  - Trussed roofs.

Pitched Roofs – Single Roof

- **Single Roof:** If the span of roof is less than 5 m the following types of single roofs are used.

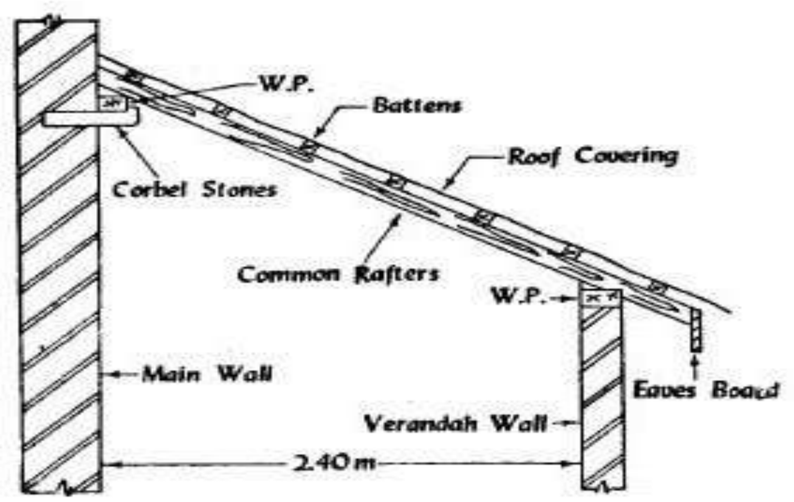
- Rafters placed at 600 mm to 800 mm spacing are main members taking load of the roof. Battens run over the rafters to support tiles



Single Roof – Lean to

- A lean-to roof is generally used for sheds, outhouses attached to main buildings verandah etc.

- This is suitable for a maximum span of 2.4m



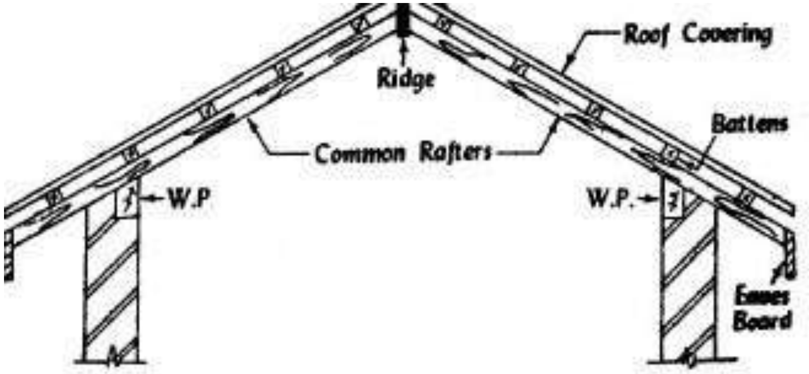
Lean-to roof

Single Roof – Couple Roof

- This type of roof is formed by couple or pair of rafters which slope to both the sides of the ridge of the roof.

- In this type of roof the common rafters slope upwards from the opposite walls and they meet on a ridge piece in the middle

- A couple roof is suitable for spans up to about 3.6m.



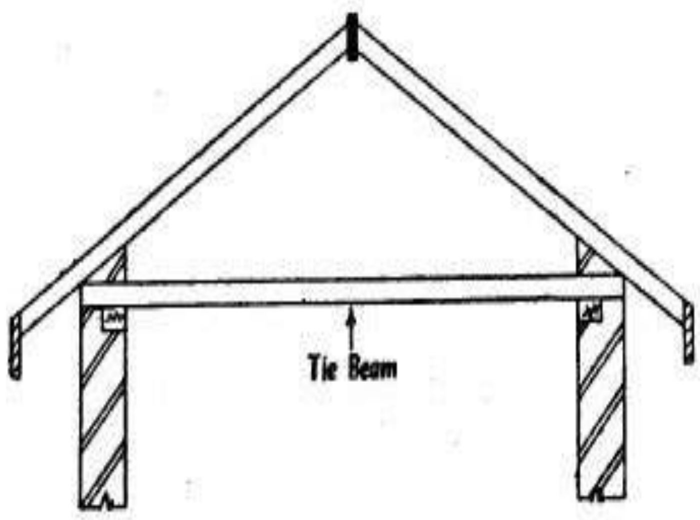
Single Roof – COUPLE CLOSE ROOF

- This roof is just similar to couple roof except that the ends of the couple of the common rafters is connected by horizontal member, called tie beam.

- The tie beam prevents the tendency of rafters to spread out and thus danger of overturning of the walls is avoided.

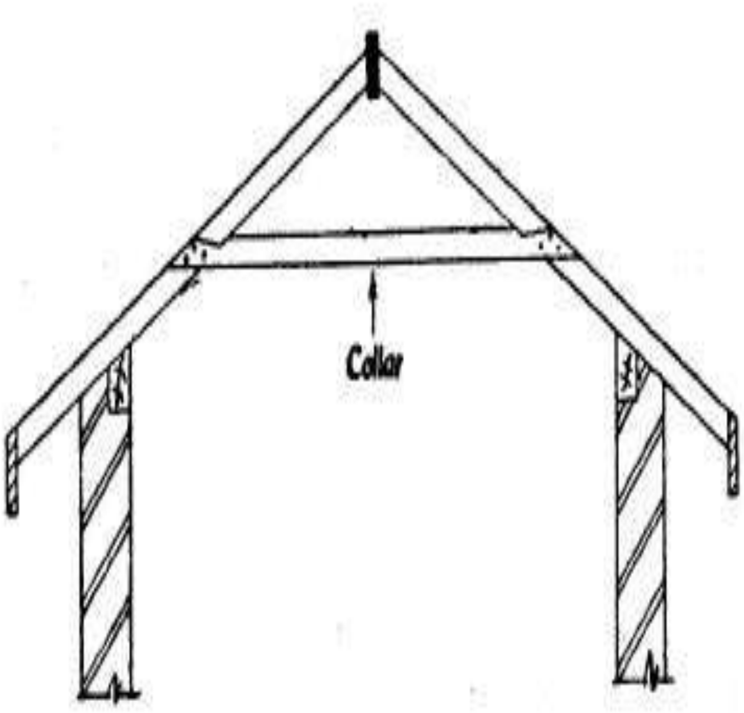
- The tie beam may be a wooden member or a steel rod.

- This roof can be adopted economically up to the span of 4.2m.



Single Roof – COLLAR BEAM ROOF

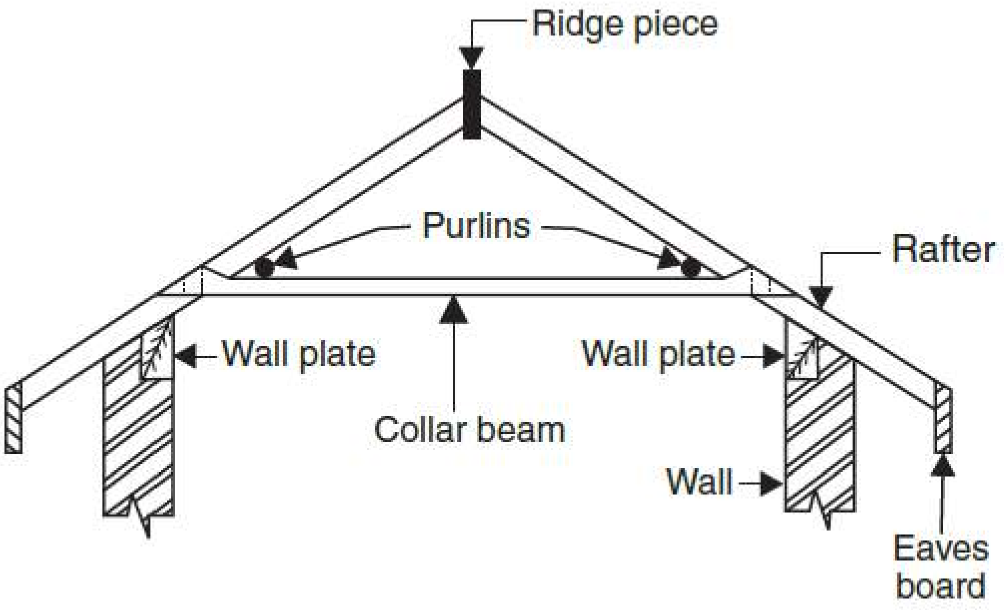
- When the span increases or when the load is more the rafters of the couple close roof have the tendency to bend.
- This is avoided by raising the tie beam and fixing it at one-third to one-half of the vertical height from the wall plate to the ridge. This raised beam is known as collar beam.
- This beam roof is adopted to economise the space and to increase the height of a room.



- This roof can be adopted up to a maximum span of 4.8m.

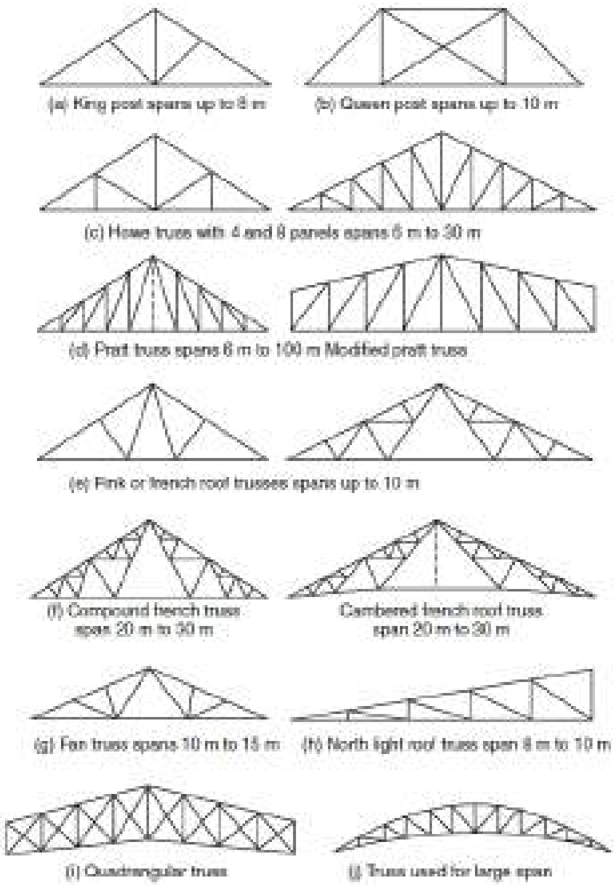
Pitched Roofs – Double Roofs

- **Double or Purlin Roofs:** If span exceeds, the cost of rafters increase and single roof becomes uneconomical.
- For spans more than 5 m double purlin roofs are preferred. The intermediate support is given to rafters by purlins supported over collar beams



Pitched Roofs – Truss Roofs

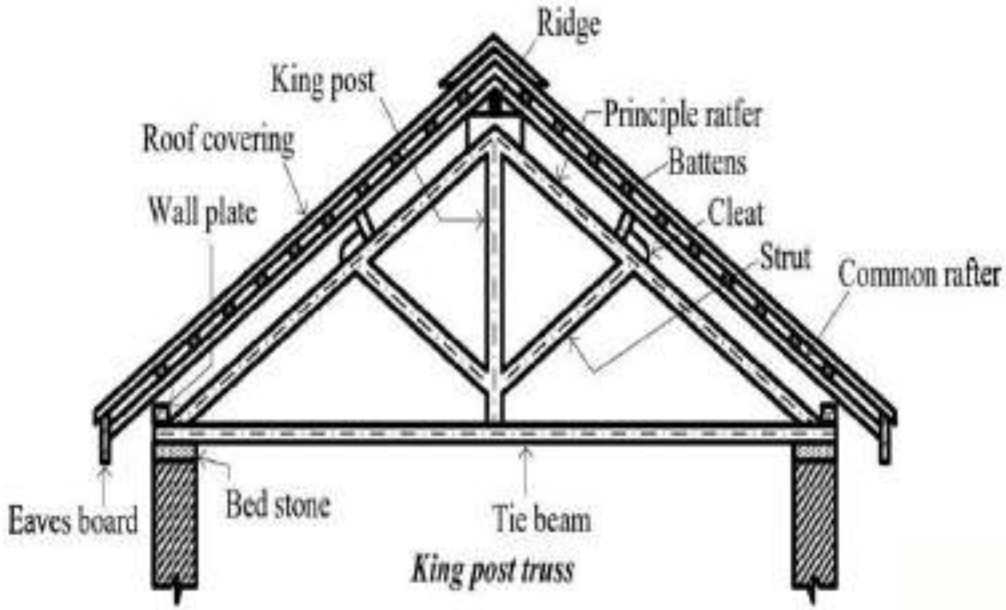
- **Trussed Roof:** If span is more, a frame work of slender members are used to support sloping roofs.
- These frames are known as trusses. A number of trusses may be placed lengthwise to get wall free longer halls.
- Purlins are provided over the trusses which in turn support roof sheets.
- For spans up to 9 m wooden trusses may be used but for large spans steel trusses are a must.



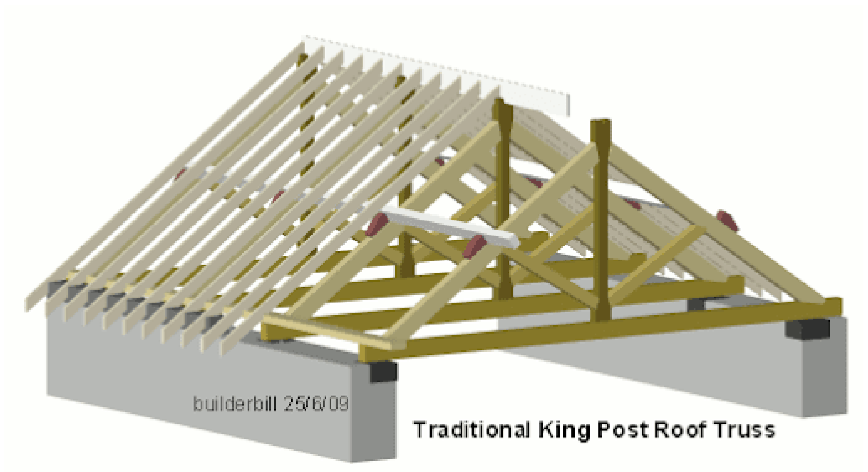
Truss Roofs

- King Post Truss
- Queen Post Truss
- Mansard Truss
- Steel Truss

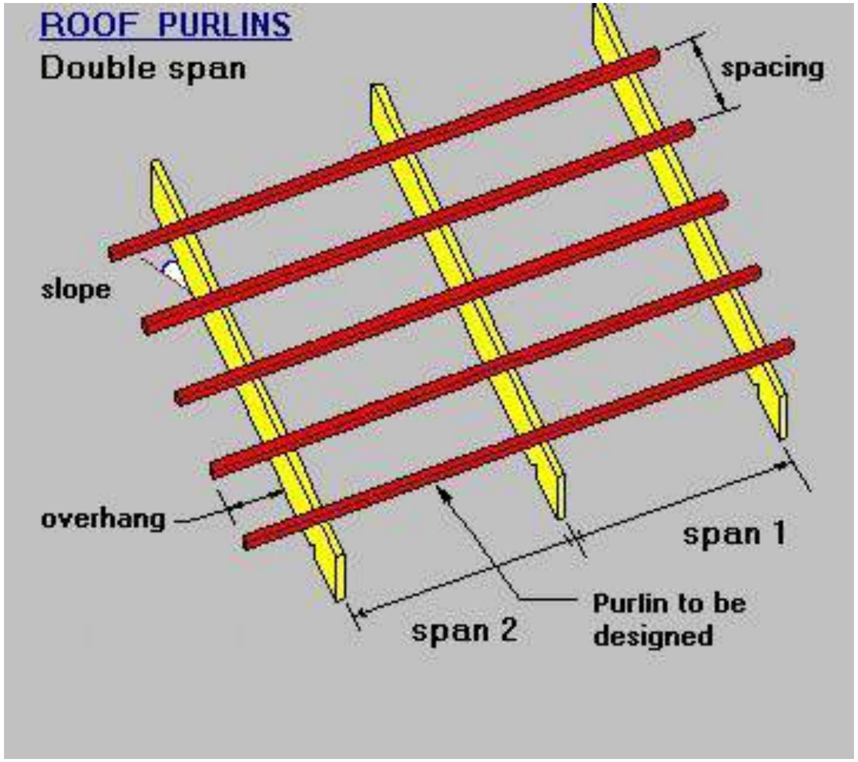
King Post Trussed Roofs



5 to 8m Span

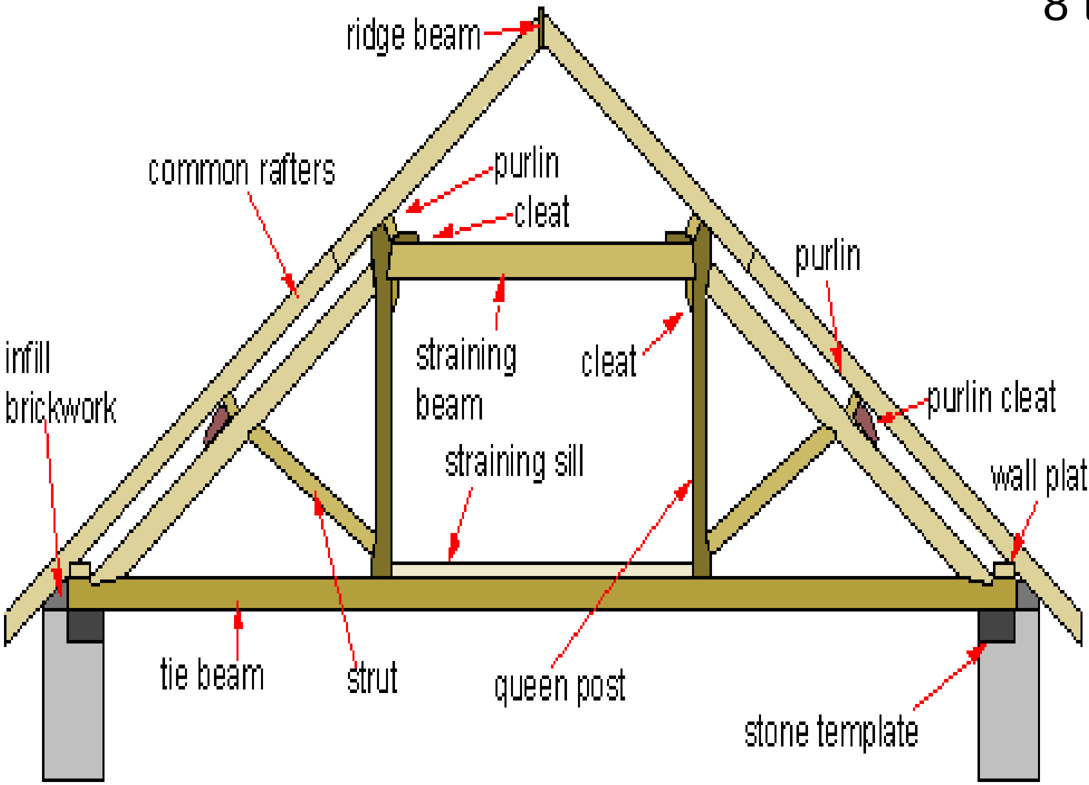


Trussed Roof



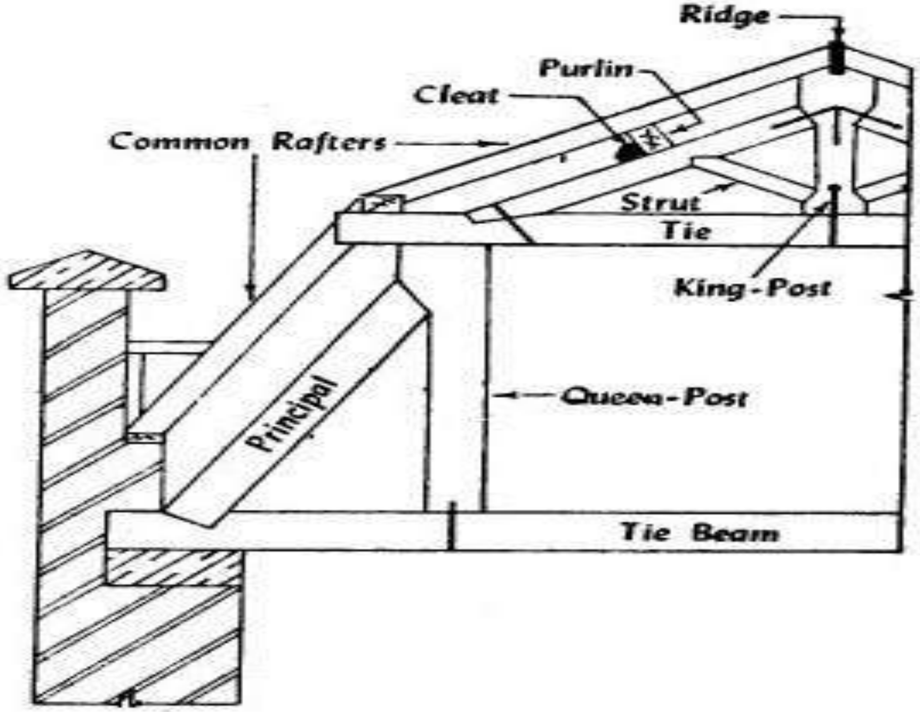
Queen Post Truss

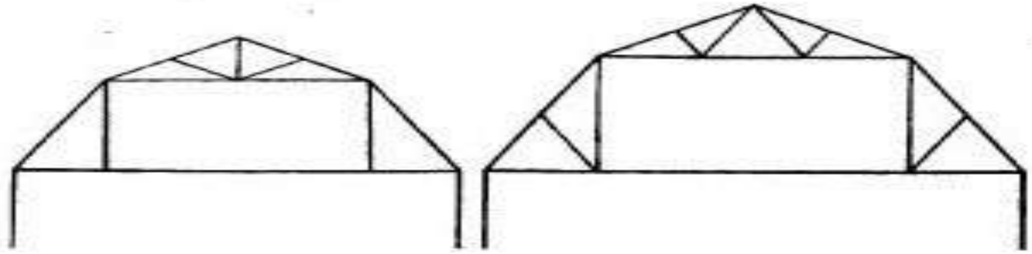
8 to 12 m spans



Queen Post Roof Truss

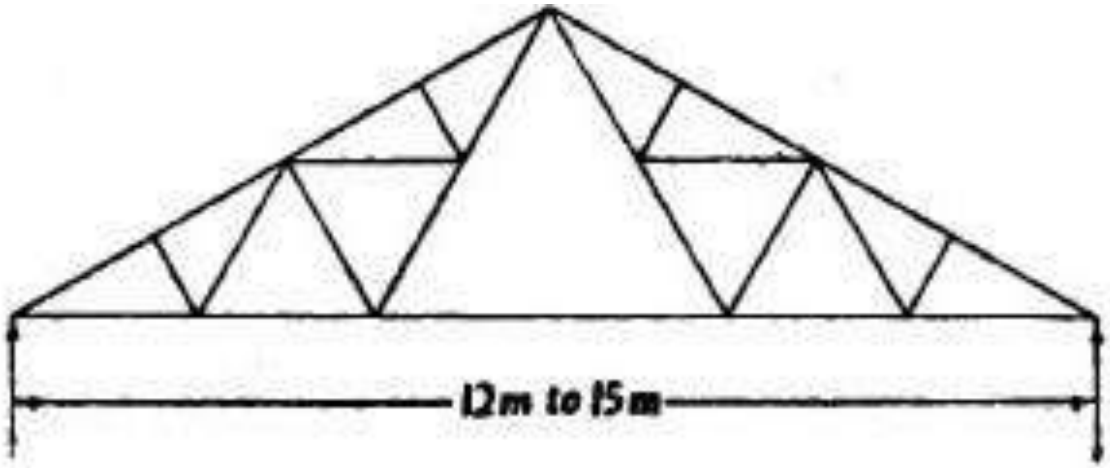
Mansard Truss

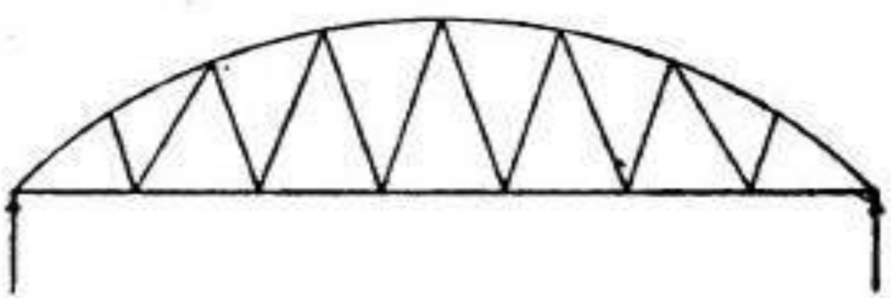




Steel Truss

- For spans greater than 12 m





Bow-string truss

Roofing Materials

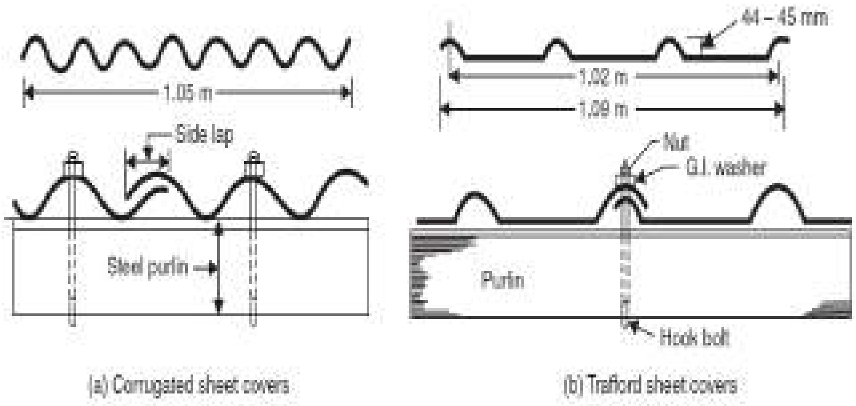
- Climatic Conditions – wind rain
- Slope of the roof
- Initial Cost
- Maintenance Cost
- Durability
- Resistance to fire
- Heat insulation
- Weight of roofing materials

Roofing Materials

- Thatched Roofing - This is the cheapest roof covering, commonly used in villages.
- It is very light, but is highly combustible.
- It is unstable against high winds. It absorbs moisture & liable to decay.
- The framework to support thatch consists of round bamboo rafters spaced 20 to 30 cm apart & tied with split bamboos laid at right angles to the rafters.
- The thickness of thatch covering should at least be
- 15cm, normal thickness varies from 20 to 30 cm.

Roofing Materials

- AC sheets (Asbestos Cement Sheet) – Manufactured from asbestos and portland cement
- Used for large buildings such as industrial building, cinema halls, auditoriums etc.
- Cheap, light weight, fire resistant, durable
- Don't require protective painting, les maintenance, faster construction
- Brittle, algae growth, dangerous to manufacture



Roofing Materials

- GI sheets or Galvanised Iron Sheets – Costly but stronger than asbestos sheet
- Iron sheets are galvanised with Zinc to prevent rusting

- They are fixed to steel purlins using J-bolts and washers.

© Can Stock Photo

- They are durable, fire proof, light in weight and need no maintenance.

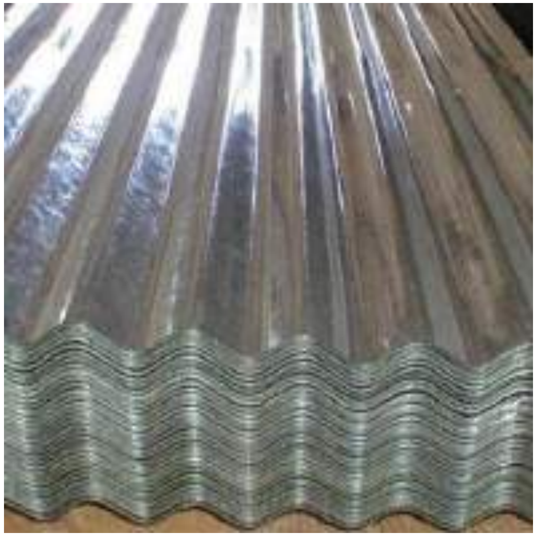
Comparison

S. No.	*GI Sheets*	*A.C. Sheets*
1.	Sheets are thin.	Not as thin as GI sheets.
2.	Light in weight.	Slightly heavier.
3.	Do not break while handling.	Chances of breaking are there during handling.
4.	Chances of corrosion can not be ruled out	No problem of corrosion.
5.	More noisy, if something falls over them.	Less noisy, if something falls over them.
6.	Less fire resistant.	More fire resistant.
7.	Less resistance to acids and fumes.	More resistant to acids and fumes.
8.	Cost is more.	Less costly.

Roofing Materials

- Aluminium sheets – sheets of aluminium with small percentage of manganese

- Corrosion free, light, eco friendly, low maintenance, economical than steel, PVC etc.



Roofing Materials

- Powder Coated Sheets – Powder coating is a type of coating that is applied as a free-flowing, dry powder. Unlike conventional liquid paint which is delivered via an evaporating solvent, powder coating is typically applied electrostatically and then cured under heat or with ultraviolet light.

- Powder coating GI and Aluminium sheets

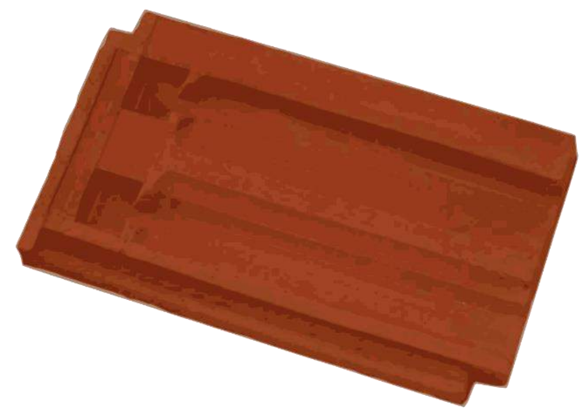
- Increase life and enhances appearance

Roofing Tiles

- Roof Tiles – Thin members made from clay or concrete
- Clay tiles are more common. Similar manufacturing process as bricks
- Plain tiles – rectangular in shape, concrete or clay
- Pot tiles – Semi circular in shape, tapering along length
- Pan tiles – Flat along longitude, wave shape along transverse
- Corrugated tiles – Tiles which have corrugations

Types of tiles

Roofing Materials



Thank You!

- Any doubts..???

Introduction to Basic Civil Engineering

Lecture 15 – Basic Infrastructure Services

Sreejith Krishnan, *PhD*

Elevator or Lift

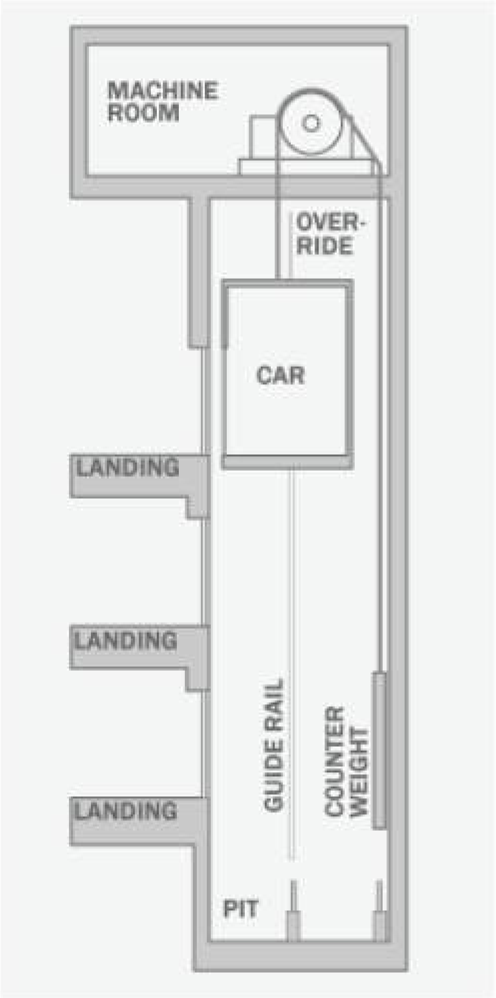
- Appliance used to transport persons or materials between two levels in a building with a guided car
- Generally for buildings with more than 4 floors
- Powered by electric motors

Based on Use -

- Passenger Elevator – transport of people
- Service Elevator – Goods along with people
- Goods Elevator – Primarily to transport goods

Based on Operating Mechanism

- **Traction elevators** are lifted by ropes, which pass over a wheel attached to an electric motor above the elevator shaft.
- They are used for mid and high-rise applications and have much higher travel speeds than hydraulic elevators.
- A counter weight makes the elevators more efficient by offsetting the weight of the car and occupants so that the motor doesn't have to move as much weight.
- It is important that traction elevator ropes and sheaves are checked for wear on a regular basis. As they wear, the traction between the sheave and the cables is reduced and slippage becomes more regular, which reduces the efficiency and can become dangerous if left unchecked.



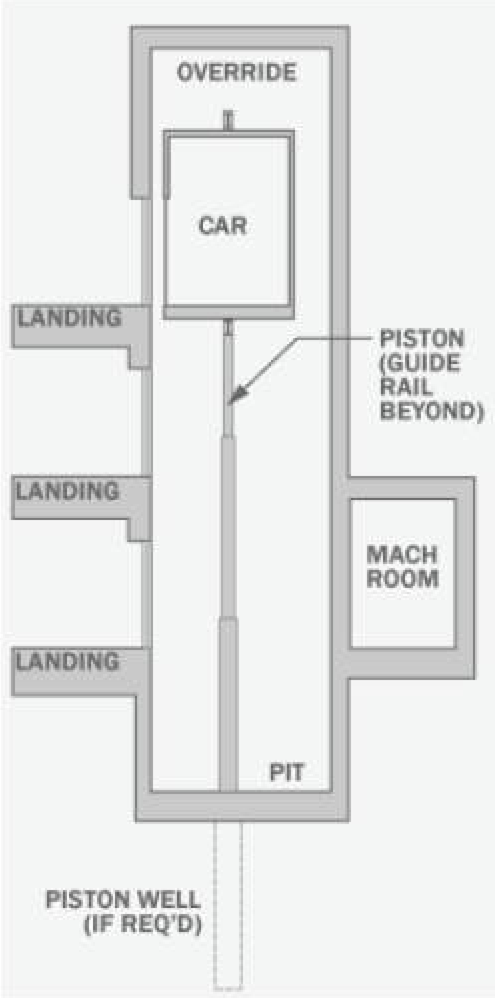
Based on Operating Mechanism

- Hydraulic elevators are supported by a piston at the bottom of the elevator that pushes the elevator up as an electric motor forces oil or another hydraulic fluid into the piston

- The elevator descends as a valve releases the fluid from the piston.

- They are used for low-rise applications of 2-8 stories and travel at a maximum speed of 200 feet per minute

- The machine room for hydraulic elevators is located at the lowest level adjacent to the elevator shaft.



Design Considerations of Lift

- Governed by Lift Acts and Rules, Indian Electricity act, NBC and local fire regulations

- Quantity and quality of the service needs to be considered
  - Handling capacity at the peak periods
  - Waiting time of passengers at different floors
  - Needs detained study of the passenger behaviour

- Floor to floor distance, number of floors, population to be served on each floor, maximum peak demand

Design Considerations of Lift

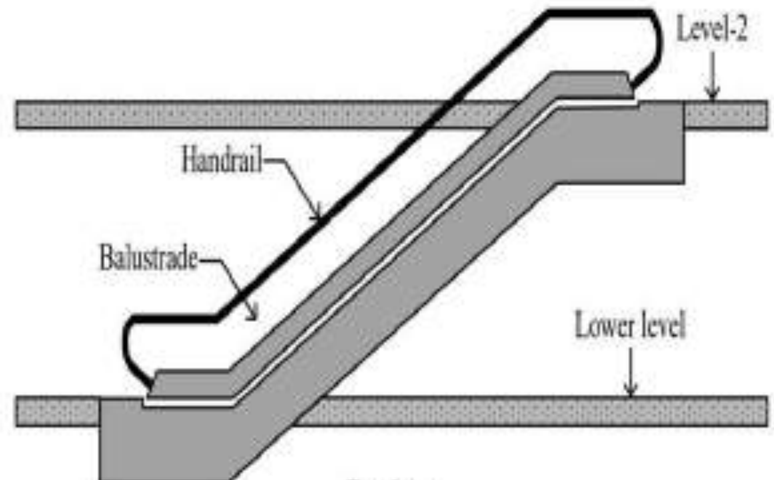
- Lift is mandatory
  - More than 3 storeys for hospital buildings/medical buildings
  - More than 4 storeys for other buildings with plinth area more than 2500 m^2
  - One lift to be provided for additional increase for 2500m^2 in plinth area
  - This is in addition to the staircase requirements
  - Minimum car size for a single purpose building 884kg
  - For commercial buildings, 2040 kg is recommended

Design Considerations of Lift

- Lift should be easily accessible from all entrances
  - Preferably near the centre of the building
  - Maximum of 3 lifts together
  - Corridor sufficiently wide for waiting and through passengers
- Can be placed near staircase if the lift is serving 2 to 3 apartments per floor
- Else in a well ventilated tower adjoining the building
- In commercial building, the lift position should aid the work flow and movement of goods

Escalators

- Moving staircase for transporting people between different levels
- Motor driven chain of steps, steel trussed frame and hand rails
- Continuous operation
- High volume of people transported at slow rate

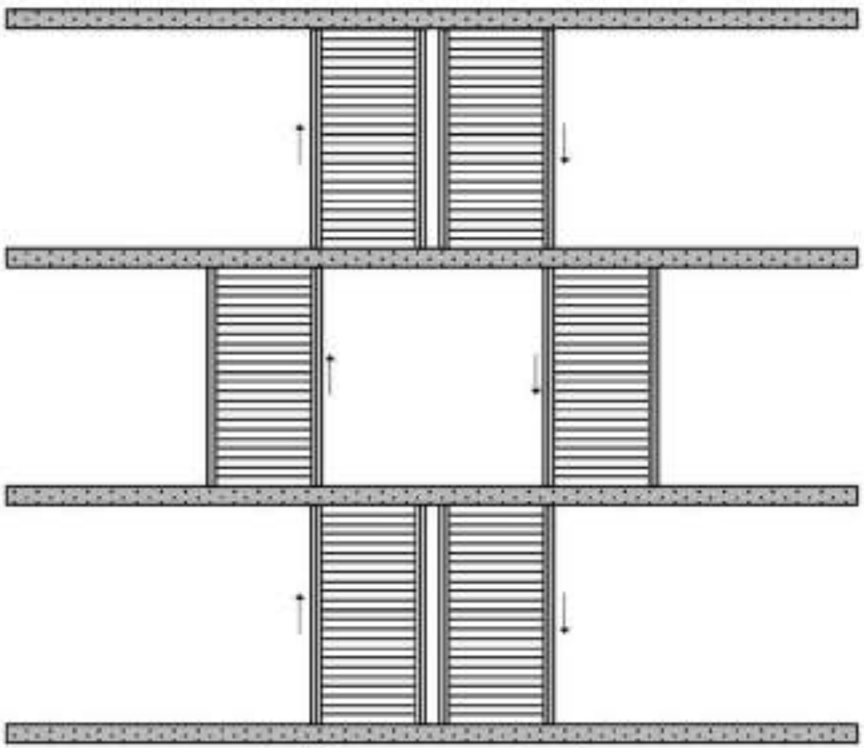


Escalator

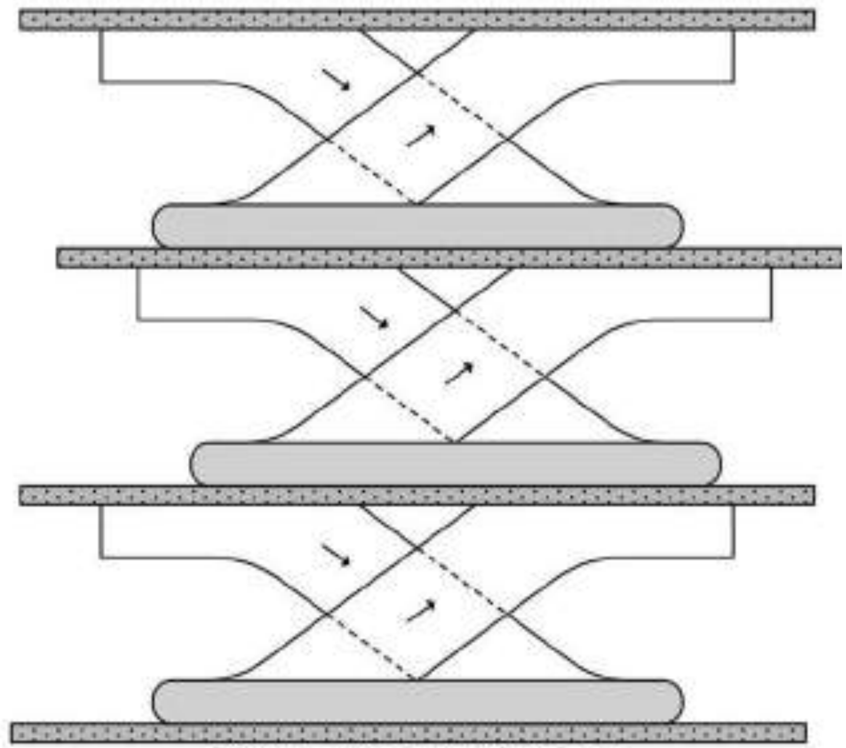
Design Criteria

- Escalators should operate at a constant speed
- Recommended capacity is 3200 to 6400 people per hour
- Angle of inclination not more than 30 degrees (expect for rises exceeding 6m and speed less than 0.5m/s, 35 degrees can be provided)
- Balustrades shall be provided with a moving handrail operating at the same speed as elevators
- Installed where the traffic is heaviest.
- Generally arranged in pairs

Design Criteria



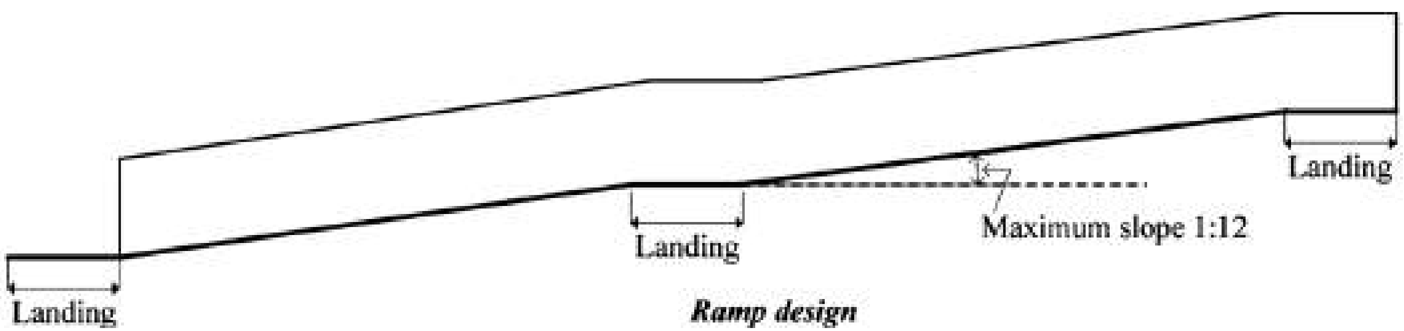
Parallel arrangement of escalators
(Top view)



Cris-cross arrangement of escalators
(Side elevation)

Ramp

- Sloping surface provided to connect between floors
- Movement of vehicles, people, PwD



Ramp design

Ramp - Design

- Hand rails on one side at least, preferably both sides (at least 0.8m)
- Curved, Zig-Zag, Spiral or U-Shaped
- Slope should not exceed 1:12, recommended 1:20
- Located in the exterior, indoor ramps require lots of space
- Should be provided with landings at change of direction/top and bottom for resting manoeuvring etc.
- Minimum landing of 1.5m

MEP

MEP stands for ***mechanical***, ***electrical*** and ***plumbing engineering***. These three technical disciplines include the systems that make building interiors suitable for human occupancy. Mechanical, Electrical, and Plumbing design are important for building construction planning, decision making, documentation, cost estimation and building construction. MEP encompasses the in depth design and selection of systems, as opposed to a tradesperson simply installing equipment. For example, a plumber may select and install a commercial hot water system based on common practice. MEP engineers will research the best design according to the principles of engineering. A brief explanation of each term follows.

