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ELECTRIC TRANSMISSION TOWER

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Introduction

When we discuss problems relating to transmission and distribution of electricity, our sphere of knowledge appears to be limited. A study of the history and literature of Electrical Engineering reveals that electrical engineers of the past have devoted far more attention to generation than to other electrical engineering problems. Consequently, the generation of electricity has been brought to a very high degree of perfection, while the science of transmission and distribution of electricity appears to have been neglected. It seems that in the pioneering days, either engineers developed their habits of mind and training in the design of machinery and were mostly interested in movable appliances or they have been rather slow, to draw the logical conclusion that the best and most economic use of electricity can only be made if the art and science of transmission and distribution are fully exploited, and it is only comparatively recently that electrical engineers have inclined more towards this question and begun to formulate and seek its answers, but only a few of the problems involved have been touched so far.

A number of various devices to protect the machinery of generating stations against every conceivable contingency can be selected. They are reliable and we know pretty accurately their working capacity and limitations ; but in the case of transmission lines, we are not well able to guard them adequately, so much so that common occurrences such as thunder and wind-storms very frequently cause interruptions.

The main object before the present-day engineer, which has necessitated exploitation of this science, has been to overcome the difficulties formerly experienced in the methods of conveyance of energy. The ease with which electricity can be transmitted from anywhere and everywhere, has even impressed the mechanically-minded person and convinced him that it would be far more advantageous to convey energy in the form of electricity rather than to transport fuel over long distances to the centres of utilization.

The science of transmission has facilitated the grouping of numbers of generating stations to a common bus-bar main whence the output so combined can be transmitted to various machines at work at distant locations and it is thrilling to see electric power generated at a distance of hundreds of miles, operating a large variety of appliances in factory, office and home.

Towers

A tower is a latticed structure mainly comprising of mild steel-angles, channels, and flats of different sizes, rivetted or bolted together.

The necessity for providing galvanized steel towers was felt comparatively recently when the tendency towards erection of longer spans, with conductors capable of bearing high stresses increased.

In the case of small and medium sizes of steel supports, the cost would apparently be higher than in the case of wood-poles, but in long span construction for extra-high-pressure lines with heavy loading, steel towers provide one of the most economic and reliable solutions.

Latticed towers in this country can be grouped as under :

(*i*) Narrow base.
(*ii*) Wide-base.

Narrow base towers are sometimes employed where the line is to be carried through cultivated fields. Other features which also govern the narrow-base construction are :

(*a*) The span length.
(*b*) The loading.

In short span construction with light conductors, narrow-base towers are mainly used, but where spans are long and heavy loading is anticipated due to one reason or another, the wide-base tower forms the only economic solution, as there is less weight in a wide-base tower for any given height and strength and moreover, foundation loadings are more easily taken care of.

Steel towers are usually designed so that they are capable of withstanding all normal loads, *viz :*

(1) Weight of conductors (coated with ice or otherwise).
(2) Wind pressure on conductors (coated with ice or otherwise).
(3) Wind pressure on tower itself.
(4) Pull, due to deviation of line.
(5) Dead weight of insulators and supports (coated with ice or otherwise).
(6) Torsional strain due to breakage of one or more conductors.

On all these combined loadings, a factor of safety of 2·5 is generally adopted.

Wind-Loading on Conductors.—This is taken at 8 to 12 lbs. per sq. ft. on the projected area of the conductors. This material difference in the allowance is due to the fact that some places are exposed to very heavy wind-storms or so-called cyclones, whereas others are comparatively calm.

Wind-Loading on Support.—This is taken at 8 to 12 lbs./sq. ft. on the exposed area of the structure. In design, this wind load is considered to be distributed up the whole height of the tower proportionately. In the case of latticed towers, the lee-side of the structure provides an area exposed to the wind but it is somewhat protected by the windward side. For all practical purposes, the shielding effect of the windward side can safely be taken as 50 per cent. This is a fair average, although a correction factor is sometimes employed for various distances between the faces of the structure. This means that the area exposed to wind-pressure would be $1\frac{1}{2}$ times the area of one face of the structure. This is a fairly safe figure for design purposes.

