DESIGN OF STEEL STRUCTURES FOR OVERHEAD LINE SUPPORTS - A REVIEW

by

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Introduction

An overhead line may be described as an assembly of conductors, insulators and supports. The bulkiest element of these, the supports, made of steel, concrete, or wood, fall within the purview of the Civil engineering discipline.

Steel structures for overhead line supports can be divided into towers and poles. The term, tower, in general includes lattice structures made of fabricated steel with a broad base and with a height 10.7m (35 ft.) or more. Steel structures with a small base and with a height less than 10.7m (35 ft.) are classified as steel poles.

Steel towers are used mainly for transmission and sub-transmission lines (33 kV and above) where the clearance height of the line, strength of the required supports and the importance of continuity of service demand the most reliable construction obtainable. Generally steel poles are made of (a) welded tubular sections with diameter reduced in sections towards the top; or (b) built-up members, uniform throughout, made of light gauged channel sections forming the flangs, tubes or T-sections or channels bent in a zig-zag shape forming the web, and connected by welding or bolting. In Sri Lanka, although steel towers remain unchallenged, steel poles are being gradually replaced by timber, pre-stressed concrete and reinforced concrete poles. Hence this paper deals with steel towers only as steel poles are unlikely to be cost effective in Sri Lanka.

This review of literature on steel transmission line towers was considered opportune as (a) more transmission lines will be required as the country expands its electrical generation capacity; (b) 40% of the cost of a new transmission line will be due to tower costs and its reduction can lead to significant cost savings; (c) greater faimiliarity will encourage engineers to design and fabricate these towers locally; (d) identification of areas where guidance is required to design for local conditions, can stimulate researchers to generate the necessary information; and (e) interest can be evoked on similar structures such as steel towers for elevated water tanks, floodlights, communications, broadcasting, telecasting and access falsework.

Different Types of Towers

Towers can be broadly divided into suspension towers and tension towers. Suspension towers are in straight line positions and carry "Suspension sets" that merely hold up the conductors,

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while tension towers carry "tension sets" that keep the conductors in tension, at the ends of each section of line. Tension towers can be further sub-divided into section towers, 10° angle towers, 30° angle towers 60° angle towers and terminal towers. Sometimes section towers and 10° angle towers are the same. Junction towers are also used. About 85% of the towers used in a line are suspension towers.

Suspension tower supports are required to withstand the dead load, and the wind load of towers, insulators and conductors. Further, unbalanced load due to the breakage of conductors should be resisted. On account of the length of the insulator string, the conductor tension in a conductor is taken as 70% of the conductor maximum working tension(1). Section towers, in addition to coping with loadings similar to those on a suspension tower, should withstand the loads imposed on it by the tension of the conductors during stringing, and under broken wire conditions with the most unfavourable combination of conductors broken. Angle towers should resist the resultant pull due to the angle of deviation of the line in addition to loads similar to those on section towers. Terminal towers should withstand the full tension of the conductors longitudinal to the line in addition to carrying the weight and wind load of insulators and conductors, weight and wind load of the individual towers, and the loads due to most unfavourable broken wire conditions.

The cross-arms of angle towers are placed to bisect the angle between the lines, while the cross-arms of suspension, section or terminal towers are placed square (at right angles) to the line of route.

Span length (the distance between towers) and proportioning of towers

Conductor type and size, number of circuits (single or double), arrangement of conductors (delta, horizontal or vertical), vertical and horizontal spacings between conductors, and minimum ground clearance of the lowermost conductor will be specified by the Electrical Engineer.

Longer the span length, (a) the fewer will be the number of towers and the number of insulators; (b) stronger must be the conductor in order to carry its own weight and the wind loads on it; (c) taller will be the tower to provide the necessary ground clearance and to overcome increased sag; and (d) greater will be the reliability of the line due to reduced supports. The determination of most economical span length involves balancing the increased cost of (i) the stronger conductor; (ii) the bigger tower; and (iii) the taller tower, against the saving due to the lesser number of towers and insulators. Some values of span lengths used for towers are:

310m(132 kV), 256m(66 kV), & 244m(33 kV).

The height of the tower depends on (a) the specified ground clearance of the lowest conductor; (b) the sag of the conductor at a maximum temperature of 150°F (65.5°C) for the adopted span length and the adopted tension; (c) the length of the suspension insulator string; (d) the vertical spacing between conductors; and (e) the arrangement of conductors. The height of tension towers will be smaller than that of suspension towers due to the different insulators used.

An approximate value for bottom base width of the tower can be taken as K_1 times the height of the tower, while an approximate value for top width (at the upper level of the highest cross-arm) of the tower can be taken as K_2 times the height of the tower. Height of the tower in the above formula is taken as the height from ground level to the highest level of the tower. Four planes of the tower sides are usually inclined to the vertical at the bottom portion of the tower so that its slope is 1 horizontal to V vertical. Suitable values for K_1, K_2 & V are given in Table 1 below.

