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Innovative methods for improving performance of transmission line tower foundations against corrosion in marine environment

S.Christian Johnson[1] & G.S.Thirugnanam[2]

[1]Excel Engineering College, NH 47, Main Road Pallakapalayam, Sankari West post, Namakkal, Tamil Nadu- 637303, India
[2]Civil Engineering, Institute of Road Transport and Technology
Erode, Tamil Nadu, India

[E.mail: glorylydiajohn@gmail.com]

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In the study a few innovative methods for rehabilitation of transmission line tower foundations based on laboratory investigations have been presented. Protective methods like O-ring provision in the stub angle concrete interface, various levels of protective methods including nano penetrant coatings to combat the crevice corrosion, has been suggested for field applications in marine environment.

[Key words: Concrete, Coatings, Corrosion, Durability, Transmission tower foundation]

Introduction

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 material gets oxidized to ferrous oxide (corrosion product), its volume is obviously more than original ferrous material. Such an increase volume of the stub angle at the interface puts the chimney concrete under strain resulting in formation of cracks. Progressive opening of cracks allows the water to drain into the chimney concrete enhancing the corrosion process leading eventually to 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 in 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. Depending upon the soil conditions and bearing capacity including other parameters like weight of the tower etc., the base part of the transmission tower will be different like RCC spread footing, RCC block, Under cut footing, Augur type footings, (vertical or battered) under reamed pile, Regular Pile, Well Type Grillage Type.

Materials and Methods

A typical and simple transmission line tower foundation have the parts like Stub, Chimney, Coping and base concrete as shown in Fig.1. While the foundations of transmission towers are expected to serve without any distresses for several years, transmission towers constructed recently in the coastal areas of the country are exhibiting more and more distresses due to aggressive marine environmental conditions are deterioration of transmission line tower stub concrete, corrosion of embedded parts of

transmission line tower foundations and corrosion at the stub angle / coping concrete interface.

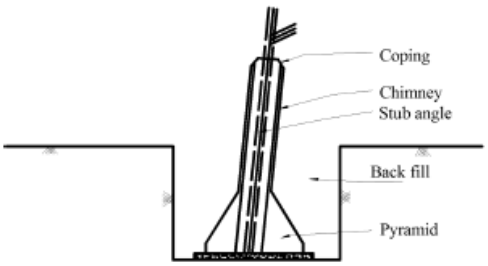

Fig.1. A typical of Transmission Line Tower Foundation

New tower concrete has a high pH value more than 12.5. This high alkalinity passivates the tower stub angle by forming a protective film of ferric oxides. This film prevents the reinforcing steel from corroding. But factors like development of cracks, high porosity/permeability of stub concrete, inadequate cover over the steel, high concentrations of chlorides or carbon di-oxide, etc., will break such a protective film. Once such a passive film is broken down, an electro chemical reaction sets in. This reaction is split into two partial or half-cell electro chemical reaction. The first reaction is the oxidation reaction called anodic reaction. The second is the reduction reaction or cathodic reaction. The two Half - cell reaction can be written as below.

Fe Fe^{2+}+2e - Anodic reaction

$2e^{-}+H_2O+1/2O_2$ ------$2OH^{-}$ ----- Cathodic reaction

This leads to the development of ferric oxide or rust. The formation of ferric oxide can be written as below.

Ferrous Hydroxide ----- $Fe^{2+}+2OH^{-}$ ------ $Fe(OH)_3$

Ferric Hydroxide - $4Fe(OH)+O_2+H_2o$ - $4Fe(OH)_3$

Hydrated ferric oxide----$2Fe(OH)_3$------$Fe_2O_3\,H_2O$

The passivated area behaves like the anode and the depasivated area behaves like cathode. The moist concrete acts as an electrolyte, making the electrons to move from anode to cathode resulting in corrosion. Mangesh V. Joshi[1] has specified novel technique of retrofitting of corrosion of damaged RCC foundations of transmission towers exposed to marine environment. A two prong approach of modern corrosion inhibitors to reduce the corrosion inside concrete and application of wrap to protect the RCC structures in aggressive environments have been dealt with.

M.Zamadeh and A.Gilpin[2] have stated that the probability of corrosion of buried transmission tower members is not only governed by the corrosiveness of the soil and the properties of the galavanized steel but also by a structures design and dimensions and by external electro chemical effects (stray currents, etc.,). It is mentioned that, agricultural soils are typically more corrosive because of the high concentration of corrosive ions in fertilizers. Like-wise structures exposed to excess amounts of road or sea water salts (sodium chloride [NaCl]) experience higher corrosion rates from more exposure to chlorides. Gupta et.al[3] have investigated and discussed about the corrosion of transmission line tower foundation due to stray current mechanism and suggested application of a liquid component consisting alkali resistant polymer dispersion and a powder component consisting, blending of cement, silica fume, quartz sand and corrosion inhibitors on the stub angle. Stray current is the leakage of current from power conductors through insulator string to the tower in different magnitude depending insulator surface contamination, atmospheric moisture and intensity of voltage in marine environments resulting in corrosive actions. Stray current can also occur due to induction in ground wires from the three phases, resulting in induced current flow through the loop formed by ground wire and the two towers at each end of the span causing corrosion of stub angle.

