IFERP connecting engineers... developing research

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 2, Issue 3, March 2017

Influence of Corrosion on Strength and Durability of RC Structure

[1] Hema MUNOT [2] Tushar DIYORA [3] Rahul PATIL

1) Assistant Prof. Applied Mechanics, College of Engineering,Pune-411005(MS)India,hema_munot2002@yahoo.com
2) M.Tech Civil(structure) student, College of Engineering,Pune-411005(MS)India
3) M.Tech Civil(structure) student, College of Engineering,Pune-411005(MS)India

***Abstract:*— Corrosion of reinforcement is one of the leading causes of the deterioration in reinforced concrete structures. Reinforced concrete is recognized to be durable and capable of withstanding a variety of environment conditions. Nevertheless, premature failures of structures still do occur as a result of steel reinforcement corrosion. RC structures damaged by reinforcement corrosion can exhibit not only reduction of the bearing capacity but also an alteration of the collapse mechanism with a reduction in the structural ductility.**

All of these actions contribute to the loss of stiffness and ductility of the RC Structure and thus, reduce the ultimate strength of the structure.

This review paper focuses on the various studies of effect of accelerated corrosion on steel bar and its influence on strength and durability of RC structure. Thereby a comprehensive review of studies on strength of corroded RC columns & beams, concrete cover depth effect on crack width and its effect on corrosion, is presented.

***Key word:*-- Ductility, concrete cover, crack width**

I. INTRODUCTION

Corrosion is one of the major causes of premature damage of RC structures. The corrosion of steel rebar in RC structure reduces cross-sectional steel area and creates local discontinuities of the steel surface, which causes a loss of the bond between the steel and the surrounded concrete. However, corrosion not only deteriorates the steel bar and its function of transferring the tensile stresses, but it deteriorates the concrete by spalling of the cover. The deterioration process depends on many factors like the quality of concrete, concrete cover for the bars, the concentration of carbon dioxide or chloride ions in the ambient environment, temperature, humidity conditions, diffusion coefficient for the concrete and the rate of corrosion for the bars.

Reinforcement corrosion also causes a volume increase due to oxidation of metallic ions, which is mainly responsible for exerting radial pressure to steel-concrete interface and develop hoop tensile stresses in the surrounding concrete, once the maximum hoop tensile stresses exceeds the tensile strength of concrete, cracks occurs. This further accelerates the corrosion which leads to reduction in the long-term serviceability and strength of the structural system. In order to avoid unexpected and sudden failure, service-life estimation, performance monitoring and maintenance of the RC structure are essential.

Most national building codes are aimed at ensuring that the structure being designed, constructed and operated would perform satisfactorily at the ultimate and the serviceability limit states. But traditional strength-based design for new concrete structure has failed to provide reliable long-term performance of structures exposed to aggressive environments.

S. Altoubat et al. (2016) (1) “Laboratory Simulation of Corrosion Damage in Reinforced Concrete” In this paper two accelerated corrosion techniques namely constant voltage and constant current were used. A total of six columns were cast for this experiment. For one pair of regular RC columns, corrosion was accelerated using constant voltage and for another pair, corrosion was accelerated using constant current. The remaining pair of regular RC columns was used as control. In the experiment, all the columns were subjected to cyclic wetting and drying using sodium chloride (NaCl) solution. After the specimens had suffered sufficient percentage steel loss, all the columns including the control were tested using compressive loads. The test results generated show that accelerated corrosion using impressed constant current produces more corrosion damage than that using constant voltage. The results suggest that the constant current approach can be better used to simulate corrosion damage of reinforced concrete structures and to assess the effectiveness of various materials, repair strategies and admixtures to resist corrosion damage.