TABLE 1

Relationship between the heights and factors K_1, K_2 & V

Tower height	K_1	K_2	V
up to 25m	0.18	0.04	10
50m > tower height > 25m	0.24	0.05	8
70m ≥ tower height > 50m	0.29	0.06	5

Values to be adopted for bottom base width, top width and slope of the sides should be decided after adjusting K_1. K_2 & V values to obtain round figures for tower dimensions. In adjusting it should be noted that higher values of K_1, K_2 & V will reduce the stresses in the tower.

Length of a cross-arm depends on electrical considerations such as conductor to conductor distance, and conductor to earth (tower body) distance when conductor is under maximum swing by the wind. Top of the cross-arms are sloped to deter birds from perching. Cross-arms in angle towers are longer and unsymmetrical to maintain the same horizontal spacings of the conductors throughout the line. An approximate value for height of a cross-arm is given by K_3 times the clear length of the cross-arm beyond the tower body.

Suitable values for K_3 are given in Table 2 below.

TABLE 2

Relationship between the clear length of cross-arm and K_3

Clear length of cross-arm (l)	K_3
2.5m ≥ l	0.5
5.0m ≥ l > 2.5m	0.4
15.0m ≥ l > 5.0m	0.3

As height of cross-arm is generally the same as panel height of the tower at that level, K_3 should be adjusted to get a round figure. In adjusting, it should be noted that higher value of K_3 will reduce stresses on the cross-arm. Width of the cross-arm is usually equal to that of the tower at that level.

Selection of structural form

As the tower is proportioned before entering this stage, distance between corner legs will be known. It should be noted that corner leg forces can be reduced by widening the corner leg spacing, and vice versa. Slenderness ratio of a corner leg is kept as low as possible between 70 and 120 by selecting a suitable section and introducing appropriate sub-framing (see B1 & B2, D2 & D, E2 & E3, F2 & F3 of figure 1).

Type of bracing to be adopted for the tower body is decided paying attention to the following considerations :-

a) Bracing members are horizontal, vertical, or inclined to the horizontal;
b) When inclined bracings are used, the preferred angle of inclination is 45° to the horizontal. This angle of inclination is generally

allowed to vary between 30° to 65° to suit the tower framing. Any increase from 45°, increases the force in the member and the overall member length, and hence such increases are suitable for members carrying low loads. Any decrease from 45°, reduces the force in the member and its length, and hence such reductions are used to reduce slenderness of corner legs and/or for bracings carrying high loads;

c) Slenderness ratio of members in transmission towers are generally not less than 70[2], although in similar structures such as drilling rigs it can be as low as 30. The bracing members[3] under compression in transmission towers are maintained with slenderness ratios between 70 and 200. Slenderness ratio of tension bracings should not exceed 350;
d) As the horizontal shear force and/or bending moment of the tower increases, bracing type should be altered from A to F (see figure 1). Note that type C is weak under stress reversal and hence it is not adopted generally for the tower body, although it is widely used for the cross-arm;
e) In any structural type, sub-framing is used to reduce slenderness of compression members (A2, B2, C2, D2 etc. - see figure 1). Sub framing carries loads only when load is applied in its vicinity;
f) In general bracings will keep the compression member lengths around 2.5m (7.5 feet);
g) Usually lowermost bracing does not contain a horizontal member just above the tower legs; and
h) Different types of bracings are normally used in the same tower to cater for the reducing bending moments and shears.

Bracings in horizontal planes (plan bracings) provide torsional rigidity to the tower and also helps to maintain cross-sectional shape of the tower under loads, particularly those in a plane containing diagonally opposite corner legs. Bracings in horizontal planes are usually provided (a) at or near bend lines where slope of the tower side changes; and (b) at levels where lower side of a cross-arm meets the tower and, in the case of a cross-arm which transfers a large torsional moment to the tower under broken wire conditions, at levels where upper side and lower side of such a cross-arm meet the tower.

Cross-arm bracings are usually of the type A1, C1, C2 or C3 (see Figure 1).

When towers of different heights of the same type (such as suspension, section, 30° angle or terminal) are designed for a project, towers of increased height are obtained by the use of body extensions to the standard height tower. Shorter towers of the same type are obtained by removing a detachable section at the base of the standard body. However, this procedure is not economical for producing shorter section towers from taller suspension towers. For steep hill country, hill side extensions with corner leg foundations at different levels are not popular now.

Materials

Steel Sections

High tensile steel is widely used as it produces a light tower and also simplifies connections due to higher strength. Accompanying higher deflection is unlikely to affect, as conductors are subjected to greater deformation due to temperature and wind. In some instances mild steel is also used for lightly stressed bracings of high tensile steel towers. This practice is now discouraged due to supervision difficulties in identifying the two steels at the site.

