IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 08, Issue 4 (April. 2018), ||VI|| PP 94-100

Evaluation of the Defects along the Interface of Reinforced Concrete structures with Fractal Dimension curves

Zhao Guoqi[1, 2], Zhang Di[1]
1(Faculty of Civil Engineering and Mechanics, Jiangsu University, China)
2(Jiangsu university civil engineering technology research institute co. LTD.)
Corresponding Author: Zhao Guoqi

Abstract: Corrosion causes concrete to crack, debonding and failure of the prestressedreinforced concrete (RC) structures, which affects the service life of the infrastructures.It isof vital importance to evaluate the defects along the interface of steel and concrete during the life-cycle of the RC structures. In this paper, the author proposed a fractal dimension curve method to evaluate and compare the difference between the defect in steel with and withoutconcrete cover. The concrete cover and the diameter of the steel were taken into account to optimize the measurement configuration, then the central frequencyof the guided ultrasonic mode is determined by longitudinal dispersion curve. By changing the depth of the crack, adding white noise in the defected signals, and calculating the box-dimension eigenvalue of each defected model, an effective way has been found to evaluate the severity of the interface defects.To conclude that, the FD curve has the potential to evaluate the severity of the RC interface defect.

Keywords: Reinforced concrete structure, Fractal dimension, Interface defect, Structural health monitoring(SHM)Material

---

DateofSubmission: 22-03-2018 Date of acceptance: 07-04-2018

I. INTRODUCTION

The reinforced concrete (RC) is fundamentally used in civil engineering for its safety, feasibility and durability. And in most RC structures, the steel plays important roles in helping the concrete to bear the tension beyond its ability[1]. The accident of corrosion usually arouses some serious problems to the service of the fundamental structures which may cause delaminationand stress concentration0. In civil engineering, the necessary of detecting the corrosion or the failure of components is directly related to the human safety[2]. And it is also acknowledged that once the corrosion happens in the steel, the concrete cover may be weakened by corrosion product such as FeO which in turn accelerates the corrosion of steel. Thus, investigation on evaluating the reinforced concrete structures resulting from the corrosion and other effects is very essential for the practical engineering work which can assist in estimating or even prolonging the service life of some important civil infrastructures.

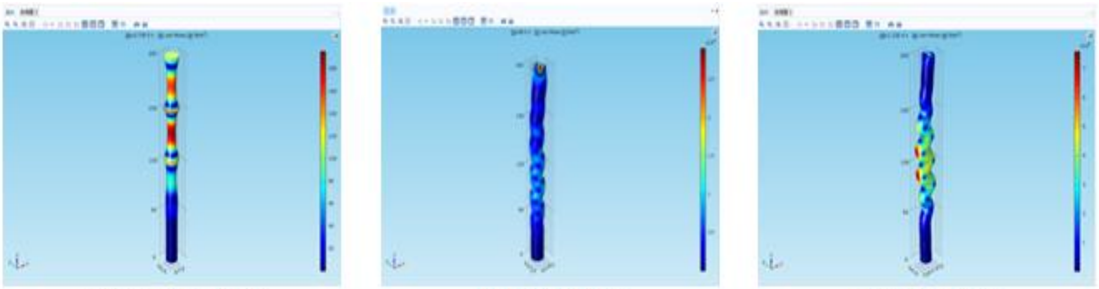
The fractal dimension derives from the natural description which means the dimension human beings have been used cannot fully identify the complex and erratic items of natural objects[4]. Mandelbrot[5] first proposed the fractal geometry of nature. Normally fractal is an accumulative fragments with several different shapes without characteristic length or features. Accompanied by some other researches, the fractal has been a subject which describes the irregularity of nature or human society. The fractal dimension of a set in a metric space such as a geometric object or the phase space trajectory of a dynamical system can be computed from several different measures[6]. Since the FD is used in many different parts, this method has been introduced in the structural detection field and a variety of experts have invest themselves in this kind of research. This technique is applied to the simulated fundamental vibration mode of a simply supported rectangular plate containing a crack parallel to one of its edges of arbitrary length, depth and location[7]. The area fractal dimension of aggregate provides a simple way to acquire the continuous gradation of asphalt concrete sample and the contour fractal dimension is an available parameter to characterize roughness and friction of pavement surface texture[8].

