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Development of Foundation for Transmission line towers

By

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In order to design a foundation it is necessary to study the mechanical and physical characteristics of the soil or sub-soil on which the structure is to be built. Intact samples of the soil are taken to a Soil Research Laboratory for following tests :-

Specific, weight, real and apparent.

Grain size.

Indication of cavities.

Compactness.

Atterbergs indexes (limits of liquidity and plasticity)

The natural and saturation water contents.

Permeability.

Internal friction angle.

Cohesion and Compressibility.

These tests though justified for the foundation of a large structure are costly in the case of foundations of a transmission line which usually passes through several types of soils with varying characteristics and would involve a very large number of tests that would be costly. Such tests however are essential wherever soils of poor consistency are encountered. Following direct measurement tests are usually carried out.

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"Table" tests.

This test consists of loading the soil through a plate with a given area, of say 4″ × 4″ or 8″ × 8″ (Fig : 1). The depth of sinking is noted as a function of the loads and an almost curve is obtained of the form shown in Fig : (2). This curve has an almost straight line portion O A, where sinking is substantially proportionate to the load. This is the elastic zone. There is a second part AB, in which sinking increases more quickly (the plastic zone) and a third part where it increase very fast without any appreciable load. This limit is generally adopted as the break-down limit of the soil; the factor of safety is established in relation to this limit. There may be special cases in which soils may not have well defined elastic plastic and break-down limits.

Type of foundation

The foundations for towers are usually of five type (1) Solid Foundations (2) Slab Foundations (3) Vertical slab foundations (4) Independent Cube foundations (5) Piles. These are described as below :-

(1) Solid foundations :— These consist of a block in which the four legs of the tower are fixed.

This block is often in the form of a parallele piped concreted in the excavation (Fig 3). It may be hollowed out so as to reduce the quantity of concrete. It is sometimes formed of a column at the base of which are one or more sole plates This type of foundation is used for wood or concrete poles, and is sometimes called a " Stake foundation ". It differs from the previous kind simply from the fact that the relationship h/a of the height to the side 'a' is greater in the latter than in the former. The height of the block may be small and it then forms a mere slab at the surface. The thrust re-action of the soil is not of importance in this case.

.2 Slab foundations :— The slab may be burried at a certain depth below the ground instead of being at the surface, and may be either in reinforced concrete or of wooden planking or structural steel (Fig : 4). This arrangement makes it possible to extend the resistance of the foundation into the soil.

The foundation may be formed of two slabs spaced apart (Fig : 5). The wood planking foundations are much used in Germany and Sweeden for angle towers.

3. Vertical Slabs Type Foundation :- These foundations consist of two seperate blocks (Fig : 6) One transverse face of the tower is fixed, to each slab. It is thus possible to provide s wide base for resisting bending stresses. This type has been more especially used in France. but at the present time there is a preference for increasing the spread of towers in both directions and for arranging a seperate foundation per leg since this involves a smaller amount of concrete.

4. Independent Cube Foundation :— In these there is one block per leg (Fig : 7). The latter is then subjected to shearing stress and to forces of compression and wrenching.

5. Piles :— Piles may be used in place of the independent cubes, or they may carry a pressure distributing slab. They may have a swelling at the base, made either mechanically or with explosives, and this largely increases the bearing surface of the piles.

The piles are either driven into the ground or run in. Among them may be mentioned "Malone" anchoring and "Rodio" and "Forte" piles. Piles are sometimes used in normal soils into a depth of some upto suitable depths to get the proper distribution of loads depending on the load of the tower. In soils of poor consistency these are taken down to depths of 45 feet or more. With light loads a single pile is used which is set in a direction which constitutes an extension of the leg of the tower, but with heavy loads it may be necessary to use two or three piles per leg. The cost of piles is largely influenced by the question of conveyance and of installing the necessary material for sinking and driving, and it would appear that it should be possible to reduce the charges by the use of lighter equipment suitable for this type of work.

