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Methodologies for Enhancing Durability of Transmission Line Tower Foundations

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Abstract

The problem of early deterioration of some of the reinforced and pre stressed concrete structures has come to the forefront in recent years. In most of the advanced countries nearly 40% of the construction industry's budget is spent on repair, restoration and strengthening of the damaged concrete structures. All this has tarnished the image of concrete as a durable, maintenance free material. As India has a large coastal line and a number of cities and metropolis located in the vicinity of coastal belt, the civil structures including transmission line tower foundations in these areas are witnessing early deterioration of reinforced concrete structures. In this paper, methodologies for enhancing durability of new and old transmission line tower foundations in different filed environments have been presented based on a research taken up on the topic Durability of transmission tower foundations.

Keywords: Corrosion, Chemical Admixture, Chloride Ingress, Durability, Foundations, Transmission Line Tower

1. Introduction

Transmission line tower is considered to be the most stable and versatile semi-permanent structure which once erected in the open space, serves the power system for years together most faithfully, facing the vagaries of nature. However, sometimes like other components of the power system, the transmission line towers also fail, resulting into disruption of transferring large blocks of power, the transmission line towers are of a variety of configurations and designs, constructed to different specifications. The oldest transmission line tower still in service in India is more than 75 years old. But the recently constructed transmission line towers which are less than 10 to 20 years are experiencing deterioration on various accounts. Many of the transmission routes pass through the coastal areas and this cause an 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. Stanish *et. al.*[1] have presented a review of various methods for determining chloride penetrability of concrete. Some theoretical background of what influences the penetration of chloride into concrete has been discussed. Shah *et. al.*[2] have presented a case study on renovation and modernization of transmission line towers in the Gujarat state, India. As a renovating measure, it was suggested that if the stub angle is found to be corroded less than 50% in thickness, the portion exposed after breaking the concrete is to be covered by an inside cleat and outside plates with a running weld. If the damage is more than 50% in thickness, the damaged portion is to be cut removed and a piece of similar stub angle is to be fitted in to the cut portion. In both the cases, newly welded assembly has been covered by a RCC cage and then encased in concrete. Taklakar[3] has briefly discussed various causes for failure of transmission line tower foundations and mentioned that the transmission line tower foundation may fail due to deficiency either in design or in construction or deterioration due to the passage of time. Also it has been pointed out that the tower failure can be minimized if the erection practice is

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standardized. Gupta *et al.*[4] 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 against corrosion.

2. Visual Inspections

From the visual inspections carried out, causes for transmission line tower foundations are found to be improper formation of pyramid / chimney, ingress of water / pollutants through the concrete and stub angle interface, corrosive environments, bush / fern growth in and around tower muffing area, unfavorable location of tower, insufficient curing, etc. The concrete above the ground level called coping concrete should have a muffing portion in slanting way. But in some cases it is observed that this is missing resulting in stagnation of water leading to pitting corrosion as in Figure 1. Insufficient curing of coping concrete as in Figure 2 leads to disintegration of concrete constituent materials Ingress of saline water or other pollutants etc., leads to the formation of local cracks and chip off, which allows salt to penetrate further into the affected stub where the process of corrosion will be more and more accelerated as in Figures 3 and 4 causing bulging and snapping of angles.



Figure 1. Formation of pitting corrosion at the angle concrete interface

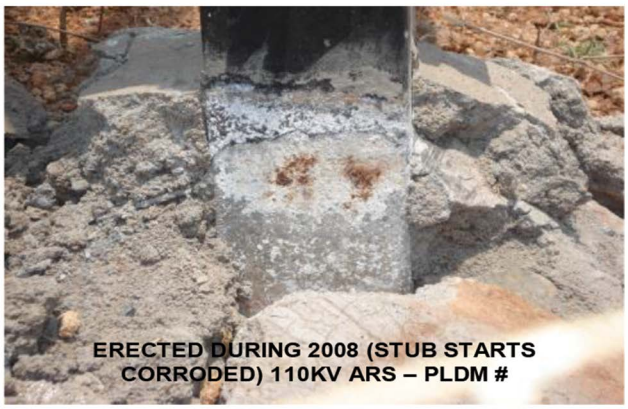


Figure 2. Disintegration of constituent materials of coping concrete.



