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Reliability Assessment of Structures Subjected To Chloride Ingress in Marine Environment

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Abstract— **Sustainability and the concrete structure durability issues have recently gained considerable attention based on the evaluation of service life and the relevant reliability level. One of the most punishing exposure conditions for concrete is a marine environment. Reinforced concrete (RC) structures in chloride environment are exposed to a particularly aggressive form of deterioration. Reinforcement corrosion from diffusion of chloride ions is the main mechanism for deterioration under such conditions; it is found that chloride penetration and chloride-induced reinforcement corrosion rates can be very high, which reduces the stiffness and often leading to a reduced service life. Corrosion induced structural failures do not necessarily imply structural collapse but in most cases are manifested by loss of structural serviceability. This paper presents results of a study performed on a 25-year-old RC jetty structure in the Chinthapalli village, Srikakulam District that had suffered extensive deterioration from chloride-induced corrosion. Corrosion-induced due to chloride ingress is observed to vary spatially over concrete surfaces. The reliability analysis predicts the probability of failure the existing structure. A structural reliability analysis based on diffusion of chlorides, and corrosion initiation is dealt in this paper. The reliability analysis allowed the effect of corrosion to be measured in a quantitative manner.**

Index Terms— **Carbonation, Chloride Induced Corrosion, Marine environment, Performance assessment, Reliability, Service life.**

I. INTRODUCTION

The exponential growth of infrastructure in the developing countries has increased the demand for concrete materials. Durability and reliability issues rank among the most decisive structural performance characteristics. Reinforced concrete is supposed to be very durable and is a widely used construction material. Despite the fact that concrete is a reliable structural material with good durability performance; exposure to severe environments makes it vulnerable. The performance of concrete structures is time dependent and hence its service life issue has been given considerable attention. The prescriptive approach of current standards does not directly allow for design focused on a specific target service life and/or a specific level of reliability.

In order to assess the condition of an existing RC structure, knowledge of the amount of reinforcing steel lost due to corrosion is essential. Corrosion of embedded reinforcing steel is the dominant cause of deterioration of reinforced concrete structures in marine environments, which results in a loss of serviceability often occurring much earlier than anticipated for the designed service life of the structure. Often, the initiation of corrosion has been treated as a serviceability failure Timely maintenance and repairs have the potential to prolong the service life of corrosion affected RC structures.

Reinforcement corrosion from diffusion of chloride ions is the main mechanism for deterioration under aggressive conditions. Chloride penetration and chloride-induced reinforcement corrosion rates can be very high, often leading to a reduced service life. **(Ali Dousti (2013)**). Corrosion induced structural failures do not necessarily imply structural collapse but in most cases are manifested by loss of structural serviceability (**C. Q. Li et al (2005)).** Corrosion is a nonlinear function of time (**Robert E. Melchers (2003))**

Figure 1: View of the Onshore cum Offshore structure

II. METHODOLOGY ADOPTED

Methodology includes identifying the building /structure exposed to aggressive marine environment.

1. Identifying various Non-Destructive Test Methods to be carried out on the structure/building.
   NDT tests like Rebound Hammer, Carbonation test and Chloride test had been carried out as per the codes.
2. Identification of the possible causes leading to the damage of the structure.
3. Assessing the amount of damage caused and to determine its suitability for future use.
4. Assessing the reliability index and the probability of failure of the structure for the remaining service life of the structure using Numerical Analysis and First Order Second Moments method.
   The failure surface equation used is as follows:

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[1] M : $C_1 X_1 - X_2 - C_3 X_3 - C_4 X_4$
[2] $C_1 : 1.2(1+ L_n/D_n + W_n/D_n)/ \gamma_R$
[3] $C_3 : L_n/D_n$,
[4] $C_4 : W_n/D_n$

Where, [5] $X_1 : R/R_n$,
[6] $X_2 : D/D_n$,
[7] $X_3 : L/L_n$,
[8] $X_4 : W/W_n$

III. RESULTS AND DISCUSSIONS

The following are the results obtained by carrying out the tests and analysis:

1. The principal mechanism responsible for the extensive deterioration of the structure studied is chloride-induced reinforcement corrosion. The intensity of cracks with cover thickness has a great bearing upon the initiation and sustenance of corrosion of reinforcement.
2. Visual investigations showed evidence of rust staining; minor cracking to spalling, and delamination of concrete cover.
3. The chloride threshold concentration may be presented by means of the total amount of chloride by weight of cement. The value of 0.2% for structures exposed to a more aggressive environment is currently suggested as the chloride threshold concentration. Chloride profiles from damaged surfaces indicated chloride content is 3.8kg/m^3. This value is higher than the suggested threshold value.
4. The key factor for the modeling of steel corrosion as a time dependent process is the corrosion rate, which is usually expressed through current density, i_{corr}. i_{corr}< 0.1 µA/cm^2 is low; 0.1<i_{corr}<0.5 µA/cm^2 is low to moderate; 0.5 <i_{corr}< 1 µA/cm^2 is moderate to high; and i_{corr}>1 µA/cm^2 is a high rate of corrosion. In this case study we got i_{corr} = 1.5 µA/cm^2 which indicates that the corrosion rate is very high in the structure due to exposure to aggressive marine environment.
5. The chloride diffusion profiles is 0.96*10^{-12} m^2/s and the corrosion rate that is 41.76 µm/year, both of which indicate high rate of chloride ingress into concrete and steel depicting signs of fast structural degradation.
6. The stiffness for onshore circular columns decreased by 37.5%.
7. For the on shore structure the reliability index of the original section is 4.325 whereas the reliability index of the deteriorated cross section is 3.169.
8. The probability of failure of the structure is observed to be increased significantly over the years from 7.80×10^{-6} to 7.62×10^{-4}
9. The average compressive strength of the deteriorated onshore columns is 28.85MPa with a standard deviation of 15.5. Taking the effect of carbonation into account the average compressive strength of the structure is obtained as 15.257MPa while the standard deviation is 4.3112. The high standard deviation values indicate the structure is subjected to high damage in marine environment.