In this paper, we mainly discussed the effect of the damage along the steel-concrete on the fractal dimension value. A finite element (FE) model of steel-concrete was proposed to monitor the crack along the interface of steel-concrete. Then some parameters were taken into account to choose the incident waves, and finally the FD evaluation and amplitude evaluation were compared to show the robustness of box-dimension evaluation.

II. MODEL DESCRIPTION

As the diameter of common steel used in civil engineering structures is the same scale as the wave length, the ultrasonic wave propagates in steel is a cylindrical guided wave which depends on the boundary condition and the incident ways[9]. By changing the incident ways, three different modes were simulated to directly display the displacement fringes as shown in Fig.1. Fig.1.a is L-mode with radial and axial displacement by force parallel to the end of the guiding configuration. Fig.1.b is T-mode with angular displacement by a couple (torque) being created on the circumference of the guiding configuration. Fig.1.ais F-mode with angular, axial, and radial displacements by acompressional transducer coupled perpendicular to the guiding configuration.

Numerical simulation of guided waves and their interactions with damage have been mainly achieved by finite element, boundary element and spectral element methods with respective advantages and disadvantages[10][11][12]. Since the corrosion directly leads to mass loss of steel, stress concentration of concrete cover and debonding along the interface of steel and concrete, we assume the defects in RC structures are symmetry to simplify the model and save computer storage. Due to geometric symmetry and incident ways, the L (0, m) modes were chosen to detect the steel-concrete models.



(a) Longitudinal mode (b) Torsional mode (c) Flexural mode

Figure 1. Cylindrical modes

In cylindrical coordinates, the wave propagation equation of homogeneous and isotropic sold rod structure can be derived as (1).

$$\frac{2\alpha}{a}(\beta^2+k^2)J_1(\alpha a)J_1(\beta a)-(\beta^2-k^2)J_0(\alpha a)J_1(\beta a)-4k^2\alpha\beta(\beta^2+k^2)J_1(\alpha a)J_0(\beta a)=0 \qquad (1)$$

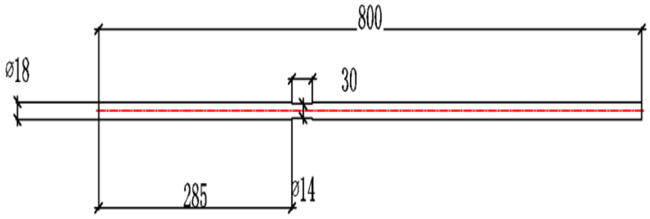
Fig.2 shows the dispersion curves of steel and steel-concrete systems with the dimensional properties in Table 1 and material parameters in Table 2. In Figure 2.a the cut-off frequency is around 100kHz which means if the input signal is less than 100kHz and the cylindrical modes can only be L(0,1); in Fig.2.b the cut-off frequency is around 50kHz and the initial velocity is 4300m/s which is less than the steel of 5226m/s.

2.1 Geometry model

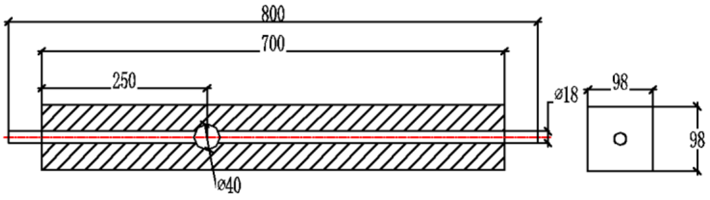
By comparing 2-D and 3-D model of steel, the results share no difference in displacement field and stress field, so the 2-D axisymmetric model was applied to build steel and RC models which can save approximately 30 times of calculation time with enough accuracy in the results. Two different kinds of models were simulated individually in this study: steel and RC both with and without defects. However, only RC models were analysis to applied FD method in evaluating the defect severity. Table 1 shows the main parameters of steel and concrete in numerical simulations. This paper only focuses on the direct effect of corrosion: the mass loss of steel that the decrease of the diameter and the stress concentration of concrete cover that the debonding or crack of concrete.