Torsional Strain due to Breakage of one or more Conductors.—The breakage of one or more conductors is liable to cause heavy twisting or torsional strain on the support, so much so that the members in shear will be subjected to heavy stress.

In the case of lines where suspension insulators are used, the tension due to a broken conductor may safely be taken as 50 to 70 per cent. of the working strength of the conductor. This is due to the fact that the breakage of one span swings the length of the insulator-string into the remaining span which considerably reduces the tension in it, but in the case of tension insulators, no reduction in stress is allowable. It can readily be seen that this tension will be resisted by all bracing members of the support, provided the bracing is diagonally placed at the cross-arm-level.

The load on each face of the tower from torsion as above will be:

$$\frac{PL}{2 \times W}$$

Where P = Pull.
L = Distance of the point of pull from centre of the tower.
W = Width of tower at cross-arm-level.

In addition to this load, the side-faces will have to resist the load due to direct pull (P) and the additional load due to wind on structure and conductors, and the pull owing to deviation, if any, will be taken care of by the front faces.

Bracing

There are different types of bracing, which are being used according to requirements, depending upon the type of tower under design. For instance, small and medium size towers are generally provided with cross-bracing. The type which is mainly used for narrow base towers is somewhat different, and comprises bracings so placed that the panel points for adjacent faces alternate up the tower leg. This arrangement has the desired effect of reducing the effective panel length of the leg to say about $\frac{2}{3}$rds of its length, measured between points on one face.

All braces must be treated as struts or compression members and unless their lengths be kept short, the slenderness ratio will necessitate the use of far larger sections than the stress itself would call for. The designer should, therefore, see that the lengths of braces are invariably kept as short as possible.

For large towers with heavy loading, the type of bracing shown in Figure "A" is generally used. In this type, the horizontal members are in compression and, therefore, treated as struts under all conditions of loading, whereas the diagonal members are in tension both operating when the tower is loaded on both sides. This type of bracing is considered to be the best from an economical point of view.

Torsion and Subsidiary Bracing.—Torsion bracings are used at the junctions of panels, whereas subsidiary bracings are employed only to shorten the un-supported lengths of main leg members. Subsidiary bracing takes no calculated stresses, therefore its design mainly depends on the slenderness ratio.

For extra-high structures where compression stresses may be great, "K" type bracings are used.

Stresses

(*a*) *Tension Members.*—In the design of towers, the factor of safety is generally based on the crippling load of compression members and on the elastic limit of tension members. The elastic limit or the yield point is generally taken as round about 16 tons per square inch for small sections although its value falls with large sections. This value of 16 tons per square inch, excluding rivet or bolt-holes is a safe figure for designing.

(*b*) *Struts or Compression Members.*—Compression members are designed on the crippling load for any particular section over any unsupported length.

Apparently even in very short lengths, the crippling load will be less than the crushing load. It will vary considerably with different types of ends. Various tables have been compiled comparing the crippling load of struts to their L/r ratio, *i.e.* the ratio of un-supported length to the radius of gyration of respective sections. There are two types of ends which are used in practice, *i.e.* fixed and pinned. With fixed ends the struts will obviously have better values, owing to the measure of support given by fixity which will have the effect of shortening the length. It is left entirely to the designer to study the conditions and to ascertain the applicability of either of two conditions. He may have, however, to select some intermediate value of crippling load if none of the conditions be applicable.

The formula for crippling load employed in design is :

$$Fe = 60{,}000 - 200 \times \frac{L}{r}$$

The usual values of L/r ratio which are considered in the design of towers are :

120 for main members.
180—200 for cross or subsidiary bracing.

Foundations

The design of the tower foundation is as important as the design of the tower itself. In fact, the designer should invariably attach more weight to the design of foundation which should be worked out in conjunction with the design of tower in relation to its base width.

For ensuring stability, the foundations should be designed to resist the overturning moment together with the direct shear due to the applied loads. Generally, a factor of safety of 2·5 is used for these loads.

For wide-base towers, required for long-span construction with heavy loading, it is imperative for the designer to be very considerate in regard to :

(*i*) Base plate areas.
(*ii*) Depth of setting.

