

UNIT-III
OVERHEAD TRANSMISSION
LINES

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- Conductor Materials
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Introduction

- [[Electric power can be transmitted or distributed either by means of **underground cables or by overhead lines**.

The underground* cables are rarely used for power transmission due to two main reasons.

- [[Firstly, the installation costs for underground transmission will be very heavy for long distance.
- [[Secondly, It is very difficult to provide proper insulation† to the cables to withstand such higher pressures.
- [[**Therefore, as a rule, power transmission over long distances is carried out by using overhead**

Main Components of Overhead Lines

- [[**Conductors** which carry electric power from the sending end station to the receiving end station.
- [[**Supports** which may be poles or towers and keep the conductors at a suitable level above the ground.
- [[**Insulators** which are attached to supports and insulate the conductors from the ground.
- [[**Cross arms** which provide support to the insulators.
- [[Miscellaneous items such as **phase plates, danger plates, lightning arrestors, anti-climbing wires** etc.

Conductor Materials

The conductor material used for transmission and distribution of electric power should have the following properties :

- [[**high electrical conductivity.**
- [[**high tensile strength** in order to withstand mechanical stresses.
- [[**low cost** so that it can be used for long distances.
- [[**low specific gravity** so that weight per unit volume is small.

Commonly used conductor materials.

Copper.

- [[Copper is an ideal material for overhead lines having high **electrical conductivity** and **greater tensile strength**. It is always used in the hard drawn form as stranded conductor.
- [[Copper has **high current density** i.e., the current carrying capacity of copper per unit of X-sectional area is quite large. This leads to two advantages.

Firstly, smaller X-sectional area of conductor is required and secondly, the area offered by the conductor to wind loads is reduced.

Cont.

- [[Moreover, this metal is quite **homogeneous, durable** and has **high scrap value**.
- [[However, due to its **higher cost** and **non-availability** , it is rarely used for these purposes.
- [[Now-a-days the trend is to use aluminium in place of copper.

Aluminium

Aluminum is cheap and light as compared to copper but it has much smaller conductivity and tensile strength.

[[The relative comparison of the two materials is briefed below :

(i)The conductivity of aluminium is 60% that of copper.

The smaller conductivity of aluminium means that for any particular transmission efficiency, the X-sectional area of conductor must be larger in aluminium than in copper.

Aluminium

The increased X-section of aluminium exposes a greater surface to wind pressure and, therefore, supporting towers must be designed for greater transverse strength.

- (ii) **The specific gravity of aluminium (2.71 gm/cc) is lower than that of copper (8.9 gm/cc).**

Therefore, an aluminium conductor has almost one-half the weight of equivalent copper conductor. For this reason, the supporting structures for aluminium need not be made so strong as that of copper conductor.

Aluminium

(iii) Aluminium conductor being light, is liable to greater swings and hence larger cross-arms are required.

(iv) Due to lower tensile strength and higher coefficient of linear expansion of aluminium, the sag is greater in aluminium conductors.

[Sag: the difference in level b/w points of supports and the lowest point on the conductor is called sag]

Steel cored Aluminium

The aluminium conductor is reinforced with a core of galvanized steel wires. The *composite conductor thus obtained is known as steel cored aluminium and is abbreviated as A.C.S.R.

- [[Steel-cored aluminium conductor consists of central core of galvanised steel wires surrounded by a number of aluminium strands.
- [[Usually, diameter of both steel and aluminium wires is the same. The X-section of the two metals are generally in the ratio of 1 : 6 but can be modified to 1 : 4 in order to get more tensile strength for the conductor. (aluminium conductor steel reinforced).

Steel cored Aluminium

The steel cored aluminium conductors have the following advantages :

(i) **The reinforcement with steel increases the tensile strength but at the same time keeps the composite conductor light. Therefore, steel cored aluminium conductors will produce smaller sag and hence longer spans can be used.**

(ii) **Due to smaller sag with steel cored aluminium conductors, towers of smaller heights can be used.**

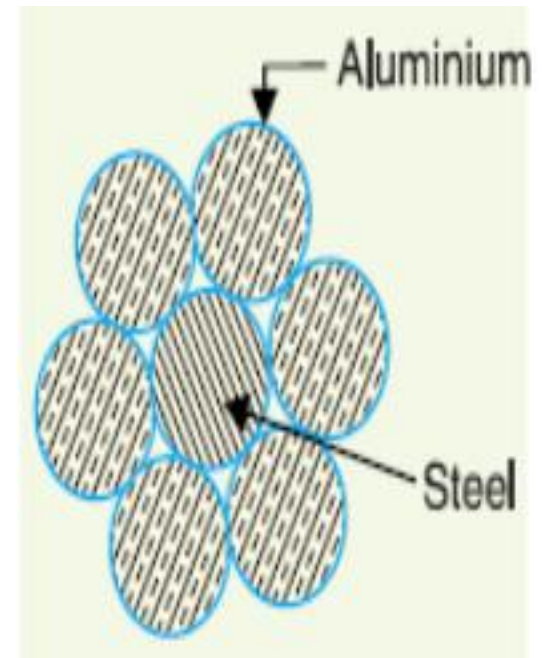


Fig. shows steel cored aluminium conductor having one steel wire surrounded by six wires of aluminium.

Galvanized steel.

- Steel has **very high tensile strength**. Therefore, galvanized steel conductors can be used for extremely long spans or for **short line** sections exposed to abnormally high stresses due to climatic conditions.
- They have been found very suitable in rural areas where cheapness is the main consideration.
- Due to **poor conductivity** and **high resistance** of steel, such conductors are not suitable for transmitting large power over a long distance.

Cadmium copper

An addition of 1% or 2% cadmium to copper increases the tensile strength by about 50% and the conductivity is only reduced by 15% below that of pure copper.

