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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – I – INDUSTRIAL STRUCTURES– SCIA7014

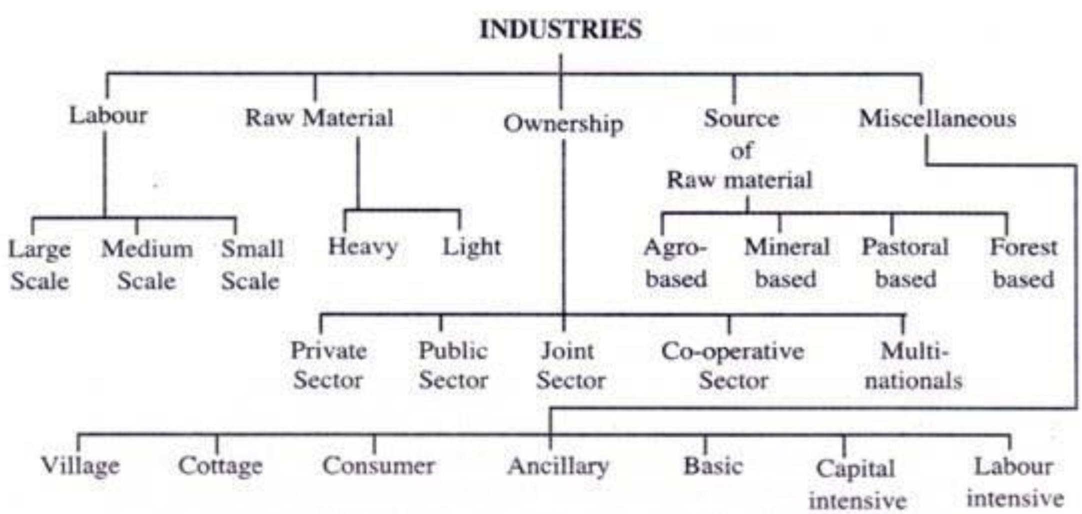
What is Industry?

- Industry refers to economic activities concerned with the production of goods, extraction of services and provision or services.
- **Industry** is the work and processes involved in collecting raw materials, and making them into products in factories.

Classification of Industry

Industries: Classification of Industries

Industries can be classified into several groups. The following table gives an understanding about them.



I. On the Basis of Strength of Labour:

1. Large Scale Industry:

Industries which employ a large number of labourers in each unit are called large-scale industries. Cotton or jute textile industries are large scale industries.

Industries

Image Courtesy : ppec.co.in/images/refineries-india.JPG

2. Medium Scale Industries:

The industries which employ neither very large nor very small number of labourers are put in the category of medium scale industries. Cycle industry, radio and television industries are some examples of medium scale industries.

3. Small Scale Industries:

Industries which are owned and run by individuals and which employ a small number of labourers are called small scale industries.

II. On the Basis of Raw-Material and Finished Goods:

Industries classified on the basis of raw materials and finished goods are:

1. Heavy Industries:

Industries which use heavy and bulky raw-materials and produce products of the same category are called heavy industries. Iron and steel industry presents a good example of heavy industries.

2. Light Industries:

The light industries use light raw-materials and produce light finished products. Electric fans, sewing machines are light industries.

III. On the basis of Ownership:

Since the start of the planned development of Indian economy in 1951, industries are divided in the following four classes:

1. Private Sector Industries:

Industries owned by individuals or firms such as Bajaj Auto or TISCO situated at Jamshedpur are called private sector industries.

2. Public Sector Industries:

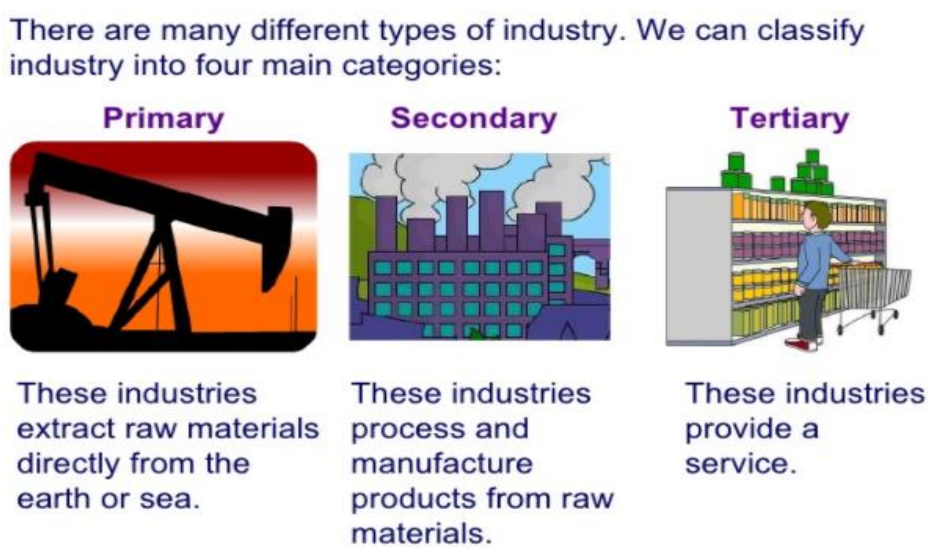
Industries owned by the state and its agencies like Bharat Heavy Electricals Ltd., or Bhilai Steel Plant or Durgapur Steel Plant are public sector industries.

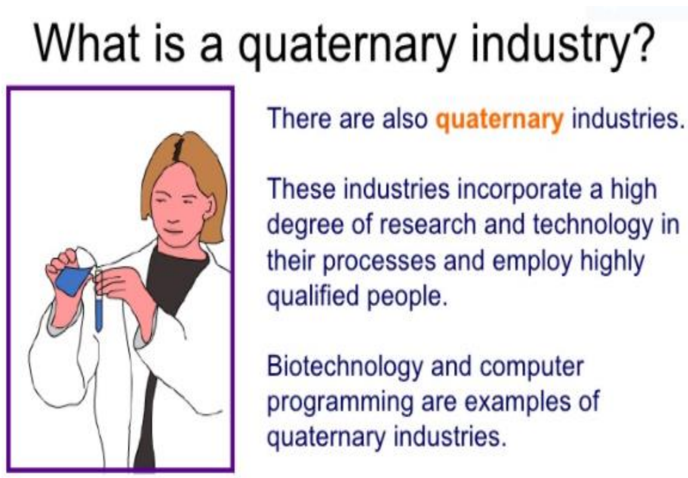
3. Joint Sector Industries:

Industries owned jointly by the private firms and the state or its agencies such as Gujarat Alkalies Ltd., or Oil India Ltd. fall in the group of joint sector industries.

4. Co-operative Sector Industries:

Industries owned and run co-operatively by a group of people who are generally producers of raw materials of the given industry such as a sugar mill owned and run by farmers are called co-operative sector industries.





IV. On the Basis of Source of Raw Material:

On the basis of source of raw materials, industries are classified as under:

1. Agro Based Industries:

Agro based industries are those industries which obtain raw-material from agriculture. Cotton textile, jute textile, sugar and vegetable oil are representative industries of agro-based group of industries

2. Mineral Based Industries:

The industries that receive raw materials primarily from minerals such as iron and steel, aluminium and cement industries fall in this category.

3. Pastoral-Based Industries:

These industries depend upon animals for their raw material. Hides, skins, bones, horns, shoes, dairy, etc. are some of the pastoral-based industries.

4. Forest Based Industries:

Paper card-board, lac, rayon, resin, tanning of leather, leave- utensils, basket industries are included in this type of industries.

V. Miscellaneous Industries:

Industries are also classified into the following miscellaneous categories.

1. Village Industries:

Village industries are located in villages and primarily cater to the needs of the rural people. They usually employ local machinery such as oil extraction, grain grinding and agricultural implements.

2. Cottage Industries:

Industries which artisans set up in their own houses, work with wood, cane, brass, stone, etc. are called cottage industries. Handloom, khadi and leather work at the artisans house fall in this category.

3. Consumer Goods Industries:

Consumer industries convert raw materials or primary products into commodities directly used by the people. Textiles, bakeries, sugar, etc. are some of the consumer goods industries.

4. Ancillary Industries:

The industries which manufacture parts and components to be used by big industries for manufacturing heavy articles like trucks, buses, railway engines, tractors, etc. are called ancillary industries.

5. Basic Industries:

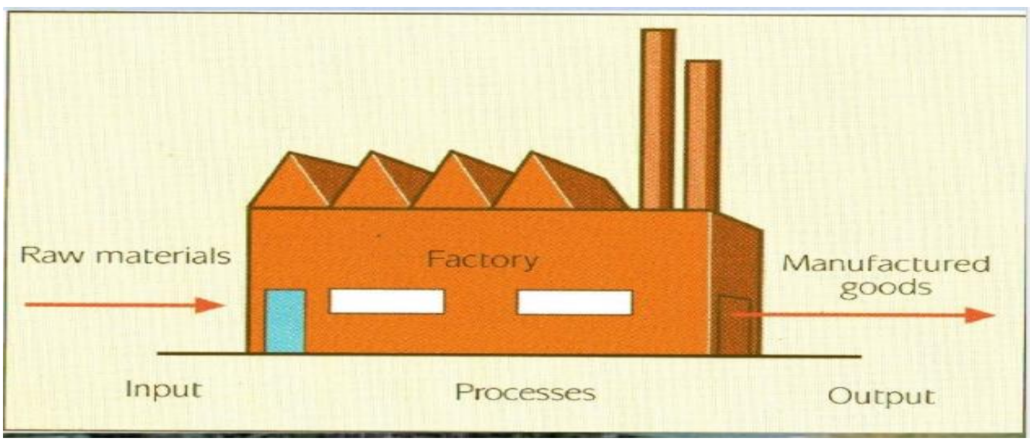
Industries on which depend many other industries for their manufacturing processes are called basic industries. Iron and steel industry and power generating industry are included in this category.

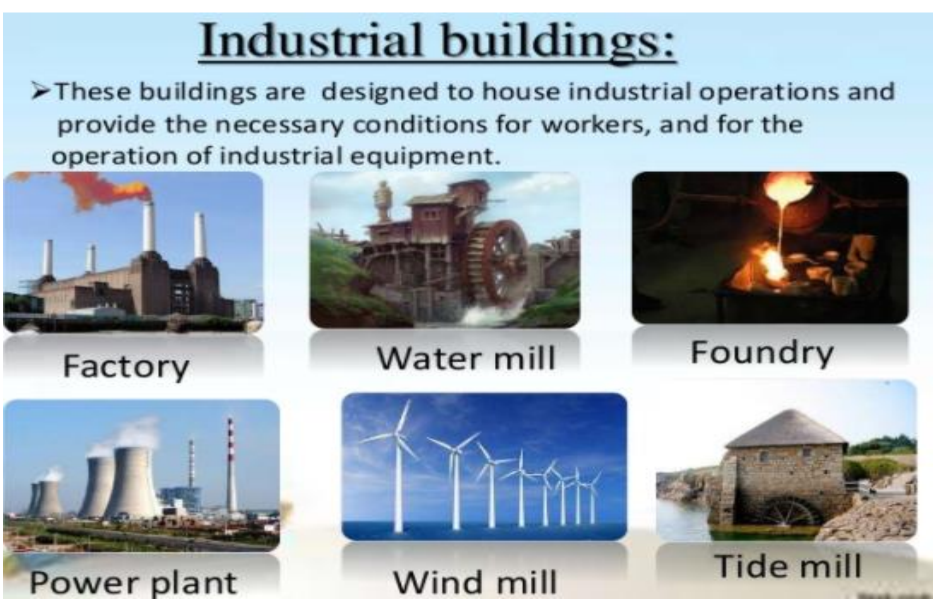
6. Capital-Intensive Industries:

Industries requiring huge investments are called capital-intensive industries. Iron and steel, cement and aluminium are outstanding examples of capital-intensive industries.

7. Labour-Intensive Industries:

Industries which require huge labour force for running them are called labour-intensive industries. In these industries, labour is more important than capital. Shoe- making and bidi-manufacturing, etc. are included in these industries.





Pollutions in Industry

Noise Pollution

Noise pollution is not physically seen like any other pollutants air and water, thus, we are not much bothered about the harmful effects of Noise pollution that affects us just like slow poison.

GENERAL SOURCES OF NOISE POLLUTION

The sources of noise pollution can be divided in two categories.

1.INDUSTRIAL SOURCES

Industrial noise is due to big machines, cutting, grinding, packaging, transportation of materials etc due to operations of Rotors, Stators, Gears, Fans, Vibrating panels, Turbulent fluid flow, Impact processes, Electrical machines, Internal combustion engines etc.

2. NON-INDUSTRIAL SOURCES

Non-industrial sources can be mainly loudspeakers, automobiles, trains, aircrafts, construction work, radio, cassettes, CD players etc.

The major noise sources are flow of oil, water and gas through pipes, valves etc.

The noise level close to valves is in between 80 - 90 dB(A).

The noise level close 40 mts. from the flare is around 70dB(A).

The general noise level ranges between 70 – 90 dB(A)

Various Noise Polluting Industries are

- Iron and steel industry
- Saw mills
- Textile mills
- Airports and aircraft maintenance shops
- Crushing mills
- Among many others

Noise limit levels vary from country to country so generally the following values

may be recommended for all type of industries

- Warning Limit Value : 85dB

- Danger Limit Value : 95dB

International & National Legislations:

(a) No matter for how short a time, a worker should not enter an area where the noise level is 115dB or more without appropriate ear protection.

(b) If these are single isolated bursts of noise which can go about 130dB

(c) No worker should enter an area where the noise level exceeds 140dB

Control Techniques for Noise Pollution

- There are various options available to control the noise pollution.
- The options of noise pollution can be selected as per the particular needs.

1. Isolate noise at source

2. Noise control in path

3. Noise control at the receiver end

1. Isolate noise at source

The first and simple way to control the noise pollution is insulation. By insulation noise can be reduced at source.

Choosing a quieter manufacturing process. E.g. DC Engines, bush bearing etc.

By reducing practicable rotational speeds, reducing flow speeds, reducing pressure of gases in stages etc.

Damping vibration of the crucial parts through the use of the correct fabrication material

2. Noise control in path

- Putting major noise sources at one place & separating it from quieter area.
- Using acoustic barriers, sound absorbing linings & sound insulating partitions.
- Complete or partial enclosure of noisy equipment
- Providing silencers on the intake as well as exhaust side of flow machines, like, blowers, fans etc.
- Insertion of damping material between machine bases and foundations and use of anti vibration mountings.

3. Noise control at the receiver end

Wherever it is not possible to reduce noise exposure to the permissible limit at the source or in the path, the workers exposed to high should be provided with suitable ear protector.

Receivers can protect himself by:

- Making use of ear muffs, ear plugs etc.
- Using acoustically closed cabin.

Effects of Noise Pollution

- Hearing Problems
- Health Issues
- Sleeping Disorder
- Cardiovascular Issues
- Trouble Communicating
- Effect on Wildlife

A 10 decibel increase in sound represents a 10 times increase in volume. If 20 decibel increase in sound represents a 100 times increase in volume. A 30 decibel increase in sound represents a 1000 times increase in volume. Sound also travels faster and further in water than in air. High intensity sound in the oceans may not dissipate for thousands of miles.

Lighting in Industries

Good lighting enables workers in factory buildings to carry out their visual tasks easily, quickly and without fatigue and to move about in work areas safely. It also helps in cutting down wastage and rejects, in utilising floor space

efficiently and in boosting morale and thus in

improving the overall performance of the factory.

INSTITUTUIONS AND RULES

- Illumination Engineering Society
- NIOSH- National Institute Of Occupational Safety And Health
- ISI- Indian Standards Institution
- Indian Factories Act

ILLUMINATION LEVELS

Task Illumination - The quantity of light at a workplace depends upon the visual task so that the individual worker can see the task clearly, accurately and without eye strain.

Lux -defined as lumens of flux per sq.m of the surface of the task

Based on visibility parameters, size of the task, brightness, Brightness contrast visual capacity in terms of time required to see the task.

Unless the precise height and location of the task is known or specified then this to be provided on a horizontal working plane at the level of 85 cm above the floor level.

For reasons of economy, the following recommended values is for the task or tasks only.

a) Most difficult seeing tasks, such as extra fine assembly, precision grading, extra-fine finishing	10 000 lux
b) Very difficult seeing tasks, such as fine assembly, high speed work, fine finishing	1 000 lux
c) Difficult and critical seeing tasks, such as ordinary bench work and assembly, machine shop work, finishing of medium and fine parts, office work	500 lux
d) Ordinary seeing tasks, such as automatic machine operations, rough grading, continuous processes, packing, and shipping	300 lux
e) Casual seeing tasks, such as stair-ways, wash rooms and other surface areas, active storages	100 lux
f) Rough seeing tasks, such as corridors, passages, inactive storages	50 lux

TABLE 1 RECOMMENDED VALUES OF ILLUMINATION

(*Clause* 2.1)

Sl No.	Industrial Buildings and Processes	Average Illumination
(1)	(2)	(3)
		lux
i)	*General Factory Areas*	
	a) Canteens	150
	b) Cloak-rooms	100
	c) Entrances, corridors, stairs	100
ii)	*Factory Outdoor Areas*	
	Stockyards, main entrances and exit roads, car parks, internal factory roads	20
iii)	*Aircraft Factories and Maintenance Hangars*	
	a) Stock parts productions	450
	b) Drilling, riveting, screw fastening sheet aluminium layout and template work, wing sections, cowling welding, sub-assembly, final assembly and inspection	300

TABLE 1 RECOMMENDED VALUES OF ILLUMINATION — *Contd*

Sl No.	Industrial Buildings and Processes	Average Illumination
(1)	(2)	(3)
		lux
	c) Cutting table and presses, stitching	1 000
	d) Bottom stock preparation, lasting and bottoming, finishing	700
	e) Shoe rooms	700
ix)	*Breweries and Distilleries*	
	a) General working areas	150
	b) Brewhouse, bottling and canning plants	200
	c) Bottle inspection	Special lighting
x)	*Canning and Preserving Factories*	
	a) Inspection of beans, rice, barley, etc	450
	b) Preparation: Kettle areas, mechanical cleaning, dicing, trimming	300
	c) Canned and bottled goods : Retorts	200

Characteristics Of Good Lighting

Glare - Glare is caused due to an uneven distribution of light sources or due to excessive contrast or abrupt changes in brightness in space and time or by seeing light sources or sun directly or after reflection from polished surfaces.

Uniformity of Distribution - It is usually desirable to provide reasonably uniform general illumination over the entire work area. A gradual transition of brightness with diversity ratio of not less than 0.7 from one area to the other within the field of vision not only ensures reasonable uniformity but also minimises glare. Maximum and minimum illumination at any point should not be more than one-sixth above or below the average level in the area.

Brightness Contrast - The brightness of an object depends upon the amount of light flux incident and proportion of that light reflected or transmitted in the direction of the eye. Excessive brightness ratios, even though not severe enough to cause glare, may be seriously detrimental to lighting quality.

Direction of Lighting and Diffusion – The light gets diffused when it flows from various random directions. It is measured in terms of the absence of sharp shadows. The degree of diffusion desirable for a task depends upon the type of work to be performed.

Colour and Colour Rendering - The efficiency of performance of visual tasks is independent of colour of light or of the object, provided the brightness and the brightness contrast remain the same. The appearance of coloured surfaces depends on their spectral reflection characteristics and the spectral composition of the light illuminating them, and is therefore different for light sources of different spectral composition.

Strosboscopic Effect and flicker from Discharge - Lamps Rotating machinery or other objects appear to slow down in Speed light output varies with alternating current and this produces certain effects known as flicker

Colour Dynamics- A good white paint reflects 80 percent or more of the light

DAYLIGHTING

Daylighting is preferable to artificial lighting Solar illumination (direct sunlight being excluded) and sky radiation. Direct sunlight over moving machinery in factory floors during certain hours of the day can cause undesirable visual fatigue and may become a source of danger

PRINCIPLES OF DAYLIGHTING DESIGN

Clear Design Sky

Relative amount of sky radiation depends on the position of the sun defined by its altitude, latitude of the locality, the day of the year and the time of the day.

It is the clear sky opposite the sun corresponding to solar altitude of 15 deg.

Daylight Factor

Daylight at a point indoors is usually measured, as a ratio of the total illumination which would be received at the same moment out-of-doors from an unobstructed view of clear design sky.

Direct sky visible from the point (excluding direct sun)

External surfaces reflecting light directly to the point

Internal surfaces reflecting and inter-reflecting light to the point.

Daylight Fenestration

- Buildings with skylight,
- Buildings with closed ceilings (multi-storeyed buildings)
- High -bay large span structures.

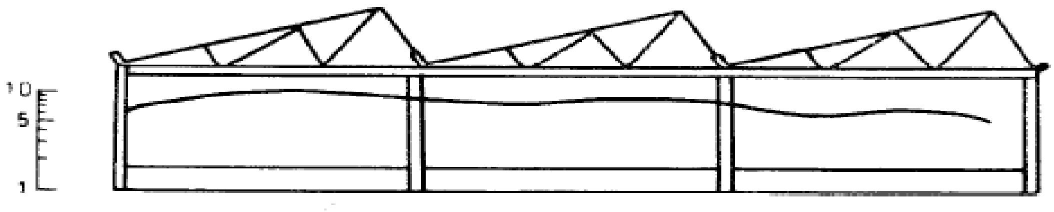
BUILDINGS WITH SKYLIGHT

- Direct sunlight should be screened as far as possible

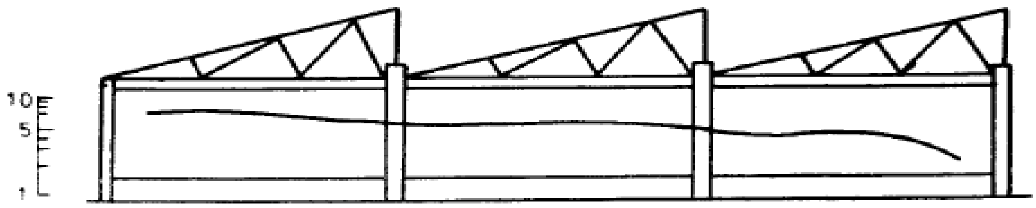
- Materials of low transmittance for glazing
- Most factories employ north light

Saw -tooth type Keeps off direct mid-day sun in latitudes north of 23 deg

SAW-TOOTH (NORTH-LIGHT) FENESTRATION



2A Inclined Glazing



2B Vertical Glazing

MONITOR ROOF FENESTRATION

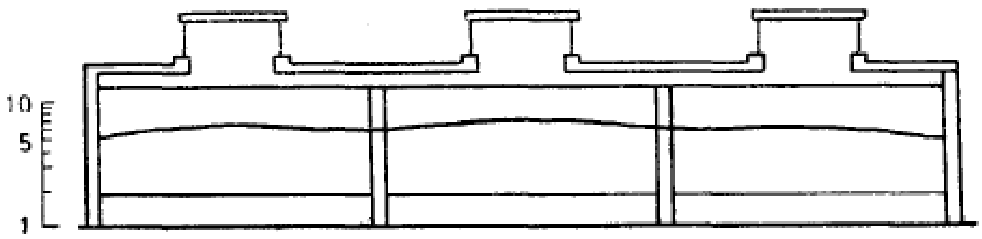


Fig. 7 Monitor Roof with Vertical Glazing
(Glass Area 30 Percent of Floor Area)

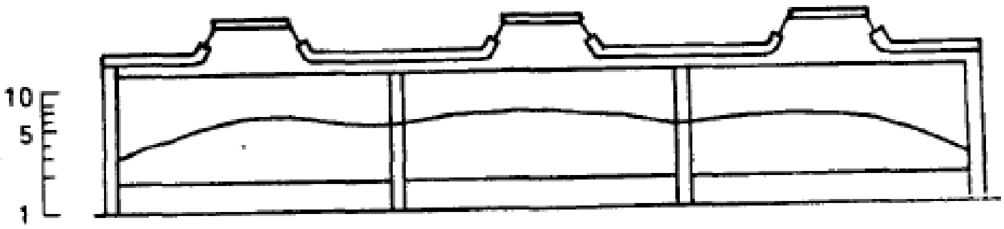


Fig. 8 Monitor Roof with 60° Slope Glazing
(Glass Area 16 Percent of Floor Area)

HORZONTAL ROOF FENESTRATION

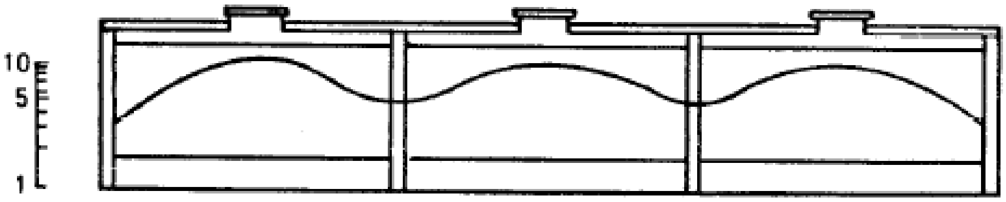


FIG. 9 CONTINUOUS HORIZONTAL ROOF LIGHTS WITH DIFFUSED GLAZING
(17 PERCENT OF FLOOR AREA)

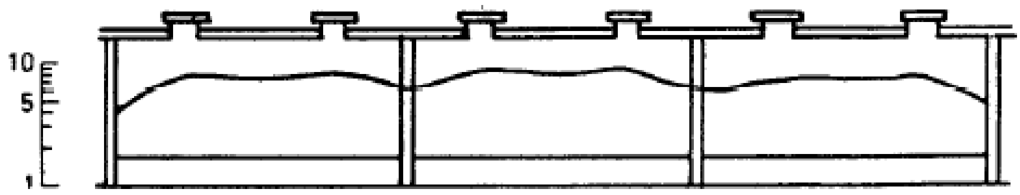


FIG. 10 CONTINUOUS HORIZONTAL ROOF LIGHTS
(GLASS AREA 11·5 PERCENT OF FLOOR AREA)

DOUBLE-PITCH INCLINED ROOF

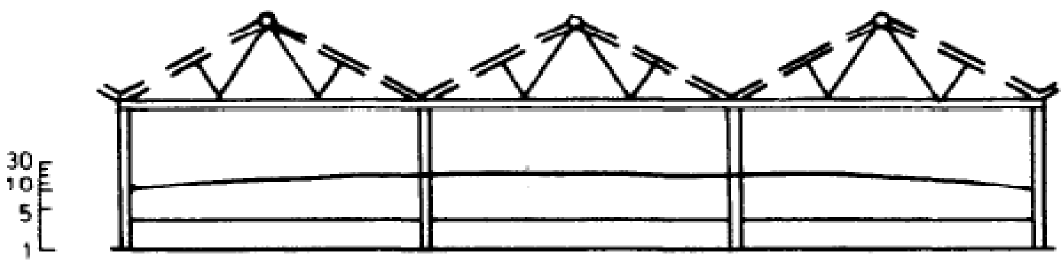


FIG. 11 SHED TYPE ROOF WITH CONTINUOUS STRIPS OF GLAZING
(GLASS AREA 20 PERCENT OF FLOOR AREA)

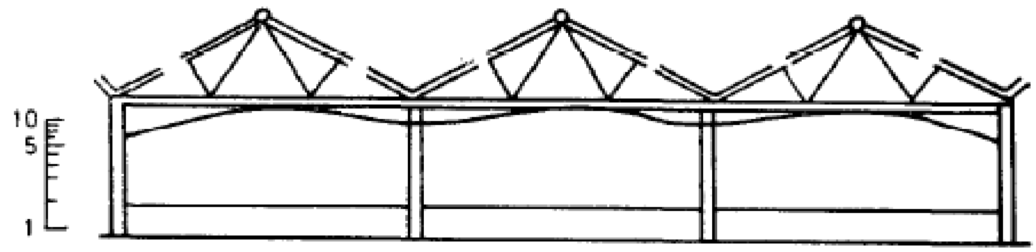


FIG. 12 SHED TYPE ROOF WITH CONTINUOUS STRIPS OF GLAZING
(GLASS AREA 20 PERCENT OF FLOOR AREA)

BUILDINGS WITH CLOSED CEILINGS

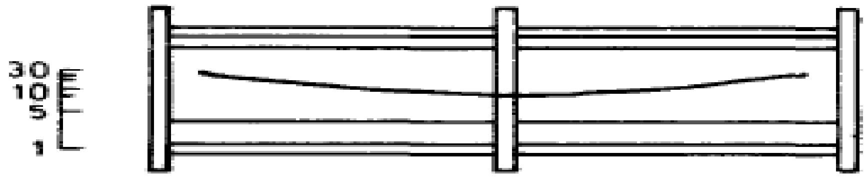


FIG. 13 SIDE GLAZING IN A MULTI-STOREY BUILDINGS (50 PERCENT OF FLOOR AREA)

FIG. 14 SIDE GLAZING IN A MULTI-STOREY BUILDING (GLASS AREA 74 PERCENT OF FLOOR AREA)

ARTIFICIAL LIGHTING

- Permanent Supplementary Lighting (PSALI)
- Quality
- Layout

Number of lamps is calculated using the formula given below

$$N = \frac{E_{AV} \times A}{F \times C \times M}$$

lumens per lamp or luminaire,

$$F = \frac{E_{AV} \times A}{N \times C \times M}$$

A - room area

E_{AV} - illumination intensity level

C – coefficient of utilization

M – maintenance factor

Industrial Ventilation

Environmental engineer's view:

The design and application of equipment for providing the necessary conditions for maintaining the efficiency, health and safety of the workers

Industrial hygienist's view:

The control of emissions and the control of exposures

Mechanical engineer's view:

The control of the environment with air flow. This can be achieved by replacement of contaminated air with clean air.