MEP

- Mechanical Systems – Space heating, air conditioning, and mechanical ventilation in commercial buildings
- Heating, cooling, ventilation and exhaustion are all key areas to consider in the mechanical planning of a building.
- These systems interact with each other to control temperature and humidity and to provide comfort
- Ensures sufficient air circulation to bring in fresh air and reduce pollutants

MEP

- Electrical Engineering – deals with the design of conduits and wiring for electricity supply
  - Reduce the circuit length
  - Optimise cost
  - Prevent conflict between mechanical and plumbing networks

- Plumbing – Laying out and optimising the pipe networks for distribution of water and removing sewage

HVAC

- HVAC stands for Heating, Ventilation, and Air Conditioning
- Part of Mechanical Engineering under MEP
- Uses principles of thermodynamics and fluid mechanics
- HVAC equipment perform cooling and heating for residential and commercial buildings
- Provides fresh air from outside, reduces pollutants etc.
- Engineers install pipework, duct work, equipment etc. to regulate air movement

HVAC

- Work to be done as per NBC Part VIII – Air conditioning and heating

- Comfort air conditioning – for providing comfort
  - Temperature Control
  - Air velocity control
  - Humidity Control

- Industrial air conditioning – for creating an environment suited for specific applications

HVAC

- Types of Air Conditioning
  - ***Central AC*** - In this system, all the equipment pertaining to air conditioning are installed at one focal or central point and then the conditioned air is distributed to all the rooms or enclosures by ducts.
  - This type of system requires less space for installation and the maintenance is also easy.
  - Due to the presence of ducts, it requires large space.

  - ***Self-contained or unit system:*** Special portable attractive cabinets which fit in with the decoration of modern rooms are placed inside the room near the ceiling or window.
  - They are self-contained in every respect and conditioned air is formed inside the unit itself.
  - The conditioned air is then directly thrown into the room without the help of any ducts.

HVAC

- ***Semi-contained or unitary central system:*** In this system, every room is provided with an air-conditioning unit and the room unit obtains its supply from the central system.
- Such a system results in the smaller size of ducts.
- Another form of this system is adopted in which conditioned air may be supplied from a central unit but the heating or cooling may be carried out in the room itself

- ***Combined Systems –*** A combination of any of the two systems

Fire Safety

- Buildings have to be designed for acceptable levels of fire safety
- Aim is always to reduce the loss of lives
- NBC – Part 4 (Fire and Life Safety – 2005)

Fire Safety

- Fire safety can be improved by
  - Using suitable materials
  - Combustible vs Non Combsutible materials
  - NC materials do not catch fire, but can decompose at higher temperatures leading to building failures
  - Combustible materials catch fire and act as fuel for the spread of fire

- Use non combustible materials as much as possible

- Design sufficient fire escapes,

Fire Safety

a) ***Walls*** – Brick walls with cement plaster gives better fire resistance.

b) ***Roof*** – RCC flat roofs have good fire resistance. Hence they should be preferred.

c) ***Ceiling*** – Ceilings should be made up of cement plaster, asbestos cement board or fibre boards.

d) ***Floors*** – R.C.C. floor is very good fire resisting floor.

e) ***Doors and Window Openings*** – All these openings should be protected against fire by taking the following precautions:

   i. The thickness of shutters should not be less than 40 *mm*.
   ii. Instead of wooden, aluminium or steel shutters should be preferred.
   iii. They should be provided with fire proof paints.

f) ***Stairs*** – Wood should be avoided in the stair cases. To minimize fire hazard, stairs should be centrally placed in the buildings so that people can approach them quickly. More than one stair case is always preferable. Emergency ladder should be provided in the building.

Fire Resistance

- Good Materials – Bricks, RCC, Terracota, etc.
- Bad Materials – Steel, Timber, aluminium, stone
- Fire alarm must be provided
- Fire extinguishers must be provided

Intelligent Building

- An intelligent buildings integrate different systems in a coordinated way so as to provide maximum comfort and performance, operating cost and flexibility

- Energy savings is one of the important characteristics of intelligent building

- Advanced security control and remote control of systems

- A powerful customised computer program will control the different aspects of the building

- Integrated camera and sensors collect the required information and informs different gadgets and application

- Informative, predictive, responsive, adaptive, diagnostic, corrective, and self-healing.

Intelligent Building - Features

- HVAC systems – Program can take into account the weather conditions and preferences

- Information fed into a control programme

- Depending on the requirements, the computer can control the building components
    - Open and close the windows, curtains etc.
    - Start and stop A/C

Intelligent Building - Features

- Security system – Closed circuit cameras and motion sensors
- Prevent unauthorised entry to the home
- Surveillance cameras that can be controlled remotely
- Alarm systems/ computer can call the police station automatically

Intelligent Building - Features

- Life safety systems – Motion sensors, glass break sensors, electronic shutter control, fire sensors, Carbon monoxide sensors etc. are connected to emergency services

- Automatically call emergency services

- Electrical Power Distribution Systems – Different power sources are coordinated to use optimise power consumption.

- In a sunny day, the computer stops using energy from the grid and switches to solar power

Intelligent Building - Features

- Communication Systems – An important feature of the intelligent building

- Person to person, machine to machine, person to machine communication within the building and outside the building using wired and wireless systems

- Connected to occupant, emergency services police etc.

- Inform stakeholders in case of an emergency

Intelligent Building - Features

- Lighting systems – Sensors that turn on the light only when there is someone in the room

- Monitor day light variations to adjust the lighting levels

- Significant energy savings

- Intelligent buildings can record all the information regarding the various functioning of the building and can use AI etc. for further optimisation

Intelligent Building

- Some disadvantages
  - Expensive
  - Complex building management
  - Computer – Know-how
  - Internet and security

Green Building

- Sustainable development has become the key objective for the present generations

- **Green building** (also known as **green construction** or **sustainable building**) refers to both a structure and the application of processes that are environmentally responsible and resource-efficient throughout a building's life-cycle: from planning to design, construction, operation, maintenance, renovation, and demolition.

- Does not imply a reduction in comfort

- Use less water, energy efficiency, less waste generaton

Green Building

- Construction activities cause significant environmental damages
  - Over mining
  - CO_2 emissions

- However, we cannot completely avoid using these materials.

- Need to use materials produced sustainably

Green Building Rating System

- LEED– Leadership in Energy and Environmental Design (LEED) is a green building certification program used worldwide

- It includes a set of rating systems for the design, construction, operation, and maintenance of green buildings, homes, and neighbourhoods which aims to help building owners and operators be environmentally responsible and use resources efficiently.

Green Buildings

- Site Selection is the first step and arguably the most important part of the green building process.

- The potential environmental effects of the project depends on where you plan to build it.

- LEED awards the location you've chosen based on items ranging from proximity to public Transit to bike storage and showers.

Green Buildings

- Water Usage - LEED awards the reduction of water used in toilets as well as the re-use of grey water

- Energy and Atmosphere - This category has the most points available and focuses on commissioning, energy efficiency, refrigerants and the original source of the energy

- Materials and Resources - MR deals with two items, reducing WASTE which is sent to landfills and Reducing the environmental impact of a building's materials. LEED looks at how Materials are: Selected, Disposed and Reduced. Points are awarded for materials reuse, recycling, renewable materials and maintaining a building already on the proposed site.

Green Buildings

- Indoor Environmental Quality - IEQ is a large section in LEED and addresses the environment inside a building and how it affects the occupants inside. IEQ awards points for lighting, temperature, ventilation, indoor pollution and the amount of daylight

- Innovation in Design - This section of LEED awards points for inventive, sustainable and green building strategies which are beyond the scope of the LEED Rating System and not properly rewarded.

Point Table - LEED

LEED 2009 for New Construction and Major Renovation

Project Checklist

Project Name

Date

Y	N	?	Item	Sustainable Sites	Possible Points: 26
Y			Prereq 1	Construction Activity Pollution Prevention	
			Credit 1	Site Selection	1
			Credit 2	Development Density and Community Connectivity	5
			Credit 3	Brownfield Redevelopment	1
			Credit 4.1	Alternative Transportation—Public Transportation Access	6
			Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
			Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3
			Credit 4.4	Alternative Transportation—Parking Capacity	2
			Credit 5.1	Site Development—Protect or Restore Habitat	1
			Credit 5.2	Site Development—Maximize Open Space	1
			Credit 6.1	Stormwater Design—Quantity Control	1
			Credit 6.2	Stormwater Design—Quality Control	1
			Credit 7.1	Heat Island Effect—Non-roof	1
			Credit 7.2	Heat Island Effect—Roof	1
			Credit 8	Light Pollution Reduction	1

Y	N	?	Item	Water Efficiency	Possible Points: 10
Y			Prereq 1	Water Use Reduction—20% Reduction	
			Credit 1	Water Efficient Landscaping	2 to 4
			Credit 2	Innovative Wastewater Technologies	2
			Credit 3	Water Use Reduction	2 to 4

Y	N	?	Item	Energy and Atmosphere	Possible Points: 35
Y			Prereq 1	Fundamental Commissioning of Building Energy Systems	
Y			Prereq 2	Minimum Energy Performance	
Y			Prereq 3	Fundamental Refrigerant Management	
			Credit 1	Optimize Energy Performance	1 to 19
			Credit 2	On-Site Renewable Energy	1 to 7
			Credit 3	Enhanced Commissioning	2
			Credit 4	Enhanced Refrigerant Management	2
			Credit 5	Measurement and Verification	3
			Credit 6	Green Power	2

Y	N	?	Item	Materials and Resources	Possible Points: 14
Y			Prereq 1	Storage and Collection of Recyclables	
			Credit 1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3
			Credit 1.2	Building Reuse—Maintain 50% of Interior Non-Structural Elements	1
			Credit 2	Construction Waste Management	1 to 2
			Credit 3	Materials Reuse	1 to 2

Y	N	?	Item	Materials and Resources, Continued	
			Credit 4	Recycled Content	1 to 2
			Credit 5	Regional Materials	1 to 2
			Credit 6	Rapidly Renewable Materials	1
			Credit 7	Certified Wood	1

Y	N	?	Item	Indoor Environmental Quality	Possible Points: 15
Y			Prereq 1	Minimum Indoor Air Quality Performance	
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	
			Credit 1	Outdoor Air Delivery Monitoring	1
			Credit 2	Increased Ventilation	1
			Credit 3.1	Construction IAQ Management Plan—During Construction	1
			Credit 3.2	Construction IAQ Management Plan—Before Occupancy	1
			Credit 4.1	Low-Emitting Materials—Adhesives and Sealants	1
			Credit 4.2	Low-Emitting Materials—Paints and Coatings	1
			Credit 4.3	Low-Emitting Materials—Flooring Systems	1
			Credit 4.4	Low-Emitting Materials—Composite Wood and Agrifiber Products	1
			Credit 5	Indoor Chemical and Pollutant Source Control	1
			Credit 6.1	Controllability of Systems—Lighting	1
			Credit 6.2	Controllability of Systems—Thermal Comfort	1
			Credit 7.1	Thermal Comfort—Design	1
			Credit 7.2	Thermal Comfort—Verification	1
			Credit 8.1	Daylight and Views—Daylight	1
			Credit 8.2	Daylight and Views—Views	1

Y	N	?	Item	Innovation and Design Process	Possible Points: 6
			Credit 1.1	Innovation in Design: Specific Title	1
			Credit 1.2	Innovation in Design: Specific Title	1
			Credit 1.3	Innovation in Design: Specific Title	1
			Credit 1.4	Innovation in Design: Specific Title	1
			Credit 1.5	Innovation in Design: Specific Title	1
			Credit 2	LEED Accredited Professional	1

Y	N	?	Item	Regional Priority Credits	Possible Points: 4
			Credit 1.1	Regional Priority: Specific Credit	1
			Credit 1.2	Regional Priority: Specific Credit	1
			Credit 1.3	Regional Priority: Specific Credit	1
			Credit 1.4	Regional Priority: Specific Credit	1

Y	N	?	Total		Possible Points: 110

LEED

- The more points, the higher the reward. With LEED, there are many rewards, ranging from healthier spaces to buildings that save money and resources. The number of points a project earns determines the level of LEED certification it receives. There are four levels of certification:

  - Certified (40–49 points)
  - Silver (50–59 points)
  - Gold (60–79 points)
  - Platinum (80+ points)

- Tax Benefits, credits etc.

GRIHA Rating

- Rating system similar to LEED developed in India by TERI and GoI
- Green Rating for Integrated Habitat Assessment

GRIHA V 2019 Rating Thresholds	GRIHA Rating
25-40	★
41-55	★★
56-70	★★★
71-85	★★★★
86 or more	★★★★★

Thank You!!!!

- Any Doubts???

Elements of Green Building Design

Following are the components of a Green Building to make it sustainable:

1. Materials for Green Building

Materials for a green building are obtained from natural, renewable sources that have been managed and harvested in a sustainable way; or they are obtained locally to reduce the embedded energy costs of transportation; or salvaged from reclaimed materials at nearby sites.

Materials are assessed using green specifications that look at their Life Cycle Analysis (LCA) in terms of their embodied energy, durability, recycled content, waste minimisation, and their ability to be reused or recycled.

Fig: Parasoleil Recycled Content Panels

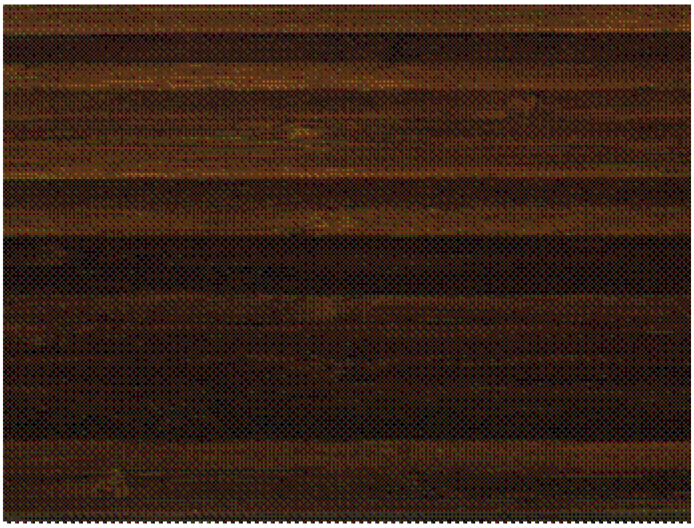
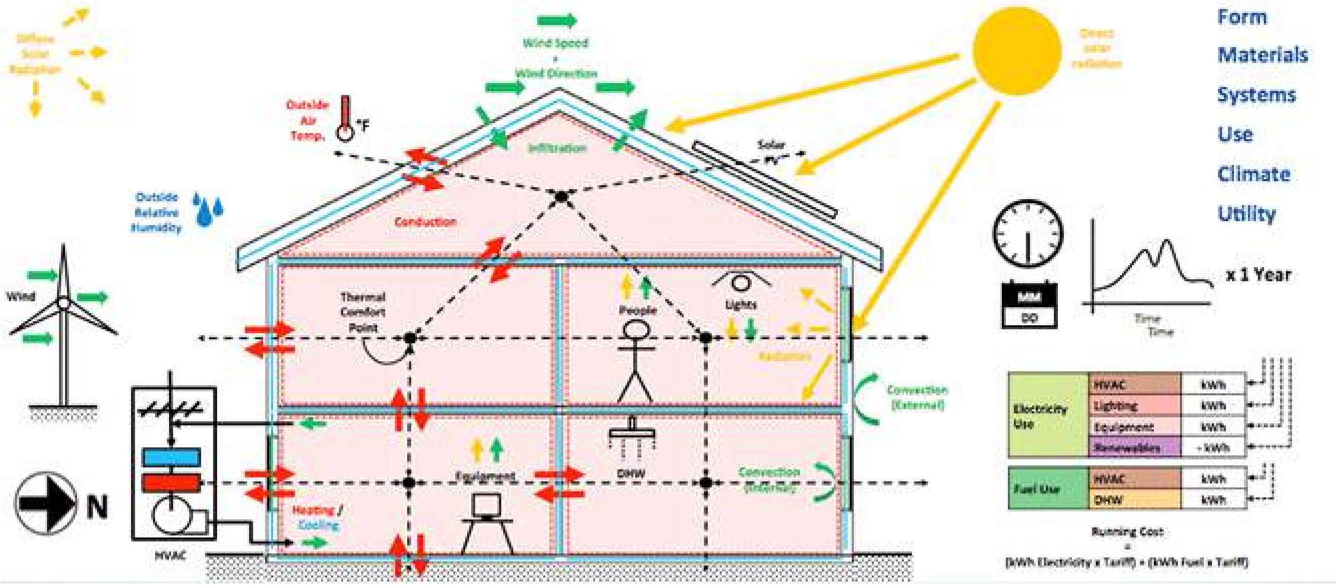


Fig: Chocolate bamboo

2 Energy Systems in Green Buildings

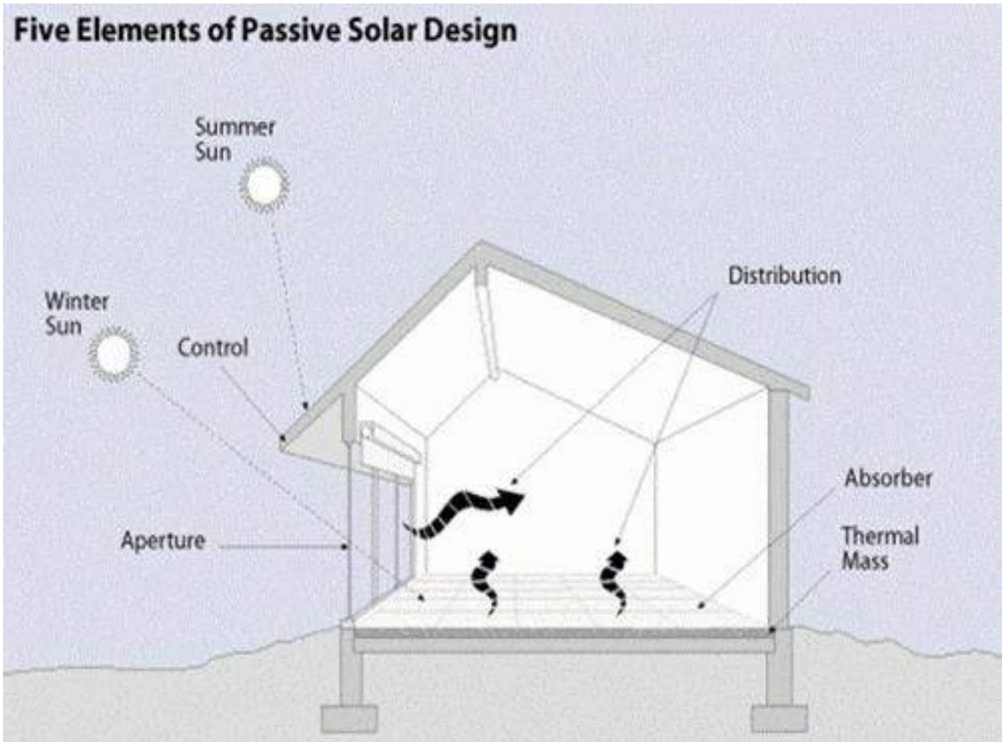
Passive solar design will dramatically reduce the heating and cooling costs of a building, as will high levels of insulation and energy-efficient windows. Natural daylight design reduces a building's electricity needs, and improves people's health and productivity.

Green buildings also incorporate energy-efficient lighting, low energy appliances, and renewable energy technologies such as wind turbines and solar panels.



2.1 Passive Solar Design

Passive solar design uses sunshine to heat, cool and light homes and other buildings without mechanical or electrical devices. It is usually part of the design of the building itself, using certain materials and placement of windows or skylights.



2.1a) Rules Of Passive Solar Systems

- The building should be elongated on an east-west axis.
- The building's south face should receive sunlight between the hours of 9:00 A.M. and 3:00 P.M. (sun time) during the heating season.
- Interior spaces requiring the most light and heating and cooling should be along the south face of the building. Less used spaces should be located on the north.

2.1b) The Advantages Of Passive Solar Design

- **H**igh energy performance: lower energy bills all year round.
- **I**nvestment: independent from future rises in fuel costs, continues to save money long after initial cost recovery.
- **V**alue: high owner satisfaction, high resale value.
- **A**ttractive living environment: large windows and views, sunny interiors, open floor plans.
- **L**ow Maintenance: durable, reduced operation and repair.
- **U**nwavering comfort: quiet (no operating noise), warmer in winter, cooler in summer (even during a power failure).
- **E**nvironmentally friendly : clean, renewable energy doesn't contribute to global warming, acid rain or air pollution.

2.2 Passive Solar Heating

The goal of all passive solar heating systems is to capture the sun's heat within the building's elements and release that heat during periods when the sun is not shining. At the same time that the building's elements (or materials) is absorbing heat for later use, solar heat is available for keeping the space comfortable (not overheated).

2.2a) Two primary elements of passive solar heating are required:

- South facing glass
- Thermal mass to absorb, store, and distribute heat.

2.2b) There are three approaches to passive systems

1. Direct Gain: Sunlight shines into and warms the living space.
2. Indirect Gain: Sunlight warms thermal storage, which then warms the living space.
3. Isolated Gain: Sunlight warms another room (sunroom) and convection brings the warmed air into the living space.

3. Water Management in Green Building

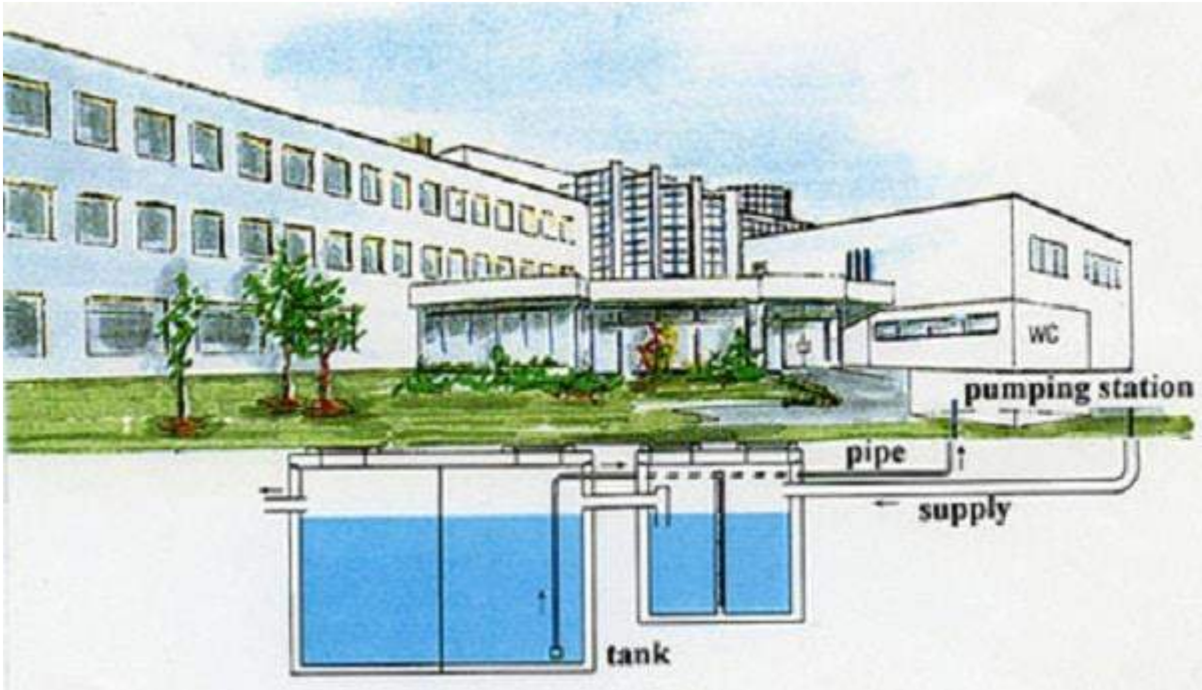
Minimising water use is achieved by installing greywater and rainwater catchment systems that recycle water for irrigation or toilet flushing; water-efficient appliances, such as low flow showerheads, self-closing or spray taps; low-flush toilets, or waterless composting toilets. Installing point of use hot water systems and lagging pipes saves on water heating.

3.1) Rainwater Harvesting in Green Building

Rainwater harvesting is the principle of collecting and using precipitation from a catchments surface.

An old technology is gaining popularity in a new way. Rain water harvesting is enjoying a renaissance of sorts in the world, but it traces its history to biblical times.

Extensive rainwater harvesting apparatus existed 4000 years ago in the Palestine and Greece. In ancient Rome, residences were built with individual cisterns and paved courtyards to capture rain water to augment water from city's aqueducts.



3.2) Rainwater harvesting is essential

Surface water is inadequate to meet our demand and we have to depend on groundwater. Due to rapid urbanization, infiltration of rainwater into the subsoil has decreased drastically and recharging of groundwater has diminished.

As you read this guide, seriously consider conserving water by harvesting and managing this natural resource by artificially recharging the system.

3.3) Rainwater Harvesting Techniques for Green Buildings

There are two main techniques of rainwater harvestings.

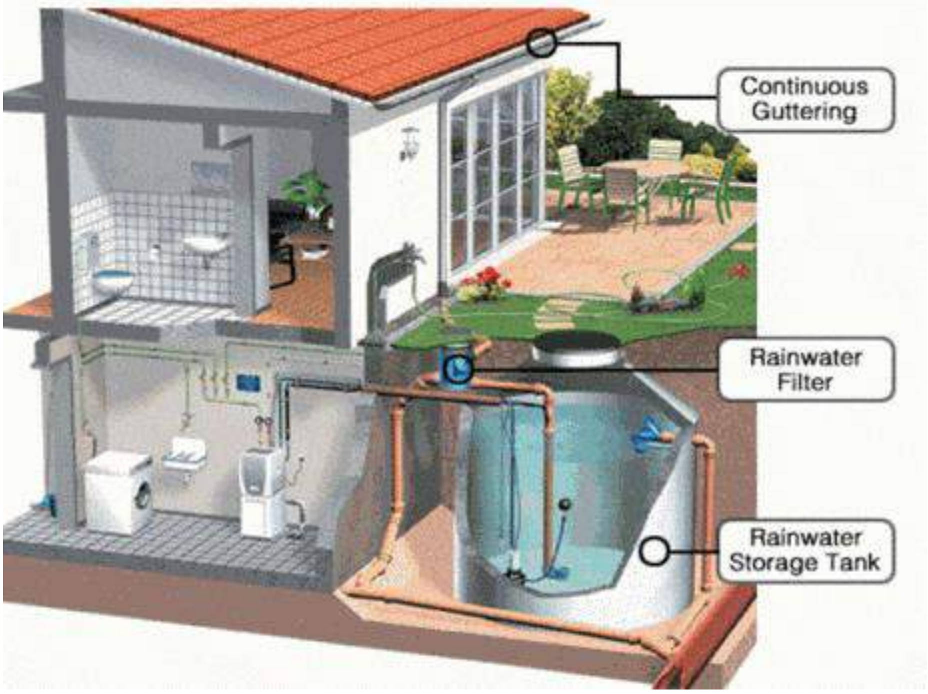
1. Storage of rainwater on surface for future use.
2. Recharge to groundwater

3.3.a) Storage of rainwater on surface for future use.

The storage of rainwater on surface is a traditional techniques and structures used were underground tanks, ponds, check dams, weirs etc.

3.3.b) Recharge to groundwater

Recharge to groundwater is a new concept of rainwater harvesting and the structures generally used are **Pits ,Trenches, Dug wells, Hand pumps, etc.**



4. Health Components of Green Building

Using non-toxic materials and products will improve indoor air quality, and reduce the rate of asthma, allergy and sick building syndrome. These materials are emission-free, have low or no VOC content, and are moisture resistant to deter moulds, spores and other microbes.

Indoor air quality is also addressed through ventilation systems and materials that control humidity and allow a building to breathe.

In addition to addressing the above areas, a green building should provide cost savings to the builder and occupants, and meet the broader needs of the community, by using local labour, providing affordable housing, and ensuring the building is sited appropriately for community needs.

+_D

A TEXTBOOK OF

BASIC MECHANICAL ENGINEERING

[*A BOOK PRESCRIBED BY THE KERALA TECHNOLOGICAL UNIVERSITY*]

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Dedicated to
my Parents

Preface to the Tenth Edition

I am glad to present this book entitled 'Basic Mechanical Engineering' to the first & second semester engineering students of Kerala Technological University. While writing this book, I had in mind the need for finding simple methods and solutions to make the subject more learner friendly. The explanations given in the book are direct, clear, simple and easy to understand. I am quite confident that the teachers and students would be immensely benefited by this book.

While retaining the framework and style of presentation of the previous editions, **this 10th edition has been modified and re-arranged according to the latest syllabus of Kerala Technological University, 2019.** The entire topic is grouped into three modules. All efforts are taken in presenting the subject matter to make the students to feel as if somebody is teaching the subject when they go through this textbook.

It is my fervent aspiration that this book will serve as an added authoritative and priceless tool for the engineering students of Kerala Technological University. The object of this book is to present the subject in the most compact and easy manner. I have gone to great lengths to ensure simplicity to entail an independent grasp of the subject.

Though much care has been taken to check mistakes and misprints, it is difficult to claim perfection. Any errors and omissions brought to my notice will be thankfully acknowledged and will be rectified in the subsequent edition.

I am really indebted to the publisher M/s. Pentex Book Publishers & Distributors for publishing this book and the authorities and staffs of Sunil Offset Press for the care and interest shown in the printing and get up of this book. My special thanks to Mr. Deepak Benjamin for the Graphics and Layout of this book and designing the cover page.

J. BENJAMIN

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Module 1

1.1. Introduction to thermodynamics

An excellent definition of thermodynamics is that it is the science of energy, entropy and equilibrium. Since we have not defined the terms energy, entropy and equilibrium, we can define thermodynamics as the science that deals with heat and work. The study of thermodynamics is of special importance to the engineers since it finds applications in almost all power producing as well as power absorbing devices. For an efficient utilization of energy a deep knowledge of the subject is essential.

Macroscopic and microscopic approach

A thermodynamic analysis can be carried out either by considering the gross behavior of matter or by considering the behavior of individual molecules of the matter. The former is called macroscopic approach and the later is called microscopic approach. Macroscopic approach is concerned with the effect of many molecules together. These effects can be perceived by human senses and can be measured directly. In microscopic approach the matter is considered to be composed of molecules and the analysis is carried out by considering the position, velocity and energy of each molecule at a given instant. ie, in microscopic approach we are concerned with the events happening at the molecular level. The microscopic approach is not essential for solving many of the engineering problems and we can obtain excellent solutions using the simple macroscopic approach.

System

A system is any prescribed and identifiable collection of matter. It can be any object, any quantity of matter, any region of space etc, selected for study. The matter or region outside the system is termed as surroundings. The real or imaginary envelope which encloses a system and separate it from its surroundings is called boundary of the system. A boundary which does not permit matter to pass through it is called impermeable boundary. A boundary which resists any normal or shear forces without changing shape or size is called rigid boundary. A boundary which does not permit matter and energy to pass through it is called isolating boundary. Fig. 1.1 shows the usual representation of system, boundary and surroundings.

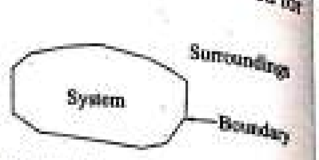

Fig. 1.1. Representation of system, boundary and surroundings

Thermodynamic systems are classified into three groups.

i) Closed system (ii) Open system and (iii) Isolated system

Closed system

If there is no transfer of mass across the boundary of a system and if the boundary permits transfer of energy across it, then such a system is known as closed system. A gas heated in a cylinder fitted with a piston, as shown in Fig. 1.2 is an example of a closed system.

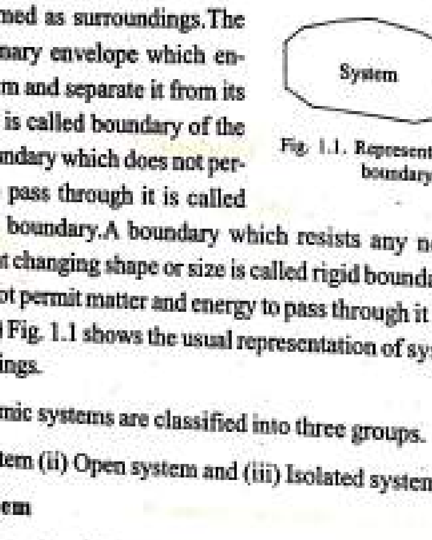

Fig. 1.2 Closed system

In this case energy (heat and work) crosses the boundary of the system but the mass does not cross the boundary. It should be noted that the boundary of a closed system may or may not move and change the position.

Open system

An open system is one with transfer of mass and energy across its boundary. Steam turbines, pumps etc, are examples of open system. In the case of a steam turbine, mass (steam) as well as energy crosses the boundary of the system as shown in Fig 1.3.

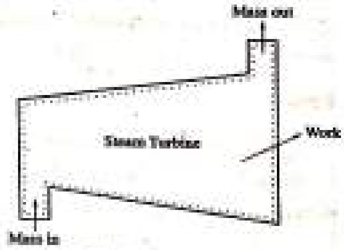

Fig 1.3 Open System

Isolated system

It is a system enclosed by an isolating boundary. It is not influenced by the surroundings. Since the system is bounded by an isolating boundary, there is no flow of mass or energy across the boundary of the system. Though such a system has no practical interest, it is a useful concept in the study of thermodynamics. If the universe itself is taken as a system then it will be an isolated system.

State of a system

The condition of physical existence of a system at any instant is called its state. The state of a system is its condition or configuration described in sufficient details such that one state may be distinguished from all other states. The state of a thermodynamic system is described by specifying its thermodynamic co-ordinates. Pressure, temperature, volume, density etc are typical examples of thermodynamic co-ordinates. Thus the state of a thermodynamic system is its condition or configuration which can be well defined by the above said thermodynamic co-ordinates.

Property of a system

Property can be defined as any quantity that depends on the state of the system and is independent of how the system is arrived at that state. The thermodynamic co - ordinates such as temperature, pressure, volume, density etc, which are used to identify or describe the state of a system are called properties. Since properties are functions of states only, these are called point functions or state functions.

Path

If a thermodynamic system passes through a series of states, it is said to describe a path. If the value of thermodynamic variable depends upon the path followed in going from one state to another, then the variable is a path function.

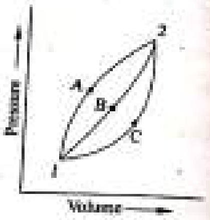

Fig. 1.4.

Consider the change of state of a system from state 1 defined by pressure p_1, volume V_1 and temperature T_1 to state 2 defined by pressure p_2 volume V_2 and temperature T_2. It is possible to go from state 1 to state 2 along different paths such as 1-A-2, 1 - B - 2 or 1 - C - 2 as shown in Fig. 1.4. At state 2 the value of pressure volume and temperature will be the same whether the state 2 is arrived along the path 1 - A - 2, 1 - B - 2 or 1 - C - 2. ie., the value of pressure , volume and temperature at state 2 is independent of the path followed and depends only on the state 2. Hence these quantities are state functions or point functions. A state function or point function is a property of the system. The change in the value of a property during a process depends only on the end states and is independent of the path followed

A variable whose value depends on the path folllowed during a change of state, is a path function. A path function is not a property of the system. Work and heat interactions during a process are examples of path functions.

Process

When a thermodynamic system changes from one state to another it is said to have undergone a process. The state of a system can be represented by a point located on a diagram using two properties as co-ordinates. When a system changes its state in such a way that at any instant during the process the state point can be located on the diagram, the

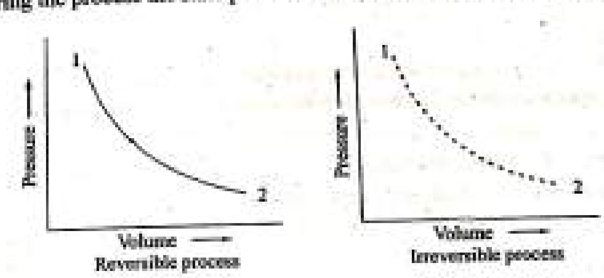

Fig. 1.5. Representation of reversible and irreversible processes.

process is said to be reversible. Thus a reversible process between two states can be shown by a continuous line on any diagram of properties. In a real process the intermediate state points cannot be located on the property diagrams. Such a real process is called irreversible process. An irreversible process is usually represented by a dotted line joining the end states to indicate that the intermediate states are indeterminate. Fig. 1.5 shows the usual representation of reversible and irreversible processes.

When a system undergoes a reversible process both the system and its surroundings can always be restored to their original state by reversing the process.

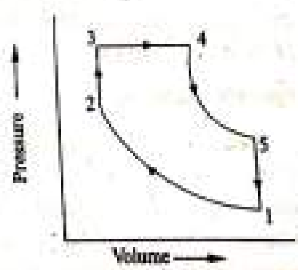

Fig. 1.6

Cycle

When a thermodynamic system changes from one state to another, it is said to have undergone a process. At the end of the last process if the system returns to its original state, it is said to have completed one thermodynamic cycle. When these processes are plotted on a property diagram, they form a closed contour as shown in Fig. 1.6. The net change in any property of the system is zero for a cycle. $\oint dx = 0$ where x is any property and the symbol $\oint$ represents integration around a cycle.

Heat

The energy transfer across the boundary of a system on account of the temperature difference between the system and surroundings is called heat. It is denoted by Q. Heat can be identified only when it crosses the boundary of a system and hence it is a form of energy in transit. A system does not contain heat because upon entering a system, heat is converted into potential or kinetic energy of the molecules. When a system changes its state the amount of heat transferred depends upon the path followed. Hence heat is a path function and therefore it is not a property of the system. The integral of a differential change in heat, dQ can be written as $\int_1^2 dQ = {}_1Q_2$ or Q_{1-2}. It should be noted that $\int_1^2 dQ \neq Q_2 - Q_1$

Q_{1-2} is the amount of heat transferred during a process 1-2.

Heat transferred to a system is considered positive and heat transferred from a system is considered negative. The unit of heat is Joule (J) or kilo Joule (kJ).

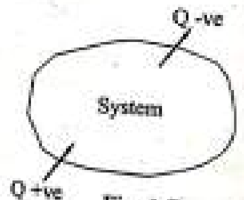

Fig. 1.7

Specific heat.

Specific heat of a substance is defined as the amount of heat required to raise the temperature of unit mass of the substance by unit degree. Since a gas can be heated under constant pressure and under constant volume, it has two specific heats, specific heat at constant pressure and specific heat at constant volume.

Specific heat at constant pressure

Whenever a gas is heated at constant pressure, the temperature and volume of the gas increases. The amount of heat required to raise the temperature of unit mass of a gas through unit degree, when it is heated at constant pressure is the specific heat of that gas at constant pressure and is denoted by C_p.

Let Q be the amount of heat supplied to a gas at constant pressure in J, m, mass of the gas in kg, T_1 and T_2 the initial and final temperature of the gas in K, then,

$$\text{Specific heat, } C_p = \frac{Q}{m\,(T_2 - T_1)} \text{ J/kg.K}$$

Specific heat at constant volume

Whenever a gas is heated at constant volume, the temperature and pressure of the gas increases. The amount of heat required to raise the temperature of unit mass of a gas through unit degree, when it is heated at constant volume is the specific heat of that gas at constant volume and is denoted by C_V.

Let Q be the amount of heat supplied to the gas at constant volume in J, m, mass of a gas in kg, T_1 and T_2, the initial and final temperature of the gas in K, then,

$$\text{Specific heat, } C_V = \frac{Q}{m\,(T_2 - T_1)} \text{ J/kg.K}$$

For air, $C_p = 1.005$ kJ/ kg. K and

$C_v = 0.718$ kJ/kg. K

Work

In mechanics work is defined as the product of force and distance moved in the direction of force. It is denoted by W and the unit of work is N - m. 1 Nm = 1 J. In thermodynamics, the energy transfer across the boundary of a system on account of reasons other than temperature difference is called work. Work is said to be done by a system if the sole effect external to the system can be reduced to the lifting of a weight.

Consider a storage electric battery as a system, which is connected to a resistor by means of a switch as shown in Fig. 1.8. When the switch is closed, current flows through the resistor and the resistor becoms warmer.