IV. CONCLUSIONS

The assessment of the onshore cum offshore structure shows that, when defective structures are exposed to aggressing environments, such as the marine environment very high deterioration rates can develop, leading to serious damage conditions in very short time periods. Based on visual inspection, in situ and laboratory tests, the evaluation of the structure degradation level was given. It was immediately evident that the main cause of the deterioration of the concrete structure was chloride-induced reinforcement corrosion stemming from ingress of chlorides. All concrete structures in the marine environment should be monitored during their service life to avoid high repair costs. Most literature references recommend lower water/cement for such environments. The existence of cracks formed a pathway for chloride ions, have increased the rate of the corrosion process and induced shortening of the structures' service life. The reliability of RC members exposed to chloride ion contamination of concrete deteriorates over time. In the present case study it reduced from 4.325 to 3.169. The loss in reliability can be blamed on the corrosion of the reinforcing steel. Achievement of absolute safety is impossible. Rational criterion for the safety of a structure is its reliability. Probability of failure is the quantitative measure of structural safety. By reliability analysis, the level of reliability of existing structures can be evaluated. It can be used for developing a design criterion, that is, calibrating codes and developing partial safety factors, the use of which will result in designs with an accepted level of reliability. Based on reliability, suitable decisions for improving the capability of existing structures can be made. Finally, reliability-based recommendations have to be developed to supplement existing Standard codal provisions for handling corrosion to reinforcement of marine structures. It can be concluded that the methodology presented in the paper can serve as a rational tool for structural engineers and asset managers to make decisions with regard to repair and strengthening of corrosion affected concrete structures.

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REFERENCES

[1] Ali Dousti, S.M.ASCE; Masoud Moradian; Seyyed Rahman Taheri; Reza Rashetnia; and Mohammad Shekarchi(2013) "Corrosion Assessment of RC Deck in a Jetty Structure Damaged by Chloride Attack", *Journal Of Performance Of Constructed Facilities © ASCE / 519-528;* DOI: 10.1061/(ASCE) CF.1943-5509.0000348

[2] C. Q. Li; W. Lawanwisut; and J. J. Zheng(2005), "Time-Dependent

Reliability Method To Assess The Serviceability Of Corrosion-Affected Concrete Structures", *Journal Of Structural Engineering © ASCE /131:1674-1680;* DOI: 10.1061/(ASCE)0733-9445(2005)131:11(1674)

[3] Chun Qing Li (2004), "Reliability Based Service Life Prediction of Corrosion Affected Concrete Structures", *Journal of Structural Engineering © ASCE 130:1570-1577*. DOI: 10.1061/(ASCE)0733-9445(2004)130:10(1570)

[4] Dan M. Frangopol, Kai-Yung Lin/ and Allen C. Estes, (1997), "Reliability of Reinforced Concrete Girders under Corrosion Attack", *Journal of Structural Engineering /123:286-297*.

[5] Dimitri V. Val, Fiodor Bljnger,and David Z. YankelevskyJ,(1997) "Reliability Assessment of Damaged RC Framed Structures", *Journal of Structural Engineering /123:889-895*.

[6] Dimitri V. Valand Leonid Chernin,(2009), "Serviceability Reliability of Reinforced Concrete Beams with Corroded Reinforcement", *Journal of Structural Engineering © ASCE.135:896-905*.

[7] H. P. Hong and W. Zhou,(2009), "Reliability Evaluation Of RC Columns", *Journal Of Structural Engineering /125:784-790*. DOI: 10.1061/(ASCE00733-9445(2009)135:8(896)

[8] John A. Mullardand Mark G. Stewart, (2012), "Life-Cycle Cost Assessment of Maintenance Strategies for RC Structures in Chloride Environments", *Journal of Bridge Engineering © ASCE 17:353-362*. DOI: 10.1061/(ASCE)BE.1943-5592.0000248.

[9] Mark G. Stewart and David V. Rosowsky, (1998) "Structural Safety and Serviceability of Concrete Bridges subject To Corrosion",*Journal of Infrastructure Systems / 4: 146-155*

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