International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 9 Issue 6 ǁ 2021 ǁ PP. 59-63

Finite Element Analysis of RC Beam Subjected To Corrosion – A Review

K. Sumangala[1] and C.M. Flora Dani[2]
[1]Assistant Professor [2]P.G. Student
Department of Civil Engineering
Government College of Engineering
Tirunelveli, India.

ABSTRACT
During long term service life, reinforcement concrete structures are exposed to different environmental conditions and consequences. Corrosion of reinforcing steel is the predominant deterioration mechanism of reinforced concrete structures throughout the world. It is commonly perceived as one of the detrimental factor causing deterioration of serviceability and durability. Traditionally much attention have been focused on models, which can predict the time of activation of the corrosion process. Consequently, there is a urgent need for numerical models, which are capable of describing the rate of attack. Until now, various simulations, numerical models, finite element methods are practiced to study different aspects of corrosion, its characteristics and structural behavior. This paper gives a summary of works available in literature regarding modelling of corrosion in reinforced concrete element using finite element analysis software.
KEYWORDS- *Corrosion, simulation, modelling, Numerical Analysis, Tool, VecTor2, ANSYS, ABACUS, LUSAS*

Date of Submission: 25-05-2021 Date of acceptance: 07-06-2021

I. INTRODUCTION

Corrosion of steel reinforcement embedded in concrete structures is the most pronounced issue with RC construction, particularly those exposed to chloride rich environment. Reinforcement corrosion is basically a electrochemical reaction, in which small anodes and cathodes are created within, flow of ions between these two electrodes leads to corrosion of steel bars. Corrosion are mainly due to carbonation due to which uniform corrosion occurs, associated with formation of brown rust iron oxides and chloride penetration which causes pitting, that leads to decrease in cross section of steel. The oxides occupy a greater volume than the parent metal and the expansion of the diameter of the bar as it corrodes, generally lead to cracking and eventually spalling of concrete cover. Also, corrosion reduces the bond between steel bar and surrounding concrete due to weakening of bar confinement produced by concrete cracking and stirrups corrosion.

Therefore it is imperative that more studies were initiated to understand the effect of rebar corrosion on the mechanical/ flexural behaviour of reinforced concrete elements experimentally. Studies also been carried out to investigate the effect of corrosion on bond between steel and concrete. With the development of FEM software, researchers have started contributing their ability in modeling various aspects of corrosion. Many works have been reported in the study on assessing residual structural capacity of corroded RC members experimentally and using finite element method which provided reliable assessment of the strength and integrity of damaged or deteriorated structures.Therefore, it was decided to review the works done by various researchers to understand the mechanism of corrosion and their effect with this useful tool.

II. LITERATURE REVIEW

Tamai et. al, studied the impact resistance of reinforced concrete beams with reinforcement corrosion. The results indicate that, for corrosion degrees higher than 10%, the impact resistance is significantly reduced and the failure mode becomes more brittle. The decrease in flexural strength was due to a decrease of the effective cross sectional area of the reinforcing bar and loss of bond capacity due to corrosion.

Akhras et al, represents a novel and innovative research to evaluate the corrosion deterioration of reinforcement steel in SCC compared to CVC using different tests. The flexural test of corroded SCC beams showed higher performance than those of corroded CVC beams. Transverse crack pattern was observed in SCC beams while longitudinal crack pattern in CVC beams.

Zhang et al, presents the correlation of steel corrosion in the transverse direction between tensile bars on the structural performance of RC beams. experimental results indicated that compared to the RC beams corroded over the entire length, the partially corroded RC beams with highly localised steel corrosion in the midspan experienced large reduction in both loading capacity and ultimate deflection.

Sun et al. (2020), presented a comprehensive probabilistic approach for corrosion induced cracking fragility analysis. The results show that increase on the concrete strength, cover depth and steel bar diameter or decrease on the carbon dioxide density, are efficient countermeasures to improve the durability performance of the RC bridge against corrosion induced cover cracking and the uncertainty of the problem mainly comes from the concrete carbonation model.