SudhirS.Kulkarni[4] has stated that the transmission line towers in marine areas and tower foundation embedded in ground, the tower stubs get heavily rusted in life span of about 10-15 years. The major causes for deterioration are wet, marshy soil around stubs on account of rain and drain water, watering of crops by cultivators, chemical reaction due to fertilizers and chemicals, in the farms as well as in industrial areas. Necessity of tower inspection has been emphasized and tower strengthening process has been explained.

The area around the tower leg is cleaned and area of one meter wide and one meter deep is excavated around the leg so as to make a room for the process. Then the chimney concrete of the tower stub is broken by vibro hammer, rusted portion of the stub is thoroughly cleaned using power tools and new angles are fitted with cleats provision. In the re concreting process, homogeneous jointing of old and new concrete, special bonding agent which is a specific epoxy adhesive is applied over the surface of the old concrete before final concreting is done.

In all the above literatures discussed here and other literatures available related with problem of corrosion of transmission line tower foundations ring of corrosion formed in the interface of the

stub angle and stub concrete is not that much presented because of scarce investigations.

Results and Discussion

As the stub angle interface is exposed to the atmosphere which has a higher concentration of oxygen with respect to the stub angle below the interface, there is a possibility of differential aeration – type of corrosion to occur like a ring of rust around the stub angle interface. The difference in moisture level and salt content at the interfacial zone prevailing in the marine zone a aggravates the corrosion process. Though such a type corrosion is quite prevalent in the interfacial zone in all the towers, the intensity is higher in the coastal zones. Ennore is one of the marine area located in the North Chennai area were lot of refineries and plastic industries are in existence. For facilitating power supply, this area is also having three major thermal power plants where around 2000 MW power is generated. For connecting the load centers with the thermal power stations through sub stations lot of transmission towers are in use in this area. But due to marine environmental exposures many towers are getting corroded and repair works are taken up on regular basis every year like painting, removal of rust, replacing the corroded angle with new angle, providing new concrete etc., Fig.2 shows a ring of rust formed at the interfacial zone of a transmission tower present in Ennore, Tamil Nadu, India.

Fig 2.Ring of Rust at Interface of transmission tower stub at ground level

By taking this into account, deterioration of stub concrete, corrosion of stub angle embedded in the stub concrete and corrosion of stub angle at the stub angle and concrete interface Christian Johnson, et.al [5] have investigated and suggested various innovative methods against corrosion of transmission line tower foundations in marine zone.

1. Application of protective coatings upon stub angle both in the buried portions and exposed portion of stub angle for a depth of 3 ft above the ground level
2. Addition of mineral and chemical admixtures including corrosion inhibitors in the stub concrete
3. Application of coatings or nano penetrant upon the stub concrete 2ft below the ground level and to the entire coping area.
4. Introduction of O-ring by deep pour grout material in the stub angle concrete interface.

Depending upon the severity of exposure, different combinations of first three of the above coatings and O-ring provision has been investigated upon lab specimens, model specimens and by rehabilitation of full scale tower stub specimen dug out of earth for diagnosing purpose. Based on the above, different levels of protections as below have been presented. They are: Single level Protection- Either coatings on stub angle or stub concrete and addition of admixtures in the concrete. Two level protection- Coatings on stub angle and coatings on stub concrete or coatings on stub angle and additions of admixture in the concrete or coatings upon stub concrete and additions of admixtures in the stub concrete. Three level Protection- Coatings on stub angle and coatings on stub concrete including additions of admixture in the stub concrete.

In various laboratory investigations made, it was observed that application of protective coatings on stub concrete specimens (2 level or 3 level) helps to reduce the rate of corrosion, i.e., prolonging the initiation period of corrosion process. It was also noted that for all coated angle specimens, the time required for cracking is higher compared to uncoated specimen. Nano Penetrant coating upon the stub concrete surface exhibited an excellent performance with very low chloride ion penetrability.

Deep grouting out of Demech chemical for forming O-ring in the stub angle and concrete interface shows no symptom of rust staining till 400 hrs of accelerated corrosion. At 500 hrs few rust spots has been noticed. The effect of O-ring against crevice corrosion is very good for nano penetrant coated specimen. Fig.3 shows performance of O-ring out of deep pour grouts after 500 hrs of accelerated corrosion.

a. O-ring and Cement slurry coated surface

b. O-ring and Nano Zycosil coated surface

Fig.3. Performance O-rings after 500 hrs of accelerated corrosion

Based on critically comparing with the literature reviewed, and rigorous laboratory investigations following innovative procedures can be adopted for enhancing the durability of transmission towers in the marine environment. Depending on the environmental exposure conditions like mild, moderate, severe, very severe and extreme, besides choosing the type of concrete suggested in codal provisions, there is a need to judiciously select and execute single level or two level or three level protections discussed in the paper. Nano repellent coating by Nano zycosil upon the stub concrete in the marine environment can be made as imperative so as to prevent entry of corrosive ions in to the concrete.

Conclusions

Provision of O-ring using chemical compounds like Demech deep pour grout in the stub angle concrete interface at the ground level have curtailed the crevice corrosion which are quite prevalent in the marine areas. Nano penetrant coatings upon the stub concrete surface have enhanced the durability of such vital tower foundations components. Hence implementation of innovative methods like O-ring provision in the marine field applications needs to be emphasized beside nano penetrant coatings.

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