Fig. 1.8

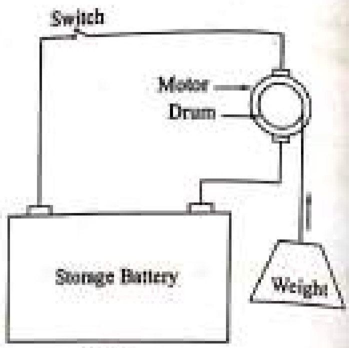

Fig. 1.9

According to the definition of work in mechanics, no work is done. The sole effect external to the system, ie., warming of resistor can be reduced to the lifting of weight, if the resistor is replaced by a motor and a load as shown in Fig. 1.9. When the switch is closed, motor shaft rotates and the load is lifted. Hence when the switch is closed, the system interacts with its surroundings and the sole effect could be reduced to the lifting of a weight. Therefore the system (battery) does work when the switch is closed.

Like heat, work is also energy in transit. A system does not contain work, upon entering the system it is converted into stored energy. Work is a path function and hence it is not a property of the system $\int_1^2 dW \neq W_2 - W_1$. $\int_1^2 dW = {}_1W_2$, ${}_1W_2$ is the amount of work transferred during a process 1 - 2.

Consider the expansion of a gas inside a cylinder fitted with a piston. Refer Fig. 1.10. Let the pressure and volume of the gas at state 1 be p_1 and V_1 respectively. This gas is expanded to state 2. This expansion process is represented in the p - V diagram by the curve 1 -2. Now consider a point A on the curve. Let the pressure of gas at state point A be p. This gas pressure acts on the piston and causes movement of the piston. At this instant the force on the piston is given by $p \times a$, where 'a' is the area of cross section of the piston. Let the piston moves through a small distance dx, the work done is $p \times a \times dx$. But $a \times dx$ is the change in volume of gas when the piston moves through the small distance dx. Hence work done is equal to $p \times dV$, the shaded area in the p - V diagram. Therefore the area under the curve 1 - 2, $\int_1^2 p\, dV$ will give the work done when the gas changes its volume from V_1 to V_2 or when the gas expands from state 1 to state 2. Work done during the process 1 - 2, ${}_1W_2 = \int_1^2 p\,dV$. Work is taken as positive when it is done by the system and negative when it is done on the system. The unit of work is Joule (Nm).

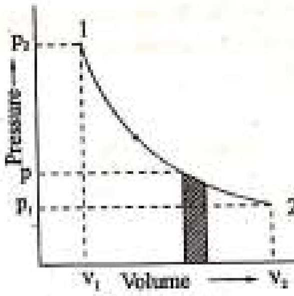

Fig. 1.10

Internal energy

Internal energy of a substance may be defined as the algebric sum of internal kinetic energy and internal potential energy of its molecules and is denoted by U. It is very difficult to determine the absolute value of internal energy possessed by a substance. In most of the thermodynamic applications we are mainly interested only in the changes in the internal energy of a system. The total energy of a system is the sum of potential energy, kinetic energy, internal energy and other energies due to electricity, magnetism etc. In engineering thermodynamics the concern is with the first three types of energies and electrical energy, magnetic energy etc, can be neglected.

$$\therefore E = PE + KE + U$$

Change in energy, $\Delta E = \Delta PE + \Delta KE + \Delta U$

For a stationary closed system undergoing a process 1 - 2,

$$\Delta PE = 0,\ \Delta KE = 0$$

$$\Delta E = \Delta U = {}_1Q_2 - {}_1W_2$$

$${}_1Q_2 = {}_1W_2 + \Delta U$$

When heat is supplied to a closed system, a portion of it is converted into work and the remaining portion is used to increase the internal energy of the system.

Problem 1.1.

5 kg of gas is contained in a cylinder fitted with a piston. 160 kJ of heat is transferred to the gas and simultaneously the piston is forced to compress the gas with an expenditure of work equivalent to 120 kJ. Determine the change in specific internal energy of the gas.

Solution:

Given: $m = 5$ kg, $W = -120$ kJ, $Q = 160$ kJ

To find: $\frac{\Delta U}{m}$

Using the relation,

$$\Delta U = {}_1Q_2 - {}_1W_2$$

$$\Delta U = 160 - (-120) = 280 \text{ kJ}$$

$$\therefore \frac{\Delta U}{m} = \frac{280}{5} = 56 \text{ kJ/kg}$$

Problem 1.2

A tank containing a fluid is stirred by a stirrer. The power input to the stirrer is 3 kW. Heat is transferred from the tank at the rate of 6000 kJ/hour. Considering the tank and the fluid as a system, determine the change in internal energy of the system in one hour.

Given: $W = -3$ kW $= -3$ kJ/s

$= -3 \times 3600$ kJ/hr

$W = -10800$ kJ/hr. $Q = -6000$ kJ/hr

To find: ΔU

We have,

$$\Delta U = Q - W$$

$$\Delta U = -6000 - (-10800) = 4800$$

$$\Delta U = 4800 \text{ kJ}$$

1.2. Thermodynamic processes

When a system changes its state from one equilibrium condition to another it is said to have undergone a process. When a gas undergoes a thermodynamic process, the various properties of the gas such as pressure, volume, temperature, energy, entropy , etc. may change. The thermodynamic process may be performed in different ways. Some of them are:

a. Constant volume (isochoric) process
b. Constant pressure (isobaric) process
c. Constant temperature (isothermal) process
d. Adiabatic process

Using the laws of thermodynamics some useful relations applicable to the above said processes can be developed.

a) Constant volume (isochoric) process

Consider 'm' kg of a gas being heated in a cylinder at constant volun from an initial temperature T_1 to final temperature T_2. This process is represented on a p-V diagram, shown in Fig. 1.11. The path of the process is represented by the vertical line 1-2 in the p-V diagram. Since there is no change in volume, no external work is done by the gas. The entire heat supplied will be stored in the form of internal energy.

(i) p - V - T relationship

For a perfect gas,

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

Since $V_1 = V_2$

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

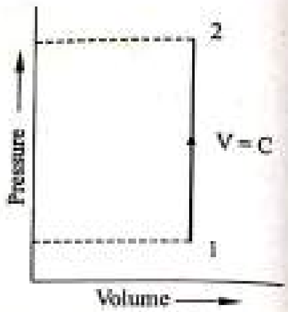

Fig. 1.11

(ii) Work done

$${}_1W_2 = \int p\,dV$$

Since V is constant, dV = 0

$$\therefore {}_1W_2 = 0$$

(iii) Change in internal energy

Since there is a temperature rise from T_1 to T_2

$$\Delta U = mC_V (T_2 - T_1)$$

(iv) Heat supplied

From first law of thermodynamics,

$${}_1Q_2 = \Delta U + {}_1W_2$$

But ${}_1W_2 = 0$

$$\therefore {}_1Q_2 = \Delta U$$

ie., ${}_1Q_2 = m\,C_V (T_2 - T_1)$

(b) Constant pressure (isobaric) process

Consider 'm' kg of gas being heated at constant pressure from state 1 to 2. The heating of the gas under constant pressure causes an increase in the volume and temperature. There will be some external work done due to the increase in the volume. This process, represented on a p-V diagram is as shown in Fig. 1.12. The horizontal line 1-2 in Fig. 1.12 represents the process in pV diagram. A part of heat supplied during the process is utilised to increase the internal energy and the remaining part is utilised to do external work.

(i) p - V - T relationship

For a perfect gas,

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

Since $p_1 = p_2$, $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

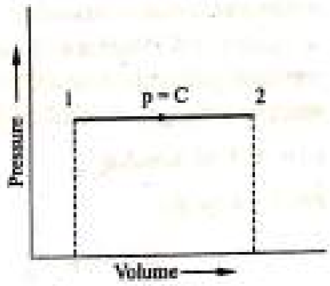

Fig. 1.12

(ii) Work done

$${}_1W_2 = \int_1^2 p\,dV$$

$$= p\{V\}_{V_1}^{V_2}$$

$${}_1W_2 = p\,(V_2 - V_1)$$

(iii) Change in internal energy

Since there is a temperature rise from T_1 to T_2

$$\Delta U = m\,C_V (T_2 - T_1)$$

(iv) Heat supplied

From first law of thermodynamics,

$${}_1Q_2 = \Delta U + {}_1W_2$$

$$= m\,C_v\,(T_2 - T_1) + p\,(V_2 - V_1)$$

For a constant pressure process, $p_1 = p_2$

$${}_1Q_2 = m\,C_v\,(T_2 - T_1) + (p_2 V_2 - p_1 V_1)$$

For a perfect gas $\qquad pV = mRT$

$$\therefore {}_1Q_2 = m\,C_v\,(T_2 - T_1) + (mRT_2 - mRT_1)$$

$$= m\,C_v\,(T_2 - T_1) + mR\,(T_2 - T_1)$$

$$= m\,(T_2 - T_1)\,(C_v + R)$$

But, $C_v + R = C_p$

$$\therefore {}_1Q_2 = mC_p(T_2 - T_1)$$

(c) Constant temperature (isothermal) process

A process in which a gas receives or rejects heat in such a way that its temperature remains constant is called isothermal process. It can be represented on p-V diagram as shown in Fig 1.13. The line 1-2 in the figures represent isothermal heat addition process. In this case, the entire heat supplied to the gas is used up in doing external external work.

(i) p - V-T relationship

For a perfect gas,

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

Since $T_1 = T_2$

$$p_1 V_1 = p_2 V_2$$

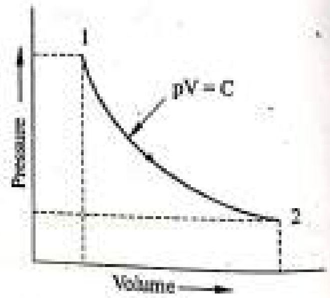

Fig. 1.13

(ii) Work done

$${}_1W_2 = \int_{V_1}^{V_2} p\,dV \text{..............(i)}$$

For an isothermal process, $\quad pV = p_1 V_1 = p_2 V_2 = \text{Constant}$

$$\text{or} \quad p = \frac{p_1 V_1}{V}$$

Substituting this value of 'p' in eq. (i)

$${}_1W_2 = \int_{V_1}^{V_2} \frac{p_1 V_1}{V}\,dV$$

$$= p_1 V_1 \int_{V_1}^{V_2} \frac{dV}{V}$$

$$= p_1 V_1 \left[\ln V\right]_{V_1}^{V_2}$$

$$= p_1 V_1 (\ln V_2 - \ln V_1)$$

$${}_1W_2 = p_1 V_1 \ln\left\{\frac{V_2}{V_1}\right\}$$

Also for an isothermal process

$$p_1 V_1 = p_2 V_2$$

$$\therefore \frac{V_2}{V_1} = \frac{p_1}{p_2}$$

Substituting this,

$${}_1W_2 = p_1 V_1 \ln\left\{\frac{p_1}{p_2}\right\}$$

(iii) Change in internal energy

Since $T_1 = T_2$

$$\Delta U = 0$$

(iv) Heat supplied

From the first law,

$${}_1Q_2 = \Delta U + {}_1W_2$$

Since $\Delta U = 0$

$${}_1Q_2 = {}_1W_2$$

$$= p_1V_1 \ln\left\{\frac{V_2}{V_1}\right\}$$

$${}_1Q_2 = p_1V_1 \ln\left\{\frac{V_2}{V_1}\right\}$$

(d) Adiabatic process

In an adiabatic process, the gas neither receives nor rejects heat. In this process, the heat exchange, Q = 0. Work is done by the gas at the expense of internal energy.

From the first law,

$${}_1Q_2 = \Delta U + {}_1W_2$$

But for an adiabatic process, ${}_1Q_2 = 0$

$$0 = \Delta U + {}_1W_2$$

$$\text{or } {}_1W_2 = -\Delta U \quad \text{.............(i)}$$

Work done, $${}_1W_2 = \int_{V_1}^{V_2} p\, dV$$

Change in internal energy, $\Delta U = m C_V (T_2 - T_1)$

Substituting in eqn (i)

$$\int_{V_1}^{V_2} p dV = -mC_V(T_2 - T_1)$$

Writing in differential form

$$p\, dV = -m\, C_v\, dT \quad \text{..................(ii)}$$

Consider the general gas equation,

$$pV = mRT$$

Differentiating,

$$p\, dV + V\, dp = m\, RdT$$

$$\text{ie., } m\, dT = \frac{pdV + Vdp}{R}$$

Substituting this in eqn (ii)

$$p\, dV = -C_V\left\{\frac{pdV + Vdp}{R}\right\}$$

$$\text{ie., } R\, p\, dV = -C_v\,(pdV + Vdp)$$

$$\text{But } R = C_p - C_v$$

$$\therefore (C_P - C_V)\, p\, dV = -C_V\, pdV - C_V\, Vdp$$

$$C_p\, pdV = -C_v\, Vdp$$

Rearranging,

$$\frac{C_P}{C_V}\frac{dV}{V} = -\frac{dp}{p}$$

$$\text{or. } \gamma\frac{dV}{V} + \frac{dp}{p} = 0$$

Integrating

$$\gamma \ \ln V + \ln p = C_1$$

$$\ln (PV^{\gamma}) = C_1$$

where C_1 is the constant of integration.

$$\text{or } pV^{\gamma} = C \text{ where C is another constant}$$

Therefore, for an adiabatic process 1 - 2,

$$p_1V_1^{\gamma} = p_2V_2^{\gamma} = \text{constant}$$

An adiabatic process can be represented an a p-V diagram as shown in Fig. 1.14. The path of the process is represented by curve 1- 2 in the p-V diagram .

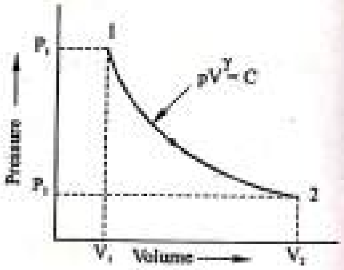

Fig. 1.14

(i) p-V - T relationship

Relation between p and V

For an adiabatic process,

$$p_1V_1^{\gamma} = p_2V_2^{\gamma}$$

$$\therefore \frac{p_1}{p_2} = \left\{\frac{V_2}{V_1}\right\}^{\gamma}$$

Relation between p and T

$$p_1V_1^{\gamma} = p_2V_2^{\gamma}$$

$$\frac{V_2}{V_1} = \left\{\frac{p_1}{p_2}\right\}^{\frac{1}{\gamma}} \text{.........(i)}$$

From the general gas equation

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$\text{or } \frac{V_2}{V_1} = \frac{T_2}{T_1} \times \frac{p_1}{p_2} \text{.........(ii)}$$

From (i) and (ii)

$$\left\{\frac{p_1}{p_2}\right\}^{\frac{1}{\gamma}} = \left\{\frac{T_2}{T_1}\right\}\left\{\frac{p_1}{p_2}\right\}$$

$$\text{or } \frac{T_2}{T_1} = \left\{\frac{p_1}{p_2}\right\}^{\frac{1}{\gamma}-1}$$

$$= \left\{\frac{p_1}{p_2}\right\}^{\frac{1-\gamma}{\gamma}}$$

$$\text{or } \frac{p_1}{p_2} = \left\{\frac{T_2}{T_1}\right\}^{\frac{\gamma}{1-\gamma}} = \left\{\frac{T_1}{T_2}\right\}^{\frac{\gamma}{\gamma-1}}$$

$$= \left\{\frac{T_1}{T_2}\right\}^{\frac{\gamma}{\gamma-1}}$$

Relation between V and T

We have,

$$\frac{p_1}{p_2} = \left\{\frac{V_2}{V_1}\right\}^{\gamma}$$

$$\text{Also } \frac{p_1}{p_2} = \left\{\frac{T_1}{T_2}\right\}^{\frac{\gamma}{\gamma-1}}$$

$$\therefore \left\{\frac{V_2}{V_1}\right\}^{\gamma} = \left\{\frac{T_1}{T_2}\right\}^{\frac{\gamma}{\gamma-1}}$$

$$\frac{V_2}{V_1} = \left\{\frac{T_1}{T_2}\right\}^{\frac{1}{\gamma-1}}$$

Thus, the p - V - T relations for an adiabatic process are:

1. $\frac{p_1}{p_2} = \left\{\frac{V_2}{V_1}\right\}^{\gamma}$

2. $\frac{p_1}{p_2} = \left\{\frac{T_1}{T_2}\right\}^{\frac{\gamma}{\gamma-1}}$

3. $\frac{V_2}{V_1} = \left\{\frac{T_1}{T_2}\right\}^{\frac{1}{\gamma-1}}$

(ii) Work done, $\quad {}_1W_2 = \int_{V_1}^{V_2} p\,dV$

For an adiabatic process,

$$p_1 V_1^{\gamma} = p_2 V_2^{\gamma} = pV^{\gamma} = C$$

$$p = \frac{C}{V^{\gamma}}$$

$$\therefore {}_1W_2 = \int_{V_1}^{V_2} C\frac{dV}{V^{\gamma}}$$

$$= C\int_{V_1}^{V_2} V^{-\gamma}\,dV$$

$$= C\left\{\frac{V^{(-\gamma+1)}}{(-\gamma+1)}\right\}_{V_1}^{V_2}$$

$$= \frac{C}{1-\gamma}\left\{V_2^{(-\gamma+1)} - V_1^{(-\gamma+1)}\right\}$$

$$= \frac{1}{1-\gamma}\left\{p_2V_2^{\gamma}V_2^{(-\gamma+1)} - p_1V_1^{\gamma}V_1^{(-\gamma+1)}\right\}$$

$$= \frac{1}{1-\gamma}\left\{p_2V_2^{(-\gamma+1+\gamma)} - p_1V_1^{(-\gamma+1+\gamma)}\right\}$$

$$= \frac{1}{1-\gamma}(p_2V_2 - p_1V_1)$$

$$= \frac{p_2V_2 - p_1V_1}{1-\gamma}$$

$${}_1W_2 = \frac{p_1V_1 - p_2V_2}{\gamma - 1}$$

Also, for perfect gas

$$pV = mRT$$

or $p_1V_1 = mRT_1$

and $p_2V_2 = mRT_2$

Substituting in the equation for ${}_1W_2$,

$${}_1W_2 = mR\frac{(T_1 - T_2)}{(\gamma - 1)}$$

(iii) Change in internal energy

$$\Delta U = m C_V (T_2 - T_1)$$

Also for adiabatic process, the heat exchanged ${}_1Q_2 = 0$ ie., work is done at the expense of internal energy.

$$\therefore \Delta U = -{}_1W_2 = -\frac{mR(T_1 - T_2)}{(\gamma - 1)}$$

$$\Delta U = \frac{mR(T_2 - T_1)}{(\gamma - 1)}$$

(iv) Heat exchanged

For an adiabatic process, heat exchanged is zero

ie., ${}_1Q_2 = 0$

Process	p,V,T relationship	${}_1W_2$	${}_1Q_2$
Const. Volume V = C	$\frac{p_1}{T_1} = \frac{p_2}{T_2}$	0	$mC_V(T_2 - T_1)$
Const. Pressure	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$	$p(V_2 - V_1)$	$mC_p(T_2 - T_1)$
Const. Temp T = C	$p_1V_1 = p_2V_2$	$p_1V_1 \ln\frac{V_2}{V_1}$	$p_1V_1 \ln\frac{V_2}{V_1}$
Adiabatic $pV^\gamma = C$	$p_1V_1^\gamma = p_2V_2^\gamma$	$\frac{p_1V_1 - p_2V_2}{\gamma - 1}$	0

1.3 Air cycles.

When any property of a system changes, there is a change of state and the system is said to have undergone a process. At the end of the last process if the system returns to its original state, it is said to have completed one cycle. When these processes are plotted on a p-V diagram they form a closed contour as shown in Fig. 1.15.

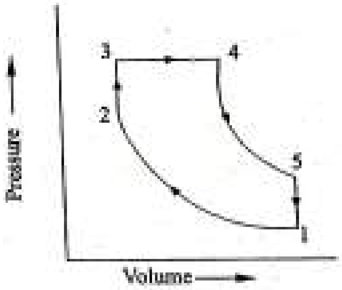

Fig. 1.15

Many of the power producing device use gas as the working fluid. The working fluid in an internal combustion engine does not operate on a cycle. For the sake of simplification, the analysis of internal combustion engine is carried out in terms of an air standard cycle. An air standard cycle is an idealized cycle in which air is taken as the working fluid. The actual combustion process is replaced by a heat transfer process. The exhaust process is replaced by a heat rejection process. All the processes are assumed to be reversible.

A part of heat transferred to the air is converted into useful work and the remainder is rejected . Therefore the work done by the air is equal to the difference between the heat supplied and heat rejected, if there is no mechanical loss, then,

Work done during a cycle = Heat supplied - Heat rejected.

Thermal efficiency of a cycle may be defined as the ratio of the work done to the heat supplied during the cycle. The thermal efficiency obtained with air as the working fluid is known as air standard efficiency.

$$\text{Air standard efficiency} = \frac{\text{Work done}}{\text{Heat supplied}}$$

$$= \frac{\text{Heat supplied - Heat rejected}}{\text{Heat supplied}}$$

$$= 1 - \frac{\text{Heat rejected}}{\text{Heat supplied}}$$

1.4. Carnot cycle

It is a thermodynamic air cycle consisting of four processes. Heat is supplied and rejected isothermally, expansion and compression of air takes place adiabatically. Refer Fig. 1.16. Consider a given mass of air in the cylinder, inside which a frictionless piston slides. Let the pressure, volume and temperature of air at state 1 be p_1, V_1 and T_1 respectively. Heat is supplied to this air isothermally from an external hot body. The air expands at constant temperature T_1 till the state 2 is reached. This process is represented by curve 1-2 in the p-V diagram. During this process heat is absorbed from the hot body and an equal amount of work is done by the

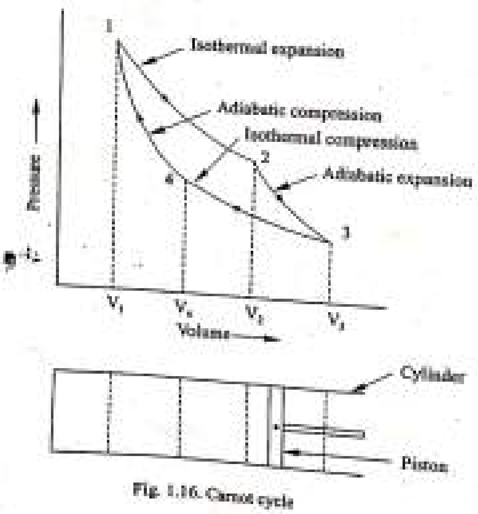

Fig. 1.16. Carnot cycle

air. At state 2, the source of heat is removed and the air is allowed to expand adiabatically till state 3. This is represented by curve 2-3 in the p-V diagram . Let the pressure, volume and temperature of the air at state 3 be p_3, V_3 and T_3 respectively. During the process 2-3 work is done by the air utilising its internal energy. At state 3, an external cold body is brought in contact with the cylinder and heat is rejected isothermally to the cold body at constant temperature T_3. This isothermal compression is represented by the curve 3-4 in the p-V diagram. During this process work is done on the air and an equal amount of heat is rejected to the cold body. At state 4, the cold body is removed and the air is compressed adiabatically to the initial state. In the p-V diagram this adiabatic compression process is representedd by curve 4-1. During this process work is done on the air to bring it to the original state.

For the adiabatic expansion process 2-3,

$$\frac{V_3}{V_2} = \left\{\frac{T_2}{T_3}\right\}^{\frac{1}{\gamma-1}} \quad \text{.......................(i)}$$

For the adiabatic compression process 4-1,

$$\frac{V_4}{V_1} = \left\{\frac{T_1}{T_4}\right\}^{\frac{1}{\gamma-1}}$$

Since $T_1 = T_2$ and $T_4 = T_3$

$$\frac{V_4}{V_1} = \left\{\frac{T_2}{T_3}\right\}^{\frac{1}{\gamma-1}} \quad \text{.......................(ii)}$$

From (i) and (ii) $\quad \frac{V_3}{V_2} = \frac{V_4}{V_1}$

ie., adiabatic expansion ratio = adiabatic compression ratio and

$$\frac{V_2}{V_1} = \frac{V_3}{V_4}$$

$$= \frac{\text{Heat supplied} - \text{Heat rejected}}{\text{Heat supplied}}$$

$$= 1 - \frac{\text{Heat rejected}}{\text{Heat supplied}}$$

1.4. Carnot cycle

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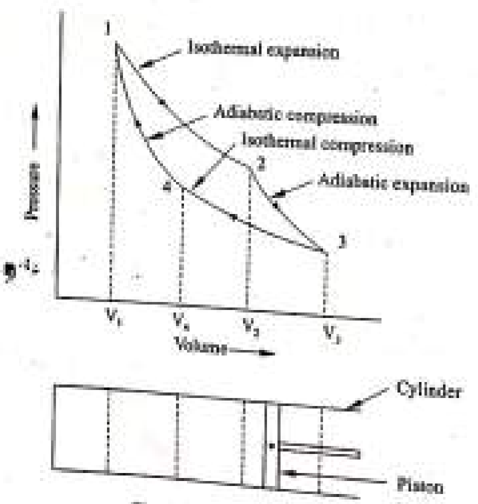

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$$\frac{V_3}{V_2} = \left\{\frac{T_2}{T_3}\right\}^{\frac{1}{\gamma-1}} \quad \text{.......................(i)}$$

For the adiabatic compression process 4-1,

$$\frac{V_4}{V_1} = \left\{\frac{T_1}{T_4}\right\}^{\frac{1}{\gamma-1}}$$

Since $T_1 = T_2$ and $T_4 = T_3$

$$\frac{V_4}{V_1} = \left\{\frac{T_2}{T_3}\right\}^{\frac{1}{\gamma-1}} \quad \text{.......................(ii)}$$

From (i) and (ii) $\qquad \dfrac{V_3}{V_2} = \dfrac{V_4}{V_1}$

ie., adiabatic expansion ratio = adiabatic compression ratio and

$$\frac{V_2}{V_1} = \frac{V_3}{V_4}$$

i.e., isothermal expansion ratio = isothermal compression ratio.

During the entire cycle heat is supplied during 1-2 and rejected during 3-4

$$\text{Heat supplied} = p_1 V_1 \ln\left\{\frac{V_2}{V_1}\right\}$$

$$= mRT_1 \ln\left\{\frac{V_2}{V_1}\right\}$$

$$\text{Heat rejected} = p_3 V_3 \ln\left\{\frac{V_3}{V_4}\right\}$$

$$= mRT_3 \ln\left\{\frac{V_3}{V_4}\right\}$$

Air standard efficiency, $$\eta = \frac{\text{Heat supplied} - \text{Heat rejected}}{\text{Heat supplied}}$$

$$= \frac{mRT_1 \ln\left\{\frac{V_2}{V_1}\right\} - mRT_3 \ln\left\{\frac{V_3}{V_4}\right\}}{mRT_1 \ln\left\{\frac{V_2}{V_1}\right\}}$$

$$\eta = \frac{mRT_1 \ln\left\{\frac{V_2}{V_1}\right\} - mRT_3 \ln\left\{\frac{V_2}{V_1}\right\}}{mRT_1 \ln\left\{\frac{V_2}{V_1}\right\}}$$

$$= \frac{mR \ln\left\{\frac{V_2}{V_1}\right\}(T_1 - T_3)}{mR \ln\left\{\frac{V_2}{V_1}\right\} \times T_1}$$

$$= \frac{(T_1 - T_3)}{T_1}$$

$$\text{or } \eta = 1 - \frac{T_3}{T_1} = 1 - \frac{\text{Temperature of cold body}}{\text{Temperature of hot body}}$$

Generally the temperature of hot body is taken as T_1 and that of cold body is taken as T_2

$$\text{Then, } \eta = 1 - \frac{T_2}{T_1}$$

Although Carnot cycle gives maximum possible efficiency, yet no engine can be made to work on this cycle due to the following reasons.

The expansion and compression processes are adiabatic and hence the two operations should be carried out as quickly as possible sothat there is hardly any time for the heat exchange to take place. On the otherhand, heat supply and heat rejection takes place isothermally which means the operations must be slow to maintain the constant temperature. It is obvious that such sudden changes in the speed of an engine in one cycle is not possible in actual practice.

Problem : 1.3

During a Carnot cycle the working fluid receives heat at a temperature of 317°C and rejects heat at a temperature of 22°C. Find the theoritical efficiency of the cycle.

Solution:

Given: $T_1 = 317^0C = 590\text{ K}$, $T_2 = 22^0C = 295\text{ K}$

To find: η

$$\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{295}{590}$$

$$= 0.5$$

$$\eta = 50\%$$

Problem : 1.4.

A Carnot cycle works with adiabatic compression ratio of 5 and isothermal expansion ratio of 2. The volume of air at the begining of the isothermal expansion is 0.3 m³. If the maximum temperature and pressure is limited to 550 K and 21 bar, determine (i) minimum temperature in the cycle (ii) thermal efficiency of the cycle (iii) pressure at all salient points and (iv) work done per cycle. Take $\gamma = 1.4$

Solution:

Given: $\frac{V_4}{V_1} = 5 \quad \frac{V_2}{V_1} = 2$

$V_1 = 0.3 m^3 \quad T_1 = T_2 = 550$ K

$\gamma = 1.4 \quad p_1 = 21$ bar $= 21 \times 10^5$ N/m²

To find:

$T_4, \eta, p_2, p_3, p_4, W$

For the adiabatic process 4-1,

$$\frac{T_4}{T_1} = \left\{\frac{V_1}{V_4}\right\}^{\gamma-1}$$

$$T_4 = T_1 \left\{\frac{V_1}{V_4}\right\}^{\gamma-1}$$

$$= 550 \left\{\frac{1}{5}\right\}^{1.4-1}$$

$$= 288.92 \text{ K}$$

$$T_3 = T_4 = 288.92 \text{ K}$$

For Carnot cycle,

$$\eta = 1 - \frac{T_3}{T_1}$$

$$= 1 - \frac{288.92}{550} = 0.4747$$

$$= 47.47\%$$

For the isothermal process 1-2,

$$p_1 V_1 = p_2 V_2$$

$$p_2 = \frac{p_1 V_1}{V_2}$$

Since, $\frac{V_2}{V_1} = 2$

$$V_2 = 2 V_1 = 2 \times 0.3 = 0.6 \text{ m}^3$$

$$p_2 = \frac{21 \times 10^5 \times 0.3}{0.6}$$

$$= 10.5 \times 10^5 \text{ N/m}^2$$

$$p_2 = 10.5 \text{ bar}$$

For the adiabatic process 2-3,

$$\frac{p_3}{p_2} = \left\{\frac{T_3}{T_2}\right\}^{\frac{\gamma}{\gamma-1}}$$

$$p_3 = 10.5 \times 10^5 \times \left\{\frac{288.92}{550}\right\}^{\frac{1.4}{1.4-1}}$$

$$p_3 = 1.10 \text{ bar}$$

For the adiabatic process 4 – 1,

$$\frac{p_4}{p_1} = \left\{\frac{T_4}{T_1}\right\}^{\frac{\gamma}{\gamma-1}}$$

$$p_4 = 21\times10^5 \times \left\{\frac{288.92}{550}\right\}^{\frac{1.4}{1.4-1}}$$

$$p_4 = 2.2 \text{ bar}$$

Heat supplied during the isothermal process 1-2,

$$_1Q_2 = p_1V_1 \ln\frac{V_2}{V_1}$$

$$= 21 \times 10^5 \times 0.3 \times \ln 2 = 4.37 \times 10^5 \text{ J}$$

Heat supplied = 437 kJ

Heat rejected during the isothermal process 3-4,

$$_3Q_4 = p_3V_3 \ln\frac{V_4}{V_3}$$

$$= p_4V_4 \ln\frac{V_4}{V_3}$$

Since isothermal expansion ratio = isothermal compression ratio,

$$\frac{V_2}{V_1} = \frac{V_3}{V_4}$$

$$\frac{V_4}{V_3} = \frac{V_1}{V_2} = \frac{1}{2}$$

$$\therefore\ _3Q_4 = 2.2\times10^5 \times (5\times0.3)\ln\left\{\frac{1}{2}\right\}$$

$$= -228.74 \text{ kJ}$$

Heat rejected = 228.74 kJ

Work done = Heat supplied - Heat rejected

= 437 - 228.74

Work done = 208.26 kJ

1.5. Otto cycle

Otto cycle is the theoretical cycle of spark ignition engine. Air standard Otto cycle consists of four reversible process. Heat is supplied and rejected at constant volume. Expansion and compression of air takes place adiabatically. Fig. 1.17 shows these processes on p-V diagram

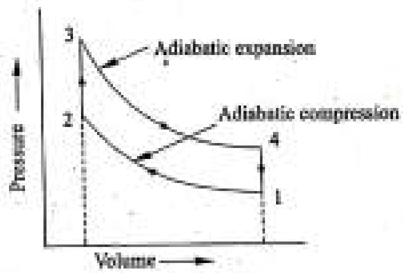


Fig. 1.17. Otto cycle

Consider a cylinder containing 'm' kg of air. Let p_1, V_1 and T_1 be the pressure, volume and temperature of air inside the cylinder, at state 1. This air is compressed adiabatically to state 2, doing work on the air. Curve 1-2 in the p-V diagram represents this process. Now heat is supplied to this compressed air at constant volume from an external hot body till state 3 is reached.

This process is represented by a vertical line 2-3 in the p-V diagram. At state 3 the hot body is removed and the air is allowed to expand adiabatically to state 4, doing external work. This process is represented by curve 3-4 in the p-V diagram. Heat is rejected at constant volume to an external cold body till state 1 is reached . This process is represented by vertical line 4-1 in the p-V diagram. Thus the air finally returns to its original state after completing a cycle.

Heat supplied during constant volume process, 2 - 3 = $m\,C_V(T_3 - T_2)$

Heat rejected during constant volume process, 4 - 1 = $m\,C_V(T_4 - T_1)$

Air standard efficiency,

$$\eta = 1 - \frac{\text{Heat rejected}}{\text{Heat supplied}}$$

$$= 1 - \frac{mC_V(T_4 - T_1)}{mC_V(T_3 - T_2)}$$

$$= 1 - \left\{\frac{T_4 - T_1}{T_3 - T_2}\right\} \text{.................(i)}$$

For the adiabatic process 1-2,

$$\frac{T_2}{T_1} = \left\{\frac{V_1}{V_2}\right\}^{\gamma-1}$$

$= r^{\gamma-1}$, where r is the compression ratio, $\frac{V_1}{V_2}$

$$\therefore T_2 = T_1 \times r^{\gamma-1} \text{.................(ii)}$$

For the adiabatic process 3- 4,

$$\frac{T_3}{T_4} = \left\{\frac{V_4}{V_3}\right\}^{\gamma-1} = \left\{\frac{V_1}{V_2}\right\}^{\gamma-1} = r^{\gamma-1}$$

$$\therefore T_3 = T_4 \times r^{\gamma-1} \text{.............(iii)}$$

Substituting equations (ii) and (iii) in the expression for efficiency, equation (i),

$$\eta = 1 - \frac{(T_4 - T_1)}{T_4 r^{\gamma-1} - T_1 r^{\gamma-1}} = 1 - \frac{(T_4 - T_1)}{(T_4 - T_1) r^{\gamma-1}}$$

$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$

The above expression shows that the efficiency of Otto cycle increases with increases of the compression ratio.

Problem : 1.5.

The efficiency of an Otto cycle is 45% and $\gamma = 1.5$. Find its compression ratio.

Solution:

Given: $\eta = 45\%$ $\gamma = 1.5$

To find: r

For an Otto cycle,

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}}$$

$$0.45 = 1 - \frac{1}{(r)^{1.5-1}}$$

$$r = 3.31$$

Problem : 1.6.

In an Otto cycle, condition of air is 27°C and 1 bar at the start of compression. If the clearance colume is 20% of the swept volume, estimate: (i) Temperature at the end of compression and (ii) Air standard efficiency of the cycle.

Solution:

Given: $T_1 = 27^\circ C = 300$ K

$p_1 = 1$ bar $= 1 \times 10^5$ N/m²

$V_2 = 0.20\,(V_1 - V_2)$

To find :

T_2, η

$$V_2 = 0.20\,(V_1 - V_2) = 0.2\,V_1 - 0.2\,V_2$$

ie., $1.2\,V_2 = 0.2\,V_1$

$$\frac{V_1}{V_2} = \frac{1.2}{0.2} = 6$$

For the adiabatic compression process 1-2,

$$\frac{T_2}{T_1} = \left\{\frac{V_1}{V_2}\right\}^{\gamma-1}$$

$$\therefore\ T_2 = T_1 \times \left\{\frac{V_1}{V_2}\right\}^{\gamma-1} = 300 \times 6^{1.4-1}$$

$$T_2 = 614.30\ K = 341.30^0C$$

For an Otto cycle,

$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$

$$= 1 - \frac{1}{6^{1.4-1}} = 0.5116$$

$$\eta = 51.16\%$$

Problem : 1.7.

Calculate the ideal air standard thermal efficiency based on the Otto cycle for a petrol engine with a cylinder bore of 50 mm and stroke of 75 mm and a clearance volume of 21.3 cm³.

Given: D = 50 mm = 5 cm $\quad V_2 = 21.3\ cm^3 \quad$ L = 75 mm = 7.5 cm

To find: η

$$V_1 = V_2 + \frac{\pi D^2}{4} \times L$$

$$= 21.3 + \frac{\pi \times 5^2}{4} \times 7.5 = 168.56\,cm^3$$

$$r = \frac{V_1}{V_2} = \frac{168.56}{21.3} = 7.91$$

$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$

$$= 1 - \frac{1}{(7.91)^{1.4-1}} = 0.5628$$

$$\eta = 56.28\%$$

Problem : 1.8.

In an ideal Otto cycle engine the expansion and compression are adiabatic. The pressure and temperature at the beginning of compression are 1 bar and 35°C respectively. The pressure at the end of compression is 8 bar and at the end of combustion is 20 bar. If the volume at the beginning of compression is 0.03 m³, find the efficiency of Otto cycle.

Solution:

Given: $V_1 = 0.03\ m^3 \quad p_2 = 8\ bar = 8 \times 10^5\ N/m^2$

$T_1 = 35^0C = 308\ K \quad p_3 = 20\ bar = 20 \times 10^5\ N/m^2$

$p_1 = 1\ bar = 1 \times 10^5\ N/m^2$

To find: η

For the adiabatic compression process 1-2,

$$\frac{V_1}{V_2} = \left\{\frac{p_2}{p_1}\right\}^{\frac{1}{\gamma}}$$

$$= \left\{\frac{8}{1}\right\}^{\frac{1}{1.4}} = 4.42$$

$$r = 4.42$$

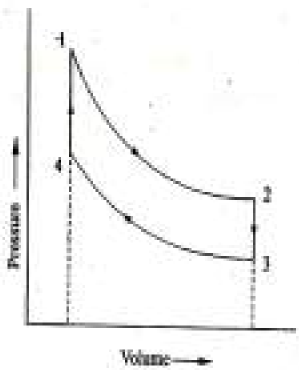
$$\eta = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{(4.42)^{1.4-1}}$$

$$\eta = 44.81\%$$

Problem : 1.9.

Find the efficiency of an Otto cycle engine relative to the Carnot cy using the same maximum pressure 21 bar and temperature 1650°C a the same minimum pressure 1.05 bar and temperature 38°C . Assu working fluid to be air.

Solution:



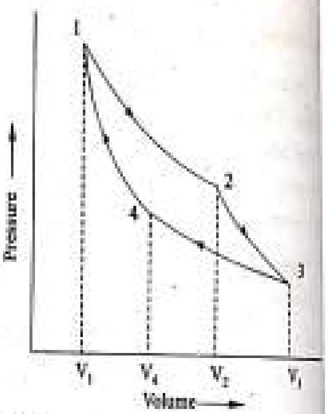


Fig. 1.18.

Given:

$T_1 = 1650°C = 1923$ K

$T_3 = 38°C = 311$ K

$p_1 = 21$ bar $= 21 \times 10^5$ N/m^2

$p_3 = 1.05$ bar $= 1.05 \times 105$ N/m^2

To find: $\dfrac{\eta(\text{Otto})}{\eta(\text{Carnot})}$

For Otto cycle,

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}}$$

$$r = \frac{V_3}{V_4} = \frac{V_3}{V_1}$$

We have,

$$\frac{p_1V_1}{T_1} = \frac{p_3V_3}{T_3}$$

$$\therefore \frac{V_3}{V_1} = \frac{p_1T_3}{p_3T_1} = \frac{21\times10^5\times311}{1.05\times10^5\times1923} = 3.23$$

ie., $r = 3.23$

$$\eta = 1 - \frac{1}{(3.23)^{1.4-1}} = 0.3744$$

$$\eta = 37.44\%$$

$$\eta\ (\text{Carnot}) = 1 - \frac{T_3}{T_1}$$

$$= 1 - \frac{311}{1923} = 0.8383$$

$$\eta = 83.83\%$$

$$\frac{\eta(\text{Otto})\times100}{\eta(\text{Carnot})} = \frac{0.3744\times100}{0.8383}$$

$$= 44.66\%$$

Problem : 1.10.

An engine working on the Otto cycle has an air standard efficiency of 56 %. It rejects heat at the rate of 544 kJ per kg of air. The pressure and temperature of air at the beginning of compression are 0.1 MPa and 60°C respectively. Compute,

(i) The compression ratio of the engine

(ii) The work done per kg of air

(iii) The pressure and temperature at the end of compression and

(iv) The maximum pressure in the cycle.

Assume suitable values for C_p and C_v.