Chen et al., presented a experimental and numerical investigation of chloride induced reinforcement corrosion and mortar cover cracking. corrosion profiles demonstrate that earlier cracking of mortar cover and faster development of surface cracks can be observed under the time varying non uniform corrosion condition. In addition, wedge shaped cracks are prone to occur as cover thickness decreases and the delaying effects on the surface cracking time is more noticeable.

Zhu et al. (2020), investigates the influence of corrosion degree and corrosion morphology on the mechanical properties of the steel reinforcement. . It was found that, for all the corrosion morphologies, that the ultimate strain of the corroded steel reinforcement was reduced in an exponential manner with the corrosion degree up to critical level which is 30% by mass loss, beyond which it then stayed sable. However, different corrosion morphologies led to significantly different degradation rates with the corrosion degree.

Lin et al. (2020), studied the bond strength evaluation of corroded steel bars via the surface cracks width induced by reinforcement corrosion. Test results indicate that the surface crack width is closely linked to the corrosion level of the tensile steel bar . It is further revealed that the bond strength decreases exponentially with the surface crack width

Cui and Alipour (2017), provides a comprehensive and critical analysis for the analytical and numerical models of corrosion induced cover crack initiation. The results show that the type of corrosion product, thickness of interfacial transition zone and rate of corrosion are the parameters that affect crack initiation time. The FE results show that the crack pattern under uniform and non-uniform corrosion differ. Non uniform corrosion causes high concentrated pressure at the pits which would lead to earlier cover cracking.

Sola et al. (2020), presents a numerical study of accelerated corrosion of steel reinforcement in concrete. The evaluation of the mass loss, average current density and monitoring of crack pattern at different level of corrosion induced damage are performed. The performed numerical mode shows that the predicted corrosion rate is significantly affected by the hysteretic moisture behaviour of concrete. The crack pattern and development of the corrosion induced damaged in time corresponds nicely with the experimental results for all investigated samples. The distribution of products in cracks is shown to be dependent on the crack width and saturation.

Maaddawy and Soudki (2003), studied the effectiveness of impressed current technique to simulate corrosion of steel reinforcement in concrete. The results showed that, up to 7.2% mass loss, using the impressed current technique was effective in inducing corrosion of the steel reinforcement in concrete. with respect to faraday law, the use of different current densities has no effect on the percentage of mass loss. However, increasing the level of current density above 200 $\mu A/cm^2$ results in a significant decrease in the strain response and crack width due to corrosion of steel reinforcement.

Faron et al. (2020), presents nonlinear numerical simulation of bending and shear crack propagation in reinforced concrete beams without transverse reinforcement. The crack patterns of real experiments are compared with the results of the different finite element method up to two crack initiation. The evaluation is based on single span beams under bending and shear. The numerical simulations make it possible to predict the fracture behaviour of concrete members and shows good agreement with the experimental results.

Chen and leung(2017), presents the mechanical consequences caused by steel corrosion with various type of models. Under the same corrosion penetration depth, corrosion expansion represented by the free increase of steel radius due to corrosion in the analytical cylinder models and hollow concrete model is larger than the final rust thickness calculated in the full model. In addition, the final rust thickness around the steel perimeter and the rust thickness/corroded depth ratio is shown to be nonuniform under both uniform and non-uniform corrosion which is caused by local cracking in concrete.

Zhang et al. (2020), investigated the random evolution process of corrosion in steel bar under a constant corrosion current density. Markov model predicted results showed that the corrosion depth followed the Poisson distribution while the longitudinal no uniformity factor of corroded steel bar followed Gumbel distribution. The probability distribution parameters of the factor was determined by Monte-Carlo simulation. The corrosion depth and the factor predicted by Markov model agreed well with the experimental results.

Yu et al. (2020), addressed carbonation induced macrocell corrosion, including the impacts of structural defects formed by concrete casting in this study. This study gives ideas for advancing the service life monitoring and assessment of ageing concrete structures.