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 3, March 2017

Raoul François et al. (2016) (2) “Influence of long-term chloride diffusion in concrete and the resulting corrosion of reinforcement on the serviceability of RC beams” This paper presents the chloride penetration and the effect of chloride ingress on the serviceability of reinforced concrete (RC) beams. A series of experimental studies were carried out on beams with various corroded ages up to 28 years. The chloride content in different locations was tested during various periods. Different states influencing the serviceability of the corroded beams were investigated, including the maximum width of the corrosion-induced cracks of the concrete cover, the mid-span deflection of the beams under the service load and their load-bearing capacity. Based on the results available from this programme, the service life of corroded beams was predicted by the corrosion process of the reinforcement. The results showed that the chloride corrosion could significantly deteriorate the serviceability of the beams. The current criteria concerning the chloride content at the level of the reinforcement of the concrete beams and the maximum width of the corrosion-induced cracks appear to be very conservative.

G. Mancini et al. (2014)(3) “Local reinforcing bar damage in R.C. members due to accelerated corrosion and loading” Corrosion attack of steel in concrete has been studied by means of an experimental analysis on reinforced concrete ties under both static/cyclic loading and accelerated corrosion. Crack opening zones across crack locations due to load have been analysed and corrosion concentration around crack site has been observed. A quantitative evaluation of local damage is presented by means of a mechanical procedure using 3D scanning and data post-processing. The results show the influence of the presence of corrosion, stress amplitude and the type of loading on local damage.

Wenjun Zhu et al. (2013) (4) “Effect of corrosion of reinforcement on the mechanical behaviour of highly corroded RC beams” This paper describes an experimental investigation of the behaviour of corroded reinforced concrete beams. These have been stored in a chloride environment for a period of 26 years under service loading so as to be representative of real structural and environmental conditions and then the beams were tested until failure by a three-point loading system. Another two beams of the same age but without corrosion were also tested as control specimens. A short span arrangement was chosen to investigate any effect of a reduction in the area and bond strength of the reinforcement on shear capacity. The relationship of load and deflection was recorded so as to better understand the mechanical behaviour of the corroded beams, together with the slip of the tensile bars. The corrosion maps and the loss of area of the tensile bars were also described after having extracted the corroded bars from the concrete beams. Tensile tests of the main longitudinal bars were also carried out. The residual mechanical behaviour of the beams has been discussed in terms of the experimental results and the cracking maps. The results show that the corrosion of the reinforcement in the beams induced by chloride has a very important effect on the mechanical behaviour of the short-span beams, as loss of cross-sectional area and bond strength have a very significant effect on the bending capacity.

M. Tapan et al. (2013) (5) “Effect of steel corrosion and loss of concrete cover on strength of deteriorated RC columns” In this paper, the effect of reinforcement corrosion and loss of concrete cover on structural behaviour of bridge columns is quantified by developing moment–axial load (M–P) interaction diagrams using modified analysis procedure and advanced deteriorated material models. The results of this study suggest that corrosion of steel bars on the compression side of column section reduces the effective depth, and causing more reduction than left side or tension side deterioration, in compression controlled region. However, in general, corrosion of tension reinforcement causes more strength reduction than corrosion of reinforcement in compression or left/right side reinforcement, particularly, in tension controlled region.

Qinghui Suo et al. (2009) (6) “Corrosion cracking prediction updating of deteriorating RC structures using inspection information” In this study, RC slabs and beams were used to show the influence of corrosion on the extent of cracking. Concrete strength, concrete cover and the surface chloride concentrations were modelled as spatial variables. Monte-Carlo simulation was used to calculate the updated cracking proportions. The analysis considers various inspection scenarios which include different inspection intervals, inspection times, cracking proportion and crack width. It was found that the occurrence or observance of cracking changes the future cracking prediction significantly.

A.Loukili & J.P. Regoin et al. (2010) (7) “Measuring crack width and spacing in reinforced concrete members.” In this paper an experimental investigation is performed to study the effect of structural size on crack width and crack spacing in reinforced concrete structures under service loadings. Bending tests were performed on three different sizes of beams which were geometrically similar in two dimensions. The main reinforcement ratio was constant in all the beams keeping the same number of bars. The cover to the main reinforcement was also scaled with the beam size. Crack width and cracks spacing were measured using digital image correlation technique. Strain in the main reinforcement was measured using embedded electric strain gauges. It was found that Euro code underestimates the crack width and crack spacing. Measured values of crack width show an important structural size effect. This effect is not considered by Euro code crack width formula. The results show that the measured values more or less agree with the calculated values at low strains and small beam size. But there is a significant size effect on the experimental crack width and crack spacing, which is not incorporated in the current Euro code design formulas.