Solution:

Given: $\eta = 56\ \%$ $\quad Qr = 544$ kJ/kg,

$p_1 = 0.1\ \text{MPa} = 0.1 \times 10^6\ \text{N/m}^2$

$T_1 = 60^0C = 60 + 273 = 333\ K$

To find: r, W, p_2, T_2, p_3

$$\eta = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{r^{1.4-1}}$$

$$0.56 = 1 - \frac{1}{r^{0.4}}$$

$$r^{0.4} = 2.27$$

$$r = 7.76$$

$$\eta = 1 - \frac{Qr}{Qs}$$

$$0.56 = 1 - \frac{544}{Q_s}$$

$$Qs = 1236.36\ \text{kJ/kg}$$

Work done $= Qs - Qr$

$= 1236.36 - 544$

$= 692.36$ kJ/kg

For the adiabatic process 1-2,

$$\frac{p_2}{p_1} = \left\{\frac{V_1}{V_2}\right\}^{\gamma} = r^{\gamma} = 7.76^{1.4} = 17.61$$

$$p_2 = 17.61 \times p_1 = 17.61 \times 0.1 \times 10^6 = 17.61 \times 10^5\ \text{N/m}^2$$

$$\frac{T_2}{T_1} = \left\{\frac{V_1}{V_2}\right\}^{\gamma-1} = r^{\gamma-1} = 7.76^{1.4-1} = 2.27$$

$$T_2 = 2.27\ T_1 = 2.27 \times 333 = 755.91\ K$$

$$= 482.91^0C$$

$$Qs = C_v (T_3 - T_2)$$

$$1236.36 = 0.718 (T_3 - 755.91)$$

$$T_3 = 2477.86\ K$$

For the constant volume process 2-3,

$$\frac{p_2}{T_2} = \frac{p_3}{T_3}$$

$$p_3 = p_2 \times \frac{T_3}{T_2} = 17.61 \times 10^5 \times \frac{2477.86}{755.91}$$

$$= 57.73 \times 10^5\ \text{N/m}^2$$

Problem : 1.11.

In an air standard Otto cycle the compression ratio is 7 and compression begins at 35^0C, 0.1 MPa. The maximum temperature of the cycle is 1100^0C. Find,

(i) Heat supplied per kg of air

(ii) Work done per kg of air

(iii) The cycle efficiency and

Take $C_p = 1.005$ kJ/kg K. and $C_V = 0.718$ kJ/kg K.

Solution:

Given: $r = 7,\ T_1 = 35°C = 35 + 273 = 308\ K$

$p_1 = 0.1\ \text{MPa} = 0.1 \times 10^6\ \text{N/m}^2$,

$T_3 = 1100°C = 1100 + 273 = 1373\ K$

To find: $Qs,\ W,\ \eta$

$$Qs = mC_V (T_3 - T_2)$$

For adiabatic process 1-2,

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$T_2 = T_1 \times 7^{1.4-1}$$

$$= 308 \times 7^{1.4-1} = 670.8 \text{ K}$$

$$Qs = 0.718\,(1373 - 670.8)$$

$$= 504.18 \text{ kJ/kg}$$

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = (7)^{1.4-1} = 2.18$$

$$T_4 = \frac{T_3}{2.18} = \frac{1373}{2.18} = 629.82 \text{ K}$$

$$W = Qs - Qr$$

$$Qr = mC_v\,(T_4 - T_1) = 1 \times 0.718\,(629.82 - 308)$$

$$= 231.07 \text{ kJ/kg}$$

$$W = Qs - Qr$$

$$= 504.18 - 231.07$$

$$= 273.11 \text{ kJ/kg}$$

$$\eta = \frac{W}{Qs} = \frac{273.11}{504.18} = 0.5417$$

$$= 54.17\,\%$$

Problem : 1.12.

The peak pressure in an Otto cycle is 210 N/cm², with a compression ratio of 5 and minimum pressure of 10 N/cm², determine the thermal efficiency. Assume the working substance as air with $\gamma = 1.4$.

Solution:

Given:

$P_3 = 210 \text{ N/cm}^2 = 210 \times 10^4 \text{ N/m}^2$

$r = 5,$

$P_1 = 10 \text{ N/cm}^2 = 10 \times 10^4 \text{ N/m}^2$

$\gamma = 1.4$

To find: η

$$\eta = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{5^{1.4-1}}$$

$$= 1 - 0.525 = 0.475$$

$$\eta = 47.5\%$$

1.6. Diesel cycle

Diesel cycle is the cycle on which the diesel engine works. Diesel cycle consists of four reversible processes. Heat is supplied at constant pressure and rejected at constant volume. Expansion and compression of air takes place adiabatically. Fig. 1.19 shows these processes on p-V diagram.

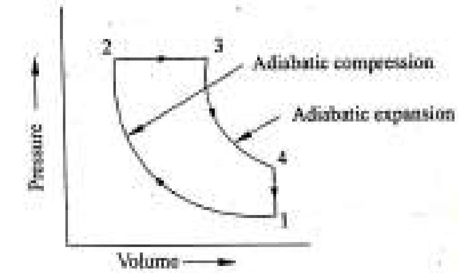


Fig. 1.19. Diesel cycle.

Consider a cylinder containing 'm' kg of air. Let p_1, V_1 and T_1 be the pressure, volume and temperature of air inside the cylinder at state 1. This air is compressed adiabatically to state 2, doing work on the air. Curve 1-2 in the p-V diagram represents this process. Now heat is supplied to the air at constant pressure from an external hot body till state 3 is reached. This process is represented by a horizontal line 2-3 in the p-V diagram. At state 3, the hot body is removed and the air is allowed to expand adiabatically to state 4, doing external work. This process is represented by curve 3-4 in the p-V diagram. Heat is rejected at constant volume to an external cold body till state 1 is reached. This process is represented by a vertical line 4-1 in the p-V diagram. Thus the air finally returns to its original state after completing a cycle.

Heat supplied during constant ~~volume~~ pressure process 2-3 = m C_p (T_3 - T_2).

Heat rejected during constant volume process 4-1 = m C_V (T_4 - T_1).

Air Standard efficiency,

$$\eta = 1 - \frac{\text{Heat rejected}}{\text{Heat supplied}}$$

$$= 1 - \frac{mC_V(T_4 - T_1)}{mC_P(T_3 - T_2)}$$

$$= 1 - \frac{C_V}{C_P}\frac{(T_4 - T_1)}{(T_3 - T_2)}$$

$$= 1 - \frac{1}{\gamma} \times \frac{(T_4 - T_1)}{(T_3 - T_2)} \quad \text{.................(i)}$$

Let $\frac{V_3}{V_2}$ be the cutoff ratio ρ, $\frac{V_4}{V_3}$ be the expansion ratio r_1 and $\frac{V_1}{V_2}$ be the compression ratio r. The relation between these three ratios is obtained as follows.

$$\frac{V_4}{V_3} = \frac{V_4}{V_2} \times \frac{V_2}{V_3}$$

$$= \frac{V_1}{V_2} \times \frac{V_2}{V_3}$$

$$r_1 = r \times \frac{1}{\rho} = \frac{r}{\rho}$$

$$r_1 = \frac{r}{\rho}$$

For the adiabatic process 1-2,

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$T_2 = T_1\left[\frac{V_1}{V_2}\right]^{\gamma-1}$$

$$\boxed{T_2 = T_1 r^{\gamma-1} \quad \text{..............(ii)}}$$

For the constant pressure process 2-3,

$$\frac{T_3}{T_2} = \frac{V_3}{V_2} = \rho$$

$$T_3 = T_2 \times \rho$$

$$\boxed{T_3 = T_1\, r^{\gamma-1} \times \rho \quad \text{.............(iii)}}$$

For the adiabatic process 3-4,

$$\frac{T_3}{T_4} = \left[\frac{V_4}{V_3}\right]^{\gamma-1} = r_1^{\gamma-1}$$

$$= \left[\frac{r}{\rho}\right]^{\gamma-1} = \frac{r^{\gamma-1}}{\rho^{\gamma-1}}$$

$$T_4 = T_3 \times \frac{\rho^{\gamma-1}}{r^{\gamma-1}}$$

Substituting for T_3 from equation (iii)

$$T_4 = T_1 r^{\gamma-1}\rho \times \frac{\rho^{\gamma-1}}{r^{\gamma-1}}$$

$$T_4 = T_1\rho^{\gamma} \quad \text{..................(iv)}$$

Substituting the expressions for T_2, T_3 and T_4 in equation (i),

$$\eta = 1 - \frac{1}{\gamma}\frac{T_1\rho^\gamma - T_1}{\left(T_1 r^{\gamma-1}\rho - T_1 r^{\gamma-1}\right)}$$

$$\eta = 1 - \frac{1}{r^{\gamma-1}} \times \frac{1}{\gamma}\left[\frac{\rho^\gamma - 1}{\rho - 1}\right]$$

The above expression shows that the air standard efficiency of Diesel cycle is a function of compression ratio, cutoff ratio and the ratio of specific heats.

Problem : 1.13.

1 kg of air at temperature of 15°C and pressure of 100 kPa is taken through a Diesel cycle. The compression ratio is 15 and the heat added is 1850 kJ. Calculate the ideal cycle efficiency.

Solution:

Given: $m = 1$ kg $\quad T_1 = 15^0C = 288$ K

$p_1 = 100$ kPa $\quad$ Q added = 1850 kJ, $\quad r = 15$

To find: η

We have:

$$p_1 V_1 = mRT_1$$

$$\therefore V_1 = \frac{mRT_1}{p_1} = \frac{1 \times 287 \times 288}{100 \times 10^3} = 0.827\,m^3$$

Given, $\frac{V_1}{V_2} = 15$

$$\therefore V_2 = \frac{V_1}{15} = \frac{0.827}{15} = 0.055\,m^3$$

For the adiabatic process 1-2,

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$T_2 = T_1\left[\frac{V_1}{V_2}\right]^{\gamma-1}$$

$$= 288 \times (15)^{1.4-1} = 850.8\text{ K}$$

For the constant pressure process 2-3,

$$_2Q_3 = mC_p(T_3 - T_2)$$

$$1850 = 1 \times 1.005 \times (T_3 - 850.8)$$

$$T_3 = 2691.6\text{ K}$$

$$\frac{V_2}{T_2} = \frac{V_3}{T_3}$$

$$V_3 = V_2 \times \frac{T_3}{T_2}$$

$$= 0.055 \times \frac{2691.6}{850.8} = 0.174\text{ m}^3$$

$$\text{Cut off ratio } \rho = \frac{V_3}{V_2} = \frac{0.174}{0.055} = 3.16$$

Air standard efficiency,

$$= 1 - \frac{1}{\gamma(r)^{(\gamma-1)}}\left\{\frac{(\rho^\gamma - 1)}{(\rho - 1)}\right\}$$

$$= 1 - \frac{1}{1.4(15)^{0.4}}\left\{\frac{(3.16^{1.4} - 1)}{(3.16 - 1)}\right\}$$

$$= 55.15\ \%$$

Problem : 1.14.

Find the percentage loss in the ideal efficiency of a diesel engine with compression ratio 15, by delaying the fuel cut off from 5 to 10 % of the stroke.

Solution:

Given: $r = 15$

Cut off is at $0.05\,(V_1 - V_2)$ and $0.10\,(V_1 - V_2)$

To find : % loss in η when the cut off is delayed from 5 to 10% of stroke volume.

When cut off is at 5 % of stroke volume,

$$V_3 = V_2 + 0.05\,(V_1 - V_2)$$

$$V_1 = 15\,V_2 \text{ (given)}$$

$$\therefore\ V_3 = V_2 + 0.05\,(15\,V_2 - V_2)$$

$$= 1.7\,V_2$$

$$\frac{V_3}{V_2} = 1.7 \text{ ie., } \rho = 1.7$$

$$\eta = 1 - \frac{1}{\gamma r^{\gamma-1}}\,\frac{(\rho^{\gamma} - 1)}{(\rho - 1)}$$

$$= 1 - \frac{1}{1.4\,(15)^{1.4-1}}\,\frac{(1.7^{1.4} - 1)}{(1.7 - 1)}$$

$$\eta = 61.94\%$$

When cut off is at 10% of stroke volume,

$$V_3 = V_2 + 0.1\,(V_1 - V_2)$$

$$= V_2 + 0.1\,(15\,V_2 - V_2) = 2.4\,V_2$$

$$\frac{V_3}{V_2} = 2.4 \quad \text{i.e., } \rho = 2.4$$

$$\eta = 1 - \frac{1}{1.4(15)^{1.4-1}}\left\{\frac{2.4^{1.4} - 1}{(2.4) - 1}\right\}$$

$$\eta = 58.44\%$$

$$\%\text{ of loss in } \eta = \left\{\frac{61.94 - 58.44}{61.94}\right\} \times 100 = 5.65$$

$$\%\text{ of loss in } \eta = 5.65$$

Problem : 1.15.

An ideal diesel cycle operates on 1 kg of air with an initial pressure of 1 bar and a temperature of 35°C. The pressure at the end of compression is 33 bar and cut off is 6 % of the stroke. Determine (i) the compression ratio (ii) the heat supplied (iii) the heat rejected and (iv) the thermal efficiency.

Solution:

Given: $m = 1$ kg

$p_1 = 1 \text{ bar} = 1 \times 10^5 \text{ N/m}^2$

$T_1 = 35^\circ C = 308 \text{ K}$

$p_2 = 33 \text{ bar} = 33 \times 10^5 \text{ N/m}^2$

Cut off = 6 % stroke volume

To find :

r, Qs, η, Qr

For the adiabatic process 1-2,

$$\frac{V_1}{V_2} = \left\{\frac{p_2}{p_1}\right\}^{\frac{1}{\gamma}} = \left\{\frac{33}{1}\right\}^{\frac{1}{1.4}} = 12.15$$

$$r = 12.15$$

$$\frac{T_2}{T_1} = \left\{\frac{p_2}{p_1}\right\}^{\frac{\gamma-1}{\gamma}}$$

$$T_2 = T_1\left\{\frac{p_2}{p_1}\right\}^{\frac{\gamma-1}{\gamma}} = 308\times\left\{\frac{33}{1}\right\}^{\frac{1.4-1}{1.4}}$$

$T_2 = 836.4$ K

$V_3 = V_2 + 0.06\,(V_1 - V_2)$

$V_3 = V_2 + 0.06\,(12.15\,V_2 - V_2) = 1.669\,V_2$

$$\therefore \rho = \frac{V_3}{V_2} = 1.669$$

For the constant pressure process 2-3

$$\frac{V_2}{T_2} = \frac{V_3}{T_3}$$

$$\frac{T_3}{T_2} = \frac{V_3}{V_2} = 1.669$$

$T_3 = 1.669\times T_2 = 1.669\times 836.4 = 1395.95$K

Heat supplied $= mC_p\,(T_3 - T_2)$

$= 1\times 1.005\,(1395.95 - 836.4)$

Heat supplied = 562.35 kJ

$$\eta = 1 - \frac{1}{r^{\gamma-1}}\frac{(\rho^{\gamma}-1)}{\gamma(\rho-1)}$$

$$= 1 - \frac{1}{(12.15)^{1.4-1}}\frac{(1.669^{1.4}-1)}{1.4(1.669-1)}$$

$\eta = 58.77\,\%$

$$\eta = 1 - \frac{Q\text{rejected}}{Q\text{supplied}}$$

$$0.5877 = 1 - \frac{Q\text{rejected}}{562.35}$$

Q rejected $= (1 - 0.5877)\times 562.35$

$= 231.86$ kJ

Problem : 1.16.

The following data pertains to a Diesel cycle:

Pressure at the suction stroke = 1 bar

Temperature at suction stroke = 300 K

Heat added = 2500 kJ/kg

Compression ratio = 16

Calculate:

(i) Pressure and temperature at each point of the cycle.

(ii) Thermal efficiency

(iii) Power output for air flow rate of 0.6 kg/s

Assume C_p = 1 kJ/kg K $\quad C_v$ = 0.714 kJ/kg K

Solution:

Given:

$p_1 = 1$ bar $= 1\times 10^5$ N/m²

$T_1 = 300$ K, $\quad r = 16$

Qs = 2500 kJ/kg $\quad$ m = 0.6 kg/s.

C_p = 1 kJ/kg K $\quad C_v$ = 0.714 kJ/kgK

To find: $p_2, T_2, p_3, T_3, p_4, T_4, \eta$, Power.

$$\frac{p_2}{p_1} = \left\{\frac{V_1}{V_2}\right\}^{\gamma} = r^{\gamma}$$

$$p_2 = p_1\,r^{\gamma} = 1\times 10^5\times 16^{1.4} = 48.5\times 10^5 \text{ N/m}^2$$

$$\frac{T_2}{T_1} = \left\{\frac{V_1}{V_2}\right\}^{\gamma-1} = r^{\gamma-1}$$

$$T_2 = T_1 . r^{\gamma-1} = 300 \times 16^{1.4-1} = 909.43 \text{ K}$$

$$Qs = mC_p (T_3 - T_2)$$

$$2500 = 1 (T_3 - 909.43)$$

$$T_3 = 3409.43 \text{ K}$$

$$p_3 = p_2 = 48.5 \times 10^5 \text{ N/m}^2$$

$$V_4 = V_1 = \frac{RT_1}{p_1} = \frac{287 \times 300}{1 \times 10^5} = 0.861 \text{ m}^3/\text{kg}$$

$$V_3 = \frac{RT_3}{p_3} = \frac{287 \times 3409.43}{48.5 \times 10^5} = 0.20 \text{ m}^3/\text{kg}$$

$$\frac{p_4}{p_3} = \left\{\frac{V_3}{V_4}\right\}^{\gamma} = \left(\frac{0.20}{0.861}\right)^{1.4} = 0.129$$

$$p_4 = p_3 \times 0.129 = 48.5 \times 10^5 \times 0.129$$

$$= 6.26 \times 10^5 \text{ N/m}^2$$

$$\frac{T_4}{T_3} = \left\{\frac{V_3}{V_4}\right\}^{\gamma-1} = \left(\frac{0.2}{0.861}\right)^{1.4-1} = 0.558$$

$$T_4 = T_3 \times 0.558 = 3409.43 \times 0.558$$

$$= 1902.46 \text{ K}$$

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}}$$

$$= 1 - \frac{1}{(16)^{1.4-1}} = 0.670$$

$$= 67 \%$$

$$\text{Workdone} = \eta \times Q_s$$

$$= 0.67 \times 2500 = 1675 \text{ kJ/kg}$$

$$\text{Power} = \text{work done} \times \text{mass flow rate}$$

$$= 1675 \times 0.6$$

$$= 1005 \text{ kW}$$

Problem : 1.17.

In an air standard diesel cycle, the compression ratio is 16 and at the beginning of compression the temperature is 15°C and the pressure is 0.1 MPa. Heat is added until the temperature at the end of the constant pressure process is 1480°C. Calculate

(i) The cut off ratio

(ii) The heat supplied per kg of air

(iii) The cycle efficiency

Assume $C_p = 1.005$ kJ/kg K and $C_v = 0.718$ kJ/kg K.

Solution:

Given: $r = 16$, $T_1 = 15°C = 15 + 273 = 288$ K

$p_1 = 0.1$ MPa $= 0.1 \times 10^6$ N/m²

$T_3 = 1480°$ C $= 1480 + 273 = 1753$ K

$C_p = 1.005$ kJ/kg K

$C_v = 0.718$ kJ/kg K

To find: ρ, Qs, η

$$\frac{T_2}{T_1} = \left\{\frac{V_1}{V_2}\right\}^{\gamma-1} = (16)^{1.4-1} = 3.03$$

$$T_2 = 3.03 \times T_1 = 3.03 \times 288 = 872.64 \text{ K}$$

$$\text{Cut off ratio } \rho = \frac{V_3}{V_2} = \frac{T_3}{T_2} = \frac{1753}{872.64} = 2$$

$$\rho = 2$$

$$Q_s = C_p(T_3 - T_2)$$

$$= 1.005\,(1753 - 872.64)$$

$$= 884.76 \text{ kJ/kg}$$

$$\eta = 1 - \frac{1}{r^{\gamma-1}} \frac{(\rho^{\gamma} - 1)}{(\rho - 1)\gamma}$$

$$= 1 - \frac{1}{16^{1.4-1}} \frac{(2^{1.4} - 1)}{(2-1)1.4} = 0.6138$$

$$\eta = 61.38\ \%$$

1.7. Comparison of Otto and Diesel cycles for the same compression ratio and heat rejection.

Fig.1.20 shows the Otto and Diesel cycles for the same compression ratio and heat rejection. Here, 1-2-3-4-1 is Otto cycle and 1-2-3'-4-1 Diesel cycle.

$$\text{Air standard cycle efficiency} = 1 - \frac{\text{Heat rejected}}{\text{Heat supplied}}$$

For the same heat rejection, efficiency will be more when heat supplied is more. Since work done is equal to the difference between heat supplied and heat rejected, for the same heat rejection work done will be more when heat supplied is more. From Fig. 1.20 it is clear that, for the same compression ratio and heat rejection, work done and hence heat supplied is more

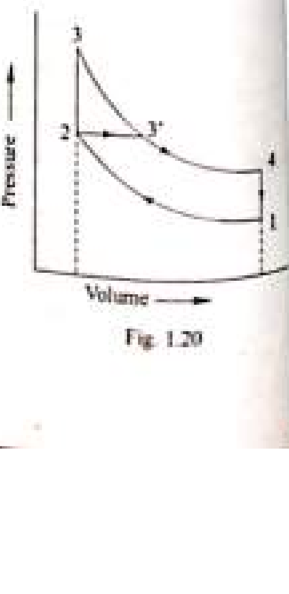


Fig. 1.20

for Otto cycle.

Therefore, η Otto $> \eta$ Diesel

In practice, the compression ratio of diesel engine ranges from 16 to 20 whereas that of Otto engine ranges from 6 to 10. Because of the higher compression ratio the diesel engines generally have higher efficiency than Otto engines.

Problems for practice

Problem 1.

An engine working on ideal Otto cycle has temperature and pressure at beginning of adiabatic compression as 25°C and 1.5 bar respectively. If $\gamma = 1.4$ and thermal efficiency of the engine is 50%, find its compression ratio. Also find the temperature and pressure at the end of compression. (5.66, 323.55°C, 17.03 bar).

Problem 2.

A certain quantity of air at a pressure of 1 bar and temperature of 70°C is compressed adiabatically until the pressure is 7 bar in an Otto cycle. 320 kJ of heat per kg of air is now added at constant volume. Determine (i) the compression ratio of the engine (ii) the temperature at the end of compression and (iii) the temperature at the end of heat addition. For air $C_p = 1.005$ kJ/kg. K. and $C_v = 0.718$ kJ/kg.K (4.01, 324.79°C, 770.47°C).

Problem 3.

An IC engine working on Otto cycle takes the air in at 0.97 bar a 35°C. The compression ratio is 7. The heat supplied during the cycle is 1.5 MJ/kg. of the working fluid. Determine:

(i) the air standard efficiency

(ii) the maximum temperature attained and

(iii) the work done per kg of working fluid.

Problem 4.

The initial conditions of air in an Otto cycle are 30°C and 1.1 bar. The air is compressed to a pressure of 12.5 bar. Then heat is added till the pressure becomes 35 bar. Determine:

(i) Compression ratio.

(ii) Air standard efficiency.

Problem 5.

An ideal Diesel cycle operates on 1 kg. of standard air with an initial pressure of 0.1 N/mm^2 and a temperature of 35°C. The pressure at the end of compression is 3.5 N/mm^2 and cut-off is 6% of the stroke. Determine

(i) the compression ratio

(ii) the percentage clearance

(iii) the heat supplied

(iv) the heat rejected

1.8. IC Engines

A device which transforms one form of energy into another form is called an engine. An engine which converts thermal energy into mechanical energy is called heat engine. Heat engine transforms the chemical energy of a fuel into thermal energy and this thermal energy is converted into mechanical energy to perform useful work. Heat engines can be broadly classified into two categories.

(i) External combustion engines (EC engines)

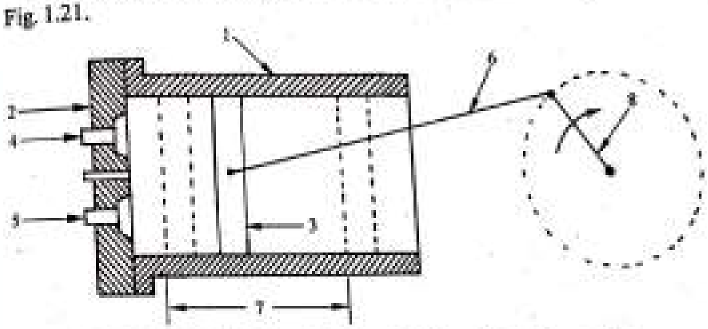
(ii) Internal combustion engines (IC engines)

In an external combustion engine, a working fluid is used for transferring the heat of combustion to the engine where the heat of combustion is converted into mechanical energy. Steam engines and steam turbines are common examples of this category. As these engines require big boilers and bulky heat exchangers, this type of engines are not generally desirable

for mobile power plants. In an internal combustion engine air is taken from the atmosphere and the combustion of fuel and air occurs in the engine which converts thermal energy into mechanical energy. This eliminates the need for heavy and bulky devices such as boilers and heat exchangers. Also high thermal efficiencies can be achieved in internal combustion engines. These factors give rise to the wide use of internal combustion engines for mobile power plants such as those used in automobiles, ships and slow speed aircrafts.

1.9. Parts of IC engines

The following are the major parts of internal combustion engine. Refer Fig. 1.21.



1. Cylinder 2. Cylinder head 3. Piston 4. Inlet valve 5. Exhaust valve 6. Connecting road 7. Stroke length 8. Crank

Fig. 1.21. Engine parts

1. Cylinder

It is a cylindrically shaped container within which the piston reciprocates. The cylinder is closed by the cylinder head at one end and the other end is covered by the moving piston. Combustion of fuel takes place inside the cylinder and power is developed.

2. Cylinder head

It is a cast iron piece bolted to one end of the cylinder. It acts as a cover to close the cylinder. It contains provisions for placing inlet and exhaust valves. In petrol engines, it houses a spark plug for igniting fuel air mixture. In diesel engines, it houses a fuel injector for injecting the fuel into the cylinder.

3. Piston

It is a close fitting member which reciprocates inside the engine cylinder. The gas tight compartment which serves as the combustion chamber is formed between the cylinder head and the piston. The main function of the piston is to transmit the force exerted by the high pressure gas to the connecting rod. It is shaped like an inverted cup and is generally made of aluminium alloy.

4. Inlet and exhaust valves

These are valves provided in the cylinder head for the admission of fresh air into the engine cylinder and for the rejection of burnt gases from the engine cylinder. These valves are usually kept closed by valve springs. Openings of these valves are made mechanically by means of a device called cam. The cam is keyed to a shaft called camshaft which is geared to the engine shaft.

5. Inlet manifold

The metal tube which connects the intake system to the inlet valve of the engine and through which air or air fuel mixture is drawn into the cylinder is called inlet manifold.

6. Exhaust manifold

The metal tube which connects the exhaust system to the exhaust valve of the engine and through which the product of combustion escape is called exhaust manifold.

7. Connecting rod

It is the element which interconnects the piston and the crank. Connecting rod transmits the gas force from the piston to the crank shaft and transforms the reciprocating motion of piston inside the cylinder into rotary motion of the crank.

8. Crank

It is a rotating member which receives power from the connecting rod and transmits to the crank shaft.

9. Flywheel

It is a heavy wheel mounted on the crank shaft. Its main function is to maintain the angular velocity of crank shaft fairly constant.

Additional parts for petrol engines

1. Carburetor

Carburetor is used to discharge into the air stream the desired quantity of liquid fuel to produce a homogeneous air - fuel mixture. A good carburetor must produce automatically the desired air-fuel ratio at all speeds and loads of the engine. The basic principle used in carburetor is that when a volatile fuel is placed in the passage of high velocity air, the fuel gets vapourised at a faster rate.

2. Low pressure fuel pump

As high pressure is not required to pump the fuel in petrol engines, a low pressure fuel pump is used to pump fuel from the fuel storage tank to the carburetor.

3. Spark Plug

The spark plug provides the required air gap between two electrodes to generate a spark to ignite the fuel-air mixture in the cylinder.

Additional parts for diesel engines

1. Fuel injector

It is used to inject fuel into the cylinder in the form of fine spray.

2. High pressure fuel pump

It is used to supply measured quantity of fuel at high pressure to the injector.

Nomenclature

The following are the various nomenclatures used in internal combustion engines

1. Cylindrical Bore

The inside diameter of cylinder is called cylinder bore.

2. Top Dead Centre (TDC) or Inner Dead Centre (IDC)

The extreme position of the piston at the top of the cylinder is the top dead centre (TDC). In the case of horizontal engines it is known as inner dead centre (IDC)

3. Bottom Dead Centre (BDC) or Outer Dead Centre (ODC)

The position of the piston when it is farthest from the top of the cylinder is the bottom dead centre (BDC). In horizontal engines, it is known as outer dead centre (ODC)

4. Stroke

The travel of the piston from one dead centre to the other is called stroke. The distance between the two dead centres is called the stroke length.

5. Swept volume

The volume of the cylinder in between the two dead centres is the swept volume. It is denoted by Vs.

6. Clearance volume

The volume of the cylinder in between the top dead centre and the cylinder head is the clearance volume. It is denoted by Vc.

7. Compression ratio

The ratio of the volume of the cylinder between the bottom dead centre and the cylinder head to the clearance volume is the compression ratio of the engine. It is denoted by 'r'

1.10. Classification of IC engines

IC engines may be classified in many ways based on the criterion selected for classification.

A. Based on the ignition system

According to the ignition system employed for igniting the charge in the engine cylinder, IC engines are classified as,

i) Spark Ignition (SI) engines : in which an electric spark is used for igniting the fuel air mixture. Most of the engines using petrol or gaseous fuel belong to this category.

ii) Compression Ignition (CI) engines : in which air is compressed to a very high temperature and pressure and fuel is injected to it in the form of a spray. The fuel gets ignited due to the high temperature of the compressed air. Most of the engines using diesel as fuel belong to this category.

B. Based on the type of fuel used

i) Gas engines : in which gaseous fuel such as methane is used as the main fuel.

ii) Petrol engines : in which highly volatile liquid fuel such as petrol is used .

iii) Diesel engines: in which less volatile liquid fuel such as diesel oil is used.

iv) Dual - fuel engines: in which a gaseous fuel or a highly volatile liquid fuel is supplied along with air during the suction stroke and a viscous liquid fuel is injected into the combustion space near the end of the compression stroke.

C. Based on the working cycle.

i) Otto engine : in which the engine works based on the Otto cycle (constant volume cycle). Most of the petrol and gas engines work on this cycle.

ii) Diesel engine: in which the engine works based on the diesel cycle. Most of the low speed oil engines work on this cycle.

iii) Dual combustion engine: in which the engine works on the dual combustion cycle. Most of the high speed oil engines work on this cycle.

D. Based on the number of strokes per cycle

i) Four stroke engines : in which one cycle of operation is completed in four strokes of the piston. ie., one power stroke is obtained in four strokes of the piston ie., in two revolutions of the crank shaft.

ii) Two stroke engines : in which one cycle of operation is completed in two strokes of the piston, giving one power stroke per two strokes of the piston ie., in each revolution of the crank shaft.

E. Based on the application of the engine

i) Stationary engines: which are used in power plants.

ii) Mobile engines: which are used in automobiles, aircrafts, etc.

F. Based on the cooling system

i) Air cooled engines : in which heat is directly dissipated into the air around the cylinder.

(ii) Water cooled engines : in which excess heat is removed from the engine cylinder and cylinder head by circulating water through the jackets provided in the engine cylinder and cylinder head

G. Based on the speed of the engine

i) Low speed engines (up to 350 rpm)

ii) Medium speed engines (350 - 1000 rpm)

iii) High speed engines (above 1000 rpm)

H. Based on the number of cylinders

i) Single cylinder engines: in which there is only one cylinder in an engine.

ii) Multi cylinder engines: in which there are more than one cylinder in an engine.

I. Based on the cylinder arrangement

i) Vertical engine: in which the axis of the cylinder is vertical

ii) Horizontal engine : in which the axis of the cylinder is horizontal

iii) In - line engine : in which all the cylinders are arranged linearly transmitting power to a single crankshaft.

iv) V- engine : in which two cylinders are kept at an angle forming the shape of the letter 'V' and utilise the same crankshaft.

v) Radial engine: in which the cylinders are placed radially and equally spaced around a common crankshaft.

vi) Opposed cylinder engine: in which two cylinders are placed on opposite sides of a common crank

1.11. Working principle of diesel engines (Compression Ignition engines)

Diesel engine is based on the work of Rudolph Diesel. It operates based on the theoretical air cycle known as Diesel cycle. These engines operate on four stroke or two stroke cycle.

Diesel cycle (Constant pressure cycle)

Atmospheric air is drawn into the engine cylinder during the suction stroke and is compressed by the piston during the compression stroke to high pressure and temperature. The temperature of compressed air will be above the ignition temperature of fuel. Just before the end of the compression stroke a metered quan-

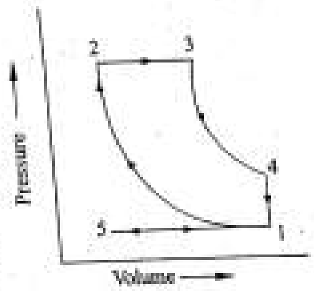
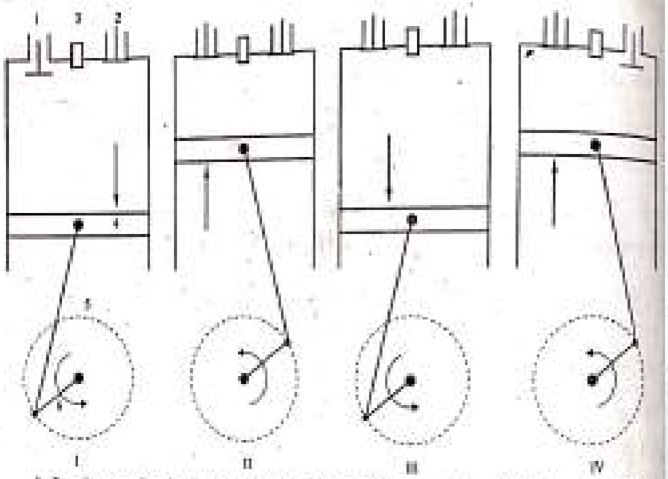


Fig. 1.22. Diesel cycle

tity of fuel under pressure is injected in the form of fine spray by means of a fuel injector. Due to very high pressure and temperature of the air the fuel ignites and the gases expand displacing the piston. After doing work on the piston the burnt gases escape from the engine cylinder through the exhaust valve. As the ignition takes place due to heat of compressed air, it is called compression ignition engine (CI engine).

1.12. Working of four stroke diesel engine

In four stroke cycle engine one cycle of operation is completed in four strokes of the piston (ie., two revolutions of crank shaft). The various strokes of a four stroke diesel engine are detailed below. Refer Fig. 1.23.



I. Suction stroke II. Compression stroke III. Working stroke IV. Exhaust stroke

1. Inlet valve 2. Exhaust valve 3. Fuel Injector 4. Piston 5. Connecting rod 6. Crank

Fig. 1.23. Working of four stroke diesel engine

1. Suction stroke

During this stroke the piston moves from top dead centre (TDC) to bottom dead centre (BDC). The inlet valve opens and air at atmospheric pressure is drawn into the engine cylinder. The exhaust valve remains closed. This operation is represented by the line 5-1 in Fig. 1.22.

2. Compression stroke

In this stroke the piston moves towards TDC and compresses the enclosed air to high temperature and pressure. This operation is represented by line 1-2 in Fig. 1.22. Both the inlet and exhaust valves remains closed during this stroke.

3. Expansion or working stroke.

Towards the end of compression stroke a metered quantity of fuel is injected into the hot compressed air in the form of fine spray by means of a fuel injector. The fuel starts burning, theoretically, at constant pressure and pushes the piston from TDC. This is shown by line 2-3 in Fig. 1.22. At point 3, fuel supply is cut off. The high pressure gas in the cylinder expand upto point 4, doing work on the piston. The inlet and exhaust valves remain closed during this stroke. At the end of this stroke the exhaust valve opens.

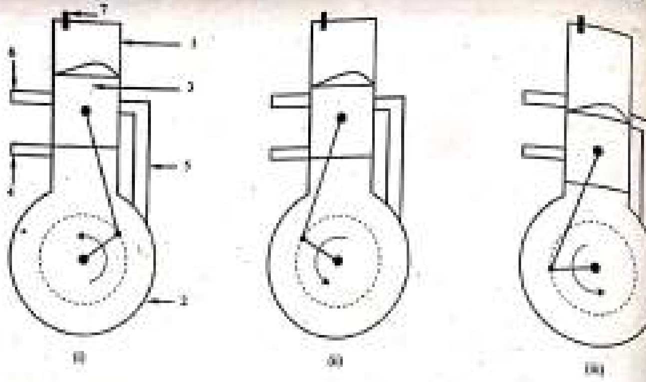
4. Exhaust stroke

The piston moves from BDC to TDC and the burnt gases escape through the exhaust valve. During this stroke the inlet valve remains closed. This stroke is represented by the line 1-5 in Fig. 1.22. During this stroke the exhaust valve remains opened and the inlet valve remains closed. By this one cycle is completed.

1.13. Working of two stroke diesel engine.

In two stroke diesel engine, one cycle of operation is completed in two strokes of the piston, (in one revolution of the crankshaft) by eliminating separate suction and exhaust strokes. Here ports are provided in place of valves.

Fig. 1.24. shows the working of a two stroke diesel engine. The cylinder is connected to a closed crankcase. During the upward stroke of the piston, the air in the cylinder is compressed. At the same time fresh air enters the crank case through the air inlet port. Fig. 1.24 (i). Towards the end of this stroke fuel is introduced in the form of fine spray by the fuel



1. Cylinder 2. Crank case 3. Piston 4. Air inlet port 5. Transfer port 6. Exhaust port 7. Fuel Injector

Fig. 1.24. Working of two stroke diesel engine

injector and due to the high pressure and temperature of the air, the fuel starts burning. The piston, then travels downwards due to the expansion of the gases (Fig. 1.24 (ii)) and near the end of this stroke the piston uncovers the exhaust port and the burnt gases escape through this port. The transfer port is then uncovered (Fig. 1.24 (iii)) and the compressed air from the crankcase flows into the cylinder. The incoming fresh air helps to remove the burnt gases from the engine cylinder.

1.14. Working principle of petrol engines. (Spark Ignition engines)

Petrol engines operate on the so called Otto cycle. These engines work based on either four stroke or two stroke cycle.

Otto cycle (Constant volume cycle)

In this cycle, heat is supplied and rejected at constant volume. A homogeneous mixture of air and petrol is supplied to the engine cylinder during the suction stroke.

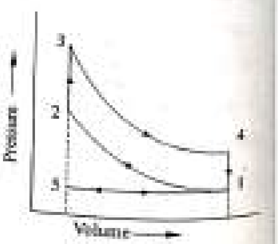
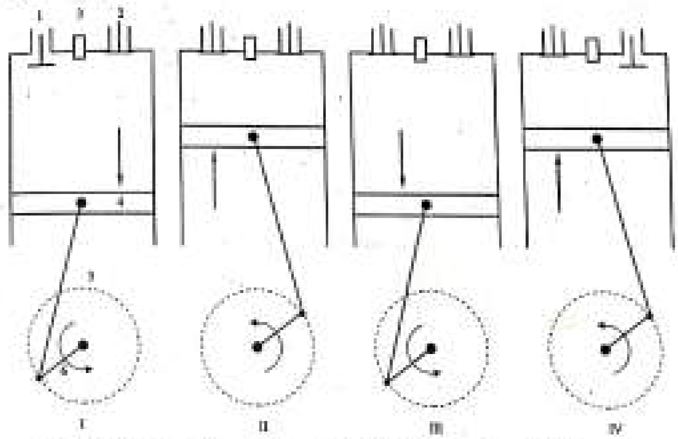


Fig. 1.25. Otto cycle

A carburetor provides a mixture of petrol and air in the required proportion. The fuel air mixture (charge) gets compressed during the compression stroke. At the end of this stroke, fuel is ignited and combustion occurs at constant volume. thus heat is supplied at constant volume. The gas expands and moves the piston downwards, doing work. The product of combustion is exhausted at constant volume.

1.15. Working of four stroke petrol engine

The various strokes of a four stroke petrol engine are detailed below. Refer Fig. 1.26



I. Suction stroke II. Compression stroke III. Working stroke IV. Exhaust stroke

1. Inlet valve 2. Exhaust valve 3. Spark plug 4. Piston 5. Connecting rod 6. Crank

Fig. 1.26. Working of four stroke petrol engine

(i) Suction stroke

During this stroke the piston moves from top dead centre (TDC) to bottom dead centre (BDC). The inlet valve opens and the fuel air mixture is sucked into the engine cylinder. The exhaust valve remains closed throughout this stroke . This is represented by the line 5-1 in Fig. 1.25.

(ii) Compression stroke

The air fuel mixture is compressed as the piston moves from BDC to TDC. Just before the end of this stroke, the spark plug initiates a spark which ignites the mixture and combustion takes place at constant volume (line 2-3 in Fig. 1.25). Both the inlet and exhaust valves remains closed throughout this stroke.

(iii) Expansion or working stroke.

As the fuel air mixture burns, hot gases are produced which drive the piston towards BDC and thus work is done . This expansion process is shown by the line 3-4 in Fig. 1.25. Both the valves remain closed during this stroke.

(iv) Exhaust stroke

The removal of the burnt gases is accomplished during this stroke. The piston moves from BDC to TDC and the exhaust gases are driven out of the engine cylinder. This operation is represented by the line 1-5 in Fig. 1.25. During this stroke the exhaust valve remain opened and the inlet valve remains closed. By this one cycle is completed.

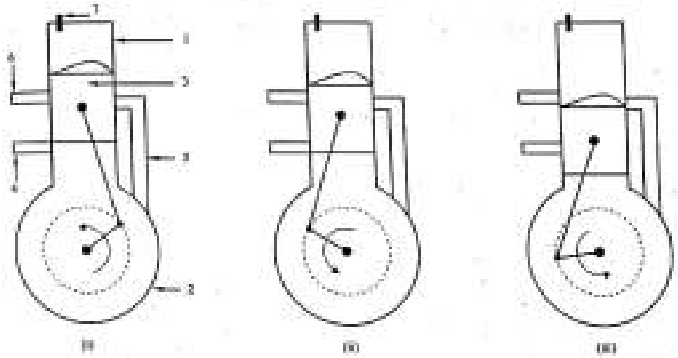
1.16. Working of two stroke petrol engine

In two stroke petrol engine, one cycle of operation is completed in two strokes of the piston, (in one revolution of the crankshaft) by eliminating separate suction and exhaust strokes.