Mai and Soghrati (2018), presents a new phase field model for simulating galvanic and pitting corrosion phenomena in metallic materials. The application of the model for simulating coupled galvanic-pitting corrosion processes in a hybrid joint and an aluminium composite material under varying environmental conditions is demonstrated. The simulation example shows the feasibility of incorporating homogeneous chemical reactions and polarisationbehaviour on the node into the proposed model.

Zhu et al. (2019), presents a new equivalent smeared layer model. In this approach, the outer portion of the steel reinforcement is reset as the hypothetical deformable material whose elastic modulus depends on the degree of corrosion. The comparison with the results of uniform corrosion illustrates that the non-uniform corrosion can significantly accelerate the damage rate of corrosion and also very suitable for actual application.

Wang and Elsayed (2020), develops a stochastic model that characterise both corrosion volume and depth growth. The corrosion growth of pit is modelled as state dependent gamma process. The influence of stresses, which include the relative humidity, pH level and temperature is incorporated into the model based on the physics of corrosion reaction mechanism. The proposed model results in more accurate prediction of the remaining lives compared with the existing models.

Zhu et al. (2017), presents a comprehensive model for the prediction of the process of steel reinforcement corrosion and concrete damage in two dimensions. Using the model, the non-uniform distribution of corrosion product, the expansive pressure and the growth of corrosion induced cracks can be predicted.

Papakonstantinou and Shinozuka (2013), presented a probabilistic model for chloride induced corrosion of the reinforcing steel in concrete structures. a time dependent model is developed that can simulate all stages of reinforced concrete corrosion. Probabilistic concept are also employed due to numerous sources of uncertainty in the degradation model and the extent of damage is quantified by considering the spatial variability of various parameters. probability density function for certain variables and random model parts are suggested as well.

Chen et al. (2020), presents the corrosion characteristics of 66 rebars extracted from un and pre cracked plain concrete and fibre reinforced concrete beams suffering from corrosion for more than 3 years. Corrosion pits were obtained near some flexural cracks. While the bars at other cracks were free from corrosion. Most rebars in FRC had less maximum local corrosion level than in plain concrete under the same loading condition and maximum flexural crack width. However, the maximum local corrosion level was not dependent on the crack width. Longitudinal cracks aggravated the total steel loss and changed the pit morphology by promoting the pit length development. A hypothesis about the time dependent interplay between transverse and longitudinal cracks and corrosion development was proposed.

Gulikers (2003), focuses on localised attack of reinforcing steel resulting from chloride contamination of the concrete cover. The results are presented in terms of local penetration depth, surface area under corrosion attack and steel volume consumed by corrosion. The improved corrosion deterioration model can be used to formulate a probabilistic model which allows calculation of the probability that a given reduction of the reinforcement cross section has taken place at a given time.

SiavashHababi (2017), this thesis presented a finite element modelling of corrosion damaged reinforced concrete structures. The employed techniques for incorporating corrosion damage in VecTor2 successfully reproduced the load-deflection response of published experiments on corroded RC beams. Stochastic simulation of the same beams, performed by employing the stochastic tools of VecTor2, demonstrated the sensitivity of response quantities such as failure load to change in various input parameters .

Haido (2020), presented a comprehensive plan for examining the behaviour of basalt fiber reinforced concrete beams under bending effects under finite element analysis and introduces a new model. The study reveals that the use of the proposed elasticplastic compressive behaviour model of BFRC with the second quadratic model of its tension stiffening phenomena shows minimum error in the predicted behaviour of BFRC beams.

Biswas et al. (2020), studied the structural behaviour of RC beams subjected to nonuniform steel bar corrosion by developing a simplified numerical model. Results from the experimental and numerical study demonstrated that non uniform steel bar corrosion led to a significant decrease in the load carrying capacity and ductility of RC beams., but the cyclic analysis revealed that ductility of RC beams could be increased when the corrosion ratio is up to 13%. Findings of this study will be useful in assessing the residual structural performance of the RC structures with nonuniform steel bar corrosion.