Sections used are steel angles and flats. Main members are generally not less than 8mm(5/16") in thickness, while other members are not less than 5mm(3/16") thick. Some designers use even thinner sections although BS 449[4] specifies a minimum thickness of 8mm.

To ease erection difficulties it is customary to specify for steel sections, a deviation from straightness of not more than L/1000 for corner leg sections, and L/500 for other members, L being the length of the complete section. The member shall also be free from kinks or twists.

All members are made from standard production jigs, holes being punched or drilled as convenient. The diameter of bolt holes should not exceed the corresponding bolt diameter by more than 1.5mm(1/16"). All members are galvanised by the hot dip process, the zinc coating being not less than 609g per m^2 (2 ozs per ft^2) of surface.

Galvanising is the widely adopted method of corrosion protection in these towers due to the need to minimise maintenance as most towers are located in remote sites. Also when painting does become necessary after the sacrificial zinc expends itself, it is much easier to prepare the galvanised surface, as millscale is not present and hence aluminium painting can be more efficiently carried out.

Any defects in galvanising should be detected before material goes to the site. Steel work which has been too long in the pickling bath generally has a galvanised coating with a poor surface. Holes formed within the zinc film are usually elongated or porous. If black patches show on the galvanising, it is an indication that the steelwork has not had sufficient time in the pickling bath and millscale or similar material has not been removed. Formation of white rust should be avoided by taking necessary precautions during packing, storage and handling.

Connections

Bolting is the preferred method of connection due to ease of erection and extensive use of galvanised parts. To simplify connection details by using fewer bolts, high tensile galvanised bolts are mostly used, although for low load carrying connections mild steel galvanised bolts are also used. The common bolt diameters used are 13mm(1/2"), 16mm(5/8"), 20mm(3/4") and 25mm(1").

The joints in the corner leg sections are generally of the butt type with inside and outside cover plates, together with packing plates where the thickness of the two members differed, although in low load carrying cases lap joints are also employed. When lap joints are used, lapping sequence it altered at adjacent joints to prevent a build-up of eccentricity.

Ideally, at joints between diagonal bracings and corner legs, the axes of all members meeting at the joint should intersect at the panel point. To achieve this it may be necessary to use a gusset plate. The expense incurred may outweigh the advantages gained and tower designer sometimes makes a suitable compromise by omitting the gusset plate at the expense of introducing a bending moment at the corner leg panel point. In some instances, gusset plate cannot be avoided in order to accommodate sufficient bolts to withstand the loads transmitted by the members.

Loads to be considered

Three different spans are used in tower design. Basic span is the distance between two towers so that requisite ground clearance is obtained on level ground at the maximum specified temperature. Wind span is used for establishing the load imposed on the tower as a result of wind on the conductor. It is taken as one-half the sum of the two spans adjacent to the tower under consideration. Weight span is used for calculating the weight of the conductor that would bear on the tower. It is the horizontal distance between the lowest points of the conductors on the two spans adjacent to the tower, where lowest point is defined as the point at which the tangent to the sag curve, or to the sag curve produced, is horizontal.

The above spans are dependent on conductor size and some typical values used in Śri Lanka are :- (a) High country design - Basic span (1000 ft.), Wind span (1600 ft.); Weight span(4000 ft.); (b) Low country design - Basic span (1000 ft.); Wind span (1100 ft.); Weight span (2000 ft.).

Once a tower is designed for selected values of basic span, wind span and weight span, it cannot often be used as designed due to varying terrain encountered. For instance if instead of level ground, a hill slope is encountered, towers may have to be positioned at a span less than the basic span to obtain required ground clearance. To take full advantage of towers at locations with a reduced wind velocity, is usual to erect towers at a wind span in excess of normal wind span. At hill-top positions, weight span is reduced to allow for the increased weight of conductor transferred to the tower, while at valley positions weight span is increased.

Towers have to satisfy two sets of conditions : - (a) normal conditions when all the conductors are said to be intact; and (b) broken wire conditions when any one or more are broken.

Under normal conditions, the vertical loads on the tower represent the dead weight of the conductors, insulators and tower itself. The transverse loads are due to the component of conductor tension caused by angular deviation of the line, together with wind loading on conductors and the tower itself. At a terminal tower, the tower has also to withstand the full tension of the conductors longitudinal to the line. The design loads are greater than these normal loads by a factor of safety of 2.5.

Under broken wire conditions, many different possible combinations of loading should be considered with wires broken singly or in combination, causing torsion and/or bending due to unbalanced pull of unbroken conductors. These should be superimposed with conditions under working conditions. As these abnormal conditions are not expected to occur often, a factor of safety of 1.5 is used.

Weight of tower can be obtained using Ryle's formula, but it can also be obtained by assuming suitable angle sizes for different tower members with a 5% increase for bolted connections.