It is necessary for the following reasons

- ❖ To maintain an adequate oxygen supply in the work area.
- ❖ To control hazardous concentrations of toxic materials in the air.
- ❖ To remove any undesirable odors from a given area.
- ❖ To control temperature and humidity.
- ❖ To remove undesirable contaminants at their source before they enter the work place air.

Application Of Industrial Ventilation Systems

- Optimization of energy costs.
- Reduction of occupational health disease claims.
- Control of contaminants to acceptable levels.
- Control of heat and humidity for comfort.
- Prevention of fires and explosions.

Solutions To Industrial Ventilation Problems

- ❖ Process modifications
- ❖ Local exhaust ventilation
- ❖ Substitution
- ❖ Isolation
- ❖ Administrative control

- Personal protection devices
- Natural ventilation

Ventilation Design Parameters

- Manufacturing process
- Exhaust air system & local extraction
- Climatic requirements in building design (tightness, plant aerodynamics, etc)
- Cleanliness requirements
- Ambient air conditions
- Heat emissions
- Terrain around the plant
- Contaminant emissions
- Regulations

Source Characterization

- Location
- Relative contribution of each source to the exposure
- Characterization of each contributor
- Characterization of ambient air
- Worker interaction with emission source
- Work practices

Types Of Industrial Ventilation Systems

- **Supply systems**

Purpose:

To create a comfortable environment in the plant i.E. The HVAC system

To replace air exhausted from the plant i.e. The replacement system

Components

- ❖ Air inlet section
- ❖ Filters
- ❖ Heating and/or cooling equipment
- ❖ Fan
- ❖ Ducts
- ❖ Register/grills for distributing the air within the work space

- **Exhaust Systems**

  Purpose

  An exhaust ventilation system removes the air and airborne contaminants from the work place air

  The exhaust system may exhaust the entire work area, or it may be placed at the source to remove the contaminant at its source itself

  Types of exhaust systems:

  I. General exhaust system

  II. Local exhaust system

  I. General exhaust system

- Used for heat control in an area by introducing large quantities of air in the area. The air may be tempered and recycled.
- Used for removal of contaminants generated in an area by mixing enough outdoor air with the contaminant so that the average concentration is reduced to a safe level.

II. Local exhaust system

- ❖ The objective of a local exhaust system is to remove the contaminant as it is generated at the source itself.

Advantages:

- ❖ More effective as compared to a general exhaust system.

- The smaller exhaust flow rate results in low heating costs compared to the high flow rate required for a general exhaust system.
- The smaller flow rates lead to lower costs for air cleaning equipment.

Components:

- Hood
- The duct system including the exhaust stack and/or re-circulation duct
- Air cleaning device
- Fan, which serves as an air moving device

What is the difference between Exhaust and Supply systems?

An Exhaust ventilation system removes the air and air borne contaminants from the work place, whereas, the Supply system adds air to work room to dilute contaminants in the work place so as to lower the contaminant concentrations.

Pressure In A Ventilation System

- Air movement in the ventilation system is a result of differences in pressure.
- In a supply system, the pressure created by the system is in addition to the atmospheric pressure in the work place.
- In an exhaust system, the objective is to lower the pressure in the system below the atmospheric pressure.

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UNIT – II –INDUSTRIAL STRUCTURES-SCIA7014

INTRODUCTION

Most industrial buildings primarily serve as an enclosure for production and/or storage. The design of industrial buildings may seem logically the province of the structural engineer. It is essential to realize that most industrial buildings involve much more than structural design. The designer may assume an expanded role and may be responsible for site planning, establishing grades, handling surface drainage, parking, on-site traffic, building aesthetics, and, perhaps, landscaping. The design of industrial buildings is governed mainly by functional requirements and the need for economy of construction. In cross section these buildings will range from single or multi-bay structures of large span when intended for use as warehouses or aircraft hangars to smaller span buildings as required for factories, assembly plants, maintenance facilities, packing plants, etc. The main dimensions will nearly always be dictated by the particular operational activities involved, but the structural designer's input on optimum spans and the selection of suitable cross-section profiles can have an important bearing on achieving overall economy. Discussions between the owner or his architect and the engineer at an early stage of planning can help to secure a good balance between operational and structural considerations. An aspect where the structural designer can make a more direct contribution is in the lengthwise dimensions, i.e. the bay lengths of the building. Here a balance must be struck between large bays involving fewer, heavier main components such as columns, trusses, purlins, crane beams, etc, and smaller bays with a larger number of these items at lower unit mass. An important consideration in this regard is the cost of foundations, since a reduction in the number of columns will always result in lower foundation costs. In large industrial buildings with heavy overhead cranes, an economical dimension for the centres of the main columns (i.e. the span of the crane girders) is 15.0 m. Another rule of thumb is to make this dimension equal to the height of the rails above floor level. In the simpler type of building an optimum purlin span can have a bearing on bay length. here crane girders are not required and the structure comprises mainly of columns, trusses (or rafters), purlins and girts, the spacing of roof principals at large intervals will nearly always be more economical. The use of continuous cold-formed purlins – sleeved or lapped at the joints – will permit truss spacing of 9.0 m or more, greatly reducing the total steelwork mass.

GENERAL DESIGN AND ECONOMICCONSIDERATIONS

No absolute statements can be made about what truss configuration will provide the most economical solution. For a particular situation, however, the following statements can be made regarding truss design:Span-to-depth ratios of 15 to 20 generally prove to be economical; however, shipping depth limitations should be considered so that shop fabrication can be maximized. The maximum depth for shipping is conservatively 14 ft (4.27m). Greater depths will require the web members to be field bolted, which will increase erection costs.The length between splice points is also limited by shipping lengths. The maximum shippable length varies according to the destination of the trusses, but lengths of 40 ft (12.2m) are generally shippable and 50 ft (15.25) is often possible. Because maximum available mill length is approximately 70 ft (21.35m), the distance between splice points is normally set at a maximum of 70 ft (21.35m). Greater distances between splice points will generally require truss chords to be shop spliced. In general, the rule ―deeper is cheaper‖ is true; however, the costs of additional lateral bracing for more flexible truss chords must be carefully examined relative to the cost of larger chords which may require less lateral bracing. The lateral bracing requirements for the top and bottom chords should be considered interactively while selecting chord sizes and types. Particular attention should be paid to loads that produce compression in the bottom chord. In this condition additional chord bracing will most likely be necessary. If possible, select truss depths so that tees can be used for the chords rather than wide flange shapes. Tees can eliminate (or reduce) the need for gusset plates. Utilize only a few web angle sizes, and makeuse of efficient long leg angles for greater resistance to buckling. Differences in angle sizes should be recognizable. For instance avoid using an angle 4×3×¼ and an angle 4×3×5/16 in the same truss. HSS, wide flange or pipe sections may prove to be more effective web members at some web locations, especially where subsystems are to be supported by web members. Designs using the Indian standard General construction in Steel – code of practice (IS 800-2007) will often lead to truss savings when heavy long span trusses are required. This is due to the LIMITSTATE approach. The weight of gusset plates, shim plates and bolts can be significant in large trusses. This weight must be considered in the design since it often approaches 10 to 15 percent of the truss weight. Repetition is beneficial and economical. Use as few different truss depths as possible. It is cheaper to vary the chord size as compared to the truss depth.

LOADING CONDITIONS AND LOADING COMBINATIONS

Loading conditions and load combinations for industrial buildings without cranes are well established by building codes. Dead load: This load represents the weight of the structure and its components, and is usually expressed in kN/m2 . In an industrial building, the building use and industrial process usually involve permanent equipment that is supported by the structure. This equipment can sometimes be represented by a uniform load (known as a collateral load), but the points of attachment are usually subjected to concentrated loads that require a separate analysis to account for the localized effects**.**

Live load: This load represents the force imposed on the structure by the occupancy and use of the building. Building codes give minimum design live loads in kN/m2, which vary with the classification of occupancy and use. While live loads are expressed as uniform, as a practical matter any occupancy loading is inevitably non-uniform. The degree of non-uniformity that is acceptable is a matter of engineering judgment. Some building codes deal with non-uniformity of loading by specifying concentrated loads in addition to uniform loading for some occupancies. In an industrial building, often the use of the building may require a live load in excess of the code stated minimum. Often this value is specified by the owner or calculated by the engineer. Also, the loading may be in the form of significant concentrated loads as in the case of storage racks or machinery Snow loads: Most codes differentiate between roof live and snow loads. Snow loads are a function of local climate, roof slope, roof type, terrain, building internal temperature, and building geometry. These factors may be treated differently by various codes.

Rain loads: These loads are now recognized as a separate loading condition. In the past, rain was accounted for in live load. However, some codes have a more refined standard. Rain loading can be a function of storm intensity, roof slope, and roof drainage. There is also the potential for rain on snow in certain regions. Wind loads: These are well codified, and are a function of local climate conditions, building height, building geometry and exposure as determined by the surrounding environment and terrain. Typically, they‘re based on a 50-year recurrence interval— maximum three-second gust. Building codes account for increases in local pressure at edges and corners, and often have stricter standards for individual components than for the gross building. Wind can apply both inward and outward forces to various surfaces on the building exterior and can be affected by size of wall openings. Where wind forces produce overturning or net upward forces, there must be an adequate counterbalancing structural dead weight or the structure must be anchored to an adequate foundation.

Earthquake loads: Seismic loads are established by building codes and are based on:

- The degree of seismic risk
- The degree of potential damage
- The possibility of total collapse
- The feasibility of meeting a given level of protection Earthquake loads in building codes are usually equivalent static loads.

Seismic loads are generally a function of:

• The geographical and geological location of the building

• The use of the building

• The nature of the building structural system

• The dynamic properties of the building

• The dynamic properties of the site

• The weight of the building and the distribution of the weight.

Load combinations are formed by adding the effects of loads from each of the load sources cited above. Codes or industry standards often give specific load combinations that must be satisfied. It is not always necessary to consider all loads at full intensity. Also, certain loads are not required to be combined at all. For example, wind need not be combined with seismic. In some cases only a portion of a load must be combined with other loads. When a combination does not include loads at full intensity it represents a judgment as to the probability of simultaneous occurrence with regard to time and intensity.

DESIGN PROCEDURES

In an effort to optimize design time, the following procedural outline has been developed for the designer. • Determine the best geometrical layout for the building in question.

• Design the crane girders and determine column and frame forces from the crane loadings.

• Perform preliminary design of the crane columns.

• the roof trusses or roof beams for dead loads and live loads.

• Determine all loading conditions for which the entire frame must be analyzed.

• Analyze the frame in question for dead, live, wind and seismic loadings.

• This analysis should be performed without load sharing from the adjacent frames. Also determine the lateral stiffness of the frame.

• Analyze the frame (considering load sharing) for crane loadings.

• Combine moments and forces from the two analyses for subsequent design

• Perform the final design of columns, trusses, braces and details.

EXPANSION JOINTS

Although industrial buildings are often constructed of flexible materials, roof and structural expansion joints are required when horizontal dimensions are large. It is not possible to state exact requirements relative to distances between expansion joints because of the many variables involved, such as ambient temperature during construction and the expected temperature range during the life of the buildings. Expansion joint recommendation as per IS 800-2007:Structures in which marked changes in plan dimensions take place abruptly, shall be provided with expansion joints at the section where such changes occur. Expansion joints shall be so provided that the necessary movement occurs with minimum resistance at the joint. The gap at the expansion joint should be such that: It accommodates the expected expansion contraction due to seasonal and diurnal variation of temperature, and it avoids pounding of adjacent units under earthquake. It avoids pounding of adjacent units under earthquake. The structure adjacent to the joint should preferably be supported on separate columns but not necessarily on separate foundations.one bay of longitudinal bracing is provided at the centre of the building or building section, the length of the building section may be restricted to 180 m in case of covered buildings and 120 m in case of open gantries If more than one bay of longitudinal bracing is provided near the centre of the building /section, the maximum centre line distance between the two lines of bracing may be restricted to 50 m for covered buildings (and 30 m for open gantries) and the maximum distance between the centre of the bracing to the nearest expansion joint end of building or section may be restricted to 90 m (60 m in case of open gantries).The maximum length of the building section thus may be restricted to 230 m for covered buildings (150 m for open gantries).

BRACING SYSTEMS

Roof Bracing (Horizontal or wind bracing)

Roof bracing is very important in the design of an industrial building. The roof bracing allows the lateral forces induced due to wind and crane to be shared by adjacent bents. This sharing of lateral load reduces the column moments in the loaded bents. This is true for all framing schemes (in other words, rigid frames of shapes, plates, trusses, or braced frames).It should be noted, however, that in the case of rigid frame structures the moments in the frame cannot be reduced to less than the wind induced moments. For lightly loaded cranes, wind bracing in the plane of the wall may be adequate for resisting longitudinal crane forces. While for very large longitudinal forces, the bracing will most likely be required to be located in the plane of the crane rails. The crane column may tend to twist if the horizontal truss is not provided. Such twisting will induce additional stresses in the column. The designer should calculate the stresses due to the effects of the twisting and add these stresses to the column axial and flexural stresses. A torsional analysis can be made to determine the stresses caused by twist, or as a conservative approximation the stresses can be determined by assuming that the twist is resolved into a force couple in the column flanges as shown in Figure 6.6.The following criteria will normally define the longitudinal crane force transfer: For small longitudinal loads (up to 18kN) use of wind bracing is generally efficient, where columns are designed for the induced eccentric load. For medium longitudinal loads (18kN -36 kN) a horizontal truss is usually required to transfer the force to the plane of X-bracing. For large longitudinal loads (more than 36 kN) bracing in the plane of the longitudinal force is generally the most effective method of bracing. Separate wind X-bracing on braced frames may be required due to eccentricities. Normally the X-bracing schemes resisting these horizontal crane forces are best provided by angles or tees rather than rods. In cases where aisles must remain open, portal type bracing may be required in lieu of designing the column for weak axis bending. It should be noted that portal bracing will necessitate a special design for the horizontal (girder) member, and that the diagonals will take a large percentage of the vertical crane forces. This system should only be used for lightly loaded, low fatigue situations. The following summary of crane girder selection criteria may prove helpful Light cranes and short spans—use a wide flange beam. Medium cranes and moderate spans use a wide flange beam, and if required reinforce the top flange with a channel. Heavy cranes and longer spans—use a plate girder, with a horizontal truss or solid plate at the top flange Limit deflections under crane loads as follows:

TRUSSES - HOW THEY WORK

The Romans found that if they leant stones against one-another in the shape of an arch, they could span greater distances than by using the stone as simple lintels or beams. In an arch the stones are in compression. The arch will perform as long as the supports or buttresses at each end of the arch provide restraint, and do not spread apart. Timber beams can also be propped against one-another to form arches. The timber members will be in compression and will also act as simple beams. To turn the arch into a truss all that is required is to provide a tie between the two buttresses to stop them from being pushed apart by the arch. The arch, beam, tie combinations is self- supporting – we call this structure a truss.

SELECTION OF ROOF TRUSSES

Architectural style, types of roofing material, methods of support of column framing, and relative economy are the principal factors influencing a choice among the three basic types of trusses bowstring, pitched, and flat. In addition, side- and end-wall height and type, roof shape, and bracing requirements must be considered. Other factors being equal, economy is the prime consideration. Economy is dependent upon efficiency in use of material relative to truss type and proportions and to fabrication labour. Theoretically, the three basic types in order of relative efficiency are bowstring, pitched, and flat. The function of a truss is to transfer load from point of application to the supports as directly as possible. Thus for a concentrated load at the centre line of a span, a simple ―All frame is the most efficient. Like-wise, if only two equal and symmetrically placed concentrated loads are involved, a truss similar to the queen-post type is the most efficient.In both trusses, the load is transferred to the support directly through the sloping top chord members without the need for web members. Economic factors. The maximum economical span of any given type of truss will vary with The material available Loading conditions SpacingType of truss Ratio of labour to material cost &Fabrication methods. TRUSS PROPORTIONS It is desirable to use as few truss panels as the use of reasonable member sizes will allow. This practice will mean fewer members to handle, fewer joints to fabricate and assemble, and theoretically improved performance. The number of panels usually should be determined by slenderness ratio of top-chord sizes rather than by any fixed formula. Depth-to-span ratio. Certain ratios of effective depth to span are recommended as being satisfactory on the basis of experience. The larger the span, the more desirable it is to use deeper trusses. Although trusses of less depth than these may be acceptable, special attention should then be given to the possibility of greater deflection and secondary stresses. Deflection in trusses of less- than-average depth may be held to a minimum by the following practices:Conservative designthe use of low or intermediate grades of materialthe use of a minimum number of chord splices (by employing the longest available lengths)the use of fastenings with the smallest deformation &the use of as few panels as possible. Stiffer members are also obtained, and therefore less deflection for a given load.It is recommended that the top chord of a bowstring truss be fabricated with a radius about equal to the span.The suggested effective depth-to-span ratio is between 1:6 and 1:8. A radius equal to the span will give a ratio slightly larger than the suggested minimum.For pitched trusses, an effective depthto-span ratio between 1:5 and 1:6 is recommended, and a minimum of not less than 1:7 unless special consideration is given to deflection.Much deeper trusses may be used for the sake of appearance, such as for the steeply pitched roofs popular in churches.For flat trusses, a minimum depth-to-span ratio between 1:8 and 1:10 is recommended, the deeper trusses being preferred for the longer spans.Roofs should have a minimum slope of ¼ in. per ft for proper drainage, although steeper slopes are often desirable.Flat roofs with no slope for drainage are not recommended unless provision is made in the design for possible accumulation of water due to a stopped drain or natural deflection.Drains on flat roofs should be located at the low points. These are at the center of the span if the truss is built flat.In longer spans, secondary deflection stresses are probably more important.As these stresses are not capable of exact computation, the larger depth-to-span ratios should be used for trusses employing such spans.Deflection of free-span trusses is usually well within acceptable limits, even that for plaster, but care should be taken to see that the natural deflection does not interfere with auxiliary framing.Suspended ceilings are often desirable. Ample clearance should be provided between trusses and so- called non healing partitions or plate glass windows.Provision should also be made for adjustment in the level of the hinges if there is a possibility that deflection may interfere with the proper operation of truss -suspended doors or machinery. Number of panels.It is desirable to use as few truss panels as the use of reasonable member sizes will allow. This practice will mean fewer members to handle, fewer joints to fabricate and assemble, and theoretically improved performance. The number of panels usually should be determined by slenderness ratio of top-chord sizes rather than by any fixed formula.

ROOF CONSTRUCTION SYSTEMS Provision should also be made for adjustment in the level of the hinges if there is a possibility that deflection may interfere with the proper operation of truss -suspended doors or machinery.Only two basic systems of roof construction need be considered in truss design.One applies roof loads to the truss only at the panel points; the other applies UDL over the top.The former system produces only direct stress in the chord member; the latter introduces bending as well as direct stress.

ROOF- TRUSS SPACING There are no fixed rules for spacing trusses in buildings. Spacing may be affected by roof framing wall construction size of material available loading conditions &the column spacing desired for material handling or traffic. In general, greater the bay spacing, lesser be the economical. Spacing limits are set by the purlin or girt sizes available for framing between trusses.

ROOF- TRUSS BRACING AND ANCHORAGE Bracing and anchorage is necessary to hold trusses and truss members in proper position so that they can resist vertical loads as well as lateral loads such as wind, impact, or earthquake. Although roof framing will usually serve as lateral bracing for the top-chord members, it is important that adequate lateral supports be provided for the bottom-chord members and also that consideration be given to the possible need for vertical- sway bracing between top and bottom chords of adjacent trusses. Horizontal cross-bracing is sometimes required in the plane of either the top and bottom chord, particularly in long buildings in which the diaphragm action of the roof framing is not adequate for end-wall forces, or in which side-wall loads are resisted by end walls or truss and its support are not designed as a bent to resist the lateral load. Trusses must be securely anchored to properly designed walls or columns and columns in turn anchored to foundations. Unless some other provision made for lateral loads on the side walls and on the vertical projection of the roof-such as for diaphragm action in walls and roof sheathing- lateral resistance should be provided in the column members by means of knee braces or fixity at the column base. The bracing should be designed and detailed with the same care as the truss itself and not left to the judgment of the contractor. The bracing requirements here suggested are minimums, and are not dependent on actual lateral- load analysis or on local code requirements. Vertical cross bracing should be installed at bottom chord at the location of the vertical bracing and be continuous from end. Design conditions vertical sway bracing is to be used in end section as a minimum, possibly two sections at each end and near mid span for long buildings. Column-and-wall bracing should be used where possible, it may consist of diagonal sheathing with studs or girt or cross-bracing.

Analysis

Manual analysis - Method of sections or Method of joints or Analysis using computers – Truss as a truss orTruss as a plane frame Design Load calculations and Load combinations Normally trusses are analyzed for Dead load, Live load, Wind load, Snow load, Seismic load and for different load combinations. All trusses in a roof structure are designed for the worst possible combination of dead, live and wind loads. The individual truss members are designed to restrain the corresponding forces i.e.., tension or compression, or a combination of bending with either the tension or compression force. The truss can be analyzed using STAAD pro software as plane frame and care is taken to do the proper analysis for Member release and Member truss options. All the loads are calculated and applied as UDL. Design can be done either by manual or using software.

Introduction to Gantry Girders:

In workshops and factories a very important and useful requirement is to have the means for lifting and moving heavy loads from one part to the other part of the shop area. Gantry girders supported on columns, carry the moving cranes. The hook-chain system is supported on a pulley.

The load can be lowered or raised from the overhead crane. The crab housing the winches is supported over the crane. The moving cranes are provided with wheels which move on rails which are fixed over the top flange of the gantry girder.

The rails are firmly attached to the top flange of the gantry girder by strong clips, preventing the rails from lateral dislocation due to lateral forces. Cranes may be of the slow motion type or quick motion type. The crane may be a slow moving manually or hand operated crane (M.O.T.) or may be an electrically operated quick acting crane (E.O.T.).

In the case of quick acting cranes stresses in the gantry girder are introduced almost instantaneously while in hand operated cranes, which are slow moving cranes stresses are introduced gradually. Hand operated cranes have a lifting capacity up to 50 kN. Electrically operated cranes have a lifting capacity in a wide range from 10 kN to 3000 kN.

Gantry Girder Sections:

Small cranes may consist of an integrated double beam unit. Large cranes consist of a double truss unit. Fig. 2.1 shows the types of beam sections used for gantry girder.

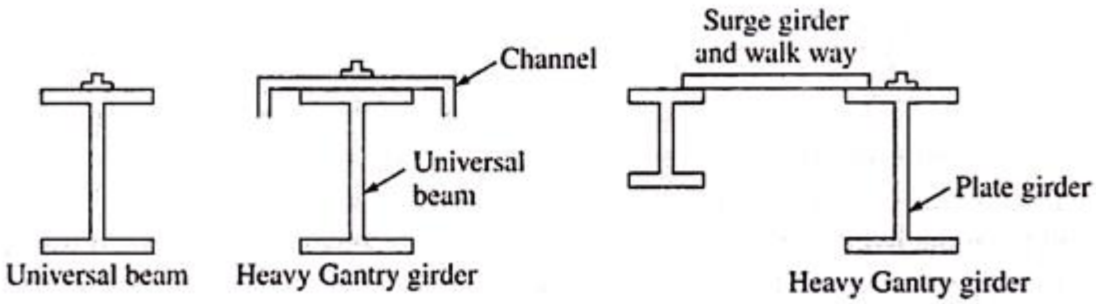


Fig.2.1 Different sections of gantry girder

These beams are subjected to vertical and horizontal loads due to dead load of the crane, the hook load and dynamic loads. Since they are also subjected to horizontal loads a larger top flange is generally provided. For a light gantry girder a universal beam only or a universal beam with a channel attached to the top flange is used. A heavy gantry girder consists of a plate girder along with a surge girder. The rails over the gantry girder are firmly fixed to the girder by bolted clamps or hook at a spacing of 0.50 m to 1 m to prevent the rail from lateral dislocation due to lateral forces. It is not usual to weld the rails to the gantry girder since welding makes it difficult for any readjustment of alignment of rails. Welding also makes it difficult for any replacement of worn out rails. The design loads on the gantry girder depends upon the minimum or the closest approach distance of the hook from the axis of the gantry girder.

In the usual case, the gantry girder is laterally unsupported. Hence it is a practice to strengthen the top compression flange by making it wider using channels. Sometimes a walk way connected to the gantry girder is provided in which case the girder may be regarded as laterally supported.

Wheel Base:

Wheel base means the distance between the two wheels resting on one gantry girder.

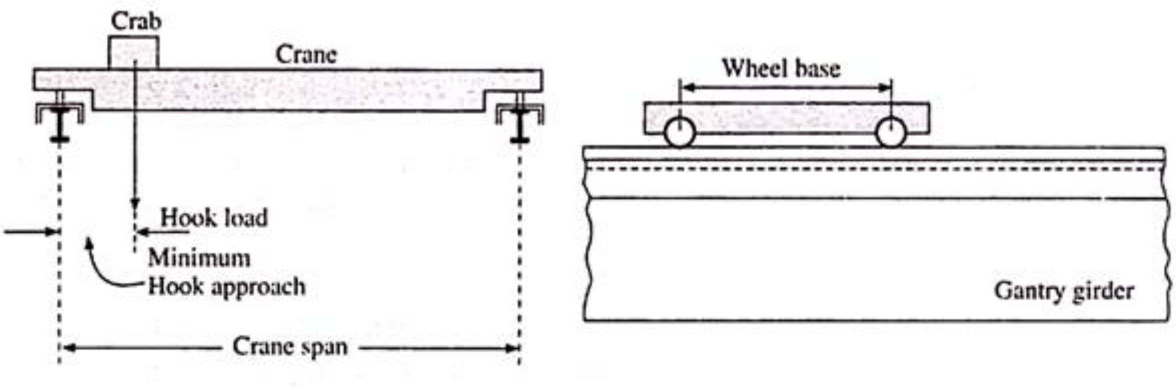


Fig. 2.2 Wheel base and crab movement

Gantry girders may be supported on brackets attached to columns or stepped columns or on a separate column set on the inner side of the main columns.

Crane and Gantry Girder Data:

Relevant data about the crane can be obtained from the manufacturer's literature. The data needed for gantry girder design are, Capacity of the crane, Crane span, Weight of the crane, End carriage wheel centres (Wheel base), Minimum hook approach, and Maximum static wheel load.

Allowances for Impact of Wheel Loads:

The following allowances are made to cover all forces caused by vibration, shock from slipping of slings, kinetic action of acceleration and retardation and impact of wheel loads.

	Type of load	*Additional load*
(*a*)	Vertical loads for electric operated cranes	25% of maximum static wheel loads
(*b*)	Vertical loads for hand operated cranes	10% of maximum static wheel loads
(*c*)	Horizontal forces transferred to rails (*i*) For electric operated cranes (*ii*) For hand operated cranes	 10% of (weight of crab + crane capacity) 5% of (weight of crab + crane capacity)
(*d*)	Horizontal traction forces along the rails, for all cranes (longitudinal forces)	5% of static wheel load

The rail provided over the gantry girder is assumed to offer no assistance to the gantry girder in supporting the wheel loads.

Loads on a Gantry Girder:

In most cases, a gantry girder is a laterally unsupported beam subjected to loads accompanied by impact. The girder is subjected to unsymmetrical bending due to various forces transmitted to it.

These forces are the following:

(i) Vertical loads transmitted by the crane.

(ii) Lateral forces transmitted due to sudden stopping or starting of the crab on the crane.

