7.2 Material properties, clearances and tower configurations

7.2.1 Material properties

Classification of steel

The general practice with reference to the quality of steel is to specify the use of steel for tower members, although some authorities have instead specified the use of steel manufactured by either the open hearth or electric furnace process for tower members, although some athorities have instead specified the use of steel manufactured by either the open hearth or electric furnace process. The usual standards specified are ASTM A-7, BSS 15, and German Steel Standard St 37. IS: 226-1975, Specification for structural Steel (Revised), is currently adopted in India.

In so far as standard structural steel is concerned, reference to IS: 226-1975 shows that

Steel manufactured by the open-hearth, electric, basic oxygen or a combination of the processes is acceptable for structural use and that in case any other process is employed, prior approval of the purchaser should be obtained.

In addition to standard structural steel (symbol A), high tensile steel conforming to IS: 226-1975 may be used for transmission line towers for greater economy. The chemical composition and mechanical properties of steel covered by IS: 226-1975 for structural steel and IS: 961-1975 for high tensile steel are shown in Tables 7.1 to 7.4.

Suitability for welding

The standard structural mild steel is suitable for welding, provided the thickness of the material does not exceed 20mm. When the thickness exceeds 20mm, special precautions such as double Vee shaping and cover plates may be required.

St 58-HT is intended for use in structures where fabrication is done by methods other than welding. St 55-HTw is used where welding is employed for fabrication.

In the past, transmission line structures in India were supplied by firms like Blaw Knox, British Insulated Callender Cables (BICC), etc. from the United Kingdom. Later, towers from SAE, Italy, were employed for some of the transmission lines under the Damodar Valley Corporation. In recent times, steel from the USSR and some other East European countries were partly used in the transmission line industry. Currently, steel conforming g to IS: 961 and IS: 226 and manufactured in the country are almost exclusively use for towers.

A comparison of mechanical properties of standard and high tensile steels conforming to national standards of the countries mentioned above is given in Table 7.5.

Properties of structural steel

A typical stress-strain curve of mild steel is shown in Figure 7.1. Steels for structural use are classified as: Standard quality, high strength low carbon steel and alloy steel. The various properties of steel will now be briefly discussed.

Behavior up to elastic limit

Table 7.1 Chemical composition

Constituent	Percent (Max)		
	Mild steel	High tensile steel	
		St 58-HT	St 55-HT
Carbon for thickness/dia 20mm and below for thickness/dia over 20mm	0.23 0.25	0.27	0.20
Sulphur	0.055	0.055	0.055
Phosphorus	0.055	0.055	0.055

Table 7.2 Mechanical properties of mild steel

Class of steel product	Nomial thickness/diameter mm	Tensile strength kgf/mm2	Yield stress, Min. kgr/mm2	Percentage elongation Min.
Plates, sections (angles, tees, beams, channels, etc.) and flats	$6 \leq X \leq 20$	42-54	26.0	23
	$20 < X \leq 40$	42-54	24.0	23
	$40 < x$	42-54	23.0	23

Up to a well-defined point, steel behaves as a perfectly elastic material. Removal of stress at levels below the yield stress causes the material to regain its unstressed dimension. Figure 7.2 shows typical stress-strain curves for mild steel and high tensile steel. Mild steel has a definite yield point unlike the high-tensile steel; in the latter case, the yield point is determined by using 0.2 percent offset[1].

Table 7.3 Mechanical properties of high tensile steel St 58-HT

Class of steel product	Nomial thickness/diameter mm	Tensile strength kgf/mm2	Yield stress, Min. kgr/mm2	Percentage elongation Min.
Plates, sections, flats and bars	$6 \leq X \leq 28$	58	36	20
	$28 < X \leq 45$	58	35	20
	$45 < X \leq 63$	58	33	20
	63<x	55	30	20

Table 7.4 Mechanical properties of high tensile steel St 55-HTw

Class of steel product	Nomial thickness/diameter mm	Tensile strength kgf/mm2	Yield stress, Min. kgr/mm2	Percentage elongation Min.
Plates, sections, flats and bars	$6 < X \leq 16$	55	36	20
	$16 < X \leq 32$	55	35	20
	$32 < X \leq 63$	52	34	20
	$63 < X$	50	29	20

Table 7.5 Comparison of mechanical properties of standard and high tensile steels

Sl. No.	Origin	High tensile steel				Standard steel			
		No. of standard	Ultimate tensile stress kg/mm2	Minimum yield stress kg/mm2	Minimum elongation %	No. of standard	Ultimate tensile stress kg/mm2	Minimum yield stress kg/mm2	Minimum elongation %
1	India	IS : 961 1975	58	36	20	IS :226 1975	42-54	23-26	23
2	USSR	CT5 20L2	50-62	28	15-21	CT4	45-52	26	19-25
3	Italy	UNI	50-60	34-38	22	UNI	37-45	24-28	25
4	UK	BS : 548 1934	58-68	30-36	14	BS : 15 1948	44-52	23.2-24	16-20