Fig. 1.27 shows the working of a two stroke petrol engine. The cylinder is connected to a closed crankcase. During the upward stroke of the piston, the air fuel mixture in the cylinder is compressed. At the same time fresh air - fuel mixture enters the crank case through the inlet port. Fig. 1.27 (i) . Towards the end of this stroke, the fuel air mixture is ignited using an electric spark from the spark plug.

The piston, then travels downwards due to the expansion of the gases (Fig. 1.27 (ii)) and near the end of this stroke the piston uncovers the

exhaust port and the burnt gases escape through this port. The transfer port is then uncovered (Fig. 1.27 (iii)) and the compressed air fuel mixture from the crankcase flows into the cylinder. The incoming fresh air fuel mixture helps to remove the burnt gases from the engine cylinder. Refer Fig. 1.27. In a two stroke petrol engine the operations are the same as that of a two stroke diesel engine with some difference. In this engine, fuel- air mixture is admitted into the crank case and compressed. A carburetor is used for mixing the fuel and air in the correct proportion. For the ignition of the fuel air mixture at the end of compression in the engine cylinder, a spark plug is provided. In this case, combustion process is assumed to take place at constant volume.



1. Cylinder 2. Crank case 3. Piston 4. Air inlet port 5. Transfer port 6. Exhaust port 7. Spark plug

Fig. 1.27. Working of two stroke petrol engine

1.17. Comparison of SI and CI engines

1. Working cycle

The SI engine, in general, works based on Otto cycle while the CI engine, in general, works based on Diesel cycle.

2. Fuel

A highly volatile fuel such as petrol is used in SI engines while non-volatile fuel such as diesel is used in CI engines.

3. Method of fuel introduction

In most of the SI engines, the fuel and air are introduced into the engine cylinder as a gaseous mixture while in CI engines, the fuel is directly introduced into the cylinder in the form of fine spray. Mixing of fuel and air takes place inside the cylinder.

4. Method of fuel ignition

The SI engine requires a spark to initiate combustion while CI engine utilizes the condition of high temperature and pressure, produced by the compression of air in the cylinder, to initiate combustion when fuel is injected.

5. Fuel economy

CI engines have better fuel economy at all operating conditions.

6. Compression ratio

Compression ratio of SI engines range from 6 to 10, whereas that of CI engines range from 16 to 20. The higher compression ratio of CI engines result in higher thermal efficiency and hence a greater power output for the same amount of fuel consumed.

7. Weight

Because of the higher compression ratio and higher pressure , CI engines require stronger engine parts and hence are heavier.

8. Initial cost

Initial cost of a SI engine is less than a comparable CI engine.

9. Maintenance costs

The maintenance costs of the two types of engines are generally about the same, with CI engine costs slightly higher.

1.18. Comparison of two stroke and four stroke engines

1. In a two stroke engine, there is one working stroke for every revolution of the crank shaft whereas in a four stroke engine there is only one power stroke for two revolutions of the crank shaft. Hence, theoretically, the power developed in two stroke engine will be double that of a four stroke engine of the same dimensions. However in practice, only about 30 percent extra power is developed. That is, in order to produce the same amount of power, a two stroke cycle engine will be of less weight and occupies less space.
2. As there is one working stroke in every revolution of the crank shaft, the turning moment of a two stroke engine will be more uniform.
3. As there is no valves in a two stroke engine the construction will be simple and hence low initial cost. The maintenance of the engine will also be easy. The mechanical efficiency will be higher.
4. As there is no separate exhaust stroke in a two stroke engine the scavenging will be poor. Due to this, the fresh charge gets diluted with exhaust gases and the thermal efficiency decreases. Also there is possibility of the fresh charge escaping with the exhaust. This will increase the fuel consumption.
5. The separate exhaust and intake strokes of the four stroke cycle provide greater opportunity for the dissipation of heat from critical parts like piston, and essentially permit the four stroke cycle engine to run at higher speed than two stroke cycle engine.
6. In two stroke engine the power needed to operate suction and exhaust valves is saved.
7. The construction of combustion chamber is simple in a two stroke engine compared to four stroke engine.

1.19. Mean effective pressure (mep)

The variations of pressure versus volume inside the cylinder of a reciprocating engine is drawn using an engine indicator. The resulting closed contour is called indicator diagram. The area enclosed by the contour is a measure of the work done per cycle.

Mean effective pressure (mep) is defined as the constant pressure acting on the piston which will produce the same amount of work as done by the actual varying pressure acting on the piston during a cycle.

The height of rectangle 1-2-3-4 as shown in Fig. 1.28 will be the mep provided the area of the rectangle 1-2-3-4 is equal to the area of the indicator diagram. Since the area of indicator diagram gives the work done during a cycle,

$$\text{mep} \times (V_1 - V_2) = \text{Work done/ cycle}$$

$$\therefore \text{mep} = \frac{\text{Work done / cycle}}{V_1 - V_2} = \frac{\text{Work done / cycle}}{\text{swept volume}}$$

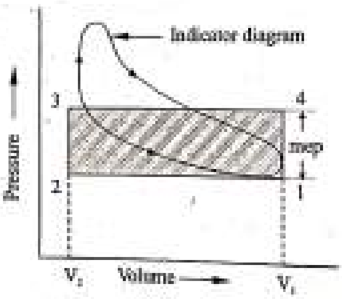


Fig. 1.28

Unit of mep is N/m^2. Mean effective pressure is used as a parameter to compare the performance of reciprocating engines of the same size

1.20. Efficiencies of IC engines.

Power developed inside the cylinder, calculated using the indicator dia-

gram (actual p-V diagram) is known as indicated power (IP) of the engine. The power available at the crank shaft is less than that developed in the cylinder due to various frictional losses. This power available at the crank shaft is called brake power (BP) of the engine. The difference of IP and BP is called friction power (FP).

$$FP = IP - BP$$

$$IP = BP + FP$$

Brake power of an engine can be measured by dynamometer in the laboratory. Indicated power can be calculated as follows:

When,

p_m = mean effective pressure in kN/m^2

A = area of piston in m^2

L = stroke length in m

N = speed of crank shaft in rpm

n = number of working stroke per minute

= N, for two stroke engine and

$= \frac{N}{2}$, for four stroke engine.

$$\text{then, } IP = p_m A L \times \frac{n}{60} \text{ kW}$$

Thermal energy supplied per second can be calculated as follows,

When, m is the mass of fuel burnt per hour and CV is the calorific value of fuel in kJ/kg.

Then, Thermal energy = $m \times CV \times$ kJ/hr

$$= m \times CV \times \frac{1}{3600} \text{ kJ/s}$$

$$= \frac{m \times CV}{3600} \text{ kW}$$

The various efficiencies of IC engines are:

1. Mechanical efficiency
2. Indicated thermal efficiency
3. Brake thermal efficiency
4. Relative efficiency
5. Volumetric efficiency
6. Combustion efficiency

1. Mechanical efficiency

It is the ratio of brake power to indicated power

$$\eta_{mech} = \frac{BP}{IP}$$

2. Indicated thermal efficiency

It is the ratio of indicated power to the energy supplied by the fuel.

$$\text{Indicated thermal efficiency, } \eta = \frac{IP}{m \times CV \times \frac{1}{3600}}$$

$$= \frac{IP \times 3600}{m \times CV}$$

3. Brake thermal efficiency

It is the ratio of brake power to the energy supplied by the fuel

$$\text{Brake thermal efficiency, } \eta = \frac{BP}{m \times CV \times \frac{1}{3600}}$$

$$= \frac{BP \times 3600}{m \times CV}$$

4. Relative efficiency

It is the ratio of indicated thermal thermal efficiency to the theoritical thermal efficiency. Theoritical thermal efficiency is the thermal efficiency when the power developed inside the cylinder is calculated based on theoritical pV diagram.

$$\eta_{relative} = \frac{\text{Indicated thermal } \eta}{\text{Theoritical thermal } \eta} = \frac{\text{Indicated thermal } \eta}{\text{Air standard efficiency}}$$

5. Volumetric efficiency

it is the ratio of actual volume of air or air fuel mixture admitted into the cylinder to the swept volume of cylinder.

$$\eta_{volumetric} = \frac{\text{Actual volume of air or charge admitted into the cylinder}}{\text{swept volume of cylinder}}$$

Swept volume of cylinder $= \frac{\pi D^2}{4} \times L$, where D is the diameter of cylinder and L is the stroke length.

6. Combustion efficiency

Hundred percent of chemical energy of fuel admitted into the cylinder cannot be converted to thermal energy. This is mainly due to the incomplete combustion of fuel inside the cylinder. Combustion efficiency.is the ratio of actual heat energy liberated to the heat energy in the fuel admitted into the cylinder.

$$\eta_{combustion} = \frac{\text{Actual amount of heat energy liberated}}{\text{Heat energy of fuel admitted into the cylinder}}$$

1.21. Air system for petrol engine

Air system for petrol engine essentially consists of air filter and carburetor. For burning of fuel, oxygen is required. In internal combustion engine oxygen is obtained from the atmospheric air. Air after cleaning in the air filter is mixed with fuel in correct ratio using a carburetor. For complete combustion, the air - fuel ratio must be about 15:1 by weight. There is a range of air - fuel ratio within which combustion of fuel can occur. This range of air - fuel ratio is approximately 8:1 to 20:1 by weight. Outside this range the mixture is either

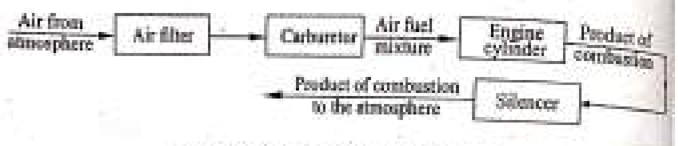


Fig. 1.29. Air system for petrol engine.

too rich or too lean. The carburetor provides air fuel mixture in the required ratio in accordance with the requirements of the engine. At the time of starting of the engine a rich mixture, about 10:1 is required. During normal running a comparatively lean mixture, 15:1, serves the purpose. During acceleration period a rich mixture is needed. This air fuel mixture is supplied to the engine cylinder through the inlet valve. Inside the cylinder, the mixture is burned and there by the chemical energy of fuel is converted into thermal energy. The product of combustion, after expanding, is discharged to the atmosphere. Generally a silencer or muffler is used to reduce the noise.

1.22. Fuel system for petrol engine

Fuel supply system for a petrol engine consists of a fuel storage tank, fuel pump, filter, carburetor, and inlet manifold from where the fuel enters the engine cylinder through inlet valve.

Fig. 1.30. Fuel supply system for petrol engine.

The fuel can be supplied to the engine either under gravity or using a pump. In the gravity system, the fuel storage tank is placed at a higher level than the carburetor so that the fuel flows to the carburetor under gravity. When storage tank is kept below the level of carburetor fuel pump is required to force the fuel to the carburetor.

1.23. Fuel system for diesel engines

Fuel supply system for diesel engine consists of a fuel storage tank, filter, low pressure or transfer pump, high pressure fuel pump and fuel injector.

Fig. 1.31. Fuel supply system for diesel engine

The main parts of this system are fuel pump and fuel injector. The fuel is supplied at very high pressure from the fuel pump to the fuel injector and is injected to the engine cylinder towards the end of compression stroke. There are two types of injection systems . (i) Air injection (ii) Solid injection

Air injection

In this method, fuel is forced into the cylinder by means of compressed air. This method is obsolute these days as it requires multistage air compressor which increases the engine weight and cost. Moreover the compressor consumes about 10% of the power developed by the engine and hence the output of the engine is reduced .

Solid injection (Mechanical injection)

In this method a fuel pump is used to supply measured quantity of fuel at high pressure to the injector. The injector injects the fuel at a very high velocity into the engine cylinder in the form of fine spray.

1.24. Cooling system

The entire heat generated by the combustion of the fuel inside the cylinder cannot be converted into work. An IC engine at the best can convert only about 30% of heat into work. About 30% of heat generated is absorbed by the piston, cylinderhead and the cylinder wall. If the heat absorbed by the engine parts is not removed it will cause excessive rise in temperature of these parts. The temperature of the cylinder wall should not exceed 250°C. At high temperature the piston will expand and it will seize with the cylinder wall. Hence the engine parts must be provided with some means of cooling so that the temperature of these parts does not exceed about 250°C. Therefore a cooling system is required to keep the engine parts from getting too hot yet permit the engine to run hot enough to ensure maximum overall efficiency. Thus the purpose of cooling system is to keep the engine parts from getting too hot and not to keep the engine parts cool.

The two types of cooling systems normally used in IC engines are,

(1) Air cooling and

(2) Liquid cooling (water cooling)

Air cooling

The cooling method in which heat is directly dissipated into the air around the cylinder is called air cooling. The basic principle involved in this type of cooling system is to have a current of air flowing continuously over the heated surface from where the heat is to be removed. It is used in motor cycles, airplane engines and small stationary engines. In this type heat is dissipated directly to the air after being conducted through the

cylinder walls. Usually, fins are provided on the outer surface of the cylinder and cylinder head to increase the area exposed to the cooling air. In some cases, a blower is fitted which throws air on these fins to increase the heat transfer rate. This is shown in Fig. 1.32. In mobile engines, the forward velocity of the engine helps in increasing the air velocity.

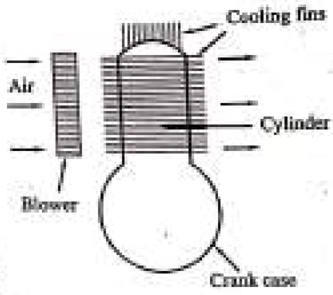


Fig. 1.32. Air cooled engine

The advantages of air cooling includes simplicity, lightness, cheapness and absence of water and its circulation system. The main disadvantage of this system is the non uniformity in cooling. Also, it is difficult to control the cooling rate.

Liquid cooling (water cooling)

In liquid cooling water is generally used as the cooling medium. It is circulated through passages around the main components which are getting heated. These passages are called water jackets. The circulation of water is obtained either by using a pump or by gravity force.

Fig. 1.33 shows water cooling system used in an automobile engine. In this, the water after passing through the engine jackets flows to a radiator. In the radiator the heated water gets cooled by an air flow caused by the forward motion of the automobile. To increase the heat transfer area the radiator tubes are provided with

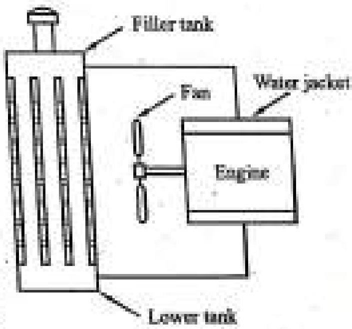


Fig. 1.33. Water cooled engine

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fins. In most cases, a fan is provided to establish forced circulation of air over the radiator tubes which increases the heat transfer rate. The radiator consists essentially of an upper filler tank and a lower tank. Radiating elements are provided in between these tanks. The upper tank is connected to the water outlet from the engine jacket by a rubber hose and the lower tank is connected by a hose to the jacket inlet.

Under extreme cold, to avoid freezing of water in radiator tubes, sometimes anti-freeze solution containing ethylene glycol is added with the cooling water. Water cooling system is classified as natural or gravity circulation system, forced circulation system and open circulation system. In natural circulation system the change in density of water due to change in temperature causes it to circulate in the system. This system is also known as thermo-syphon cooling system. In forced circulation system water is circulated through the water jackets using pump. The power required to run the pump is taken from the engine itself. In this a pump is used to draw water from a cooling pond and to circulate it thorough the engine jackets. The water after circulation returns to the cooling pond as shown in Fig. 1.34.

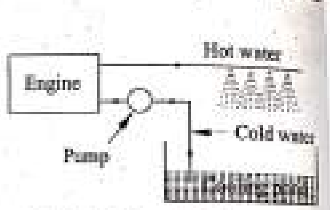


Fig. 1.34. Open circulating system

1.25. Lubrication of IC engines

Lubrication of engine parts are necessary in order to reduce friction between moving parts of the engine. If the moving parts are allowed to rub against each other, they will develop considerable friction and heat, resulting in excessive wear. This can be reduced by placing a film of lubricating oil between the moving part so that they ride on the oil film instead of against each other. This will decrease the power required to overcome friction and will reduce the wear between rubbing parts.

The oil in the engine has several functions to perform. It must remove the heat from the parts it comes in contact with, keep the metal surfaces apart and prevent friction and wear by maintaining an unbroken film of oil between the moving and stationary surface. The oil must also seal the space between piston rings and cylinder walls to prevent leakage of working gases. In addition, the oil must clean the metal parts it comes in contact with and hold in suspension any dirt, metal and carbon particles in the oil.

Main parts to be lubricated in an IC engine are crankshaft, bearings, crank pin, piston, cylinder walls, cams, valve stems, gears etc.

Types of lubricating systems

Several types of lubricating systems are employed to provide efficient lubrication for the internal moving parts of an engine. The various systems supply oil to the moving parts by splash, by gravity, by pressure feed or by some combination of these methods.

The splash system is the simplest method of lubrication. Such systems are usually designed with an oil reservoir in the base of the engine. When the connecting rod moves up it splashes the oil in the form of a spray. The internal parts of the engine are lubricated by this oil spray. This type of lubrication is employed in some types of small single cylinder stationary engines and on engines employed in scooters.

The splash and circulating system is similar in operation to the splash system, except that an oil pump is employed to keep the reservoir with oil.

In a splash and pressure system, an oil pump supplies oil under pressure to the main and crankshaft bearings. The oil pump also supplies oil to the reservoir. Other main parts to be lubricated get oil by the splash system.

In a forced feed (pressure) system, oil is forced by an oil pump to all main bearings connecting rod bearings, camshaft bearings and the gears. The valve mechanism also gets oil under pressure. The cylinder walls, piston and the piston pins are lubricated by the oil spray thrown off from the connecting rod and crank shaft. Most of the present day engines are lubricated by this type of lubricating system.

Desirable properties of lubricants

1. The oil should maintain sufficient viscosity under all ranges of temperatures. Oil with high viscosity index is preferred. This will avoid very high viscosity at cold temperatures and very low viscosity at high temperatures.
2. The oil must not vaporise in its operating temperature range.
3. The oil should have high specific heat to remove the heat generated in the parts.
4. The oil must be free from corrosive acids, moisture etc.
5. The oil should have considerable adhesive quality to permit the oil particles to cling to metal surface.
6. The oil should have good cohesive quality so that a continuous film is formed betwen rubbing surfaces.

1.26. CRDI vehicles

Common Rail Direct Injection [CRDI] is a modern variant of direct injection system for diesel engines. It features a high pressure solenoid or piezoelectric valves make possible fine electronic control over the injection time and amount. In the conventional diesel engines a distributor type injection pump regulated by the engine itself supplies bursts of fuel to injectors through which the diesel is sprayed into the engines combustion chamber. As the fuel is at relatively low pressure and precise control of fuel delivery is not possible the spray is relatively coarse and the combustion process is relatively crude and inefficient. In common rail system the distributor injection pump is eliminated. Instead an extremely high pressure pump stores a reservoir of fuel at high pressure upto 200 MPa, in a common rail. The common rail is basically a tube which in turn branches off to computer controlled injector valves. Each of these injection valves

contains a precision machined nozzle and a plunger driven by a solenoid. Driven by a computer the valves control the precise moment when the fuel injection into the cylinder occurs and also allow the pressure at which the fuel is injected into the cylinders to be increased. The computer also controls the amount of fuel to the pump. As a result the fuel that is injected atomises easily and burns cleanly reducing exhaust emissions and increasing efficiency. Common rail engines require no heating up time and produce lower engine noise and lower emissions than traditional systems. In order to lower engine noise the engines electronic control unit can inject a small amount of diesel just before the main injection event. This reduces the explosiveness and vibration. Some advanced common rail fuel systems perform as many as five injections per stroke which gives a more uniform and controlled combustion and helps extract maximum energy from the combustion cycle. In the 90's all major european passenger vehicle manufacturers used this technology to get more refined, powerful and fuel efficient diesel engines into the demanding market. Some Indian companies have also successfully implemented this technology. Different car makers refer to thier common rail engines by different names as given below.

BMW - D-engines, Honda - i - CTDi, Hyundai-CRDi, Mitsubishi - DI-D, Toyota - D-4D, Mahindra - CRDe, Maruti - DDiS

In CRDI engine high pressure fuel is supplied by one pump unit to a manifold [Common Rail] and individual cylinders have solenoid valves timely injection. The advantages of this system are:

1. Higher efficiency due to variable injection timing.
2. Better combustion and low speeds.
3. Better power balance.
4. Less moving parts.
5. More compact engine.

1.27. MPFI vehicles

Gasoline injection system can be classified as

1. Gasoline direct injection into the cylinder
2. Port injection
3. Manifold injection

In single point injection system one or two injectors are mounted inside the throttle body assembly of the engine. Multi Point Fuel Injection [MPFI] system has one injector for each engine cylinder. Fuel is injected in more than one location. This system injects fuel into individual cylinders based on commands from the on board engine management system computer popularly known as Engine Control Unit [ECU]. The ECU primarily controls the ignition timing and quantity of fuel to be injected.

The ECU is controlled by the data input from a set of sensors located all over the engine and its auxillaries. These sensors detect the various operating conditions of the engine and the performance required out of it. Such sensors constantly monitor, ambient temperature, engine coolant temperature, exhaust gas temperature, oxygen content of exhaust, engine speed, vehicle road speed etc. Based on a programme interpretation of all these input data the ECU gives the various commands to the engines fuel and a spark ignition timing system.

Fig 1.35 shows the block diagram of an MPFI system. Air enters into the intake manifold. The manifold pressure sensor detects the intake manifold vaccum and sends the information to the ECU. The speed sensors also sends information about the rpm of the engine to the ECU. The ECU in turn sends commands to the injector to control the amount of gasoline supply for injection. When the injectors spray fuel into the intake manifold the gasoline mixes with the air and the mixture enters the cylinder of the engine.

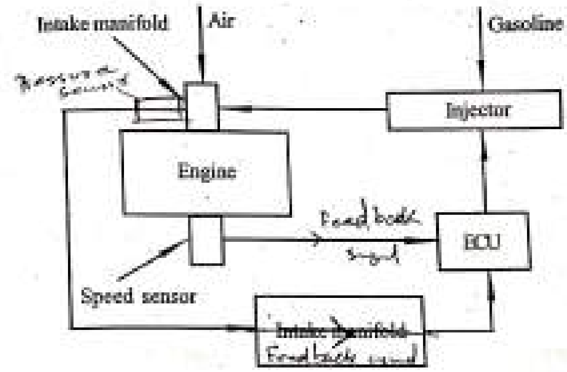


Fig. 1.35. MPFI system

Advantages of MPFI

1. The difference in power developed in each cylinder is minimum.
2. Vibration of engine equipped with the system is less.
3. Immediate response to sudden acceleration and deceleration
4. Since the engine is controlled by ECM [Engine Control Module] more accurate amount of air fuel mixture will be supplied and as a result complete combustion takes place. This leads to effective utilization of fuel supplied and hence low emission level.
5. The mileage of the vehicle is more.

1.28. Concept of hybrid engines

The sharply rising crude oil price has put a technical challenge to the automotive sector to reduce the fuel consumption of the engine. Automotive business is looking towards electric vehicles to reduce the dependance on oil. Vehicles that make use of two or more distinct power sources are known as hybrid vehicles. they usually come with a fuelled power source and an onboard rechargable energy storage system for powering the vehicle. Petroleum Electric Hybrid Vehicles [PEHV] or Hybrid Electric Vehicles [HEV] generally make use of an internal combustion engine and electric batteries to provide the required power to the electric motor.

Advantages of Hybrid vehicles

1. Reduced petroleum consumption due to less weight.

2. Since braking is controlled by the electric motor to some extent, a part of the kinetic energy of the vehicle is recaptured and is used to recharge the batteries. This process is called regenerative braking.

3. Higher efficiency due to regenerative braking.

4. Due to less fuel consumption, air pollution can be kept under control to a great extent.

5. Less noise due to substantial use of the electric motor.

Module 2

2.1. Refrigeration

Refrigeration is the process of maintaining a system at a temperature below the temperature of its surroundings. It can be accomplished by removing heat from the system. For example the household refrigerator absorbs heat from the food products and release this heat into the room where it is kept and thus a constant temperature is maintained inside the refrigerator cabinet. The equipments employed to maintain the system at a lower temperature is termed as refrigerating system and the system which is kept at lower temperature is called refrigerated system. The working fluid used in a refrigerating system is known as refrigerant.

Refrigeration may be obtained by adopting either natural methods or artificial methods. Natural methods include melting of ice. When ice melts, the heat from its surroundings flows into the ice and the surrounding space gets cooled. The natural methods of refrigeration were used in early days. Now, with the development of artificial means of refrigeration (mechanical refrigeration) the application of natural methods becomes insignificant. Hence the term refrigeration is actually used in these days for cooling by mechanical means.

The applications of refrigeration can be broadly classified into three groups as:

(i) Industrial processes which includes processing of food stuffs, farm crops, photographic materials, petroleum and other chemical products, treatment of concrete for dams, processing in textile mills, printing works etc.

(ii) Preservation of perishable goods which includes storage and transportation of food stuffs (eg. Fish, fruits, vegetables, meats, dairy products, poultry products etc).

(iii) Providing comfortable environment which includes comfort air conditioning of residences, hospitals, theatres, offices etc.

2.2. Unit of refrigeration

The rate of heat absorbed from a body or space to be cooled is termed as refrigerating effect. The standard unit of refrigeration is ton refrigeration or simply ton.

The rate of heat absorbed by the system from the body to be cooled, equivalent to the latent heat of fusion of one ton of ice from and at 0°C in 24 hours is called one ton refrigeration. The term ton refrigeration is a carry over from the time ice was used for cooling. This unit of refrigerating capacity is currently used in USA, UK and India. In many countries the standard MKS unit of kcal per hr. is in use. In general, one ton refrigeration always means 3.5167 kJ of heat removal per second.

2.3. Reversed Carnot cycle

A Carnot cycle consists of four reversible processes: two isothermal processes and two adiabatic processes [Refer section 1.4]. Here heat is absorbed from a hot reservoir at constant temperature T_1 and rejected to a cold reservoir at constant temperature T_2. The efficiency of Carnot cycle

$$= \frac{\text{Work done}}{\text{Heat absorbed}} = \frac{\text{Heat absorbed - heat rejected}}{\text{Heat absorbed}}$$

$$= 1 - \frac{\text{Heat rejected}}{\text{Heat absorbed}}$$

$$= 1 - \frac{T_2}{T_1}$$

Since all the four processes in the Carnot cycle are reversible processes, it is possible to have a cycle with all the four processes reversed. This cycle is called reversed Carnot cycle. In this cycle, heat is absorbed from a cold reservoir and is rejected to a hot reservoir with the expenditure of external work. The effectiveness of this cycle is the ratio of heat absorbed to the work required for this heat absorption from the cold reservoir. This effectiveness is expressed by a term known as coefficient of performance, COP.

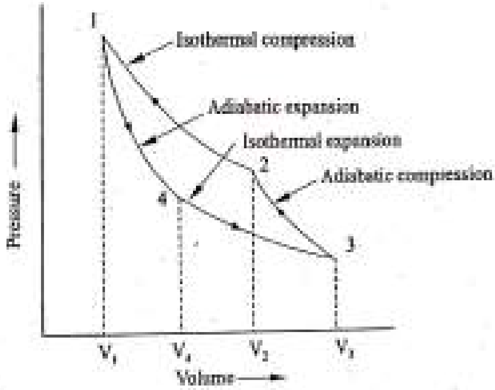


Fig. 2.1. Reversed Carnot cycle

$$\text{COP} = \frac{\text{Heat absorbed}}{\text{Work done}}$$

$$= \frac{\text{Heat absorbed}}{\text{Heat rejected - Heat absorbed}}$$

$$= \frac{1}{\dfrac{\text{Heat rejected}}{\text{Heat absorbed}} - 1}$$

$$=\frac{1}{\frac{T_1}{T_3}-1}$$

Example 2.1.

A Carnot cycle operates between temperatures 400K and 300K. Calculate the efficiency of Carnot cycle and COP of reversed Carnot cycle.

Solution

Given

Temperature of hot reservoir, $T_1 = 400K$

Temperature of cold reservoir, $T_3 = 300K$

$$\eta_{Carnot} = 1 - \frac{T_3}{T_1}$$

$$= 1 - \frac{300}{400} = 0.25$$

$$= 25\%$$

$$COP = \frac{1}{\frac{T_1}{T_3}-1} = \frac{T_3}{T_1 - T_3}$$

$$= \frac{300}{400-300}$$

$$= 3$$

2.4. Coefficient Of Performance (COP)

The effectiveness of a refrigerator is expressed by a term known as coefficient of performance. It is the ratio of desired refrigerating effect to the work spent to produce the refrigerating effect

$$COP = \frac{\text{Desired refrigerating effect}}{\text{Work spent in producing the refrigerating effect}}$$

COP of a refrigerator will be greater than unity.

2.5. Vapour compression system

In a vapour compression refrigerator the working fluid is a vapour which readily evaporates and condenses. During the evaporation process it absorbs heat and gets converted from liquid to vapour. During the condensing process it rejects heat and gets converted from vapour to liquid.

A simple vapour compression system of refrigeration consists of the following basic components:

i) Compressor

ii) Condenser

iii) Expansion valve

iv) Evaporator

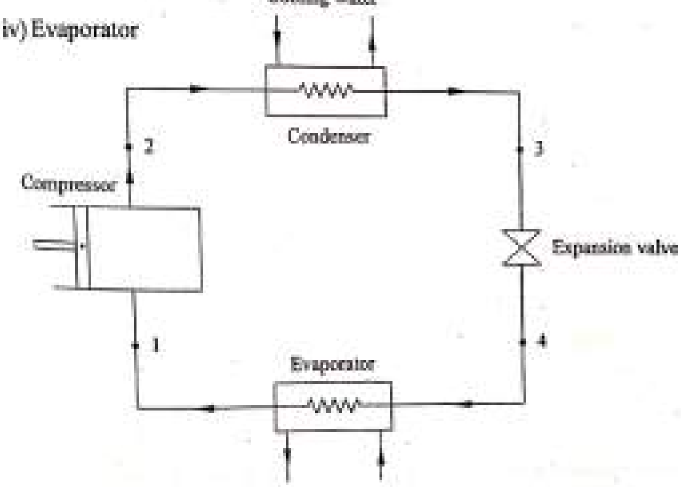


Fig. 2.2. Vapour compression cycle

The line diagram of the arrangement is shown in Fig. 2.2. Let the vapour leaving the evaporator be dry saturated. This dry saturated vapour at pressure p_1 and temperature T_1 is drawn into the compressor cylinder during its suction stroke and during the compression stroke the vapour is compressed isentropically to pressure p_2 and temperature T_2. At the end of compression the vapour is in a superheated state. The vapour at this condition passes to the condenser in which cooling water is circulated to remove heat from the vapour. The vapour is first cooled to the saturation temperature and further removal of latent heat of condensation it condenses to liquid till point 3 is reached. The high pressure liquid is expanded in an expansion valve (throttle valve). The pressure of liquid is lowered to p_1 and the condition obtained after the expansion process is shown by point 4. During throttling the liquid partly evaporates and after throttling we get wet vapour at the low temperature T_1 and low pressure p_1. This wet vapour passes through the evaporator coils immersed in the brine solution. The wet refrigerant vapour absorbs latent heat of vaporisation from the brine solution and evaporates. After evaporation the vapour reaches the condition given by point 1 ie., dry saturated at pressure p_1. This completes one cycle of operation. The cold brine solution is circulated in coils around the space to be refrigerated.

The net refrigerating effect of this system is the heat absorbed by the refrigerant from the brine solution. The work done by the compressor is the work spent to produce this refrigerating effect. Therefore,

$$COP = \frac{\text{Heat extracted in the brine solution}}{\text{Work done by the compressor}}$$

2.6. Refrigerants

The working substance used in a refrigerating system is known as refrigerant. It is actually a carrier of heat from a cold place to a hot place. It changes from liquid to vapour state during the process of absorbing heat and condenses to liquid while liberating heat. The most common refrigerants in use are ammonia, fluorinated hydrocarbons (trade name - Freon), carbon dioxide, sulphur dioxide, air, water etc.

Desirable properties of refrigerants

The important properties to be possessed by an ideal refrigerant are :

1. Condensing and evaporating pressure: Both condensing and evaporating pressure of the refrigerant should be above atmospheric pressure to avoid leakage of air into the system. But the pressure should not be very high as it requires heavy compressor, condenser etc. which increases the cost of the system.
2. Critical temperature : The critical temperature of the refrigerant should be high enough as compared to the condensing temperature, to reduce the power requirements.
3. Freezing temperature : The freezing temperature of the refrigerant should be much below the operating temperature of the plant to prevent the solidification and choking of the flow.
4. Specific heat : The specific heat of the refrigerant liquid should be low to minimise the amount of vapour formed during the throttling process.
5. Latent heat of vapourization: The latent heat of vapourisation of the refrigerant should be high to reduce the quantity of refrigerant to be circulated.
6. Specific volume: The specific volume of the refrigerant vapour should be low to reduce the size of the compressor.
7. Viscosity : Viscosity of the refrigerant should be low to reduce pressure drops, size of pipes, valves etc.
8. Thermal conductivity : The thermal conductivity of the refrigerant should be high to increase the efficiency of the condenser and evaporator..
9. Stability: The refrigerant should be chemically stable throughout the required range of operation.
10. Inflammability : The refrigerant should be non-inflammable (ie, it must not easily catch fire) to avoid fire during overheated conditions.

11. Corrosiveness: The refrigerant should be non-corrosive when comes in contact with metals.

12. Toxicity: The refrigerant should be non-toxic so that it is non-injurious to food stuff and other materials preserved.

13. Leakage detection: The refrigerant should be such that its leakage detection is simple.

14. Oil solubility: The refrigerant must not react with oil, but it must be mixable with the oil for better lubrication of the compressor.

15. Electrical resistance: The refrigerant should have high electrical resistance.

16. Availability: The refrigerant should be cheap and easily available.

2.7. Air conditioning

The science of air conditioning deals with supplying and maintaining a desired internal atmospheric condition irrespective of external conditions. This involves the simultaneous control of air purity, air motion, temperature and humidity of the air inside an enclosed space. The condition to be maintained is dictated by the need for which the conditioned space is intended.

Psychrometric properties

The properties of moist air are called psychrometric properties and the subject which deals with the behaviour of moist air is known as psychrometry. It is the foundation on which most of the air conditioning calculations are based. Several special terms used in the study of psychrometry are defined below:

1. Dry air: Dry air is a mixture of oxygen, nitrogen, carbon - dioxide, hydrogen, argon, neon, helium etc with oxygen and nitrogen as its major constituents. The volumetric composition of air is 79 % nitrogen and 21 % oxygen.

2. Moist air: It is ordinary atmospheric air which is a mixture of dry air and water vapour.

3. Saturated air: It is the air which contains maximum amount of water vapour which the air can hold at a given temperature and pressure. The maximum quantity of water vapour that can be present in the air depends up on the temperature and pressure of air.

4. Specific or absolute humidity or humidity ratio: It is defined as the ratio of the mass of water vapour to the mass of dry air in a given volume of moist air..

5. Relative humidity: It is the ratio of mass of water vapour in a given volume of moist air at a given temperature to the mass of water vapour contained in the same volume of moist air at the same temperature when the air is saturated.

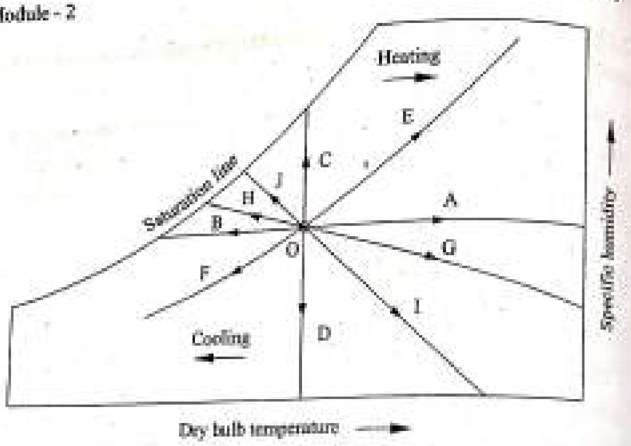
6. Dry bulb temperature: It is the temperature of air measured by an ordinary thermometer.

7. Wet bulb temperature: It is the temperature recorded by a thermometer, when its bulb is covered by a wet cloth and is exposed to a current of moving air. The difference between the dry bulb temperature and wet bulb temperature is known as wet bulb depression and it depends on the relative humidity of air. If relative humidity is high , the rate of evaporation from the wet cloth is low and hence wet bulb depression will be low. When air is dry saturated the DBT and WBT are the same.

8. Dew point temperature: It is the temperature at which the condensation of moisture begins when the air is cooled at constant pressure . The difference between dry bulb temperature and dew point temperature is known as dew point depression.

Psychrometric chart

A psychrometric chart is the graphical representation of the various thermodynamic properties of moist air. The chart enables the properties of moist air to be read off directly.



AOB - Constant dew point temperature line, COD - Constant dry bulb temperature line,

EOF - Constant relative himidity line, GOH - Constant wet bulb temperature line, IOJ - Constant specific volume line.

Fig. 2.3. Psychrometric chart

Fig. 2.3 shows a typical psychrometric chart constructed for a particular value of barometric pressure. The vertical scale of the chart is the specific humidity and the horizontal scale is the dry bulb temperature. In addition, it contains the following lines.

i) Dry bulb temperature lines: These are vertical lines drawn parallel to the ordinate.

ii) Specific humidity lines: These are horizontal lines drawn parallel to the abscissa.

iii) Wet bulb temperature lines: These are straight lines which extend diagonally.

iv) Relative humidity lines: These are curved lines parallel to the saturated line. The saturation line represents 100 % relative humidity

v) Specific volume lines: These are straight inclined lines and uniformly spaced. These lines gives the volume of dry air in m^3/kg

vi) Dew points temperature lines: These are horizontal lines, non uniformly spaced and drawn upto saturation curves.

The various basic process involved in air conditioning are :

i) Sensible heating - Process OA

(ii) Sensible cooling - Process OB

(iii) Humidifying - Process OC

(iv) Dehumidifying - Process OD

(v) Heating and humidifying - Process OE

(vi) Cooling and dehumidifying - Process OF

(vii) Cooling and humidifying - Process OH and OJ

(viii) Heating and dehumidifying - Process OG and OI.

Sensible heating and sensible cooling involve a change in dry bulb temperature. The process of humidifying and dehumidifying involve a change in the specific humidity. When the state of air moves from O to A or to B, there is no change in the moisture content of the air. Similarly when the state of air changes from O to C or to D, the DBT remains constant. The last four processes listed above involved both changes in temperature as well as humidity.

2.8. Cooling and dehumidification

Temperature control is a major process in air conditioning system. It is intended to regulate the dry bulb temperature by various psychrometric processes. This is attained by simple heating or cooling, which may be associated with humidification process.

Cooling of air means lowering its dry bulb temperature. It can be attained by passing the air over evaporator coils of a refrigerating system. In a small room air conditioner the intake air is forced to flow over the evaporator coil directly. In such a case the relative humidity aspect is neglected or is of such order that it gets adjusted by itself. In most cases, an indirect evaporator system is used for cooling the air. In such cases, chilled water (or chilled brine solution) is used to cool the air. The chilled water after absorbing heat from the air rejects heat to the refrigerant in the evaporator.

Humidity control

Another important process in air conditioning is the control of humidity. This is achieved by the process of humidification (increasing humidity) or dehumidification (decreasing humidity).

Dehumidification

Dehumidification is the process of reducing water vapour content of air. It can be accomplished by the use of an air washer or by the use of absorbents. In the absorption method, air is passed through a chemical (known as drying agent). The moisture in the air enters into chemical combination with the drying agent. The chemicals like H_2SO_4 and NH_3 are normally used as drying agents. Dehumidification can also be achieved by using absorbents. These are materials having capacity to absorb moisture. Common absorbents in use are: activated alumina, calcium chloride and silica gel. Normally, this method of dehumidification is used in small air conditioners.

2.9. Summer Air Conditioning

In summer air conditioning air is cooled and generally dehumidified. The schematic arrangement of a typical summer air conditioning system is shown in Fig. 2.4. The atmospheric air flows through a damper to the air filter where dirt, dust and other impurities are removed. Air now passes through a cooling coil whose temperature is much below the required dry bulb temperature. Water is sprayed to the air. The temperature of water is below the dew point temperature of air. Due to the vapourisation of water the temperature of air further decreases. An eliminator is placed in the

path to remove water droplet carried with air. Finally this conditioned air is supplied to the required space using a blower.

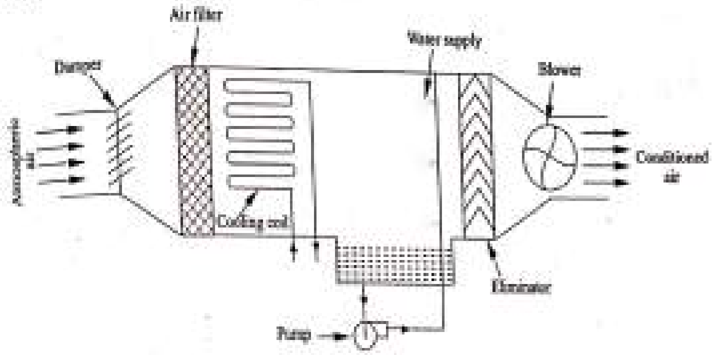
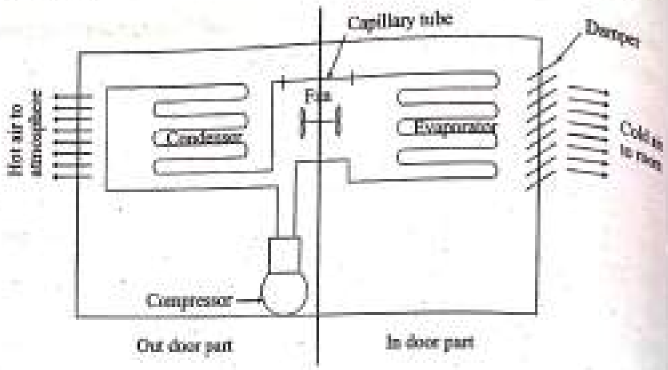


Fig. 2.4. Summer air conditioning

2.10. Unit air conditioner

A window air conditioner which is a unit air conditioner consists of a case divided into two parts, outdoor and indoor parts, by a partition. The outdoor part consists of compressor, condenser and a fan. The indoor part consists of evaporator and a fan. Capillary tube is provided in between the condenser and evaporator. The outdoor portion ramains outside the window. Dampers are provided at the front of indoor portion for changing the direction of airflow.

