Fundamentals of Transmission Line Tower Foundations and Some Life Extension Measures for New Lines

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Abstract--- *Transmission line towers are vital for facilitating power transmission from generation to load centers. Transmission line towers of various configurations and designs have to be constructed to different specifications. Many of the transmission line towers are passing though areas of different environmental conditions causing adverse effect on the life of such important structures. In this article various types of transmission line tower foundations being practiced in our country and causes for failures of foundation have been discussed. Life extension measures for new transmission line tower foundations have been presented.*

I. INTRODUCTION

ELECTRICAL energy is the most convenient and cleanest form of energy and is being utilized in a larger way across the world for the development and growth of economy. Therefore the generation, transmission and utilization of the electrical energy is ever increasing. The electric power generated in various power stations at lower voltage level at 6.6 kV / 11 kV / 15.75 kV / 22 kV has to be stepped up to an extra higher voltage level using generating transformers at 66 kV / 110 kV / 220 kV / 230 kV / 400 kV/765 kV in order to reduce the transmission loss while transmitting power to the distribution ends. For facilitating transmission of such an extra high voltage power, transmission towers of different designs are constructed in various places connecting substations to substations and sub stations to generating station forming a transmission network. The sizes of transmission line towers are increasing because of the present day high, extra high and ultra high voltage transmission, resulting in heavier loads and as such requiring bigger and heavier foundations. A large number of foundations are normally required in any transmission line project making the total cost of foundations in a transmission line project a quite substantial one. Apart from the financial aspects, past records show the failures of tower foundations have also been responsible for collapse of towers. These failures have usually been associated with certain deficiencies either in the design or classification or construction of foundations.

From engineering point of view, the task of design and selection of most suitable type of tower foundation is really a challenging one because of the variety of soil conditions encountered enroute the transmission line and remoteness of construction sites.

II. BASICS OF TRANSMISSION TOWER FOUNDATIONS

The foundations in various types of soils have to be designed to suit the soil conditions of particular type. In addition to foundation of normal towers, there are situations where one has to decide the most suitable type of foundation system considering techno - economical aspects for special towers where river crossings are encountered. This is generally decided based on the actual river crossing requirements; and the choice of type of foundation and its design would be based on actual soil exploration data, high flood level, velocity of water, scour depth etc. Santhakumar .A.R. and Murthy. S.S. (1990) have presented different types of transmission line tower foundations rising due to varied soil conditions and water table as below.

A. Normal Dry Soil Foundations

In this type of foundation, water table is below foundation level. Soil is cohesive and homogeneous up to the full depth. Clay content is between 10 -15%.

B. Wet Soil Foundations

In this type of foundation, water table is above foundation level and up to 1.5 m below ground level. The foundation in the soil which has standing surface water for a long period with water penetration not exceeding 1.0 m below ground level (e.g. Paddy fields).

C. Partially Submerged Foundations

In this type of foundation, water table is at a depth between 1.5 m and 0.75 m below ground level and the soil is normal and cohesive.

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D. Fully Submerged Foundations

In this type of foundation, water table is within 0.75m below ground and the soil is normal and cohesive.

E. Black Cotton Soil Foundations

In this type, the soil is cohesive, having inorganic clay exceeding 15% and characterized by high shrinkage and swelling property.

F. Partial Black Cotton Soil Foundations

Here the top layer of soil up to 1.5 m is black cotton. Thereafter it is normal dry cohesive soil.

G. Soft Rock / Fissured Rock Foundations

When decomposed or fissured rock, hard gravel or any other soil of similar nature is met, which can be executed without blasting under- cut foundation is to be used at these locations.

H. Hard Rock Foundations

Hard rock foundation is chosen when cleaning, drilling and blasting and blasting operations are required for excavation.

I. Sandy Soil foundations

Sandy Soil Foundation is provided when the soil present in the site is with negligible cohesion because of its low clay content (0 -10%).

III. TYPES OF TRANSMISSION TOWER FOUNDATIONS

Based on structural arrangement of foundation, various types of foundation are possible. The necessity of erecting towers on a variety of soils has made it possible and necessary for the designers to adopt new innovations and techniques. Chinnasamy.K. (1992) had discussed several types of tower foundations that have been devised and successfully used. They are as below.