Analysis

As wind moment on the tower is known now, a more accurate range of values for bottom base width of the tower can be obtained using Ryle's formula. As its applicability for Sri Lankan conditions is not known, it is better to assume four other bottom base width values around the already assumed value and final selection made later, after design, based on cost.

Tower structure should be analysed for each loading case and force in each member should be determined and tabulated. Different load combinations that may occur together should be considered next, critical load combination for each member identified, and design load for each member evaluated. In general, corner legs are usually stressed most under normal working conditions, or with the maximum number of broken conductors all in one span. Diagonal bracings usually experience maximum stress when the tower is subjected to heavy torsion, such as with broken conductors in adjacent spans at opposite cross-arm ends.

Four methods[6] currently used for analysis are :- (a) Dividing the tower into determinate plane trusses (with extra members considered inactive) and analysing them by means of stress diagrams or resolution of forces; (b) Treating the tower as a space truss, statically determinate or indeterminate with strength of a member assumed to be same in compression or in tension; (c) Treating the tower as a space truss similar to (b) above with the exception of treating compression members after buckling to be different in strength to the tension members; and (d) Treating the tower as a space frame.

Space frame analysis is not appropriate for transmission line towers as (i) slenderness ratio of members are above 70 with little capacity to carry significant bending moments; (ii) joints are bolted, not welded, thus resembling pin joint connections. Method (c) above, using space truss theory gives the best results, but superior computer facilities are required as many iterations should be done and advanced procedures are needed to treat geometric instability of towers which contain large number of planner nodes. Method (b) considers all members of the tower without reducing it to a statically determinate tower, but may or may not produce results superior to those of method (a) depending on compressive load carrying capacity of slender tension members. For Sri Lankan designers, method (a) is recommended as it produces a safe design although it may be conservative compared to method (c).

Analysis using method (a) for a tower under a force system consists of (i) evaluating nodal loads acting on the tower; (ii) resolution of each nodal force into components along the planes of the two inclined trusses meeting at that node; (iii) analysing each truss separately; (iv) algebraically adding forces in members common to any two trusses; (v) considering a tower with changing side slopes as an assembly of separate towers each with uniformly sloping sides, and analysing from top to ground level one tower at a time.

Analysis using method (a) for a tower under a torsional moment consists of (i) determining force on each side truss of the tower to balance the torsional moment as well as to maintain a constant value for shear force per unit length of a tower side measured at a horizontal section plane; (ii) analysing each truss separately; (iii) following the procedure after truss analysis similar to a tower under a force system stated in the earlier paragraph.

Design

Using design loads of members and adopting BS 449[4] design procedure, suitable angle sections for members should be selected. Effective length necessary for design can be obtained for each member as illustrated in Figure 2 and Figure 3, where 'eperp' refers to the effective length perpendicular to the truss considered and 'epera' refers to the effective length in the plane of the truss considered.

Connections should be designed so as to minimise joint eccentricities as well as to simplify the joint. If joint eccentricities are unavoidable to obtain simple joints, then eccentric moments induced on members should be evaluated and each member checked for axial forces as well as eccentric bending moments.

Erection stresses should also be considered as erection method is expected to apply unaccounted forces and moments to the members and their connections. The three main methods of erection are : (a) built-up method - This consists of erecting the tower member by member with a guyed light derrick pole used to raise steel members into position. As the tower is constructed light derrick pole is moved up the tower; (b) Prone method - This consists of assembling the tower on the ground and erecting it as a complete unit using one or more cranes; (c) modified method - This consists of assembling major sections of the tower and erecting as units. Sometimes the whole of one face of the tower can be assembled and erected, and when both faces have been erected the bracing angles are fitted.

Finally, as the weight used and wind load on tower were estimates, the weight of the tower and exposed area to wind should be calculated using the designed member configuration. If the assumed values appear to be unfavourable, analysis and design should be repeated with better estimates for weight and wind load.

Foundations

Foundations[5] can be broadly divided into those in soil and those in rock. Different type of foundations in soil are given in Figure 4. Some designers concrete the foundations only in the vicinity of ground level while others concrete the entire foundation. The latter is preferable as it provides better corrosion protection as well as greater weight against uplift. Different types of foundations in rock are given in Figure 5.

Foundation of a tower leg should be designed[7] to resist the horizontal shear, compression and uplift loads imposed on a tower leg.

The use of piles to support transmission line structures is limited[7], and the more popular spread foundation can be analysed as given below.

For the design spread of foundation subjected to horizontal shear, advanced analytical methods are available[7]. Due to their complexity, a simpler method is recommended[8,9] which consists of evaluating resistance to sliding as the sum of frictional resistance at the base and the passive resistance of ground in front of the foundation. For computing the frictional resistance at the base, a coefficient of friction of 0.33 is suitable for granular soils while for cohesive soils no frictional resistance is considered to be available. Passive resistance of cohesionless and cohesive soils can be obtained using appropriate formulae [8,9]. The computed value of resistance to sliding should not be less than twice the horizontal shear on the tower leg.