(iii) Longitudinal forces transmitted due to sudden stopping or starting of the crane.

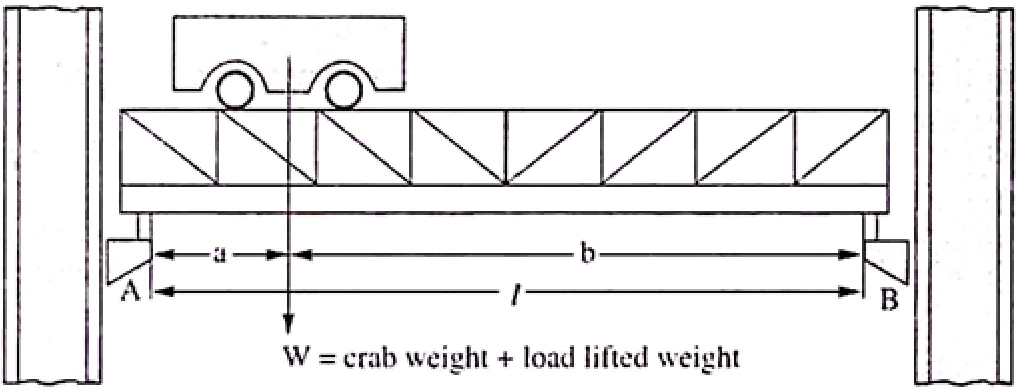


Fig. 2.3 Truss girder with trolley

(i) Vertical Loads:

The vertical load transmitted to the gantry girder is numerically equal to the reaction on the crane at its end and is due to the weight of the crane, the weight of the crab and the lift load (crane capacity). The load transmitted is maximum when the crab is closest to the gantry girder.

The girder is also subject to loads due to its own weight and the weight of the rails. The weight of the crab and the lift load is shared by the two gantry girders inversely proportional to the distances of the crab from the girders. For instance, if the span of the crane is L and if the crab is at a distance a from the girder A and W is the weight of crab and lift load the load transmitted to the girder A

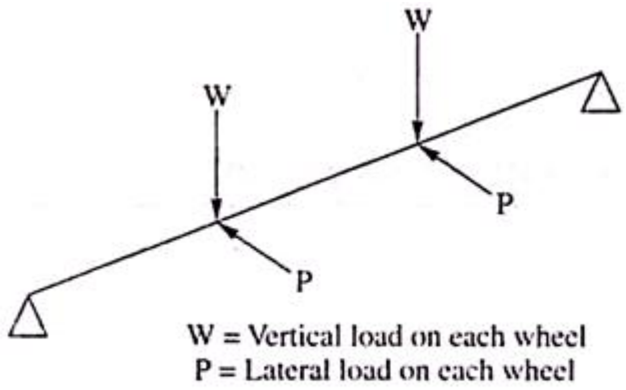


Fig.2.4 Free body diagram of forces on girder

(ii) Lateral Forces on the Gantry Girder:

The lateral or horizontal forces on the gantry girder are caused by the following:

(a) Sudden stopping or starting of the crab and load while moving on the crane.

(iii) Longitudinal Force:

Sudden stopping or starting of the crane introduces a longitudinal force on the gantry girder. The longitudinal force in fact is first induced in the rail which transmits the same to the gantry girder with a bending moment due to eccentric transmission of the force. The longitudinal force transmitted can be estimated as-

Let the coefficient of friction be μ. Then the total longitudinal force for one gantry girder will be times the actual wheel loads on the girder. Usually the coefficient of friction is assumed to be 0.12. Hence the longitudinal force on the gantry girder will be 12 per cent of the total wheel loads on one girder.

Design Details of Gantry Girders:

The relevant details in the design of a gantry girder are briefly given below:

1. Determination of the Maximum Wheel Load:

For the gantry girder under consideration the crab on the crane should be at the closest permissible distance from the gantry girder in order to produce the most critical shear force and bending moment. This distance is the minimum hook approach distance obtained from the manufacturer's literature. In this condition maximum load is transmitted to the gantry girder.

With the crab in this position we can determine the part of [Lift load + crab weight] transmitted to the gantry girder. The total vertical load transmitted from the crane is equally distributed to the two wheels on the gantry girder. The gantry girder carries the two wheel loads and its own weight.

2. Maximum vertical shear force and maximum vertical bending moment for the gantry girder are now determined.

The wheel loads must be placed on the gantry girder in such positions:

(i) To produce the maximum shear force, and

(ii) To produce the maximum bending moment.

In the usual situations the span of the gantry girder is considerably large compared with the wheel base distance.

The following discussions are based on this condition:

(i) Maximum Shear Force for the Gantry Gilder:

Let W = Each wheel load

a = Wheel base

l = Span of the gantry girder

The maximum shear force for the girder will occur when one wheel load tends to reach a support (Fig. 2.5). For this condition, maximum shear force-

$$= V = W + \frac{W(l-a)}{l}$$

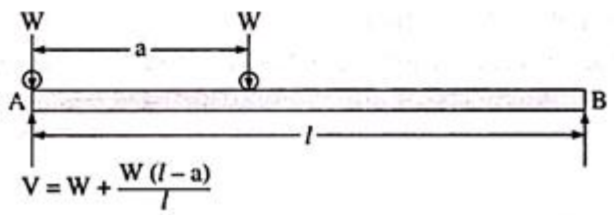


Fig.2.5 Position of wheels for max shear force

(ii) Maximum Bending Moment for the Girder:

The maximum bending moment occurs when the centre of gravity of the loads and one wheel load are placed equidistant from the mid section of the span of the girder (Fig. 2.6)

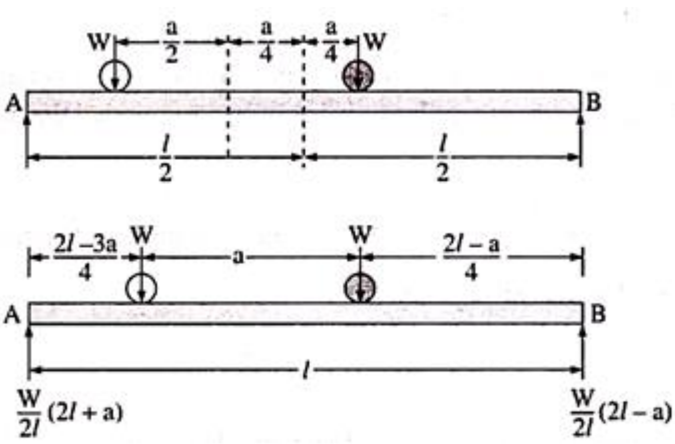


Fig. 2.5 Position of wheels for max bending moment

With this condition, Maximum bending moment = W/8l (2l – a)^2

The shear force and bending moment due to impact effect are calculated.

Thus, the maximum vertical shear force and the maximum vertical bending moment are calculated.

3. Corresponding to the wheel loads the appropriate lateral forces are determined. Maximum horizontal shear force and maximum horizontal bending moment due to the lateral forces are determined. Position of loads for maximum horizontal shear is the same as that for maximum vertical shear. Position of loads for maximum horizontal bending moment is the same as that for maximum vertical bending moment.

4. Selection of Gantry Girder Section:

Approximate plastic modulus (about z – axis) required is estimated as-

$$Z_p = (1.4 \text{ to } 1.5)\ \frac{M_u}{f_y}$$

A section consisting of an I-section with a channel section attached to the top flange is proposed. The depth of the I-section may be 1/12 to 1/13 of the span of the girder. The width of the flange (the depth of the channel) may be about 1/30 of the span of the girder.

5. Analysis of the Selected Girder Section:

(i) The properties of the selected section are noted. Their sectional classification (Plastic semi- plastic etc.) is made. The preferred choice for a plastic type, i.e., b/t_f < 8.4 and d/t_w < 8.4 for both I and channel sections.

(ii) Plastic moduli about the z and y axes are determined for the combined section. In case the top flange of the girder is laterally supported then the section is checked for the moment capacity of the entire section. For this condition, the design bending strength-

$$M_{dz} = \frac{\beta_b Z_p f_y}{\gamma_{mo}} \leq \frac{1.2 Z_e f_y}{\gamma_{mo}}$$

This design strength should be greater than the maximum vertical bending moment determined.

For the case of the girder whose top flange is laterally unsupported the design bending strength is determined as-

$$\frac{\beta_b Z_p f_{bd}}{\gamma_{mo}} \leq \frac{1.2 Z_e f_{bd}}{\gamma_{mo}}, \quad [f_{bd} = \text{bending compressive stress}]$$

(iii) Check for Local Moment Capacity:

$$M_{dz} = \frac{Z_p f_y}{\gamma_{mo}} \leq \frac{1.2 Z_e f_y}{\gamma_{mo}}$$

A check for top flange is made for its bending about both axes to satisfy the condition.

$$\frac{M_z}{M_{dz}} + \frac{M_{yf}}{M_{dyf}} \leq 1$$

where, M_z = Total vertical factored moment

M_{yf} = Maximum horizontal moment (resisted by top flange only)

M_{dz} = Design bending strength about z-z – axis

M_{dyf} = Design bending strength of compression flange about y-y – axis.

(iv) Check for Buckling Resistance:

We will determine the local torsional buckling moment M_{cr} given by-

$$M_{cr} = c_1 \frac{\pi^2 EI_y h_f}{2(KL)^2}\left[1+\frac{1}{20}\left(\frac{\frac{KL}{r_y}}{\frac{h_f}{t_f}}\right)^2\right]^{0.5}. \quad [c_1 = 1.132]$$

$$\lambda_{LT} = \sqrt{\frac{\beta_b Z_p f_y}{M_{cr}}}, \quad \phi_{LT} = 0.5[1+\alpha_{LT}(\lambda_{LT}-0.2)+\gamma_{LT}^2]. \alpha_{LT} = 0.21$$

$$X_{LT} = \frac{1}{\phi_{LT}+(\phi_{LT}^2-\lambda_{LT}^2)^{0.5}} \leq 1$$

$$f_{bd} = \frac{X_{LT} f_y}{\gamma_{mo}}$$

$\therefore \quad M_{dz} = \beta_b Z_p f_{bd}$ $\quad M_{dz}$ should be greater than the maximum vertical B.M.

(v) Check for biaxial bending

The following condition should be satisfied

$$\frac{M_z}{M_{dz}} + \frac{M_y}{M_{dy}} \leq 1$$

(vi) Check for shear capacity

Shear capacity of the section = $\frac{A_v f_y}{\sqrt{3}\gamma_{mo}}$ This should be greater than the maximum vertical shear force.

(vii) Weld connection between *I*-section and channel

There are two longitudinal rows of welds

Longitudinal shear load per *mm* length of weld = $\frac{1}{2}\left[\frac{Va\bar{y}}{I_z}\right]$

Let s = size of the weld

Shear capacity of the weld per *mm* length = $\frac{0.7s f_y}{\sqrt{3}\cdot\gamma_w}$

(viii) Check for deflection : Maximum deflection due to service wheel loads

$$\delta = \frac{Wa(3l^2-4a^2)}{24EI}.$$

a = Wheel base

l = Span of gantry girder

w = Unfactored wheel load

Permissible deflection $= \frac{\text{Span}}{500}$

CONCRETE CORBELS

A corbel is a short cantilever projection which supports a load bearing member and where:

a) the distance a_v between the line of the reaction to the supported load and the root of the corbel is less than *d (the* effective depth of the root of the corbel); and

b) the depth af the outer edge of the contact area of the supported load is not less than one-half of the depth at the root of the corbel.

The depth of the corbel at the face of the support is determined

Simplifying Assumptions

The concrete and reinforcement may be assumed to act as elements of a simple strut-and-tie system, with the following guidelines:

- The magnitude of the resistance provided to horizontal force should be not less than one-half of the design vertical load on the corbel Compatibility of strains between the strut-and tie at the corbel root should be ensured.
- It should be noted that the horizontal link requirement described in 28.2.3 will ensure satisfactory serviceability performance.

Reinforcement Anchorage

At the front face of the corbel, the reinforcement should

be anchored either by:

a) *welding to a transverse bar of equal strength* - in this case the bearing area of the load should stop short of the face of the support by a distance equal to the cover of the tie reinforcement, or

b) *bending back the bars to form a loop* - in this case the bearing area of the load should not project beyond the straight ~portion of the bars forming the main tension reinforcement.

Shear Reinforcement

Shear reinforcement should be provided in the form of horizontal links distributed in the upper two-third of the effective depth of root of the corbel; this reinforcement should be not less than one-half of the area of the main tension reinforcement and should be adequately anchored.

Resistance to Applied Horizontal Force

Additional reinforcement connected to the supported member should be provided to transmit this force in its entirety.

SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – III – INDUSTRIAL STRUCTURES– SCIA7014

STEEL CHIMNEY OR STACK

Chimneys or stacks are very important industrial structures for emission of poisonous gases or smoke from a boiler, stove, furnace or fireplace to a higher elevation such that the gases do not contaminate surrounding atmosphere. These structures are tall, slender and generally with circular cross-sections. Different construction materials, such as concrete, steel or masonry, are used to build chimneys. Steel chimneys are ideally suited for process work where a short heat- up period and low thermal capacity are required. Also, steel chimneys are economical for height up to 45m. They are typically almost vertical to ensure that the hot gases flow smoothly, drawing air into the combustion through the chimney effect. Chimneys are tall to increase their draw of air for combustion and to disperse the pollutants in flue gases over a greater area in order to reduce the pollutant concentrations in compliance with regulatory or other limits.

Types and Design of steel Chimney

The design of steel chimney can be done as two types:

- Self-supporting steel chimneys
- Guyed steel chimneys.

Self-supporting steel chimneys: When the lateral forces (wind or seismic forces) are transmitted to the foundation by the cantilever action of the chimney, then the chimney is known as self-supporting chimney. The self-supporting chimney together with the foundation remains stable under all working conditions without any additional support. A self-supporting chimney is shown in Fig1. The self-supporting chimneys are made upto 10 m diameter and from 50 m to 100m in height.

Guyed steel chimneys: In high steel chimneys, the mild steel wire ropes or guys are attached to transmit the lateral forces. Such steel chimneys are known as guyed steel chimneys. In guyed steel chimneys, all the externally applied loads (wind, seismic force, etc.) are not totally carried by the chimney shell. These attached guys or stays do share these applied loads. These guys or stays ensure the stability of the guyed steel chimney. These steel chimneys may be provided with one, two or three sets of guys. In each set of guys, three or four or sometimes six wires are attached to the collars. When one set of guy is used, then the guys are attached to a collar at one-third or one-fourth of the height from the top. When- more than one set of guys are used, then these are used at various heights.

A particular type of steel chimney is selected depending on the advantage and disadvantages with reference to economy. A choice between self-supporting and guyed steel chimney is made by considering some of the important factors, number of units, type of equipment and the type of fuel to be used are considered. In case the chimney is to be used for boilers, the surface area, output efficiency, draft requirements etc. are taken into account. The mode of operation of the equipment shall also be considered. The temperature of the flue gases before entering the chimney and its likely variation, are studied. The type of lining is decided knowing the composition of the flue gases. The specific weight, the quantity of dust and data about the aggressiveness of the flue gases must be known. The local statutory regulations, relating to height, dispersion of ash, provision for earthing aviation warning lamp, health etc. are the factors which should be considered for selecting a type of steel chimney. The mode of erection is also considered.

Steel -plates for Chimney

The width of steel plates required for the steel chimney varies from 0.9 m to 2.5 m. The steel plates of 1.50m width are most commonly used. The thickness of steel plates should not be less than 6 mm. The thickness of steel plates in the two upper sections of the chimney should not be less than 8 mm to resist more corrosion likely at the top of chimney. The thickness of steel plate in the flared portion should not be less than the thickness at the lowest section of the cylindrical portion. The steel plates are available in thickness of 5, 6, 8, 10, 12, 14, 16, 18, 20, 22, 25, 28, 32, 36, 40, 45, 50, 56 and 63 mm. For the ease in construction, the upper diameter of plates forming the side of chimney is kept less than the lower diameter. Each course fits telescopic over the lower course.

Breech Opening The breech opening is also known as flue opening, The flue opening is provided for the entrance of flue gases. The flue gases come from furnaces of the boilers. A breech opening is provided in the steel chimney as shown in Fig 3. The area of breech opening is kept about 20 percent larger than the internal cross-sectional area of the chimney. The maximum width of the breech opening should not be greater than two-thirds of the diameter. In, order to compensate the removed material. The reinforcement should be provided all around the breech opening. The vertical reinforcement provided should be 20 percent larger than the material removed in the ratio of diameter to the long chord perpendicular to the face of the opening. The horizontal reinforcement provided at the top and bottom of the opening is kept equal to the vertical reinforcement. The reinforcing material provides sufficient vertical stiffness. In order to transfer distribute the stress

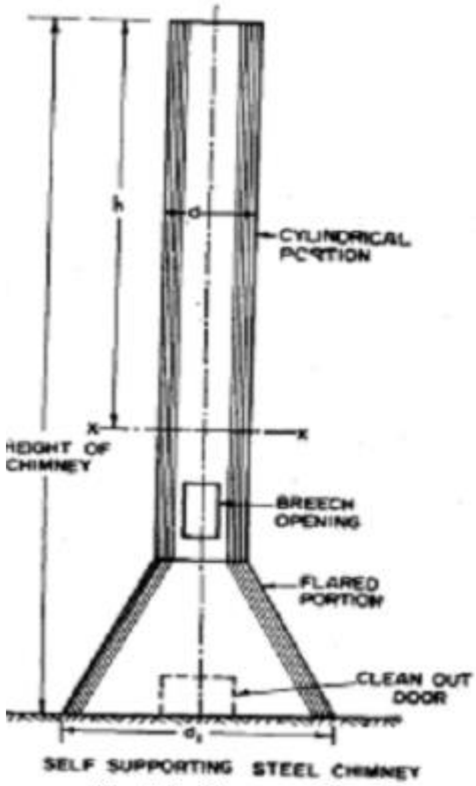


Fig 1 Self supporting chimney

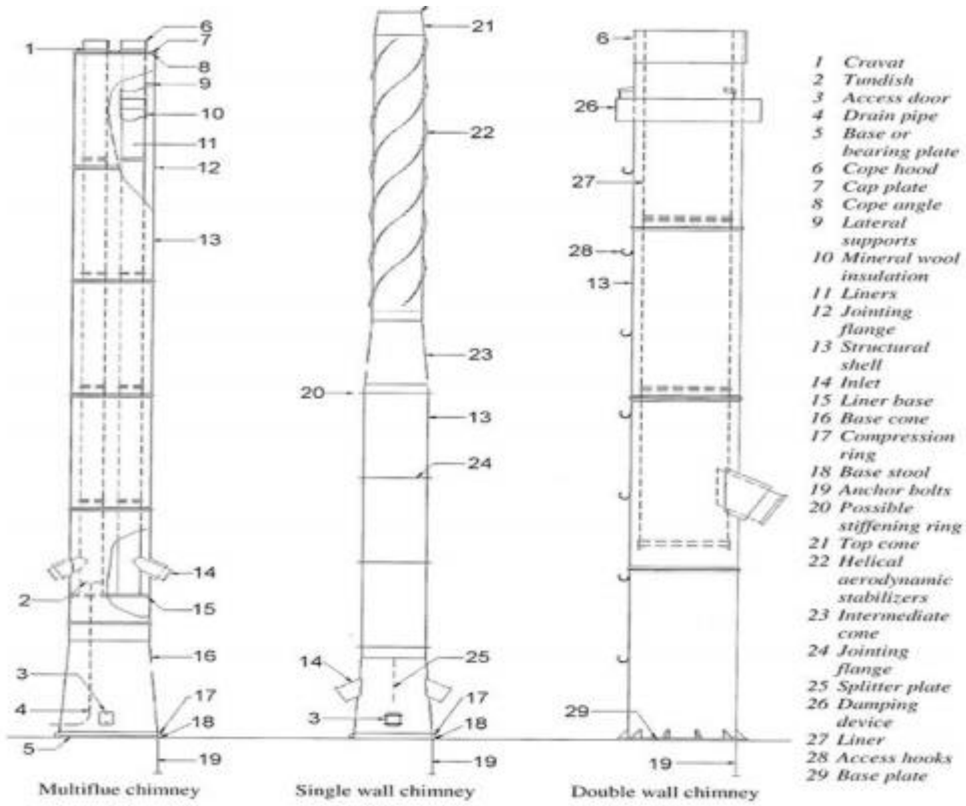


Fig 2 Guyed Steel chimney

into the steel of the chimney, the reinforcing material should be extended above and below the opening. In the self-supporting steel chimney the breech opening is kept well above the flared base, so that it does not extend into the flared base. The steel chimneys may have one breech opening, two breech openings in the same direction two breech openings at right angles and three breech openings as shown in Fig. The number of flue-openings maybe one, two, three or four depending on the requirement. It is suggested that a maximum of two flueopenings may be provided at one level so that the chimney remains enough to resist the applied forces at the plane of the openings. However, it is possible to provide three openings in one plane. This is done only when the number of flue openings is three only. The width of opening does not exceed one third of the diameter of the chimney at that plane.

Clean Out door A clear out door as shown by dotted lines in Fig. 1 is provided preferably on the opposite side of the breech opening near the base. The minimum size of Cleanout door shall be 500 mm x 800 mm clear. The cleanout doors are also properly reinforced. Forces acting on Steel Chimney The various forces acting on the self-supporting steel chimney are as follows: 1. Self-weight of the steel chimney 2. Weight of lining3. Wind pressure 4. Seismic forces 1. Self-weight of the chimney. The self-weight of steel chimney, Ws acts vertically. Consider a horizontal section XX as shown in Fig1. The thickness of steel plates of chimney above the section XX, may be assumed constant. The self-weight of chimney is given by

$$w_s = \rho \cdot (\pi d) \cdot t \cdot h$$

where ρ= Unit weight of steel = 79 kN/m^3 d = Diameter of chimney in meters

t = Thickness of steel plates in meters

h = *Height* of steel chimney above the section XX in meters

$$w_s = 79 \cdot (\pi d) \cdot t \cdot h$$

The compressive stress in the steel plates at the section XX due to the self weight of chimney is, given by

$$f_{s1} = \frac{w_s}{\pi dt} = \frac{\rho \cdot (\pi d) \cdot t \cdot h}{\pi dt} = 0.079h\,(N/mm^2)$$

2. Weight of lining. The weight of the lining in the steel chimney WL, also acts vertically. The thickness of brick lining may be assumed as 100 mm. The weight of brick lining,

$$w_L = \rho_1 \cdot (\pi d) \cdot (0.1) \cdot h$$

ρ_1=Unit weight of brick lining = 20 kN/m^3

The compressive stress in the steel plates at the section *XX* due to the weight of lining

$$f_{s2} = \frac{w_L}{\pi dt} = \frac{20 \cdot (\pi d) \cdot (0.1) \cdot h}{\pi dt} = 0.002\left(\frac{h}{t}\right)$$

3. Wind pressure. The wind pressure acts horizontally. The wind pressure acting on a structure depends on the shape of the structure, the width of the structure, the height of the structure, the location of the structure, and the climatic condition. The wind pressure per unit area increases with the height of the structure above the ground level. In order to simplify the· design, the steel chimney is divided into number of segments of equal height. Each segment may be kept equal upto 10 m. The intensity of wind pressure in throughout the area of each segment may be assumed as uniform. The intensity of wind pressure corresponding to the mid-height of each segment may be noted from IS: 875-1987. The wind pressure on the flared portion may be found by using average diameter. The wind pressure is assumed to act at the mid-height of each segment and as also in the flared portion. It has also been practice to take uniform wind pressure over the full height of chimney. The wind pressure Pz = $0.6V^2$

Design wind speed V z = $V_b\ k_1\ k_2\ k_3$

V_b = Basic wind speed

k 1 = Probability factor or risk coefficient

k 2 = Terrain and height factor

k 3 = Topography factor IS 875 (Part 3) gives the basic wind speeds having a return period of 50 years and at a height of 10 m above ground level. Entire country is divided into six wind zones. Basic wind speed is in m/s (Based on 50yr return period). For some important cities, basic wind speed is given in Appendix A of the code

4. Seismic forces

The seismic forces also act horizontally. The seismic forces act on a structure, when the structures are located in the seismic areas. The total design lateral force or design base shear along any principal direction shall be determined by this expression:

$V_b = A_h W$

where, Ah = design horizontal seismic coefficient for a structure W= seismic weight of building

The design horizontal seismic coefficient for a structure A_h is given by: $A_h = ZIS_a/2R_g$

The fundamental natural period for buildings are calculated as per Clause 7.6 of IS 1893:2002 (part 1). as Ta= $0.085h^{0.75}$ h is the height of the building in m . After the total design base shear is calculated, it is distributed along the height of the building. The base shear at any floor or level depends on the mass of the level and deformed shape of the structure. Earthquake forces can deflect a building into a number of shapes, the natural mode shapes of the building which in turn depend upon the degree of freedom of the building. A building can have infinite degree of freedoms but we convert it to finite degree of freedom by idealizing a multi storeyed building into a lumped mass model by assuming the mass of the building lumped at each floor level with one degree of freedom in the direction of lateral displacement in which the structure is being analysed per floor, resulting in degrees of freedom equal to the number of floors. Distribution of base shear along the height is done according to this equation: Qi = Wihi2/ ∑Wjhj 2 where Qi = design lateral force at floor i Wi = seismic weight of floor i hi = height of floor I measured from foundation n = number of stories in the building or the number of levels at which masses are located Bending Moment The wind force acts as uniformly distributed load on the self-supporting steel chimney. For the purpose of determining bending moment at any section XX Fig. 1, the wind force is assumed to act at the middle height above the section. The bending moment due to wind at section XX, h metres below the top, Mw = (p x h/2) where P = Total wind force Bending Stress on Steel chimney due to wind

$$F_w = \frac{M_w \cdot d}{2I}.$$

The bending stress, fw at the extreme fibre of steel chimney due to overturning moment Mw is Z =0.77 $d^{2*}t$

The bending stress, fw at the extreme fibre of steel chimney due to overturning moment Mw is Z =0.77 d 2*t Permissible Stresses The windward side of steel chimney is subjected to tensile stress due to the combined effect of the wind and weight of steel chimney. The leeward side of steel chimney is subjected to compressive stress due to the combined effect of the wind, weight of steel chimney and the weight of lining. On the compressive side the efficiency of the joint depends on the strength of rivet in shear and in bearing and does not depend on the tensile strength of plate. The efficiency of joint on compression side is 100 percent. The efficiency of joint on the tension side is 70 percent. In order to prevent the flattening of the steel plates on the tension or windward side, and buckling of the steel plates on compression or leeward side, the permissible stress in compression on gross-sectional area is adopted less than the permissible stress in tension on the net sectional area. The permissible stresses in steel chimney in axial tension, shear and bearing shall be adopted as specified in IS: 800-1984. The allowable stresses in axial compression and in bending from the table of IS 6533.

Nuclear Power Containment Structure

- A gas-tight shell or other enclosure around a nuclear reactor to confine fission products that otherwise might be released to the atmosphere in the event of an accident. Such enclosures are usually dome-shaped and made of steel-reinforced concrete.

- Reactors are designed with the expectation that they will operate safely without releasing radioactivity to their surroundings.
- It is, however, recognized that accidents can occur. An approach using multiple fission product barriers has been adopted to deal with such accidents.
- These barriers are, successively, the fuel cladding, the reactor vessel, and the shielding.
- As a final barrier, the reactor is housed in a containment structure, often simply referred to as the containment.

Design Principles For Containment

- The containment basically consists of the reactor building, which is designed and tested to prevent elevated levels of radioactivity that might be released from the fuel cladding, the reactor vessel, and the shielding from escaping to the environment. To meet this purpose, the containment structure must be at least nominally airtight. In practice, it must be able to maintain its integrity under circumstances of a drastic nature, such as accidents in which most of the contents of the reactor core are released to the building.

- It has to withstand pressure buildups and damage from debris propelled by an energy burst within the reactor, and it must pass appropriate tests to demonstrate that it will not leak more than a small fraction of its contents over a period of several days, even when its internal pressure is well above that of the surrounding air. The containment building also must protect components located inside it from external forces such as tsunamis, tornadoes, and airplane crashes.

- The most common form of containment building is a cylindrical structure with a spherical dome, which is characteristic of LWR systems. This structure is much more typical of nuclear plants than the large cooling tower that is often used as a symbol for nuclear power. (It should be noted that cooling towers are found at large modern coal- and oil-fired power stations as well.)