Methods of calculation for different type of foundations.

Solid foundation :- At the earlier stage of transmission line foundation design, the calculation were based on the assumption that the footing was resting directly on the ground. The pressure surface was provided so that maximum pressure on the compressed area would not exceed a selected value for the soil concerned. Later on specially in Germany account was taken of the lateral soil resistance and instead of adopting only the weight of the block and the tower with fittings as the stablising weight, there was added to this load the weight of the soil comprised in a volume limited by the planes tangent to the basic surface and forming an angle with the vertical equal to that of the " Caving-in " angle, that is 30° usually (Fig : 7A). This method is known as the " Mohr method ' . As this method results in increasing vertical load, it necessitates the width of the foundation rather than its depth and as a result makes less use of the strength of the soil. This method is now being used less & less and equations have been formulated in different countries that take the thrust of the soil into account. These equations are either purely theoratical or based on test. The standard practice on the continent is also followed in this country. Principal equations are reproduced below. For a detailed information reference can be made to the arricles by M. Carpentier in Revue Generale de Electricite.

1. French Method:- This is more commonly known as the " State-network-method". It assumes that the block turns rounds the arris " O " and that it is in equilibrium from the effect of the lateral thrust R, the lateral thrust reaction " Q " and under the pressure " P ". Writing the equation for the moment of the forces in relation to " O ". we get (Fig : 8).

$$M_r = F(H + h) = P/2\,(a - 4P / 3\delta b) + (Q - R)\,h/3.$$

δ being the maximum pressure permissable beneath the arris 0 with

$$Q = \frac{\delta h^2}{2} b \tan^2 \left(\frac{\tilde{\Pi}}{4} + \frac{\phi}{2} \right)$$

$$R = \frac{\delta h^2}{2} b \tan^2 \left(\frac{\tilde{\Pi}}{4} - \frac{\phi}{2} \right)$$

The expression for M_r is put in the form

$$M_r = P/2\,(a - \underbrace{4p}_{3\delta b}) + cbh^3$$

$$\text{with } C = -\frac{\delta}{6}\left[\tan^2 \left(\frac{\tilde{\Pi}}{4} + \frac{\phi}{2} \right) - \tan^2 \left(\frac{\tilde{\Pi}}{4} - \frac{\phi}{2} \right) \right]$$

C can be determined when δ and ϕ are known.

Following values are recommended for adopting for the coefficient C:—

Very hard soil	...	3300
Average soil	...	2000
Damp soil	...	960
Coarse sand	...	670
Fine sand	...	280

Some engineers do not take into account the negative term due to the pressure of the soil, since they consider that the soil beneath the foundation has infinite resistance and thus we get :—

$$M_r = \frac{Pa}{2} + C\ bh^3$$

(2) Swiss Method :—(Sulzblrger's equation).

1. This equation which was formulated as a result of tests by Gosgen in 1923, is based on the following presumption :—

1. The resistance of soil along vertical faces is proportional to the distance below the ground level.

2. The axis of rotation is assumed to be at a point O situated at a distance h/3 from the bottom of the excavation and at a horizontal distance a/4 from the edge of the compressed face (fig. 9). We have

$$M_r = F\left(H + \frac{2h}{3}\right) = \frac{bh^3}{36} K_o \tan a + P\left(\frac{a}{2} - 0{\cdot}47 \sqrt{\frac{p}{bk_2 \tan a}}\right)$$

with K_o, coefficient of compressibility of the soil on the lateral faces of the excavation at the depth h K_2, the same coefficient beneath the foundation; 'a' angle through which the foundation turns round the axis O under the influence of the force 'p'.

This angle is taken in first approximation, as being equal to arc tan 0·01. The vertical load is given, taking into account the soil adhering to the blocks, this being contained in a frustrum of a pyramid whose faces form an angle β with the vertical and whose smaller base is that of the block.