The ground under the foundation should carry the compressive load applied to the foundation and the weight of the foundation itself without exceeding the allowable bearing pressure, or ultimate bearing capacity with a factor of safety of 2. Ultimate bearing capacity for cohesive soils, allowable bearing pressure for cohesionless soils, and allowable bearing pressure for rocks are available[7].

Uplift resistance of a circular foundation in cohesionless soil is considered[7] to be equal to the combined weight of the concrete footing and the inverted cone of soil whose surface makes on angle of 30° to the vertical. The above value is reduced by applying a factor of safety of 2. For calculating volume of soil for square and rectangular foundations, as a conservative assumption, those can be approximated to the largest circular foundation inscribed within the square or rectangle and the above theory applied. In cohesive soils, the uplift resistance of the foundation is considered to be approximately equal[7] to the load calculated on the basis of direct bearing on the soil above the bell (or pad) together with the cohesive forces developed around the shaft surface and the weight of the footing. The above value should be reduced by applying a factor of safety of 2. For cohesive soils, when the pull is directed at an angle to the vertical, value of cohesion should be reduced by the extent specified[7].

If piles are needed to support the structure, then a pile analysis method should be used[7].

Testing

In transmission tower design, four or five standard designs are used to cover the towers needed for the entire transmission system. Thus the designer attempts to obtain maximum economy for each tower type as any saving per tower will accumulate to give a substantial saving. This is of considerable importance for suspension towers as any small saving made can lead to considerable savings in the entire project. Similarly client would like to achieve the specified factor of safety for the tower, if not the entire project is in jeopardy. Hence transmission tower remains as one of the few structures in structural engineering which is tested full-scale to destruction.

Following considerations also make testing of towers very desirable: (a) space truss idealization implies that the structure consists of pin joints capable of rotation in any direction in 3-dimensional space, which is unlikely to be achieved perpendicular to the tower sides; (b) space frame idealization implies fully rigid connections in any direction in 3-dimensional space, which is unlikely to be achieved due to difference in rigidity parallel and perpendicular to any tower side; (c) strength of compression members are different from that of tension members after onset of buckling; (d) bracings in horizontal planes in cross-sections of the tower are decided in general arbitrarily; (e) due to indeterminate form of the tower, deflections are best obtained and assessed experimentally.

Acceptance tests are conducted first by applying various load combinations with specified factors of safety. Load deformation behaviour, ability to resist the specified applied loads and ability to retain original shape after release of loads are assessed during this test.

On completion of acceptance tests, it is tested to destruction generally with loads representing normal conditions with no conductors broken, as this test generally puts maximum stress on corner legs. The applied loads are gradually and proportionately increased above the specified design load until failure occurs. A slack wire is usually attached to the tower in order to prevent complete collapse.

Research needed in the local context

Research on following areas will provide valuable design information applicable to Sri Lankan conditions and will lead to further economies in tower design: (a) Improvement of design information on preliminary proportioning of towers; (b) Refinement of Ryle's formula for determination of economic base width; (c) Refinement of Ryle's formula for determination of tower weight; (d) Economics of a tower with different bracing arrangements; (e) Economics of various foundation types; (f) Determination of economic tower spacings for transmission lines of various voltages;

(g) Comparative costs of using mild steel or high tensile steel sections for towers; and (h) Effect of different soil on total cost of the tower.