Santiago Guzmán et al. (2011) (8) "Cover cracking of reinforced concrete due to rebar corrosion induced by chloride penetration." This paper presents two models that deal with the chloride-induced corrosion and its effect on cracking of concrete cover in RC structures. The first method analyses the chloride diffusion within partially saturated concrete. A comprehensive model was developed through the governing equations of moisture, heat and chloride-ion flow. Nonlinearity of diffusion coefficients, chloride binding isotherms and convection phenomena were also highlighted. The second method describes the internal cracking around the bar due to expansive pressures as corrosion of the reinforcing bar progresses. Once a certain chloride concentration threshold is reached in the area surrounding the bar, oxidation of steel begins and oxide products are generated, which occupy much greater volume than the original steel consumed by corrosion. An embedded cohesive crack model is applied for cracking simulation. Both models were incorporated in the same finite element program. Comparisons with experimental results were carried out, with reasonably good agreements being obtained.

Kapilesh Bhargava al. (2006) (9) "Model for cover cracking due to rebar corrosion in RC structures". The paper presents an analytical model to predict the time required for cover cracking and the weight loss of reinforcing bars in corrosion affected reinforced concrete structures. The proposed model also incorporates the modelling aspects of the residual strength of cracked concrete and the stiffness contribution from the combination of reinforcement and expansive corrosion products. It has been found that the model is quite capable of providing the estimates of predicted time to cover cracking and weight loss of reinforcing bars that are in reasonably good agreement with the experimentally observed values as well as the analytical predictions of other researchers. It has also been found that both, predicted time to cover cracking and weight loss of reinforcing bars are significantly influenced by tensile strength of cover concrete, annual mean corrosion rate and modulus of elasticity of reinforcement plus corrosion products combined.

Shu-Yan Yang et al. (2016) (10) "Experimental research on hysteretic behaviours of corroded reinforced concrete columns with different maximum amounts of corrosion of rebar" In this paper, the hysteretic behaviours of corroded RC columns were studied, which were considered as the condition of tide region or splash zone. Experiments were designed for five groups of corroded RC columns with different maximum amounts of corrosion of rebar under cyclic lateral loads combined with a constant vertical load. The traditional soaking method was replaced by a new wrapping method in order to obtain the desired amount of corrosion of rebar that was similar with the environment condition. The results showed that the flexural strength, the circular stiffness, the ductility, and the energy absorption of corroded RC column degraded with the increase of the maximum amount of corrosion of rebar. The maximum amount of corrosion of 13.25% and the dilation crack width of 1.2 mm were two critical parameters.

Ngoc Son Vu et al. (2016) (11) "Prediction of strength and drift capacity of corroded reinforced concrete Columns" In this paper, the behaviour of corroded RC columns under the seismic loading was studied using a three-dimensional non-linear Finite Element analysis, considering the material properties deterioration of reinforcement and concrete induced by corrosion. The experimental results of nine reinforced concrete columns in three experimental studies in literature were selected to verify the accuracy of the proposed 3D non-linear FE model. Thereafter, an extensive parametric investigation, including the FE models of 240 RC columns subjected to the simulated seismic loading was performed to study the influence of various crucial parameters on the seismic performance of corroded RC columns, particularly their lateral load resistance and ultimate drift capacity deterioration. Finally, these key parameters were incorporated into two prediction equations of the lateral load resistance and ultimate drift capacity for corroded RC columns.