(3) **Belgian Methods :**—As a result of systamatic tests made on models, the Belgian investigation Committee presided over by M. Ramelot accepted the following equations :—

$$M = K_1 + k_2 h^3$$

which is valid for $h/2 > 0{\cdot}75$, with

$$K_1 = \left| 0{\cdot}5136 - \frac{0{\cdot}175}{0{\cdot}54} + \frac{b}{a} \right| ap$$

$$K_2 = \left| 0{\cdot}0042 - \frac{0.1445}{68{\cdot}5 + (100 \frac{p}{abc})^3} \right| (1 + 0{\cdot}225 \frac{a}{b}) b$$

with

b, width in centimeters of the perpendicular area of the plane of inversion.

a, width in centimeters of the area in the plane of inversion.
c, the smallest of these two dimensions.
p, vertical load in kg.

This question would give.

$$M2 = 0{\cdot}4\ pa + 2560\ bh^3.$$

with a = b and ignoring $(\frac{100p}{a3})^3$ which is small as compared with 68·5,

This can be compared with the French equation.

$$M = \frac{pa}{2} + c\,b\,h^3$$

It will be seen that the minimum value of C calculated here is higher than the figure accepted in France. For blocks in powdery soil, resistance moments will thus be obtained with the Belgian method, which are higher that those found by French method.

B:—Calculations for Slab type foundations.

1. **Two slab :**—The raised slab is calculated with the weight of the soil contained within a surface limited by planes making an angle with the vertical. In actual fact this method is preferably replaced by another which takes account of soil friction.

$$R_u = 0.8 \tan \phi \; yh^2 \; (a+b)$$

2. **Single Slab :**—It was formerly considered that there was a non-active part in the centre of the slab. and calculations were made as for the two Slab foundation. It should preferably be calculated taking into account the resultants of friction against the soil on the three faces which rise (Fig : 10).

C.—Vertical Slab blocks :—Calculation for these are made by the so called "PO" method which takes account of the thrust-re-action and friction on the lateral face.

D.—Independent Slab Foundation :— These foundations are calculated in the majority of countries by considering that the shear forces are absorbed by the thrust reaction of the soil and that resistance to wrenching corresponds to the weight of the block increased by that of the soil situated within a volume, the faces of which form an angle with the vertical equal to the angle of "Cave in" of the earth, its smallest base being that of the area of the block in contact with the soils. Certain engineers take the frustrum of a pyrmid above the level of the tower slab and thus ignore the effect of the friction of this slab on the sides of the excavation (Fig. 11). This method appears to be illogical.

The pressure on the form is checked by assuming a central force equal to the weight of the block increased by that of the soil situated on the tower slab.

E.—Piles :—Calculations for short piles can be made by the method of the volume of soil lifted, as is done for blocks. Calculations for very long piles should be made with the appropriate equations, which are numerous and diverse. Some are static equations which take account of the characteristics of soil, among which may be mentioned those attributed to :

Dorr
Benabenq
Frochlich
Ferrandon
Caquot-Kerisel.

Others are dynamic equations based on the refusal of piles. when they are being driven. The most commonly used are

The Dutch
Kreuter's
Hiley's.

The work-ability of the various equations for the different type of foundations. has been established by taking actual tests of such foundations Following description of such tests carried out by Pacific Gas and Electric Co., would bear this out. "Tests were carried out in 1928 on blocks of the shape shown in Fig : 12. They were intended to find the most economical type for the 110 KV line for Nervak to Morgan Hill.

All the excavations, except those for blocks 37 and 40, were made with an earth anger which was the cheapest way of making them.

Blocks 28, 39 and 40 were enlarged at the base by hollowing a sloping space beneath the natural soil and thus forming what is commonly called an " elephants foot type."

With Blocks 1 and 2, the enlarged place was made after completion with a special tool, whereas with blocks 5 and 6 of the Malone type the hollow was made with a charge of dynamite.