- Therefore, cadmium copper conductor can be useful for exceptionally long spans.
- However, due to high cost of cadmium, such conductors will be economical only for lines of small X-section i.e., where the cost of conductor material is comparatively small compared with the cost of supports.

Line Supports

The supporting structures for overhead line conductors are various types of poles and towers called line supports.

Properties of line support are:

- [[**High mechanical strength** to withstand the weight of conductors and wind loads etc.
- [[**Light in weight** without the loss of mechanical strength.
- [[**Cheap in cost** and economical to maintain.
- [[**Longer life.**
- [[**Easy** accessibility of conductors for **maintenance.**

Line Supports

- The line supports used for transmission and distribution of electric power are of various types including **wooden poles, steel poles, R.C.C. poles** and **lattice steel towers**.

The choice of supporting structure for a particular case depends upon

- **the line span,**
- **X-sectional area,**
- **line voltage,**
- **cost and local conditions.**

Wooden poles

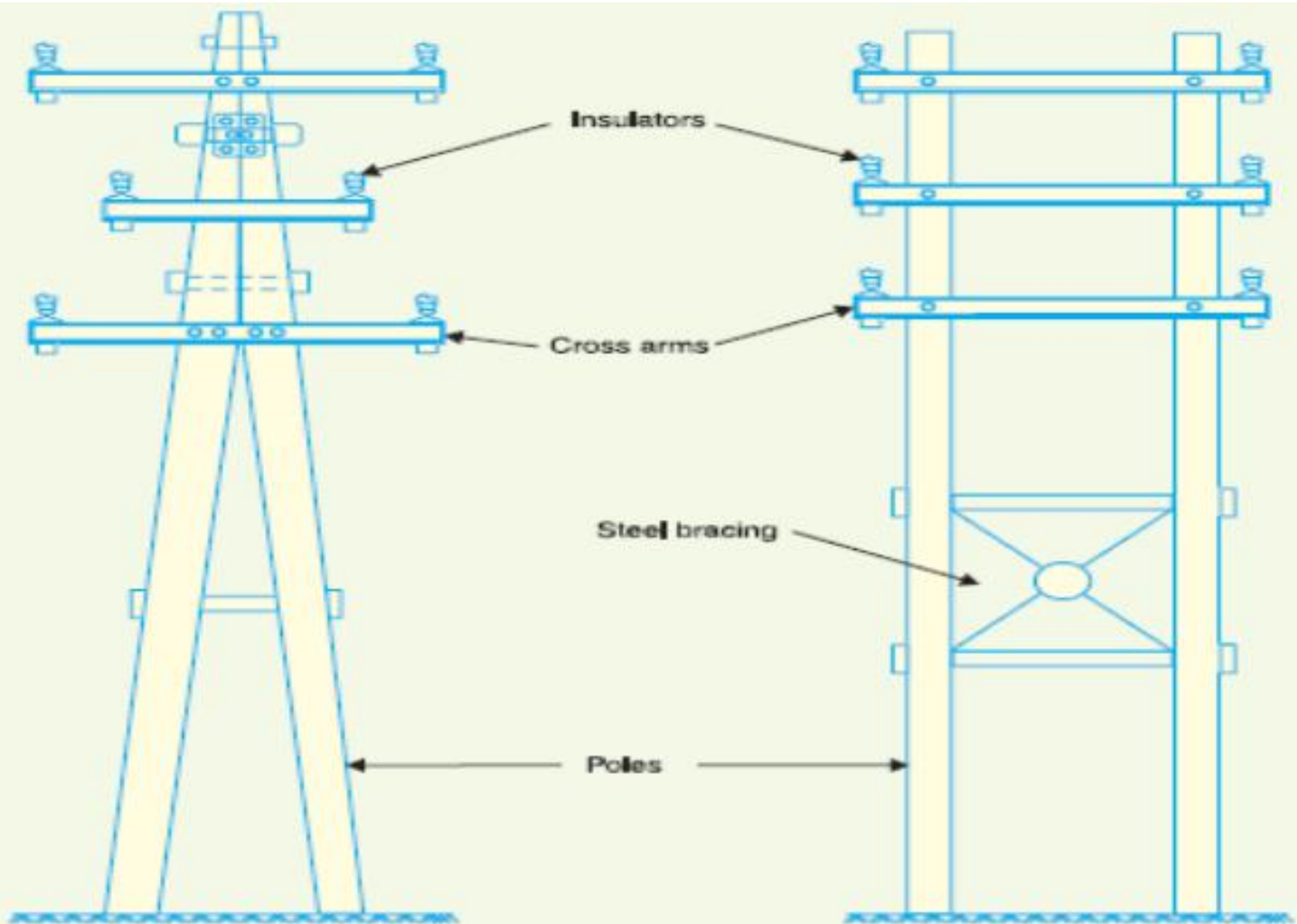
- These are made of **seasoned wood (sal or chir)** and are suitable for lines of moderate X-sectional area and of relatively shorter spans, say up to **50 meters**.
- Such supports are **cheap, easily available, provide insulating properties** and, therefore, are widely used for distribution purposes in **rural areas** as an economical proposition.
- Double pole structures of the **'A' or 'H'** type are often used to obtain a higher transverse strength than could be economically provided by means of single poles.

Wooden poles

The main objections to wooden supports are :

- (i) tendency to **rot** below the ground level [reduced by applying **creosote oil**]
- (ii) comparatively **smaller life** (20-25 years)
- (iii) cannot be used for voltages higher than **20 kV**
- (iv) **less mechanical strength** and
- (v) require periodical **inspection**.

Wooden poles



Steel poles

- [[The steel poles are often used as a substitute for wooden poles.
- [[They possess greater **mechanical strength**, **longer life** and permit **longer spans** to be used.
- [[Such poles are generally used for distribution purposes in the cities.
- [[This type of supports need to be galvanized or painted in order to prolong its life.
- [[The steel poles are of three types viz.,
(i) rail poles (ii) tubular poles and (iii) rolled steel joints.

