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A Novel Protective Measure and Nano Penetrant Coatings against Corrosion of Power Transmission Line Tower Embedded Parts

CHRISTIAN JOHNSON S[1] AND GURUNAATHAN K[2]
[1]*Excel Engineering College, Komarapalayam – 637303, India*
[2]*Anna University, Chennai - 600025, India*
Email: *Cjnlef@gmail.com, kgurunaathan@yahoo.com*

Abstract: The problem of corrosion of some of the reinforced concrete structures has come to the forefront in recent years. It is noticed that nearly 50% of the construction industry's budget is spent on repairs, restoration and strengthening of the damaged concrete structures in advanced countries. In India, the civil engineering structures including transmission line towers, especially the embedded parts (foundations), located in the coastal areas are witnessing early deterioration due to corrosion. In this article, literatures dealing with the rehabilitation measures of transmission line towers against corrosion have been reviewed. Performance of a new protective measure against crevice corrosion in the stub angle/ coping concrete interface upon a model transmission line tower has been investigated and discussed. A novel protective measure named as woring, which resembles a rubber like socket has been introduced in the stub angle-coping concrete interface and performance of which has been discussed. Effect of nano water repellant coatings on stub concrete surface including coatings on stub angle, addition of admixtures in stub concrete, and woring in the crevice of stub angle-coping concrete in resisting the onset of corrosion has been presented.

Keywords*: Corrosion, Durability, Half-cell potential, Stub angle-coping concrete interface, Transmission line tower, Foundations, Nano penetrants, Woring.*

1. Introduction

The risk of transmission line towers due to structural distresses in foundations is commonly observed these days which may result in disruption of transfer of large blocks of power. Over the years, many researchers and constructors across the world have attempted to address the issue of corrosion problems in the embedded parts of transmission line towers. It is observed that the articles dealing with performance improvement against corrosion of transmission line tower foundations are very scarce. Many new nano penetrants compatible with concrete surface have emerged in the recent past that can improve the performance of transmission tower foundations, if effectively utilized. But, publications in connection with nano penetrants on transmission line tower foundations are only very few.

2. Literature Review

Gonzalez J.A. et.al[1] have studied the effect of chloride ions on the corrosion of rebars and stated that while normal service life is more than 30 years in mild environment, it may reduce the structure life by less than 10 years under extreme environmental conditions. Corrosion of transmission line tower foundations due to stray current mechanism have been investigated by Gupta et.al[2]. Existence of leakage of current (stray current) from power conductors through insulator strings to tower in variable magnitude depending on voltage intensity, insulator surface contamination and atmospheric moisture have been discussed. It is emphasized that this stray current has caused corrosion at foundation locations where the current leaves the structure and enters the ground through contaminated water electrolyte or chloride or sulphates dissolved water electrolyte. It seems that this stray current is one of the causes for the formation of pitting or crevice corrosion in the stub angle-coping concrete interface of the transmission line tower foundations.

Haji Sheik Mohammed and Samuel Knight[3] have investigated the performance evaluation of protective coatings such as inhibited cement slurry coatings, cement polymer anti corrosive coatings, cement polymer composite coatings on steel and galvanized bars as per Indian standard specifications 13620:1993[4]. Coated rebars are found to prolong the time required for cracking compared to uncoated rebars. Ha-Won Song and Velu Saraswathy[5] have reviewed the electrochemical and nondestructive techniques from the view point of corrosion assessment and their applications to bridges, buildings and other civil engineering structures.

Jagadheesan[6] has extensively conducted half-cell potential experiments to study the corrosion of reinforcement in concrete beams and concluded that there is a reduction of shear capacity of beams by 20% due to corrosion. Kirkpatrick[7] has presented actual case histories of sacrificial anode and cathodic protection installations on tower foundations and recommended cathodic protection system for future transmission tower line projects. Rokade etal[8] have discussed about various factors affecting the durability of tower stubs and foundations and presented steps to repairs of tower foundations and stub replacement procedure. Santhakumar and Murthy[9] have dealt many topics related with transmission line structures and pointed out that the collapse of tower is often initiated by foundation failures. Shah etal[10] have presented a case study on renovation and modernization of transmission line towers in the Gujarat state, India. It is commented that towers erected in 1500 km (932.25 miles) long coastal length of the state had been severely affected due to corrosion.

Taklakar [11] has discussed various causes for failure of transmission line tower foundations and stated that the transmission line tower foundation may fail due to deficiency either in design or construction or deterioration due to the passage of time.

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3. Research Significance and Methodology

Incidences of corrosion of embedded parts of transmission line tower foundations are experienced across the globe. Irrespective of the environmental conditions, crevice corrosion in the stub angle-concrete interface of the transmission tower foundations is commonly encountered in the field and pouring of bitumen/tar in the crevice point and application of epoxy paint in that particular zone is often resorted to. But, the durability of such treatment is not good which results in recurrence of maintenance cost.