The blocks 3 and 4, the excavations were made of the some diameter as the base and the space between the Chimney and the hole was filled in.

It will be seen from the curves for these tests that the 15 cm enlargement beneath the virgin soil raised the lifting force from 15 to 35 tons for block 3, and the 20 cm enlargement for block 7 raised this force, from 25 to more than 37 tons.

A comparison between the break down loads and those calculated is given below :—

No. of test.	Resistance Calculated. R1	From test. R 2	Ratio $\frac{R\,2}{R\,1}$	Observations.
1.	13,600	38,300	2.82	
2.	7,700	25,000	3.24	
3.	7,700	16,800	2.18)	Excavation filled in $7\frac{1}{2}$ months
4.	7,700	17,200	2.24)	before test.
5.	8,600	25,000	2.90)	
6.	...	—	...	
7.	...	37,000	...	
38.	...	33,000	—	
38 (a)	15,900	16,100	1.00)	Excavation filled in 2 weeks
40.	15,900	24,500	1.55)	before test.

As a result of these tests the Pacific Gas and Electric Co., Chose block 39 as being the easiest to make ; the excavation being vertical.

The results for this tower are not given because of premature fracture of the concrete, Fig : 13 gives the different lifts as a function of the force applied."

In the transmission lines erected on lattice steel towers in the Punjab (Uhl River Project) the earlier form of foundation was that popularly known as the "Grillage Type" (Fig : 14). This consists of an angle usually of the same section as the main tower leg, joining it, with a strong frame fabricated from angle section tied down to it at the base. The frame is embeded in concrete so as to give it a covering. The vertical leg is however covered with a thick coating of bitumen. Presence of excessive salts in the alluvium of the Punjab plain however soon made it necessary to cover the stub angle also with concrete as the salts had begun to attack the same. This type of foundation though very popular in the United States, has been given up by us in favour of a type composed of a pyramid and a chimney shrouding the stub angle. Cleats are attached to the stub angles to ensure a better grip with concrete. This type of foundation has been used on transmission lines of the Rasul project. Incidentlv this type is also adopted for the transmission lines of the British Electricity Authority for their 66 KV, 132 & 275 KV lines of rigid construction A typical block of a 275 KV footing is shown in Fig : 15. This type of foundation has almost all the advantage of a grillage type foundation and in addition provides a suitable covering to the steel angle against salt attacks. It is further argued that the concrete covering also helps in dissipating part of the shear stresses which are prominent near the ground line. The concrete covering is usually carried to about one foot above this line. This type of foundation allows of the use of steel formers for their casting in excavated pits. and is thus conducive to economy in the cost of erection. Another type of foundation that has been used in the Punjab and N.-W. F. P., is the cube type as shown in Fig : 16. This was used on the 132 KV line connecting the former N.W.-F.P.,and Punjab Grids, between Dargai and Jhelum.

The comparatively large volume of foundation block permitted of the use of a leaner mixture which considerably eased the situation.

A very serious problem in preparing the conventional pyramid type foundations which needs greater depth in the canal irrigated areas is the water logged condition of the soil. In most cases along the lower Jhelum and lower Chenab Canals we had to provide a 6" thick pad for each footing on which the foundation was cost In other cases where the soil was too water logged and did not permit of excavation beyond a few feet without costly timbering and shoring the footings were placed only two to three feet below ground surface and raised earth platforms had to be provided to give the foundation the desired stability. This however materially added to the cost.

It seems that towers for lines in the water logged areas shall have to be designed with a broad base so that the foundation may not have to go deep. This would add to the cost of the steel structure but may be off-set by a saving in the cost of placing foundations at a greater depth An alternative to this would be pile foundations but these have not so far been tried in our conditions.