- The Containment Structure of a Reactor Building in a Nuclear Power Plant is a very important structure as it houses the main reactor. The containment system has to be designed and constructed to withstand high pressures and temperatures released during postulated accidents in case of any accidents and to act as a biological shield against leakage of radiation. Construction of the Containment structure, which is a safety-related structure, is a key activity in the overall project implementation of a Nuclear Power Project.

- Typically in India, the containment system consists of a double containment structure with a part-spherical dome on top. Usually the inner containment is in prestressed concrete and the outer containment is in reinforced concrete. Special types of concrete such as High Performance Concrete with temperature control and Heavy Concrete are used in the construction. The need for accurately positioning many special embedded parts and through pipes at various locations poses a challenge.

- The construction methodologies, techniques for prestressing, special formwork systems etc need special attention. Other techniques such as mechanisation, use of automated climbing formwork system, increase in height of concrete pours after mock-ups, use of threaded couplers for rebars, etc also merit attention.

- The functional requirements of the containment structure can be summarised as: housing the reactor, the primary coolant and moderator systems and other systems connected with steam generation; providing adequate shielding to restrict the level of radiation at site within acceptable limits; and containing the radioactive release
- For the sake of additional safety, the containment system is conceived as a double containment system and it is expected to satisfy the above requirements with the following specifications: a. Not more than 0.3% of enclosed volume should escape in one hour from the inner containment under the design pressure of 1.44 kg / sq. cm. gauge b. Not more than 0.3% of enclosed volume should escape in one hour from the volume contained between inner and outer containments under the pressure of 0.13 kg / sq.cm gauge. c. The containment has been given a safety classification of Class 2 and SSE category structure (Seismic Classification).
- Apart from the pressure and temperature criteria for design of the structures, the design for seismic effects is an important aspect in the engineering of the nuclear power projects and soil and foundation conditions are also considered to be important. Traditionally, the inner containment wall of the double containment is a prestressed concrete structure and the outer containment is a reinforced concrete structure. In view of the circular-shaped wall and the curvilinear dome traditionally adopted, shell-type of structural behaviour is predominant. In view of the high magnitude of applicable forces and effects and to ensure a crack-free structure, there is a need for large prestressing forces and a large quantity of steel reinforcement has to be provided in the structures.
- The reactor building base raft and the containment are designed using High Performance Concrete (M60) from the viewpoint of higher structural strengths and better functional performance. Heavy Concrete using Iron Ore aggregate is used for Calandria Vault and Fuelling Machine Vault for the purpose of radiation shielding. To minimize the thermal gradient effects the concrete is produced and placed at 19 deg C. The structures have to be built to a high degree of quality control to ensure leak tightness under accident conditions. The functional requirements of the structures demand the incorporation of a large number of inserts or embedded parts. All these require a high degree of quality control and deployment of special construction practices to ensure that the desired results are achieved.

General structural details

- The Double Containment System consists of an Inner Containment Wall with an internal diameter of 49.5m and an Outer Containment Wall with an outer diameter of 56 m, with an annular gap between the two walls of 1860 mm. Both the walls are connected to the base raft at about 15 m below ground level. The Inner Containment Wall continues for a height of 55 m. The Inner Containment is covered by an inner dome springing at its top. The Outer Containment wall continues upto the outer dome springing point. The outer dome crown is about 65 m above ground level. The containment walls are pierced by three large openings for the three air locks- Main, Emergency and Fuelling Machine with sizes ranging from 3m dia to 7.7 x 8.8 m. The airlock barrels are connected to the containment by leak-tight flexible joints. The reactor building is founded about 20 m below the ground level on very hard rock strata and also anchored down using ground anchors to provide additional safety during severe earthquakes.

Inner Containment

- The prestressed primary containment, or the Inner Containment provides primary leak tightness. It has a cylindrical structure with an Inner Containment Wall (Fig.3) covered with a part-spherical shaped dome, the Inner Containment Dome. The Inner Containment Wall has a general thickness of 750 mm and is thickened locally around large openings for the air locks. Four vertical stressing ribs are provided on the outer side where total thickness is of the order of 1395mm. The Inner Containment Wall is monolithically connected to the base raft where it is thickened for a height of about 4.2m above top of raft to 1400 mm.

Fig.3- IC Wall Construction in progress

- The Inner Dome is of prestressed concrete and the junction of Inner Containment Wall and Inner Dome is thickened to resist the thrust on wall from the dome as well as to accommodate the anchorages of prestressing cables of Dome and Inner Containment Wall. Two Circular openings of 4500 mm clear diameter in a direction normal to the dome are provided in the Dome to facilitate lowering of the Steam Generator subsequent to the construction of the Containment structure. The thickness of the dome is generally 650mm and thickened locally around the Steam Generator openings. Similarly, it is gradually thickened at springings of the dome to 1650 mm.

Fig.4 -Reactor building internals-structural steel framework

- Structural steel columns and composite concrete slab floor systems are provided inside the containment to construct the various operating floors (Fig.4). The concrete quantity in the Outer Containment is about 17000 cum.

Outer Containment

- The inner containment structure is fully enveloped by a RCC secondary containment called Outer Containment. The general thickness of Outer Containment Wall is 610 mm. The reinforced concrete Outer Containment Wall is monolithic with the base raft, where it is uniformly thickened to 1200 mm up to a height of 4.2m above top of base raft. It is thickened locally around major openings mainly to accommodate expansion joints with bellows. The Outer Dome over Outer Containment Wall is of reinforced concrete, forming a part of the Outer Containment. The wall and the dome are thickened at the junction.
- Prestressing ring cables are placed at this junction to counteract the thrust of the dome on the wall and thus eliminating a heavy ring beam. The outer dome too has two 5750mm dia circular openings concentric in plan with those in inner dome for erection of steam generators which will be closed by a hatch cover made of steel plates. Polyurethane foam is used as a lightweight material for waterproofing over the dome and also as an insulation layer. About 12000 cum of concrete is involved in the Outer Containment.

Raft

- The containment structure is supported on a common foundation raft having a diameter of 62 m and thickness of 5.5m. The grade of concrete for the raft is M60. This raft is anchored to the rock below by means of 200 pre-stressed rock anchors of 27K13 system. The total concrete quantity is 17000 cum, placed through a number of pours. Due to limitation of earth fill involving long compaction / consolidation time periods and area constraints for movement of earthmoving machines, Sand-cement fill which could be pumped was adopted. This resulted in faster filling and could be pumped to locations where approach was a constraint.
- To suit the site conditions, a boom placer was erected within the pour of the Reactor building raft by burying left- in stools (modified base) inside the raft. To facilitate cleaning of the areas high pressure pumps capable of developing 125 bars pressure and which were easy to handle on account of their lightweight were used.

HIGH PRESSURE BOILERS

- Steam boiler is a closed vessel in which heat produced by the combustion of fuel is utilized to generate steam from water, at desired temperature and pressure.

- Boiler is a device used for generating steam which is used for driving prime movers like steam turbines or industrial purpose like heating.
- According to Indian Boiler Regulation (I.B.R) Act 2007,"Boiler is a closed pressure vessel in which steam is generated with capacity exceeding 25 liters, gauge pressure greater than or equal to 1 kg/cm2, and water is heated at 1000 or above"

APPLICATIONS OF BOILERS:

1. Power generation: Mechanical or electrical power may be generated by expanding steam in the steam

engine or steam turbine.

2. Heating: The steam can be used for heating residential and industrial buildings in cold weather and for producing hot waters for hot water supply.

3. Industrial processes: Steam can also be used for industrial processes such as for sizing and bleaching etc. in textile industries and other applications like sugar mills, cement, agricultural and chemical industries.

HIGH PRESSURE BOILERS

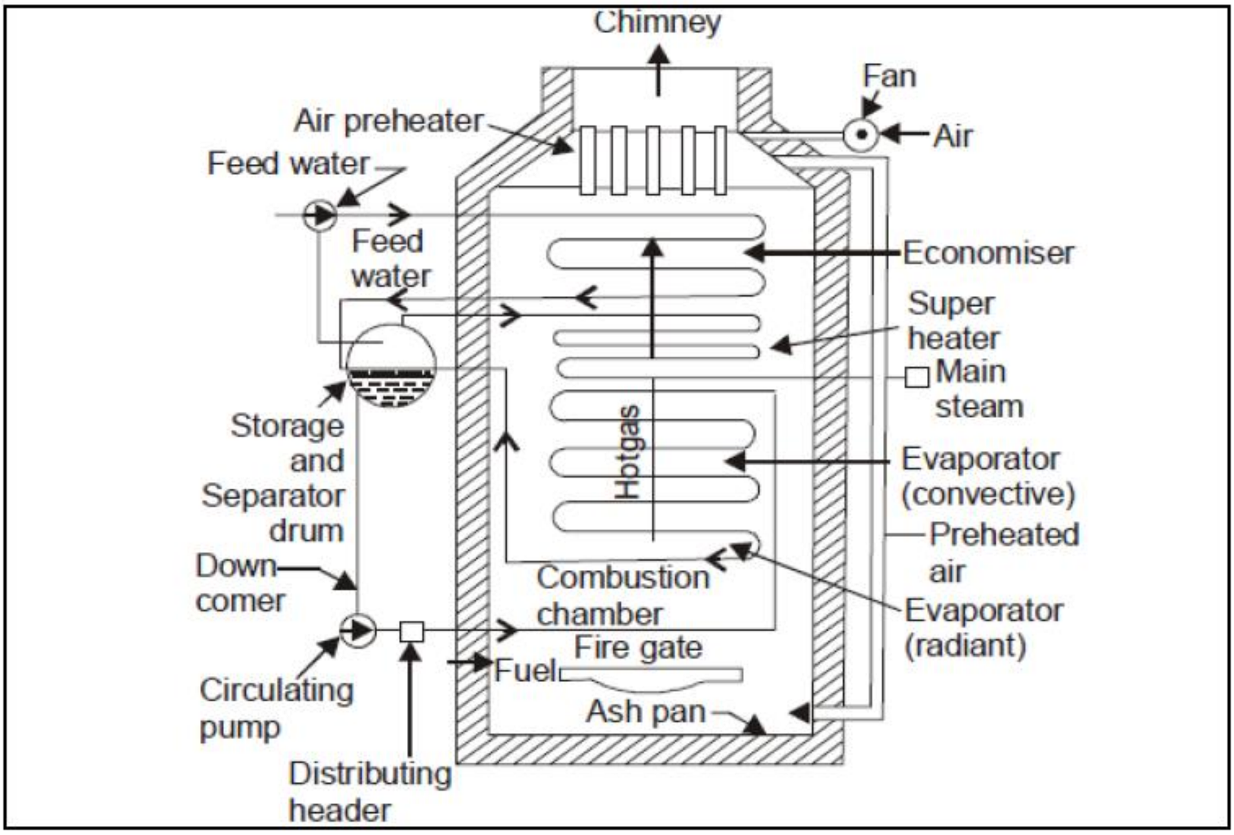
- A boiler is called a high pressure boiler when it operates with a steam pressure above 80bar.
- The high-pressure boilers are widely used for power generation in thermal power plants.
- Example: Lamont boiler, Benson boiler, loeffler boiler, Babcock and Wilcox boiler
- In high-pressure boiler if the feed-water pressure increases, the saturation temperature of water rises and the latent heat of vaporization decreases.
- The feed water can be heated to saturation of temperature in the economizer with the help of waste heat recovery from the exhaust gases escaping to chimney.
- Then the boiler supplies only latent heat of vaporization and superheat.
- Thus, a boiler operation at high pressure will require less heat addition for steam generation.

MAJOR TYPES

1. La Mont boiler
2. Benson Boiler

La Mont boiler

- The La Mont boiler is a high-pressure, water type boiler.
- It was first introduced in 1925 by La Mont.
- LaMont boiler works on the principle of forced circulation.
- The water circulation in La Mont boiler is maintained by centrifugal pump.
- The arrangement of water circulation and different components of La Mount Boiler are shown in the below figure.



- The feed water from hot well is circulated through the water walls and drums continuously and prevents tubes from being overheated.
- The feed water first passes through economizer.
- Most of the sensible heat is supplied to the feed water passing through the economizer.
- This water enters the boiler drum.

- A water circulation pump draws water from the drum and delivers to the tubes of the evaporating section, where water is heated in large number of small-diameter tubes and a mixture is stored in the drum.
- The convective super heater water draws wet steam from the drum and heats the steam for its super heating.
- The superheated steam is supplied to prime mover.
- La Mont boiler generates approximately 45 to 50 tonnes of steam per hour at a pressure of 13 bar and a temperature of 500°C.

Advantages of a La Mont Boiler

1. Small diameter tubes are used, so that high heat transfer rate is maintained.

2. The multiple tubes circuit gives flexibility for suitable location of heat transfer equipments.

3. A high evaporation rate is achieved in this boiler due to forced circulation of water

Benson Boiler

- The main difficulty experienced in the La Mont boiler is the formation and attachment of bubbles on the inner surfaces of the heating tubes.
- The attached bubbles reduce the heat flow and steam generation as it offers higher thermal resistance compared to water film.
- Benson in 1922 argued that if the boiler pressure was raised to critical pressure (225 atm.), the steam and water would have the same density and therefore the danger of bubble formation can be completely.
- Natural circulation boilers require expansion joints but these are not required for Benson as the pipes are welded.
- The erection of Benson boiler is easier and quicker as all the parts are welded at site and workshop job of tube expansion is altogether avoided.

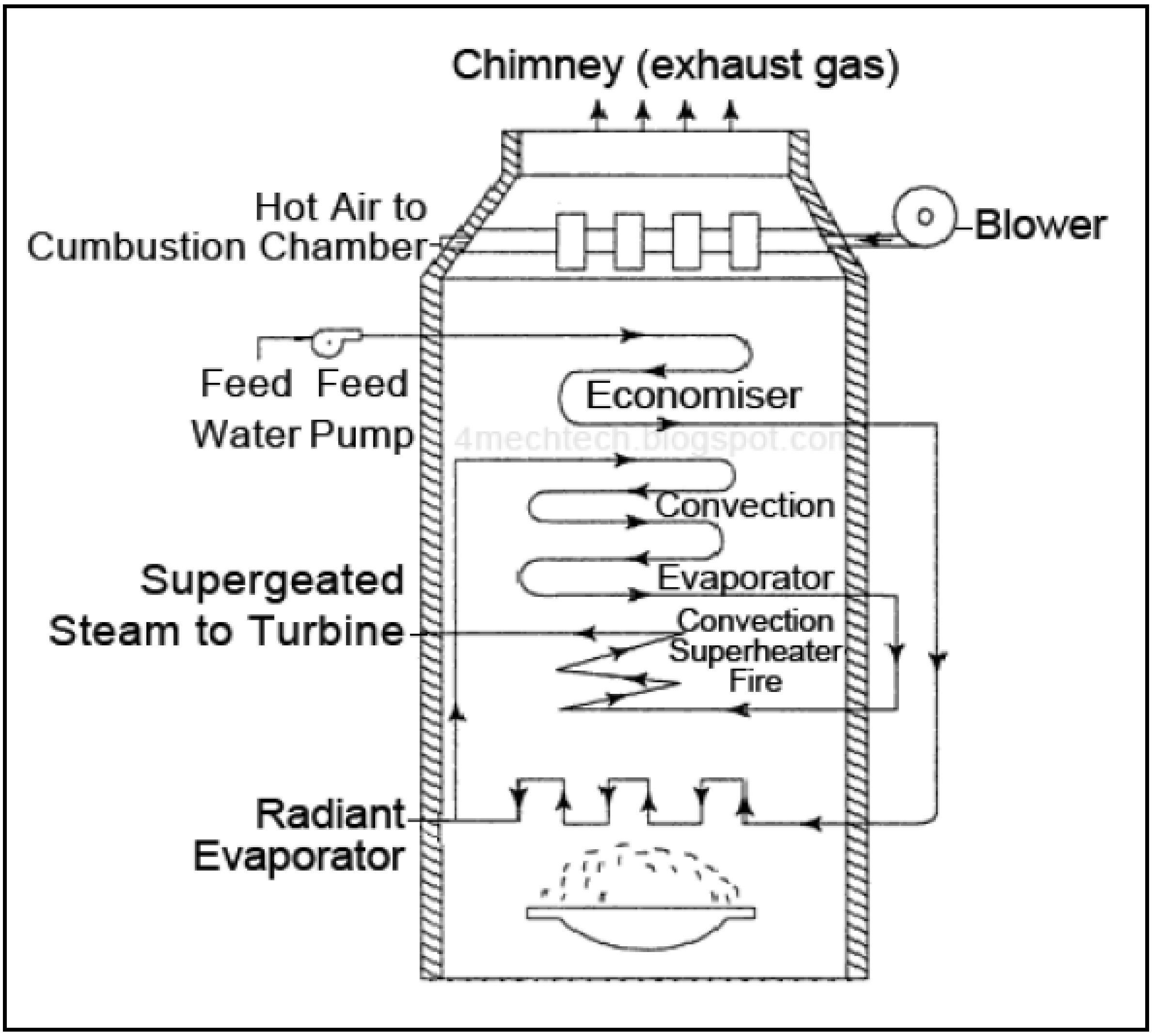


Fig2. Benson Boiler

- The transport of Benson boiler parts is easy as no drums are required and majority of the parts are carried to the site without pre-assembly.
- The Benson boiler can be erected in a comparatively smaller floor area.
- The space problem does not control the size of Benson boiler used. The furnace walls of the boiler can be more efficiently protected by using small diameter and close pitched tubes.
- The superheater in the Benson boiler is an integral part of forced circulation system therefore no special starting arrangement for superheater is required.
- The Benson boiler can be started very quickly because of welded joints.
- The Benson boiler can be operated most economically by varying the temperature and pressure at partial loads and overloads.

- The desired temperature can also be maintained constant at any pressure.
- Sudden fall of demand creates circulation problems due to bubble formation in the natural circulation boiler which never occurs in Benson boiler.
- This feature of insensitiveness to load fluctuations makes it more suitable for grid power station as it has better adaptive capacity to meet sudden load fluctuations.
- The blow-down losses of Benson boiler are hardly 4% of natural circulation boilers of same capacity.
- Explosion hazards are not at all severe as it consists of only tubes of small diameter and has very little storage capacity compared to drum type boiler.

PIPING FUNDAMENTALS

PIPE:

It is a Tubular item made of metal, plastic, glass etc. meant for conveying Liquid, Gas or any thing that flows.

It is a very important component for any industrial plant. And it's engineering plays a major part in overall engineering of a Plant.

Components of Piping

The individual components necessary to complete a piping system are

1. Pipe.
2. Piping fittings.
3. Valves.
4. Bolts and gaskets (fasteners and sealing).
5. Piping special items, such as steam traps, pipe supports, and valve interlocking.

Pipe:

- Pipe is the main artery that connects the various pieces of process and utility equipment within a process plant.

- The term ***Piping*** means not only pipe but includes components like fittings, flanges, valves, bolts, gaskets, bellows etc.

Selection of Piping Materials

- Materials selection for achievement of metallurgical stability shall be made on the basis of design condition and to resist possible exposures against fire, corrosion, operating condition, service etc.
- The designer is confronted with the following concerns regarding the material of construction as he begins the design. These are:

a) Resistance to stress

b) Resistance to wear , Design Life, Resistance to corrosion etc.

ENGINEERING MATERIALS

(1) METALLIC	(2) NON-METALLIC	(3)COMPOSITES
(i) FERROUS	(i) ORGANIC	
(ii)NON-FERROUS	(ii) INORGANIC	

FERROUS	NON-FERROUS	ORGANIC	INORGANIC
Carbon Steel	Nickel	Plastics	Ceramics
Low Alloy Steels	Monel	Thermo-Plastics	Graphite
Stainless Steels	Brasses	Thermo-Setting	Glass

Most commonly used materials in refineries are

- **Carbon Steel**
- This is the most common and cheapest material used in process plants. Carbon steels are used in most general refinery applications. It is routinely used for most organic chemicals and neutral or basic aqueous solutions at moderate temperatures. Carbon steels are extensively used in temperature range of (-) 29 deg cent to 427 deg cent... Low Carbon steel (LTCS) can be used to a low temperature of (- 46) deg cent...
- **Alloy Steels**
- Low Alloy Steels contain one or more alloying elements to improve mechanical or corrosion resisting properties of carbon steel. Nickel increases toughness and improves low temperature properties & corrosion resistance. Chromium and silicon improve hardness, abrasion

resistance, corrosion resistance and resistance to oxidation. Molybdenum provides strength at elevated temperatures. Some of the low alloy steels are listed below.

- **Stainless Steels**
- They are heat & corrosion resistant, noncontaminating and easily fabricated into complex shapes. There are three groups of Stainless steels, viz, Martensitic, Ferritic & Austenitic.
- Various codes, symbols in piping design are:
- ASME - American society of mechanical engg.
- API - American petroleum institute.
- ANSI - American National Standards institute.

Methods of manufacturing pipes

- Steel pipe is generally made by one of the following methods: seamless, longitudinally welded, or spirally welded.
- The first two are the most commonly used with seamless pipe available up to 24"; and longitudinally welded pipe generally is specified for sizes above 16", but it can be manufactured in smaller sizes.

1. Seamless pipe is formed by passing a solid billet with a mandrel through a metal bar that is at an elevated temperature. The bar is held between sizing rollers that dictate the outside diameter (O.D.) of the pipe, and the size of the billet creates the inside diameter (I.D.).

2. Longitudinally welded pipe is created by feeding hot steel plate through shapers that roll the plate into a hollow circular section. The two edges of the pipe are squeezed together and welded. Initially, longitudinal pipe has a lower integrity than seamless pipe; however, if the longitudinal weld is radiographically x-rayed successfully, then it is considered equal to seamless pipe.

3. Spiral welding is the least common method of manufacturing pipe. It is formed by twisting strips of metal into a spiral pattern. This type of pipe is the cheapest, and it generally is used only for piping systems in nontoxic service, such as cooling water at atmospheric or very low pressures and for very large sizes

Wall thickness of pipe is calculated acc. to ASME B31.3 (304, Pressure Design of Components; 304.1, Straight Pipe; 304.1.1, General)

$$t = \frac{PD}{2(SE + PY)}$$

P is the internal design gauge pressure.

D is the outside diameter of pipe as listed in tables of standards or specifications or as measured.

S is the stress value for material from Table A-1.

E is the quality factor from Table A-1B.

P is the internal design gauge pressure.

Y is the coefficient from Table 304.1.1, valid for $t\ D/6$ and for the materials shown.

The lower the quality factor E, the greater the wall thickness will be calculated in these formulae. This increases the amount of material required for the pipe and increases its weight.

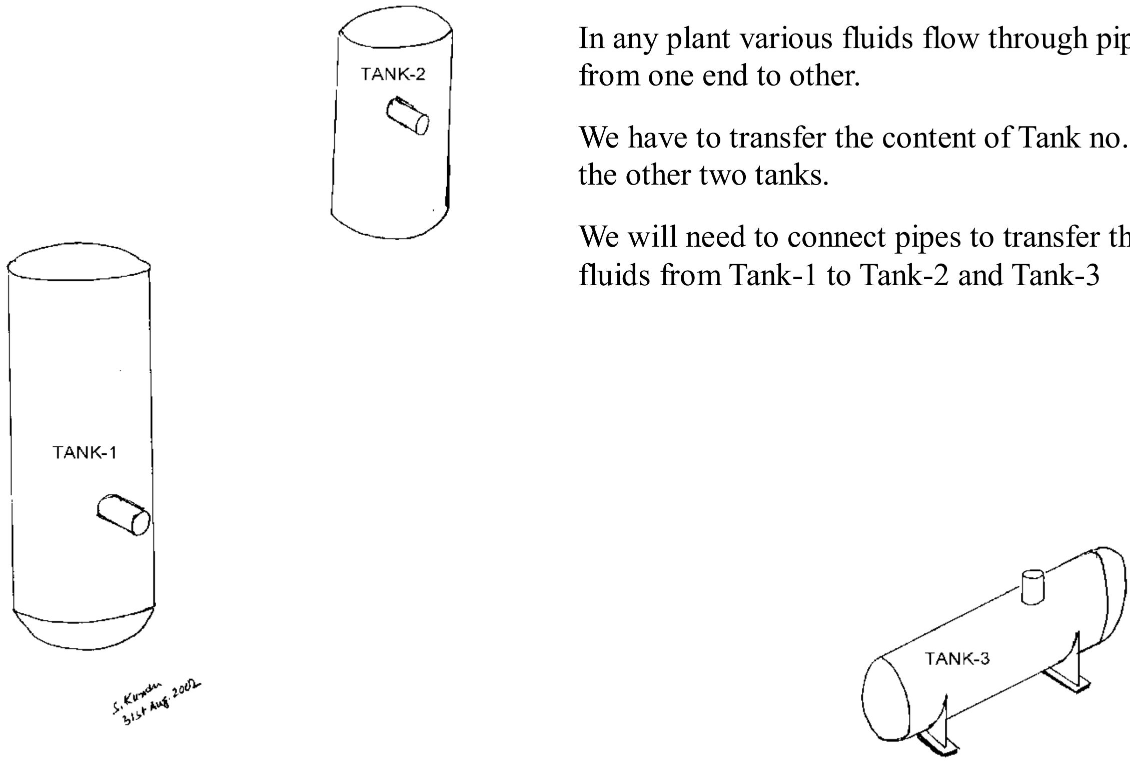
PREPARATION OF STANDARD PMS/VMS

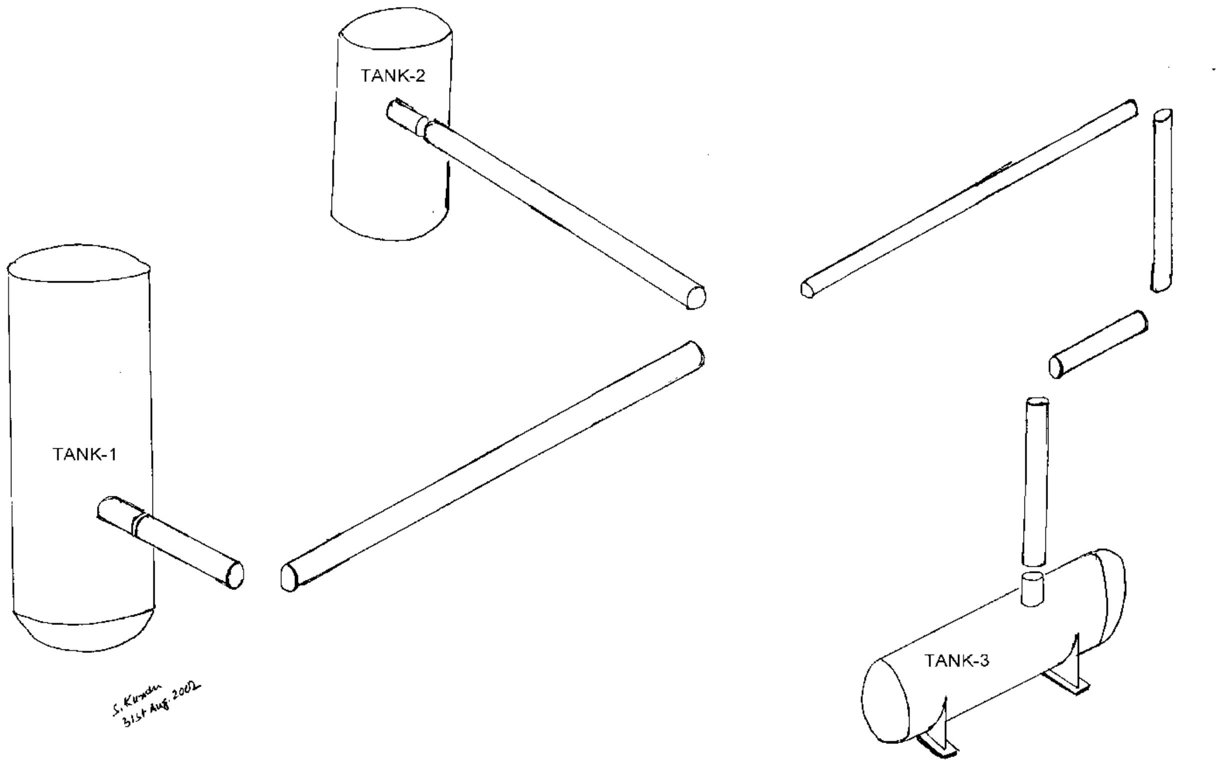
- PMS is a Bible for a Piping Engineer. It consists all about material details, dimension details, type of ends, schedules/thicknesses, branch offs, NDT requirements, various codes/standards being followed etc for all Piping items. Main Piping items detailed out in PMS are listed below:
- Pipes
- Fitting
- Flanges
- Misc items (Steam traps/Strainers) etc
- Bolts
- Gaskets
- Valves

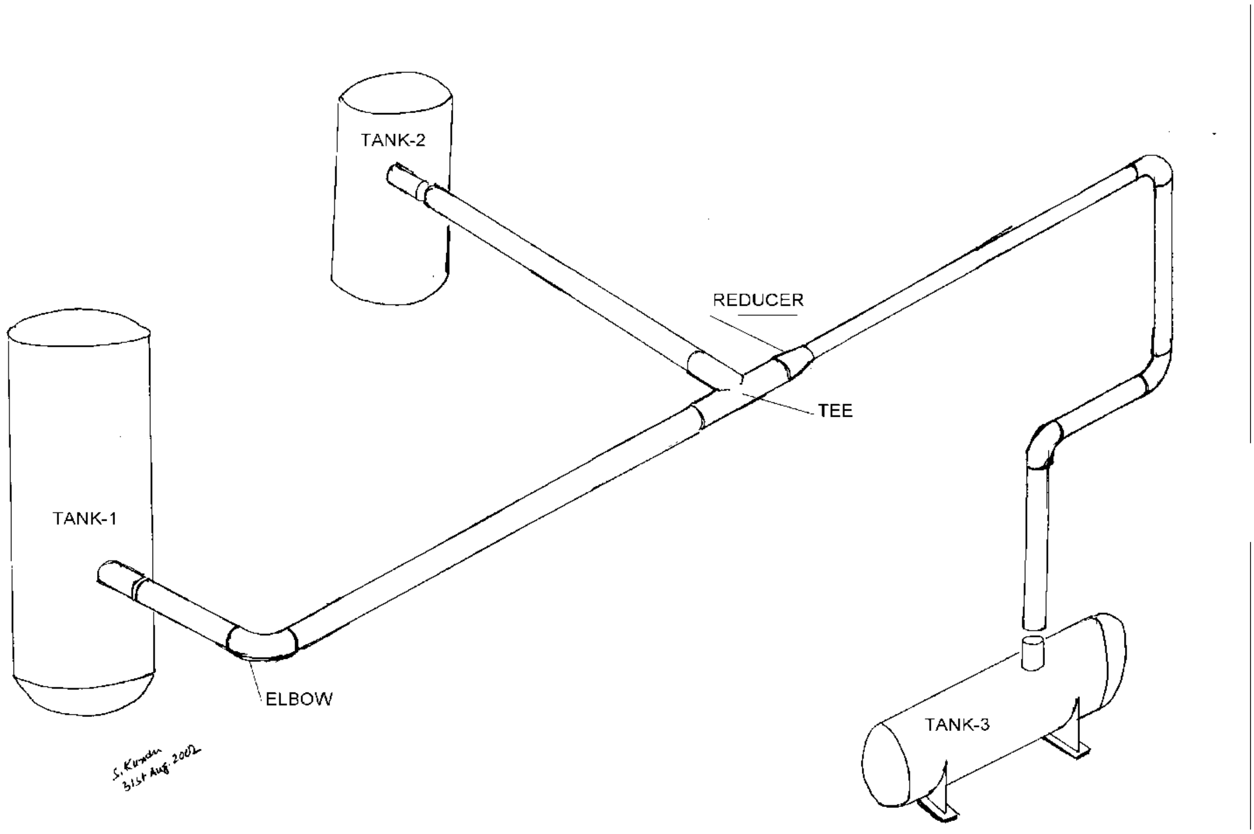
In any plant various fluids flow through pipes from one end to other.