A. PCC Type

This Type of foundation consists of a plain concrete footing pad with reinforced chimney. This is the most common type of footing used in India and in some countries of the continent. It consists of a plain concrete footing pad with reinforced chimney. In this type of foundation, the stub angle is taken inside and

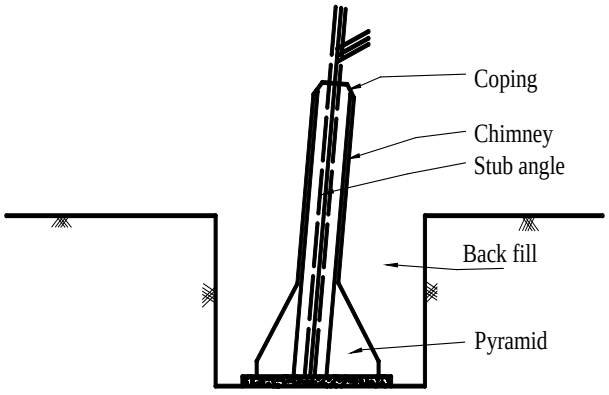

Fig. 1: PCC Type Pyramid Foundation

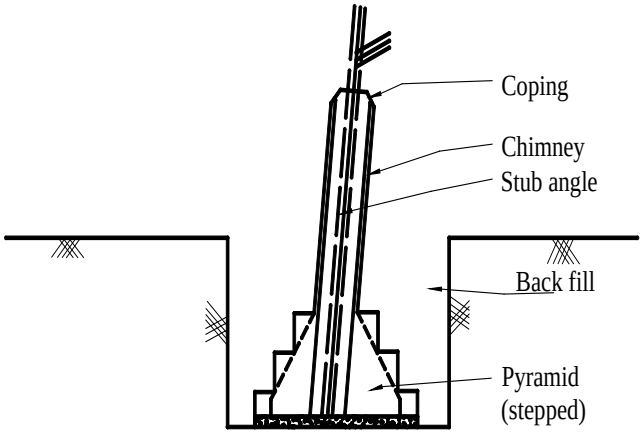

Fig .2: PCC Type Stepped Foundation

Effectively anchored to the bottom pad by cleat angles and / or keying rods, and the chimney with reinforcement and stub angle inside works as a composite member. The pad may be either pyramidal in shape as shown in Fig.1 or stepped in shape as shown in Fig.2. Stepped footings will require less shuttering materials but need more attention during construction to avoid cold joints between the steps.

B. RCC Type

It consists of a RCC base slab or mat and a square chimney. There are several types of RCC foundations. One such type is RCC spread type foundation (Chamfered Type) as shown in Fig.3

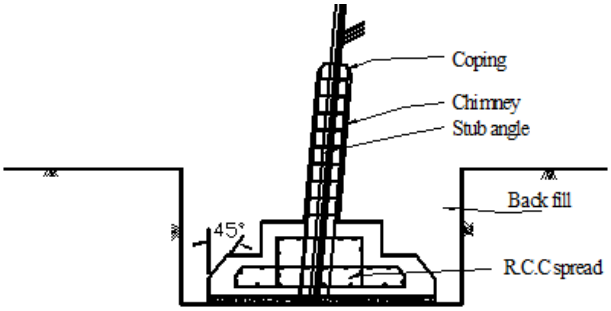

Fig. 3: RCC Spread Type Foundation (Chamfered Type)

The RCC spread footing can be suitably designed for variety of soil conditions. RCC footings in some situations can be higher in cost although structurally these are the best. When loads on foundations are heavy and / soils poor, the pyramid type foundations may not be feasible for techno economical considerations. Under such situations, RCC spread type footings are technically superior and economical.

C. Block Type

This type of foundation is shown in Fig.4. It consists of a chimney and block of concrete. This type of foundation is usually provided where soft and soft rock, soil mixed with clinker, where soil is not collapsible type i.e., it can stand by itself.