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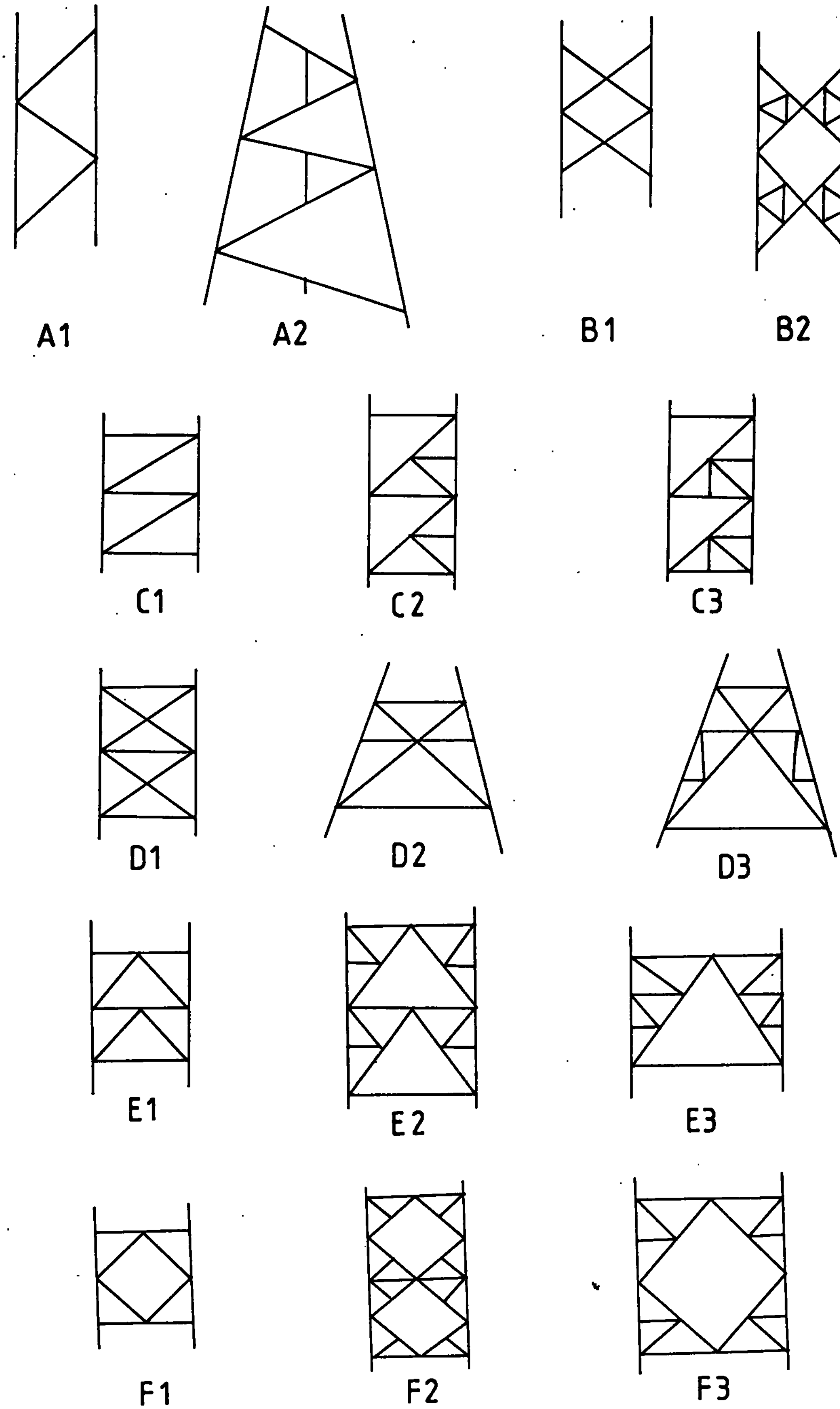
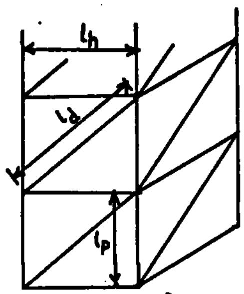


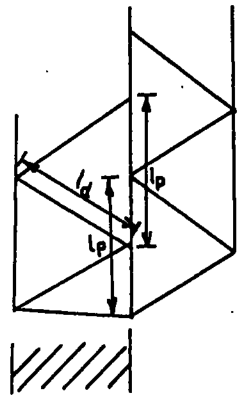
FIG.1 - STRUCTURAL FRAMING TYPES

Suffixes - p = post
d = diagonal brace
h = horizontal brace

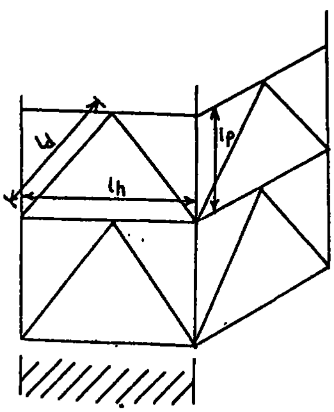


truss plane considered

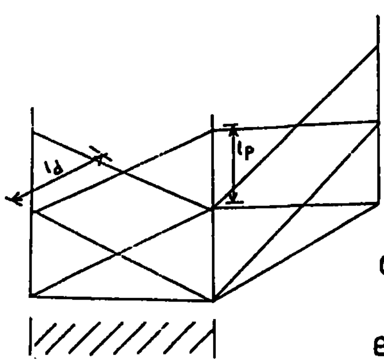
	eperp	epara	
		single bolt	more bolts
p	$0{\cdot}85\,l_p$	$0{\cdot}85\,l_p$	$0{\cdot}85\,l_p$
d	$0{\cdot}85\,l_d$	l_d	$0{\cdot}85\,l_d$
h	$0{\cdot}85\,l_h$	l_h	$0{\cdot}85\,l_h$



	eperp	epara	
		single bolt	more bolts
p	$0{\cdot}85\,l_p$	$0{\cdot}85\,l_p$	$0{\cdot}85\,l_p$
d	l_d	l_d	$0{\cdot}85\,l_d$



	eperp	epara	
		single bolt	more bolts
p	$0{\cdot}85\,l_p$	$0{\cdot}85\,l_p$	$0{\cdot}85\,l_p$
d	$1{\cdot}5\,l_d$	l_d	$0{\cdot}85\,l_d$
h	$0{\cdot}85\,l_h$	$(l_{h/2})$	$0{\cdot}85(l_{h/2})$