We have to transfer the content of Tank no. 1 to the other two tanks.

We will need to connect pipes to transfer the fluids from Tank-1 to Tank-2 and Tank-3







FLANGES

- Flanges provide a bolted, separable joint in piping. The most of valves have flanged ends and must have a companion or matching flange attached. A gasket is then inserted between them, and the bolts are tightened to form a flanged joint.

When to use Flanges?

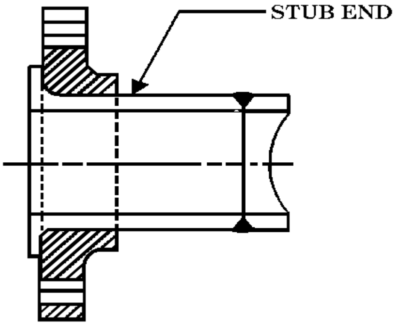
- Where there is a clear need for removal of valves or equipment, for access of maintenance, or for blinding.
- Because all flanged connections are potential leak source, their use should be kept to the minimum needed for safe and reasonably convenient operation and maintenance.

TYPES OF FLANGES

- Weld Neck (WN):The welding neck flanges are attached by butt-welding to the pipes.
- Socket Weld (SW):The socket weld flanges are welded only on one side and are not recommended for severe services. These are used for small-bore lines only.
- Slip-on (SO):The slips on flanges are attached by welding inside as well as outside.

- Lap-Joint (LJ):The lap joint flanges are used with the stub ends when piping is of a costly material.

LAP-JOINT FLANGE (with Stub-end)



- Flanges are made of carbon steel forging having a highly refined grain structure and generally excellent physical properties well in excess of recognized minimum requirements. In addition to this, flanges in 300 pound and higher pressure classes can be made of Chrome-Molybdenum Forged steel (ASTM A182 GRADE F5A).

<u>BOLTS & GASKETS</u>

- Choice of bolting material is governed by service fluid and its temperature.
- The most commonly used bolts for flanges in refinery piping are the ASTM A193 Gr.B7 Stud bolts which fall into the high strength group. The temperature range is from –29°C to 454°C.
- A gasket is a thin circular disc, made up of soft compressive material. The most of valves have flanged ends and must have a companion or matching flange attached. A gasket is then inserted between them, and the bolts are tightened to form a flanged joint.

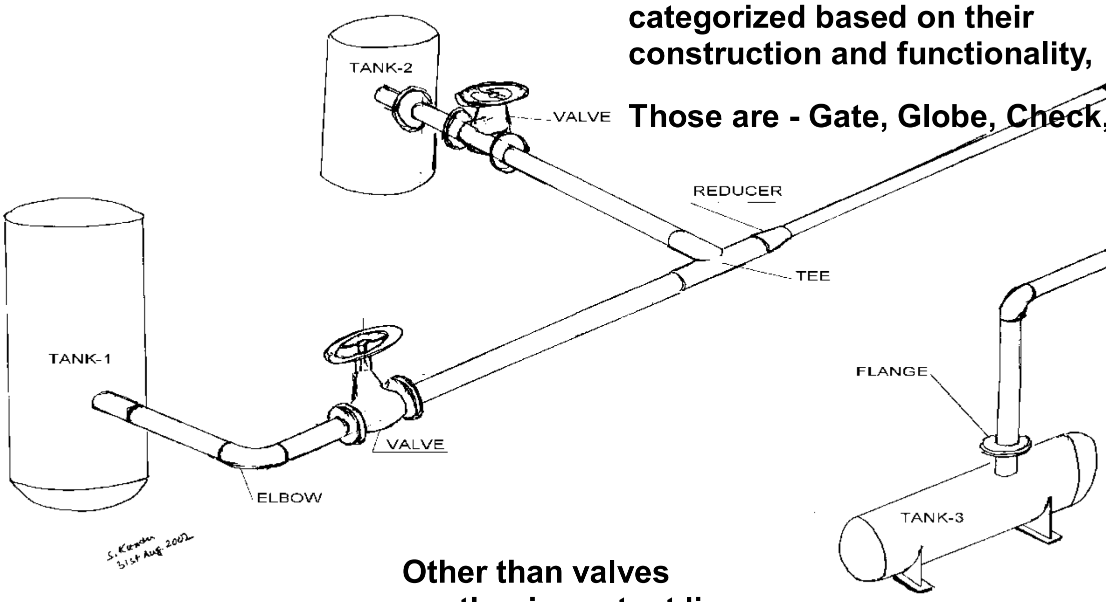
VALVES

- Valves stop or open and regulate flow. Some of the basic valve types are gate, globe, check, Ball, Plug, etc.
- **GATE VALVE**: It is usually manually operated and is designed for open or shut operation. Flow can enter either end of the gate body.
- ***<u>GLOBE VALVE:</u>*** is for throttling. Good examples of globe valves are the faucets on washbasin which throttle or adjust the flow to suit a person's needs. Flow must enter the valve and flow up, against the seat, and change the direction again to the outlet.

- ***CHECK VALVE:*** “checks” flow. It lets flow go one way and will not let it reverse. When you have a check valve in a line, you have made a one-way street. The flow can go one way.

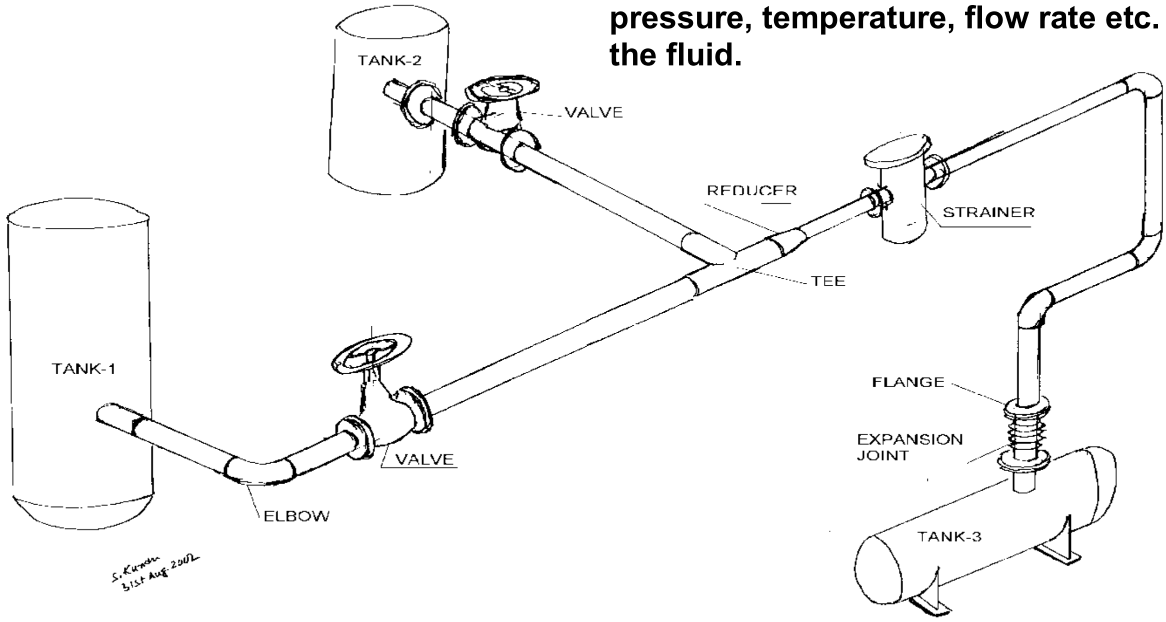
There are many types of valves, categorized based on their construction and functionality,

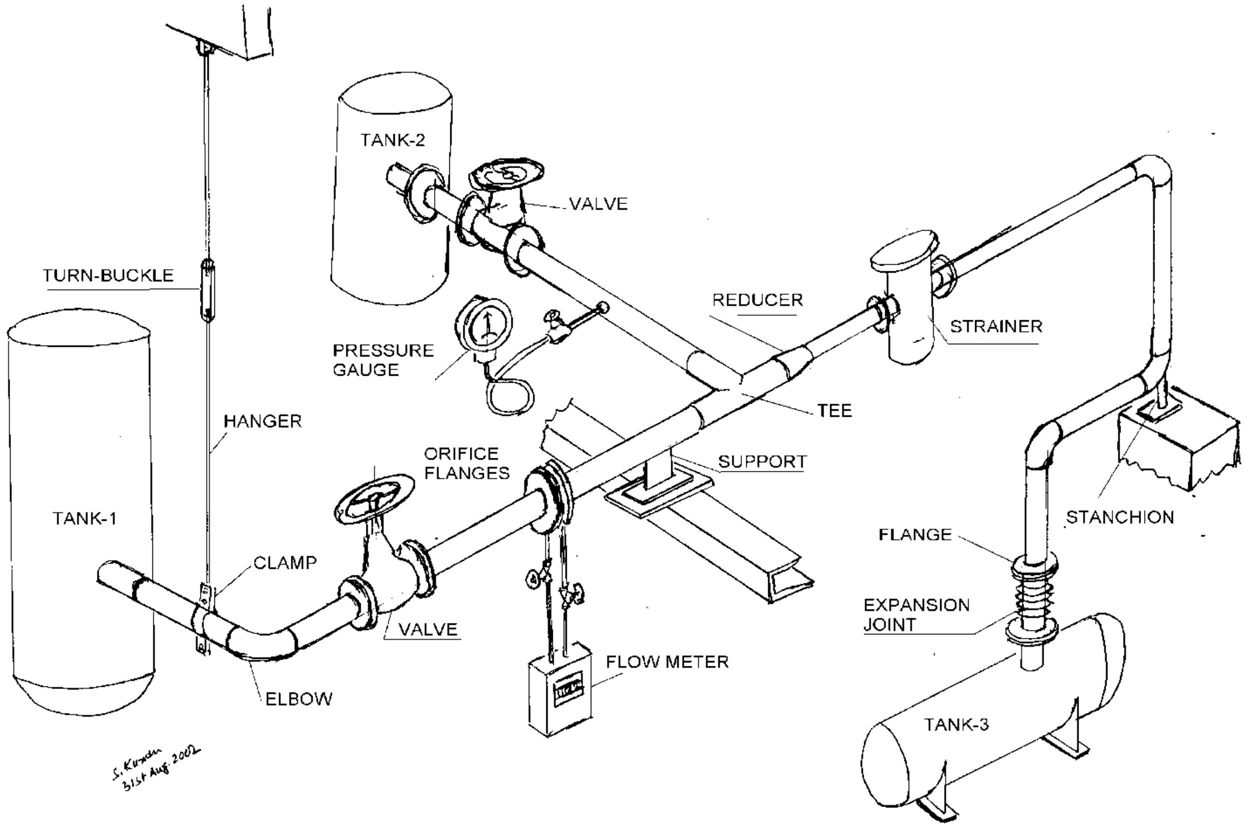
Those are - Gate, Globe, Check, etc.

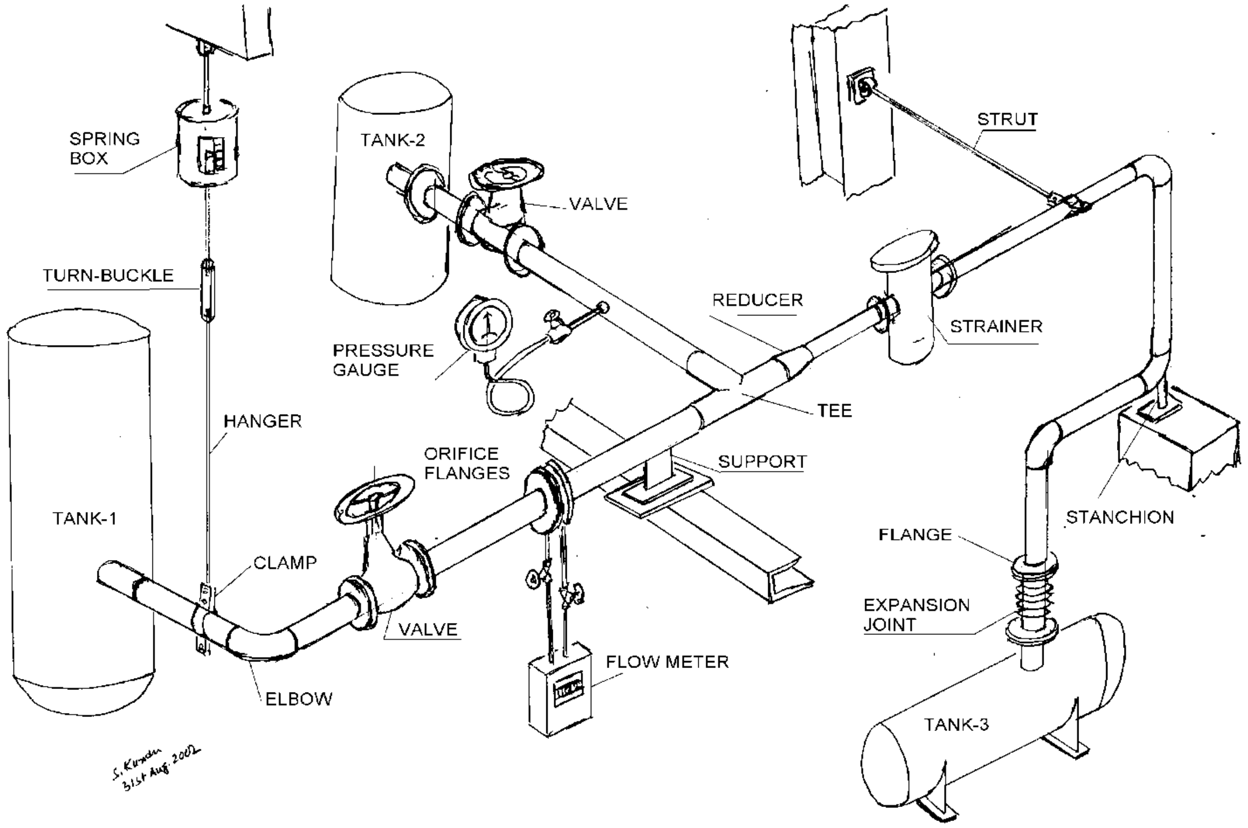


Other than valves another important line component of pipe line is a filter, which cleans out derbies from the flowing fluid. This is called a STRAINER

When some fluid is flowing in a pipe we may also like know the parameters like, pressure, temperature, flow rate etc. of the fluid.







PIPING FLEXIBILITY

All piping must be designed for thermal expansion under start up, operating and shut down conditions without over stressing the piping, valves or equipments. Adequate flexibility for the steam out conditions at temp of 120deg.c provisions for expansion or contraction shall normally be made with bends, off-sets.

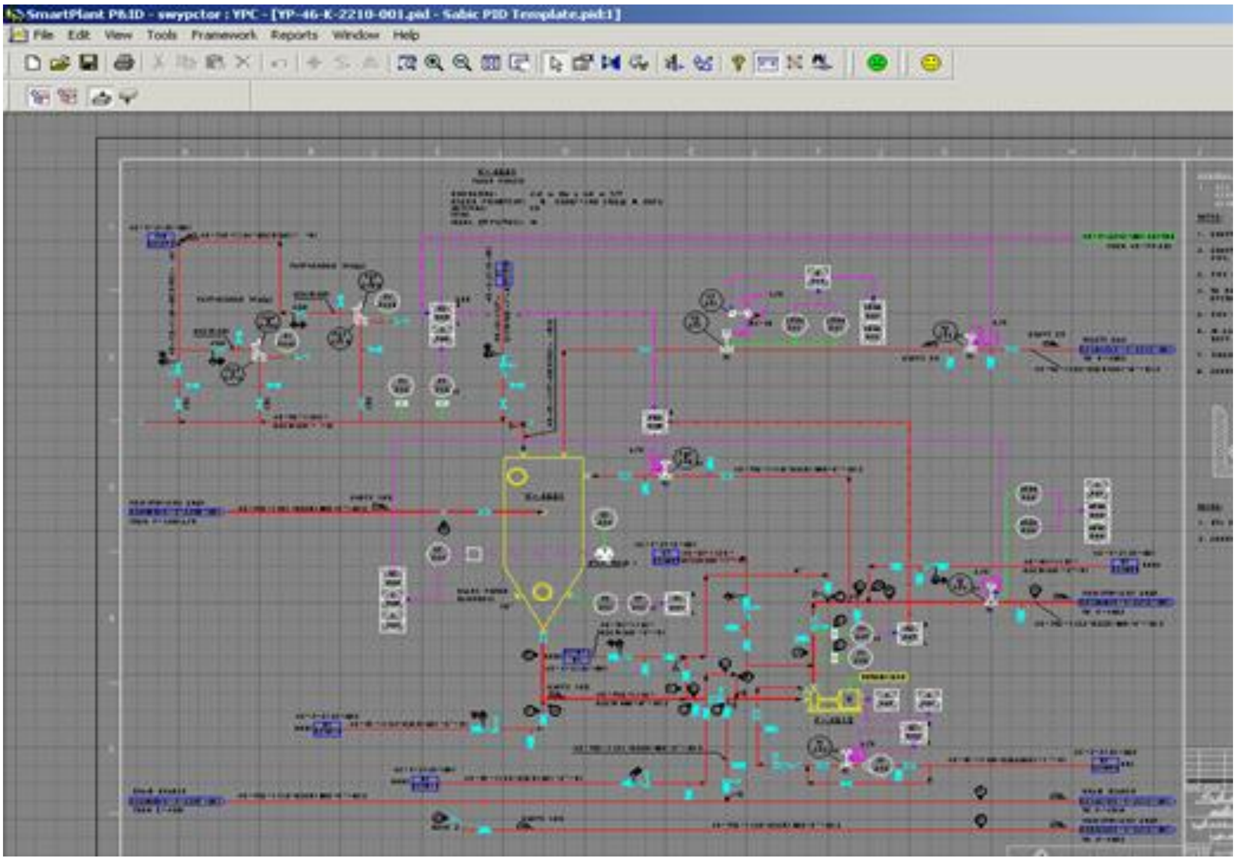
DESIGN CONDITIONS:

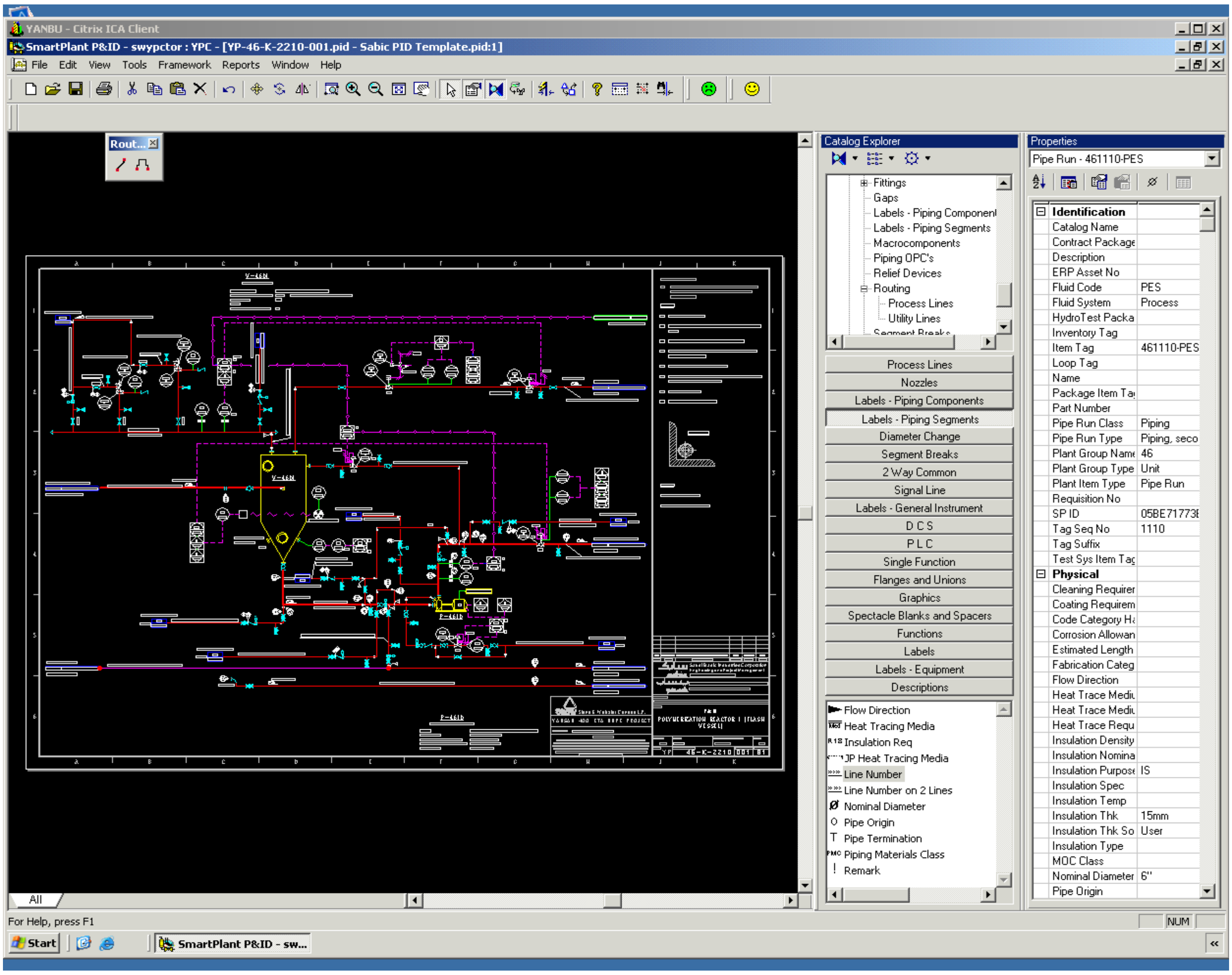
- Operating conditions: - normal design conditions of pressure & temperature are expected to co-exist. These usual operations include all manipulations & control functions such as throttling, blowing, and bypassing.
- Temporary conditions: - these do not include more severe temporary conditions such as those incidentals to start up, steam out or abnormal.
- Pipe sizes are selected, pipe material and pipe wall thickness are selected.
- Types of Valves are planned
- Also the types of instruments required are planned

We represent the whole thing in a drawing which is called Piping and Instrumentation Drawing, in short P&ID. For P&ID generation we use SPP&ID software.

All the pipe lines system information in the drawing has to enter for P&ID .

So the SPP&ID drawing is an Intelligent drawing which under it’s surface carries all the information about a pipe like, Pipe size, Flowing Fluid, etc.





INSULATION

Insulation of piping & fitting is required for the following purpose:

- Heat conservation.
- Process stabilization to assist process control.
- Steam tracing.
- Steam jacketing.
- Fire hazard protection to prevent fast boil- off of liquid.

MATERIALS USED FOR INSULATION:

HOT INSULATION

- High quality & good appearance.
- Low chloride content.
- Chemically inert.
- Impervious to hot water & steam.

- Non corrosive to steel & aluminum.

COLD INSULATION

- All material s used for insulation, fixing, sealing, etc. shall be used as under:

Operating temp range	Insulation material
-195 to +85 deg.c	PUF or Polystyrene
-195 to +120 deg.c	PUF
-30 to +120 deg.c	PUF or polystyrene

- Other requirements for insulating materials remain same as for hot insulation.

The most commonly used pipe material in the oil and gas industry is carbon steel (CS) and a chemically modified version for operating at temperatures down to -46”C, aptly called low-temperature carbon stee2 (LTCS).

- Both versions of carbon steel combine strength and a basic level of resistance to corrosive services.
- In slightly more corrosive ser- vice, an additional calculated allowance can be added to the wall thickness of the pipe, called a corrosion allowance (CA).
- The corrosion allowance increments usually are 1/16” (1.5 mm), 1/8” (3 mm), or ¼” (6 mm) and it is very rare for the CA to exceed ¼”, because a more corrosion-resistant metal will be specified.

COOLING TOWER

Cooling water is an essential service in any chemical plant or refinery, and control of the temperature plays a critical part in any plant process.

Therefore, any water used for cooling picks up heat from the medium being cooled and must itself be cooled before being recirculated.

The cooling tower enables this water cooling to be carried out.

Regardless of type of tower selected, there always is a reservoir of water at the base of tower, from which water is drawn and pumped around the plant.

It is returned, via a header pipe, back to the top of the tower.

The water then is dispersed over the whole area of the tower by means of wooden slats or sprinkler nozzles.

This breaks the water up into fine droplets, similar to rain, thus exposing a greater surface area and enabling cooling to be much more effective.

The cooled water is collected in the basin under the tower and is ready for reuse.