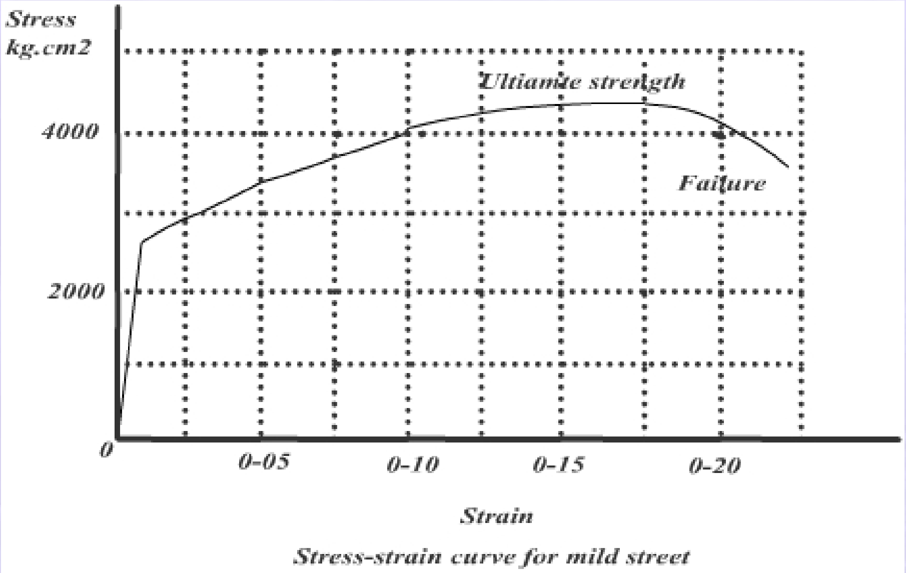


Figure 7.1 Stress-strain curve for mild steel

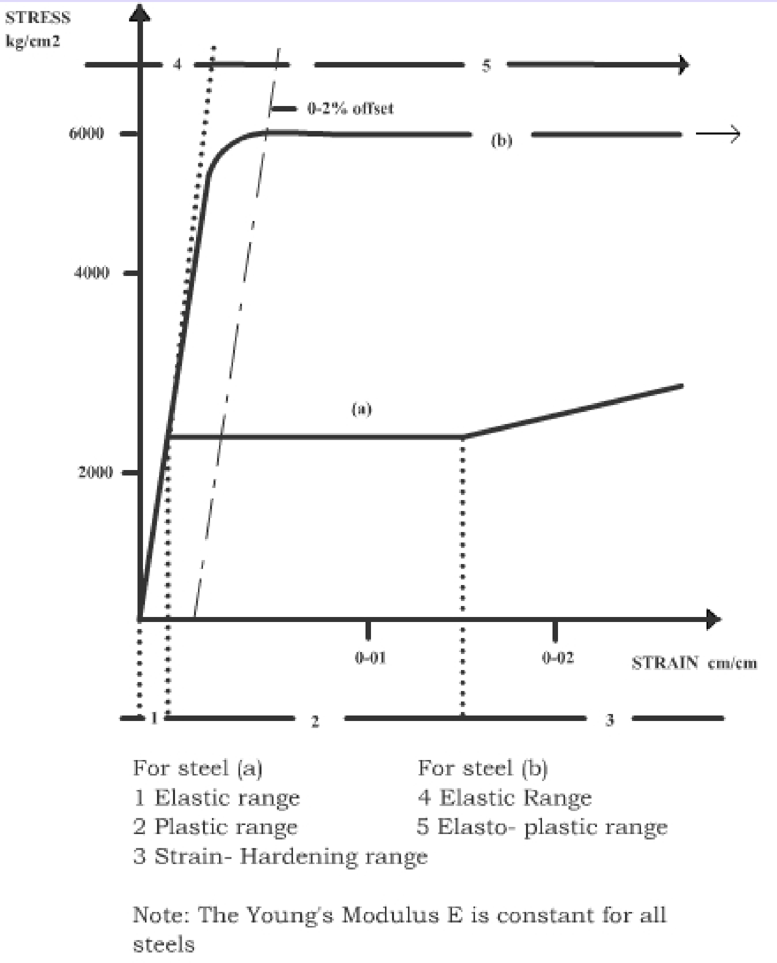


Figure 7.2 Stress-strain curves for various types of steel

Tensile strength

The applied stress required to cause failure is greater than the yield stress and is generally defined as tensile strength.

Ductility

This is important property of steel which enables it to undergo large deformations after yield point without fracture.

Design span lengths

In transmission line calculations, the following terms are commonly used

1. Basic or normal span
2. Ruling oe equivalent span
3. Average span
4. Wind span
5. Weight span

Table 7.6a properties of SAIL-MA steels (kg/cm^2)

	Type of steel			
	IS:226 Mild steel	SAIL-MA 300	SAIL- MA 350	SAIL-MA 410
Yield strength	2,600	3,100	3,600	4,200
Allowable stress in tension	1,500	1,850	2,125	2,450
Allowable stress in bending section other than palte girders	1,650	1,950	2,285	2,650
Allowable stress in shear	1,100	1,350	1,575	1,800
Allowable stress in bearing	1,890	2,300	2,675	3,100

Table 7.6b Allowable stresses of SAIL-MA steel in axial copression (kg/cm^2)

L/r	Type of steel			
	IS:226 Mild steel	SAIL-MA 300	SAIL- MA 350	SAIL-MA 410
0	1,250	1,537	1,785	2,083
20	1,239	1,520	1,762	2,055
40	1,203	1,464	1,685	1,946
60	1,130	1,317	1,522	1,710
80	1,007	1,155	1,255	1,352
100	840	920	960	1,005

Basic or normal span

The normal span is tha most economic span for which the line is designed over level ground, so that the requisite ground clearance is obtained at the maximum specified temperature

Ruling span

The ruling span is the assumed design span that will produce, between dead ends, the best average tension throughout a line of varying span lengths with changes in temperature and loading. It is the weighted average of the varying span lengths, calculated by the formula:

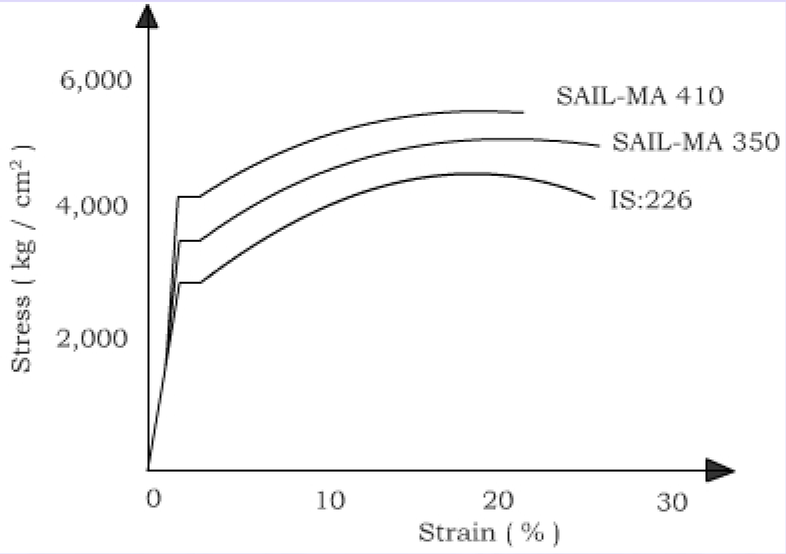


Figure 7.3 Stress strain curves of SAIL-MA 350 and 410 and IS: 226 steels

$$\text{Ruling span} = \sqrt{\frac{l_1^3 + l_2^3 + \ldots . l_n^3}{l_1 + l_2 + l_n}}$$

Where l_1, l_2 ... l_n are the first, second and last span lengths in sections. The erection tension for any line section is calculated for this hypothetical span.