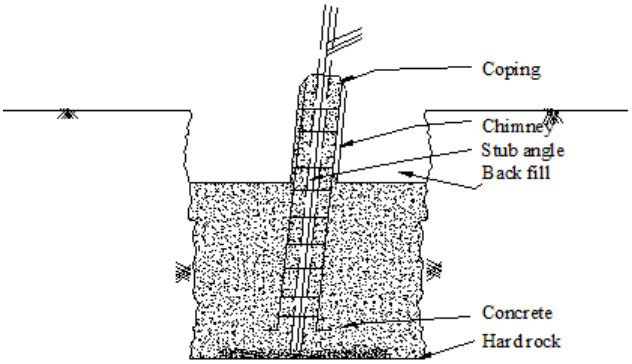

Fig. 4: Block Type Foundation (Friction Type)

Hard rock strata are encountered at the tower location. In this type of foundation, concrete is poured in direct contact with the inner surfaces of the excavated rock so that concrete develops bond with rock. The uplift resistance in this type of footing is provided by the bond between concrete and rock. The thickness and size of the block is decided based on uplift capacity of foundation and bearing area required.

D. Under Cut Type

The different type of undercut foundations is shown in Fig. 5 and Fig. 6. These are constructed by making under cut in soil / rock at foundation level. This type of foundation is very useful in normal dry cohesive soil, hard morrum, fissured /

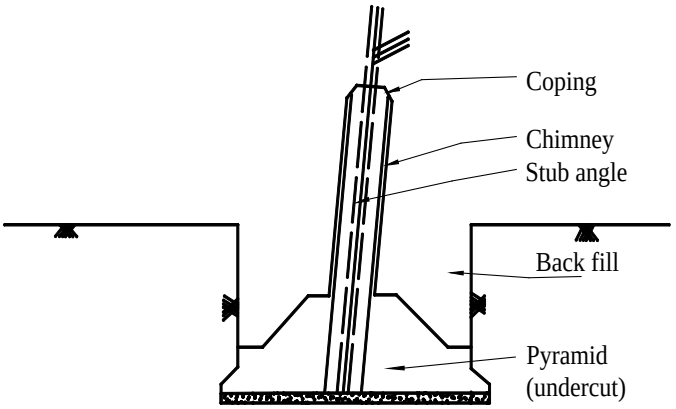

Fig. 5: Pyramid Type Foundation (Under Cut)

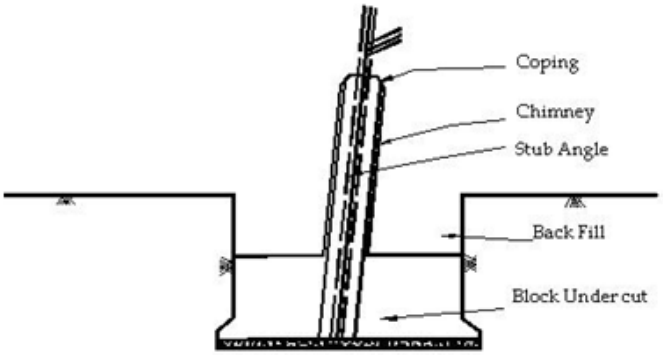

Fig.6: Block Foundation (Under Cut)

A footing with an undercut generally develops higher uplift resistance as compared to that of an identical footing without under cut. This is due to the exchange in undisturbed virgin soil. The size of undercut shall not be less than 150 mm. At the discretion of power utility and based on the cohesiveness of the normal dry soil, the owner may permit undercut type of foundation for normal dry cohesive soil.

E. Augur Type

Typical Augur type footings are shown in Fig. 7 and Fig. 8.The cast-in-situ reinforced concrete augured footings has been extensively used in some western countries like USA, Canada and many Asian countries. The primary benefits derived from this type of foundations are the saving in time and manpower. Holes can be driven upto one meter diameter and six meter deep. Since, the excavated hole has to stand for some time before reinforcing bars and cage can be placed in position and concrete poured. Usually, stiff clays and dense sands are capable of being drilled and standing up sufficiently long for concreting works and installation of stub angle or anchor bolts, whereas loose granular materials may give

trouble during construction of these footing. Betonies slurry or similar material is used to stabilize the drilled hole. In soft soils, a steel casing can also be lowered into the hole as the excavation proceeds to hold the hole open.