Du et al. (2013), made finite element analysis of cracking and delamination of concrete beams due to steel corrosion analysed using the finite element software LUSAS. The amount of corrosion in terms of radial expansion required to causes, varies almost linearly with bar diameter d, bar clear distance s, concrete cover c, respectively. If the ratio s/c was less than the critical value of about 2.2, the delamination of concrete cover would occur before the cracks can be visualised on the concrete surface.

TanaratPotisuk et. al, (2020) developed Finite element (FE) modeling to isolate the different contributions of corrosion damage to structural response of experimental reinforced concrete beams with sheardominated behavior. Corrosion-damage parameters included concrete cover spalling due to the expansion of corrosion products; uniform stirrup cross-sectional loss from corrosion; localized stirrup crosssectional loss due to pitting; debonding of corrosion- damaged stirrups from the concrete. FE analyses were performed including both individual and combined damages. The FE results matched experimental results well and quantitatively estimated capacity reduction of the experimental specimens.

Guifeng Zhao et. al, (2018) studied the static load carrying capacity of a non corroded reinforced concrete(RC) simply supported beam which is numerically simulated by ABAQUS software. The results show that, under conditions of slight corrosion, the degradation of bond-slip performance between the rebar and concrete has no significant influence on the bearing capacity of the beam, while the degradation of the corroded rebar had a significant effect. Under moderate and severe corrosion conditions, the bearing capacity and ductility degradation caused by bond-slip are dominant in the mechanical property degradation of the beam. . With the increase in the corrosion rate, the bearing capacity and ductility of the beam are decreased, and its brittleness is increased.

Hamdi Ahmed Mohammed Al-Sakkaf, (2016) proposed a finite element model to include all damage parameters due to corrosion in the model and use the appropriate reduction empirical models available in the literature for corrosion-induced damages. Results illustrated that the most critical corrosion-induced damage is the complete loss of bond between reinforcement and the concrete as it causes sudden failure and the beam behaves as un-reinforced beam. Moreover, this failure can happen in situations where the corrosion is only at extreme quarters of the beam span, where bond is most critical at these locations. It was also noted that variation of corrosion level in the lateral direction caused lateral deflection due to the developed unsymmetry of the cross section.

Coronelli and Gambarova (2004) studied the evolution of the structural behaviour in reinforced concrete beams by developing a suitable numerical procedure. Non-linear finite element is used and the effect of corrosion are modelled by reducing the geometry of the finite elements representing separately the steel bars and the concrete and by modifying the constitutive laws of the materials and of their interface. Both the service and limit states are studied showing the importance of stiffness decay because of impaired tension stiffening, crack pattern evolution accompanied by enhanced shear effect, strength deterioration in bending and shear, bond failure along the span at the beam ends.

Irina Sæther and Bjørnar Sand (2007) is devoted to the application of finite element analysis to simulate the mechanical behaviour of reinforced concrete members with corroding steel bars using the finite element program DIANA.The effects of corrosion are taken into consideration. Accordingly, loss of steel bar section, and reduced bond between deteriorated concrete and corroded rebar are accounted for in the present work. The results of the simulations are validated against published results from laboratory tests on medium scale beams. The load-deflection behaviour obtained from the finite element simulations are in agreement with the test data.

Akshatha Shetty et. al, (2015) studied the detrimental effect of corrosion on bond behaviour. From the experimental investigation, it has been observed that bond strength degradation of 2.6 % at slip initiation and 2.1 % at end of slip have been observed for every percentage increases in corrosion level. Numerical investigation with concrete is modelled as solid 65 element and reinforcement modelled as Link 8 elements. ANSYS has yielded 3 and 2.4 % bond strength degradation values at initiation and end of slip per percentage increase in corrosion levels.

Ali Ghods et. al, (2014) presents a corroded reinforced concrete beam, whose experimental results are available, is modelled based on the finite element method using ANSYS. . It was observed that with an increase of the reinforcement corrosion rate, the load-carrying capacity of the concrete beam and the bond strength decreases. In addition, the area under the load-displacement curve of the concrete beam decreases with the increase of the reinforcement corrosion.