Tower spotting on the profile is done by means of a sag template, which is based on the ruling span. Therefore, this span must be determined before the template can be made.

The ruling span is then used to calculate the horizontal component of tension, which is to be applied to all the spans between the anchor points

Average span

The average span is the mean span length between dead ends. It is assumed that the conductor is freely suspended such that each individual span reacts to changes in tension as a single average span. All sag and tension calculations are carried out for the average span, on this assumption.

Wind span

The wind span is that on which the wind is assumed to act transversely on the conductors and is taken as half the sum of the two spans, adjacent to the support (Figure 7.4). In order to take full advantage of towers located on elevated ground, it is usual to allow a wind span of 10 to 15 percent in excess of the normal span. This additional strength can be used in taking a samll angle of deviation on an intermediate tower, where the actual wind span is less than the design wind span. The angle of deviation to be taken in such cases is approximately given by:

$$\theta = \frac{wl}{\pi T} x180$$

Where w = total ind load per unit run of span length of all conductor carried by the tower,

l = difference between the wind span used for design and the actual wind span, and

T = the total maximum working tension of all conductors carried by the tower.

Weight span

The weight span is the horizontal distance between the lowest point of the conductors, on the two spans adjacent to the tower (figure 7.4). The lowest point is defined as the point at which the tangent to the sag curve, or to the sag curve produced, is horizontal. The weight span is used in the design of cross-arms.

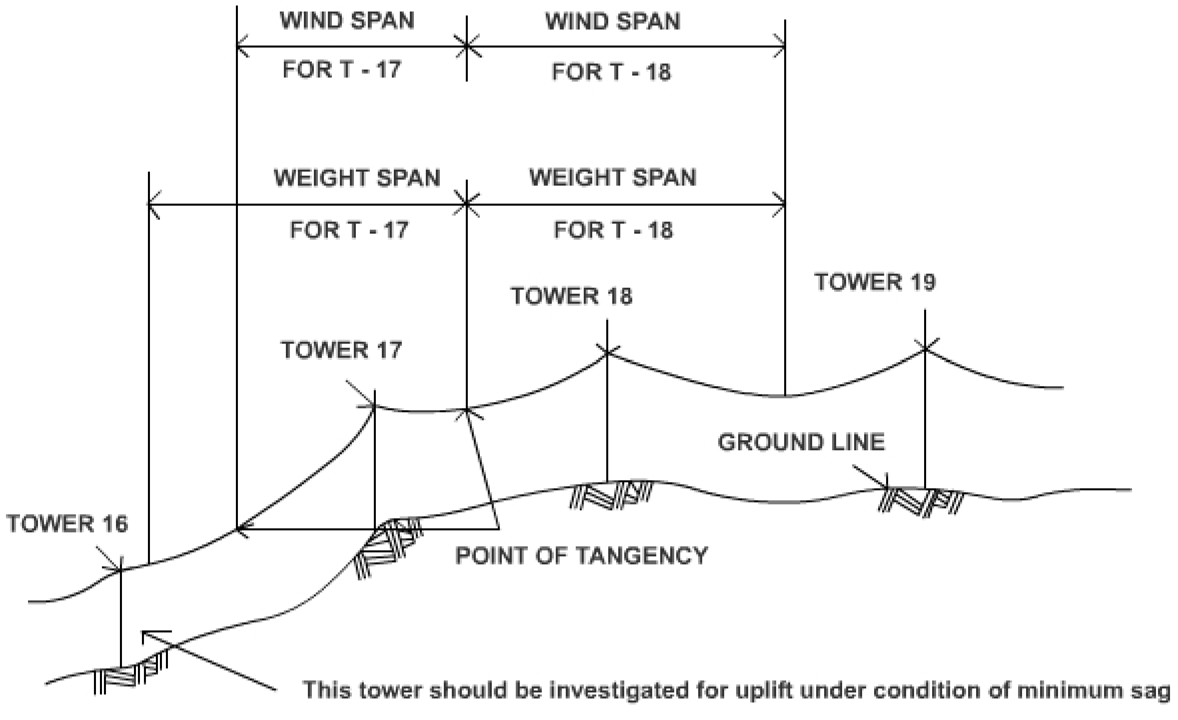


Figure 7.4 Wind span and weight span

7.2.2 Tower configurations

Depending upon the requirements of the transmission system, various line configurations have to be considered - ranging from single circuit horizontal to double circuit vertical structures and with single or V strings in all phases, as well as any combination of these.

The configuration of a transmission line tower depends on:

1. the length of the insulator assembly

2. the minimum clearances to be maintained between conductors, and between conductors and tower

3. the location of ground wire or wires with respect to the outermost conductor

4. the mid-span clearance required from considerations of the dynamic behaviour of conductors and lightning protection of the line

5. the minimum clearance of the lowest conductor above ground level.

The tower outline is determined essentially by three factors: tower height, base width, and top hamper width.

Determination of tower weight

The factors governing the height of the tower are:

1. Minimum permissible ground clearance (h_1)
2. Maximum sag (h_2)
3. Vertical spacing between conductors (h_3)
4. Vertical clearance between ground wire and top conductor (h_4)

Thus the total height of the tower is given by

$$H = h_1 + h_2 + h_3 + h_4$$

in the case of double circuit tower with vertical configuration of conductors (figure 7.5)

The calculation of sags (h_2) is covered later. The principles and practices in regard to the determination of ground clearance and spacings between conductors and between the ground wire and top conductor will now be outlined.

Minimum permissible ground clearance

For safety considerations, power conductors along the route of the transmission line should maintain requite clearance to ground in open country, national highways, rivers, railways tracks, telecommunication lines, other power lines, etc.., as laid down in the Indian Electricity Rules, or Standards or codes of practice in vogue.

Rule 77(4) of the Indian Electricity Rules, 1956, stipulates the following clearances above ground of the lowest point of the conductor:

For extra- high voltage lines, the clearance above ground shall not be less than 5.182 metres plus 0.305 metres for every 33,000 volts or part there of by which the voltage of the line exceeds 33,000 volts.

Accordingly, the values for the various voltages, 66kV to 400 kV, are:

66kV - 5.49m
132kV - 6.10m
220kV - 7.01m
400kV - 8.84m

The above clearances are applicable to transmission lines running in open country.

Power line crossings

In crossings over rivers, telecommunication lines, railway tracks, etc.., the following clearances are maintained:

1. Crossing over rivers
   a. Over rivers which are not navigable. The minimum clearance of conductor is specified as 3.05 over maximum flood level.

   b. Over navigable rivers: Clearances are fixed in relation to the tallest mast, in consultation with the concerned navigation authorities.