Fig.2.a describes the geometry dimension of the defected steel to simulate the mass loss caused by corrosion, as steel rusts with the product of less density and large volume. Fig.2.b shows the dimension of RC model with defects not only in steel but also in concrete because the corrosion or defects happened from steel to concrete or from concrete to steel. And the defect depth ranges from 2mm to 12mm with anincrement of 2mm and the width is 40mm of the six defected RC cases. However, in the RC model the wave can leak into the surrounding system of steel which accounts for the decrease of the cut-off frequency and the lower of initial velocity. Normally the concrete cover is as thick as the max-diameter of the embedded steel, the 40mm concrete cover can ensure the leaky waves not to reflect back into the embedded steel.

Fig.3 represents the simulation and experimental sample. Different from some civil engineering structures or real experimental model, four sheets of steel are embedded at the four corners of a concrete beam as a longitudinal tensile bar to form the steel frame and work together with concrete to bear the tension. However, we applied one -fourth of the model to calculate the effect of the concrete cover in the numerical model[13]. Meanwhile, cylindricalcoordinatesystem was set to demarcate the dimension and location of each defects caused by corrosion. The incident side (Z=0mm) is regarded as an origin and the other side(Z=800mm) is the positive Z-axialdirection.



(a)geometry of steel with a symmetric defect



(b)geometry of the steel-concrete with symmetric defects

Figure 3. Simulation models

2.2 Material model

2.2.1 Concrete and steel

Table 1 shows the parameters of the main material which were used both in numerical simulation and in experimental testing.

Table no 1: The main parameters of simulation materials

Material	Young modulus	Density	Poisson ratio
Steel	200GPa	7850kg/m^3	0.33
Concrete	25GPa	2300kg/m^3	0.3

In this model, the force is applied at the bottom section (Z=0mm), and the incident wave parameters are shown in Table 2.

Table 2 Parameters of the incident waves

Material	Central frequency	Amplitude	Number of cycles	Sampling frequencies
Steel	75kHz (C_g=2917m/s)	100	5	10MHz
Concrete	35kHz (C_g=3800m/s)	100	5	10MHz

Since the RC structures are commonly used in infrastructures and we analyzed the models to make some practical suggestions for the further experimental research. This finite element model is analyzed in COMSOL Multiphysics. By calculating the wave length and take the concrete aggregate into consideration, we finally decided the max-mesh is 2mm and the mini-mesh is 0.01mm which can satisfy the efficiency and accuracy demand in simulation the ultrasonic wave propagation. In this model, the only longitudinal reinforcing bar was simulated which can be seen in RC components such as beams and columns. However, there was no tension or compression applied to the components and some other effects should be considered in the further work.

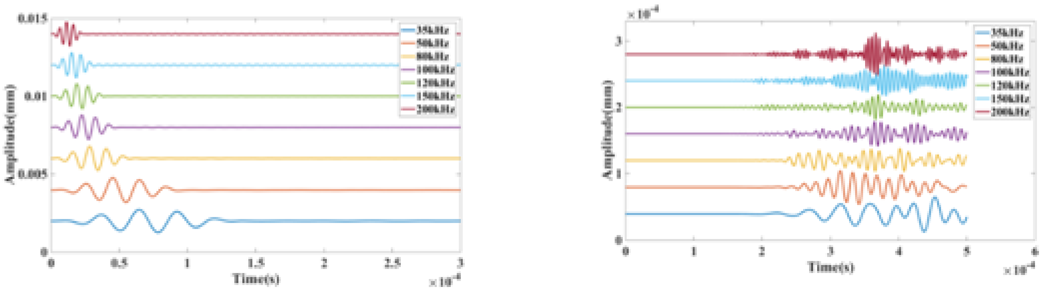
2.2.2 Interface of the steel-concrete

As concrete structure normally consists of at least three different materials which make the interface of the steel and concrete may not totally continuous, the boundary condition at this place has to take the discontinuity into consideration. There are different kinds of element in designing the boundary condition with different FE soft wares. In this research, the self-adapting triangular element in COMSOL Multiphysics which can fully transmit the wave from the embedded steel to the outside concrete was chosen to allow the propagation of leaky waves and the leakage of wave energy.