The area of the base-plate is dependent on the type of soil. It should be such as to give a safe intensity of pressure on the ground and to ensure that the compression will be taken care of by direct earth reaction on the base plate.

The designer should give careful consideration to the depth of setting in relation to soil condition as faulty design might unnecessarily involve heavy expenditure which could otherwise be avoided. The depth of setting should, therefore, be designed keeping in view the following main points :

(*a*) The uplift which should be resisted by the weight of a frustrum of earth on the base plate.
(*b*) The cost of concreting should be reduced to the minimum.
(*c*) The factor of safety against overturning should be adequate.

It is obvious, that the greater the depth of excavation, the cost per cubic yard will proportionately be higher. The designer should, therefore, visualise carefully all these factors with a view to exercise economy.

There are different kinds of concrete foundations. For wide-base heavy angle and terminal structures, concrete block foundations are generally used. Another type of foundation employed for wide-base intermediate towers is the "Malone anchor." For narrow-base, light towers, stubs of different varieties are employed.

The Figure "K" is an illustration of narrow-base single-circuit tower carrying three steel-cored aluminium conductors equivalent to .125 square inch copper and a 7/10 S. W. G. galvanized steel earth wire on 800 feet span length. The loading to be with a factor of safety of 2·5. The tower to be designed with a factor of 1.5 to withstand all loading inclusive of the torsion strain and the pull due to any one broken conductor. The L/r value is not to exceed 120 for leg members and 200 for bracing members. It is presumed that radial thickness of ice is ½ inch.

CONDUCTOR	*Coated with Ice*	*Without Ice*
(*i*) Normal strength ..	5,271 lbs.	5,271 lbs.
(*ii*) Diameter ..	1·62 inch.	·62 inch.
(*iii*) Weight ..	·33 lb. per ft.	·33 lb. per ft.
(*iv*) Weight of ice ..	1·246×R (D+R) =1·246×·5 (·62+·5) =·68 lb. per ft.	..
(*v*) Total weight per foot run	1.01 lb.	·33 lb.
(*vi*) Wind load per ft. run	$\frac{8}{12}\times 1{\cdot}62 = 1{\cdot}08$ lb.	·41 lb.
(*vii*) The length of suspension insulator string	2 feet	2 feet.
(*viii*) Ground clearance ..	20 feet	20 feet.
EARTH WIRE		
Diameter ..	1·384 inch	·384 inch.
Weight per foot run ..	·326 lb.	·326 lb.
Weight of ice per foot run	1·246×·5 (·384+·5) =·55 lb.	
Total weight per foot run	·876 lb.	·326 lb.
Wind load per foot run ..	8/12×1·384=·922 lb.	·256 lb.
WIND LOADING AT SUPPORT		
Per conductor coated with ice	800×1·08 = 864 lbs.	
Earth wire coated with ice	800×·922 = 645 lbs.	
Wind on tower itself ..	Say 750 lbs.	
WEIGHT AT SUPPORT		
Per conductor coated with ice	800×1·01 = 808 lbs.	
Earth wire coated with ice	800×·876 = 701 lbs.	
Weight of support and insulators	Say 3,500 lbs.	

As suspension insulators have been used, consequently, the longitudinal pull will be 70 per cent. of the normal strength.

Therefore=5,271×70/100 = 3,689·7 ; say 3,690 lbs.

The loadings on the tower with their points of application have been shown in Figure " K." The load at the cross-arm carrying the assumed broken conductor is being halved as only one span on one side of the tower is in existence. Whereas the wind loadings and the weight at the support are to be halved as they are resisted by two faces of the tower, the torsion load applies equally to each face and thereby produces torsion stresses in all the bracing members.

Suppose the torsion load is P_1 lb.