2. Crossing over telecommunication lines. The minimum clearances between the conductors of a power line and telecommunication wires are

66 kV - 2,440mm
132 kV - 2,740mm
220 kV - 3,050mm
400 kV - 4,880mm

3. Crossing over railway tracks: The minimum height over the rail level, of the lowest portion of any conductor under conditions of maximum sag, as stipulated in the regulations for Electrical Crossings of Railway Tracks, 1963, is given in Table 7.7.

4. Between power lines
   a. Between power lines L.T up to 66 kV - and 66 kV line 2.44m
   b. Between power lines L.T up to 132 kV - and 132kV line 2.75m
   c. Between power lines L.T up to 220kV - and 220kV line 4.55m

d. Between power lines L.T up to 400kV - and 400kV line 6.00m(Tentative)

Spacing of conductors

Considerable differences are found in the conductor spacings adopted in different countries and on different transmission systems in the same country.

Table 7.7 Minimum height of power conductors over railway tracks

1. For unelectrified tracks or tracks electrified on 1,500 volts D.C. system

	Broad gauge		Metre and Narrow gauge	
	inside station limits	outside station limits	inside station limits	outside
66 kV	10.3	7.9	9.1	6.7
132 kV	10.9	8.5	9.8	7.3
220 kV	11.2	8.8	10.0	7.6
400 kV	13.6	11.2	12.4	10.0

2. Tracks electrified on 25 kV A.C. system

	for Broad, Metre and Narrow gauge	
	Inside station limits	Outside station limits
66 kV	13.0	11.0
132kV	14.0	12.0
220 kV	15.3	13.3
400 kV	16.3	14.3

The spacing of conductors is determined by considerations which are partly mechanical. The material and diameter of the conductors should also be considered when deciding the spacing, because a smaller conductor, especially if made of aluminium, having a small weight in relation to the area presented to a crosswind, will swing out of the vertical plane father than a conductor of large cross-section. Usually conductors will swing synchronously (in phase) with the wind, but with long spans and small wires, there is always a possibility of the conductors swinging non-synchronously, and the size of the conductor and the maximum sag at the centre of the span are factors which should be taken in to account in determining the distance apart at which they should be strung.

There are a number of empirical formulae in use, deduced from spacings which have successfully operated in practice while research continues on the minimum spacings which could be employed.

The following formulae are in general use:

1. Mecomb's formula

Spacing in cm = 0.3048V + 4.010 $\frac{D}{w}\sqrt{S}$

Where V = Voltage in kV,
D = Conductor diameter in cm,
S = sag in cm, and
W = Weight of conductor in kg/m.

2. VDE (verbandes Deutscher electrotechnischer) formula

Spacing in cm = $7.5\sqrt{S} + \frac{V^2}{200}$

where S= sag in cm, and V= Voltage in kV.

3. Still's formula

Distance between conductors (cm)

$$= 50.8 + 1.8.14\,V + \left[\frac{l}{27.8}\right]^2$$

Where l = average span length in metres ,and V = line voltage between conductors in kV.

The formula may be used as a guide in arriving at a suitable value for the horizontal spacing for any line voltage and for the value spans between 60 and 335 meters

4. NESC, USA formula

Horizontal spacing in cm

$$= A + 3.681\sqrt{S + \frac{L}{\sqrt{2}}}$$

Where A= 0.762 cm per kV line voltage S = Sag in cm, and

L = Length of insulator string in cm

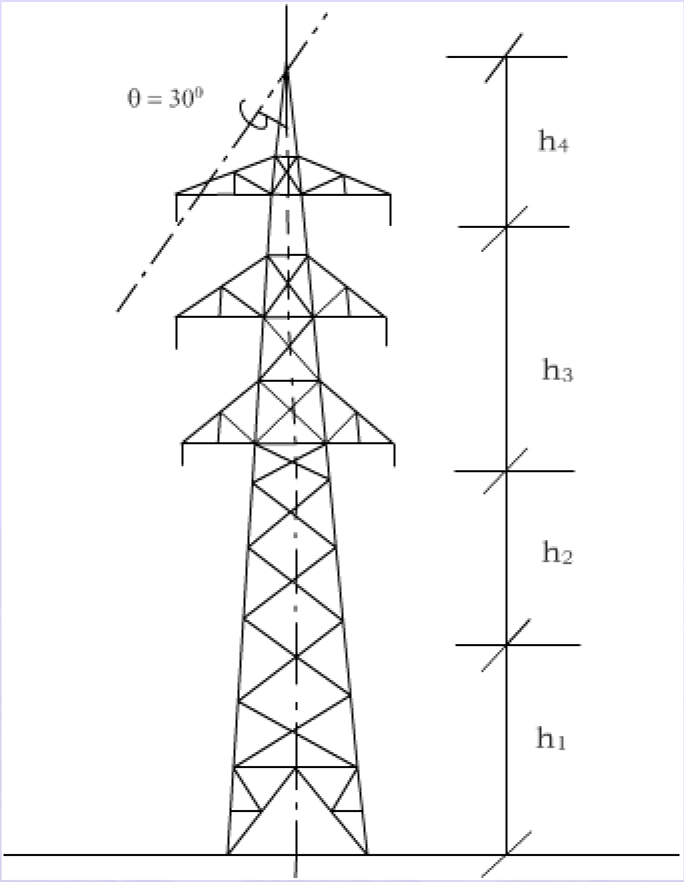


Figure 7.5 Determination of the tower height

5. Swedish formula

Spacing in cm = 6.5 $\sqrt{S}$ + 0.7E

Where S = Sag in cm, and E = Line voltage in kV

6. French formula

Spacing in cm = $8\sqrt{S+L}+\frac{E}{1.5}$

Where S = Sag in cm, L = Length of insulator string in cm, and

E = Line voltage in kV.