Special positions of towers requires special treatment, *e.g*, for the river crossing towers that have to be placed in a soil usually saturated, the conventional type of solid or slab foundation cannot be built because the laying of the slab below the saturated soil involves heavy pumping and is not economical. At such locations well type of foundations are provided, The wells can be sunk easily in such cases and are generally taken down to firm strata. The depth of the wells safeguards against any scour due to flow. A typical foundation used on Chenab X'ng tower is shown in fig. 17.

Even the anchor towers which are placed immediately at the back of the crossing towers are prvided with similar foundations. In this case a relatively deeper foundation is necessary. Such foundations installed on Uhl River project lines have with-stood the test of time and have shown no weakness to this day. Each such foundation is tested under artificially provided load of pig iron which allows the well foundation to settle before the same is sealed off finally at the bottom and upper structure erected thereon

At places where the soil is more compact the conventional raft foundation has provided to be good enough. An example of this type of foundation would be seen on the special river crossing tower installed at Mangla where the 132 Kv lines crosses the river Jhelum, as also on the Jatli stream crossing on the Upper Jhelum canal. The ground at both these places was firm and allowed of this type of construction. Fig : 18 gives an idea of such a foundation.

An account of the foundations for the Bhimber Nallah crossing towers near Gujrat will be found interesting. Here the span of the Nallah did not necessitate installing towers of a special height. The crossing was therefore, done on a ordinary 10° degree tower placed in a straight line position. A raft type foundation was designed for it. The raft proposed to be laid at a depth of 9 feet. In order to prepare a hamogenous base a 10" thick pad of ordinary P C. concrete 1 : 3 : 6 ratio was spread. This pad did not hold and sank. It was concluded that a raft foundation was not suitable and a well type foundation was tried at a different point. This foundation too gave way under subsidence load and was not considered safe A compromise was, therefore, effected by adding a raft to the top of the wells as shown in fig : 10. The entire vertical load was to be taken by the raft which was placed only a few feet below the ground level where the soil was pretty stable. The shells of the well foundation were to provide the extra stabilising load and whatever frictional resistance they could offer against vertical movement. A raised embankment was added to the foundation so as to make it stable against upward movements under broken wire conditions. The failure of the well type of foundation of this place was attributed to Collodial clay under the foundation, which when dry was fairly hard but as soon as the Nallah was in flood was rendered extremely plastic by the water which penetrated through the banks.

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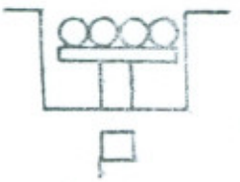

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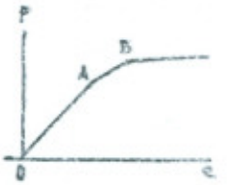

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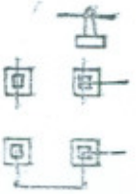

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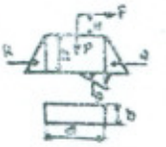

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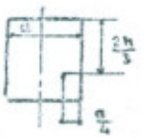

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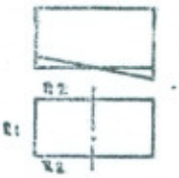

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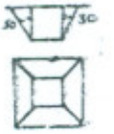

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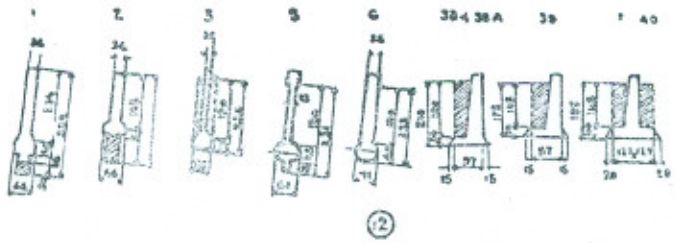