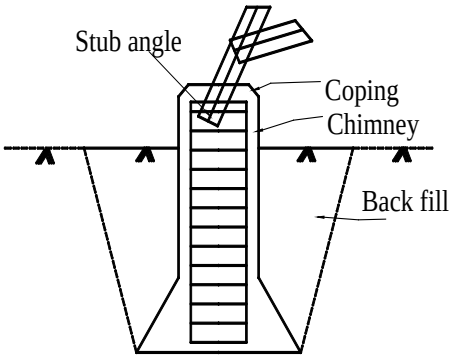

Fig. 7: Augur Type Foundation (Vertical)

Augured footing can be constructed according to the requirements, vertical or battered and with or without expanded base.The under-reamed piles are more or less similar to augured footings except that they have under reaming above bottom of shaft. These can be generally constructed with hand augur. The bore in drilled vertically or at a batter with the augur, having an arrangement of cutting flanges (edges) to be opened by the lever. This arrangement makes it possible to make under-reams at various levels of bores as shown Fig.9. The advantage of this foundation is faster construction.

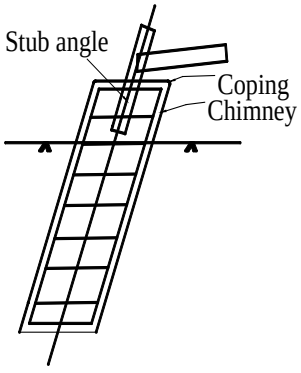

Fig. 8: Augur Type Foundation (Battered)

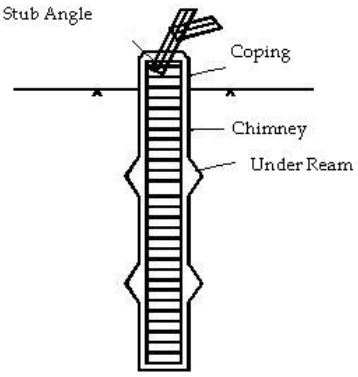

Fig. 9: Augur Type Foundation (Under Reamed Type)

The determination of whether a rock formation is suitable for installation of rock anchors is an engineering judgment based on rock quality. Since, the bearing capacity of rock is usually much greater, care must be exercised in designing for uplift. The rock surfaces may be roughened, grooved, or shaped to increase the uplift capacity. The uplift resistance will be determined by considering the bond between reinforcement bar and grout / concrete. However, an independent check for uplift resistance should be carried out by considering the bond between rock and concrete block which in turn will determine the minimum depth of concrete block to be provided in hard rock. Anchor strength can be substantially increased by provision of mechanical anchorages, such as use of eye bolt, fox bolt or threaded rods as anchoring bars or use of keying rods in case of stub angle anchoring. The effective anchoring strength should preferably be determined by testing.

F. Pile Type

This type of foundation is usually adopted when soil is very weak and has very poor bearing capacity or foundation has to be located in filled up soil or sea mud to a large depth or where tower location falls within river bed and creek bed which are likely to be scoured during floods. The pile foundations are designed based on the data of soil exploration at the tower location. The important parameters for design of pile foundation are the type of soil, angle of internal cohesion and unit weight of soil at various depths along the shaft of pile, maximum discharge of the river, maximum velocity of water, high floor level, secure depth etc.,.Pile foundation usually costs more and may be adopted only after detailed examination of the site conditions and soil data. The downward vertical load on the foundation is carried by the piles through skin friction or by point bearing or both; while the uplift is resisted by the dead weight of the concrete in piles and pile caps and frictional resistance between pile and soil surrounding the pile. For carrying heavy lateral loads, battered piles may be advantageously used. Piles are of different types

such as driven pre-cast pile, cast-in-situ concrete bored piles and cast-in-situ concrete driven piles. Concrete driven piles whether pre-cast or cast-in-situ, requires heavy machinery for their construction and as such they are not used for transmission line tower foundations because of remoteness of the sites and small volume of work. A typical pile foundation is shown in Fig.10.