Offset of conductors (under ice-loading conditions)

The jump of the conductor, resulting from ice dropping off one span of an ice-covered line, has been the cause of many serious outages on long-span lines where conductors are arranged in the same vertical plane. The 'sleet jump' has been practically cleared up by horizontally offsetting the conductors. Apparently, the conductor jumps in practically a vertical plane, and this is true if no wind is blowing, in which cases all forces and reactions are in a vertical plane. In double circuit vertical configuration, the middle conductors are generally offset in accordance with the following formula:

$$\text{Offset in cm} = 60 + \text{Span in cm} / 400$$

The spacing commonly adopted on typical transmission lines in India are given in the table

Vertical clearance between ground wire and top conductor

This is governed by the angle of shielding, ie., the angle which the line joining the ground wire and the outermost conductor makes with the vertical, required for the interruption of direct lightning strokes at the ground and the minimum midspan clearance between the ground wire and the top power conductor. The shield angle varies from about 25^{o} to 30^{o}, depending on the configuration of conductors and the number of ground wires (one or two) provided.

Table 7.8 Vertical and horizontal spacings between conductors

Type of tower	Vertical spacing between conductors (mm)	horizontal spacing between conductors (mm)
1. 66 kV: Single circuit		
A(0-2^o)	1,030	4,040
B(2-30^o)	1,030	4,270
C(30-60^o)	1,220	4,880
2. 66 kV: Double circuit		
A(0-2^o)	2,170	4,270
B(2-30^o)	2,060	4,880
C(30-60^o)	2,440	6,000
3. 132 kV: Single circuit		
A(0-2^o)	4,200	7,140
B(2-15^o)	4,200	6,290
C(15-30^o)	4,200	7,150
D(30-60^o)	4,200	8,820
4. 132 kV: Double circuit		
A(0-2^o)	3,965	7,020
B(2-15^o)	3,965	7,320
C(15-30^o)	3,965	7,320
D(30-60^o)	4,270	8,540
5. 220 kV: Single circuit		
A(0-2^o)	5,200	8,500
B(2-15^o)	5,250	10,500
C(15-30^o)	6,700	12,600
D(30-60^o)	7,800	14,000
6. 220 kV: double circuit		
A(0-2^o)	5,200	9,900
B(2-15^o)	5,200	10,100
C(15-30^o)	5,200	10,500
D(30-60^o)	6,750	12,600
7. 400 kV: Single circuit	horizontal configuration	
A(0-2^o)	7,800	12,760
B(2-15^o)	7,800	12,640
C(15-30^o)	7,800	14,000
D(30-60^o)	8,100	16,200

Determination of base width

The base width at the concrete level is the distance between the centre of gravity at one corner leg and the centre of gravity of the adjacent corner leg. There is a particular base width which gives the minimum total cost of the tower and foundations

Ryle has given the following formula for a preliminary determination of the economic base width:

$$B = 0.42\sqrt{M} \text{ or } 0.013\sqrt{m}$$

Where B = Base width in meters,

M = Overturning moment about the ground level in tonne-meters, and

M= Overturning moment about the ground level in kg.meters.

The ratio of base width to total tower height for most towers is generally about one-fifth to one-tenth from large-angle towers to tangent towers.

The following equations have been suggested9,based on the best fit straight line relationship between the base width B and $\sqrt{M}$

$$B = 0.0782\sqrt{M} + 1.0$$
$$B = 0.0691\sqrt{M} + 0.7$$

Equations are for suspension and angle towers respectively.

It should be noted that Ryle's formula is intended for use with actual external loads acting on the tower whereas the formulae in Equations take into account a factor of safety of 2.0.

Narrow-base towers are commonly used in Western Europe, especially Germany, mainly from way-leave considerations. British and American practices generally favor the wide base type of design, for which the total cost, of tower and foundations is a minimum. In the USA, a continuous wide strip of land called the ‘right of way’ has usually to be acquired along the line route. In Great Britain, the payments made for individual tower way-leaves are generally reasonably small and not greatly affected by tower base dimensions. Therefore, it has been possible to adopt a truly economical base width in both the United States and Great Britain.

A wider taper in the tower base reduces the foundation loading and costs but increases the cost of the tower and site. A minimum cost which occurs with a tower width, is greater with bad soil than with good soil. A considerable saving in foundation costs results from the use of towers with only three legs, the tower being of triangular section throughout its height. This form of construction entails tubular legs or special angle sections. The three-footing anchorage has further advantages, e.g., greater accessibility of the soil underneath the tower when the land is cultivated.

Determination of top hamper width

The width at top hamper is the width of the tower at the level of the lower cross-arm in the case of barrel type of towers (in double circuit towers it may be at the middle level) and waist line in the case of towers with horizontal configuration of conductors.

The following parameters are considered while determining the width of the tower at the top bend line:

1. Horizontal spacing between conductors based on the midspan flashover between the power conductor under the severest wind and galloping conditions and the electrical clearance of the line conductor to tower steel work.

2. The sloe of the legs should be such that the corner members intersect as near the center of gravity (CG) of the loads as possible. Then the braces will be least loaded. Three cases are possible depending upon the relative position of the CG of the loads and intersection of the tower legs as shown in Figure 7.6.

In Case (1) the entire shear is taken up by the legs and the bracings do not carry any stress. Case (2) shows a condition in which the resultant of all loads O' is below the inter-section of tower legs O. The shear here is shared between legs and bracings which is a desirable requirement for an economical tower design. In Case (3), the legs have to withstand greater forces than in cases (1) and (2) because the legs intersect below the center of gravity of the loads acting on the tower. This outline is uneconomical.

The top hamper width is generally found to be about one-third of the base width for tangent and light angle towers and about 1.35 of the base width for medium and heavy angle towers. For horizontal configurations, the width at the waistline is, however, found to vary from 1/1.5 to ½.5 of the base width.

7.2.3 Types of towers

Classification according to number of circuits

The majorities of high voltage double circuit transmission lines employ a vertical or near vertical configuration of conductors and single circuit transmission lines a triangular arrangement of conductors. Single circuit lines, particularly at 400kv and above, generally employ a horizontal arrangement of conductors. The arrangement of conductors and ground wires in this configuration is shown in Figure7.8