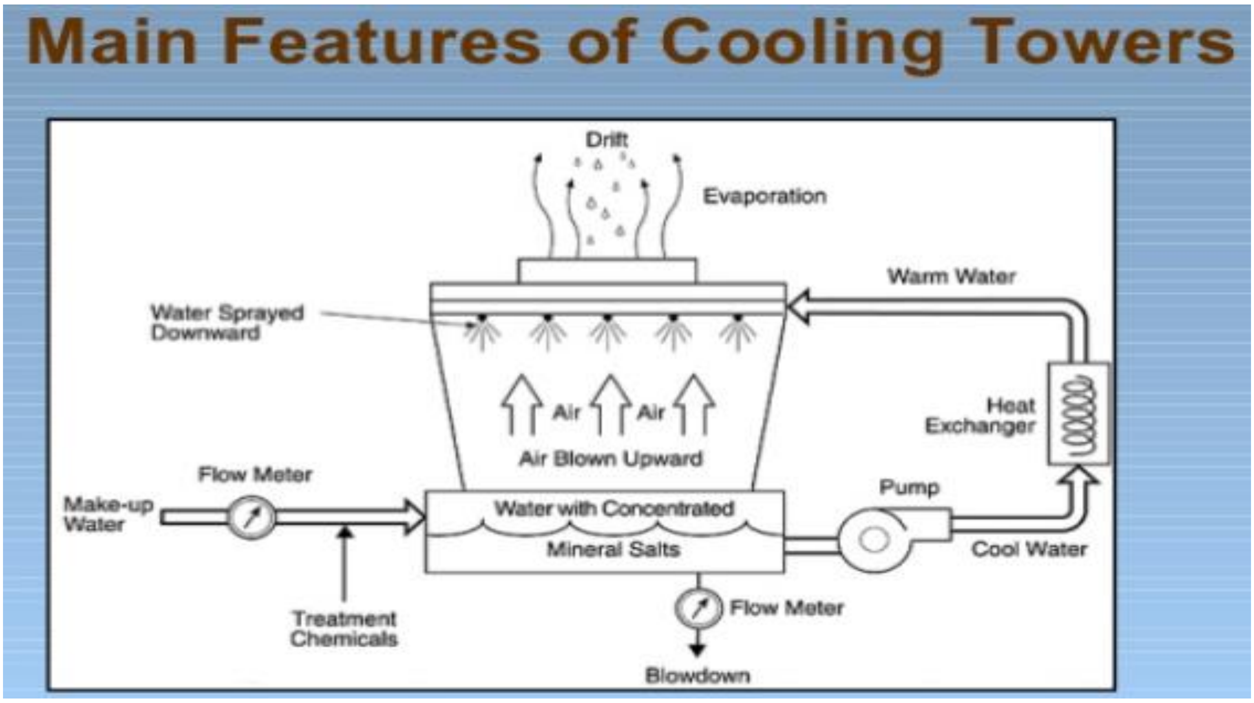
Types of Cooling Towers

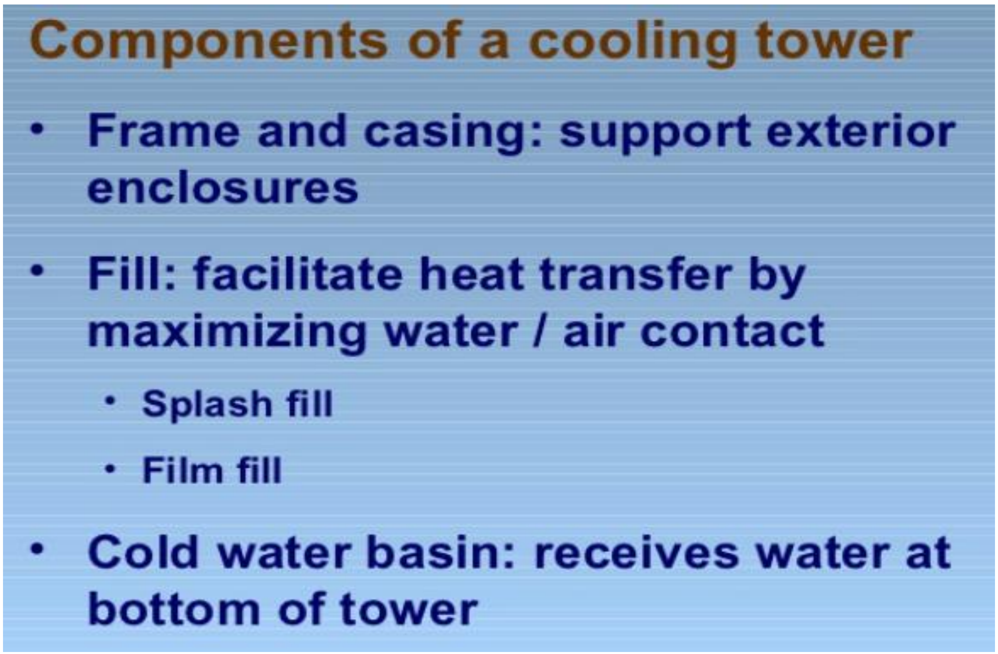
The two most commonly types of towers used in refineries and chemical plants operate via natural draft (venturi or chimney type) or induced draft (box type).

Natural Draft Cooling Towers

The natural draft type is not often used and normally is used only when the contours of the ground provide a high position on which they can be located.

The higher position gives unimpeded exposure to the cooling tower.

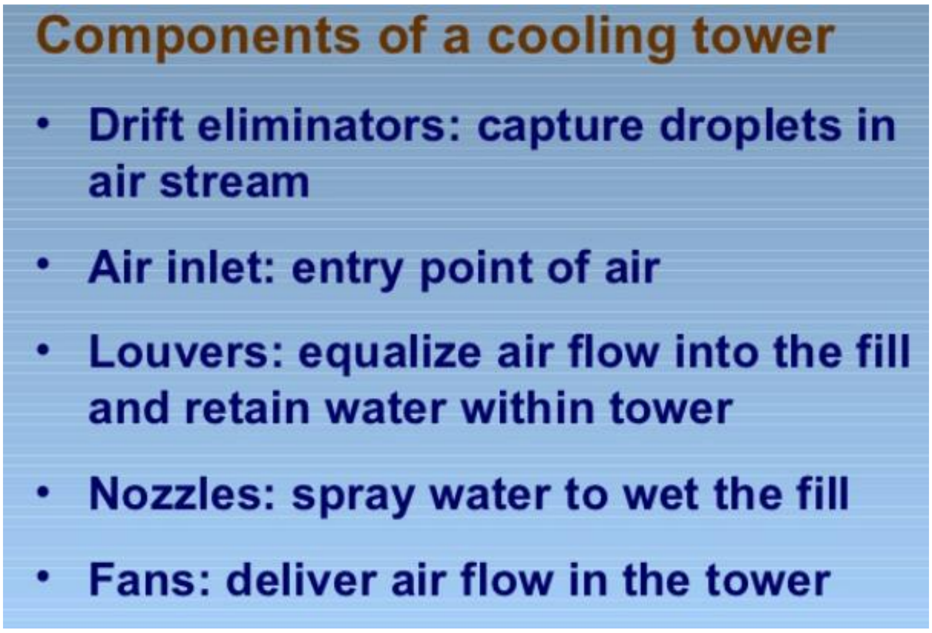


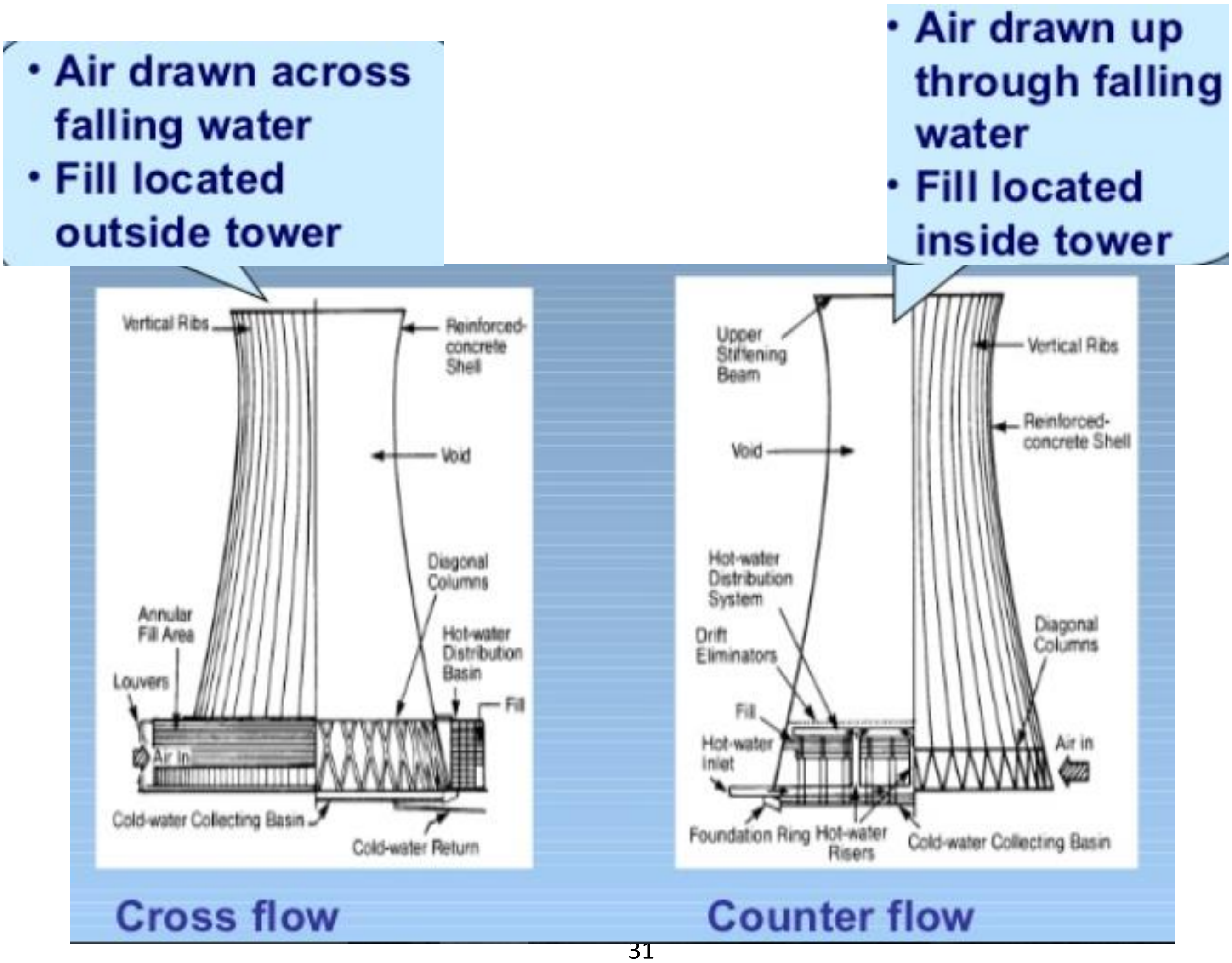


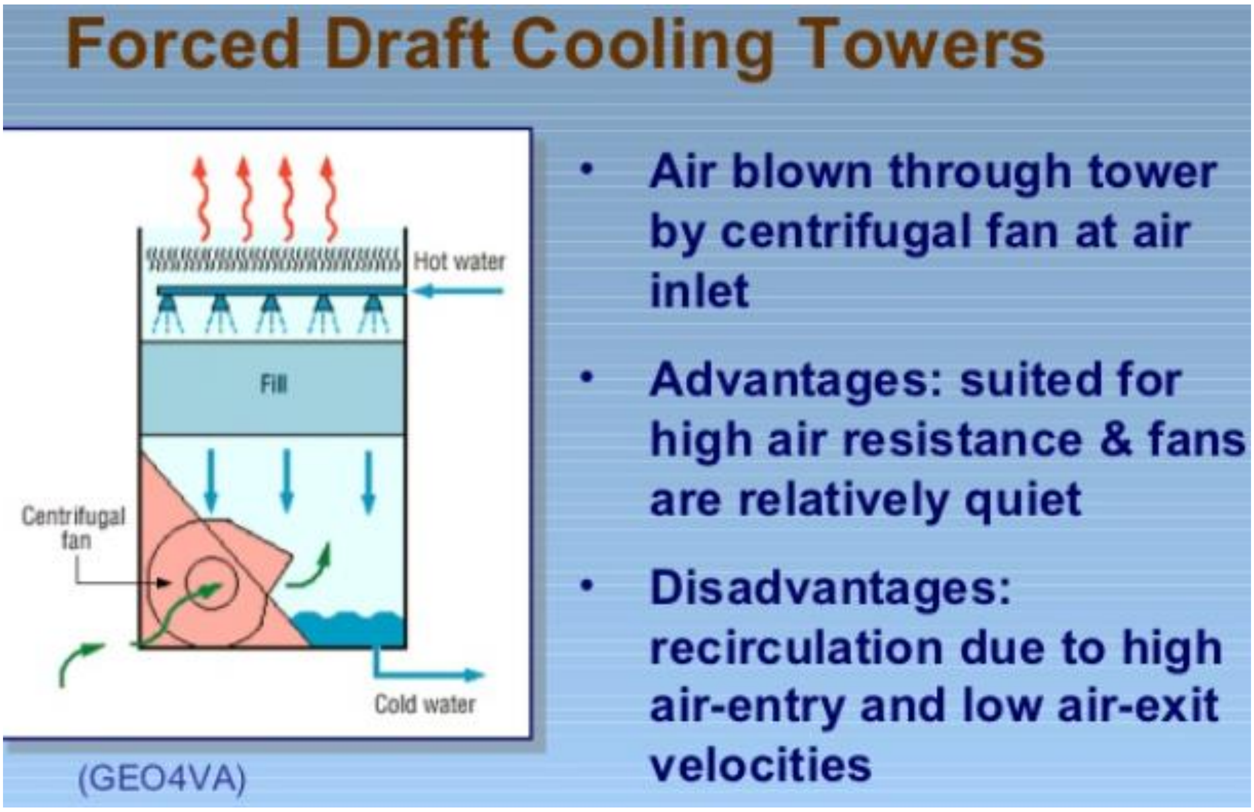
Induced Draft Cooling Towers

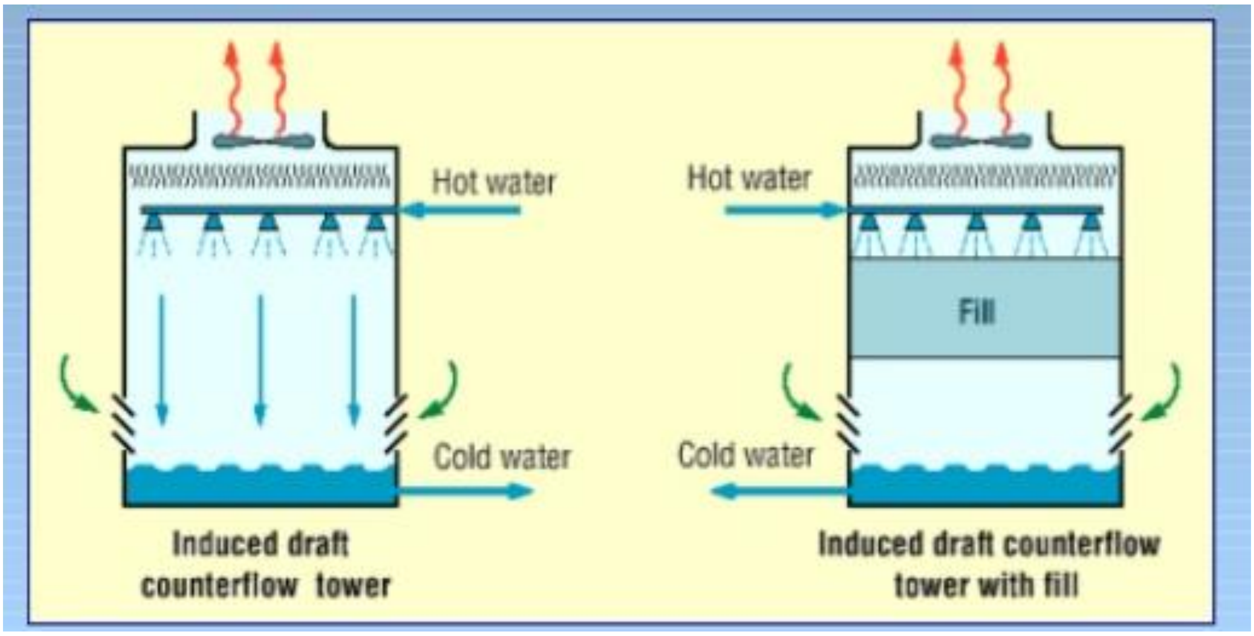
Induced draft cooling towers are furnished in two types, based on the direction of air flow relative to the water flowing through the tower: cross flow or counter flow.

In the **cross flow cooling tower**, the sides are entirely open; and air is passed through the sides to a central plenum chamber, across the downward flow of water, and exhausted through the top of the structure by one or more fans.





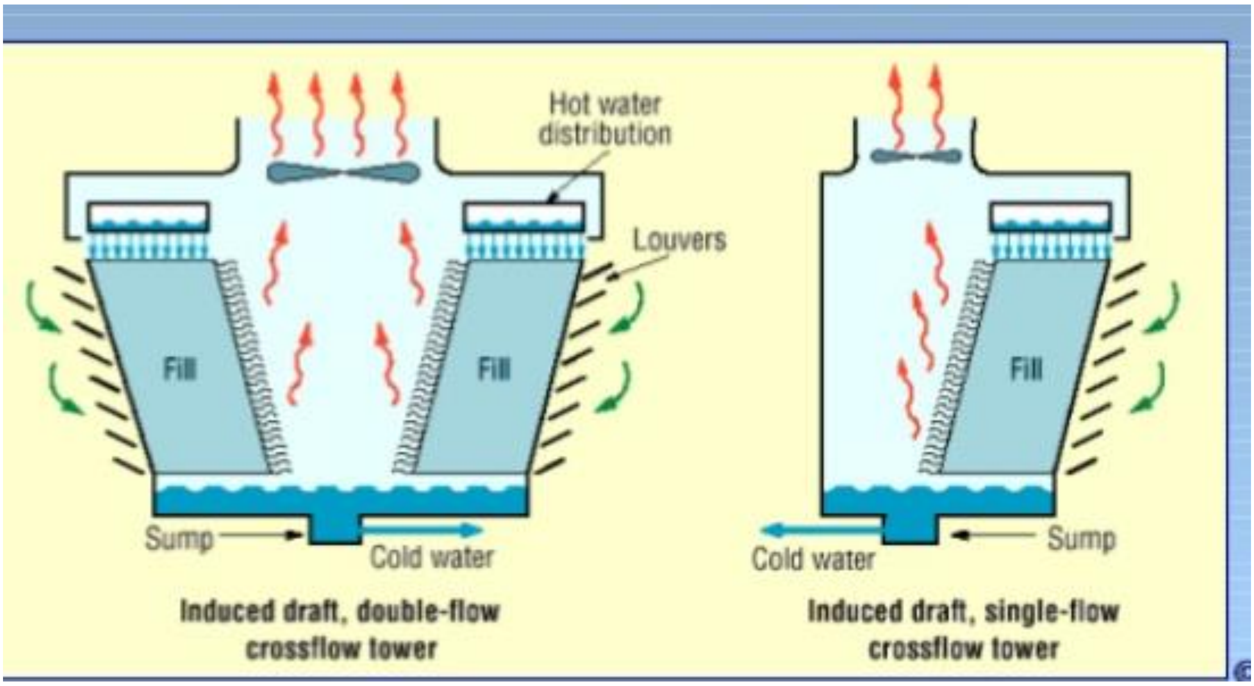




Characteristics of cross flow towers

- The contact surface is less effective.
- The air flow quantity is greater.
- Icing is more of a problem in winter months.

The fan horsepower may be higher



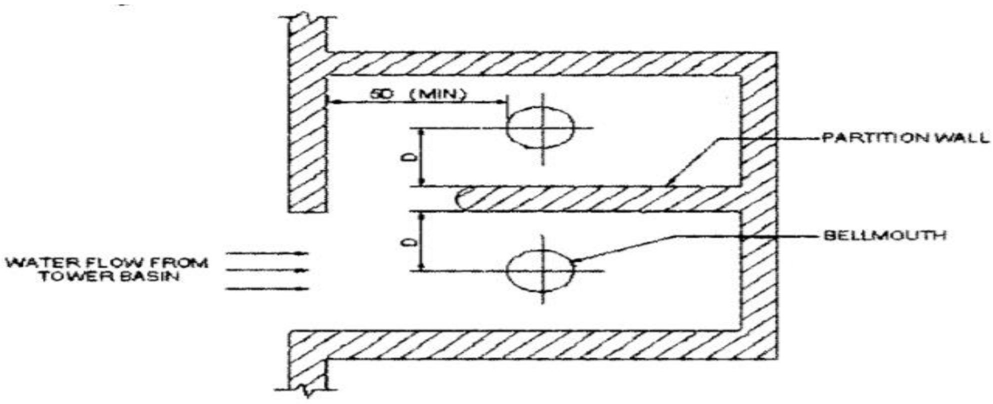
The **counter flow tower** has straight enclosed sides, except for an air entrance near the bottom.

Air is taken in at the bottom of the tower, raised countercurrent to the downward flow of water, and exhausted at the top by means of one or more fans.

Characteristics of counter flow towers

compared to cross flow towers, are

- Lower air flow quantity.
- Lower pumping height.
- The fan horsepower is lower.
- Generally, lower fire protection cost.
- Alarger basin area is required



TYPICAL SECTION AND PLAN OF COOLING TOWER PUMP BASIN

•

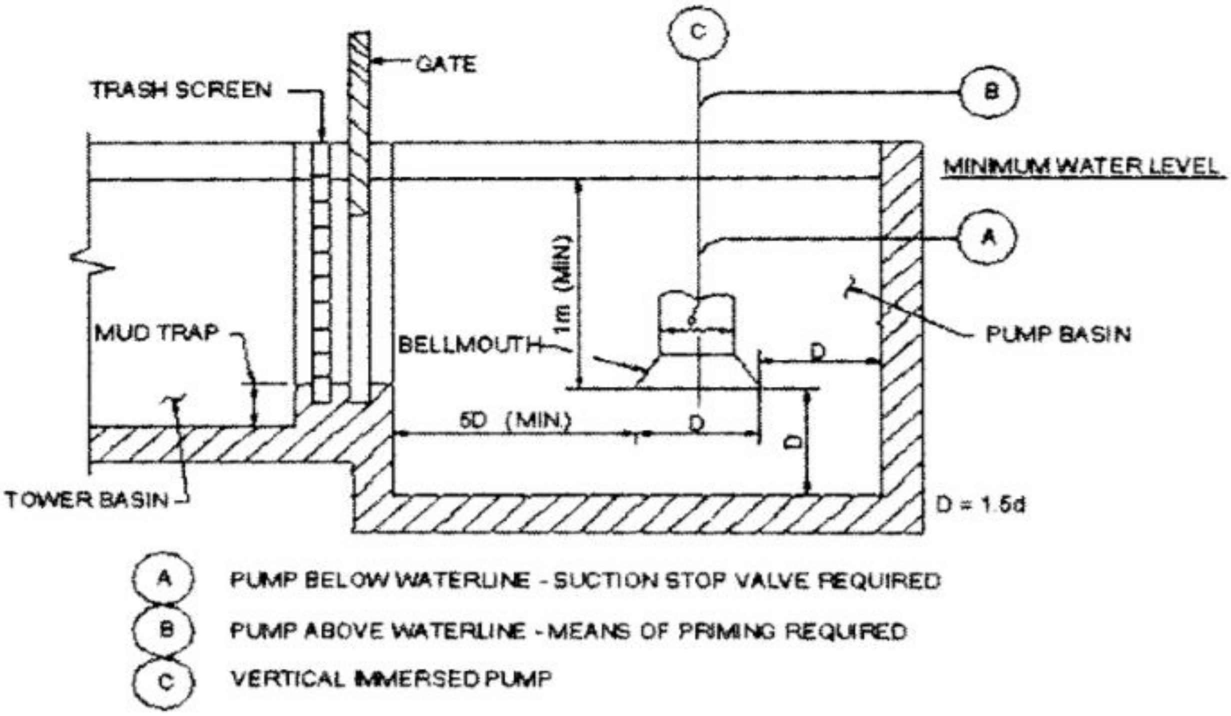
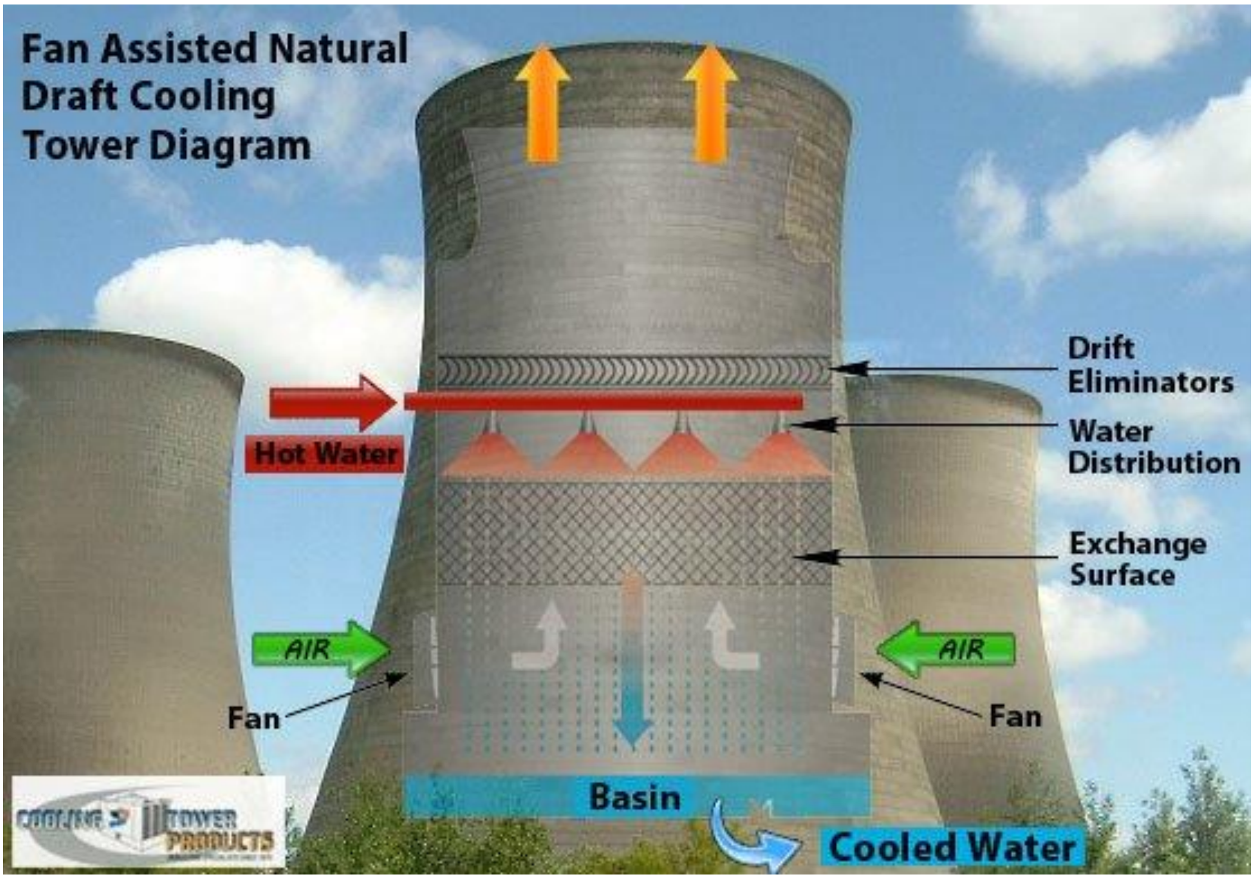


Fig. 3.6 Section of cooling tower pump basin



Cooling Tower Performance

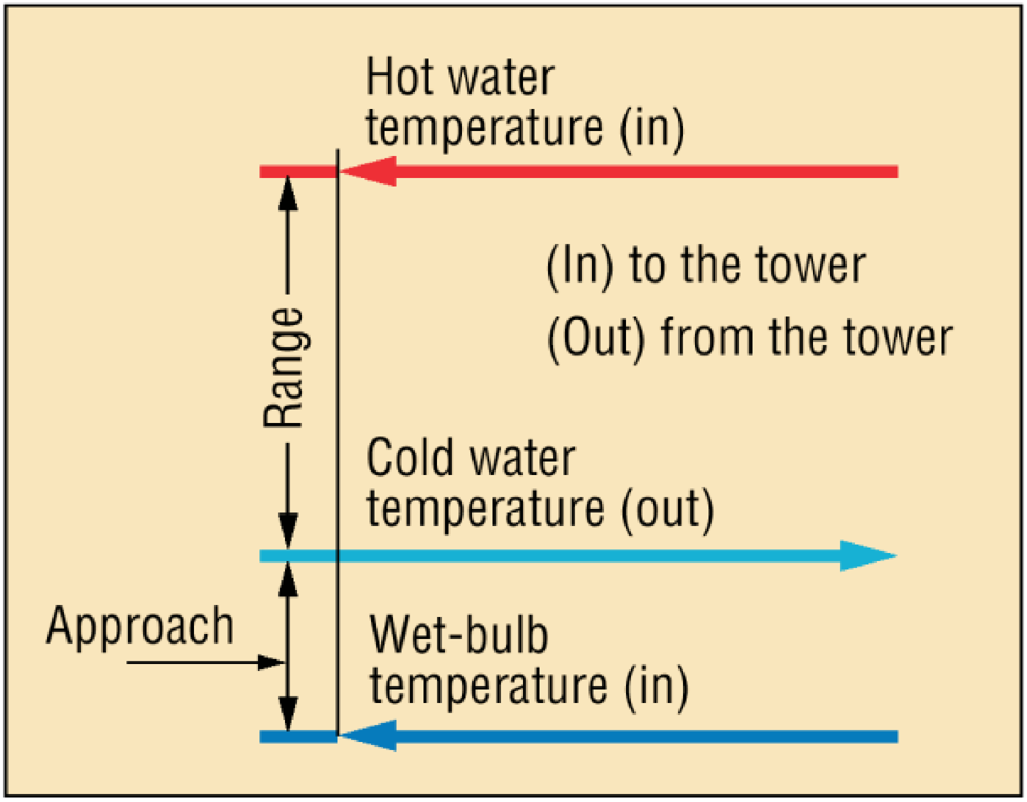


Figure 7.3 Range and Approach

Factors that affect cooling tower size

Cooling tower size is affected by the heat load, range, approach, and WBT. When three of these four quantities are held constant, tower size varies in the following manner:

- Directly with the heat load
- Inversely with the range
- Inversely with the approach
- Inversely with the entering WBT

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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – IV – INDUSTRIAL STRUCTURES– SCIA7014

TOWERS AND MASTS

Introduction

• Towers and Masts are typically tall constructions specially designed to support the phase conductors and shield wires of transmission lines, antennas for radio communication (television, radio, GSM and Internet traffic), floodlight projectors, wind turbines or platforms for inspection.