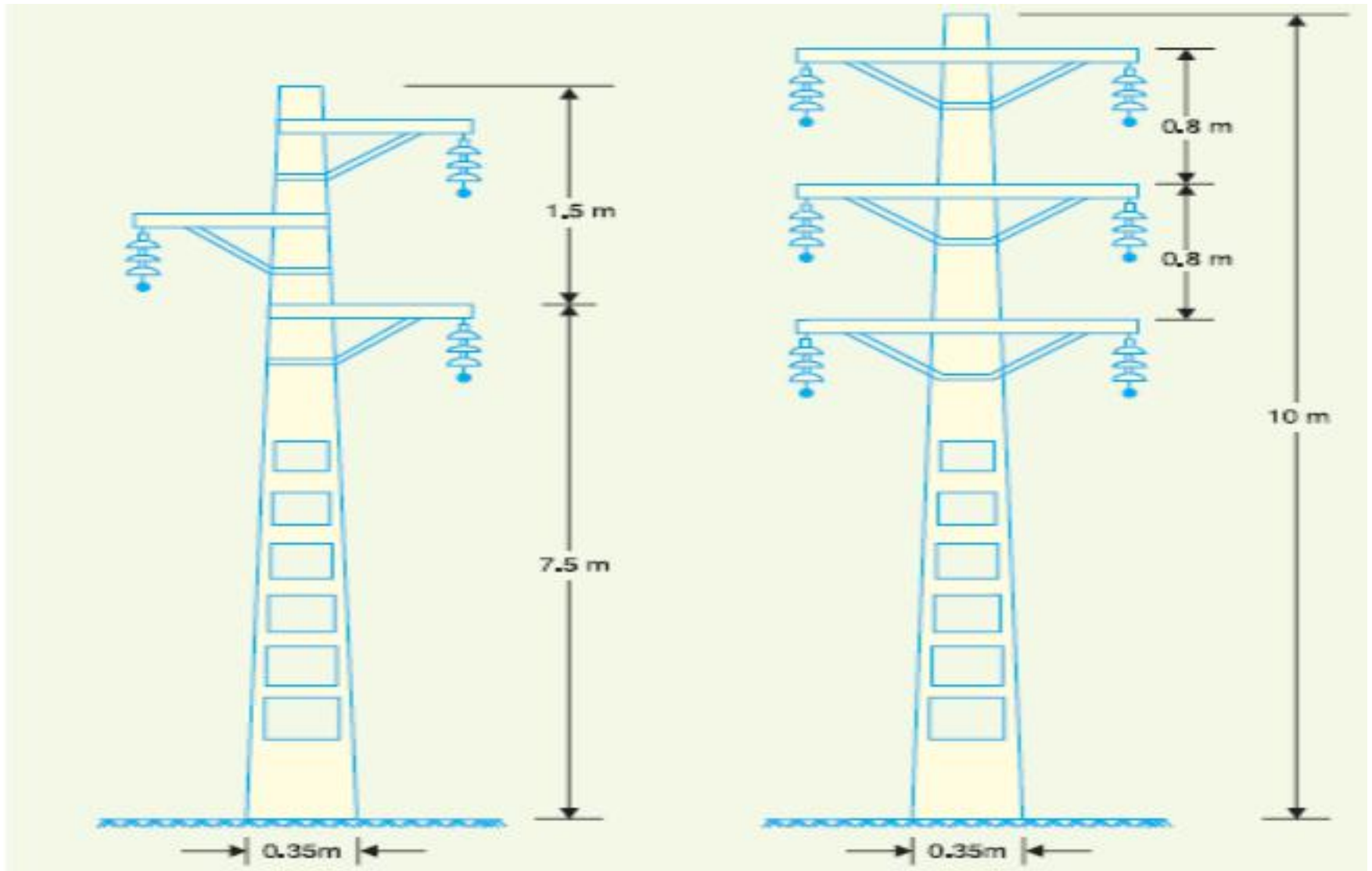
RCC poles

The reinforced concrete poles have become very popular as line supports in recent years.

- [[They have greater **mechanical strength**, **longer life** and **permit longer spans** than steel poles.
- [[Moreover, they give **good outlook**, **require little maintenance** and **have good insulating properties**.
- [[The holes in the poles facilitate the climbing of poles and at the same time reduce the weight of line supports.

RCC poles

- [[The main difficulty with the use of these poles is the **high cost** of transport owing to their heavy weight.
- [[Therefore, such poles are often manufactured at the site in order to avoid heavy cost of transportation.