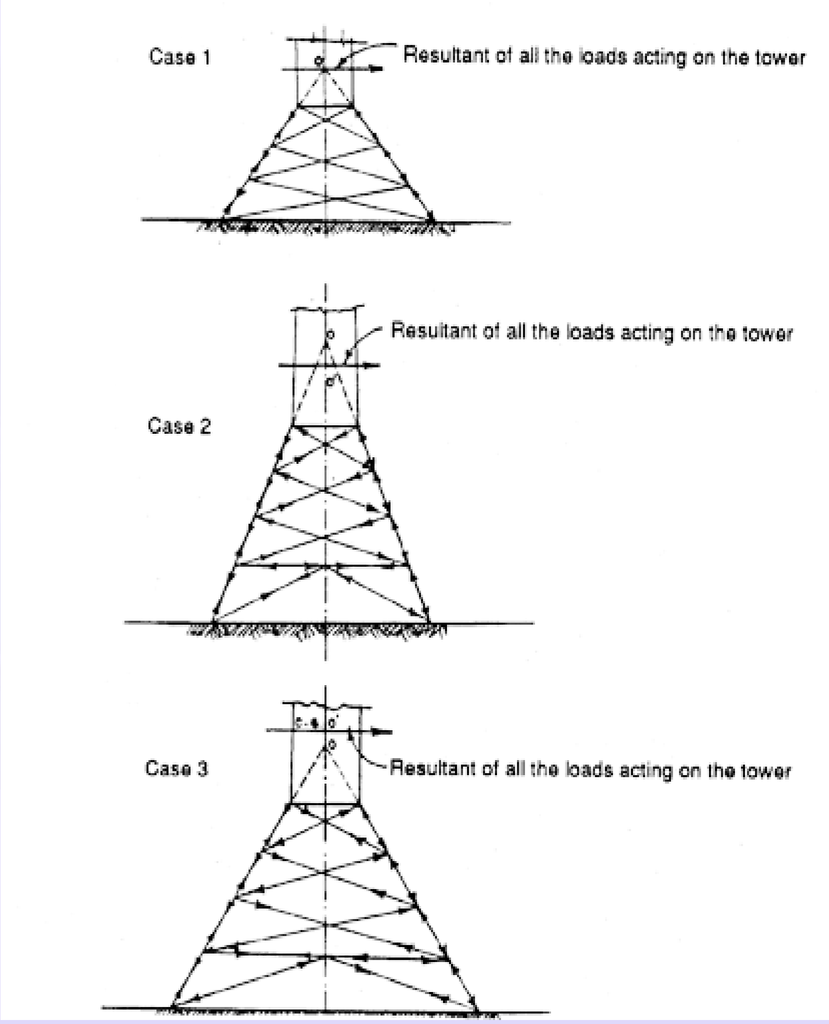


Figure 7.6 Relative position of C.G of loads intersection of tower legs

The number of ground wires used on the line depends on the isoceraunic level (number of thunderstorm days/hours per year) of the area, importance of the line, and the angle of coverage desired. Single circuit line using horizontal configuration generally employ tow ground wires, due to the comparative width of the configuration; whereas lines using vertical and offset arrangements more often utilize one ground wire except on higher voltage lines of 400 kv and above, where it is usually found advantageous to string tow ground wires, as the phase to phase spacing of conductors would require an excessively high positioning of ground wire to give adequate coverage.

Classification according to use

Towers are classified according to their use independent of the number of conductors they support.

A tower has to withstand the loadings ranging from straight runs up to varying angles and dead ends. To simplify the designs and ensure an overall economy in first cost and maintenance, tower designs are generally confined to a few standard types as follows.

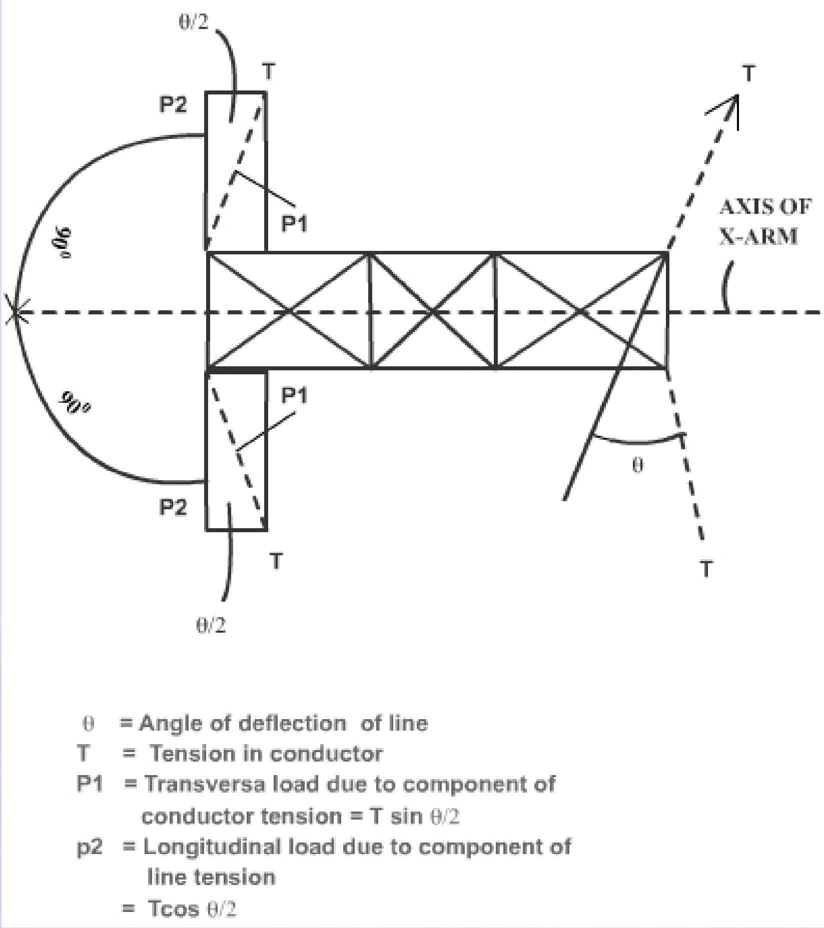


Figure 7.7 Orientation of tower in an angle

Tangent suspension towers

Suspension towers are used primarily on tangents but often are designed to withstand angles in the line up to tow degrees or higher in addition to the wind, ice, and broken-conductor loads. If the transmission line traverses relatively flat, featureless terrain, 90 percent of the line may be composed of this type of tower. Thus the design of tangent tower provides the greatest opportunity for the structural engineer to minimize the total weight of steel required.

Angle towers

Angle towers, sometimes called semi-anchor towers, are used where the line makes a horizontal angle greater than two degrees (Figure). As they must resist a transverse load from the components of the line tension induced by this angle, in addition to the usual wind, ice and broken conductor loads, they are necessarily heavier than suspension towers. Unless restricted by site conditions, or influenced by conductor tensions, angle towers should be located so that the axis of the cross-arms bisects, the angle formed by the conductors.