Haitao Li, Xi Ba et al. (2015) (12) "Experimental investigation on the cyclic performance of reinforced concrete piers with chloride-induced corrosion in marine environment" This paper presents a cyclic experiment of coastal bridge piers considering the corrosion effects. Four test specimens, among which one was a sound structure and the others structures with different levels of corrosion damage from accelerated corrosion, were used for the cyclic tests in this study. Using the measured force–displacement hysteretic responses, the effects of the corrosion damage on the seismic behaviour of the specimens were investigated. The test results indicated that the seismic performance of the structure showed obvious degradation with the increase in the level of corrosion.

Alberto Meda et al. (2014) (13) "Experimental evaluation of the corrosion influence on the cyclic behaviour of RC columns" Corrosion of reinforcement is one of the leading causes of the deterioration in reinforced concrete structures. RC structures damaged by reinforcement corrosion can exhibit not only reduction of the bearing capacity but also an alteration of the collapse mechanism with a reduction of the structural ductility. In order to study the problem, full scale experimental tests on column specimens have been performed under cyclic loads. Preliminary tests for the calibration of the corrosion process were carried out both on bare and embedded bars. The results of the cyclic experimental tests show how the reinforcement corrosion can lead to a reduction of the structural ductility, such that it could become a critical aspect particularly for buildings in seismic regions.

Tomoaki Tsutsumi et al (2016) (14) "Residual load capacity of corroded reinforced concrete beam undergoing bond failure" 20 rebar reinforced concrete beams, including 3 non-corroded beams, 3 unbonded beams, 9 fully corroded beams and 5 partly corroded beams, were loaded under four point static bending test. As a result of the experiment, the unbonded beams suffer arch action at any load level, and the load resisting mechanism of the 13 corroded beams which undergo bond failure changes to arch action near the later loading stage. The 13 corroded beams in the experiment fails as the maximal bond stress in the anchorage region reaches its critical value which cannot keep the balance of the arch rib. The maximal bond force in the anchorage region is taken into account as a key factor in the prediction method, as it has a great effect on the residual load capacity of the corroded beam undergoing bond failure. Based on the experimental result, the maximal bond force in the anchorage region and the residual load capacity are normalized by the values of the unbonded beam, and a model is proposed to predict the residual load capacity of the corroded beam undergoing bond failure based on arch action.

Takafumi Noguchi et al. (2016) (15) "Evaluation of Bond Properties of Reinforced Concrete with Corroded Reinforcement by Uniaxial Tension Testing" In this study, uniaxial tensile tests were conducted on specimens with irregular corrosion of their reinforced concrete. The development of cracks in the corroded area was found to be dependent on the level of corrosion, and transverse cracks developed due to tensile loading. Based on this crack development, the average stress versus deformation in the rebar and concrete could be determined experimentally and numerically. The results, determined via finite element analysis, were calibrated using the experimental results. In addition, bond elements for reinforced concrete with corrosion are proposed in this paper along with a relationship between the shear stiffness and corrosion level of rebar.

Ashhad Imam (2016) (16) "Prediction of residual shear strength of corroded reinforced concrete beams" This paper presents the test results of 13 corroded and 4 un-corroded beams. Corrosion damage was induced by accelerated corrosion induction through impressed current. Test results show that loss of shear strength of beams is mostly attributable to two important damage factors namely, the reduction in stirrups area due to corrosion and the corrosion-induced cracking of concrete cover to stirrups. Based on the test data, a method is proposed to predict the residual shear strength of corroded reinforced concrete beams in which residual shear strength is calculated first by using corrosion-reduced steel area alone, and then it is reduced by a proposed reduction factor, which collectively represents all other applicable corrosion damage factors. The method seems to yield results that are in reasonable agreement with the available test data.