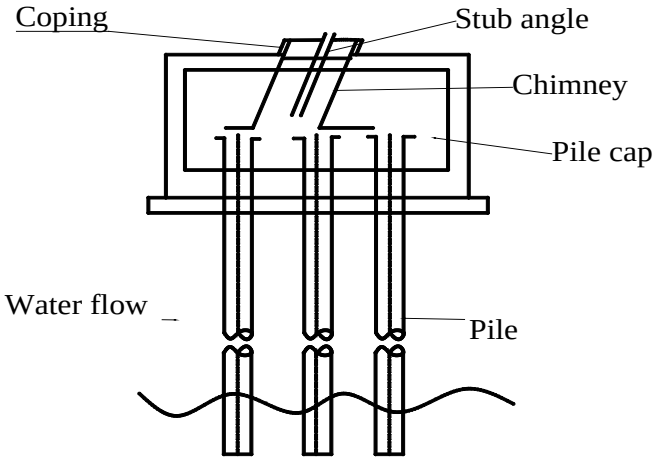

Fig. 10: Pile Foundation

G. Well Type

This type of foundation is usually provided where tower location falls within the course of major river having larger discharge, heavy floods during monsoon and large scouring of river bed during floods. The cast-in-situ wells of RCC or brick masonry are sunk by continuous excavation from within the wells. The basic parameters required for the design of well are soil properties like angle of internal cohesion, density at various levels along the depth of well, maximum flood discharge, maximum velocity of water etc. The well has to be taken below the estimated scour level to a sufficient depth for obtaining desired depth of the well. Central edge may have to be used during driving of the well for penetrating the hard strata and also to prevent its tilting during sinking operation. A typical well type of foundation for transmission line tower is shown in Fig.1.11.

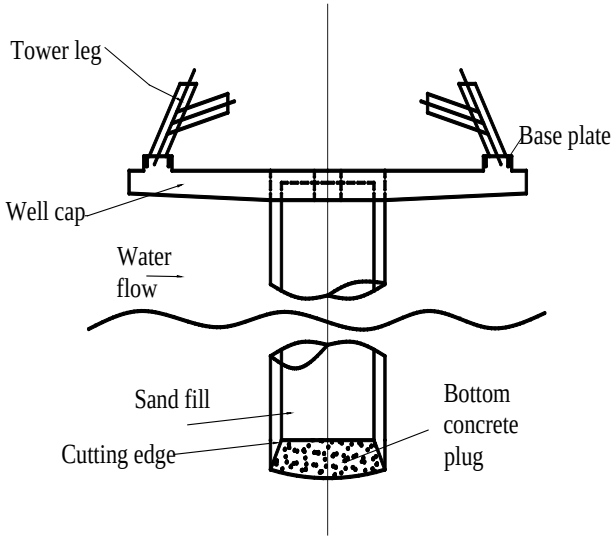

Fig. 11: Well Type Foundation

The top of the well is normally kept above the high flood level. After the well has been sunk to its design depth, the well is filled up with sand and suitable well cap is constructed on the top of the well to accommodate the lower end and its anchor bolts / stubs. The filled up well acts as solid pier. Well type foundations are very costly and require more time for their construction and may be adopted only after detailed examination of the site conditions and soil data.

H. Steel Grillage Type

The grillage is designed to resist the down thrust and uplift. The angle of earth frustum is developed from the bottom of the footing. In this type of foundations, there is no need of solid slab as compared to concrete foundations. These foundations are very helpful in restoring the collapsed transmission lines because of quicker construction. These types of foundations are generally provided in case of firm soils and are usually adopted for locations where concreting is not possible and head loading is difficult.

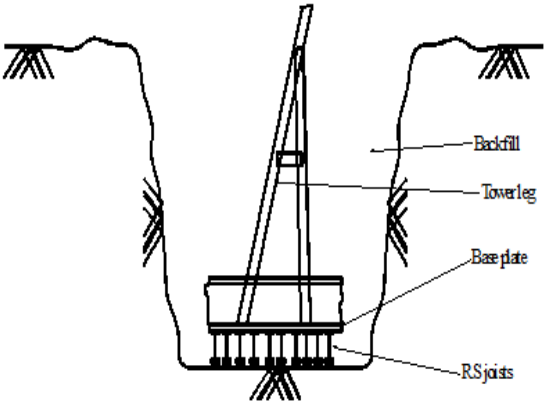

Fig. 12: Steel Grillage Type Foundation

A typical steel grillage type foundation is shown in Fig.12. They require much more steel than a comparable concrete footing, but erection cost is small in comparison with that.