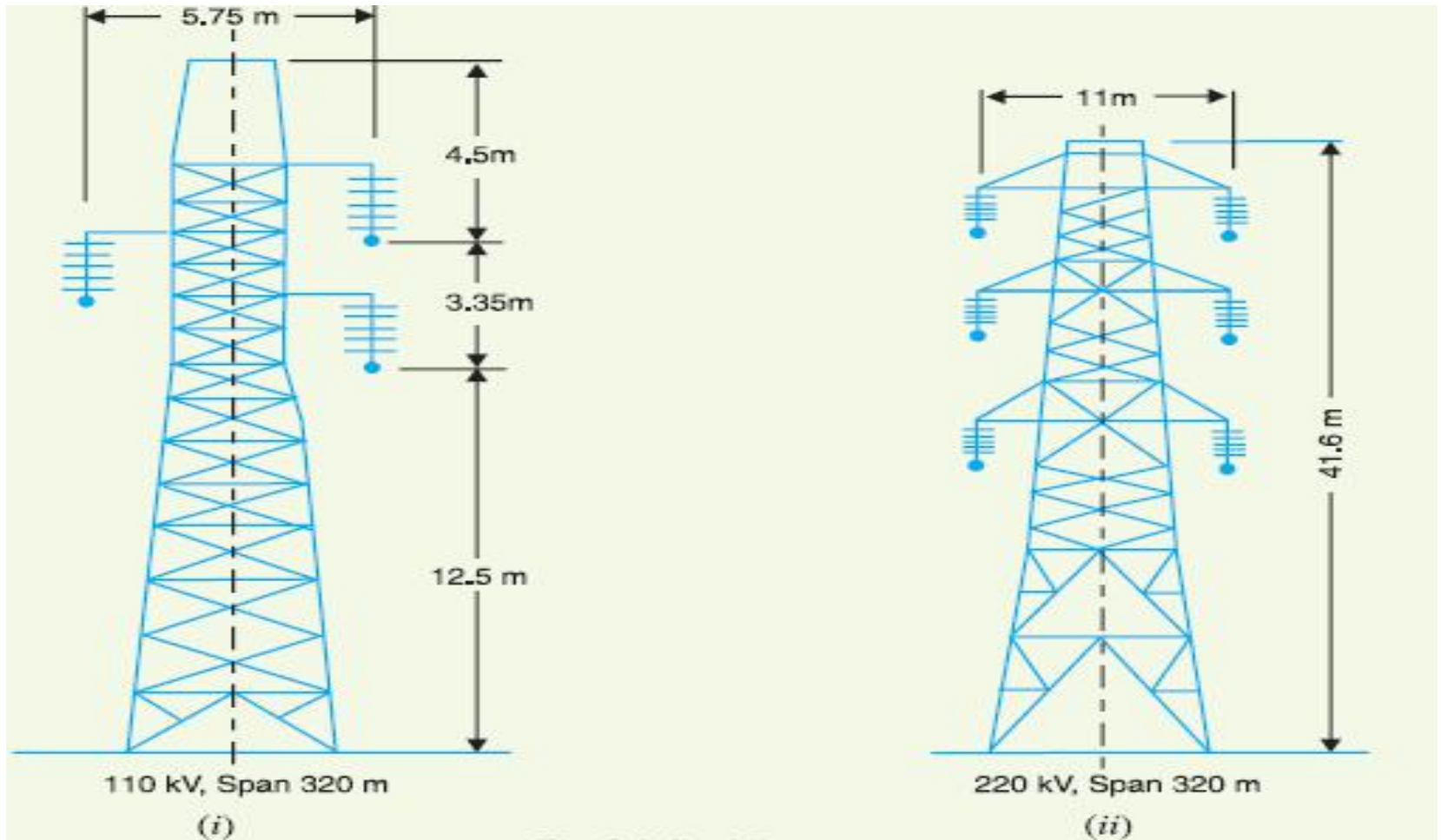


single circuit tower & double circuit tower .

Steel towers

- For **long distance** transmission at **higher voltage**, steel towers are invariably employed.
- Steel towers have **greater mechanical strength**, **longer life**, can withstand most severe climatic conditions and permit the use of **longer spans**.
- The risk of interrupted service due to **broken or punctured insulation** is considerably reduced owing to **longer spans**.

Steel towers



Steel towers

- Tower footings are usually grounded by driving rods into the earth.
 - **This minimizes the lightning troubles as each tower acts as a lightning conductor.**
- The double circuit has the advantage that it ensures continuity of supply.
 - **In case there is breakdown of one circuit, the continuity of supply can be maintained by the other circuit.**

Insulators

The insulators provide necessary insulation between line conductors and supports and thus prevent any leakage current from conductors to earth.

The insulators should have the following properties :

- [[**High mechanical strength** in order to withstand conductor load, wind load etc.
- [[**High electrical resistance** of insulator material in order to avoid leakage currents to earth.
- [[**High relative permittivity** of insulator material in order that dielectric strength is high.

Insulators

- [[**The insulator material should be non-porous, free from impurities and cracks otherwise the permittivity will be lowered.**
- [[**High ratio of puncture strength to flashover.**

The most commonly used material for insulators of overhead line is **porcelain** but **glass, steatite and special composition materials** are also used to a limited extent.

Porcelain is produced by firing at a high temperature a mixture of **kaolin, feldspar and quartz**.

It is stronger mechanically than glass, gives less trouble from leakage and is less effected by changes of temperature

Types of Insulators

Pin type insulators:

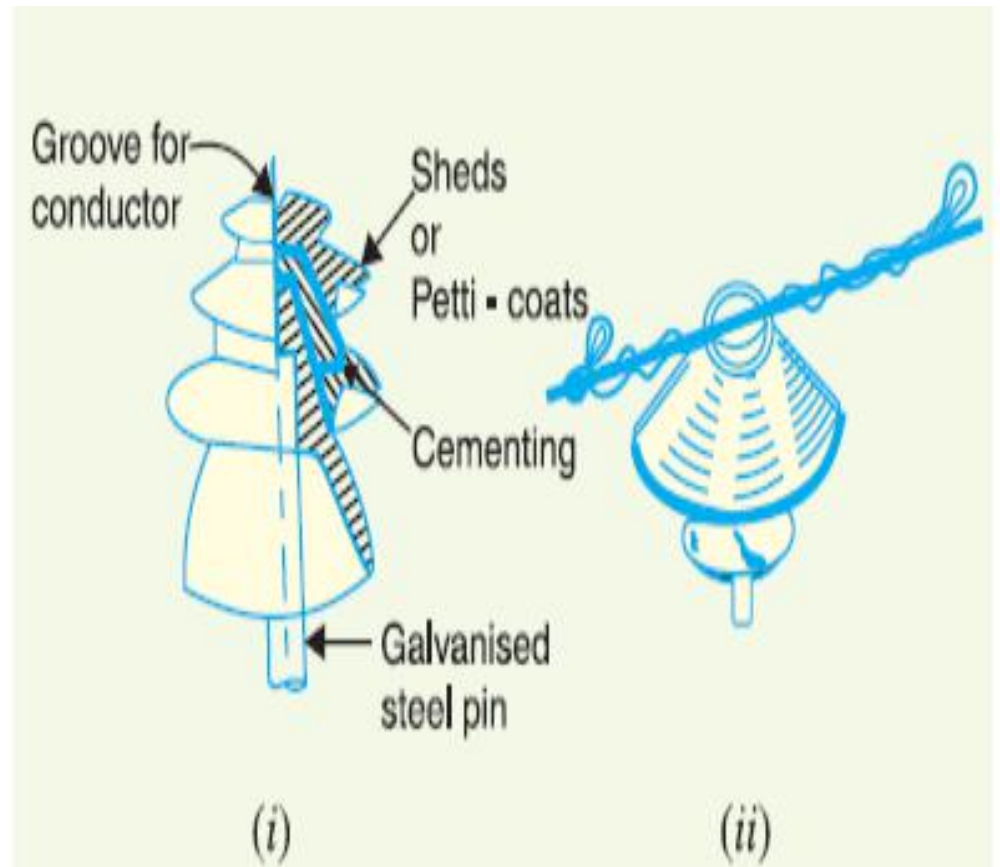
The pin type insulator is secured to the cross-arm on the pole. There is a groove on the upper end of the insulator for housing the conductor. The conductor passes through this groove and is bound by the annealed wire of the same material as the conductor.