Figure 3. Bulging of Stub angle.



Figure 4. Snapping of stub angle.

The tower stubs as shown in Figures 5 and 6 were cut removed for testing purposes with due permission from the concerned authorities. The stub of these towers was erected nearly 30 years ago, and the super structures had been already dismantled for expansion purposes. The stubs have been tested for half-cell potential to assess the level of corrosion.

The Half-cell potential readings taken on inland stub and coastal stub are as shown in Figures 7 and 8. Other tests like rebound hammer test and carbonation test also have been conducted apart from chemical analysis of the stub concrete and soil samples. Afterwards the stubs were broken in order to study the crack depth, crack pattern and extent of deterioration of concrete. Also the thickness

of the existing corroded stub angle has been measured and compared with the original thickness. The size of the stub angle measured after destruction is shown in Table 3. The close up view of the specimen at the broken stage is shown in Figure 9.

The pH value, chloride and sulphate content of the stub concrete at the coping portion and the soil around the stub are shown in Table 1. The crack depths and widths of the coastal and inland specimens are given in Table 2.

3. Laboratory Investigations

To assess the corrosion resistance efficacy of the different level of coating systems, it was decided to make specimens with different levels of protection for different tests and the legends of the specimens are as below:



Figure 5. Removal of inland stub.



Figure 6. Removal of coastal stub.

CS 1 = Plain angle + Plain Concrete (NP) - Controlled specimen- No protection

CS 2 = Plain angle + SP Concrete (SP3) - Single level protection

CS 3 = FACSR Coated Angle + SP Concrete. (TP4)- Two level protection

CS 4 = FACSR Coated Angle + Conventional Concrete (TP5) - Two level protection

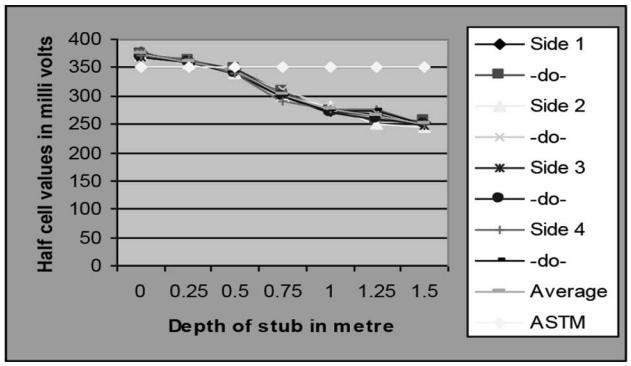


Figure 7. Half-cell values of inland stub.

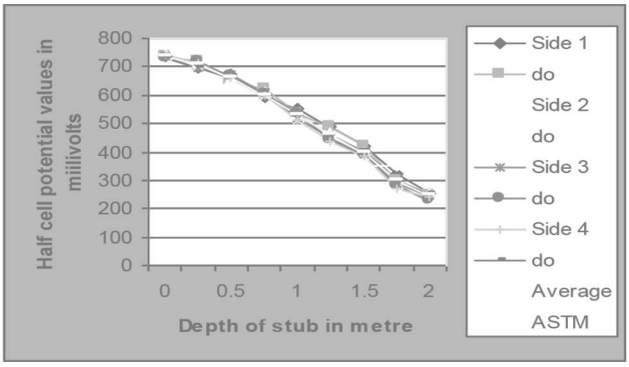


Figure 8. Half-cell values of Coastal stub.



Figure 9. Close up view of the Stub specimen.