III. RESULTS AND DISCUSSIONS

3.1 Wave propagation of the steel and steel-concrete models

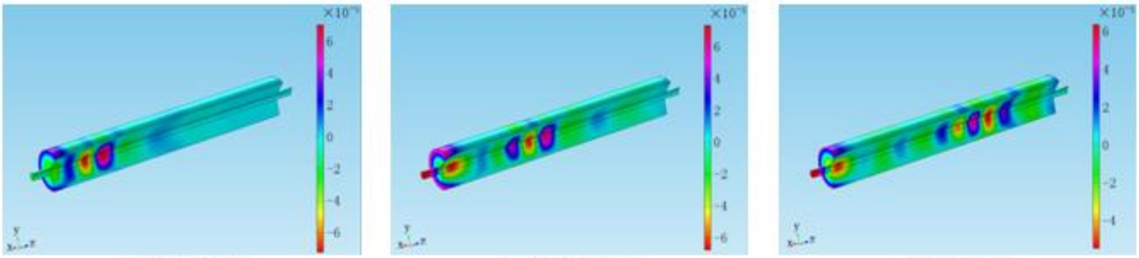
Before analyzing the defects along the interface of RC components, an intact RC model was built to understand the wave propagation both in steel and in concrete. Figure 4 displays the received signals that were simulated by different central frequencies ranging from35 kHz to 200 kHz which can be obtained that the increase of the frequency can lead to more modes propagate in the RC structures and the decrease of the frequency may leak more energy to the surrounding concrete. This can verify the results in Figure 3 and Table 2. Moreover, the concrete structure is relatively rough than most mechanical structures so that lower frequency is chosen to identify the defects and the wave velocity in 35 kHz of L (0, 1) mode is higher than others.



(a) input signals (b) received signals

Figure 4. Effects of different central frequencies

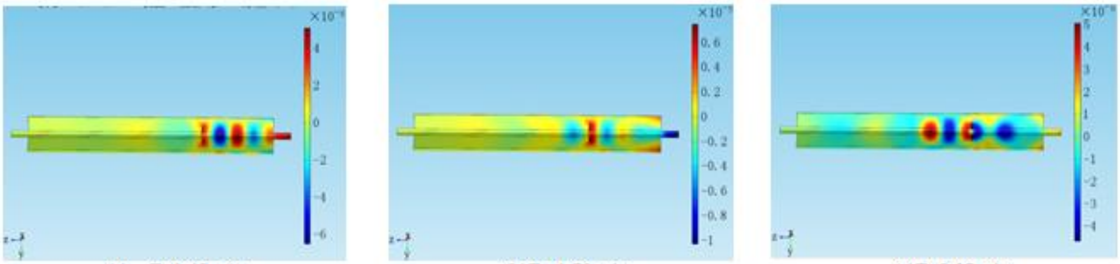
Fig.5 shows the snapshots of guided wave propagation in RC structures with the central frequency of 35 kHz. The amplitude of the displacement contour decreases as the wave travels to the other side of the numerical model and the leakage can also account for the amplitude attenuation.



(a) T=1.286e-4s (b) T=2.056e-4s (c) T=3e-4s

Figure 5. Wave propagation of 35kHz central frequency

Fig.6 shows the snapshots of the wave propagation in damaged RC model. When the wave front encounters the crack along the interface of steel and concrete, there will be less leakage into the sounding concrete, some of the wave energy will reflect from the crack which can be detected by the transducer at the original side of the model, and another part of the wave energy will continue propagating to the other side of the model which can be received by the transducer of the other side.



(a) T=1.43e-4s (b)T= 1.73e-4s (c)T=2.07e-4s

Figure 6. Wave propagation of 35kHz central frequency

3.2 Fractal dimension of the defects

The experimental results may be influenced by the circumstance, and the amplitude of the waveform is difficult to identify in conventional detecting methods which usually refer to the amplitude or energy of the wave to determine the severity of defects. In order to minimize the environment effects, fractal dimension (FD) is taken into consideration. The detailed information and application of FD can be seen in the first section of the paper.

After extracting the signals at the incident edge of steel, some noise may affect the effectiveness of the amplitude or shape of the wave form, so we adopt FD method to evaluate the defects severity by adding the original waveform with white noise. The main steps in calculating the box-dimension are as follows:

First we have to extract the waveform contains the certain defect. This is easy in a numerical simulation that the defect location in the wave field is known by multiplying the wave velocity which can be calculated in an intact model and the time-of-flight. However, in experiment, the defect wave form should be identified by comparing the intact and damaged samples to extract the aiming signal. There is another technique as Time reversal Method (TRM) to testify the existence of defect. This method is not introduced here but when performing the experiment, the correlation coefficient in TRM can show the possibility of defects.