IV. Durability Related Issues

The penetration of water, chloride, and other aggressive ions into concrete is the most important factor in the physical and chemical process of deterioration. It is the micro structure of the concrete that mainly controls the physical / chemical phenomena associated with water movements and the transport of ions in concrete. A variety of factors may govern the transport of these fluids into concrete. Some of the factors are - the substance flowing and its concentration, the environmental conditions, the pore structure of the concrete, the pore radius, the degree of saturation of the pore system and the temperature. Considering the wide range of pore sizes and varying moisture conditions in the concrete as a function of the climate exposure, the transport of fluid into concrete occurs not due to one single mechanism but due to several mechanisms, tend to act simultaneously. The micro structure of the concrete is strongly affected by several factors including chemical composition of cement, water to cement ratio and amount of mineral admixtures, particle size, distribution of cementitious materials and the aggregate. Therefore in order to improve the durability of concrete, the mixture proportions of concrete should be carefully selected, considering the effect of durability. The permeability of concrete depends on the porosity and on the connectivity of the pores. More the opening of pore structure of the concrete, the more vulnerable will be for materials to degradation mechanism, caused by penetrating substances. SubramaniaPillai, (2002) and Taklakar .S.M, (2005)had classified the common defects and durability related issues in transmission line tower foundations as below.

A. Under Sizing of Foundation due to Wrong Classification of Soil

The soil may be dry black cotton but the foundation cast may be that for normal dry soil. If the corrective measures are not taken, the foundation can fail.

B. Improper Formation of Pyramid / Chimney etc. due to Improper Concrete Laying

If the concrete is simply poured from the top of the form box, without taking care to fill the voids using Crow bar or Vibrator etc., the concrete does not reach to the bottom of the form and thus the foundation may not be completely formed.

C. Damage to Stub Top Part of the Chimney

Due to ingress of saline water or other chemical pollutants etc., the stub top part of the steel in the chimney gets corroded. Repairing can be done by welding the damaged portion of the stub and providing RCC collar to the damaged chimney top. For providing a welded joint, the part of the cast concrete in the top part of the chimney is broken.

Most of the Pyramid and Chimney type foundations in Tata power system are located in highly polluted areas of Mumbai city and suburbs. Usually, defects observed in these types of foundations are cracking of concrete and corrosion of reinforcement steel due to weathering action.

D. Design Deficiency

The chances of failure due to design deficiency are comparatively less, while those due to construction deficiency and deterioration are common. This is due to the reason that higher factor of safety in design takes care of any eventuality. The design deficiency will be derived out of over estimation of design parameters or under estimation of design loads. The design parameters like safe bearing capacity of soil, soil density, angle of repose, minimum depth of foundation have to be well within limit. Otherwise the chances of failure will increase. On the other hand, conservative estimation of these parameters will tend to make the foundations very expensive (without much justification). This type of deficiency will result in the failure due to settlement as in Fig. 13. or due to uplift as in Fig .14.

Other form of design deficiency can be the improper layout of the reinforcement. In most of the cases, it is not possible to pour the total concrete quantity at a time due to site conditions. The result would be uprooting of chimney and stub leaving the pad and the cleat in the soil or uprooting of chimney clear & stub leaving the pad below.

The most unknown design deficiency is the unworkable foundation design, while offering the most competitive quantities of foundation. Sometimes

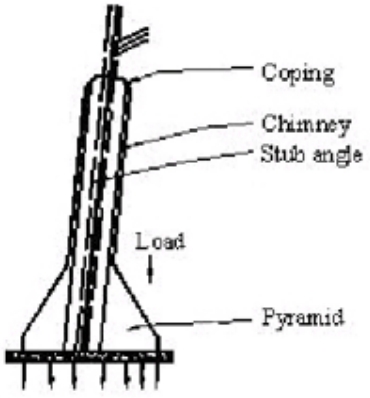

Fig. 13: Failure due to Settlement

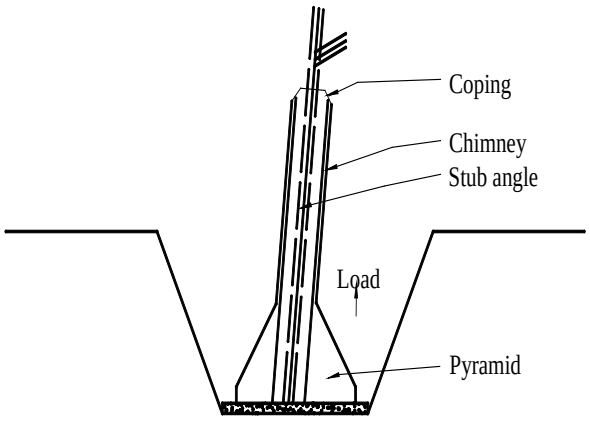

Fig. 14: Failure due to Uplift

The construction part is forgotten. The result is improper formation or footing which may fall short of the design load requirement.