Theoretically, different line angles require different towers, but for economy there are a limiting number of different towers which should be used. This number is a function of all the factors which make up the total erected cost of a tower line. However, experience has shown that the following angle towers are generally suitable for most of the lines:

1. Light angle - 2 to 15^{o} line deviation
2. Medium angle - 15 to 30^{o} line deviation
3. Heavy angle - 30 to 60^{o} line deviation

(And dead end)

While the angles of line deviation are for the normal span, the span may be increased up to an optimum limit by reducing the angle of line deviation and vice versa. IS: 802(Part I)-1977 also recommends the above classification.

The loadings on a tower in the case of a 60^{0} angle condition and dead-end condition are almost the same. As the numbers of locations at which 60^{0} angle towers and dead-end towers are required are comparatively few, it is economical to design the heavy angle towers both for the 60^0 angle condition and dead-end condition, whichever is more stringent for each individual structural member.

For each type of tower, the upper limit of the angle range is designed for the same basic span as the tangent tower, so that a decreased angle can be accommodated with an increased span or vice versa.

In India, then angle towers are generally provided with tension insulator strings.

Appreciable economies can be affected by having the light angle towers (2 to 15^0) with suspension insulators, as this will result in lighter tower designs due to reduced longitudinal loads to which the tower would be subjected under broken-wire conditions because of the swing of the insulator string towards the broken span. It would be uneconomical to use 30^0 angle tower in locations where angle higher than 2^0 and smaller than 30^0 are encountered. There are limitations to the use of 2^0 angle towers at higher angles with reduced spans and the use of 30^0 angle towers with smaller angles and increased spans. The introduction of a 15^0 tower would bring about sizeable economies.

It might appear that the use of suspension insulators at angle locations would result in longer cross-arms so as to satisfy the clearance requirements under increased insulator swings because of the large line deviation on the tower. In such a case, it is the usual practice to counteract the excessive swing of insulator string by the use of counter weights (in some countries counter weights up to 250kg have been used) and thus keep the cross-arm lengths within the economic limits. It is the practice in Norway and Sweden to use suspension insulators on towers up to 20^0 angles and in France up to as much as 40^0. The possibilities of conductor breakdown in modern transmission lines equipped with reliable clamps, anti-vibration devices, etc., are indeed rare, and should the contingency of a breakdown arise, the problems do not present any more difficulties than those encountered in the case of plain terrain involving tangent towers over long stretches.

Calculation of counterweights

The calculation for the counterweights (Figure 7.8) to be added to limit the sing of the insulator string is quite simple and is illustrated below:

Let $\theta_1 =$ Swing of insulator string with-out counterweight.

$\theta_2 =$ Desired swing of insulator string (with suitable counterweight).

H = Total transverse load due to wind on one span of conductor and line deviation.

W_1 and W_2 = Weight of one span of the conductor, insulators, etc., corresponding to insulator swings $\theta 1$and $\theta 2$ respectively

Now, $\tan\theta_1 = H / W_1$

and $\tan\theta_2 = H / W_2$

Therefore, the magnitude of the counterweight required to reduce the insulator swing from θ_1 to $\theta_2 = W_2 - W_1$.

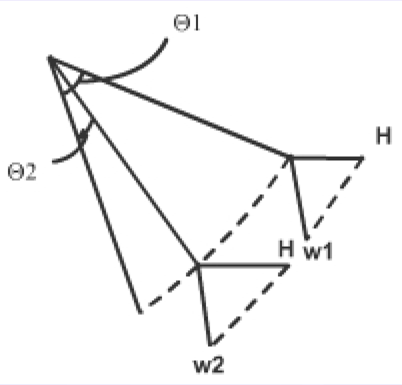


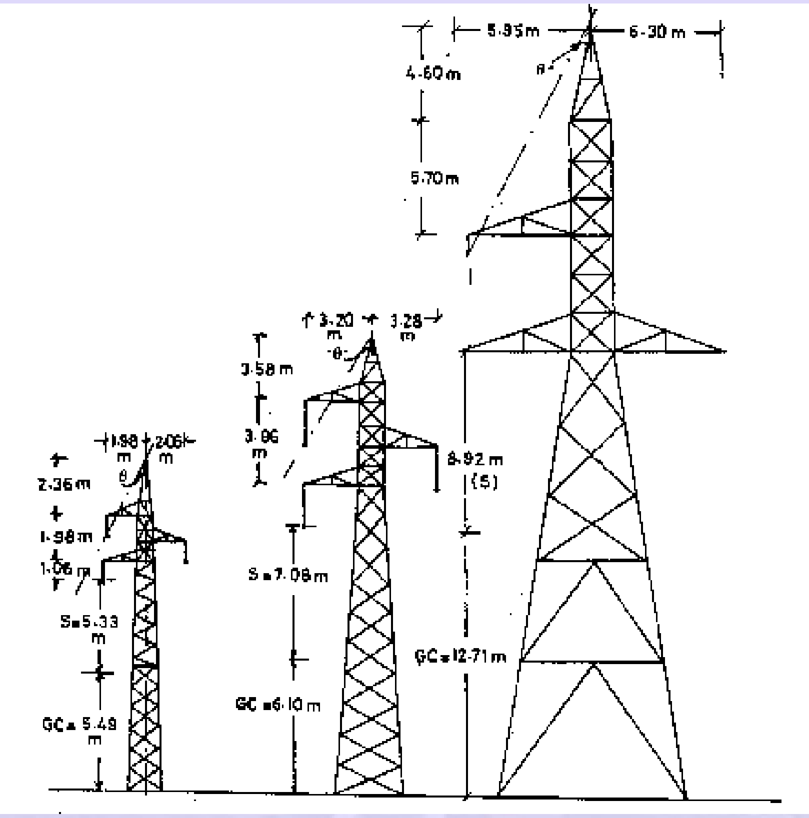
Figure 7.8 Insulator swing using counterweight

Unequal cross-arms

Another method to get over the difficulty of higher swings (if suspension strings are used for 150 line deviations) is to have unequal cross-arms of the tower. The main differences in the design aspects between this type of tower and the usual towers (with equal cross-arms) are:

1. The tower will be subjected to eccentric vertical loading under normal working conditions.
2. For calculation of torsional loads, the conductor on the bigger half of the cross-arm should be assumed to be broken, as this condition will be more stringent.

These features can be taken care of at the design stage. An example of unequal cross-arms widely used in the USSR. Note also the rectangular section used for the tower.