Second, the white noise has to be added to the certain waveform. Both the environment and the equipment can cause some noise to the received signals, and white noise is used to simulate the influence of the environment.

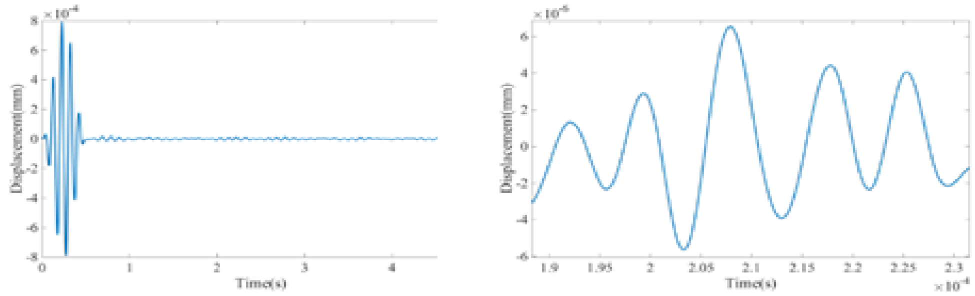
Third, box-dimension was programmed in MATLAB to calculate each case, the sampling points are the same which means the start time and the finish time of each defect case are the same. And this can be verified by different groups of defected cases.

$$\mathrm{D}=-\lim_{\Delta t\to 0}\left[\frac{\log(\sum_{i=1}^{N-1}\left|x_{i+1}-x_i\right|/\Delta t)}{\log(\Delta t)}\right]\cong\frac{\log(\sum_{i=1}^{N-1}\left|x_{i+1}-x_i\right|/\Delta t)}{\log(\Delta t)}$$

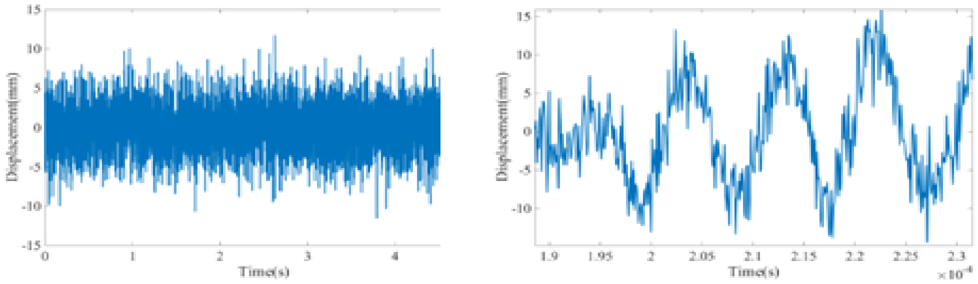
Where,Δt is time step, x_i represents the displacement value of each time step, and n means the sampling number of the defected signals.

At last, the box-dimension eigenvalues can be calculated with the formula, and match them to draft the FD curve which is the criterion of defect evaluation.

Fig.7 shows the steps of the FD evaluation process. Fig.7.a shows the original signal of one defected model, Figure 7.b is the defect reflected signal which was elected by comparing the intact and defected signals received at the input end (Z=0mm), Fig.7.c is the simulated white noise, and Fig.7.d is combined by adding the white noise and defected signal to simulate the real signal in experiment.



(a) the original signal (b) the defect reflected signal

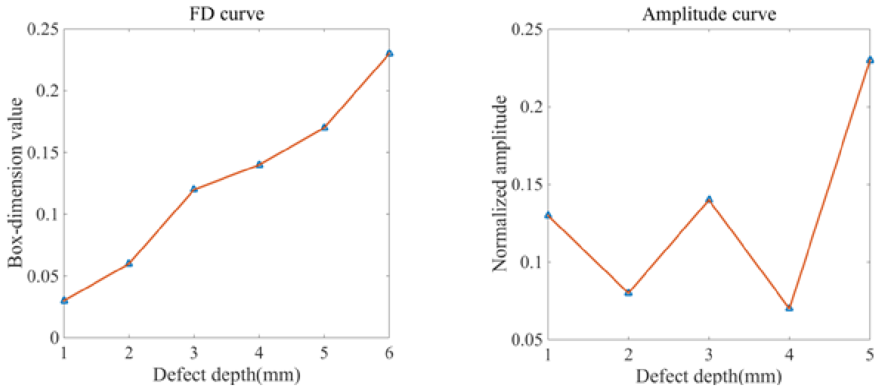


(c) white noise wave form (d) the simulated real signal

Figure 7 Fractal dimension evaluation of defect in RC structure (d=14mm)

3.3 FD curve of the RC models

By comparing the detecting curve of the FD and amplitude as shown in Fig.8, the conclusion can be made as the FD curve shows a decrease as the depth of the defect increase and the amplitude curve gives no trend as the severity of the defect grows.