III. CONCLUSION

Many works have been reported in the literature on assessing residual structural capacity of corroded RC members experimentally and using finite element method which provided reliable assessment of the strength and integrity of damaged or deteriorated structures. Reports were found about the studies being carried out using various models mentioned here to correlate the effect of corrosion with depth of pitting corrosion and corrosion volume, intensity of current, cover spalling pressure, reduced bond between steel and concrete, mass loss of rebar and so on. Hypothesis is being proposed about the time dependent interplay between transverse and longitudinal cracks and corrosion development. Behaviour of RC beams subjected to nonuniform steel bar corrosion were studied using simplified numerical model, ABACUS and much more were noted.

REFERENCES

[1]. Hiroki Tamai, Yoshimi Sonoda, John E Bolander (2020) "Impact resistance of RC beams with reinforcement corrosion: experimental observation". *Construction and building materials 263, 120638.*

[2]. Nabil Al Akhras, RawanAleghnimat (2020) "Evaluating corrosion deterioration in self compacter reinforced concrete beams and prisms using different tests". *Construction and building materials 256, 11937.*

[3]. Ming yang Zhang, Naoki Nishiya, Mitsuyoshi Akiyama, Lim, Masuda (2020) "Effect of the correlation of steel corrosion in the transverse direction between tensile bars on the structural performance of RC beams". *Construction and building materials 264, 120678.*

[4]. Bo Sun, Ru Chen Xiao, weidongRuan, Pengbo Wang (2020) "Corrosion induced cracking fragility of RC bridge with improved concrete carbonation and and steel reinforcement corrosion models" *Engineering Structures*, 208.

[5]. Junyu Chen, Weiping Zhang, Tang, Huang (2020) "Experimental and numerical investigation of chloride induced reinforcement corrosion and mortar cover cracking". *Reliability engineering and system safety 204, 107120.*

[6]. Wenjun Zhu, Raoul Francois, Chi Sun Poon, Jian Dai (2017) "Influences of corrosion degree and corrosion morphology on the ductility of steel reinforcement". *Construction and building materials 148, 297306.*

[7]. Hongwei Lin, Yui Zhao, JoskoOzbolt, Hans-wolf (2017) "Bond strength evaluation of corroded steel bar via the surface crack width induced b reinforcement corrosion". *Engineering structures, 152 , 502522.*

[8]. Zhen Cui, Alice Alipour, (2017) "Concrete cover cracking and service life prediction of reinforced concrete structures in corrosive environment". *Construction and building materials.*

[9]. E. Sola, J. Osbolt, Balabanic, Mir (2020) "Experimental and numerical study of accelerated corrosion of steel reinforcement in concrete: transport of corrosion product", *Engineering Structures 20, 110313.*

[10]. Tamer A Maaddawy, Khaled A Soudki, (2003) "Effectiveness of impressed current technique to simulate corrosion of steel reinforcement in concrete".*10.1061/(ASCE)0899156115:1(41).*

[11]. Adrian Faron, Gunter AelRombach, (2020) "Simulation of crack growth in reinforced concrete beam using etended finite element method". *Engineering Failure Analysis (2020), doi: https://doi.org/10.1016/j.engfailanal.2020.104698.*

[12]. E Chen , Christopher Leung (2017) "Mechanical aspect of simulating crack propagation in concrete under steel corrosion". *Construction and building materials 191, 165175.*

[13]. Weiping Zhang, Jinping Chen, Qian Quian Yu, Lin Gu (2020) "Corrosion evolution of steel bars in RC structures based on Markov chain modelling". *Structural safety 88, (2020)102037.*

[14]. Yugyo Yu, wei Gao, Arnaud Castel, Airong Liu, Chen (2020) "Modelling steel corrosion under concrete non-uniformity and structural defects". *Cement and concrete research 135, 106109*

[15]. Weiji Mai, SoheilSogherti (2020) "New phase field model for simulating galvanic and pitting corrosion process".*<![CDATA[Corrosion Science]]> (2017), http://dx.doi.org/10.1016/j.corsci.2017.06.006.*