- [[Pin type insulators are used for transmission and distribution of electric power at voltages upto **33 kV**.
- [[Beyond operating voltage of **33 kV**, the pin type insulators become too **bulky** and hence **uneconomical**

Pin type insulators



Pin type insulator



Causes of insulator failure

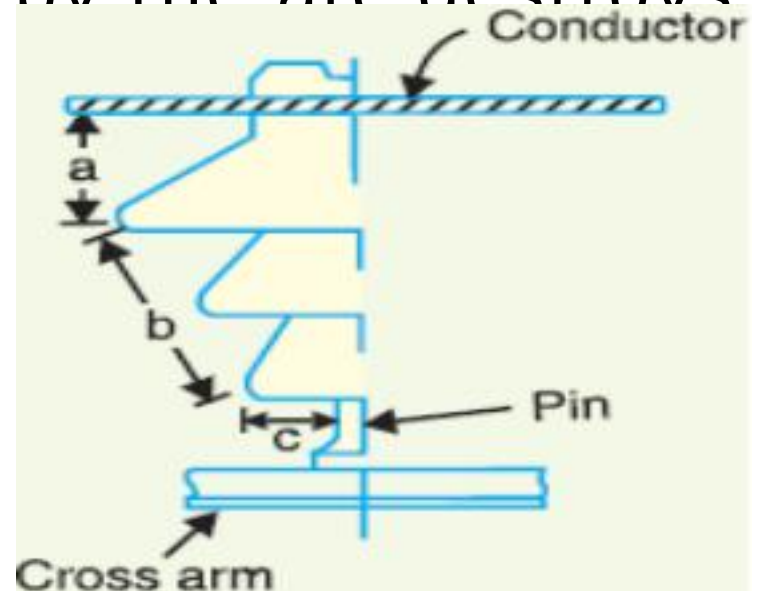
Insulators are required to withstand both mechanical and electrical stresses.

- [[The stress is due to line voltage and may cause the breakdown of the insulator.
- [[The electrical breakdown of the insulator can occur either by flash-over or puncture.

Insulator failure

- In flashover, an arc occurs between the **line conductor** and **insulator pin** (i.e., earth) and the discharge jumps across the *air gaps.
- In case of flash-over, the insulator will continue to act in its proper capacity unless extreme heat produced by the arc destroys the insulator.

Fig. shows the arcing distance (i.e. $a + b + c$) for the insulator.



Insulator failure

- In case of puncture, the discharge occurs from conductor to pin through the body of the insulator.
 - **When such breakdown is involved, the insulator is permanently destroyed due to excessive heat.**
- In practice, sufficient thickness of porcelain is provided in the insulator to avoid puncture by the line voltage.

Insulator failure

- [[The ratio of puncture strength to flashover voltage is known as **safety factor** i.e.,

$$\text{Safety factor of insulator} = \frac{\text{Puncture strength}}{\text{Flash - over voltage}}$$

- [[It is desirable that the value of safety factor is high so that flash-over takes place before the insulator gets punctured.
- [[For pin type insulators, the value of safety factor is about 10.

Suspension type insulators

- [[For **high voltages** (133 kV), it is a usual practice to use **suspension type insulators**.
- [[They consist of a number of **porcelain discs** connected in **series** by metal links in the form of a **string**.
- [[The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross-arm of the tower.

Suspension type insulators

Each unit or disc is designed for low voltage, say 11 kV.

The number of discs in series would depend upon the working voltage.



Suspension insulator

Advantages

- [[Suspension type insulators are cheaper than pin type insulators for voltages beyond 33 kV.
- [[Each unit or disc of suspension type insulator is designed for low voltage, usually 11 kV. Depending upon the working voltage, the desired number of discs can be connected in series.
- [[If any one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.

Advantages

- [[The suspension arrangement provides greater flexibility to the line.

The connection at the cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.

- [[The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.
- [[The suspension type insulators are generally used with steel towers.

As the conductors run below the earthed cross-arm of the tower, therefore, this arrangement provides partial protection from lightning.