E. Construction Deficiency

The construction deficiencies include:

- Eccentricity of stub in chimney.
- Improper shaping of the footing. (Fig. 15)
- Excess excavation in depth & width.
- Improportionate concrete mix.
- Improper classification of soil.

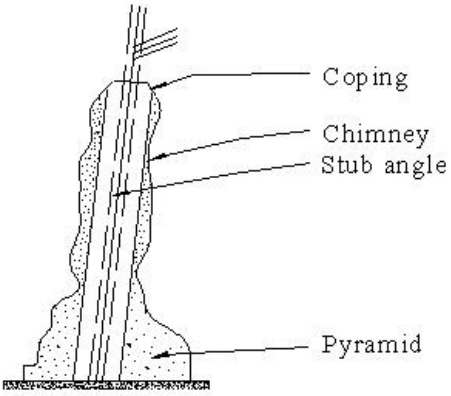

Fig. 15: Improper Shaping of Footing

The eccentricity of the stub in chimney may result into uneven distribution of stress along the length and the cross section of the chimney. It may result into cracking and shearing of the chimney, thus exposing the stub to the soil and water. The improper shaping of the footing takes place due to improper handling of concrete in the form boxes. Insufficient concrete volume cannot withstand the test of design loads. If the excavation exceeds the approved excavation plan dimensions, the footing may face decrement in its designed strength and therefore may tend to fail. If the depth is excess, the foundation may settle under downward load.

F. Deterioration due to the passage of time

In transmission line towers, the tower legs are usually set in concrete which generally provides good protection to the steel. However defects and cracks in the concrete can allow water and salts to penetrate with subsequent corrosion and weakening of the leg. When ferrous materials oxidized to ferrous oxide (corrosion product), its volume is obviously more than original ferrous material; hence the chimney concrete will undergo strain resulting in formation of cracks. The cracks open, draining the water into chimney concrete enhancing the corrosion process resulting finally in spalling of chimney concrete. This form of corrosion of stub angle just above the muffing or within the muffing is very common in saline areas. If this is not attended at proper time, the tower may collapse under abnormal climatic conditions. Factors like improper selection of tower and tower foundation, poor grade of concrete, inferior quality of concrete, insufficient curing of coping / muffing concrete, wrong shape of coping, improper selection of angles, paints, improper alignments, stub levels, and improper tightening of bolts, etc., will directly or indirectly affects the durability of tower foundations.

V. Life Extension Measures for Transmission Line Tower Foundations

The transmission line towers are of a variety of configurations and designs, constructed to different specifications. Many of the transmission line towers are passing though the coastal lines and this has adverse effect on the durability of transmission line tower foundations. The transmission line towers running in industrial areas are very much affected by industrial wastes and other chemical pollutants. Transmission line towers running through agricultural fields are affected by fertilizers like ammonia and other manures.

Based on a systematic real time investigations Christian Johnson (2010) have suggested the following life extension measures for new transmission line tower foundations.

VI. General

- Coping should be formed in a slanting way (cone shape) in order to drip down the water without stagnation at stub angle / concrete interface.
- If curing is difficult due to distant factor, self curing concrete may be provided and checked with measurements.