(a) (b)

Figure 8 Evaluation curves

However, for different samples or real structures, the FD curve or the certain FD value may be different due to the geometry or the strength of the materials. This can bring a lot of more work for the standardization of different samples.

IV. EXPERIMENT VERIFICATION

Experiment has been doing by casting the RC components with cement, sand, water and aggregate to construct the concrete sample. Before casting, the steel was cut at certain place of Z=250mm with different depth ranging from 1mm to 5mm by the same increment of 1mm. Then the six concrete samples were under the same experimental condition to verify the effectiveness of the proposed method.The system consistof an arbitrary function generate a wideband power amplifier send signal to the PZT. The generator and oscilloscope were controlled by a computer.

V. CONCLUSION

By studying the fractal dimension curve, the defects along the interface of the steel-concrete interface can be evaluated. The fractal dimension provides us an effective way to evaluate the defects along the interface of steel and concrete of RC structures when the environment noise is taken into consideration.

In this paper, we discussed only one defect in the steel and the effect of the multi-defect should also be taken into consideration in the future paper. Since this method is not applicable for all the structures, more work has to be done to popularize this means and put it into practice.

ACKNOWLEDGEMENT

This work was supported by National natural science key international cooperation project (No. 11520101001). Special appreciation is expressed to supervisor and well-learned experts who are going to review this paper.

REFERENCE

[1]. Bossio A, Monetta T, Bellucci F, et al. Modeling of concrete cracking due to corrosion process of reinforcement bars,Cement and Concrete Research, 2015, 71: 78-92.
[2]. Zhang J, Ling X, Guan Z. Finite element modeling of concrete cover crack propagation due to non-uniform corrosion of reinforcement, Construction and Building Materials, 2017, 132: 487-499.
[3]. Qiao D, Nakamura H, Yamamoto Y, et al. Crack patterns of concrete with a single rebar subjected to non-uniform and localized corrosion. Construction and Building Materials, 2016, 116: 366-377.
[4]. Sarkar N, Chaudhuri B B. An efficient differential box-counting approach to compute fractal dimension of image. IEEE Transactions on systems, man, and cybernetics,24(1), 1994, 115-120.
[5]. Mandelbrot B B. The fractal geometry of nature(New York: WH freeman, 1983).
[6]. Liebovitch L S, Toth T. A fast algorithm to determine fractal dimensions by box counting, physics Letters A, 141(8-9),1989, 386-390.
[7]. Hadjileontiadis L J, Douka E. Crack detection in plates using fractal dimension, Engineering Structures, 29(7),2007, 1612-1625.
[8]. Hou Y, Huang Y, Sun F, et al. Fractal analysis on asphalt mixture using a two-dimensional imaging technique,Advances in Materials Science and Engineering, 2016, 2016.
[9]. Na W B, Kundu T, Ehsani M R. Ultrasonic guided waves for steel bar concrete interface testing,ARIEL, 2002, 129: 31-248.

[10]. Rose J L. Boundary element modeling for defect characterization potential in a wave guide,International Journal of Solids and Structures, 40(11), 2003, 2645-2658.
[11]. Wang Y, Zhu X, Hao H, et al. Guided wave propagation and spectral element method for debonding damage assessment in RC structures, Journal of sound and vibration, 324(3-5),2009, 751-772.
[12]. Willberg C, Duczek S, Vivar-Perez J M, et al. Simulation methods for guided wave-based structural health monitoring: a review,Applied Mechanics Reviews, 67(1),2015, 010803.
[13]. Jin L, Zhang R, Du X, et al. Investigation on the cracking behavior of concrete cover induced by corner located rebar corrosion,Engineering Failure Analysis, 2015, 52: 129-143.

Zhao Guoqi "Evaluation of the Defects along the Interface of Reinforced Concrete structures with Fractal Dimension curves". IOSR Journal of Engineering (IOSRJEN), vol. 8, no. 4, 2018, pp. 94-100.