Strain insulators

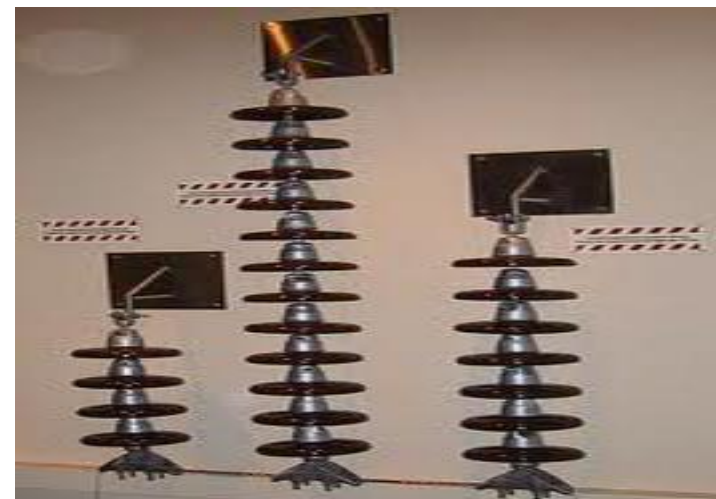
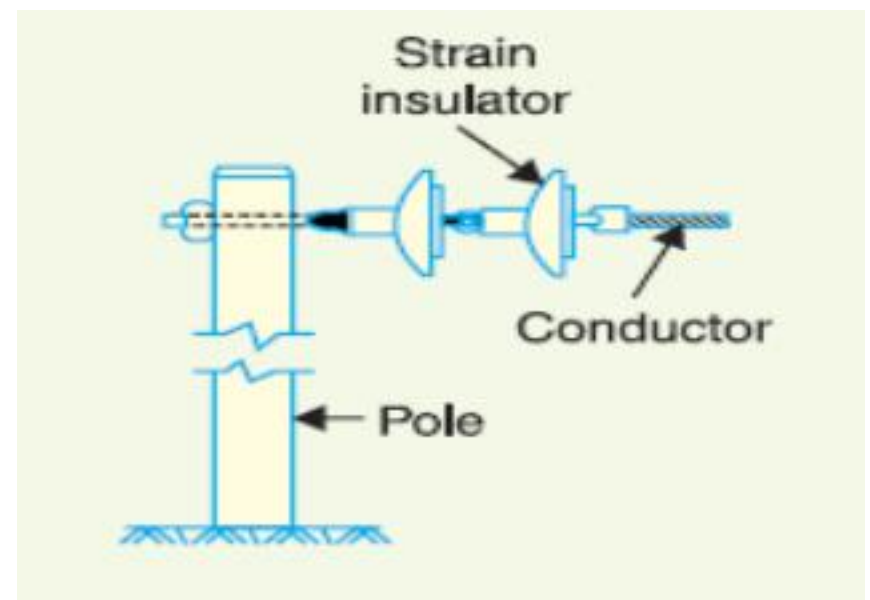
When there is a dead end of the line or there is corner or sharp curve, the line is subjected to greater tension. In order to relieve the line of excessive tension, strain insulators are used.

- [[For low voltage lines (< 11 kV), **shackle insulators** are used as **strain insulators**.
- [[However, for high voltage transmission lines, strain insulator consists of an assembly of suspension insulators

Strain insulators

[[The discs of strain insulators are used in the vertical plane.

[[When the tension in lines is exceedingly high, as at long river spans, two or more strings are used in parallel.