Sergio Navarro-Gutierrez et al (2007) (17) "Residual flexure capacity of corroded reinforced concrete beams" This work presents results from an experimental investigation which correlated flexure capacity loss with steel cross-section loss due to generalized corrosion of the embedded steel in a humid environment. Concrete beams (100 × 150 × 1500 mm) cast with chlorides were used in this investigation. Further acceleration of the corrosion process was achieved by applying a nominal 80 μA/cm2 constant anodic current for approximately 50–180 days. The specimens were subsequently tested in flexure under three-point loading. The average corrosion penetration, xAVER, the maximum concrete surface crack width, CWMAX, and the maximum rebar pit depth, PITMAX, were estimated for each corroded beam using gravimetric metal loss procedure. The results obtained showed: (1) the corrosion-induced concrete crack propagation was enhanced if dry rather than wet environment is used during the accelerated corrosion stage; (2) wet environment during corrosion acceleration enhanced pit formation at the rebar surface; (3) a decrease of as much as 60% in the flexure load capacity values was observed with only 10% of xAVER/r0, where r0 = rebar radius; and (4) PITMAX, not the xAVER/r0 ratio, was the most important parameter affecting flexural load capacity reduction in corroded beams.

REFERENCES

1) S. Altoubat et al. "Laboratory Simulation of Corrosion Damage in Reinforced Concrete" International Journal of Concrete Structures and Materials Vol.10, No.3, pp.383–391, September 2016.

2) Raoul François et al. "Influence of long-term chloride diffusion in concrete and the resulting corrosion of reinforcement on the serviceability of RC beams" Construction and Building Materials 121 (2016) 345–357.

3) G. Mancini et al. "Local reinforcing bar damage in R.C. members due to accelerated corrosion and loading" Construction and Building Materials 69 (2014).pp- 116–123.

4) Wenjun Zhu et al. "Effect of corrosion of reinforcement on the mechanical behaviour of highly corroded RC beams" Construction and Building Materials 121 (2013) 305–313.

5) M. Tapan et al. "Effect of steel corrosion and loss of concrete cover on strength of deteriorated RC columns" Engineering Structures 105 (2013).pp- 202–211.

6) Qinghui Suo et al. "Corrosion cracking prediction updating of deteriorating RC structures using inspection information" Reliability Engineering and System Safety 94 (2009), pp. 1340–1348.

7) A.Loukili& J.P. Region et al. "Measuring crack width and spacing in reinforced concrete members." Korea concrete institute, ISBN (May2010), pp. 377-382.

8) Santiago Guzmán et al. "Cover cracking of reinforced concrete due to rebar corrosion induced by chloride penetration." Cement and Concrete Research 41 (2011), pp. 893–902

9) Kapilesh Bhargava al. "Model for cover cracking due to rebar corrosion in RC structures" Nuclear Engineering and Design 236 (2006) 1123–1139.

10) Shu-Yan Yang et al. "Experimental research on hysteretic behaviours of corroded reinforced concrete columns with different maximum amounts of corrosion of rebar" Construction and Building Materials 121 (2016) 319–327.

11) Ngoc Son Vu et al. "Prediction of strength and drift capacity of corroded reinforced concrete Columns" Construction and Building Materials 115 (2016).pp- 304–318.

12) Haitao Li, Xi Ba et al. "Experimental investigation on the cyclic performance of reinforced concrete piers with chloride-induced corrosion in marine environment" Engineering Structures 105 (2015).pp- 1–11.

13) Alberto Meda et al. "Experimental evaluation of the corrosion influence on the cyclic behaviour of RC columns" Engineering Structures 76 (2014) 112–123.

14) Tomoaki Tsutsumi et al "Residual load capacity of corroded reinforced concrete beam undergoing bond failure" Engineering Structures 127 (2016).pp- 159–171.

15) Takafumi Noguchi et al. "Evaluation of Bond Properties of Reinforced Concrete with Corroded Reinforcement by Uniaxial Tension Testing" International Journal of Concrete Structures and Materials Volume 10, Number 3 Supplement, pp.S43–S52, September 2016.

16) Ashhad Imam "Prediction of residual shear strength of corroded reinforced concrete beams" Int J Adv Struct Eng (2016) 8:307–318.

17) Sergio Navarro-Gutierrez et al. "Residual flexure capacity of corroded reinforced concrete beams" Engineering Structures 29(2007).Pp.-1145–1152.