While many new coatings and admixtures are available in the market, the maintenance wing, while undertaking the repair/restoration of defects/repairs in such transmission line tower foundations, are having a lot of apprehensions to use such materials for want of knowhow and methods. Hence, there is a dire necessity to identify protective methodologies for transmission line tower embedded parts against corrosion for improving the durability of transmission line tower foundations.

4. Experimental Investigations

Materials used

Cement: Ordinary Portland cement (OPC) 53 grade having a specific gravity of 3.15, conforming to Indian Standards Code - 12269 was used.

Fine aggregate: Natural river sand that conforms to grading zone –II of Indian Standard Code- 383 having a fineness modulus of 2.96 and specific gravity of 2.60 was used.

Coarse aggregate: Crushed stones conforming to graded aggregates of nominal size 12 mm as per Indian Standard Code -383 having a specific gravity of 2.80 was used.

Water: Potable tap water available in the laboratory with a pH value of 7.0 and conforming to the requirements of Indian Standard Code 456 was used for mixing concrete and curing of specimens as well.

Mineral admixture: For replacing cement by 20% in specimens, C- Class fly ash procured from Mettur Thermal Power station, Tamil Nadu, India was used.

Chemical admixture: A commercially available super plasticizer called “Silpas super” a product of National Repair and Restoration company limited, Salem, Tamil Nadu, India, has been used to give concrete a very high early strength.

Corrosion Inhibitor: Calcium Nitrite, 2% by weight of cement was mixed in the concrete used for making specimens.

Coatings:

i. A commercially available polymer-based coating called “Flexi bond ACSR” (FACSR), a product of National Repair and Restoration company limited, was mixed with cement and water in the ratio of 1:1:3 and applied over surfaces of concrete and stub angle.
ii. A commercially available protective coating called “Demech Chemical”, a product of Demech chemical products private limited, Tamil nadu, India was applied by brush or sprayed over the duly prepared metal/concrete surface.

Nano Water repellent: A commercially available nano water repelling compound called “ Nano zycosil” a product of Zydex Industries, Vadora, Gujarat, India, that penetrates the substrate and provides water repellency to 5 to 2000 nm pores have been applied on concrete surface.

Deep pour Grout: A commercially available three part product of Demech Chemical products private Ltd., called “Deep pour grout” in the mixing ratio of 16 Resin: 4 Hardener: 80 Aggregates by weight has been used for filling the interface of the stub concrete-angle in the transmission line tower foundation model. Thus, formed rubber like socket has been named as woring (It is a regional term and the meaning is defined to broader audience).

Concrete: M20 grade concrete, whose mix design prepared as per Indian Standards Code 10262 was used for making specimens.

Stub angle: Mild steel angle of size 50x50X6 mm.
Sacrificial anode: A small size zinc sheet has been wrapped on the stub angle very close to leg as a sacrificial anode in one of the leg members.

Mix design: For Concrete strength of 20 N/mm^2, Mix proportion is

Cement: F A: CA: w/c ratio
1: 1.43: 3.1: 0.49

5. Experimental Program:

In the experimental program, performance of experimentally proven coatings upon stub angle, admixtures in stub concrete and coatings on stub concrete surface i.e., three level protections and the formation of woring in the stub angle- coping concrete interface against crevice corrosion have been examined under accelerated corrosion upon a model tower. For this purpose, a model tower was fabricated using the angles of size 45 mm x 45 mm x 6 mm and the test set up is shown in figure 1.

Different coatings were applied on different leg angles and admixture concrete designed for M 20 grade was cast around its four leg angles as coping concrete. After setting, the best protective coatings found through laboratory test results, were applied over the coping concrete surface. Besides, the protective coatings on stub angle and concrete surface, a deep pour grout out of a three part product polymer based material have been poured in the crevice of stub angle and concrete as a woring and observation was made under accelerated corrosion. The whole tower was lifted and placed upon 4 tubs filled with 3.5% Sodium chloride water electrolyte, so that each leg is in separate tub as shown in the set up shown in figure 2. The tower legs immersed in sodium chloride water electrolyte was subjected to accelerated corrosion.

A schematic view of acceleration set up is shown in figure1. Fly ash has been added in concrete as 20 % cement requirement in all the legs except the controlled specimen. FACSR coating has been applied over the stub angle as well as on the stub concrete. Demech chemical also has been applied over the stub angle and on the concrete surface. As for Nano Penetrant coating is concerned, the penetrant called Nano Zycosil, which has been used in this study is to be applied only on the concrete surface. A small zinc sheet has been wrapped on the stub angle very close to leg as a sacrificial anode in one of the leg members. After one test was over, the tower was lifted out of tubs, legs were replaced with new foundations with different coatings and test was repeated three times. The average Half – Cell potential values taken on the tower foundations of model tower are shown in table 1. The close up view of woring upon model tower foundation after corrosion acceleration is shown in figure 3. Observations made on woring are recorded in the table 2.