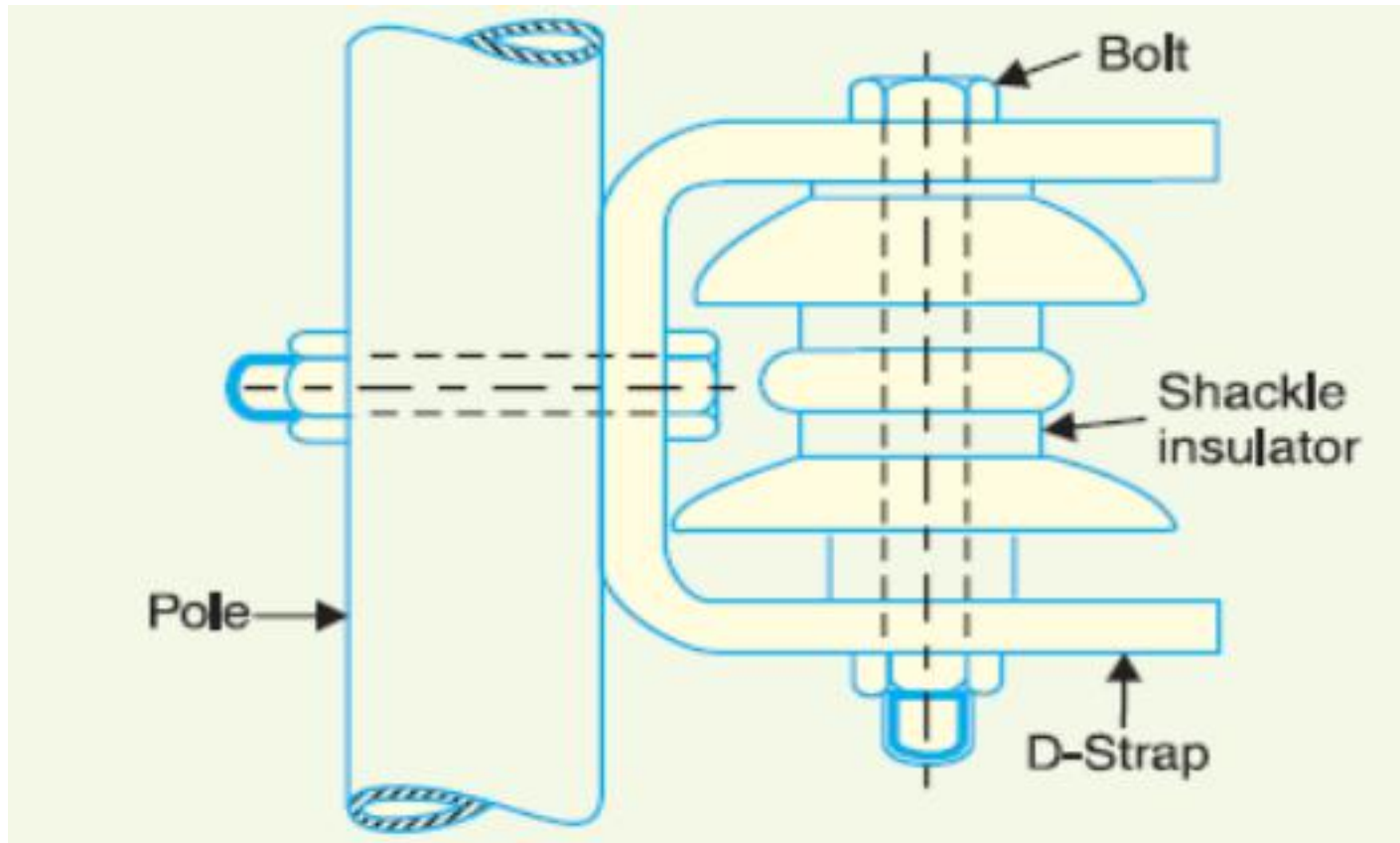


Shackle insulators

In early days, the shackle insulators were used as strain insulators. But now a days, they are frequently used for low voltage distribution lines.

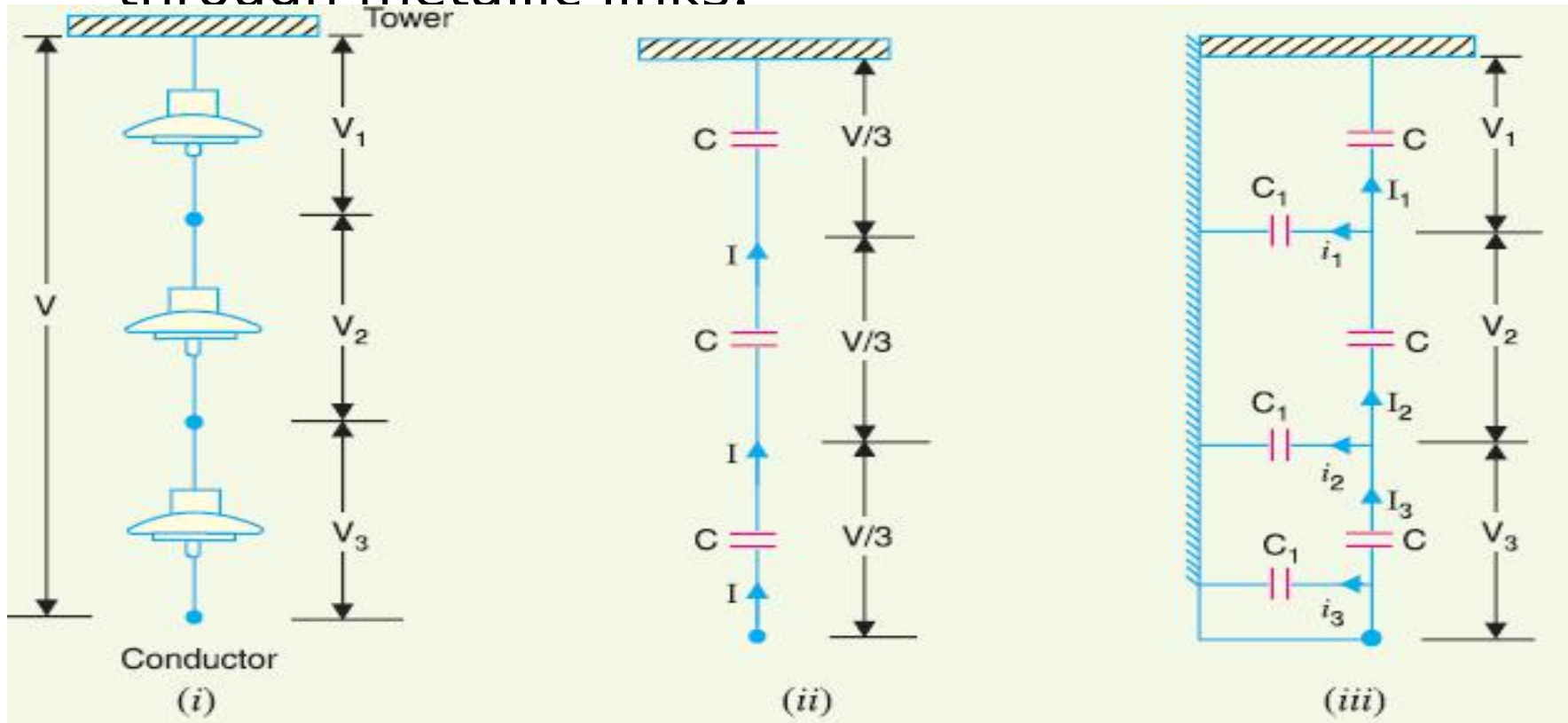
- Such insulators can be used either in a **horizontal position** or in a **vertical position**. They can be directly fixed to the pole with a bolt or to the cross arm.
- The conductor in the groove is fixed with a soft binding wire.

Shackle insulators



Potential Distribution over Suspension Insulator String

A string of suspension insulators consists of a number of porcelain discs connected in series through metallic links.



String of suspension insulators

The following points may be noted regarding the potential distribution over a string of suspension insulators :

- [[The voltage impressed on a string of suspension insulators does not distribute itself uniformly across the individual discs due to the presence of shunt capacitance.
- [[The disc nearest to the conductor has maximum voltage across it. As we move towards the cross-arm, the voltage across each disc goes on decreasing.

String of suspension insulators

- [[The unit nearest to the conductor is under maximum electrical stress and is likely to be punctured. Therefore, means must be provided to equalize the potential across each unit.
- [[If the voltage impressed across the string were d.c., then voltage across each unit would be the same. It is because insulator capacitances are ineffective for d.c.

String Efficiency

The voltage applied across the string of suspension insulators is not uniformly distributed across various units or discs. **The disc nearest to the conductor has much higher potential than the other discs.**

This unequal potential distribution is undesirable and is usually expressed terms of string efficiency.