Table 1. pH value, Sulphate and chloride content of stub specimens

Item / Parameter	Soil around the Inland stub	Concrete of the inland stub at coping area	Soil around the stub coastal stub	Concrete of the coastal stub at coping area
pH Value	8.40	8.90	7.80	7.40
Chloride	0.01%	0.03 %	0.12 %	0.19%
Sulphate	0.07%	0.23 %	0.18 %	0.26%

Table 2. Crack dimension of stub specimens

Crack depth of the stubs		Crack width of the stubs	
Inland	Coastal	Inland	Coastal
30 cm (1 ft)	45 cm (1.50 ft)	< 2mm (0.08 in)	3-4 mm (0.11-0.15 in)

Table 3. Size of stub angles measured after destruction.

Item / Depth	Original size of the inland stub angle	Actual size of the inland stub angle	Original size of the coastal stub angle	Actual size of the coastal stub angle
0 m (0 in)	65x65x6 mm (2.5x2.5x0.24 in)	65x65x5 mm (2.5x2.5x0.19 in)	150x150x12 mm (5.9x5.9x0.47 in)	130x130 x2 mm (5.1x5.1x0.078 in)
0.25 m (9.75 in)	65x65x6mm (2.5x2.5x0.24 in)	65x65x6 mm (2.5x2.5x0.24 in)	150x150x12 mm (5.9x5.9x0.47 in)	130x130x6 mm (5.1x5.1x0.236 in)
0.40m (15.75 in)	65x65x6 mm (2.5x2.5x0.24 in)	65x65x6 mm (2.5x2.5x0.24 in)	150x150x12 mm (5.9x5.9x0.47 in)	150x150x10 mm (5.9x5.9x0.39 in)

CS 5 = Plain Angle + Conventional Con. + Ext. Coated by FACSR (TP6) – Two level protection

CS 6 = Epoxy Coated Angle + Conventional Concrete (TP2) - Two level protection

CS 7 = FACSR Coated Angle + SP Concrete + Ext. Coated by FACSR (TEP1) -Three level protection

CS 8 = Plain Angle + Recron Mixed Concrete. (SP4) – Single level protection

CS 9 = Plain Angle + Corrosion Inhibitor Mixed Concrete (SP5) - Single level protection

CS 10= Demech Coated angle + Conventional Concrete + Ext. coated by Demech (TEP2) -Three level protection

CS11= Cement slurry coated angle+ SP Concrete Ext. coated by Zycosil (TEP3) -Three level protection.

The performance of coated angles against corrosion cracking in impressed voltage test is shown in Figure 10. It can be seen that for all the coated angle specimens, the time required for cracking is higher compared to uncoated specimen. For ACSR and Demech coatings, the variations of current density show that there is an initiation period followed by propagation period.

The chloride ion penetrability of various specimens and the comparison of charges passed in coulombs for various specimens are shown in Table 4.

In order to confirm the performance of protective measures on transmission tower model a model tower as shown in Figure 12 was fabricated for testing the transmission line tower foundation stub with admixtures and coatings. In this model tower, the best protective coatings found through laboratory test results, was applied over the leg members. Then the accelerated corrosion was induced by using a DC power pack. Nano penetrant, FACSR and Demech coated specimen and sacrificial anode specimens perform very well in both accelerated corrosion test and impressed voltage test.

The accelerated corrosion test was carried out on the model tower stub. The test results are presented in Table 5. Besides the above tests, Demech deep pour grout

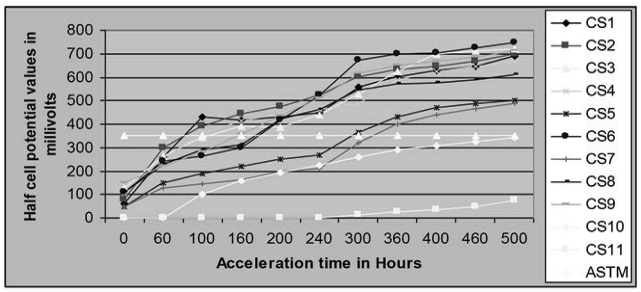


Figure 10. Effect of coatings on half-cell readings.