Low pressure vapour drawn from the evaporator is compressed to a high pressure and is delivered to the condenser. In the condenser the refrigerant vapour is condensed by releasing latent heat oil condensation to the surrounding air. This hot air is driven out using a fan. The high pressure liquid refrigerant enters the capillary tube where the pressure is reduced. This low pressure liquid vapour enters the evaporator.



Unit air conditioner

This liquid re-frigerant evaporates by absorbing latent heat of vaporization from the surrounding air. This cold air is delivered to the room using a fan. The direction of air flow can be changed using a damper. The low pressure refrigerant vapour leaving the evaporator is sucked into the compressor and is compressed to very high pressure. This high pressure vapour is condensed in the condenser. Thus one cycle of operation is completed.

2.11. Central air conditioner

This is the most important type of air conditioner. It is adopted,

(i) When the cooling capacity required is 25tons or more.

(ii) When the air flow is more than $5m^3/hr$.

(iii) When different zones in a building are to be air conditioned.

In this system all the components of the system are installed in a seperate central room. The conditioned air is distributed through ducts from this central room to various rooms to be air conditioned.

2.12. Reciprocating pump

Pump is a mechanical device used to increase the pressure energy of a liquid. In most of the applications, pump is used for lifting liquids from a

lower to higher level. This is achieved by creating a low pressure at the inlet and a high pressure at the outlet of the pump. Due to the low pressure at the inlet of the pump, liquid is lifted from the sump to the pump. Due to high pressure at the outlet of the pump the liquid is lifted from the pump to the required height. Based on the working principle, pumps are classified as positive displacement and rotodynamic pumps. Reciprocating pump, gear pump, screw pump, vane pump etc., are examples of positive displacement pumps. Centrifugal pump, propeller pump etc, are examples of rotodynamic pumps. Based on a number of stages in which the pressure of the liquid is increased, rotodynamic pumps are classified as single stage and multistage pumps.

Reciprocating pump is a positive displacement pump in which the required low pressure at the inlet and the required high pressure at the outlet of the pump is obtained by the reciprocating motion of a piston or plunger inside a close fitting cylinder. The following are the main components of a reciprocating pump. 1. Cylinder, 2. Piston, 3. Piston rod, 4. Connecting rod, 5. Crank, 6. Strainer, 7. Suction pipe, 8. Suction valve, 9. Delivery valve, 10. Delivery pipe.

Working principle

Refer Fig. 2.5. Movement of piston towards right creates a vacuum inside the cylinder and atmospheric pressure forces the liquid up through the suction pipe into the cylinder. During the movement of piston towards left liquid is pushed into the delivery pipe. The suction and delivery pipes are provided with non-return valves. These non- return valves or one way valves ensure unidirectional flow of liquid. Thus the suction valve allows the liquid only to enter the cylinder and prevents the flow of liquid from the cylinder to the suction pipe. Similarly the delivery valve allows the liquids only to discharge from the cylinder and prevents the flow of liquid from the delivery pipe to the cylinder. The movement of piston inside the cylinder is obtained by connecting the piston rod to a crank by means of a connecting rod. The crank is rotated using an electric motor. Thus when the crank rotates, the piston reciprocates inside the cylinder, alternately filling and emptying the cylinder. The volume of liquid delivered is constant

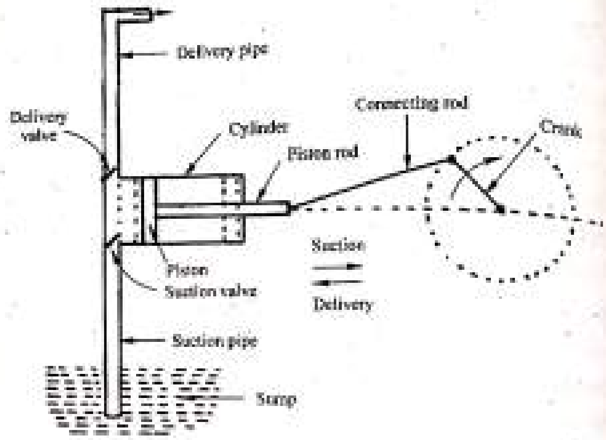


Fig. 2.5. Reciprocating pump.

regardless of pressure and is varied only due to the change of speed of rotation of the crank. A strainer is provided at the end of suction pipe in order to keep leaves, wooden pieces and other rubbish away from the pump.

2.13. Centrifugal pump

It is a rotodynamic pump in which the required low pressure at the inlet of pump and the high pressure at the outlet of the pump is obtained mainly due to centrifugal action. When a certain mass of liquid is made to rotate by an external force, it is thrown away from the axis of rotation and a centrifugal head is impressed which enables the liquid to rise to a higher level. In centrifugal pumps, in addition to the centrifugal action, as the liquid passes through the revolving wheel or impeller, the angular momentum of the liquid changes which also results in increasing the pressure of the liquid.

Impeller , casing , delivery pipe, suction pipe, foot valve and strainer are the main components of a centrifugal pump.

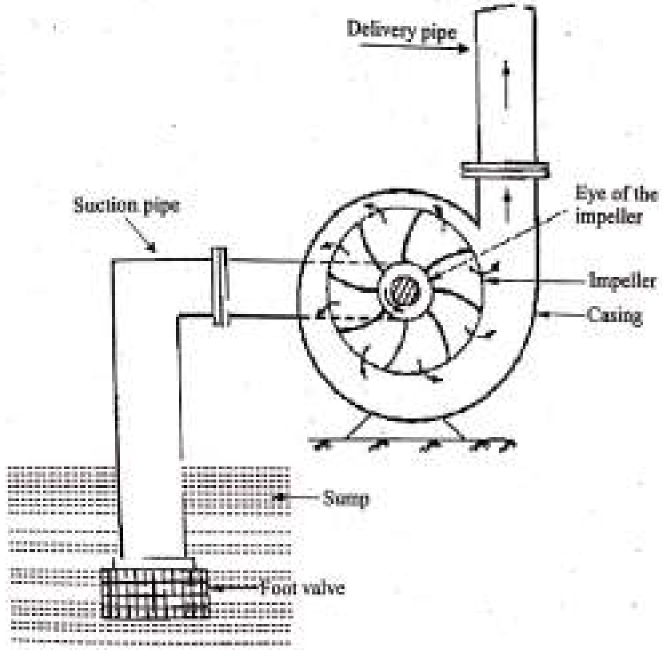


Fig. 2.6. Centrifugal pump

Refer Fig. 2.6. The impeller is a wheel or rotor which is provided with a number of curved blades or vanes. It is mounted on a shaft which is coupled to an electric motor. Casing is an air tight chamber which surrounds the impeller. The shape of the casing is such that the sectional area of flow around the periphery of the impeller gradually increases towards the delivery pipe. This gradual increase in area gradually reduces the velocity of the liquid leaving the impeller to that in the delivery pipe. This reduction in the kinetic energy of the liquid while passing through the casing is converted into useful pressure energy. Suction pipe connects the centre of the impeller to the sump from which liquid is to be pumped. The lower part of the suction pipe is fitted with a foot valve and a strainer. The liquid after filtering by the strainer passes through the foot valve. The foot valve is a non-return valve which opens only in the upward direction. Through the foot valve liquid enters the suction pipe. Delivery pipe connects the outlet of the pump to the delivery point. A valve is provided on the delivery pipe , closed to the outlet of the pump, to control the flow of liquid through the delivery pipe.

Working principle

After priming, the impeller is rotated by means of an electric motor. Filling the suction pipe and casing with the liquid to be pumped is known as priming. Priming is required to remove air and vapour from the suction pipe and casing. The removal of air from the casing is required because the vaccum crated in the eye of the impeller is proportional to the density of the liquid that is in contact with the impeller. If the impeller is made to rotate in the presence of air, the vacuum created may not be sufficient to lift the water from the sump to the eye of the impeller. Therefore it is essential to prime a centrifugal pump before it can be started. The rotation of the impeller in the casing full of liquid produces a forced vortex which imparts a centrifugal head to the liquid. This results in an increase of pressure of liquid. If the speed of the impeller of the pump is sufficiently high the pressure of liquid in the impeller will be increased. When the delivery valve is opened the liquid within the impeller flows in an outward direction therby leaving the vanes of the impeller at the outer circumference with high velocity and pressure. The vacuum created at the eye of the impeller causes the liquid from the sump to rush through the suction pipe, replacing the liquid which is being discharged from the impeller. While the liquid flows through the rotating impeller it receives energy from the vanes which results in an increase of both pressure and velocity. The kinetic energy thus increased is converted into pressure energy while flowing through the volute casing. Thus the liquid is discharged from the pump to the delivery pipe with very high pressure.

2.14. Comparison of centrifugal and reciprocating pumps

1. The flow of liquid from a centrifugal pump is smooth and even whereas that from a reciprocating pump is pulsating.

2. Centrifugal pumps are suitable for large discahrge and low heads. Reciprocating pumps are suitable for high heads and low discharge.

3. Initial cost of centrifugal pump is less compared to the initial cost of reciprocating pumps.

4. Centrifugal pump is compact and occupies less floor space. The floor space required for a reciprocating pump is about 6 to 8 times that for a centrifugal pump.

5. Efficiency of a low head centrifugal pump is more than that of a low head reciprocating pump.

6. For small discharge and high head, the efficiency of a reciprocating pump is more than that of a centrifugal pump.

7. A centrifugal pump needs priming wheras no priming is required in a reciprocating pump.

8. Highly viscous liquid such as oils, muddy and sewage water , paper pulp etc. can be easily handled by centrifugal pumps. Valves and glands in reciprocating pumps cause trouble when it is used to pump the above said liquids.

9. Compared to reciprocating pump, the installation of centrifugal pump is easy.

10. Construction of centrifugal pump is simple. More number of parts in the reciprocating pump make the construction complicated.

11. Maintenance cost of centrifugal pump is low.

12. Due to the high speed of centrifugal pump, impeller can be directly coupled to an electric motor. In the case of reciprocating pump, some speed reduction device is required.

13. Centrifugal pump has no reciprocating parts and hence the wear and tare is less.

14. For a given discharge, the weight of centrifugal pump is less than the weight of a reciprocating pump.

2.15. Hydraulic turbine

Hydraulic turbine is a device which converts the energy of water into mechanical energy. The turbine drives the generator which converts the mechanical energy into electrical energy. Hydraulic turbine consists of a wheel called runner provided with a number of curved or straight vanes (blades) on its periphery.

Hydraulic machines are classified on the basis of the action of water on these moving blades. According to the action of water, turbines are classified as impulse turbine and reaction turbine.

2.16 Impulse turbine

In an impulse turbine, the potential energy of water is converted into kinetic energy by a set of nozzles. This produces powerful jets impinging on the vanes, buckets provided on the periphery of a wheel. The wheel is fixed to a shaft, which is coupled with a generator.

2.17. Pelton turbine

Fig. 2.7. shows a Pelton wheel hydraulic turbine, which is the most commonly used impulse turbine. The nozzle producing the jets is shown in the Fig. 2.7. There is a spear head provision in the nozzle to control the opening, which controls the velocity of the issuing jet. The buckets provided on the wheel are in the form of double hemispherical cups. The water after imparting its energy to the turbine, is discharged into the tailrace.

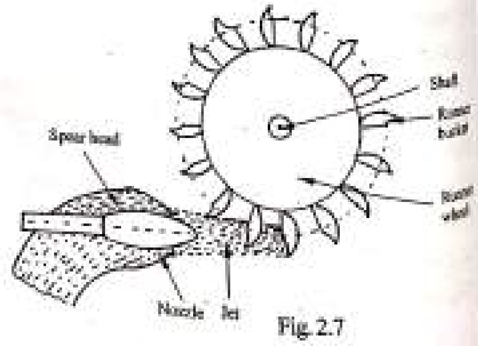


Fig. 2.7

This type of turbine is used where high head of water is

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available. Other examples of impulse turbine include Turgo wheel, Jonval turbine and Girard turbine.

2.18. Francis turbine

It is a reaction turbine. In reaction turbines the water entering the runner possess pressure energy and this water in turn does work on the vanes by the principle of reaction.

Fig. 2.8. shows a simple diagramatic representation of a Francis turbine, which is the mostly used reaction turbine. It consists of an inner of rotating vanes forming the runner, surrounded by an outer ring of stationary guiding mechanism. Water from the penstock which is the pipe connecting the reservoir and the turbine flows into a scroll casing surrounding the turbine runner. From the scroll casing water flows through the guiding mechanism and enters the runner.

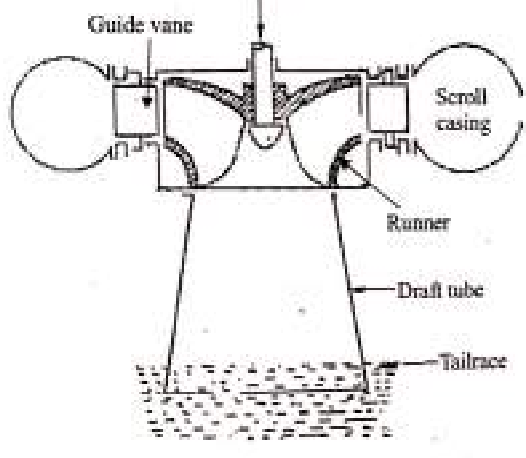


Fig. 2.8. Francis turbine

After imparting energy to the runner, the water discharges through draft tube. Draft tube is a metallic pipe or concrete tunnel having gradually increasing cross-sectional area. It connects the runner exit of the reaction turbine and the tailrace. Draft tube provides a negative suction head at the runner outlet which increases the net working head on turbine and thus the output.

2.19. Kaplan turbine

It is an axial flow reaction turbine where water enters and leaves the runner vanes parallel to the axis of shaft. It is particularly suited for low head (upto 30m) and high discharge of water. The main components of Kaplan turbine are:

1. Scroll casing
2. Guide vane mechanism
3. Boss with adjustable vanes
4. Draft tube

Since Kaplan and Francis turbines are reaction turbines, the working principle of Kaplan turbine is same as that of Francis turbine. Water from the penstock flows into the scroll casing surrounding the turbine runner. From the scroll casing water flows through the guide mechanism and enters the runner vanes. The force exerted by water on the vanes causes the runner shaft to rotate. After imparting energy to the runner, the water is discharged through the draft tube.

2.20. Overall efficiency of centrifugal pump

Pump is a hydraulic device which convert mechanical energy of rotating shaft into kinetic and pressure energy of water. It is generally used to lift water from a low to a high level. Static head is the total vertical lift through which water is lifted by the pump. It is denoted by H. When Q m^3/s water is lifted through a height, H, the workdone/s is $\rho \times g \times QH$.

ρ is the mass density of water, $1000 kg/m^3$.

g is the acceleration due to gravity, $9.81 m/s^2$.

Q is the discharge of water in m^3/s.

H is the total head in m.

P is the power supplied from the electric motor to the pump in kW (Input power).

$$\text{Output power of pump} = \frac{\rho g QH}{1000} \text{ kW}$$

$$\text{Overall efficiency } \eta_0 = \frac{\text{Output power}}{\text{Input power}}$$

$$= \frac{\rho g QH}{1000 P}$$

Example 2.1

A centrifugal pump discharges water at a rate of 2000 litres/s against a head of 16m when running at 300 rpm. Calculate the power required to run the pump if the overall efficiency of pump is 50%.

Solution

Given

$$Q = 2000 lit/s = 2 m^3/s$$

$$H = 16m$$

$$\eta_0 = 0.5$$

To calculate, P

$$\text{Overall efficiency, } \eta_0 = \frac{\rho g QH}{P \times 1000}$$

$$\text{Power required, } P = \frac{\rho g QH}{\eta_0 \times 1000}$$

$$= \frac{1000 \times 9.81 \times 2 \times 16}{0.5 \times 1000}$$

$$= 627.84 \text{ kW.}$$

Example 2.2

A centrifugal pump discharges water at 120 litres/s against a head of 25m. If power required is 40kW, calculate the overall efficiency of the pump.

Solution

Given

$$Q = 120 \text{ lit/s} = 0.12 \text{ m}^3/\text{s}$$

$$H = 25\text{m}$$

$$P = 40\text{kW}$$

To calculate, η_0

$$\eta_0 = \frac{\rho g QH}{P \times 1000}$$

$$= \frac{1000 \times 9.81 \times 0.12 \times 25}{40 \times 1000} \text{ kW}$$

$$= 73.58\%$$

2.21. Overall efficiency of turbines

A hydraulic turbine converts hydraulic energy of water into mechanical energy of a rotating shaft. Mechanical energy is the output and hydraulic energy, kinetic and potential energy of water is the input to the turbine. The overall efficiency is the ratio of output power to input power.

$$\eta_0 = \frac{\text{Output power}}{\text{Input power}}.$$

Input power to Pelton wheel is the kinetic energy of jet striking the bucket

$$KE = \frac{1}{2} mv^2 = \frac{1}{2} \rho QV^2$$

Potential energy of water of head H is

$$mgH = \rho QgH$$

Equating KE and PE of water,

$$\frac{1}{2} \rho QV^2 = \rho QgH$$

$$V = \sqrt{2gH}$$

When a is the area of cross section of jet striking the bucket, then discharge from the nozzle, Q = aV.

a is the area of jet im m² and V is the velocity of jet in m/s.

$$Q = aV \text{ m}^3/\text{s}$$

Output power being the power of shaft it can be measured directly.

$$\text{Overall efficiency, } \eta_0 = \frac{P \times 1000}{\rho g QH}$$

P = output power in kW

ρ = mass density of water in kg/m³

g = acceleration due to gravity in m²/s

Q = discharge in m³/s

H = head in m.

Example 2.3

A Pelton wheel working under a head of 500m produces 15 MW at 500rpm. If the overall efficiency of the turbine is 85%, calculate the discharge of turbine.

Solution

Given

$H = 500m$, $P = 15MW = 15 \times 10^6 W = 15 \times 10^3 kW$

$\eta_0 = 85\% = 0.85$

To calculate, Discharge Q

$$\eta_0 = \frac{P \times 1000}{\rho g Q H}$$

$$Q = \frac{P \times 1000}{\eta_0 \rho g H}$$

$$= \frac{15 \times 10^3 \times 1000}{0.85 \times 1000 \times 9.81 \times 500}$$

$$= 3.6 \text{ m}^3/\text{s}$$

Example 2.4

Two jets strike the buckets of Pelton wheel which develops 15MW. The diameter of each jet is 15cm and the net head is 500m. Calculate the overall efficiency of the turbine.

Solution

Given

No. of jets = 2

Power $P = 15MW = 15 \times 10^3 kW$

diameter of jet = 15cm = 0.15m

$H = 500m$

To calculate, η_0

Discharge from one nozzle $= a \times V$

Discharge from two nozzles $= 2 \times a \times V$

Velocity of jet, $V = \sqrt{2gH}$

$$= \sqrt{2 \times 9.81 \times 500}$$

$$= 99.05 \text{ m/s}$$

$$Q = 2 \times a \times V$$

$$= 2 \times \frac{\pi d^2}{4} \times 99.05$$

$$= 3.5 \text{ m}^3/\text{s}$$

$$\eta_0 = \frac{P \times 1000}{\rho g Q H}$$

$$= \frac{15 \times 10^3 \times 1000}{1000 \times 9.81 \times 3.5 \times 500}$$

$$= 0.8737 = 87.37\%$$

Example 2.5

Calculate the discharge from a Francis turbine with overall efficiency 75%, working under a head of 7.5m and producing a power of 150kW.

Solution

Given

$\eta_0 = 75\% = 0.75$

$P = 150kW$

$$H = 7.5m$$

To calculate, Q

$$\eta_0 = \frac{P \times 1000}{\rho g Q H}$$

$$Q = \frac{P \times 1000}{\eta_0 \times \rho g H}$$

$$= \frac{150 \times 1000}{0.75 \times 1000 \times 9.81 \times 7.5}$$

$$= 2.72\ m^3/s$$

Example 2.6

A Kaplan turbine working under a head of 20m develops 12000kW power. Calculate the overall efficiency of the turbine when the discharge from the turbine is $70m^3/s$.

Solution

Given

$$H = 20m$$
$$P = 12000kW$$
$$Q = 70m^3/s$$

To calculate, η_0

$$\eta_0 = \frac{P \times 1000}{\rho g Q H}$$

$$= \frac{12000 \times 1000}{1000 \times 9.81 \times 70 \times 20}$$

$$= 0.8737$$

$$= 87.37\%$$

2.22. Belt drive

Whenever power is to be transmitted from one shaft to another which are at a considerable distance apart, a belt drive is generally used. Pulleys are mounted on the driver and driven shafts and an endless belt is fitted tightly over these pulleys. The factor responsible for power transmission, or in other words making the belt and pulleys run together, is the frictional resistance between the belt and the pulley. The amount of power transmitted depends upon the velocity of belt, the tension under which the belt is placed on the pulleys and the arc of contact of the belt and smaller pulley.

Types of belts

Though there are many types of belts for transmission of power, flat belts and V-belts are widely used. Flat belts are used to transmit moderate amount of power. These are used upto 10m distance between driving and driven shafts. V-belts are more suitable for transmission of large amount of power between two shafts having a short center to center distance. The ideal distance is 1.25 to 1.5 times the diameter of the larger pulley.

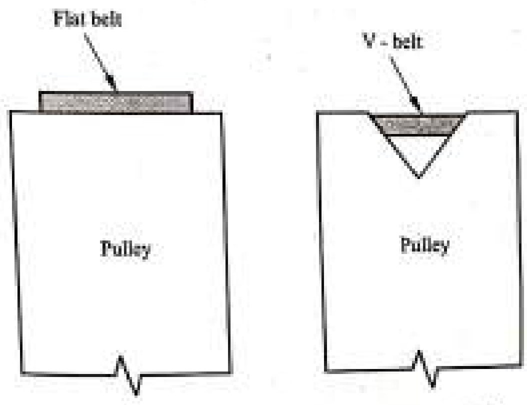


Fig. 2.9. Flat belt

Fig. 2.10. V - belt

The belts used for transmission of power must have larger strength, flexibility and life and must have a high coefficient of friction. In addition to leather belts, belts made of rubber, balata and cotton or fabric are also widely used. Rubber belts, consisting of layers of fabric impregnated with a rubber composition and having a thin layer of rubber on the faces, are very flexible but are quickly destroyed if allowed to come in contact with oil or grease. Balata belts are similar to rubber belts except that balata gum is used in place of rubber. It is about 25 % stronger than rubber belt. Cotton or fabric belts are made from canvas or cotton duck in which a number of layers, depending upon the thickness desired are put and stitched together. These are treated with linsoil to make it water proof. The cotton belts are cheaper and suitable for rough service where little attention is needed.

Types of belt drives

(i) Open belt drive

It is used with shafts arranged in parallel and to be rotated in the same direction. The driver pulley pulls the belt from one side and delivers the

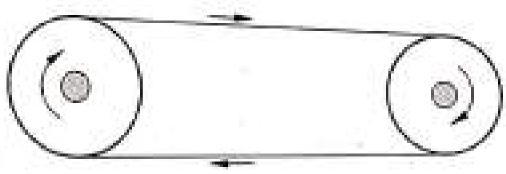


Fig. 2.11. Open belt drive.

same to the other side. Hence the tension on the former side will be greater than the later side. The side where tension is more, is called tight side and the other side is called slack side.

(ii) Cross belt drive

It is used with shafts arranged in parallel and to be rotated in opposite directions. At the point where the belt crosses, it rubs against itself and wears.

Fig. 2.12. Cross belt drive

In order to minimize wear, the shafts should be placed at a minimum distance of 20 b, where b is the width of belt. Also the speed of the belt should be less than 15 m/sec.

2.23. Chain drive

Chain drive consists of an endless chain running over special profile toothed wheels called sprockets. One of the sprockets will be the driver and the other driven. The smaller sprocket is called pinion and the bigger one is called wheel. The chain is made up of plates, pins and bushing. These parts are usually made of high grade steel.

From the application point of view chain drives are classified as power transmission chains, hoisting chains and pulling chains. Power transmission chains are used when power is to be transmitted from one shaft to another. Hoisting chains are used for lifting loads. Pulling chains are used in elevators, conveyors etc.

Main types of chains used to transmit power are:

i) Roller Chain: Refer Fig. 2.13. It consists of rollers, bushes, pins inner plates and outer plates. The pin passes centrally through the bush and the roller surrounds the bush. The roller turns freely on the bush and the bush turns freely on the

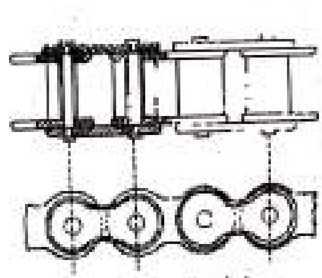


Fig. 2.13. Roller chain

pin. Two adjacent rollers are held by two inner plate (roller link plates). These inner plates connect the two bushes as shown in the figure. The bushes turn freely on the inner plates. Two adjacent bushes are held by two outer plates called pin link plates. These outer plates connect the two central pins and keep them in position. To prevent the sliding of outer plates laterally outwards, the pin ends are hammered to the shape of rivet head. In order to reduce friction all the contact surfaces are lubricated.

ii) Silent or inverted tooth chain: Refer Fig. 2.14. It consists of special profile plates corresponding to the profile of the sprocket teeth.

Fig. 2.14. Silent chain

These types of chains are more complex in design and require careful maintenance. It is employed when heavier loads are to be transmitted and maximum quietness is desired.

2.24. Gear Drive

The term gear is generally used to denote toothed wheel. For transmission of power one gear is mounted on the driving shaft and another one of the driven shaft, their teeth meshing with each other. The distance between the two shafts should be just sufficient to enable meshing of the gear teeth. If the driving and driven shafts are at a long distance so that a direct meshing of two gears is not possible, then required number of gears may have to be incorporated in between the two gears so as to make the drive possible.

Gear teeth are formed either by casting or by machine cutting. The cutting of gear teeth is done by milling, shaping or hobbing. A variety of

materials are used for the manufacture of gears depending on requirement. The cheapest material used is ordinary grey iron. For heavy duty gears cast steel and alloy steel are preferred. Non-ferrous metals like phosphor bronze, nickel, manganese etc. are used under corrosive environments.

There are many types of gears and the following are the important ones:

(i) Spur gears: Spur gears are those which have teeth cut parallel to the axis of the shaft. Spur gears are used to transmit power between parallel shafts. Fig. 2.15 (a)

(ii) Helical gears: Helical gears are used in the same way as spur gears, but the teeth cut on the periphery are of helical screw form. A helical tooth is thus inclined at an angle to the axis of the shaft. Fig. 2.15 (b)

(iii) Bevel gears : Bevel gears are used to connect two non parallel shafts with intersecting axes. Even though bevel gears are meant for shafts at right angle to each other, it can also be used for any angle. Fig. 2.15 (c)

(iv) Worm gears: Worm gears are used for power transmission between non-intersecting shafts that are generally

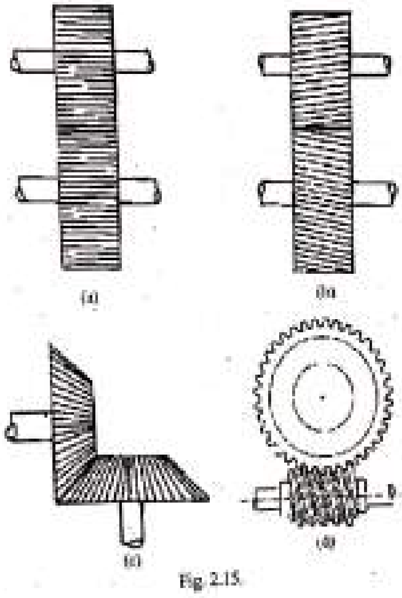


Fig. 2.15.

at right angles to each other. The worm gearing consists of worm and worm wheel. A worm is a threaded screw and is used as the driver. The worm wheel is a toothed wheel. The teeth of the worm wheel remain engaged with the threads of the worm. Fig. 2.15 (d).

Fields of Application

Belt drive is commonly used for transmission of power when exact velocity ratio is not required. Flat belts are used when the distance between the shafts is more and only moderate amount of power is to be transmitted . When the distance between the shafts is less and a large amount of power is to be transmitted, the V - belts are used. Belt drive is comparatively cheaper than other drives.

Some of the advantages of flat belts are:

(i) Can be used with high speed drives.

(ii) Can be used in industrial and abbrassive environment.

(iii) Absorbs shock and vibrations.

(iv) Offers longer life when properly maintained.

Some of advantages of V- belts are:

(i) Can be used for high speed ratios as high as 10:1.

(ii) No possibility of belt coming out of grooves.

(iii) Low percentage of slip.

(iv) A number of drives can be taken from a single pulley by providing a number of grooves on the same pulley.

Chain drives are used in bicycles, motorcycles, agriculture machinery, rolling mills, conveyors , transport mechanisms etc.

Advantages of chain drives are:

(i) Can provide non-slip drive

(ii) Very high efficiency

(iii) Less load on shafts

(iv) Occupies less space

(v) Can be operated at adverse temperatures.

(vi) Can transmit motion to several shafts by a single chain.

Disadvantages of chain drives are:

(i) High cost

(ii) More weight

(iii) Velocity fluctuations due to stretching during use.

(iv) Needs accurate mounting and careful maintenance

Gear drives are used when positive drives are necessary and when the centre to centre distance between the shafts is relatively short. Also gears are used whenever motion is to be transmitted between non parallel and non-intersecting shafts. Gears are of great practical utility in almost all kinds of precission engineering works. Hardened gear find application in aircraft, automobile and other industries.

Advantages of gear drives are:

(i) High efficiency

(ii) Less maintenance cost

(iii) Can be used for non intersecting and non parallel shafts.

(iv) Very high accuracy.

2.25. Gear

Various terms used in the study of gears have been explained below:

1. Pitch cylinders: Pitch cylinders of a pair of gears in mesh are the imaginary cylinders which by rolling together transmit the same motion as the pair of gears.

2. Pitch circle: It is the circle with radius equal to the radius of the pitch cylinder.
3. Pitch circle diameter: It is the diameter of pitch circle.
4. Pitch point: It is the point of contact of two pitch circles.
5. Circular pitch: It is the distance measured along the circumference of pitch circle from a point from one tooth to the corresponding point on the adjacent tooth. It is denoted by p_C.

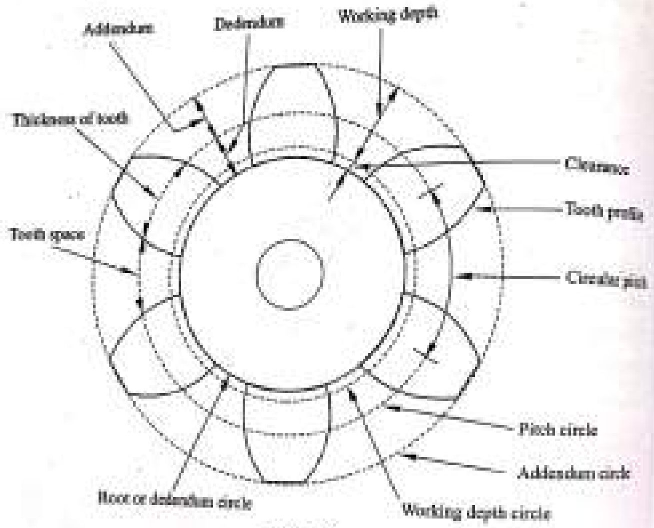


Fig. 2.16

$p_C = \frac{\pi d}{T}$, where d is the pitch circle diameter and T is the number of teeth.

6. Pitch angle: It is the angle substended by the circular pitch at the centre of the pitch circle.
7. Diametral pitch: It is the number of teeth per unit length of the pitch circle diameter. It is denoted by P.

$$P = \frac{T}{d}$$

8. Module: It is the ratio of pitch circle diameter in millimeter to the number of teeth. It is denoted by m.

$$m = \frac{d}{T}$$

9. Addendum circle: It is the circle passing through the tips of teeth.
10. Addendum: It is the radial distance between pitch circle and addendum circle.
11. Dedendum or root circle: It is the circle passing through the roots of the teeth.

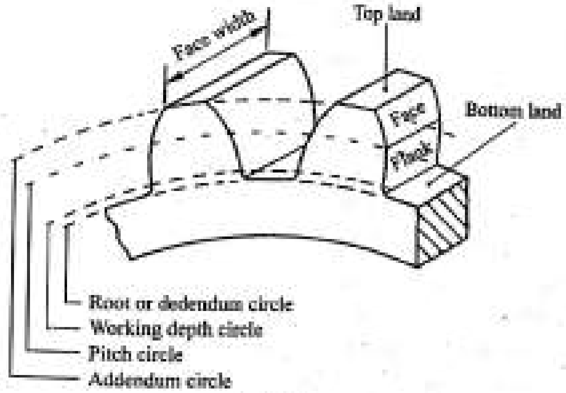


Fig. 2.17.

12. Dedendum: It is the radial distance between pitch circle and dedendum circle.
13. Full depth of teeth: It is the radial distance between dedendum circle and addendum circle

Full depth = Addendum + Dedendum

14. Clearance: It is the radial difference between the addendum and the dedendum of a tooth.

15. **Top land:** It is the surface at the top of tooth.
16. **Bottom land:** It is the surface at the root of tooth, in between two adjacent teeth.
17. **Tooth thickness:** It is the width of the tooth measured along the pitch circle
18. **Tooth space:** It is the width of space between the two adjacent teeth measured along the pitch circle.
19. **Backlash:** It is the difference between the tooth space and the tooth thickness, measured along the pitch circle.
20. **Face:** It is the tooth surface between the pitch circle and the top land.
21. **Flank:** It is the tooth surface between the pitch circle and the bottom land.
22. **Face width:** It is the length of tooth measured parallel to the axis of gear.
23. **Profile:** It is the curve formed by the face and flank of the tooth.

Velocity ratio of gear drive

The gear ratio is defined as the ratio of the speed of driven gear to the speed of driving gear. It is denoted by the letter 'G'. A schematic diagram of two mating spur gears A and B is shown in Fig. 2.18. Let the pitch circle diameters of A and B be d_1 and d_2 respectively.

In case the driving gear A rotates with N_1 rpm (ω_1 rad/sec) in clockwise direction, then the driven gear B rotates with N_2 rpm (ω_2 rad/sec) in anticlockwise direction.

The peripheral velocity of driving gear A is equal to $\frac{\omega_1 d_1}{2}$

The peripheral velocity of driven gear B is equal to $\frac{\omega_2 d_2}{2}$. Since the gear drive is positive, the peripheral velocity of driven gear will

Fig. 2.18

be equal to the peripheral velocity of the driver gear.

Hence, $$\omega_2 \frac{d_2}{2} = \omega_1 \frac{d_1}{2}$$

$$\frac{\omega_2}{\omega_1} = \frac{d_1}{d_2}$$

$$\text{or } \frac{N_2}{N_1} = \frac{d_1}{d_2} \quad \text{...(i)}$$

Circular pitch of gear A, $p_{C1} = \pi \frac{d_1}{T_1}$ where T_1 is the number of teeth on driving gear A.

Circular pitch of gear B, $p_{C2} = \pi \frac{d_2}{T_2}$ where T_2 is the number of teeth on driven gear B:

Two gears will mesh together correctly, only if the gears have the same circular pitch.

$$\therefore p_{C1} = p_{C2}$$

$$\pi \frac{d_1}{T_1} = \pi \frac{d_2}{T_2}$$

$$\text{or } \frac{d_1}{d_2} = \frac{T_1}{T_2} \quad \text{...(ii)}$$

From (i) and (ii) $$\frac{N_2}{N_1} = \frac{T_1}{T_2}$$

i.e., Velocity ratio or gear ratio, 'G', $\frac{N_2}{N_1} = \frac{T_1}{T_2} = \frac{d_1}{d_2}$

Example 2.7.

Two spur wheels, A and B, on parallel shafts, are in mesh. A has 40 teeth and rotates at 250 r.p.m. B is to rotate at 100 r.p.m. Find the number of teeth on B.

Solution:

Given: $T_A = 40$ $N_B = 100$ rpm $N_A = 250$ rpm

To find: T_B

We have, $\dfrac{N_B}{N_A} = \dfrac{T_A}{T_B}$

$$T_B = T_A \times \frac{N_A}{N_B}$$

$$= 40 \times \frac{250}{100} = 100$$

$$T_B = 100$$

Example 2.8.

Two mating spur gears have 60 and 40 teeth. Their common module is 5 mm. Determine the centre to centre distance between the gears axis.

Solution:

Given: $T_1 = 60$, $m = 5$ mm, $T_2 = 40$

To find : L

$$\text{Module, } m = \frac{d}{T}$$

$$d_1 = mT_1 = 5 \times 60 = 300 \text{ mm.}$$

$$d_2 = mT_2 = 5 \times 40 = 200 \text{ mm}$$

We have,

$$L = r_1 + r_2 = \frac{d_1}{2} + \frac{d_1}{2} = \frac{300}{2} + \frac{200}{2}$$

$$= 150 + 100 = 250$$

$$L = 250 \text{ mm.}$$

2.26. Gear trains

Any combination of gear wheels by means of which motion is transmitted from one shaft to another shaft is called gear train.

Simple gear train

A simple gear train is one in which each shaft carries one gear only. Each of the intermdiate gear acts both as a driven and as a driver. These intermediate gear have no effect on the velocity ratio and hence these gears are known an idlers. Fig. 2.19 (a) shows a simple gear train with one idler and Fig. 2.19(b) shows a simple gear train with two idlers.

Referring Fig. 2.19 (a),

$$\frac{N_2}{N_1} = \frac{d_1}{d_2}; \frac{N_3}{N_2} = \frac{d_2}{d_3}$$

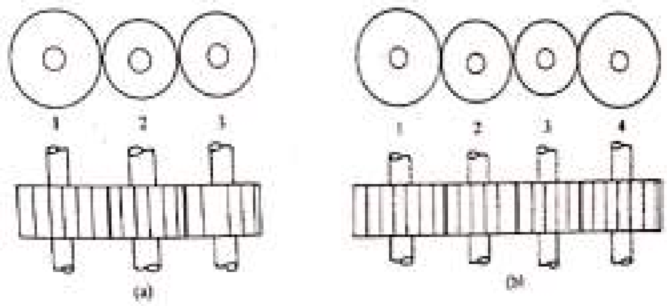


Fig. 2.19. Simple gear train

$$\frac{N_2}{N_1} \times \frac{N_3}{N_2} = \frac{d_1}{d_2} \times \frac{d_2}{d_3}$$

$$\frac{N_3}{N_1} = \frac{d_1}{d_3} \text{ ....(i)}$$

Referring Fig. 2.19 (b),

$$\frac{N_2}{N_1} = \frac{d_1}{d_2}; \frac{N_3}{N_2} = \frac{d_2}{d_3}; \frac{N_4}{N_3} = \frac{d_3}{d_4}$$

$$\frac{N_2}{N_1} \times \frac{N_3}{N_2} \times \frac{N_4}{N_3} = \frac{d_1}{d_2} \times \frac{d_2}{d_3} \times \frac{d_3}{d_4}$$

$$\frac{N_4}{N_1} = \frac{d_1}{d_4} \text{ ....(ii)}$$

From equations (i) and (ii), it can be seen that the speed ratio is independent of the number and diameter of intermediate gears. It can also be seen that when the number of idlers is odd, the driver and driven gears rotates in the same direction and when the number of idlers is even, the driver and driven gears rotate in opposite directions. In simple gear train the function of idlers is to fill the gap between the of rotation of the driven gear as required.

Compound gear train

When a series of gears are connected in such a way that two or more gears rotates about same axis, it is called a compound gear train. The intermediate shafts carryy more than one gear. The speed ratio depends on the diameter of driver, the driven and the intermediate gears. Refer Fig. 2.20. Gears 1 and 3 are driver gears 2 and 4 are the driven gears.

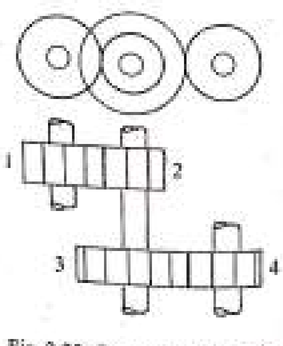


Fig. 2.20. Compound gear train

Referring Fig. 2.20.

Reverted gear train

A reverted gear train is one in which the axes of the first and last gears coincide. Such an arrangement is shown in Fig. 2.21, which has its application as a speed reducer.

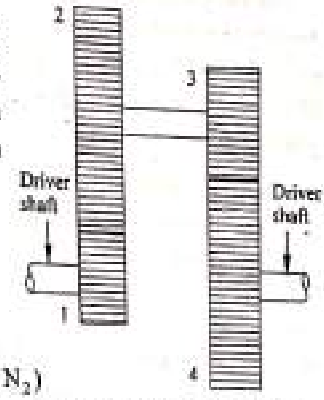


Fig. 2.21. Reverted gear train

Referring Fig. 2.21

$$\frac{N_2}{N_1} = \frac{d_1}{d_2}; \frac{N_4}{N_3} = \frac{d_3}{d_4}$$

$$\frac{N_2}{N_1} \times \frac{N_4}{N_3} = \frac{d_1}{d_2} \times \frac{d_3}{d_4} \quad (N_3 = N_2)$$

2.27. Single plate clutch

A clutch is a device used to connect a driving shaft to a driven shaft so that the driven shaft may be started or stopped at will, without stopping the driving shaft. Single plate clutch is a friction clutch, which transmits power by friction.