String Efficiency

- **The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as string efficiency i.e.**

$$\text{String efficiency} = \frac{\text{Voltage across the string}}{n \times \text{Voltage across disc nearest to conductor}}$$

where n = number of discs in the string.

Methods of Improving String Efficiency

- The maximum voltage appears across the insulator nearest to the line conductor and decreases progressively as the cross arm is approached.
- If the insulation of the highest stressed insulator (***i.e. nearest to conductor***) ***breaks down or flash over*** takes place, the breakdown of other units will take place in succession.
- This necessitates to equalise the potential across the various units of the ***string i.e. to improve the string efficiency.***

By using longer cross-arms

- The value of string efficiency depends upon the value of K i.e., ratio of shunt capacitance to mutual capacitance.
- The lesser the value of K , the greater is the string efficiency and more uniform is the voltage distribution. The value of K can be decreased by reducing the shunt capacitance.
- In order to reduce shunt capacitance, the distance of conductor from tower must be increased i.e., longer cross-arms should be used.
 - **However, limitations of cost and strength of tower do not allow the use of very long cross-arms. In practice, $K = 0.1$ is the limit that can be achieved by this method.**

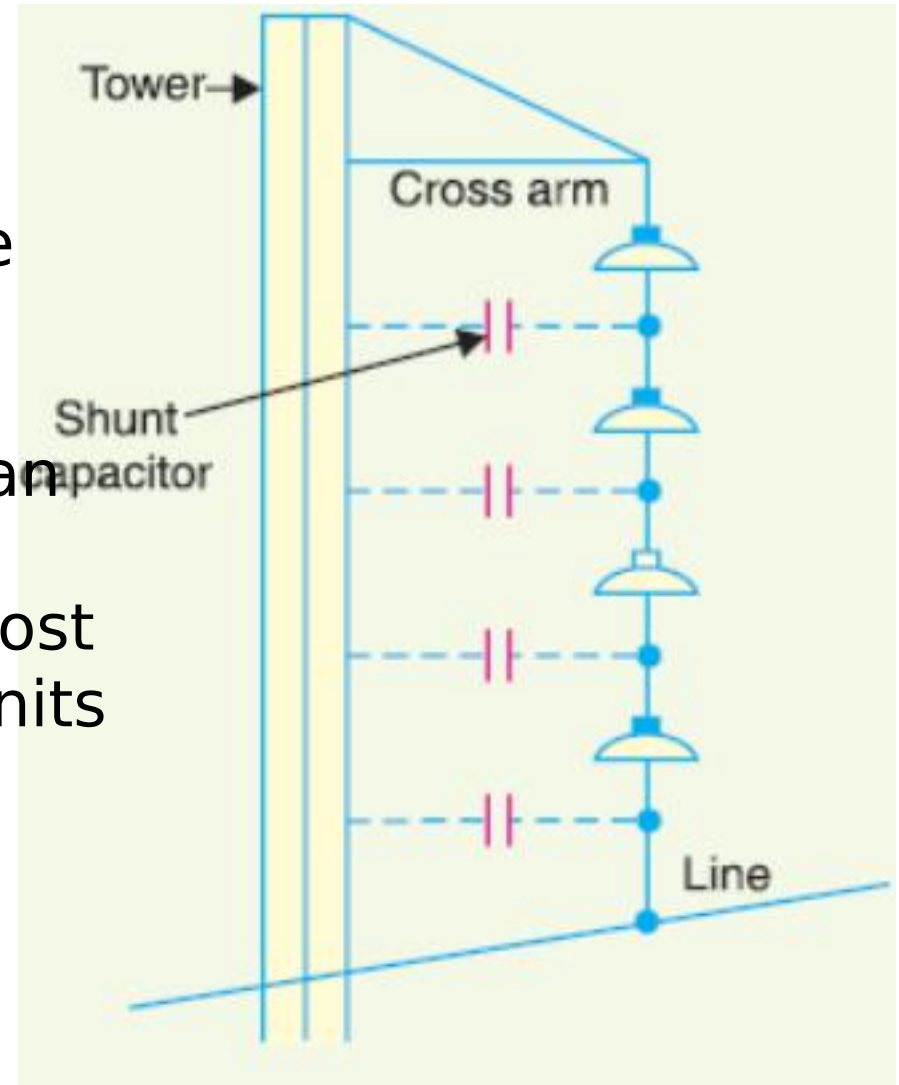
By grading the insulators

- In this method, insulators of different dimensions are so chosen that each has a different capacitance.
- The insulators are capacitance graded i.e.
 - **they are assembled in the string in such a way that the top unit has the minimum capacitance, increasing progressively as the bottom unit (i.e., nearest to conductor) is reached.**
 - **Since voltage is inversely proportional to capacitance, this method tends to equalize the potential distribution across the units in the string.**

By grading the insulators

This method has the disadvantage that a large number of different-sized insulators are required.

However, good results can be obtained by using standard insulators for most of the string and larger units for that near to the line conductor.



By using a guard ring.

- The potential across each unit in a string can be equalised by using a guard ring which is a metal ring electrically connected to the conductor and surrounding the bottom insulator.
- The guard ring introduces capacitance between metal fittings and the line conductor.
- The guard ring is contoured in such a way that shunt capacitance currents i_1, i_2 etc. are equal to metal fitting line capacitance currents i'_1, i'_2 etc.
- The result is that same charging current I flows through each unit of string. Consequently, there will be uniform potential distribution across the units.

Important Points

While solving problems relating to string efficiency, the following points must be kept in mind:

- (i) The maximum voltage appears across the disc nearest to the conductor (i.e., line conductor).
- (ii) The voltage across the string is equal to phase voltage i.e., Voltage across string = Voltage between line and earth = Phase Voltage
- (iii) Line Voltage = $3 \times$ Voltage across string