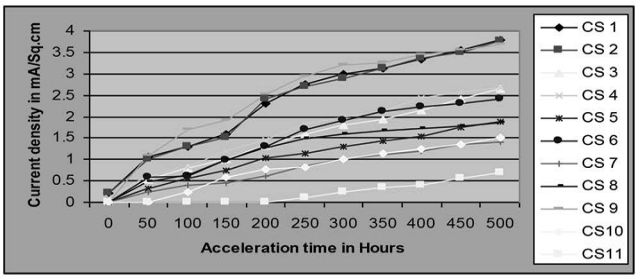


Figure 11. Effect of coatings on Current density.

Table 4. Chloride ion penetrability of different specimens

Sl.no.	Specimens	Charge passed in coulombs	Chloride ion penetrability
1	RCPT1- Plain Concrete (without fly ash)	4225.5	High
2	RCPT2- Plain concrete with 20 % CRM by fly ash	2225.59	Moderate
3	RCPT 3 - Plain concrete + Silplas super &20% Fly ash mixed Concrete	2192.00	Moderate
4	RCPT 4- Corrosion inhibited concrete	4548.6	High
5	RCPT 5- Recron 3s fibre mixed concrete	5860.8	High
6	RCPT 6 – SP. concrete Coated with FACSR	1743.3	Low
7	RCPT7-SP. Concrete Coated with Demech Chemicals	1515.6	Low
8	RCPT8- SP. concrete coated with Nano Zycosil	688.56	Very Low



Figure 12. Model tower. **(a).** Coatings being applied **(b).** Corrosion test in progress.

Table 5. Half- cell potential readings 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

was poured as o-ring in the artificially made crevice and observation has been made under accelerated corrosion condition. The effect of o-ring at the crevice of concrete and stub angle of the model tower after 500 hours of accelerated corrosion is shown in the Figure 13.

4. Effectiveness of Coatings on Stub with Galvanized Stub Angle

In order to experimentally study the durability of transmission line tower foundations embedded with Galvanized stubs, four numbers of stubs have been firmly fixed on the open ground by proper concreting. After 28 days of curing, outer coating with FACSR has been applied on one stub concrete and Demech chemical coating on the other stub concrete. The remaining two legs have been uncoated to observe the effect of coatings on stub concrete in the field. The corrosion is induced in all the stub concrete by spraying salt water which has 3.5% NaCl. From the half-cell readings taken from stub model set on ground, it is observed that the galvanized stub angle shows a superior performance.

5. Rehabilitation of Stub

By adding mineral admixtures like fly ash at 20% as Cement Replacing Material (CRM) and chemical admixtures like Silpas Super at the dosage of 2% by weight of cement in the concrete, the durability property of concrete is improved considerably. FACSR coating on the prepared concrete surface and on the surface of the stub angle, and coatings like Demech chemical or Zycosil Nano penetrant on the concrete surface in the rehabilitation of the transmission tower stub prove to be very effective. Based on the series of investigation and the remedial measures adopted in different regions of the country methodologies for improving the durability aspects of transmission tower foundations is suggested.

6. For New Towers

6.1 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 one level protection may be made as below:
- FACSR coating on the stub angle or on the concrete surface for 2 ft (0.60 m) below and 2 ft (0.60 m) above the ground level.
- In dry areas one level protection like FACSR coating either on stub angle or concrete surface in the coping /muffing area and 1 ft (0.30 m) 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 concrete stub angle interface to be introduced.

6.2 Agricultural or Hilly 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. The two level protections can be made as below:
- FACSR coating on the stub angle, 2 ft (0.60 m) below and 2 ft (0.60 m) above the ground level.
- Nano Zycosil water repellant coating on the concrete surface of the coping and muffing area and 3 ft (0.90 m) below the ground level.
- O-ring to be provided in the stub angle concrete inter face by pouring the Demech deep pour grout.



Figure 13. Deep pour grout o-rings after 500 hrs. of accelerated corrosion.