- Recommendations in IS 456: 2000 and IS 800: 2007 for various exposure conditions in regard to cover concrete, mix design, w/c ratio and usage of mineral admixtures like fly ash, silica fume and paints etc., should be followed.
- In extremely contaminated areas with chloride and other pollutants, paints specified in IS 800: 2007 can be tried to withstand the pitting corrosion in tower body.
- Bearing capacity of the soil should be verified. If the bearing capacity of soil is very low such as clay soil, black cotton soil, recently made up soil, water logged soils, RCC type foundation should be proposed at least 0.30m depth and three level coatings to be followed.
- During the excavation of the pit unequal foundation depth should be avoided or otherwise unequal settlement of the tower foundation will occur during stringing operation.
- Improper stub levels, alignments, without cleat in the stub bottom, improper tightening of the cleat should be avoided during the concreting.
- Poor quality of concrete materials such as sand, metal, cement and water should be avoided
- The tower foundation concrete frustum and chimney form box should be smooth.
- Proper consolidation of concrete should be verified during the concreting otherwise one of the tower leg will topple during the stringing operation.
- The template should be dismantled after proper back filling and consolidation of the back filling or otherwise counter weight of the tower foundation will not act.
- All the tower foundation concrete should be consolidated by vibrator or otherwise self compacting concrete should be recommended.

VII. Inland Plain Areas

- The concrete used in chimney as well as in coping and muffing of transmission tower foundations should be minimum of M 20 as per IS 456: 2000
- In the wet areas single level protection may be made as below.
- Application of readily available coating on the stub angle surface for 1.0m below and 1.0 m above the ground level.
- In dry areas single level protections like FACSR coating on stub angle surface for 1.0m above and below the ground level.
- In both the wet and dry cases, provision of O- ring out of Demech deep pour grout at the stub angle coping concrete interface should be introduced.
- 20 % Cement replacement by fly ash or use of PPC (PortlandPozzolanacement)or blended is preferred for construction of transmission line tower foundations.

VIII. Agricultural or Hilly Areas

- The concrete used in chimney as well as in coping / muffing of transmission tower foundations should be minimum of M 20 as per IS 456: 2000
- In agricultural areas, two level protections can be made as below.
- FACSR coating on the stub angle, 1.0 m below and 1.0 m above the ground level.
- Nano penetrant coating on the concrete surface of the coping concrete, 1.0 m below the ground level
- O - ring to be provided in the stub angle concrete / coping interface by pouring the Demech chemical deep grout.
- 20% fly ash as cement replacement or use of PPC or blended cement is preferred for making transmission tower foundation concrete.

IX. Coastal or Industrial Areas

- The concrete used in chimney as well as in coping and muffing of transmission tower foundations should be a minimum of M25 concrete as per IS 456: 2000 depending upon the exposure conditions.
- Three level protections may be made as below.
- FACSR coating on the stub angle to the full length of the stub and 1.0 m above the ground level.
- 20 % Cement replacement by fly Ash in the concrete or use of blended cement or PPC and addition of 2% Silplas super(Super plasticizer) in the concrete with reduced water cement ratio.
- FACSR coating or Nano penetrant on the concrete surface of coping and muffing area and 1.0 m below ground level.
- O-ring to be provided in the stub angle concrete interface by pouring the Demech deep grout chemical.

X. Coastal Cum Industrial Areas

The concrete used in chimney as well as in coping and muffing of transmission tower foundations should be a minimum of M 30 as per IS 456: 2000 depending upon the exposure conditions.

- Three level protections may be made as below.
- Demech coating on the stub angle to the full length of the stub and 2.0m above the ground level.
- 20 % Cement replacement by fly Ash in the concrete or use of PPC / blended cement and addition of 2 % Silpas super (Super plasticizer)for making tower foundations.
- Nano penetrant coating on the whole concrete surface area of the foundation including pedestal sides and bottom, stub coping and muffing.
- Demech Deep pour grout should be introduced at the interface.

Besides the above, following provisions also can be included based on the site conditions

- RCC cage can be recommended in vulnerable area incorporating coatings on reinforcements and admixtures in concrete.
- Based on durability point of view, in the coastal lines and industrial pollution areas, high performance concrete should be used. High performance concrete is not costlier than ordinary concrete, but by means of replacing certain quantities of cement with fly ash or silica fume, good performance can be achieved
- Sulphate resisting cement may also be recommended in foundations of industrial cum coastal areas.

XI. Conclusion

A glimpse on the basics of transmission line tower foundations have been briefly reviewed. Causes for defects in transmission line tower foundations have been presented. As there are varied exposure conditions in the case of new transmission line tower foundations, suggesting a uniform methodology for all situations to enhance their life would be uneconomical. Hence according to the site conditions, protecting methodologies as reviewed in the article if followed will extend the life of transmission line tower foundation.

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