Figure 1. *Model Tower foundation [Under corrosion acceleration]*

Figure 2. *Close up view of leg of model tower [Casting of concrete around the stub angle and woring in the crevice]*

MTF1 ***MTF2***

MTF3 ***MTF4***

MTF5 ***MTF6***

Fig.3. *Deep pour grout worings after 500 hrs. of accelerated corrosion*

6. Discussion on Test Results

From the accelerated corrosion test conducted on foundations of transmission line tower, following observations were made. Nano penetrant, FACSR and Demech coated specimen and sacrificial anode specimens perform very well in accelerated corrosion test.

Table 1: *Half-cell potential test values of model tower with various protections*

Time in Hrs.	Half-cell potentiometer readings in mv					
	MTF1 Controlled	MTF 2 (Corrosion Inhibitor)	MTF3 (FACSR 3 level)	MTF4 (Demech 3 level)	MTF5 (Nano Zycosil)	MTF6 (Sacrificial anode)
0	-98	-21	-15	0	0	0
50	-156	-69	-28	0	0	0
100	-233	-96	-45	0	0	0
150	-259	-109	-57	0	0	0
200	-301	-126	-78	0	0	0
250	-372	-159	-86	-10	0	-35
300	-397	-168	-98	-48	0	-78
350	-423	-182	-123	-77	0	-87
400	-465	-198	-156	-116	0	-95
500	-563	-332	-167	-145	0	-112

Table 2: *Observations for crevice corrosion*

Time in hrs.	MTF 1	MTF 2	MTF 3	MTF 4	MTF5	MTF6
0	No rust	No rust	No rust	No rust	No rust	No rust
100	No rust	No rust	No rust	No rust	No rust	No rust
200	No rust	No rust	No rust	No rust	No rust	No rust
300	Few rust	Few rust	No rust	No rust	No rust	No rust
400	Rust staining	Rust staining	No rust	No rust	No rust	No rust
500	Rust staining	Rust staining	Few rust	Few rust	No rust	No rust

From the Half-Cell readings, the corrosion initiation time required for controlled specimen was nearly about 200 hours. After 200 hours, the corrosion mechanism propagates rapidly. The effect of woring at the crevice of concrete and stub angle of the model tower after 500 hours of accelerated corrosion is shown in the Fig. 3. The inclusion of corrosion Inhibitor delays the initiation period considerably by up to 400 hours, which is nearly twice that of controlled concrete. The results clearly indicated that the corrosion mechanism was not initiated even up to 500 hours in the nano penetrant coated specimens and sacrificial anode fixed specimens.

On comparing the test results, it is seen that the three level coated legs (FACSR coated angle + Silpas super and fly ash mixed concrete + externally coated by FACSR) exhibits good performance. Three level coatings (Demech chemical coated angle + Silplas super and fly ash mixed concrete + externally coated by Demech chemical) show a superior corrosion resistance. Transmission line tower leg coated with Nano penetrant does not show any corrosion symptoms even after 500 hours of accelerated corrosion. Stub specimens fixed with sacrificial anode show a very good resistance to corrosion. Deep pour grouting out of Demech chemical for providing woring like part in the stub angle-coping concrete interface shows no symptom of rust till 400 hours of accelerated corrosion in the three level protected legs. Where as in the single level protected and controlled specimen legs, many rust spots after 300 hours and rust staining after 400 hours of accelerated corrsoion have been noticed. Hence, introduction of woring in combination with three level protections will definetly enhance durability of tower foundations. This methodology of pouring deep grout for protecting the stub angle-coping concrete interface against crevice corrosion may be encouraged during the construction of transmission line tower foundations.

7. Conclusions and Recommendations

A kind of crevice corrosion noticed in the stub angle-coping concrete interface at the muffing portion of the stubs is quite prevalent in all the stubs. But, for stubs in coastal areas, it is to a higher extent. Though it seems to be a local distress, if it is not attended or prevented in time, it may lead to crack propagation, endangering the life of embedded portion of stubs.

Problem of corrosion in transmission line tower foundation can be answered effectively by adopting three level protections (cement slurry coatings on stub angle, fly ash and super plasticizer mixed concrete and Nano Zycosil coatings on concrete surface) as it resists corrosion effectively. Woring concept formed using Demech deep pour grout in the stub angle-coping concrete interface shows a better resistance to crevice corrosion.

As of the woring concept is concerned, it can be introduced in all the towers irrespective of exposure conditions. As far as the rehabiliation of the existing transmission tower foundations are concerned, the damages can be categorized based on the crack patterns, loss of stub angle thickness and environmental exposures, etc., and accordingly single level or two level or three level protective measures with inclusion of woring and appropriate grade of concrete based on the exposure conditions can be selected.

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