6.3 Coastal or Industrial Areas

- The concrete used in chimney as well as in coping and muffing of transmission tower foundations should be 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 3 ft (0.90m) above the ground level.
- 20 % CRM (Cement replacement) by fly ash in the concrete and addition of 2% Silpas super (Super plasticizer) in the concrete.
- FACSR coating or Nano water repellant coating on the concrete surface of coping and muffing area and 3 ft (0.90 m) below ground level.
- O-ring to be provided in the stub angle concrete inter face by pouring the Demech deep grout chemical.

6.4 Coastal cum Industrial Areas

- The concrete used in chimney as well as in coping and muffing of transmission tower foundations should be as per IS -456 2000 depending upon the exposure conditions.
- 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, silica fume good performance can be obtained.
- Sulphate resisting cement may be used for foundations in industrial cum coastal areas. Three level protections may be made as below:
- Demech coating on the stub angle to the full length of the stub and 5 ft (1.50m) above the ground level.
- 20 % CRM by fly ash in the concrete and addition of 2 % Silpas super (Super plasticizer) Nano Zycosil water repellant coating on the whole concrete surface area of the foundation including pedestal sides and bottom, stub coping and muffing.
- O-ring out of Demech deep grout should be provided in the interface.
- RCC cage can be recommended in vulnerable area incorporating coatings on reinforcements and admixtures in concrete.

7. Tower Foundations in Service

7.1 Mild Damages

If the existing coping /muffing concrete of the legs appears to be slanting, if there are only hair line cracks, and if the reduction in thickness of the stub angle is negligible. i.e. less than 10 %, the damage may be considered to be mild and has to be strengthened as below in the following sequence.

- All the rust and flakes from the corroded stub angle at the inter face should be removed using emery sheet.
- A small groove in the interface of the stub angle/ coping, for a depth of 1 inch (2.54 cm) to be formed without making new cracks or aggravating the cracks and it has to be cleaned thoroughly.
- Polymer coating (Polymer:water:Cement at the ratio of 1:1:3) to be applied on the stub angle from the lower most point of the groove up to the depth of 2 ft (0.60 m) above ground level.
- Elastober acrylic material to be poured in the groove and allowed to set.
- The concrete surface to be cleaned thoroughly, Nano Zycosil penetrant at the ratio 1:10 (1 Part of Zycosil and 10 parts of water) to be applied on the concrete horizontal and slanting surface by wet and wet method and at the ratio of 1: 20 (1 part of Zycosil and 20 parts of water) in the vertical surface up to a depth of 2 ft (0.60 m) below ground level.

7.2 Moderate Damages

If the cracks in the coping area are wider and if the crevice corrosion at the interface seems to be developing, and if the reduction in thickness of the stub angle is less than 20 %, and more than 10 %, the damage may be considered to be moderate and stub has to be strengthened as below.

- The loosened carbonated concrete in the coping area should be completely removed so that the resulting surface would be conducive to achieve high bond strength with over lay concrete.
- A simple carbonation test using spraying of phenolphthalein may be done for knowing the depth of carbonation and all the carbonated concrete should be scrapped, and the concrete surface should be cleaned by water jet.

- All the rust and flakes from the corroded stub angle should be removed using emery sheet.
- Flexi bond ACSR coating (Flexi bond ACSR: water: Cement at the ratio of 1:1:3) to be applied on the stub angle from the lower most point of the groove up to the depth of 2 ft (0.60 m) above ground level.
- Application of overlay concrete out of M20 grade with 20 % CRM by fly Ash and Silpas super chemical admixture and smooth slanting surface should be formed to drain out the water.
- A groove to be formed in the stub angle /concrete interface and allowed to cure and after setting, Elastober acrylic material to be poured in the groove to form a o-ring and allowed to set.
- After the curing of over lay concrete and the setting of Elastober, the concrete surface to be coated with Zycosil Nano penetrant at the ratio 1:10 (1 Part of Zycosil and 10 parts of water) to be applied on the concrete horizontal and slanting surface by wet and wet method and at the ratio of 1: 20 (1 part of Zycosil and 20 parts of water) in the vertical surface up to a depth of 2 ft (0.60 m) below ground level.