• Towers and masts may also be required to raise antennas above tree lines and roof tops for line of sight connections. The characteristic dimension of a tower is its height.

• The terms ―tower and ―mast are often used for the same type of structure. In order to avoid confusion, a tower will be considered as a self-supporting structure while a mast is supported by stays or guys.

• There are three most common types of towers/masts that are used today:

• Monopoles

• Self supporting towers

• Guyed masts.

• Selecting one solution or another is based in general on four major considerations: load, footprint, height and budget. Each factor can be critical in the selection of the type of structure.

Loads on tower

• The loading capability of a tower depends on the structure of the tower. The more surface area of equipments (eg. antennas), coaxial cables, brackets and other equipment mounted on the tower and exposed to the wind, the more robust tower is required.

• The wind load is proportional to the area of the exposed structure and distance from the attachment to the ground. Curved and perforated shapes (grids and trusses) offer less wind resistance and are therefore preferred to achieve a low wind load. Solid dishes are quite vulnerable to wind load and should be avoided in windy environments.

• When it is considered necessary, wind tunnel tests may be performed to evaluate the wind action.

Tower footprint

• The footprint of a tower is the amount of free space on the ground that is required

• Depending on the structure of the tower, it requires more or less space for installation.

• For tall guyed masts (> 30m), each guy anchor is typically 10-15m from the base of the mast. For a mast with 3 guy wires per level, that results in a footprint of approx. 90 – 200 m2.

Height of tower

• Adding guys cables to a structure will allow higher height.

• The smaller the tower base, the more costly to purchase and install the tower

• Monopoles have the smallest footprint of all towers, and are hence the most expensive towers. It is followed by self supported towers and then guyed masts which require the largest footprints. Depending on the tower type, certain tools, machinery and cranes are needed to assemble the tower which must be taken into consideration in the final budget.

Other factors to be considered in design

• mean aerial height for each aerial system

• directions for the various directional antennas,

• wind drag on each element of the array and dependent on wind direction, size, weight and disposition of all feeders and cables,

• the permitted angular rotations in azimuth and elevation of each aerial above which the broadcast signal is significantly reduced,

• the need for all-weather access to some of the aerials

• besides the known antenna and aerial configuration the possible future extension should be defined,

• atmospheric ice formation on the structure and aerials and its likelihood to occur with high wind,

• wind drag of the structure itself without ice and with ice if feasible,

• the degree of security required,

• the available ground area and access to the site,

• the geological nature of the site,

• the overall cost of land, foundations and structure,

• the cost and implications of future maintenance or structural replacement,

• any special planning considerations imposed by statutory bodies,

• the aesthetic appearance of the structure. Other factors to be considered in design:

Towers

• A self supporting tower (freestanding tower) is constructed without guy wires.

• Self supporting towers have a larger footprint than monopoles, but still require a much smaller area thanguyed masts.

• Self supporting towers can be built with three or four sided structures.

• They are assembled in sections with a lattice work of cross braces bolted to three - four sloping vertical tower legs. They can be used for power transmission lines, lighting, wind turbines, communications, etc.

Types of towers

• An overhead transmission line connects two nodes of the power supply grid.

• The route of the line has as few changes in direction as possible, based on the line route and the type of terrain it crosses.

Depending on their position in the line various types of towers occur, such as:

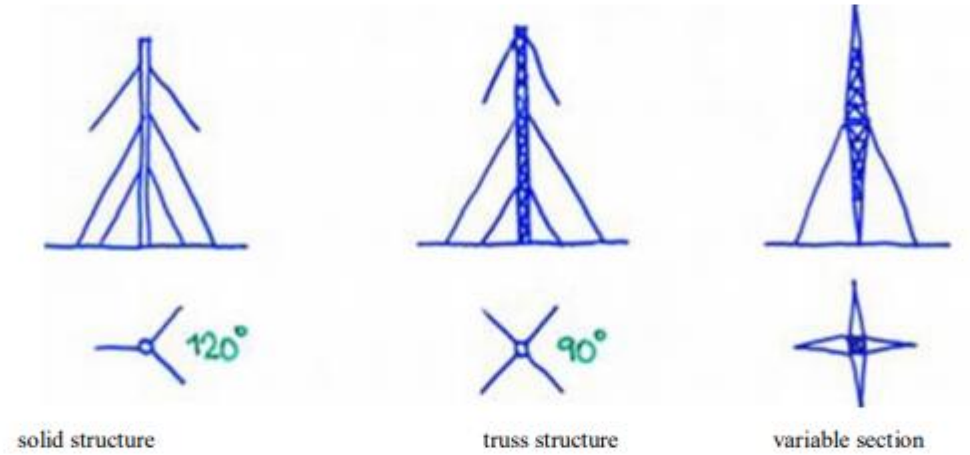
- suspension towers
- angle suspension towers
- angle towers
- tension towers
- terminal towers (dead-end type).

Power transmission line

Wind Turbine - Lattice Tower

Radio Lattice Tower

A guyed mast is one of the most complicated structures an engineer may be faced with the number of masts collapses is relatively far greater than for other types of structures carry aerials of TV, radio etc., or may be themselves emitters (then isolation - separation from ground is necessary).



The component parts of a guyed mast are:

- the foundation
- the steel mast, which generally has a pinned
- foot
- the guy cables
- the structural accessories
- the equipment (antenna)

Design of steel mast

- Steel mast anchored at different heights, is loaded in bending due to wind, and compression from vertical loads (dead load, live load, pretension forces in the cables.

- Pretension force in cables is determined so that in case the cable is unloaded due to wind action, the cable should still be subjected to a tension force.

- Value of pretension force is about 0.10 – 0.15 fu

- After the internal efforts in members is determined (legs, diagonals), they are designed using relevant verifications.

- For one segment of the mast, members of the same type have similar sections

• Steel mast anchored at different heights, is loaded in bending due to wind, and compression from vertical loads (dead load, live load, pretension forces in the cables.

• Pretension force in cables is determined so that in case the cable is unloaded due to wind action, the cable should still be subjected to a tension force.

• As a rule, if the guy is attached in the top of the tower (100%), the tension should be 8% of the tensile strength.

• For 80% of the tower's height, 10% tension should be applied.

• If the anchor point is at 65% of tower height, 15% tension can be applied as you loose a lot of wind load in this last type of installation.

• The breaking strength will improve the control of the flexibility and still not cut down on the cable strength. Normally, a tower has 2 – 3 levels of guys (depending on the height of the tower/mast) and three guys on each level. It is recommendable to use turnbuckles as it will allow you to fine tune your adjustments later on.

• After the internal efforts in members is determined (legs, diagonals), they are designed using relevant verifications.

• For one segment of the mast, members of the same type have similar sections.

Typical design problems are:

• establishment of load requirements.

• consistency between loads and tower design.

• establishment of overall design, including choice of number of tower legs.

• consistency between overall design and detailing.

• detailing with or without node eccentricities.

• sectioning of structure for transport and erection.

The loads acting on a transmission tower are:

• dead load of tower.

• dead load from conductors and other equipment.

• load from ice, rime or wet snow on conductors and equipment.

• ice load, etc. on the tower itself

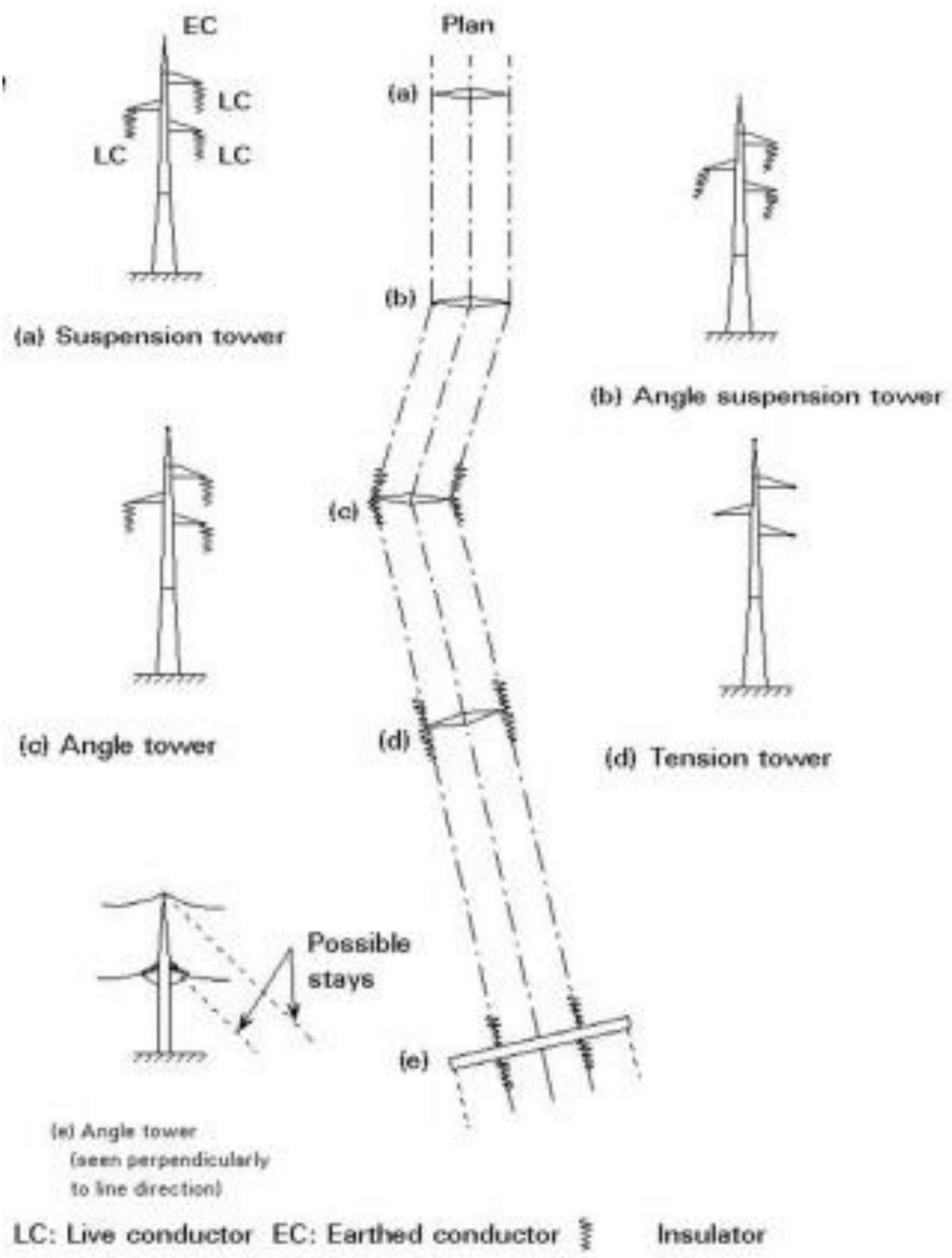


Fig.3 Types of transmission towers

• erection and maintenance loads.

• wind load on tower.

• wind load on conductors and equipment.

• loads from conductor tensile forces.

• damage forces

• earthquake forces.

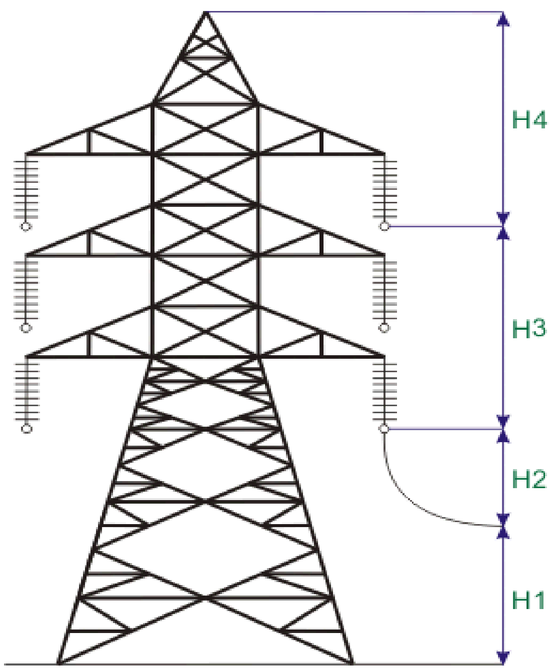
DETERMINATION OF TOWER HEIGHT

To determine the actual transmission tower height by considering the above points, we have divided the total height of the tower into four parts:

1. Minimum permissible ground clearance (H1)
2. Maximum sag of the overhead conductor (H2)
3. Vertical spacing between the top and bottom conductors (H3)
4. Vertical clearance between the ground wire and top conductor (H4)

Thus the total height of tower is given by

H= h1+h2+h3+h4



Transmission Tower

CRITICAL PARAMETERS OF TOWER

The following aspects are considered essential for fixing the tower outline:

a. Maximum sag of lower conductor.

b. Height and location of ground wire.

c. Length of cross arm and conductor spacing.

d. Minimum mid-span clearance.

e. Tower width at base and at top hamper

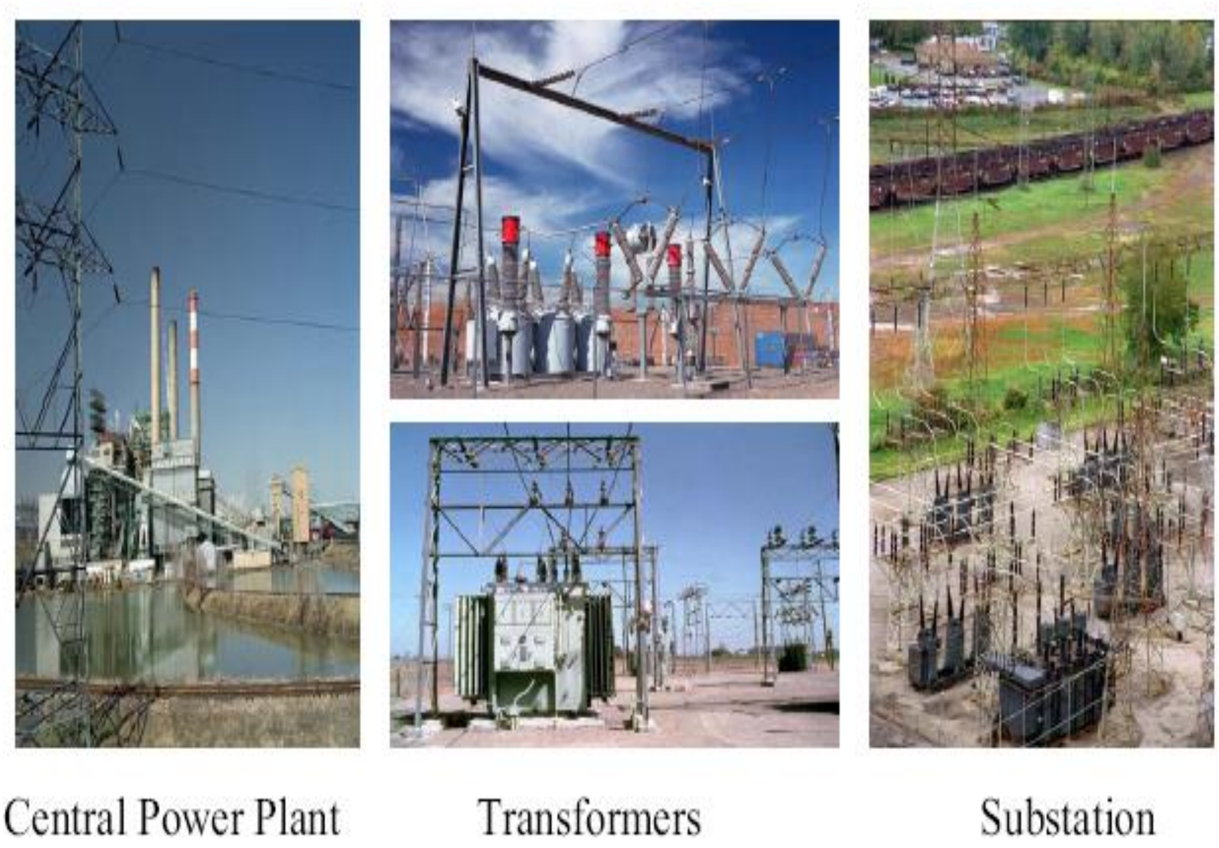
SUBSTATIONS

What is a Substation?

1. Substation are integral parts of a power system and form important link between the generating stations, transmission syst., distribution system and the load. [James R. Lusby]

2. Substation is an installation that interconnects elements of an electric utility's system. (include generator, transmission line, distribution lines and even neighboring utility system). [Jhon D. Mc. Donald]

3. An electrical Substation is an assemblage of electrical components including busbars, switchgear, power transformer, auxiliaries, etc [S.Rao]



THE FUNCTION OF A SUBSTATION

1. To isolate a faulted element from the rest of the utility system.
2. To allow an element to be disconnected from the rest of the utility syst. for maintenance or repair.
3. To change or transform voltage levels from one part of the utility system to another.
4. To control power flow in the utility system by switching elements into or out of the utility system.
5. To provide sources of reactive power for power factor correction or voltage control.
6. To provide data concerning system parameters (voltage, current and power flow) for use in operating the utility system).

KINDS OF AC SUBSTATIONS

1. *Generating station S/S,* transform generation voltage

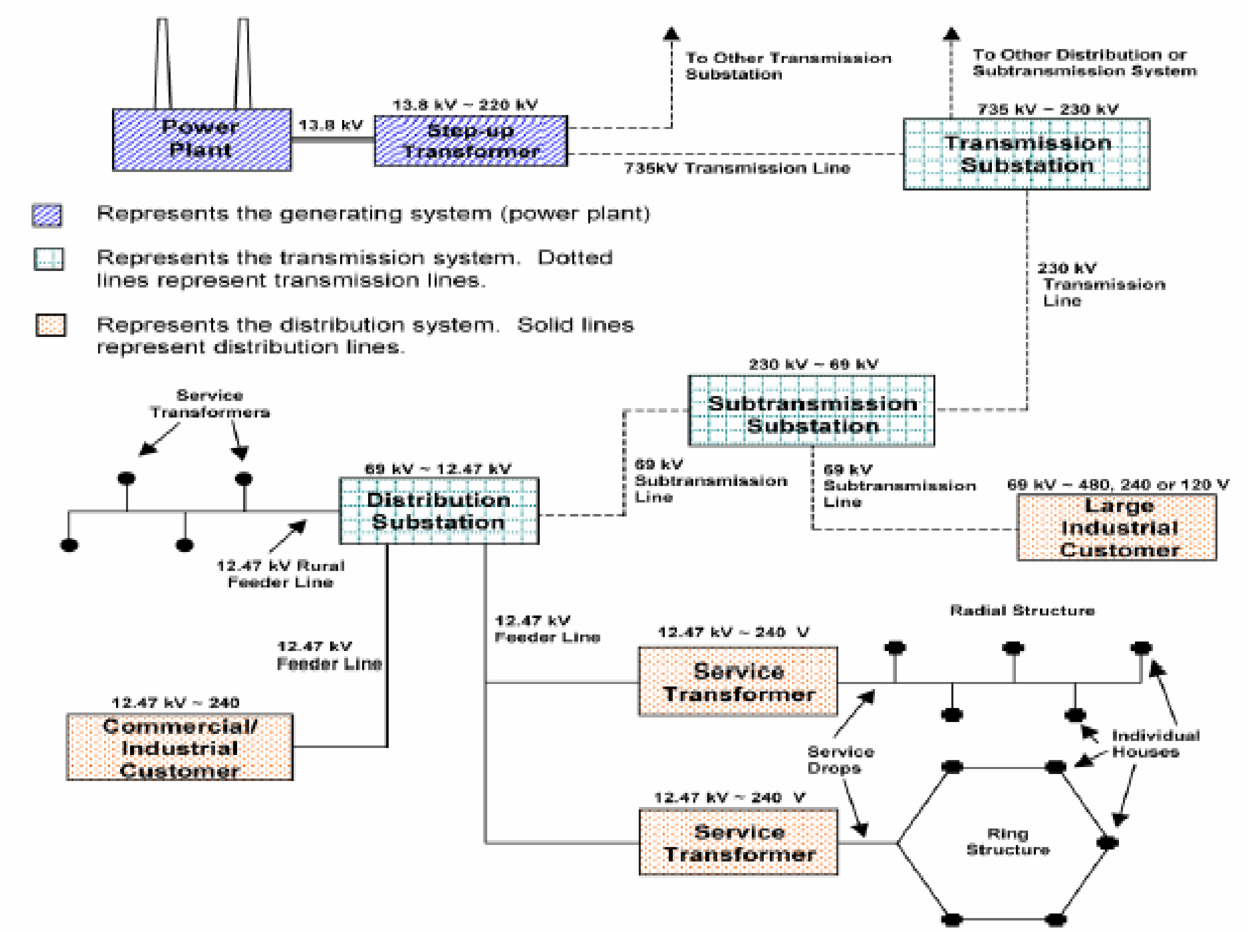
(15 - 23 kV) up to Trans.Network (69 -500 kV).

2. *Transmission Switching S/S,* interconnect portions of the utility syst. Transmission network.

3. *Transmission step down (or step up, depending on your point of view) S/S,* interconnect portion of the utility syst. Transmission network, and include transformation between trans. Network voltage levels.

4. *Distribution step-down S/S,* include transformation between Trans. Network and Dist. Network voltage levels, and interconnect portions of the utility syst. Dist. Nework.

5. Distribution S/S, interconnect portions of the utility Sys. Dist. network (transformation between Dist. Voltage Level



PARTS OF SUBSTATION

1. Site related system
2. Switchyard system
3. Control Building Syst.
4. Protection, control, and metering system
5. Auxiliary system

A). Site Related Systems (security, site access, Site grading, Drainage, and Surfacing syst.).

B). Switchyard Systems (Switching equipment systems, Power transformation eq., Bus, Measuring and Relaying Commu. Eq., Direct stroke and Surge protection, Grounding, Switchyard support structure, Race way).

C). Control Building System (Building: Architectural, Structural, Grounding, Raceway, lighting and comunication)

D). Protection, Control, and Metering Systems (Protective Relay, control, metering, Indication and Annunciation syst.

E). Auxiliary Systems (AC station service, Fire Protection.

Site Related system

- **<u>Security fence/Wall system</u>,**

to prevent entry of unauthorized person to substation, provides adequate electrical clearance from energized buses and equipment to areas accessible to the public, and provide entry to the substation for equipment delivery, removal and maintenance.

- **<u>Site access system</u>,**

This system allow access to the substation from public roads, and access inside the substation fence/wall for the installation, removal, and maintenance of the substation equipment, bus-work, and structure.

- **<u>Site grading, drainage, and surfacing system.</u>**

To provides a reasonably level switchyard for access to equipment, a drivable surface within switchyard, and a layer of constant resistivity crushed rock above grid for personal safety.

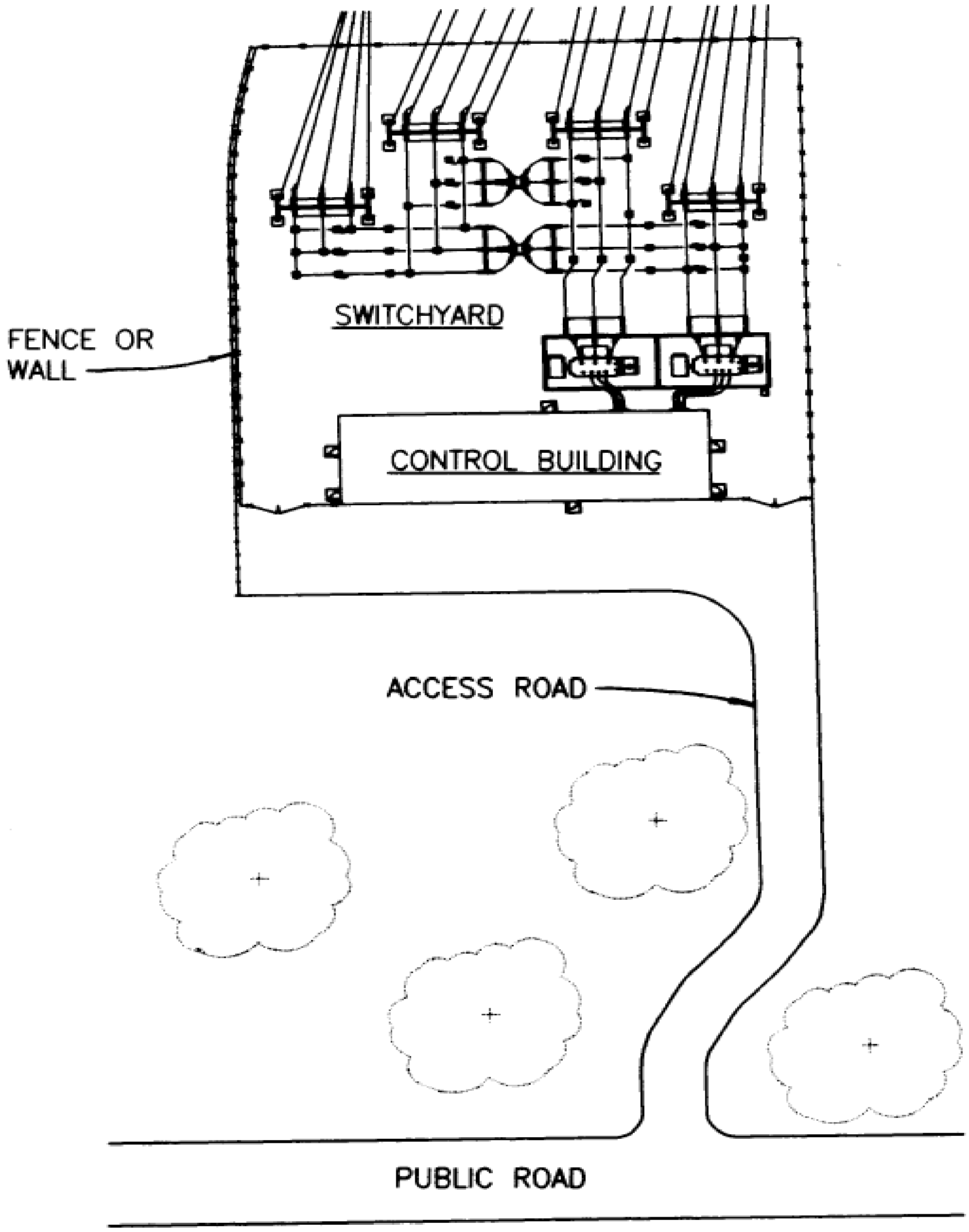
- **<u>Site Landscaping system,</u>**

The site landscaping system beautifies the site and complements the substation fence/wall to screen the substation from public view.