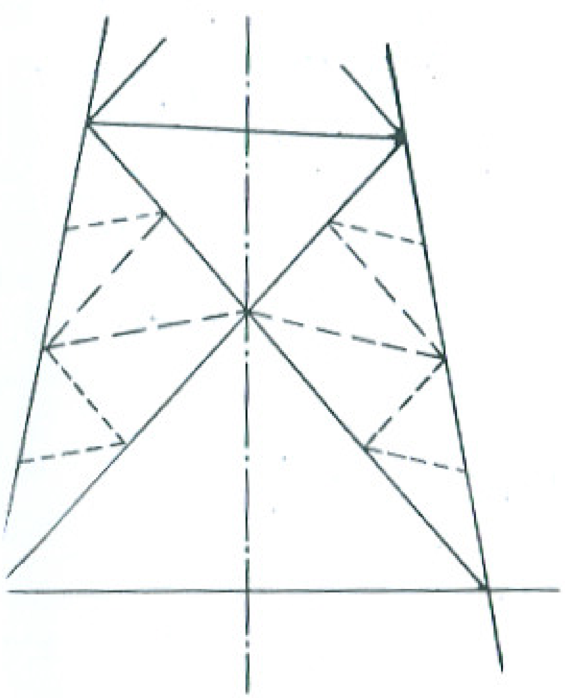
Taking moments about the centre of the tower (see Figure " K ")—

$$3{,}690\times 4 = P_1\ (4\times \tfrac{1}{2}\ W) \text{ where } W=1{\cdot}5 \text{ ft.}$$

$$\text{Therefore } P_1 = \frac{3690\times 4}{4\times {\cdot}75} = 4{,}920 \text{ lbs.}$$

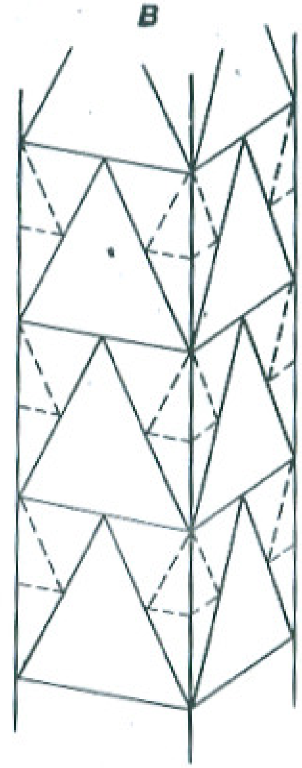
Having completed the stress diagrams and tabulated all the members with their stresses, the steel sections can then be determined.