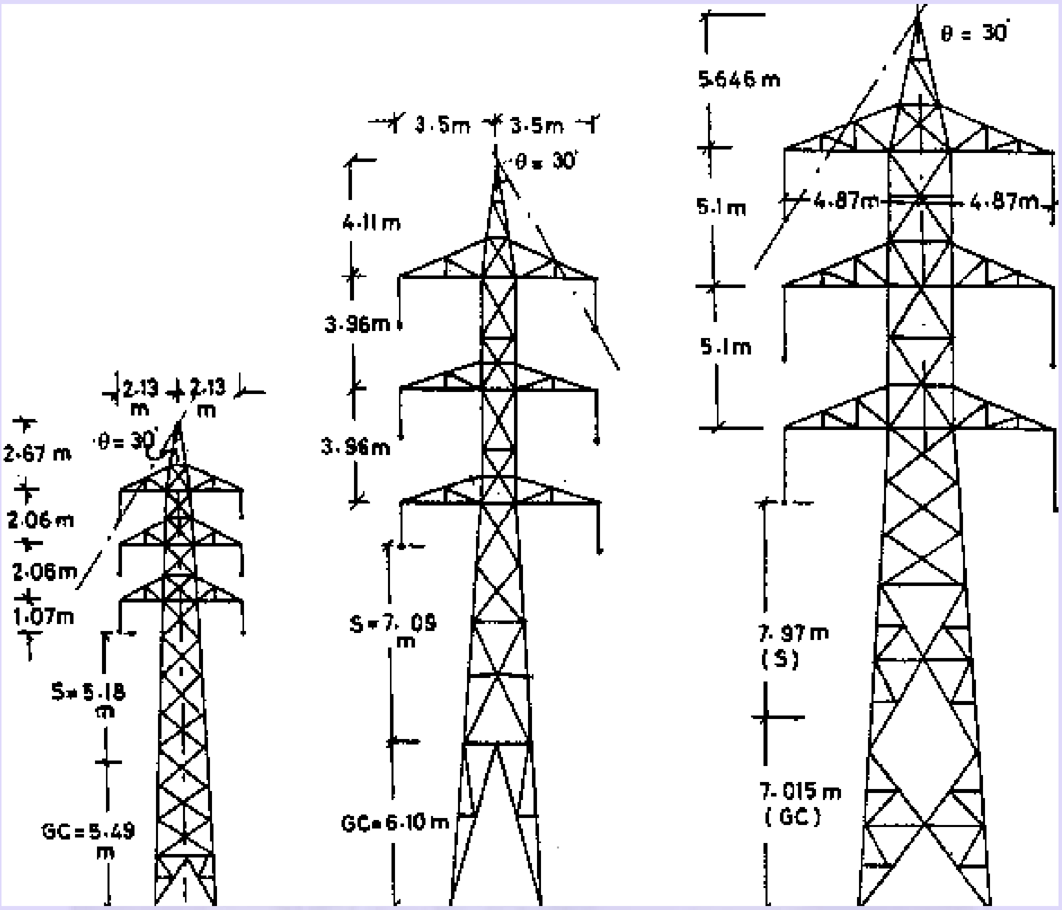


Normal span = 250m Conductor : 6/4.72mm Al + 7/1.57mm St Ground wire: 7/2.55mm ($110kg/mm^2$ quality)	Normal span = 350m Conductor : 30/3mm Al + 7/3mm St Ground wire: 7/3.15mm ($110kg/mm^2$ quality)	Normal span = 350m Conductor : 54/3.18mm Al + 7/3.18mm St Ground wire: 7/3.15mm ($110kg/mm^2$ quality)

Figure 7.9 66kV, 132 kV, 220 kV Single circuit tangent towers

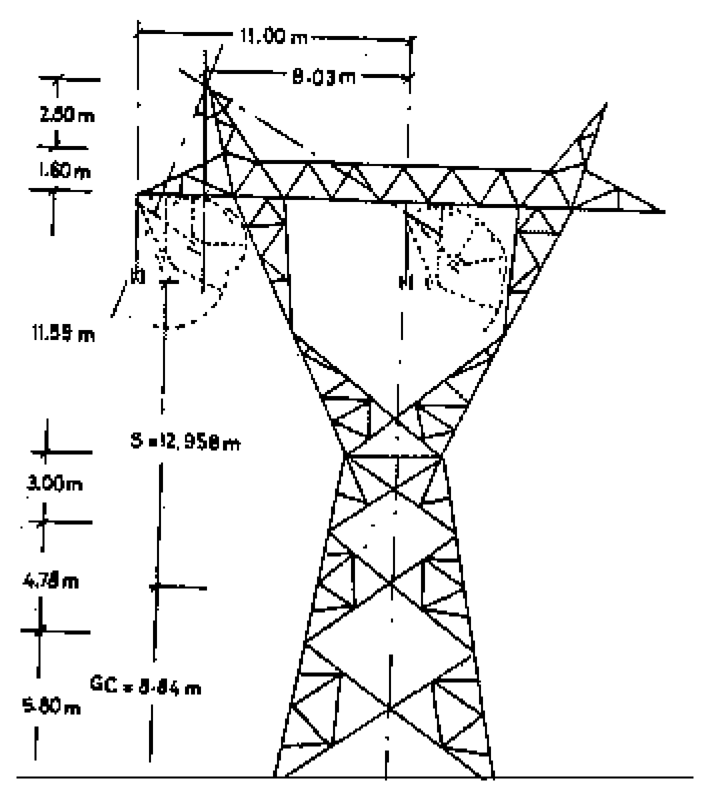
The standardized 400 kV towers presently employed in France are given in Figure 7.9 together with the corresponding weights, sizes of the conductor and ground wire employed and the ruling span. The extension and

S = Maximum Sag GC = Minimum Ground Clearance



Normal span = 245m Conductor : 6/4.72mm Al + 7/1.57mm St Ground wire: 7/2.5mm (110kg/mm^2 quality)	Normal span = 350m Conductor : 30/3mm Al + 7/3mm St Ground wire: 7/3.15mm (110kg/mm^2 quality)	Normal span = 320m Conductor : 54/3.18mm Al + 7/3.18mm St Ground wire: 7/3.15mm (110kg/mm^2 quality)

Figure 7.10 66 kV, 132 kV, 220 kV double circuit tangent towers



Normal span: 400m

Conductor: "Moose"

(54/3.53mm Al + 7/3.53mm St)

Ground wire: 7/4mm (110 kg/mm^2 quality)

Figure 7.11 400kV single circuit tangent towers (2^o)