[16]. Xingji Zhu ,Zhao zhengMeng, Lu Liu ,Longjun Xu (2017) "An equivalent smeared layer method for simulating the non uniform corrosion-induced damage of concrete". *Engineering Fracture Mechanics, https://doi.org/10.1016/j.engfracmech.2019.106791.*

[17]. Changxi Wang and Elsayed A Elsayed (2020) "Stochastic modelling of corrosion growth". *Reliability engineering and system safety 204, 107120.*

[18]. Xingji Zhu, GoangseupZi (2017) "A 2D mechano chemical model for the simulation of reinforcement corrosion and concrete damange". *Construction and building material 137, 330 334.*

[19]. K.G. Papakonstantinou, M. Shinozuka (2013) "Probabilistic model for steel corrosion in reinforced concrete structures of large dimension considering crack effects". *Engineering structures 57, 306326.*

[20]. Junyu Chen, Weiping Zhang, Tang, Huang (2020) "Experimental and numerical investigation of chloride induced reinforcement corrosion and mortar cover cracking". *Cement and concrete composites 111, 103620.*

[21]. J Gulikers (2002) "Critical review of corrosion deterioration models for reinforced concrete". *civil engineering division, ministry of transport Utrecht, The Netherlands.*

[22]. Sivash Habibi (2017) "Finite element modelling of corrosion damaged reinforced concrete structures". *A thesis submitted for degree of masters of applied science, University of Toronto .*

[23]. James H Haido(2020)"Flexural behaviour of basalt fibre reinforced concrete beams: finite element simulation with new constitutive relationships". *Department of civil engineering, college of engineering, university of Duhok, Iraq.*

[24]. Biswas, Iwanami, Chijiwa, Uno (2013) "Finite element analysis of RC beams subjected to non-uniform corrosion of steel bars". *Fifth International Conference on Sustainable Construction Materials and Technologies. http://www.claisse.info/Proceedings.htm*.

[25]. Y.G. Du, A.H.C Chan, Clark, Wang, Gurkalo, Bartos (2013) "Finite element analysis of cracking and delamination of concrete beams due to steel corrosion". *Engineering structures 56, 8-21.*

[26]. TanaratPotisuk, Christopher C Higgins, Thomas H. Miller, and SolomonC.Yim (2020), "Finite Element Analysis of Reinforced Concrete Beams with Corrosion Subjected to Shear*". Volume 2011, Article ID 706803, 14 pages doi:10.1155/2011/706803.*

[27]. Guifeng Zhao, Jiankun Xu, Yaoliang Li, and Meng Zhang (2018) "Numerical Analysis of the Degradation Characteristics of Bearing Capacity of a Corroded Reinforced Concrete Beam". *Volume 2018, Article ID 2492350, 10 pages https://doi.org/10.1155/2018/2492350.*

[28]. Hamdi Ahmed Mohammed Al-Sakkaf (2016), "Modelling of corroded reinforced concrete beams" *A thesis presented to the deanship of graduate studies,King Fahd university of petroleum and minerals, Saudi Arabia.*

[29]. Coronelli and Gambarova (2004) "Structural assessment of corroded reinforced concrete beams". *1214 / Journal of Structural Engineering, © ASCE / AUGUST 2004. 2004.130:12141224.*

[30]. Irina Sæther and Bjørnar Sand (2007) "FEM simulations of reinforced concrete beams attacked by corrosion". *The research work has been carried out in Northern Research Institute Narvik (NorutNarvik) through the European founded research project "Sustainable bridges".*

[31]. Akshatha Shetty , Kata Venkataramana ,K. S Babu Narayanan (2015) "Experimental and numerical investigation on flexural strength behaviour of NBS RC beams".*Int j advStructEng (2015) 7:223-231, doi 10.1007/s40091015-093-6.*

[32]. Ali Ghods, Mohammed Reza Sohrabi, Mahmoud Miri (2014) "Effect of rebar corrosion on the behaviour of a reinforced concrete beam using modelling and experimental result". *ISSN 1580-2949, MTAEC9, 48(3)395(2014).*