A



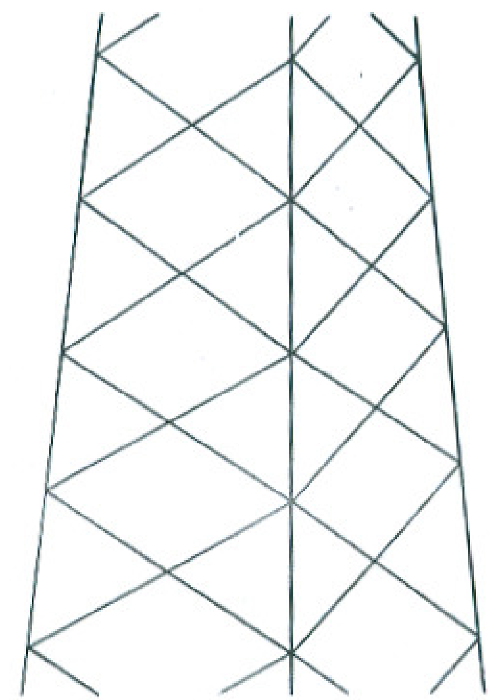
BRACING EMPLOYED ON
LARGE SIZE TOWER

B



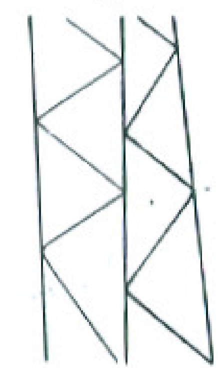
K. TYPE BRACING

C



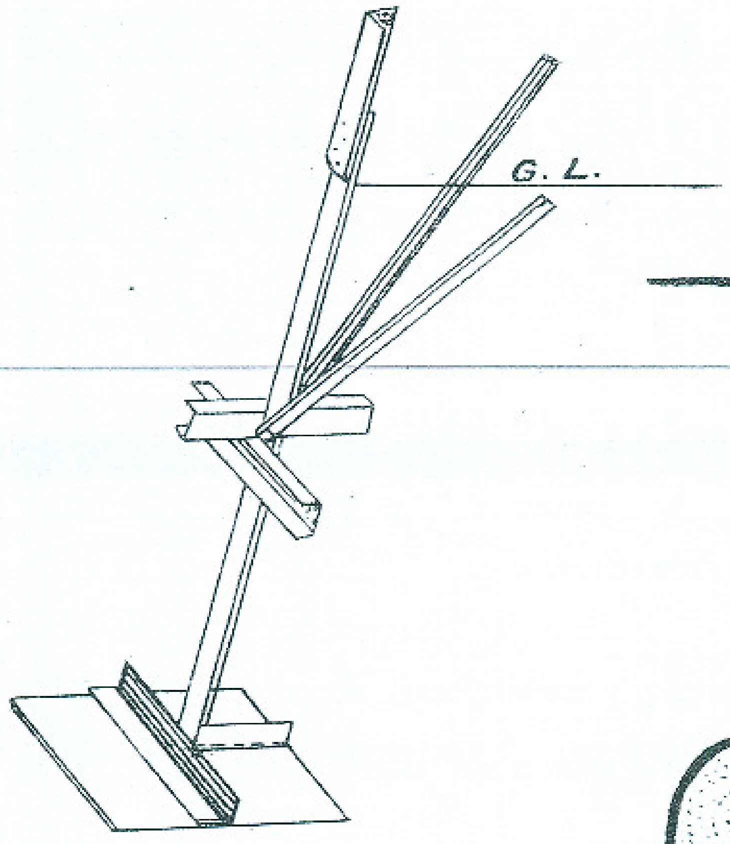
BOUBLE BRACING

D

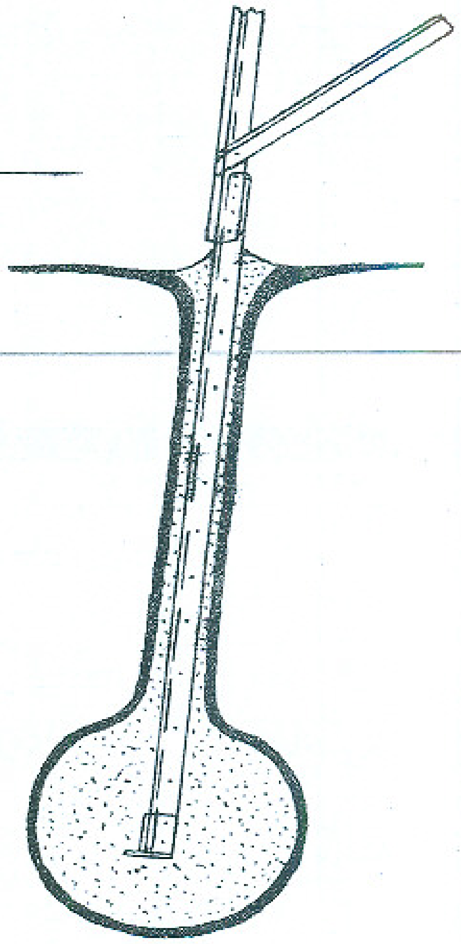


SINGLE BRACING

E

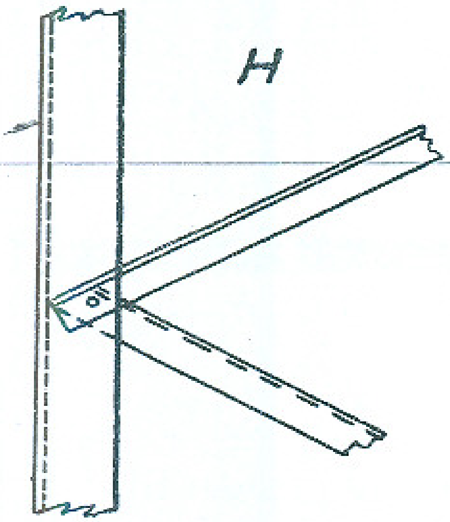


F

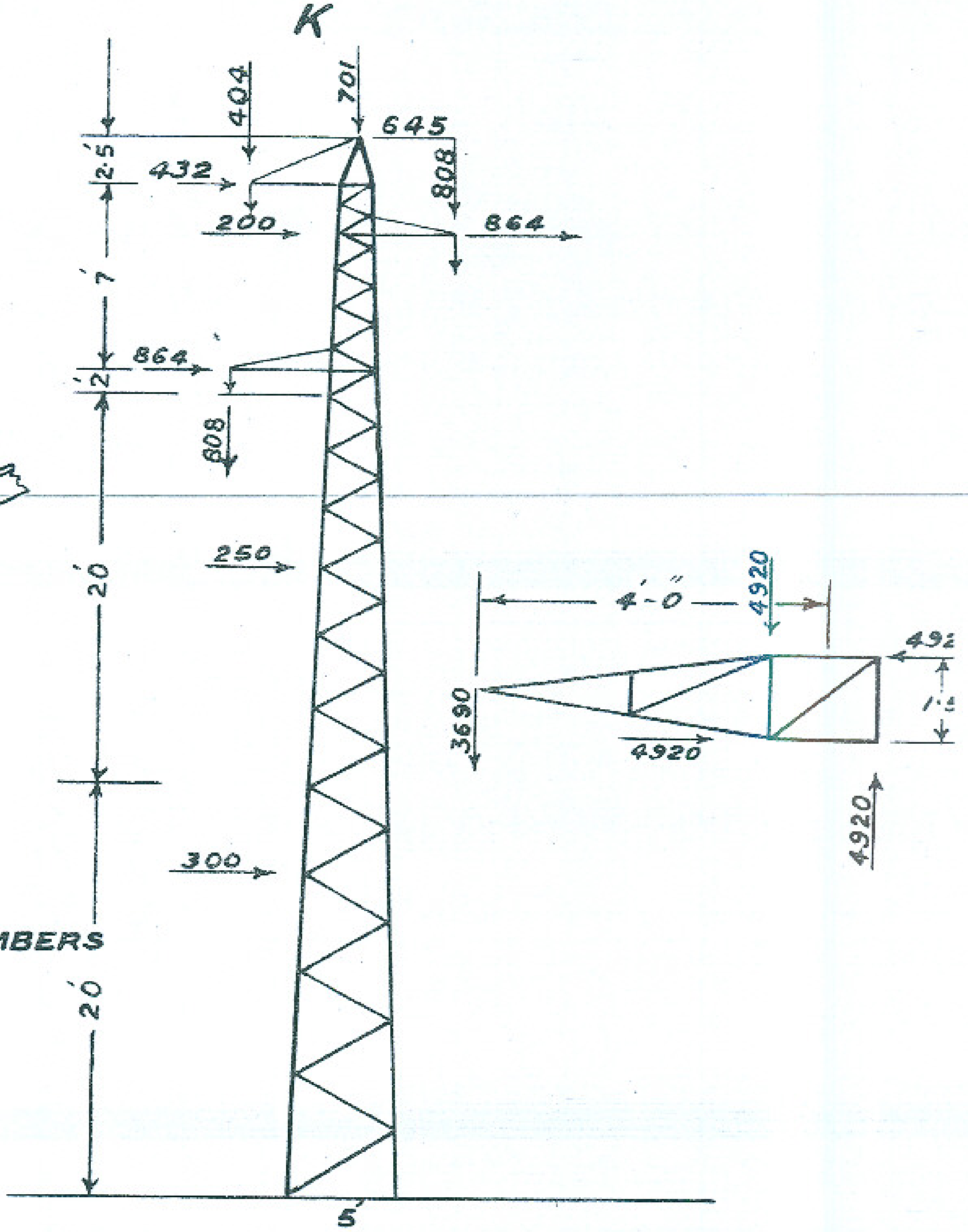


BATTENED STUB

MALONE ANCHOR



STRUTS
OR
COMPRESSION MEMBERS



DISCUSSION

MR. TALWAR, in introducing the Paper, said that it was a matter of great satisfaction that an opportunity was given for open discussion of problems on which the future of this country largely depended. He remarked that continual progress in the art of engineering should be the aim of every present-day engineer, that every field of engineering should be fully exploited and that no effort should be spared in order to bring this country to the forefront by increasing its industrial output whose gigantic resources, when fully mobilised, would greatly accelerate industrial expansion.