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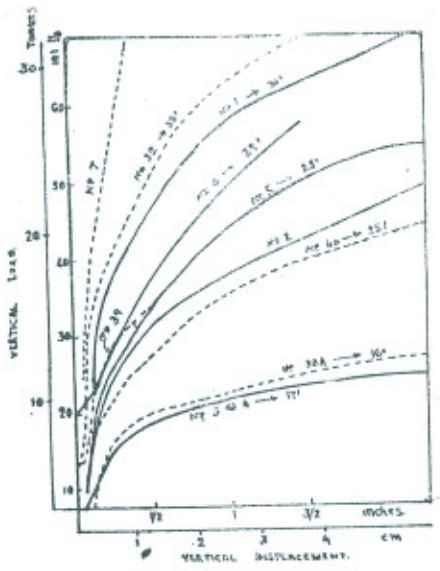

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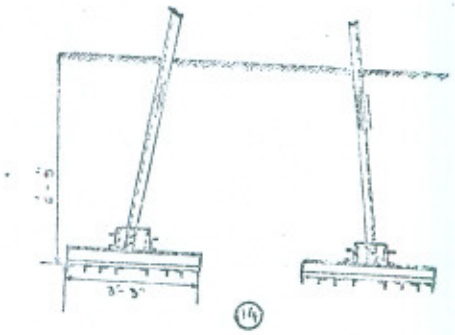

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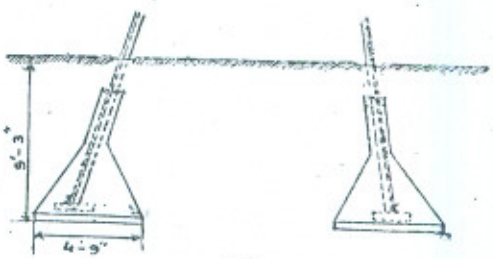

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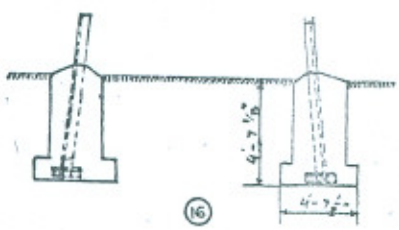

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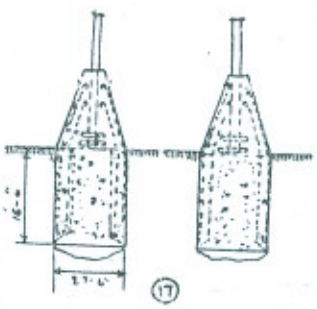

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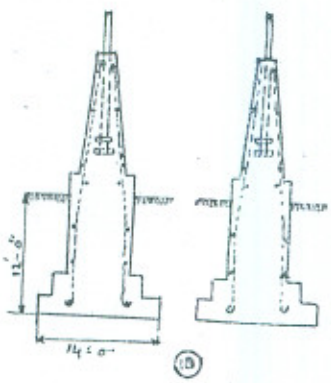

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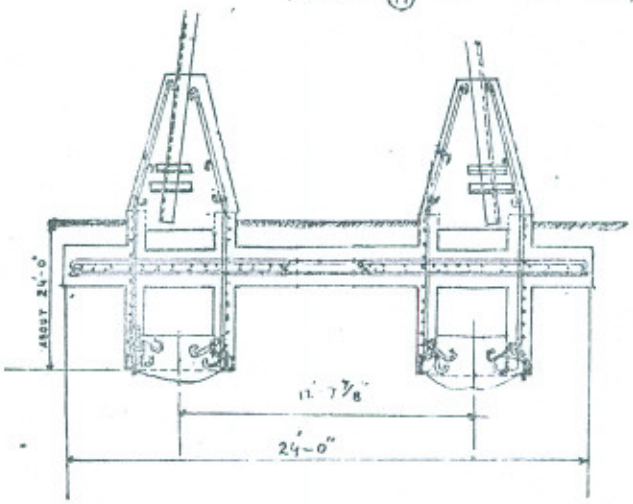

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