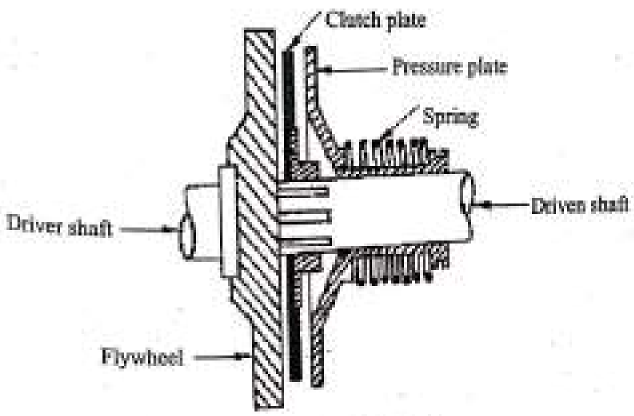


Fig. 2.22. Single plate clutch

It is mostly used in automobiles to connect the engine to the shaft. It consists of a clutch plate made of steel and having frictional lining on each side. This clutch plate is attached to a hub, which rotates along with the driven shaft and is free to slide axially on the driven shaft. A flywheel is attached to the end of crankshaft as shown in Fig. 2.22.

A spring loaded pressure plate presses the clutch plate against the flywheel, when the clutch is engaged. A friction between the lining on the clutch plate and the flywheel on one side and the friction between the lining on the clutch plate and pressure plate on the other side cause the clutch plate and the driven shaft to rotate. When the pressure plate is pulled back by further compression of the spring, contact between the flywheel and clutch plate breakes and then the flywheel rotates without driving the clutch plate and the driven shaft. Thus the rotation of driven shaft can be stopped without stopping the engine.

MODULE 6

- Transformation of Raw material from its original state to finished state by changing its shape, size and properties in a series of steps is called Manufacturing process.
- Broadly classified into **five**

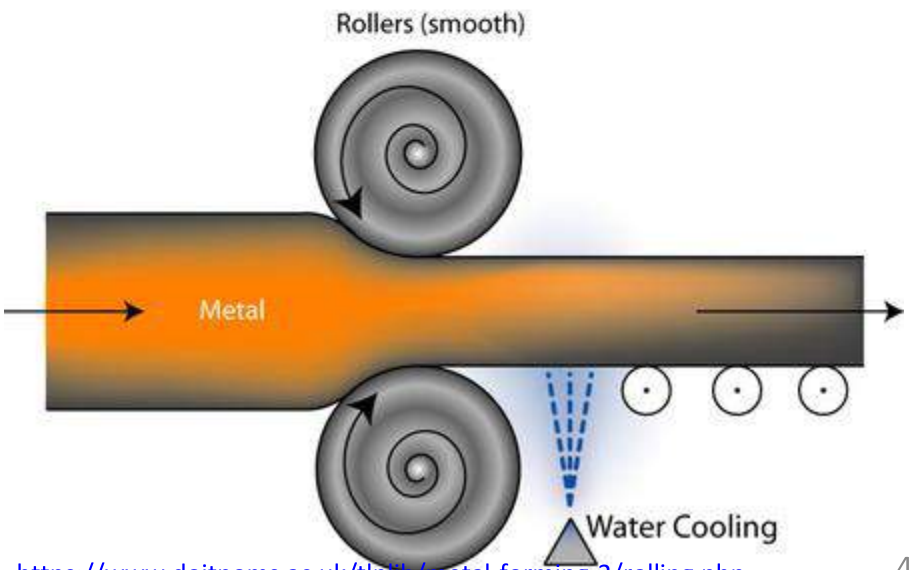
1. SHAPING PROCESS	2. MACHINING PROCESS	3. JOINING PROCESS	4. FINISHING PROCESS	5. PROPERTY CHANGING PROCESS
Process in which shape and size of the material is changed without removal of material. Eg: Casting, Forging, Rolling, Extruding	Process in which shape and size of the material is changed by removing the material from unwanted portions of the work piece. This process require cutting tool to remove the material. Eg: Turning, Drilling, Grinding, Milling	Process in which two or more parts are joined together, generally for fabrication work. Eg: Welding, Brazing, Soldering, Bolting, Riveting	Process in which required surface finish or protective coating is provided to the part. Small amount of material removal but not treated as machining process. Eg: Electroplating, galvanizing Honing, Lapping	Properties like hardness, ductility etc are changed so as to suit different applications. Eg: Heat treatment process

For better understanding watch this video before proceeding to slides

https://www.youtube.com/watch?v=ZD8gW_OzkCQ

Module 6

Rolling



https://www.doitpoms.ac.uk/tlplib/metal-forming-2/rolling.php

Rolling definition

Process of forming metals into desired shapes by passing the metal in between a pair of rolls. Rolls squeeze the cross section of the metal while increasing its length. The process of rolling basically consists of metal between two rolls rotating in opposite direction at same speed.

Types of Rolling

Hot rolling

- Hot rolling is the process in which metal is fed to the rolls after being heated above the recrystallization temperature.

Cold rolling

- Here metal is fed to the rolls when it is below the recrystallization temperature.

Application : *Bars, Plates, Sheets, Rails and other structural sections*

Advantages

1. More economical than forging when metal is required in long lengths of uniform cross section.
2. High rate of production.
3. Suitable for large reduction in size.

Disadvantages

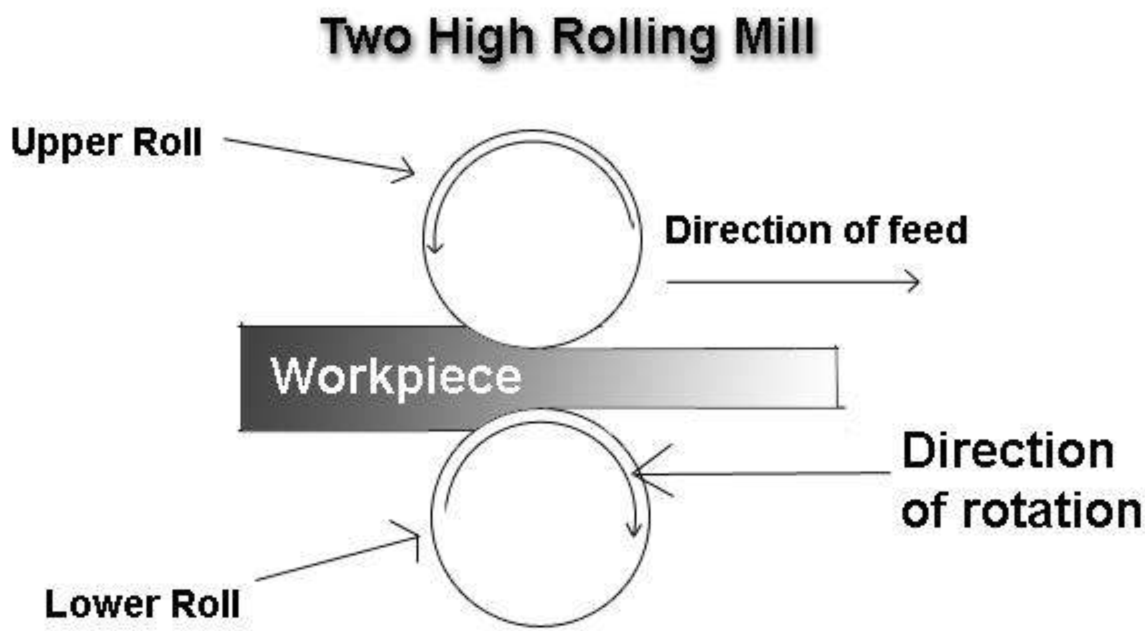
1. High cost
2. Poor surface finish
3. Less dimensional accuracy

Classification of Rolls (*Based on number of rolls and their arrangement*)

- Two High Mill
- Three High Mill
- Four High Mill
- Cluster Mill

1. Two High Mill

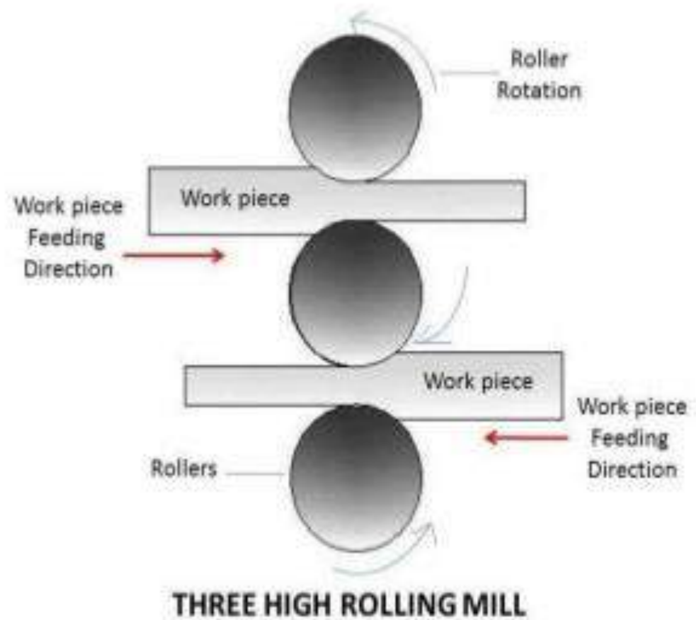
http://www.mechanicalwalkins.com/types-of-rolling-mills-with-detailed-information/



It consist of two heavy rolls placed exactly one over the other. Mostly the lower roll will be fixed in position. Upper roll can be moved to adjust the space between the rolls. Both rolls rotate at the same speed in opposite directions.

2. Three High Mill

https://www.slideshare.net/BasittiHitesh/conclave-of-rolling-processs

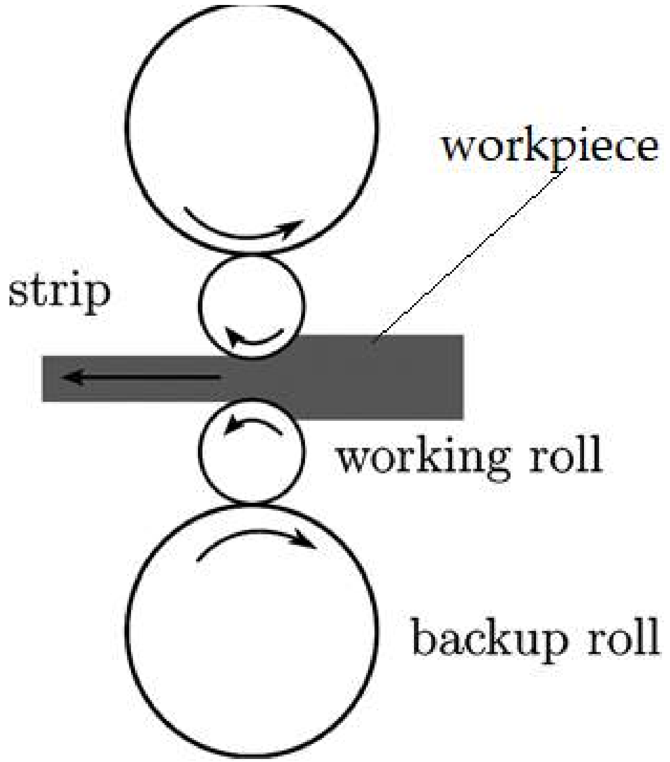


It consist of three rolls positioned one over the other as shown in figure. The upper and lower roll rotate in the same direction while the middle roll rotates in the opposite direction. Here the middle roll is kept fixed and the upper and lower rolls are moved to adjust the roll gap.

First pass	Second pass
The work piece is made to pass in one direction between the upper roll and middle roll.	The work piece is made to pass in opposite direction between the middle roll and lower roll.

3. Four High Mill

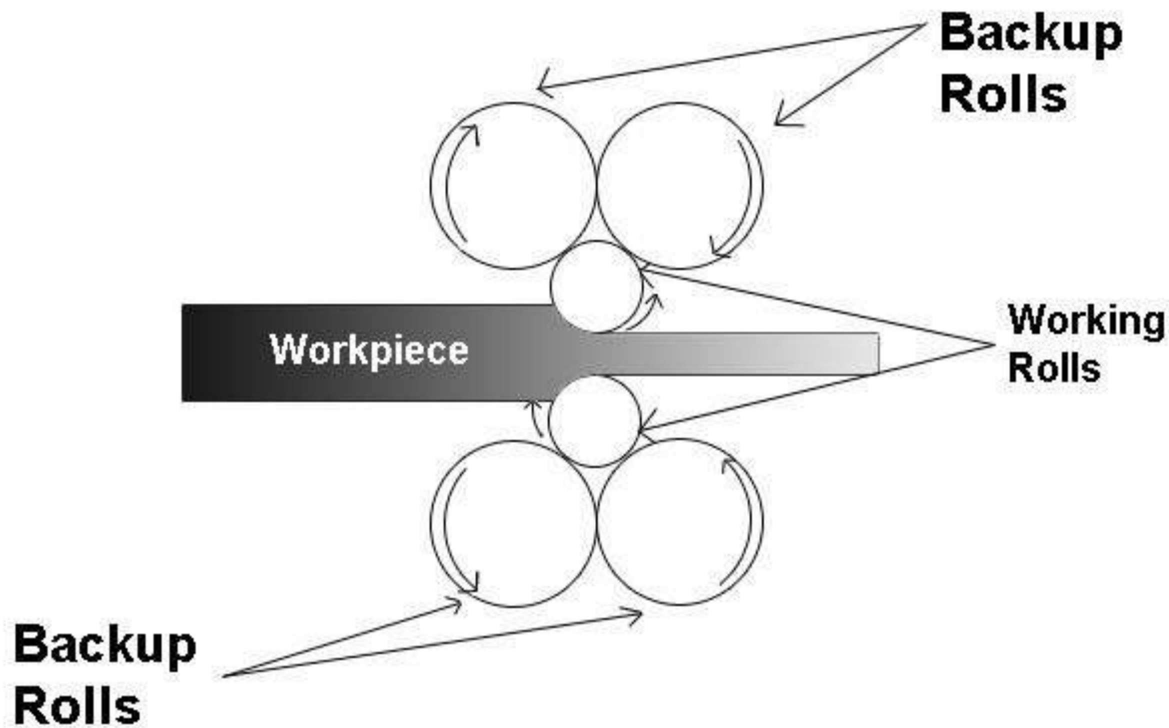
https://www.researchgate.net/figure/a-Schematic-diagram-of-a-four-high-rolling-mill-b-coordinate-system-and-c_fig1_270773160



It consist of four rolls, two of which are working rolls and the other two backup rolls. The back up rolls are larger in size and are required for preventing the deflection of working rolls.

4. Cluster Mill

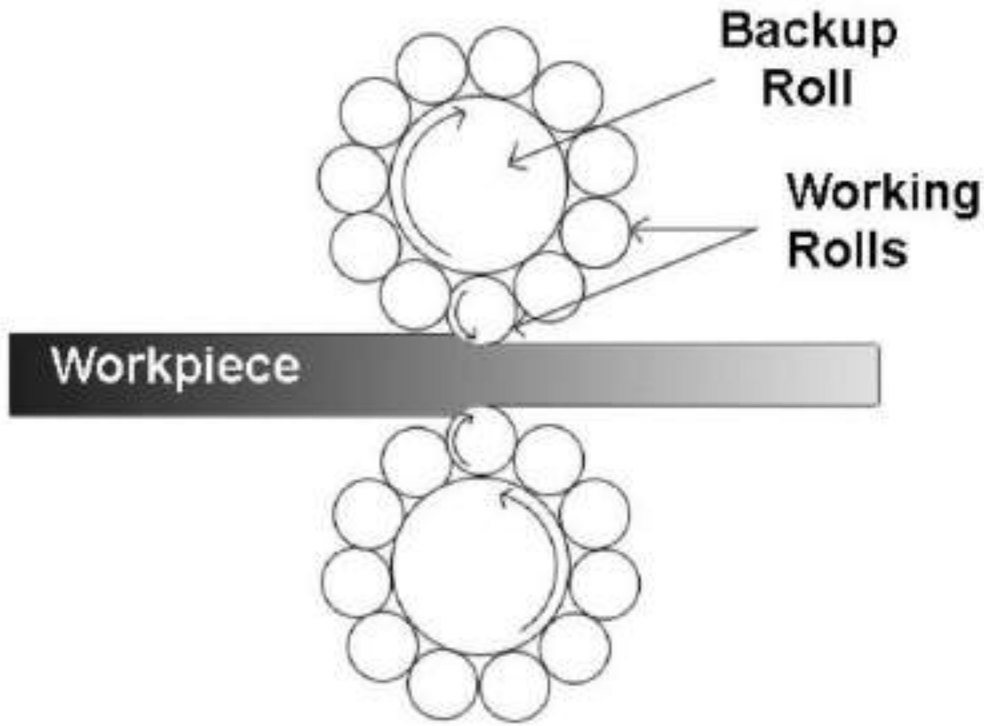
http://www.mechanicalwalkins.com/types-of-rolling-mills-with-detailed-information/



For rolling very thin sheet or foils, an arrangement of cluster mill is provided.
It consist of a pair of working rolls of very small diameter, supported by a number of back up rolls on either side.

5. Planetary mill (*optional*)

http://www.mechanicalwalkins.com/types-of-rolling-mills-with-detailed-information/



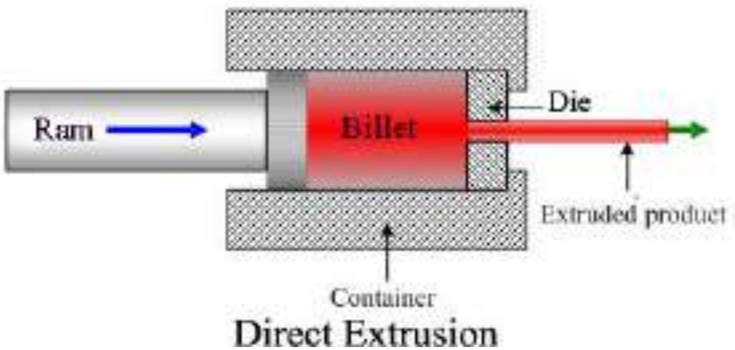
It is used to reduce large thickness of single pass of steel strip.

For better understanding watch this video before proceeding to slides
Look for direct extrusion and indirect extrusion only, ignore others

https://www.youtube.com/watch?v=743fHkOvOkA

Module 6

Extrusion



https://techminy.com/extrusion/

Extrusion definition

Process of forming products of uniform cross sectional shapes in convenient length. It consists of compressing the metal inside a chamber and forcing it out through a die having an opening in the shape of the product. Compression is achieved either mechanically or hydraulically.

Based on operating temperature

Hot extrusion

- When extrusion is carried out at above recrystallization temperature.

Cold extrusion

- If extrusion is carried out at below recrystallization temperature. Metals such as *lead*, *tin* and *aluminium* are extruded at room temperature.

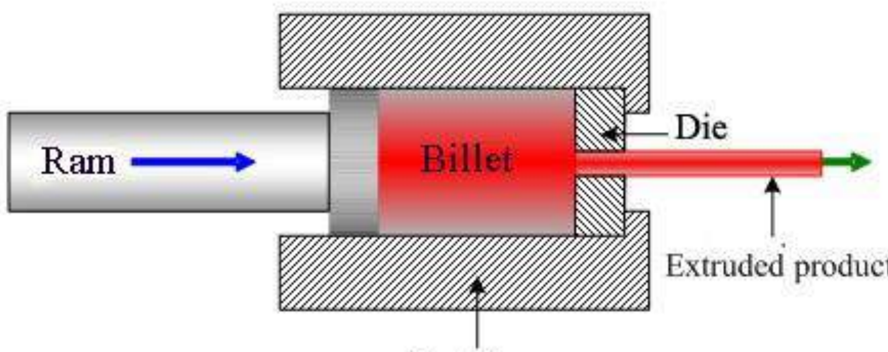
Based on working

1. Direct Extrusion
2. Indirect Extrusion

1. Direct extrusion(Forward Extrusion)

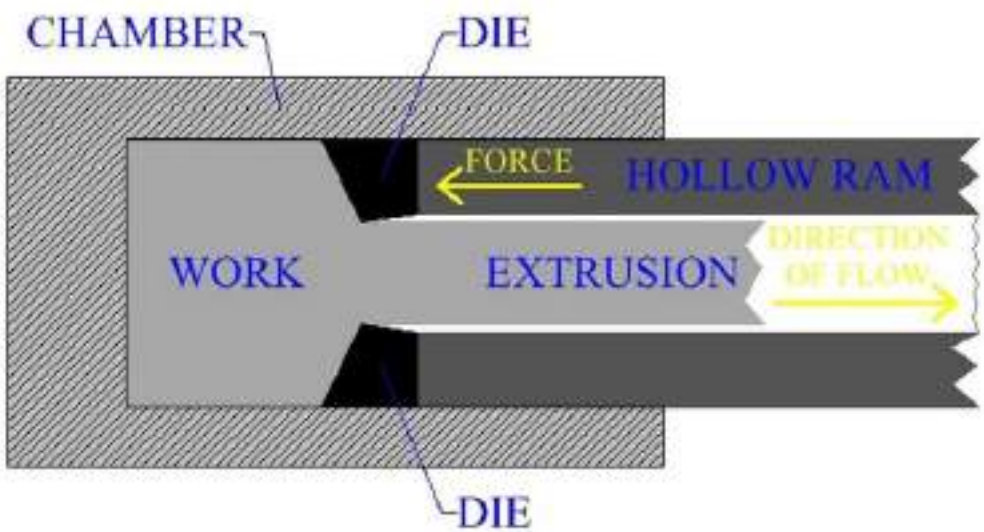
- Here metal(also called billet) is placed in the die chamber and the metal is forced through the die opening by applying pressure on the ram. The extruded part coming out through the die is then cut into required length.

https://techminy.com/extrusion



2. Indirect Extrusion(Backward extrusion)

- In this process the extruded part which is forced out of the die is taken out through the ram (plunger), which is made hollow. Here extruded product comes out in opposite direction to that of the ram movement



http://www.wiredrawingdies.co.in/indirect-backward-extrusion/

Application: Rods, Tubes, Structural shapes

Advantages

- High production volume
- Surface finish obtained is good.
- Many type of raw materials can be used

Disadvantages

- High initial cost
- Only one type of cross section can be obtained at a time

For better understanding watch this video before proceeding to slides

https://www.youtube.com/watch?v=7L4wnXz_JYI

Module 6

Forging

https://www.steelavailable.com/en/what-is-steel-forging/

Forging definition

Process of changing the shape of metals when it is in the plastic state, by applying compressive force. Generally employed for those components which require high strength and other mechanical properties.

Based on operating temperature

Hot Forging

- When forging is done above recrystallization temperature.

Cold Forging

- If forging is carried out below recrystallization temperature.

Application: bolts, spanners, nails, axles, connecting rod, crankshaft

Advantages

- Always have better mechanical properties than casted components.

Disadvantages

- Operation is costly
- Difficult to maintain dimensional accuracy
- Atmost care to be taken in temperature control

Watch this video

Types of Forging

https://www.youtube.com/watch?v=dFnN1YtomNc

1. Hand forging
2. Drop forging
3. Press forging
4. Machine forging

1. Hand Forging

- Traditional work carried by a blacksmith in a smithy shop.
- Heating of metal is done in open fire and for various operation hand tools are used.
- Its purely skilled work and can be done for low production volume only.

2. Drop Forging

- Forging operation which is done in closed impression dies.
- Dies will be having two halves and inside the same required shape of the product will be there in the form of a cavity.
- Drop hammers are used for applying force.
- This can be applied for mass production small and medium sized, simple and complex shapes are possible.

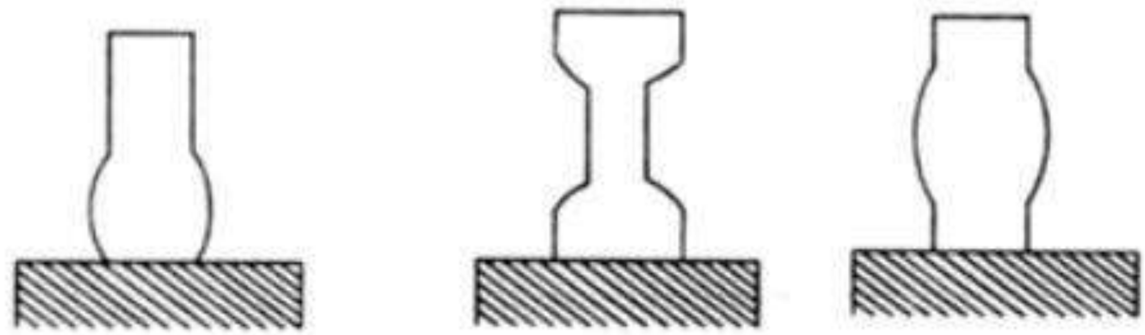
3. Press Forging

- Similar to drop forging but here force is applied by a continous squeezing operation by means of a hydraulic press.
- Applications are similar to drop forging

4. Machine Forging

- Here forging machines are used to get the required product.
- Dies are used which contain the impression of the required product.
- Bolt heads, small shafts, rivets are widely made using machine forging.

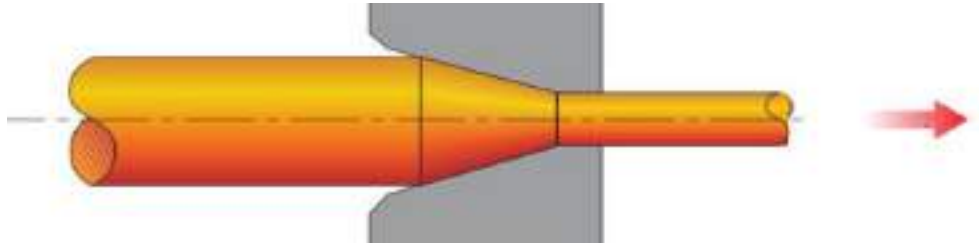
In Forging to obtain the desired shape of material a number of operations are to be performed. Some common forging operations are given following http://www.yourarticlelibrary.com/metallurgy/operations-employed-in-open-die-forging-metallurgy/95428



1. Upsetting

Process of incresing cross sectional area of the desired portion of workpiece at the expense of its length. The portion where the cross sectional area is to be increased is heated at first and blown with hammer axially.

https://mechatronicsly.com/learn/manufacturing/wire-drawing-and-extrusion/



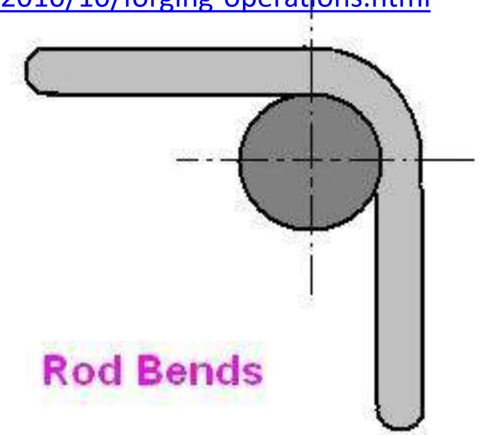
2. Drawing down

Process of reducing the cross sectional area of the workpiece by increasing its length

3. Swaging

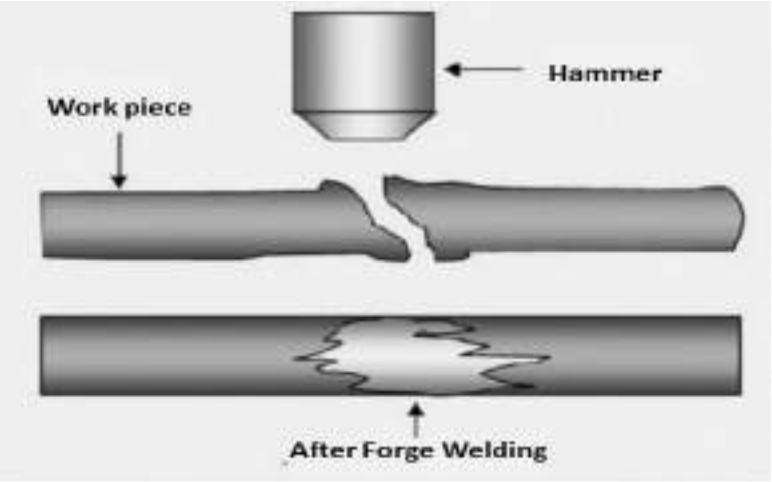
Forging operation by which required cross section is obtained. Two swage blocks namely top swage and bottom swage are used for swaging operation. The job is held in between top and bottom swage and then hammered.

http://engineeringhut.blogspot.com/2010/10/forging-operations.html



4. Bending

Operation by which bars and rods are bent to form rings, hooks etc https://www.mech4study.com/2017/04/forge-welding-principle-working-application-advantages-and-disadvantages.html

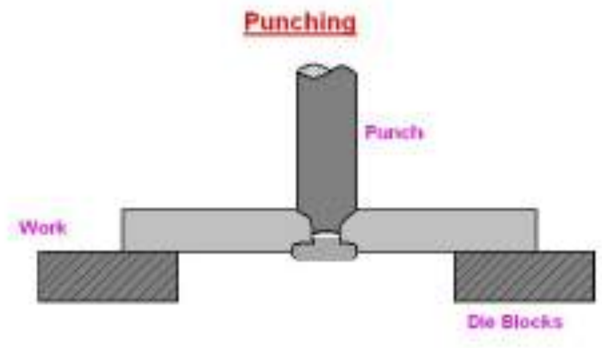


5. Forge welding

Here two metallic surfaces are joined without using a filler materials. The portion to be joined are heated to higher temperature less than melting point and joined together by hammering.

6. Cutting

Process of removing pieces of metal from a billet by using chisel.



http://engineeringhut.blogspot.com/2010/10/forging-operations.html

7. Punching

Process in which a punch is forced through a workpiece to produce a hole. The work piece is heated and supported on a block as shown in figure.

8. Drifting

Process of increasing the diameter of a punched hole. A drift which has tapered end is made to pass through the punched hole to produce a finished hole of required size.

9. Setting down

Local thinning operation performed by set hammer.

For better understanding watch this video before proceeding to slides

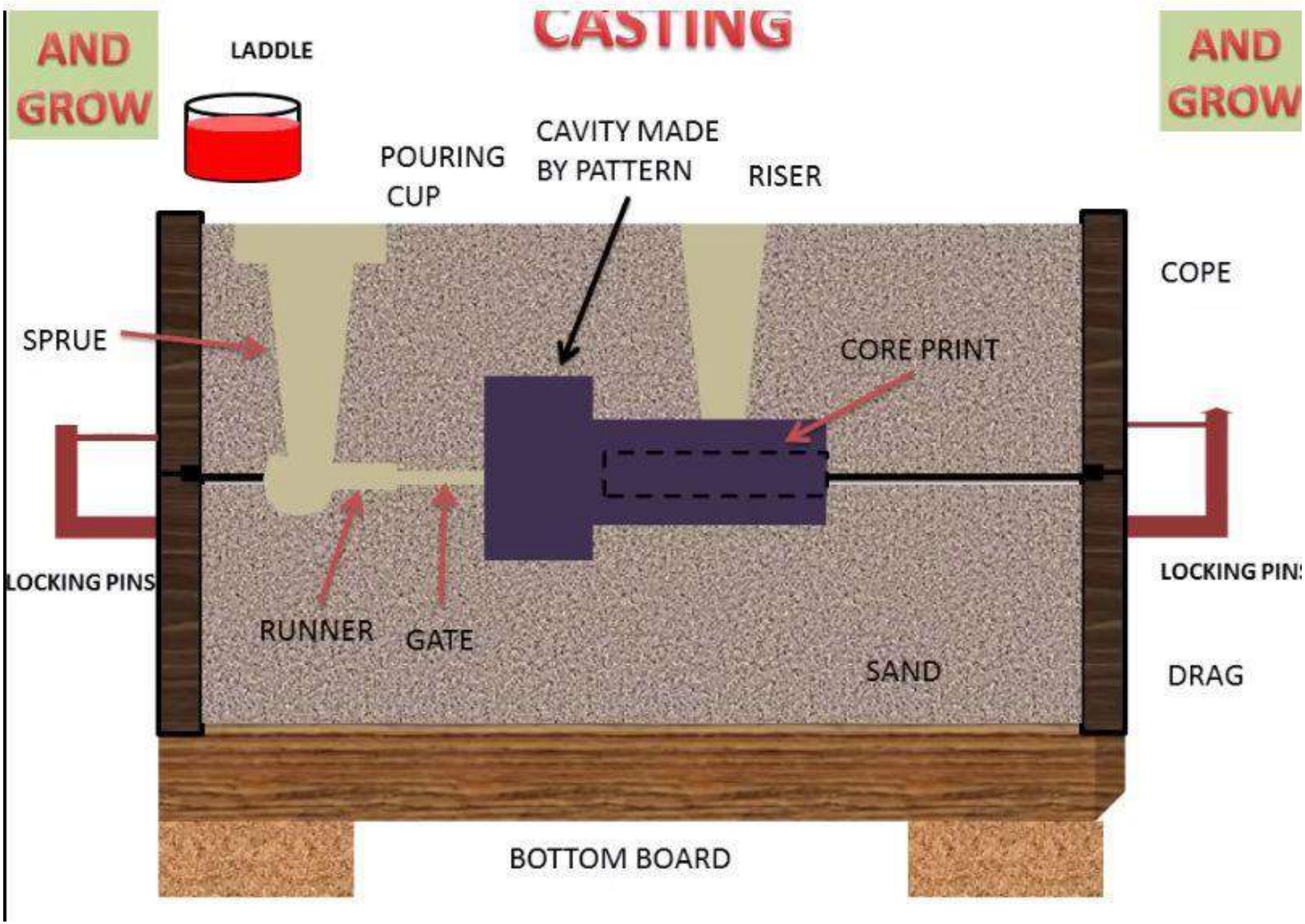
https://www.youtube.com/watch?v=cjebklLgrf8&list=PLSWRPBzGkib_GAPASbMnBZ9uKsKcS7w9z

MODULE 6

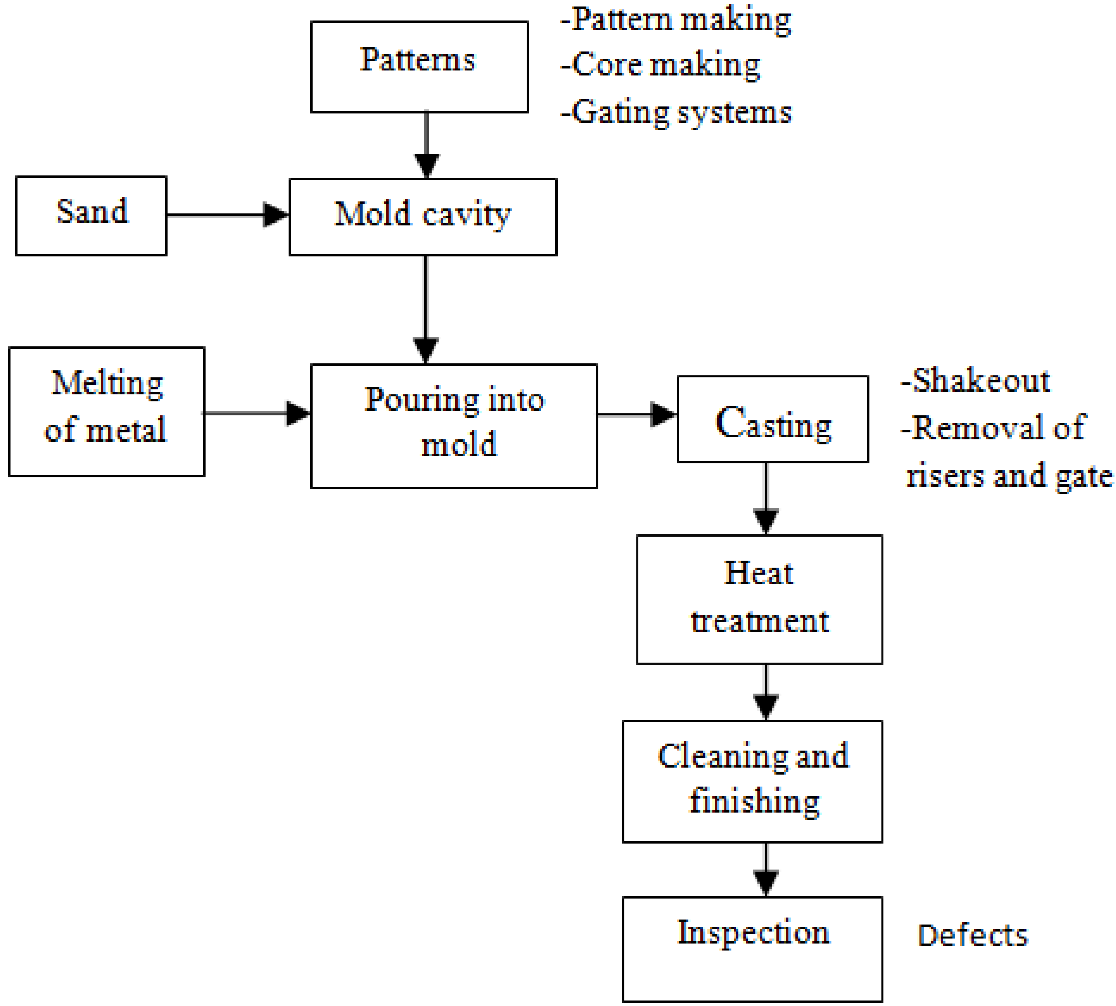
Sand Casting

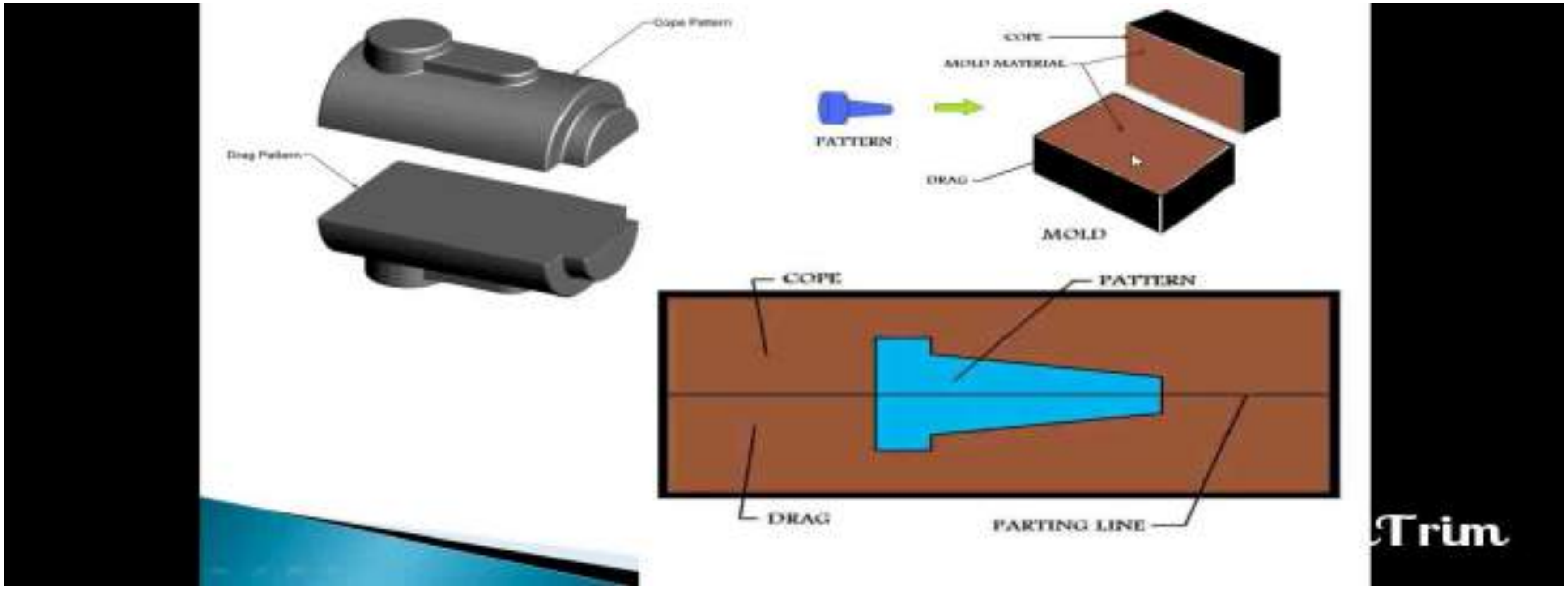
Definition

Casting is a process in which the liquid molten metal is poured into the casting cavity whose shape remains same as that of casting to be produced. Allowing to solidify and after solidification the casting will be taken out by breaking the mould.


AND
GROW
LADDLE
CASTING
AND
GROW
POURING
CUP
CAVITY MADE
BY PATTERN
RISER
COPE
SPRUE
CORE PRINT
LOCKING PINS
LOCKING PIN
RUNNER
GATE
SAND
DRAG
BOTTOM BOARD

Steps in Sand Casting





Pattern

Pattern is a replica of the casting to be produced. Replica means the shape of the pattern remains same as that of the casting to be produced.