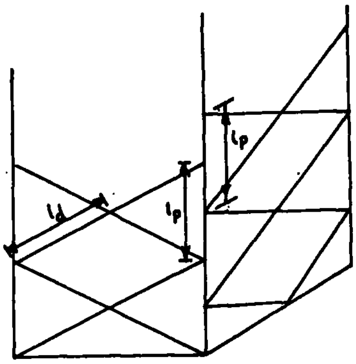


	eperp	epara	
		single bolt	more bolts
p	$0{\cdot}85\,l_p$	$0{\cdot}85\,l_p$	$0{\cdot}85\,l_p$
d	$1{\cdot}5\,l_d$	l_d	$0{\cdot}85\,l_d$

eperp. = effective length perpendicular to the truss considered

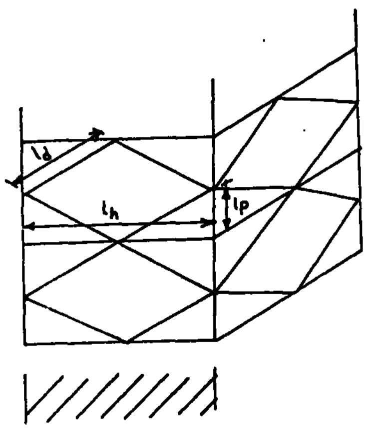
epara = effective length in the plane of the truss considered

FIG. 2 - EFFECTIVE LENGTH OF TOWER MEMBERS

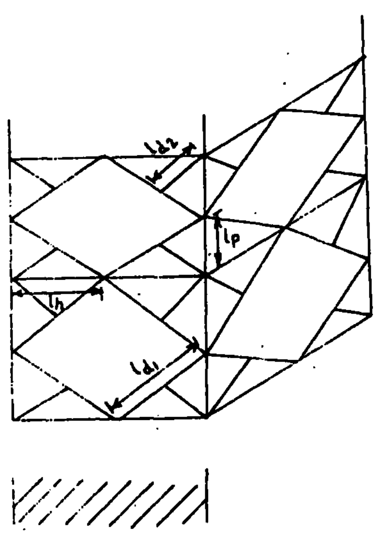


	eperp	epara	
		single bolt	more bolts
p	$0{\cdot}85\,l_p$	$0{\cdot}85\,l_p$	$0{\cdot}85\,l_p$
d	$1{\cdot}5\,l_d$	l_d	$0{\cdot}85\,l_d$

truss plane considered



	eperp	epara	
		single bolt	more bolts
p	$0{\cdot}85\,l_p$	$0{\cdot}85\,l_p$	$0{\cdot}85\,l_p$
d	$1{\cdot}5\,l_d$	l_d	$0{\cdot}85\,l_d$
h	$1{\cdot}5\,(l_h/2)$	$(l_h/2)$	$0{\cdot}85(l_h/2)$



	eperp	epara	
		single bolt	more bolts
p	$0{\cdot}85\,l_p$	$0{\cdot}85\,l_p$	$0{\cdot}85\,l_p$
d_1	$1{\cdot}5(l_{d1}/2)$	$(l_{d1}/2)$	$0{\cdot}85(l_{d1}/2)$
d2	$1{\cdot}5\,l_{d2}$	l_{d2}	$0{\cdot}85\,l_{d2}$
h	$1{\cdot}5\,l_h$	l_h	$0{\cdot}85\,l_h$