Mr. Talwar continued that the main object in introducing his Paper was to emphasize the desirability of taking every possible step to improve the art of transmission and distribution so as to bring it to a very high degree of perfection and that with the continual expansion of electric supply systems it had become increasingly important to find means to overcome the difficulties experienced on transmission and distribution lines, both during construction and operation.

He observed that in the construction of transmission lines the supports provide a difficult problem and that it was most desirable that their design should be both reliable and economical. He added that defective design would lead to serious troubles, both during erection and operation, and uneconomical design to waste of material and labour with consequent increased expenditure. In his Paper he examined the main principles governing the design of towers and their limitations and drew attention to the stress produced through torsional strain due to breakage of one or more conductors which were resisted by the bracing members. He also described their loadings as well as their points of application.

MR. CRITCHLEY remarked that the Author was to be congratulated on having produced a very useful Paper but opined that some of his introductory remarks were unduly pessimistic. He added that experience in India with properly-designed transmission-line towers showed that the trouble experienced due to lightning and windstorms was relatively small and that it might be expected that in the tropical climate of India flashovers on transmission-line towers would be fairly frequent during lightning as experience showed, that flashovers due to lightning were relatively less frequent in India and other tropical countries than in temperate climates. This, he added, was due to the fact that in tropical countries the general level of lightning disturbances is much higher than in temperate climates with the result that the majority of the lightning discharges take place between cloud and cloud instead of between cloud and ground—the latter being more common in temperate climates and that experience in the Punjab during eight years had shown that the Punjab P.W.D., Electricity Branch, tower-transmission lines were almost entirely free from troubles due to windstorms.

Mr. Critchley then referring to the Author's viewpoint observed that a tower was a latticed structure mainly consisting of mild-steel angles, channels and flats of different sizes, rivetted or bolted together that efficient and economical designs had been developed in Europe employing steel tubular sections and that it was understood that towers of that type were giving satisfactory service.

He added that under "Torsional Strain due to Breakage of one or more Conductors," where the Author referred to "working strength of the conductor" should apparently be "working load of the conductor."

In regard to the foundations, he remarked that the Author had not referred to the necessity of concreting the stub angles of transmission-line towers as a protection against corrosion due to salts in the soil which was particularly important in some areas in the plains where certain salts in the presence of moisture caused rapid corrosion of the steel work, particularly from ground level down to a depth of about 3 to 4 feet. He suggested that a minimum cover of 2 inches of dense concrete would provide the cheapest and most satisfactory form of protection to the steel work known at present.

The AUTHOR in replying to the discussion, said that the remarks made on his Paper by his Chief Engineer were greatly appreciated; he considered that some of his own introductory remarks were unduly pessimistic. In support of his argument, he referred to the tower-lines of the Punjab Electricity Branch on which troubles due to lightning and wind-storms were relatively small.

He added that while writing his Paper, the general position was kept in view. No special reference was made to the conditions obtaining in any particular country. The Paper dealt essentially with the general aspects of the problem of tower design, and comment on the design of towers in India was hardly necessary. Recent experience indicated that lightning discharges had caused heavy surges in the Electricity Branch system, resulting in interruptions on many an occasion.

He further remarked that the spacing of the conductors should be kept as small as possible to decrease the effective length of the cross-arm, the inductance of the line and the corona losses. It was an admitted fact that windstorms did not usually cause the conductors to swing out of synchronism. It was only with a wind blowing in gusts that swinging of the conductors out of synchronism occurs. If the spacings were adequate, the liability of the conductors coming within arcing distance or being short-circuited decreases.

He said that it was agreed that the word "strength" was not appropriate and that it would be more suitable to refer to "maximum stress on the conductor" instead of either "strength" or "load" of the conductor.

With regard to concreting the stubs and legs of supports, he remarked that it was observed that this part of the probem, which required analysis of the properties of dense concrete and steel, did not come within the scope of his Paper and consequently its inclusion was not considered necessary.

In conclusion, he remarked that the relative resisting power of dense concrete against the action of salts being very great, it would obviously, therefore, provide the best protection.