Properties of pattern materials

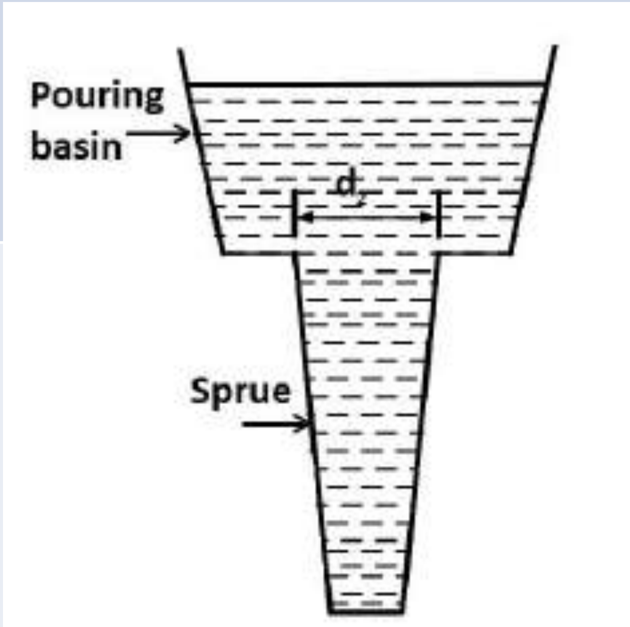
- No or low moisture absorption
- Low density
- Good surface finish
- Easiness of fabrication
- Cheaper

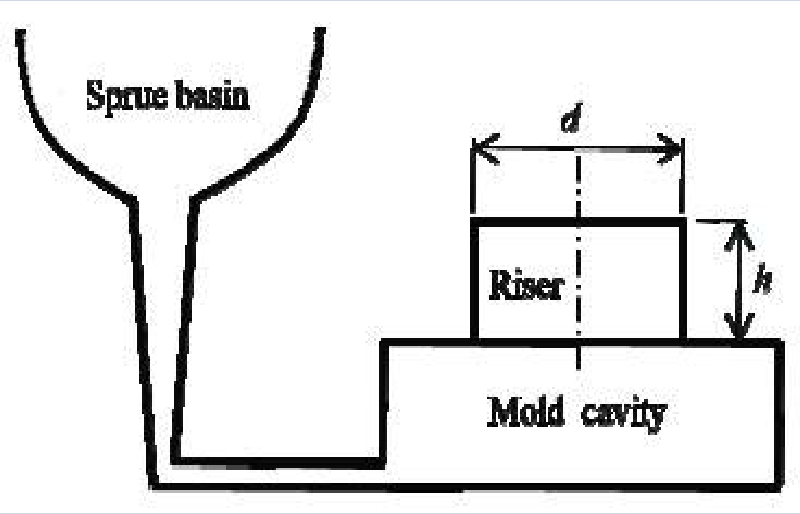
Materials used for making pattern

- Wood
- Metal
- Plastics
- Wax

Gating system

The passage of bringing the molten metal into the mould cavity is known as gating system. It consists of a pouring basin , sprue and gate

Part	Function
Pouring basin 	Help to maintain the required rate of flow of molten metal into the mould cavity.
Sprue	Sprue is the vertical passage that passes through the cope and connects the pouring basin with the gate.
Gate	Gate is the passage through which molten metal flows through the sprue base to the mould cavity.

Part	Purpose
Riser 	Riser is the passage made in the cope to permit the molten metal flow after the mould cavity is filled up. If the molten metal does not appear in the riser, it indicates that mould cavity is not filled up completely. Riser also act as a reservoir and feed molten metal into the mould cavity to compensate for the solidification of shrinkage of castings.
Core	Core is the element used in the casting process for producing hollow cross sectioned castings. By placing the core inside the cavity the molten metal is filled into the cavity and allowing to solidify.

Properties of Moulding sand

Cohesiveness property : The ablity of formation of bond between same material particles. Should have sufficient sufficient cohesive strength.

Adhesive property : The ability of formation of the bond by the sand particles with other materials such as pattern, mould boxes etc. Should have sufficient adhesive strength.

Refractoriness : The ability of withstanding higher temperature without losing its strength and hardness is called refractoriness property.

Flowablity : The ablity of flowing of moulding sand into each and every corner of a mould box is called as flowablity.Porosity or Permeablity : The property that allows passage of gases through the mould is termed as porosity or perm,eablity. The moulding sand must be sufficiently porous to allow the gases and steam generated to escape.

Plasticity : The property of acquiring predetermined shape under pressure and to retain it when the pressure is removed is termed as plasticity. Moulding sand should have sufficient plasticity to get a good impression of the pattern.

Chemical stability : The property of sand to resist chemical reaction with molten metal is termed as chemical stability. A good moulding sand must have sufficient chemical stability to withstand chemical reaction so that the reusability of moulding sand is possible.

Sand casting

Advantages

- Complex shapes can be made
- Wider material choice
- Good design flexiblity

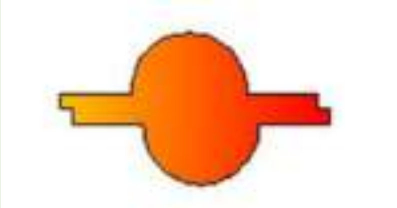
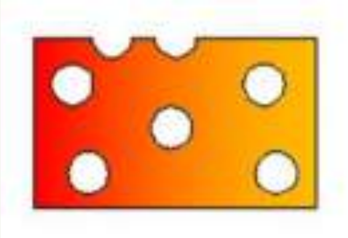
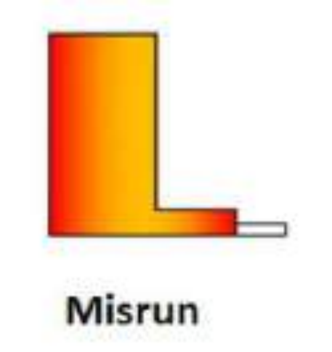
Disadvantages

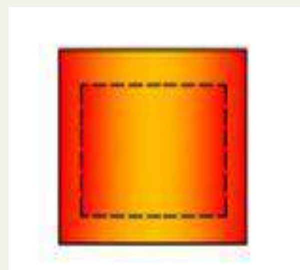
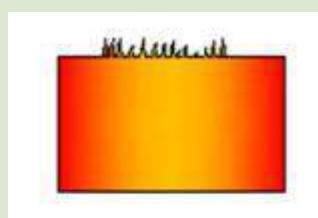
- It gives poor surface finish and so mostly require surface fininishing operations.
- Strength of casted components is less compared to forging.
- Casting defects involves

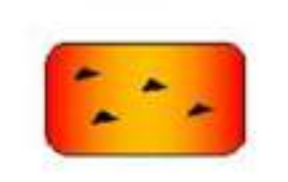
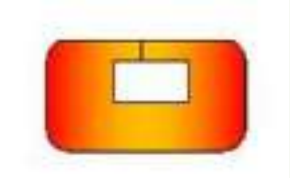
Applications

- Automobile parts
- Machine tools
- Heavy equipments

Casting Defects

Sl.No	Defect	Figure	Cause of Defect	Remedy
1	Shift or Mismatch		Due to mismatch present in the cavities of cope and drag box	Proper use of dowel pins
2	Blow hole (Air or gas bubble present inside the casting)		Low porosity propertyof moulding sand	Proper ramming
3	Misrun (Non filling of projected portion)		Solidification has been started before complete filling of molten metal	Reduce the pouring time, Increase the degree of superheat

Sl.No	Defect	Figure	Cause of Defect	Remedy
4	Shrinkage cavity or voids		Due to non availability of molten metal for compensating liquid shrinkages.	Eliminated by providing chills
5	Swell (Localized or overall enlargement of casting)		Caused by loose ramming of sand	Proper ramming of sand
6	Fins (Thin projection of metal, which is not a part of the required casting)		Improper clamping of mould boxes	Proper care in clamping

Sl.No	Defect	Figure	Cause of Defect	Remedy
7	Slag inclusion		Presence of foreign particles in the form of oxides, slag, dirt	Should be prevented from entering the cavity
8	Cold shut (Two streams of molten metal establish a physical contact between them, but fail to fuse together)		Due to low fluidity of molten metal	Increase degree of heat

For better understanding watch this video before proceeding to slides

https://www.youtube.com/watch?v=jF4F8Zr2YO8

Module 6

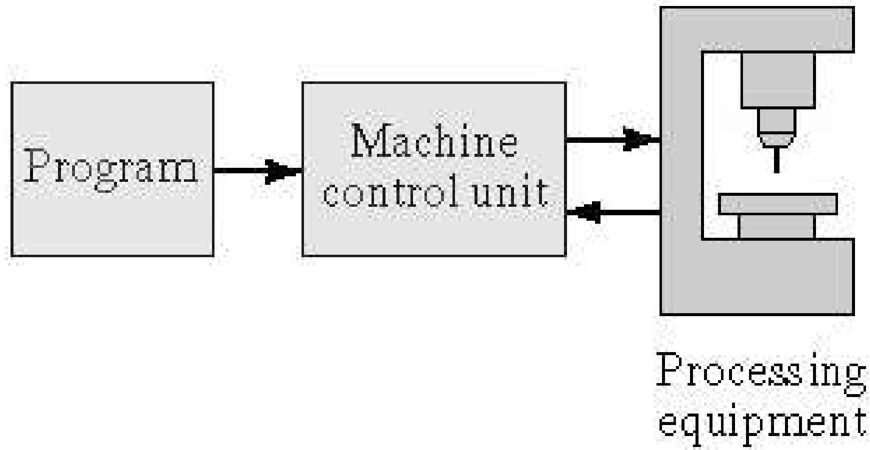
CNC

https://www.indiamart.com/proddetail/cnc-lathes-tl-20-machine-18718028433.html

About Numerical Control

Operation of machine tools using numerical data. It is a technique for automatically controlling machine tools, equipment or process. Numerical control can be defined as a **form of programmable automation in which the manufacturing process is controlled by numbers, letters and symbols. These are logically organized(NC program) to perform a specific task (say for example turning, drilling).**

Thus a numerically controlled machine tool is basically a machine tool where the operator is replaced by a NC program



Computer Numerical Control(CNC)

CNC is a NC system in which a dedicated computer is used to perform some or all the NC functions in accordance with control programs stored in the memory of the computer. Such a machine having a computer assigned to one particular task or a group of related tasks is known as Computer Numerical Control machine.

Application: Advanced industries where high rate of production is done, especially in automobile industry

Advantages

- Saving of job setting time and process time.
- Eliminate human error
- Increased consistency and quality
- Flexiblity(possiblity to incorporate changes by editting the program)

Disadvantages

- Programming skill required
- High initial cost
- Not economic for low production volumes

Module 6

CAD and CAM

https://www.youtube.com/watch?v=ETz67OUsXC0

Watch this video

CAD (Computer Aided Design)

Use of computer systems to help in the creation, modification, analysis or optimization of a design problem. Computer system consist of hardware and software to perform a particular task.CAD is used by architects, engineers, drafters, artists, and others to create precision drawings or technical illustrations. CAD software can be used to create two-dimensional (2-D) drawings or three-dimensional (3-D) models.

Some CAD soft wares are following

- Auto CAD
- Solid works
- CATIA

https://www.youtube.com/watch?v=FdipJNG_vV8

Watch this video

CAM (Computer Aided Manufacturing)

Use of computer systems to plan, manage and control the operations of a manufacturing process.

CAM is used for :

- Higher speed of production
- Greater accuracy
- Greater consistency
- Greater efficiency

Some CAM softwares are following

- Solid CAM
- PowerMILL
- Work NC

Module 6

Rapid Manufacturing

https://www.indiamart.com/proddetail/cnc-lathes-tl-20-machine-18718028433.html

About Rapid Manufacturing

It is the use of software automation and related manufacturing equipments to rapidly accelerate the manufacturing processes. This is highly flexible and very cost effective than conventional manufacturing.

Advantages

- Don’t require a specific product tool.
- Any prototype model can be produced in a computer system. ie. Unlimited virtual freedom
- New products can be defined

Disadvantages

- Computer skill required
- High cost
- Economic for higher production volumes only

Rapid Prototyping

Also called Desktop manufacturing. Is a process by which a solid physical model of a part is made directly from a three dimensional CAD drawing.

[WOW! Amazing 3D Printer | Artillery Sidewinder - YouTube]

Watch above link for working of a 3D printer

Module 6

Additive Manufacturing

Additive Manufacturing

It is the Industrial production name for 3D printing. It is a computer controlled process in which three dimensional objects are formed by depositing layer by layer through fused deposition of work material.

Any Design can be done through computer software and the corresponding file is fed into 3D printer for obtaining required product.

Thermoplastic, biochemical materials are examples for work materials used.

Applications : Automotive components, Medical and Dental related components

Advantages

- Design flexiblity
- Complicated shapes
- No requirement of pattern as in casting for making a product

Disadvantages

- Limited material choice
- Costly equipment
- Skilled labour required

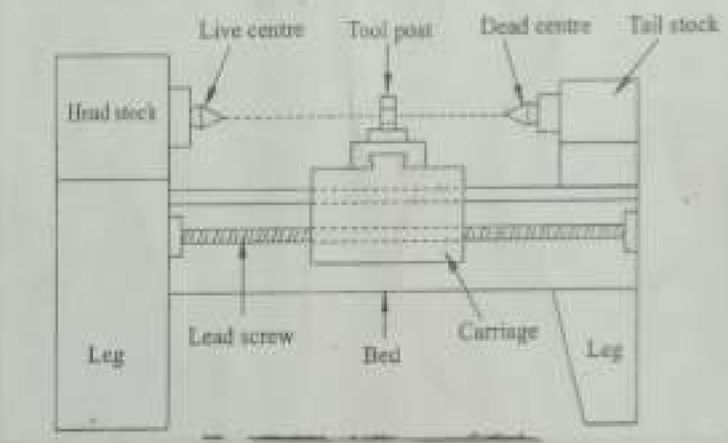
Reference

[1] Basic Mechanical Engineering by J. Benjamin

[2] Internet(*links attached*)

LATHE

Lathe machine is found in almost all workshops. And it is the most general purpose machine tool in which workpiece is held and rotated against suitable cutting tool for obtaining required surface

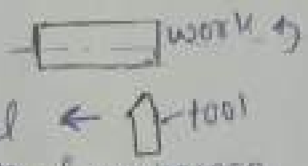
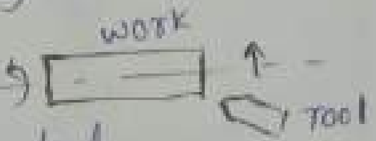


Major components are

1. Head stock
2. Tail stock
3. Bed
4. Carriage
5. Lathe centres
6. Tool post
7. Lead screw
8. Feed mechanism

Component	Function
Bed	Head stock, tail stock, carriage and other components are mounted on the bed. It provides required strength and rigidity to the machine by forming a structure.

→ Head stock -	Mounted on the bed at the left end. It contains spindle for obtaining rotation, chuck for work holding and gear box for changing the speed as required.
→ Tail stock -	Mounted on the bed at the right end. It supports one end of the work piece. For performing operation like drilling and reaming in lathe drill bit, reaming tool are holded by tail stock part.
→ Carriage -	Support and action of cutting tool is served by carriage. It can be moved along the bedways provided at the top of the bed ⟷
→ Lathe centres -	Lathe centres are provided in the head stock and tail stock. Live centre ↓ Centre connected to head stock Dead centre ↓ Centre connected to tail stock
→ Tool post -	Mounted on carriage. It holds the cutting tool and enables the cutting tool to be adjust to requirements.

→ Lead screw	Long threaded shaft which is brought into action only when threads have to be cut on the workpiece.
→ Feed mechanism	The movement of tool relative to the workpiece is termed as feed. Three types of feed possible are: i) Longitudional feed  - Tool is moved parallel to axis of rotation of workpiece - Done for turning operation 2) Cross feed  - Tool is moved perpendicular to axis of rotation of workpiece - Done for facing operation 3) Angular feed - when tool is moved at an angle to the axis of rotation of workpiece - Done for taper turning

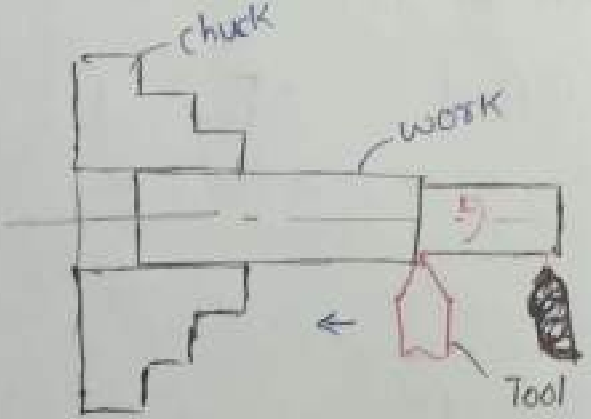
- Work holding device used in lathe is known as chuck.
- Operations that can be performed in lathe are

Turning, Taper turning, Facing, Thread cutting, Drilling, Boring, Reaming, Grinding etc.

→ Turning

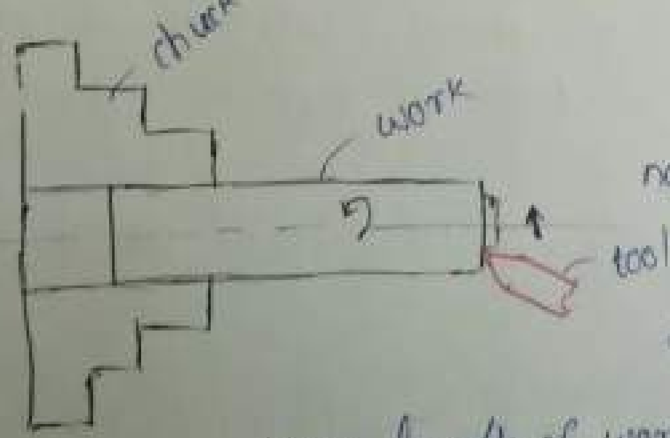
Turning is the removal of material from the periphery of a workpiece to obtain a cylindrical surface. It is the most common operation done in lathe.

In Turning operation workpiece is held in chuck. On receiving power from the spindle workpiece keeps rotating. During this time a sharp single point tool is fed into the workpiece either parallel or perpendicular to the axis of work.



If tool is moved parallel to the axis of rotation of the work then a cylindrical surface is produced as shown

Here diameter of the work reduces



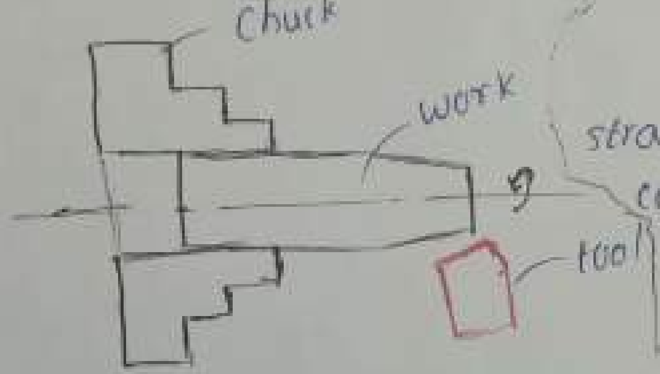
If tool is moved perpendicular to the axis of rotation of the work, then a flat surface is produced at the end of the workpiece

Here length of workpiece get reduced. Also known as Facing operation.

→ Taper turning

Some machine elements and other parts are required to be turned with a taper. Taper turning means producing a conical surface by gradual reduction in diameter from a cylindrical workpiece. Following methods are used for taper turning

① Forming tool method



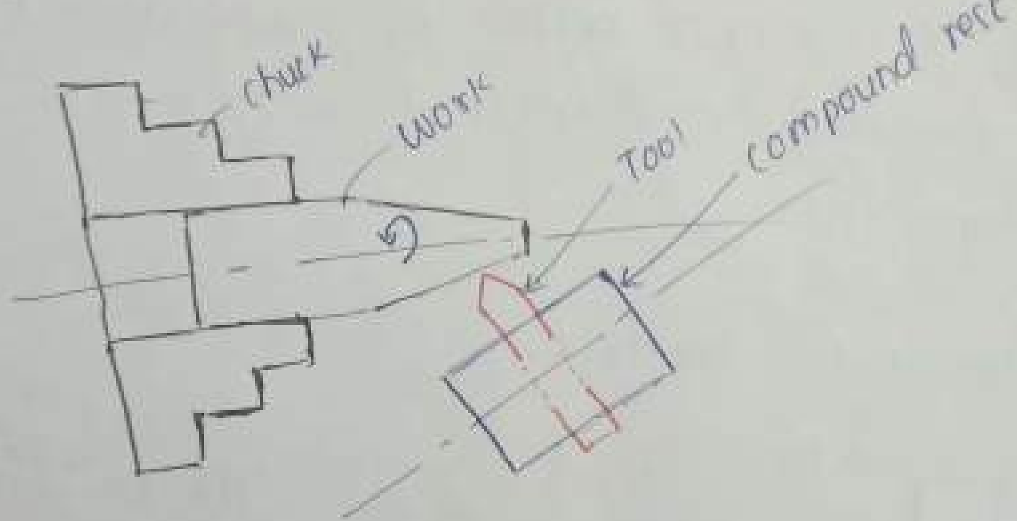
The tool having a ~~set~~ straight cutting edge is set at correct angle and is fed straight into work to generate the tapered surface. This method is limited to turn short external tapers only.

② Tailstock set over method

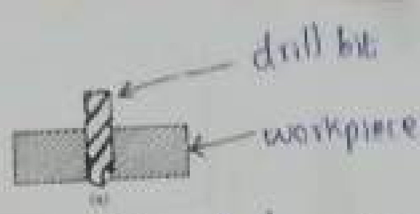
Shift the axis of rotation of the workpiece at an angle to the lathe axis and feeding the tool parallel to lathe axis. The tool will cut a taper on the work.

⑤ Compound rest method

By swiveling compound rest, it can be set at any desired angle

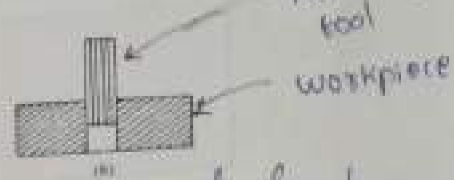


Drilling



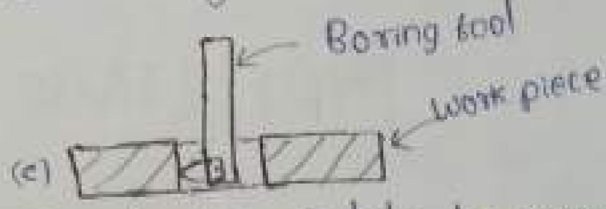
Operation of producing a circular hole using a drill by removing metal from the workpiece (fig (a))

If required following operations are followed after drilling operation.



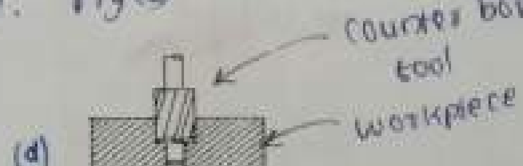
① Reaming

Reaming is the operation of sizing and finishing a hole by means of a reaming tool. It just follows a already drilled hole and removes a very small amount of metal. (Fig (b))



② Boring

Boring is the operation of enlarging a hole by means of an adjustable single point tool. Fig(c)



③ Counter boring

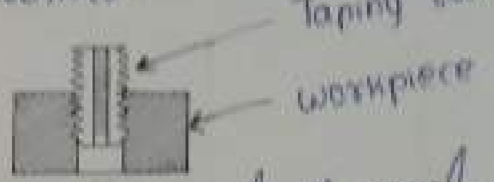
It is the operation of increasing the diameter of a hole for a certain distance down. It is done with a special cutter as shown in fig (d)

④ ~~Spot~~ Counter sinking

It is the operation by which a cone shaped enlargement is made at the end of a hole.

(5) Spot facing

It is the operation of smoothening and squaring the surface around a hole drilled in a rough surface. It provides a flat seating for nut and washer.

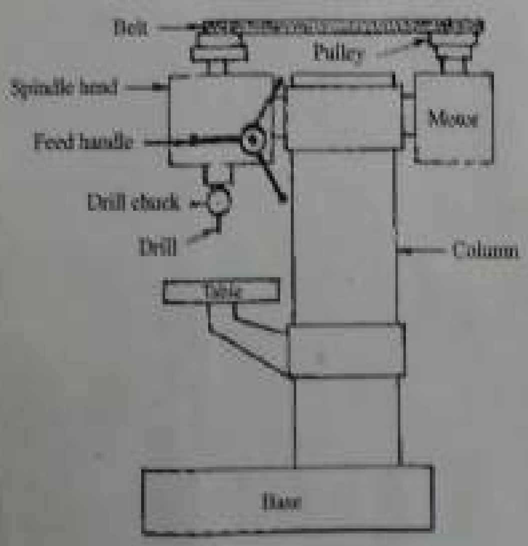


(6) Taping

It is the operation of cutting internal threads by means of a tool called tap. Generally done to obtain internal threads to a drilled hole.

DRILLING MACHINE

working : Making holes in a fixed workpiece by forcing a rotating tool called drill against it.



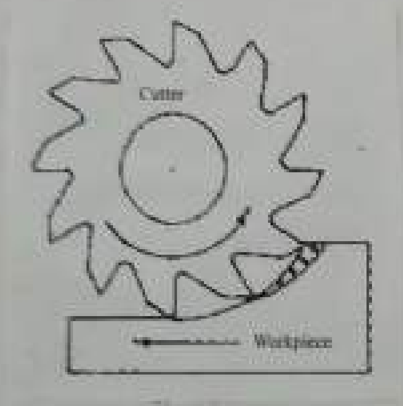
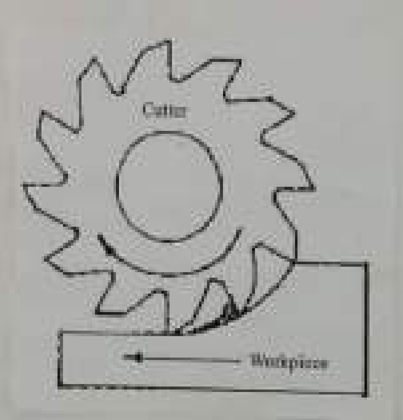
→ Principal parts of a drilling machine

	PART	FUNCTION
①	Base	- It is a rectangular casting on which column is mounted.
②	Column	- Vertical member of the machine which supports a table. The head supporting the motor and spindle is mounted on the top of the column.
③	Table	- Work piece and work holding devices are supported by table. It can be moved [up] and [down] as well as various position in horizontal plane
④	Drill head	Mounted on the top of column and consist of spindle head and motor spindle head: It houses drill holding and rotating device. A hand wheel is provided for upward and downward movement of the spindle. A drill chuck is mounted in the spindle for holding the drill motor: Spindle recieves power from motor, connected through belt pulley arrangement

Milling

Process of removing ~~the~~ metal by feeding the workpiece against a rotating multipoint cutter. As the cutter rotates, each cutting edge removes a small amount of material from the advancing workpiece for each rotation of the cutter. ~~The~~ Higher rate of material removal is possible.

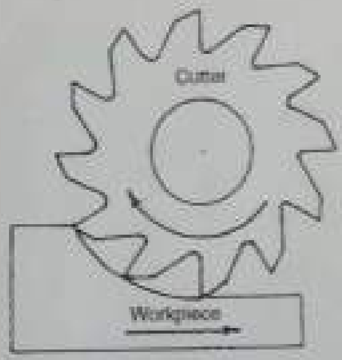
→ Based on the direction of cutter motion and workpiece feed milling operation can be classified into

- Upmilling	Down milling
- Also known as conventional milling 	
- In Upmilling direction of rotation of milling cutter and feed of workpiece are in opposite direction	- Rotation of milling cutter and workpiece feed are in same direction.
- Chip thickness vary min at the begining to max at the end of operation	- Chip thickness vary max at the begining to min at the end of operation.

- Due to opposite direction tool will try lifting the workpiece, so strong workholding devices are required	- strong work holding devices are not required
- Poor surface finish	- Better surface finish

→ Various milling operations

① Slab or plain milling



Process by which flat, horizontal surfaces parallel to the axis of cutter can be produced. Plain milling cutter is used as shown in figure.

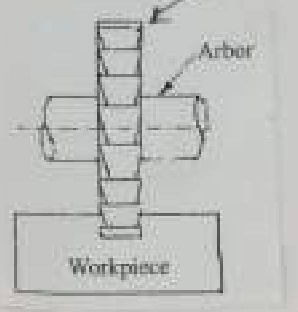
② Face milling

face milling cutter

Process by which flat surfaces perpendicular to the axis of cutter is produced.

③ Side milling

side milling cutter



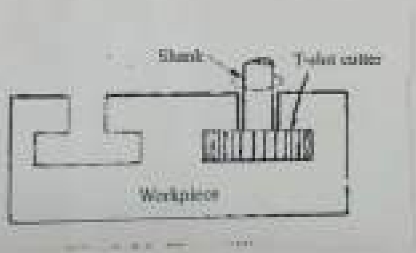
Process by which flat vertical face is produced at the side of a workpiece. side milling cutter is used.

④ End milling

end milling cutter

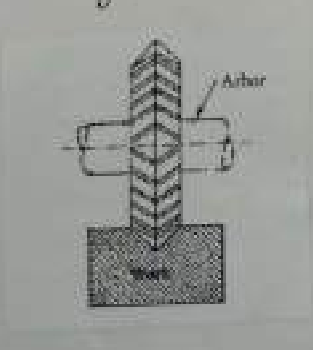
End milling is used for producing slots, Keyways etc using an end milling cutter. Here flat surface may vertical or horizontal.

⑤ T-slot milling



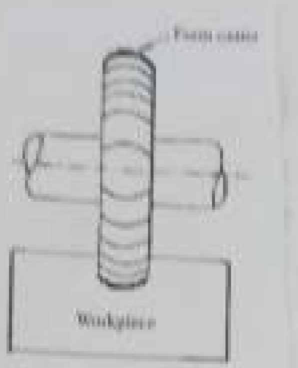
Here first a plain slot is cut on the workpiece using an endmilling cutter. Then T-slot cutter is fed from one end of the workpiece. The neck portion of the T-slot cutter passes through the already milled plain slot.

⑥ Angular milling



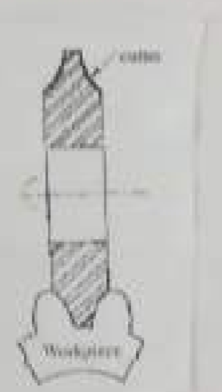
Here angular surfaces are produced using angular milling cutter.

7 Form milling



Milling process by which profiles on the workpiece are produced Shape of ~~p~~ form milling cutter corresponds to profile of the surface to be produced.

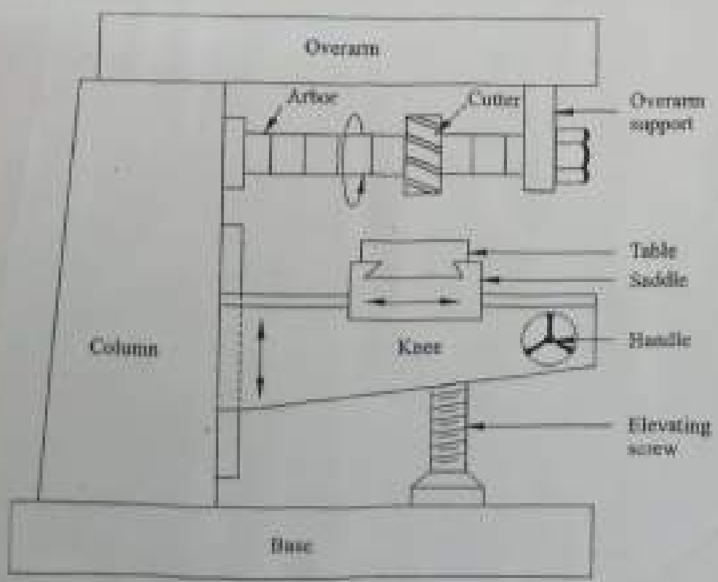
8 Gear cutting



Milling process by which gears are produced using form cutters. The profile of the cutter corresponds to tooth space of the gear.

→ MILLING MACHINE

Working : Removal of material (metal) by feeding the same to a rotating multi point cutter.



Principle parts of a Milling machine

Part	Function
① Base	Foundation member for all other parts of the milling machine. It provide required rigidity and strength
② Column	Main supporting frame mounted vertically on the base. The front face of the column has vertical guide ways.
③ Knee	Rigid casting that slides up and down on the vertical guideways on top surface. It supports the saddle and the table. The height of knee is adjusted through elevating screw.
④ Saddle	The saddle supports and carries the table. It is adjustable on the guideways of the knee
⑤ Table	The table rests on guideways on the saddle and can be moved longitudionally. It supports and holds the workpiece.
⑥ Elevating screw	The height of the knee is adjusted by the elevating screw. It also supports the knee.
⑦ Spindle	The spindle obtain its power from the motor and transmits it to an arbor. The spindle has a tapered socket for inserting the arbor.

(9)

(8) Overarm	- Mounted on top of the column. Overarm support is provided at the free end of overarm.
(9) Arbor	- It is the rod on which cutter is mounted. It is tapered at one end to fit into the spindle. The other end of the arbor is mounted in a bearing provided in the overarm support.

WELDING

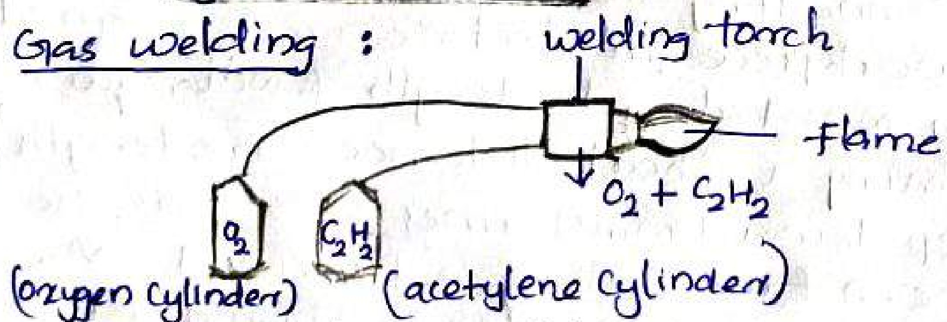
Welding is the process of joining metals by the aid of heat with or without application of pressure, with or without filer material. For the purpose of welding we make use of a welding machine. Welding provides excellent strength properties. Based on the source of heat used welding can be classified as following.

Heat source

Electric	Gas fumes	Electric Resistance	Exothermic	Smith's hearth
• Arc welding	• Gas welding	• Resistance welding	• Thermit welding	• Forg welding

1. → Electric Arc Welding: Here, an electric arc is obtained by means of a stepdown transformer.
eg: Arc welding

2. → Gas welding :



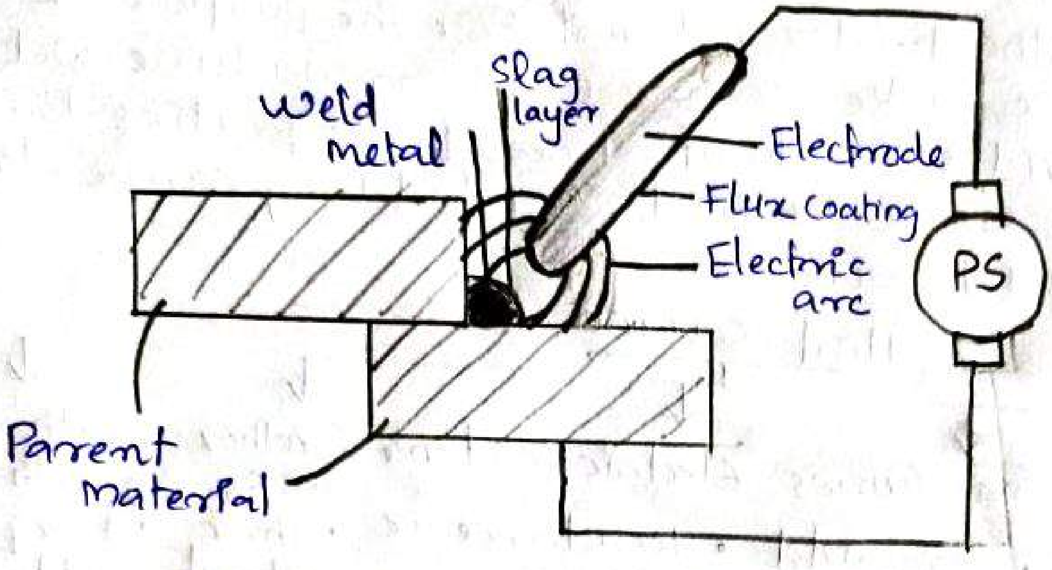
eg: Oxyacetylene welding

3. → Electric Resistance : Here electric Current is passed over the work piece to be Joined. The Resistance at the mating Portion results in generational heating ($H=I^2Rt$) After sufficient amount of Pressure is applied for obtaing the required weld. eg: Electric Resistance weld

4. → Exothermic : In welding like thermit weld, heat source is taken from the chemical reaction happening in a thermit mixture.

5. → Smith's hearth : welding can also be done by doing required forging operation eg: Forge welding

Arc Welding



Flux + Gangue → slag

An Arc welding essentially consist of workpiece, electrode, Electrode holder, Power house, earthing mechanism and connecting cable. Here when the electrode touches the workpiece an electric arc is formed which is then moved along the length of weld required by maintaining a short distance (arc length). Usually a step down transformer is used as the power source. A flux coating is provided over the electrode surface inorder to obtain a sound weld (Flux coating provides a protective environment at the weld area by avoiding oxidation}. And also avoiding impurities entering.)

APPLICATIONS:

- Metal Fabrication
- Repair work

Brazing

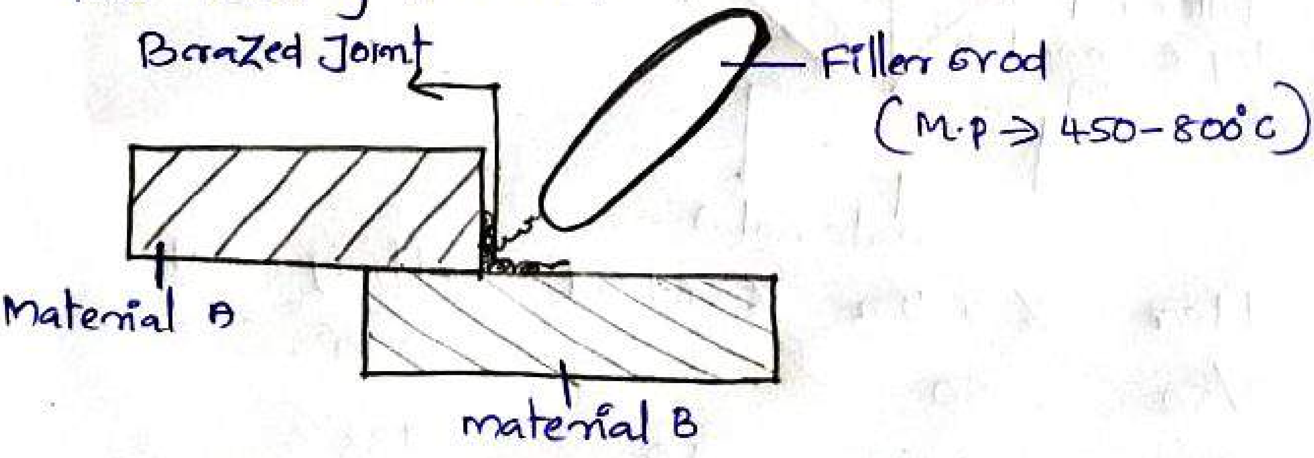
Brazing is a metal Joining process ideal for Joining of dissimilar metals. Here the Parent materials to be Joined doesn't melt. A compactible filler rod (Generally with melting point 450° - 800°) is used. For the purpose of necessary heating Induction method, Resistance method is are used.

A flux is used (Borax) for obtaining clean brazed Joint. Brazed Joint are known for providing better leak proof Joints also it will be having good electrical conductivity.

Applications:

Gas pipe Joint, Joining of cooling fins in engine.

The melting point of filler rod will be less than the melting point of parent material.



★ [Mechanism of Joint Formation is Surface ~~melting and alloy formation~~]

wetting and alloying

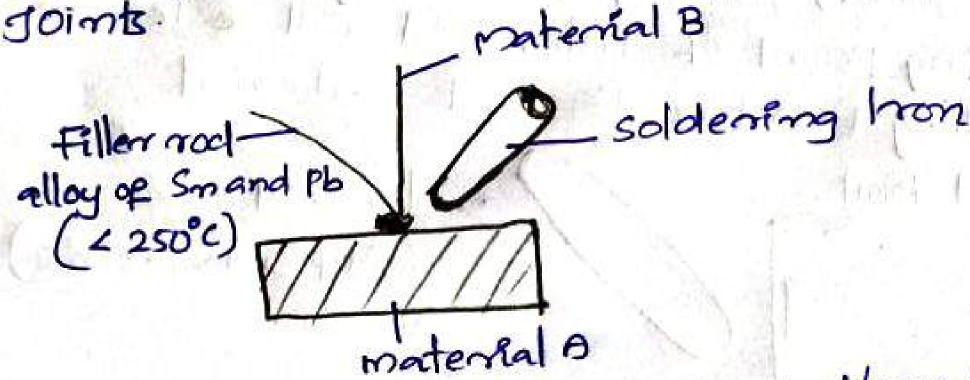
Soldering

it is generally done in electronic circuit joining works. It essentially consist of a soldering iron, filler material of M.p in range of less than 250°c usually fillering material is a alloy of ~~met~~ Tin and led. A flux will be used to obtain clean solder ~~Rosin Light~~ (Rosin type)

A soldering iron is heated to red hot condition and is introduced at the point of required joint, filler material melts and a soldered joint is obtained. As in brazing, here also parent material ~~will~~ won't be melting

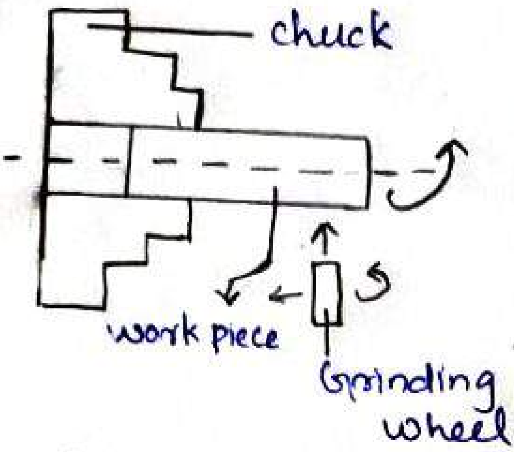
Application:

- Joining works in electronic circuits, wiring joints.



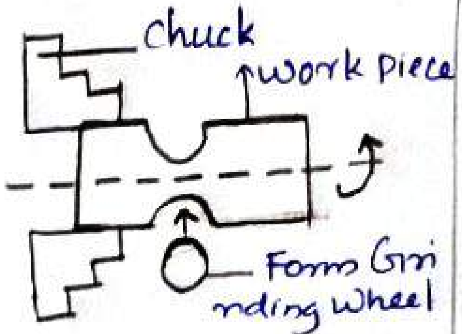
solder	% of tin	% of lead	melting point
50/50	50	50	220°c
60/40	60	40	188°c
63/37	63	37	183°c

Grinding



*cylindrical Grinding

*Surface Grinding.



*Form Grinding

Grinding is a machining process done inorder to obtain following requirments.

1. To obtain excellent surface finish
2. For sharpening of cutting tools
3. Two machine surface which are otherwise different to perform with other manufacturing operations.

In Grinding process, material removal will be in the order of micrometres. Grinding operation essentially consist of an abbresive wheel (large no. of tiny and small abbressive particle are held together in the form of a wheel.