PROJECT PLANNING

The major steps in executing project include the following

- Award of contract
- Preparation of quality of plan
- Design of civil work, layout and Design of equipment
- Opening of site office and preparation of site
- Civil works: excavation, foundation, support structures, finishing
- Receipt of equipment, structure at site, storing
- Laying control cable and power cables
- Laying of ground grid, ground spikes and ground riser
- Installation of overhead shielding wire, steel structures, equipment
- Transportation of power transformers
- Installation on plinth, drying out and pre-commisisoning
- Quality check of equipment, connection of control cables
- Final commisionning and observation
- Handing over to the customers operating staff



TOWER FOUNDATIONS

Steel towers are very extensively used for transmission line towers, TV towers, and flood lighting towers. As the cost of foundations of these towers can be as much as 10 to 15% of their total cost and as electric transmission requires a large number of towers (as much as 12 towers per kilometre of transmission line) cost of foundation forms a large part of any transmission line project. Transmission line towers are classified according to their angle of deviation from their main direction.

When deviation is only up to 2°, they are called tangent towers. Light angled towers deviate 2 to 15°, medium angled over 15 to 30°, and heavy angled ones over 30°. In tower design, there is an optimum base width which gives the minimum cost of tower and foundation. One of the thumb rules

used is the Rye's formula $B = 0.013\sqrt{m}$

where

B = base width in metres

m = overturning moment at G.L. kg m

The ratio of base width to total height for most towers is generally 1/5 to 1/10t, depending also on the electrical requirements. The foundation design procedures given below are those used in India and described in detail in the Manual on Transmission Towers published by the Central Board of Irrigation and Power

Loads on Foundations

Structural analysis of a tower gives the following forces shown in Fig.4.4, for which the foundation has to be designed:

Σ Downward load

Σ Uplift load

Σ Shear forces in transverse and longitudinal directions.

These forces are determined for the normal working conditions (NCs) and also for the broken wire conditions (BWCs). As certain calculations like the lateral analysis of pile use ultimate load analysis, a load factor of 2 is given for NC and 1.5 for BWC.

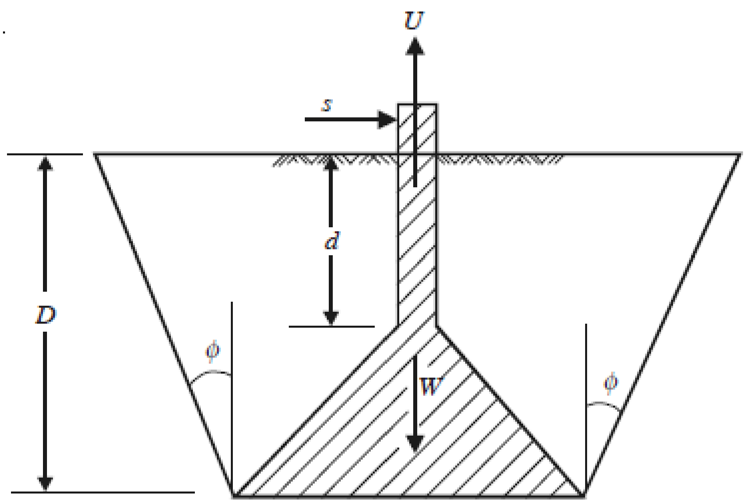


Fig.4.4 Chimney and pad foundation for transmission line towers. Forces acting on the foundation.

Types of Foundations Used

The type of foundation to be selected for steel towers depends on the site and soil condition. As protection against corrosion is very important, modern foundations, as a rule, are exclusively made of reinforced concrete with special precautions for durability. The following are the main types of foundations we can choose from:

1. Concrete block foundation (suitable for small uplift forces)
2. 'Concrete pad and chimney type footing' (with stub angle or in reinforced concrete) shown in Fig. 4.4. (The bottom part is the pad and the shaft is called chimney.)
3. Steel grillage encased in concrete
4. Concrete spread footings
5. Augured foundations
6. Grouted rock anchors
7. Pile foundations
8. Well foundations
9. Concrete mat foundation under the tower
10. Precast foundations.

Of these, the most commonly used type for steel towers is the '*concrete pad and chimney footing*' which we will examine in more detail. Pad and chimney footing foundations isolated foundations relying on the weight of earth to balance the uplift forces. Each leg of the tower is provided with one such foundation. However, when the size of the footing required for the downward forces is small, it may be found cheaper to provide under-reamed piles than a pad and chimney foundation for the uplift forces. When the forces are very large, we adopt R.C. foundations as shown in Fig. 4.5b. Isolated footings should be preferably interconnected at or below the ground level by beams to ensure their unified action.

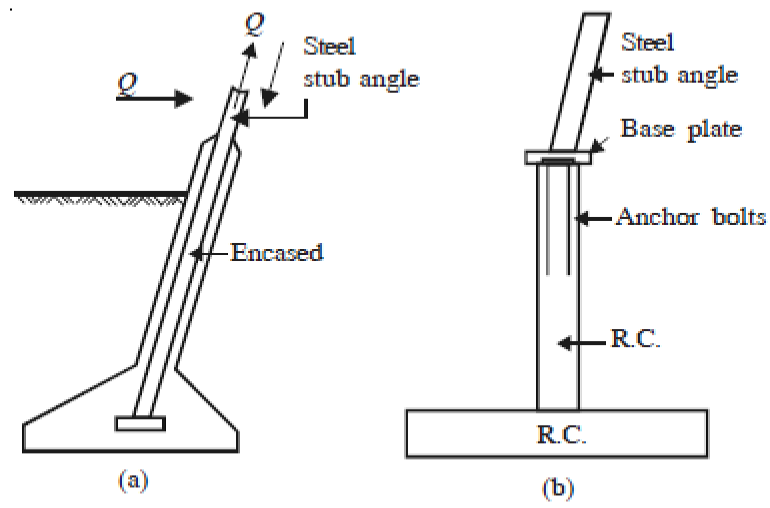


Fig. 4.5 Types of steel tower foundations: (a) Chimney and pad footing; (b) R.C. footing.

DESIGN OF CHIMNEY AND PAD FOUNDATION

As we have already seen, two arrangements as shown in Fig. 4.5, can be adopted for these foundations. When the forces acting are not large, the stub angle is taken inside the shaft to the pad portion and anchored by cleat angle and keying rods. In such cases, the member acts as a composite member. When the lateral forces acting are large, it may be necessary to adopt a reinforced
concrete foundation as shown in Fig. 4.5b, where the stub angles are bolted to a base plate fixed in an R.C. shaft.

There are two parts in the design of chimney and pad foundations, namely, stability, analysis and strength design. They are carried out under the following heads:

1. Check the safety against uplift.
2. Check the stability against overturning.
3. Check lateral resistance.
4. Check uprooting of stub.
5. Determine the stress resultants and carry out strength design (structural design).
6. Check bearing capacity of pad in shallow foundation.

The first four aspects only are dealt in detail in the following sections.

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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – V – INDUSTRIAL STRUCTURES– SCIA7014

INTRODUCTION

Fortunately most of the problems of machine vibrations can be solved by assuming that they obey the laws of simple harmonic motion, well known to all engineers. An oscillation is said to have only a single degree of freedom when the motion can be described by one coordinate in space. However in general, a machine foundation can have six degrees of freedom, three translational and three rotational.

TYPES OF MACHINE FOUNDATIONS

The layout of the foundation depends on the position of the operating floor level, as well as that of the auxiliary equipment and also on many other factors. Considering the structural forms, machine foundations can be classified into the following types

1. Block foundation
2. Box type foundation with hollow inside
3. Wall type or pedestal type of foundation with a pair of walls on a base slab supporting the machine on top
4. Framed type foundation consisting of a base slab, vertical columns and top slab
5. Foundations of other shapes to suit the machine.

In general, machines producing impulsive or periodic forces at low frequencies are supported on block foundations while machines working at high speeds like turbines are usually mounted on framed type of foundations. In Fig. 5.1, except for the block type, the machinery is supported on the upper floors and transmits load to soil at the basement levels.

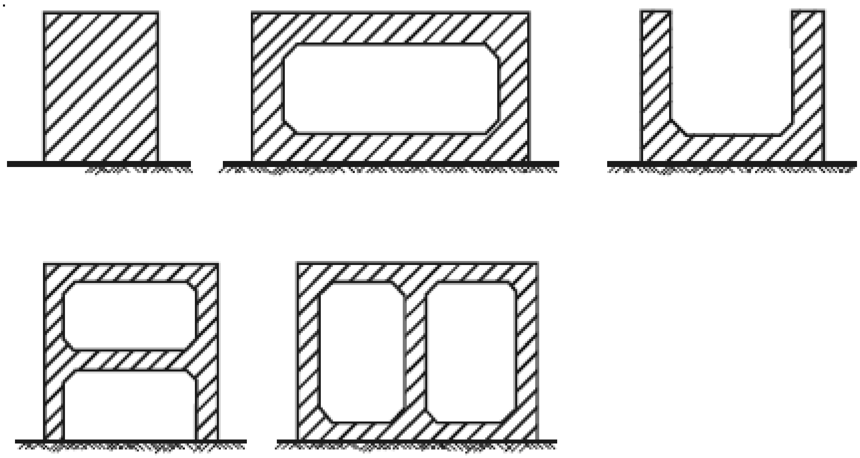

Fig.5.1 Block and frame types of machine foundations

FOUNDATION ANALYSIS

As we have seen, two types of analysis are to be made for machine foundations, namely static analysis and dynamic analysis. *Static analysis deals with foundation pressures and settlements while dynamic analysis deals with resonance and amplitudes of vibration*. However, in many low speed machines only the static analysis may be necessary, though in many other machines like compressors and hammers, where unbalanced forces are high, both analyses are always needed. A list of the usual machines met in practice and the type of analysis to be made with them are given below.

1. Rotary type machines of low frequency.

(a) Rolling mills—static analysis only

(b) Crushing mills (jaw and core crushes)—both static and dynamic analysis

(c) Pumps—both static and dynamic analysis

(d) Grinding mills— static analysis only

(e) Motors/generators—both static and dynamic analysis

2. Lathes, milling machines, drilling machines and boring machines generally do not require analysis, but only isolation from other sources of vibration.

3. Impact machines, other than drop hammers, forging and stamping press generally require only static analysis. Dynamic analysis is of very little significance for these machines.

4. Impact machines like drop hammers, forging and stamping press, and drop weight-crushers require both static and dynamic analysis.

5. Fans and blowers require both static and dynamic analysis.

6. Spinning or other looms when installed on the upper floors, it must be ensured that the natural frequency of the floor is not near the operating speed of the loom. Dynamic effects should also be considered in these cases.

The more difficult machines to deal with are those, which run at low frequency of 200–500 cycles per minute. As most *buildings have low natural frequencies*, care should be taken to prevent resonance.

DYNAMIC ANALYSIS

Dynamic analysis is the calculation of frequencies and amplitudes. Earlier, machines were usually bolted to the foundation block, which served the function of spreading the load to the soil and increasing the mass of the vibrating system. In cases where fine-tuning of the foundation was to be done after the construction of the foundation, cavities were left to adjust the weight of the foundation and thus adjust its frequency.

DESIGN OF CONCRETE FOUNDATION

As in many other civil engineering practices, we first fix the type and dimension of the foundation from past experience. Thus, we have typical foundation arrangements for each type of machines. The foundation for a compressor will be different from that for a drop hammer. Easiness in erecting, disbanding, provision of anchor bolts and other details should always be taken care of when detailing. In general, the foundation should extend 15 cm or more beyond the base of the machine.

The foundation, where isolation is not required can be cast directly against the soil rather than by using side forms to take advantage of the shear resistance of the soil for vertical motion and rocking. For the latter purpose, the width should be as large as the depth. However, where the amplitudes should not be transmitted to other parts of the building, the foundation has to be isolated by proper methods. The method of analysis of the various types consist of first choosing the design parameters of the soil and then adopting the most appropriate mathematical model for analysis. Depending on the foundation, one degree or two degrees or even three degrees systems may be adopted.

DESIGN OF A BLOCK FOUNDATION FOR A COMPRESSOR

For compressors, we generally adopt block foundations. Compressors can be the vertical type or horizontal type. The foundation for compressor machines is subjected to *forced vibration with damping*. We make both static and dynamic analysis. In static analysis, we ensure that the foundation pressure and settlement are within their permissible values. In dynamic analysis, we ensure that resonance is avoided and the amplitude of vibration is within limits.

Static analysis

Step 1: From the machine dimensions and data, draw a tentative layout of a suitable type of block foundation based on past experience. In practice, a block approximately 2.5 times the weight (2 to 3 times) of the machine is chosen for this purpose.

Step 2: From the dimensions of the block foundation, find the eccentricities x , y and z with the machine founded on it and determine the static pressure and stresses due to moments. In general, eccentricity should always be as small as possible. Soil pressure is calculated as follows:

$$\text{Soil pressure} = W/A \pm M/Z$$

Step 3: From the dimensions of the machine and its characteristics, calculate the following forces and moments depending on whether it is a vertical or horizontal compressor.

Σ Vertical unbalanced force

Σ Horizontal unbalanced force

Σ Unbalanced rocking moments

Determine the additional stresses in the foundation due to these forces. To make these forces into static forces, assume the equivalent static force. This is taken as 3 times the dynamic force. The effect of these loads is added to the forces due to gravity forces.

Dynamic analysis for resonance and amplitudes.

Let X be along the length, Y along breadth and Z along the vertical.

Step 1: Find probable frequencies and amplitude in uncoupled modes and check their magnitudes for the following (see Fig.5.2).

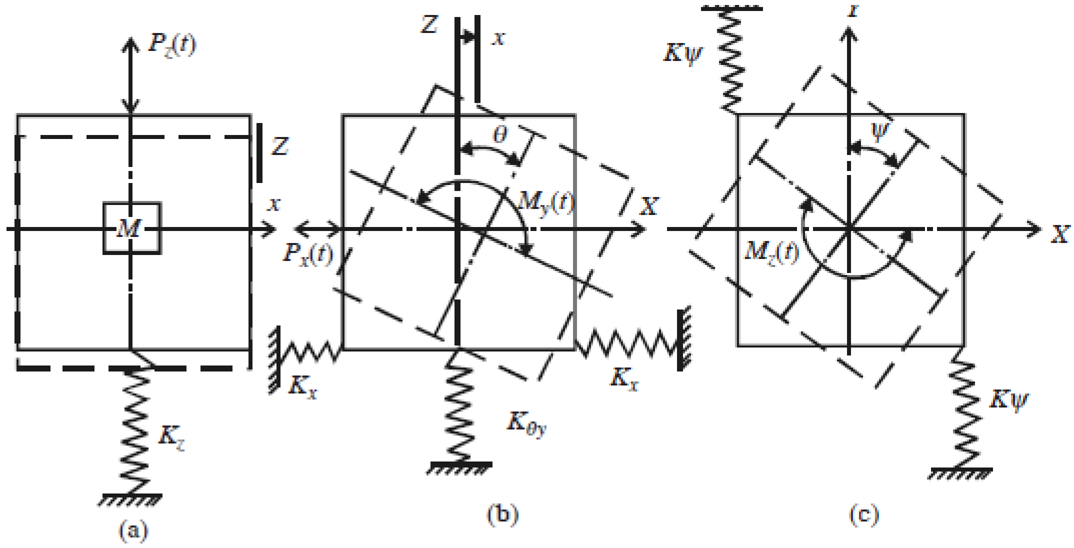

Fig.5.2 Modes of vibration of block foundation: (a) Uncoupled vertical mode; (b) coupled rocking and sliding; (c) uncoupled torsion (plan view).

(a) Consider vertical mode and find frequency and amplitude. Use the eq. given below

$$f_{nz}^2 = \frac{C_u A}{4\pi^2 m} \qquad \text{(vertical)}$$

(b) Values for *Cu* are taken from test results or from I.S. Code.

IS also recommends the following values in Table 5.1 for routine design of machine foundations.

TABLE 5.1 RECOMMENDED VALUES OF *Cu*

(Area of base 10 m^2)
As recommended by Barkan [4]

Category	Soil group	Static load pressure (kN/m^2)	C_u (kN/m^3)
1	Weak soils	Up to 150	Up to 30,000
2	Medium strong	150–350	30–50,000
3	Strong soils	350–500	50–100,000
4	Rocks	> 500	> 100,000

(a) Consider sliding mode and find its frequency and amplitude using Eq given below.

$$f_{nx}^2 = \frac{C_\tau A}{4\pi^2 m} \qquad \text{(sliding)}$$

(b) Consider rocking mode and find its frequency and amplitude using Eq. given below.

$$f_{n\phi}^2 = \frac{C_\phi I - Wz}{4\pi^2 M_{m0}} \qquad \text{(rocking)}$$

(c) Consider torsional mode and find its frequency and amplitude using Eq. given below.

$$f_{n\psi}^2 = \frac{C_\psi J_z}{M_{mz}} \qquad \text{(torsion or yawing)}$$

where
m = mass of foundation and machine
I = moment of inertia of contact area $a \times b = ba^3/12$
M_{m0} = mass moment of inertia of machine and foundation block about the axis of rotation
J_z = polar moment of inertia of machine and foundation about z axis.

Step 2: Consider coupled modes (rocking and sliding or vertical, rocking and sliding) and find the frequencies and amplitudes in these modes and ensure that their magnitudes are within limits using Eq. given below.

$$rf_n^4 - \left(f_{nx}^2 + f_{n\phi}^2\right) f_n^2 + f_{nx}^2 f_{n\phi}^2 = 0$$

where

$$r = \text{ratio of } \frac{\text{M.I. about C.G. of system}}{\text{M.I. about the } Y\text{-axis}}$$

The allowable amplitude in machine foundation depends on the frequency of the machine.
For machines up to 1000 rpm an amplitude value of 0.2 mm is considered safe.

DESIGN OF A BLOCK FOUNDATION FOR A FORGE HAMMER

The foundation for a forge hammer will undergo *free vibration* and the usual requirements are the following:

1. The maximum stresses in soil due to static and equivalent dynamic forces should not exceed the allowable values.

2. For maximum vertical amplitude of vibration of the *foundation block* (due to the impact of hammer) should not exceed 1.2 mm. In the case of foundation in sand below ground water table, the permissible amplitude is limited to 0.8 mm.

3. The permissible amplitude *of anvil depends* on the weight of *falling tup*. It is to be kept as 1 mm for a tup of 1 ton, 2 mm for a tup of 2 tons and 3 to 4 mm for a tup of 3 tons.

Depending on the requirements, the foundation can rest on soil, piles, cork, springs or rubber pads. As shown in Fig.5.3, the anvil is placed on a suitable insulation layer in the form of timber

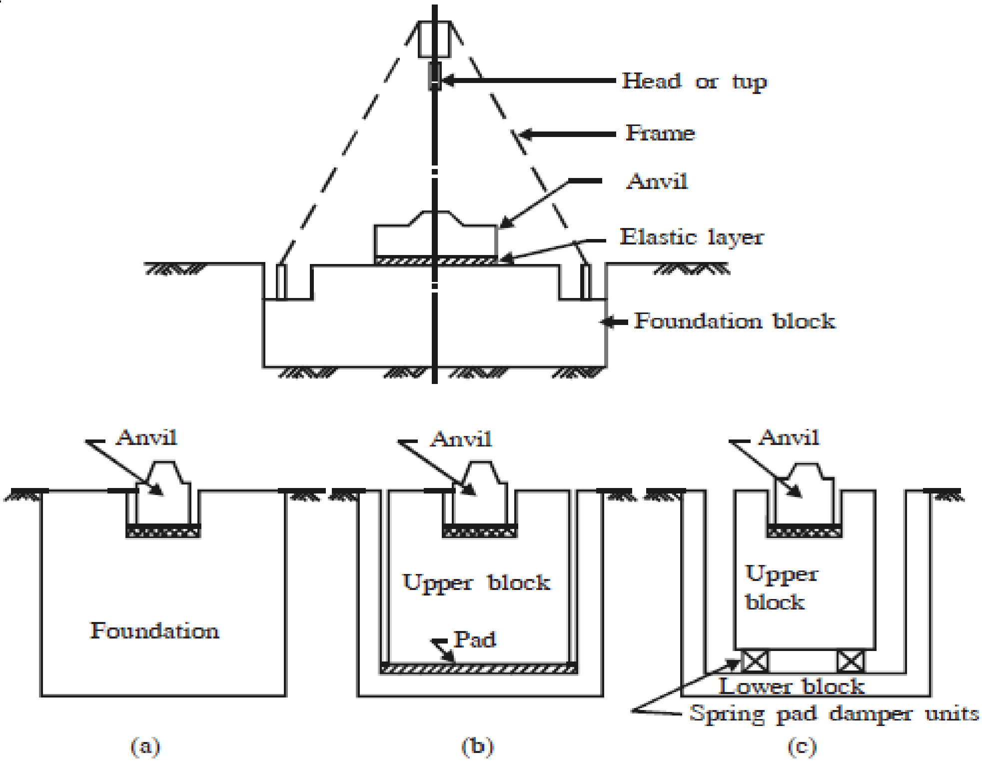

Fig. 5.3 Types of foundations for forge hammers.

grillage or other resilient material. The metal to be forged is placed on the anvil and the tup falls on it repeatedly at regular intervals, the movement of the tup being controlled mechanically by steam or compressed air.

The vertical/horizontal dynamic test is conducted on the foundation for determining their spring constants and the wave propagation test for determining the shear modulus, or else values are assumed for the various parameters. For the dynamic analysis of hammer foundations, it is conventional to assume that the foundation is under free vibration caused by the initial velocity imparted on the anvil by the tup. The hammer foundation can be idealized as shown in Fig. 5.4.

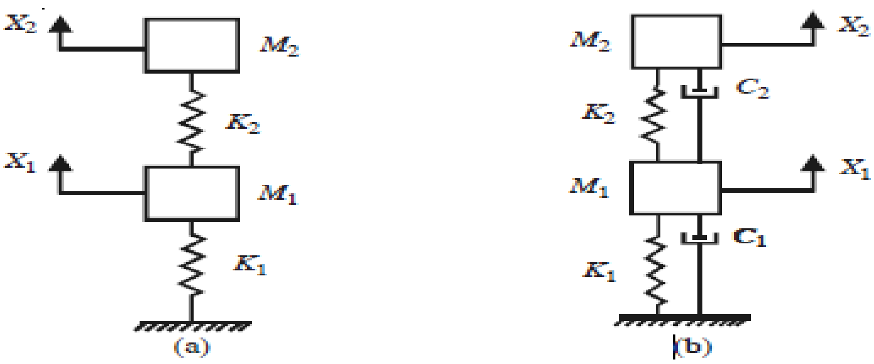

Fig. 5.4 Idealization of hammer foundation: (a) Undamped vibration; (b) damped vibration.

It may be noted that the amplitudes are derived from the velocities imparted by the fall of the tup on the anvil and their frequencies are calculated by using the relation,

Amplitude of vibration = Velocity/ 2π(frequency)

The amplitudes of foundation and anvil should be investigated to ensure that they fall within the limits specified above.

CONSTRUCTION DETAILS

Machine foundations should always be constructed with care as it is difficult to rectify any initial defects once they are constructed. Also as any stopping of machines will considerably affect the working of a factory, *the design of these foundations should include a higher factor of safety than adopted for normal structures.* Under no circumstances, should the foundations of important machines like generators, compressors etc. in a factory pose problems.

Block foundations should be cast in horizontal lifts avoiding cold joints. It should be liberally reinforced on all surfaces, around openings. The minimum steel specified is 25 kg/m^3 of concrete (16 to 25 mm rods at 20 to 30 cm spacing in both directions and also on the lateral faces).

Concrete cover should be atleast 75 mm for the earth side of concrete and 50 mm for the sides exposed to air.

In the case of a framed foundation, the base slab may be separately cast with a minimum reinforcement of 50 kg/m3. Around all openings, steel reinforcement equal to 0.5 to 0.7 per cent of the area of the opening should be provided in the form of a cage. Standard detailing practice should be used in all cases. In massive constructions, it may be necessary to reduce the heat of hydration of the concrete by suitable method. It is advisable to cast the whole foundation by continuous casting. Otherwise, liberal steel should be provided at designed construction joints

Machines on Pile Foundations

As f_n^2 varies with k/m, any increase in spring constant k increases the natural frequency of the system. Piles provide additional springs and also damping factors. Piled foundations are used for machines for the following reasons:

1. To increase bearing capacity and reduce settlements under static or dynamic loads.
2. To increase the natural frequency of a foundation by increasing the spring constant (the variation of frequency with rigidity can be seen from Fig. 5.5. A fixed beam is more rigid than a cantilever).
3. To decrease the possible amplitude of natural vibration or the resultant of a forced vibration.

Such designs need special data and analysis for a satisfactory solution

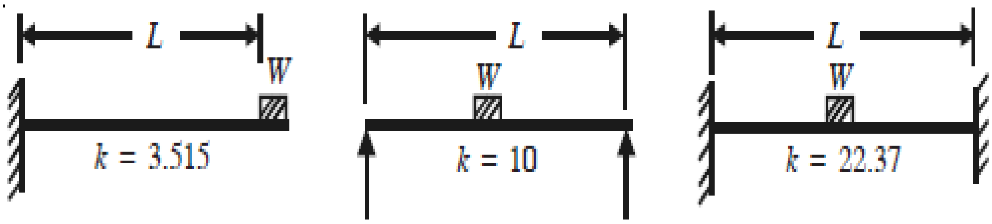

Fig. 5.5 Increase in rigidity with conditions of fixity.

DETERMINATION OF SOIL PROPERTIES FOR DYNAMIC ANALYSIS

We have seen when dealing with free vibrations from Eq. given below that the natural frequency of a system depends on mass in vibration and the spring constant:

$$\omega_n^2 = 4\pi^2 f_n^2 = \frac{k}{m} \quad \text{or} \quad f_n^2 = \frac{k}{4\pi^2 m} \quad \text{or} \quad f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

where f_n is the natural frequency of the system.

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{\delta_{st}}}$$

where

$$\delta_{st} = \frac{W}{k} = \frac{\text{weight}}{\text{spring constant}} = \text{displacement}$$

Soil spring constant depends on the soil condition which has to be estimated from experience or determined by field tests. The more commonly adopted tests are the *cyclic plate load test* and the *block vibration test*.

Cyclic plate load test. A plate is placed on the ground and it is subjected to increasing loads. As different from ordinary plate load tests, each successive load is maintained till settlement is complete. The load is then reduced to zero and the plate allowed to rebound. The readings for this load will consist of the reading at full load and the settlement at no load. The load is then increased to the next increment and settlements taken at full load and zero load. This cycle of loading and unloading is continued till the required final load is reached. A graph is drawn between load on the *Y* axis and total elastic settlement for that load on the *X* axis. The slope of this curve is the coefficient of elastic uniform compression in kN/m^3.

$$C_u = \frac{p}{s}, \ \text{kN/m}^3$$

where p = pressure and s = settlement.

The spring constant $k = C_u \times$ (area of contact) in kN/m

The following correction for the actual area *A* of the real foundation should be used as against the area '*a*' of the test when we use the value for a practical problem (*A* is usually taken as 10 m^2 for expressing C_u):

$$C_u = C_{test}\sqrt{\frac{a}{A}}$$

Block vibration test. For the block vibration test, a concrete block 0.7 m height and 1.5 m × 0.75 m in plan is cast in a pit at the foundation level with the necessary bolts for fixing the oscillator. In the block, the eccentric masses and motor can be set at different angles to produce different vibrations. Accelerator pick ups can be mounted and from the acceleration and known frequency values, the amplitudes can be calculated using the following relation:

$$\text{Amplitude} = \frac{\text{acceleration}}{4\pi^2\ (\text{frequency})}$$

For vertical oscillation, readings are made to obtain plots with amplitude along *Y* axis and frequency along *X* axis. From the plots, the resonant frequency for the given size can be obtained by observing the shape of the curves. The value of *k* is calculated as follows.

$$k = m\omega_n^2 = (\text{mass of block})(2\pi\ f_n^2)$$

where f_n is the resonant frequency.

We should note that arrangement for similar tests can be made for horizontal vibration also.

Damping factor test. In case of block foundation damping factor is contributed mainly by soil (as for example its embedment). Two tests, one based on free vibration, and the other on forced vibration are available in IS 5249:1992 for this test.

IS recommendations. In the general analysis of machine foundations, we use separate coefficients for each type of vibration. I.S. recommends the following rough correlation between them:

Coefficient of uniform elastic compression C_u

Coefficient of uniform elastic shear $_t$ = 1/2 C_u

Coefficient of elastic non-uniform compression $C_f = 3.46C_t$

Coefficient of elastic non-uniform shear $C_y = 0.75C_u$