7.3 Severe Damages

If the cracks are extensive in the coping or if the concrete in the stub are deteriorated to a larger extent and if the reduction in the thickness of the stub angle is more than 30 % and less than 50 %, the damages may be considered as severe.

- All the concrete from the bottom of the corroded portion up to the muffing point should be removed and the surface of the left out stub concrete should be cleaned thoroughly by water jet.
- All the rust and flakes from the corroded stub angle should be removed using emery sheet.
- Inner cleats and outer cover plates equal to the thickness of the stub angle for 2 ft (0.60 m) length in the corroded length have to be welded by fusion welding
- Flexi bond ACSR coating (Flexi bond ACSR: water: Cement at the ratio of 1:1:3) to be applied on the stub angle from the lower most point of the groove up to the depth of 3 ft (0.90 m) above ground level.
- Concrete out of M20 grade with 20 % CRM by fly Ash and Silpas super chemical admixture should be used for forming the new stub from the bottom point of the corroded portion and smooth slanting surface should be formed to drain out the water in the muffing area.
- Groove to be formed in the stub angle /concrete interface and allowed to cure and after setting, Elastober acrylic material to be poured in the groove to form a o-ring and allowed to set, if the location is dry one. If the tower leg has to stand in a water stagnated area or coastal area, the stagnated, the o-ring may be introduced.
- After the curing of concrete and the setting of Elastober, the concrete surface to be coated with Nano Zycosil penetrant at the ratio 1;10 (1 Part of Zycosil and 10 parts of water) to be applied on the concrete horizontal and slanting surface by wet and wet method and at the ratio of 1: 20 (1 part of Zycosil and 20 parts of water) in the vertical surface up to a depth of 2 ft (0.60 m) below ground level.

7.4 Very Severe Damages

If the cracks are extensive in the coping or if the concrete in the stub are deteriorated to a larger extent and if the reduction in the thickness of the stub angle is more than 50 % the damages may be considered as very severe.

- All the concrete in the corroded portion should be completely removed so that the resulting surface would be conducive to achieve high bond strength with over lay concrete.
- The corroded angle has to be cut removed by the gas welding after guying the tower.
- The rust and flakes in the remaining portion of the stub angle should be removed using emery sheet.
- New stub angle to be welded and splice jointing be made in the corroded portion by fusion welding
- Flexi bond ACSR coating (Flexi bond ACSR: water: Cement at the ratio of 1:1:3) to be applied on the stub angle from the lower most point of the groove up to the depth of 3 ft above ground level.
- Concrete out of M20 grade with 20 % CRM by fly Ash and Silpas super chemical admixture should be used for forming the new stub from the bottom point of the corroded portion and smooth slanting surface should be formed to drain out the water in the muffing area.
- Groove to be formed in the stub angle /concrete interface and allowed to cure and after setting, Elastober acrylic material to be poured in the groove to form a o-ring and allowed to set, if the location is dry

one. If the tower leg has to stand in a water stagnated area or coastal area, the o-ring should be formed out of Demech deep grout.

- After the curing of concrete and the setting of Demech grout, the concrete surface to be coated with Nano Zycosil penetrant at the ratio 1;10 (1 Part of Zycosil and 10 parts of water) to be applied on the concrete horizontal and slanting surface by wet and wet method and at the ratio of 1: 20 (1 part of Zycosil and 20 parts of water) in the vertical surface up to a depth of 2 ft (0.90 m) below ground level.

8. Conclusion

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 durability property would be uneconomical. Similarly, for the existing transmission line tower foundations, adopting same method for all sorts of damages would not be reasonable. Based on reconnaissance survey, visual inspection, literature review and laboratory investigations, methodologies for providing good durability to the foundations of new towers under different environmental conditions and existing tower foundations with different damage levels have been suggested.

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