eperp = effective length perpendicular to the truss considered

epara = effective length in the plane of the truss considered

FIG. 3 - EFFECTIVE LENGTH OF TOWER MEMBERS

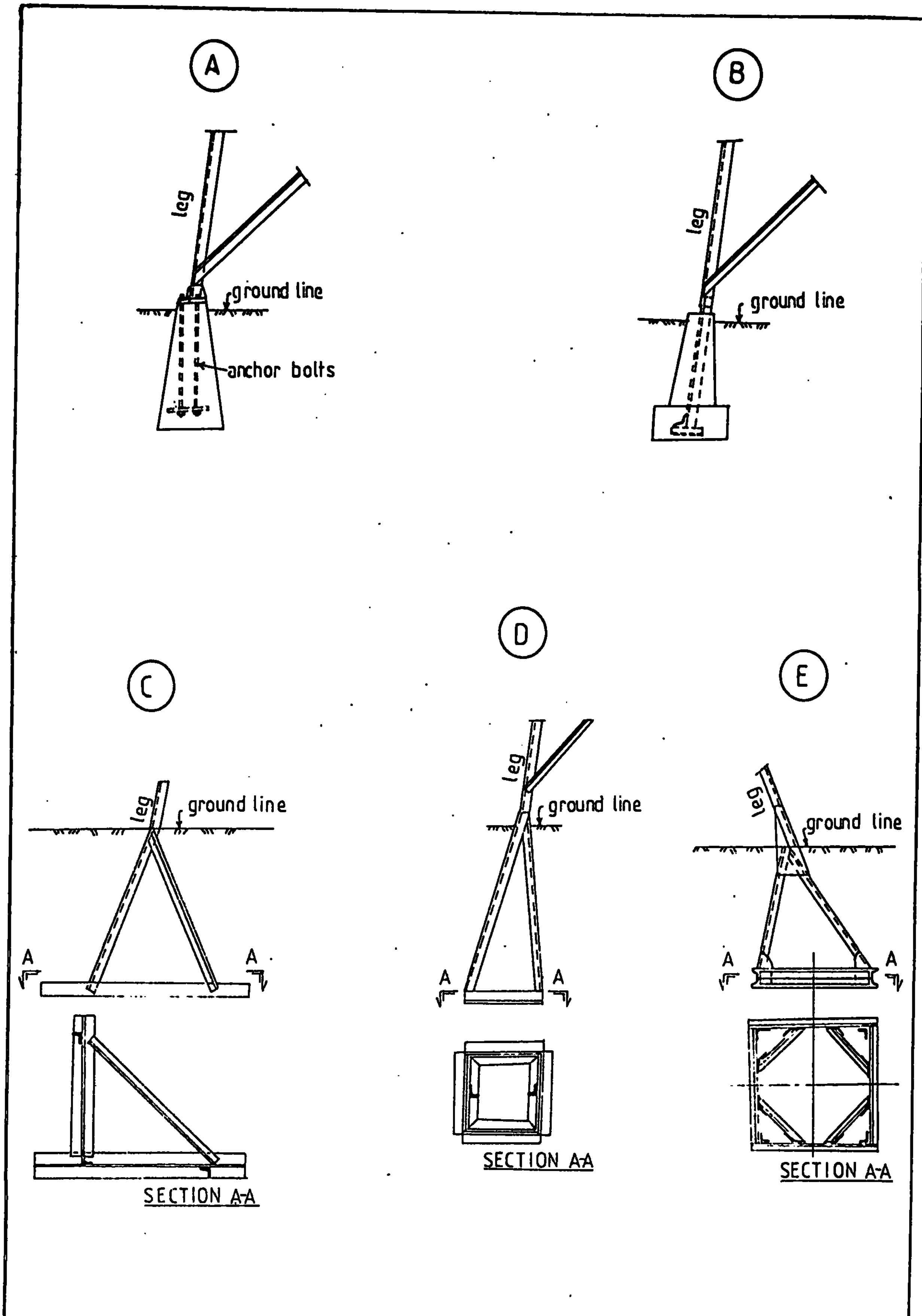


FIG. 4 - FOUNDATIONS IN SOIL

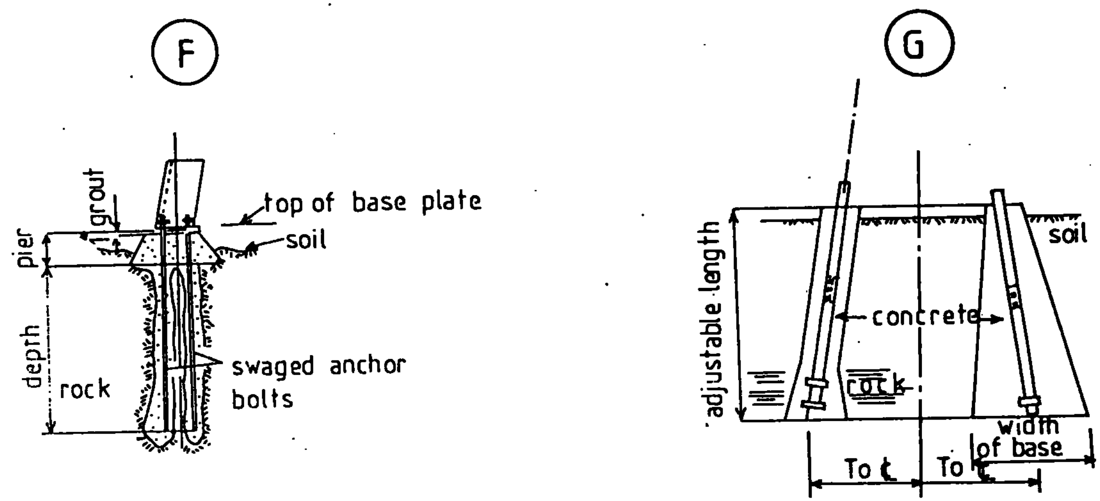


FIG. 5 - FOUNDATIONS IN ROCK