Effects of Different Patterns of Reinforcement Corrosion on Concrete Cover and Residual Strength in Aged Bridge Piers: State-Of-The-Art-Review

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1 Introduction

Aging infrastructure is increasingly becoming vulnerable to climate change coupled with heavy traffic. As a result, deterioration in bridges due to environmental exposure leads to premature failure and reduce their intended service life. In Canada, it is expected that extreme climate conditions such as cyclic precipitations and temperature fluctuations will increase over the next years [3]. In turn, global warming will have adverse effects on Canada's vulnerable concrete infrastructure leading to serious climate-induced deterioration. This problem is exacerbated in the presence of de-icing agents, which are heavily used on roads during Canada's winter season. Reinforced concrete (RC) structures are vulnerable to multiple environmental mechanisms coupled with increased volume of traffic and service loads, which accelerate the risk of progressive failure. Generally, the main cause of steel corrosion is attributed to chloride contamination due to extensive use of de-icing agents during the winter season. Along with cyclic precipitation, the ingress of chloride ions through pre-existing cracks proceeds at a faster rate. This leads to premature deterioration due to material degradation and overall reduction in the ultimate capacity, ductility and stiffness of aged structures.

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2 Corrosion Effects on RC Columns

Analytical, numerical and experimental studies have been conducted to investigate the effect of reinforcement corrosion on the structural performance of RC columns. Several factors affect structural performance of corroded RC columns such as extent and pattern of reinforcement corrosion, load eccentricity, and reinforcement details such as tie spacing. The focus of this review is only on corroded RC columns with rectangular cross sections and subjected to an eccentric compressive load.

2.1 Experimental Studies

Rodriguez et al. [16] tested corroded RC columns, 2000 mm long with three different reinforcing details. An axial load was applied concentrically atop of the column. The longituinal rebars were subjected to a current density of 100 μA/cm^2. A 3% by weight of cement of $CaCl_2$ was added to the concrete mix to accelerate the corrosion process. The experimental results highlighted a reduction in the overal load capacity, mean strain and the compressive stiffness of the RC columns. It was found that the overall capacity of the column is affected by several parameters, mainly an increase in the load eccentricity due to asymetrical deterioration associated with reinforcement corrosion. This led to premature buckling of the reinforcement and craking/spalling of the concrete cover. Premature buckling of the rebar, which was observed after column failure, was attributed to reduction in sttifness of the concrete cover and failure of the tie. The authors estimated the reduction in the reinforcement capacity using Eurler's formula (Eq. 1), but using the effective length of the longitudinal bar as 0.75 s.

$$f_{cr} = \pi^2 E_s (0.25d)^2/(0.75s)^2 \quad (1)$$

where E_s is the modulus of elasticity, d is the reinforcing bar diameter, and s is the tie spacing.

Wang and Liang [23] tested 11 RC columns (1300 mm). The authors subjected partial length (350 or 700 mm) of the longitudinal bars at the mid-zone of the column to an accelerated corrosion regime using a DC power supply for specified time. To maintain the corrosion process, wet sheets were wrapped around the mid-section of the columns, which were sprayed several times a day. Subsequently, a compressive load was applied at two eccentricities (50 and 150 mm). For the smaller eccentricity, a greater reduction in ultimate capacity was found with partial corrosion of the longitudinal bars along the compression zone, whereas for the larger eccentricity, it was found that a larger reduction in ultimate capacity resulted from partial corrosion of the longitudinal bars along the tension zone. In general, partial corrosion of the column generated longitudinal cracks and spalling of the concrete cover along the corroded longitudinal bars, reduced the overall load capacity, generated irregularities (due to asymmetry of corrosion), and reduced the confinement effects due to corrosion of the ties in the mid-section.

Wang (2012) extended previous work [23] to include all tested specimens in this study. The author investigated the effect of extent and location of corrosion on the structural performance of 20 (1300 mm long) RC columns subjected to loading at a small (50 mm) and large (150 mm) eccentricities. For both eccentricity values, 18 columns were either corroded along the tensile, compressive, or tensile and compressive zones for a partial length of 700 mm. For small eccentricity, a larger reduction in mass loss in the compression zone resulted in larger reduction in the ultimate capacity and stiffness, in addition to higher mid-span deflection. For equally corroded reinforcement on both compression and tension zones, it was observed that there is a higher decrease in the column stiffness compared to columns which were partially corroded along either the tension or compression zones. Also, the reduction in ultimate capacity was more significant when the corrosion level was increased and spread along the compression and tension zones of the column. As the corrosion level was increased on both tension and compression reinforcement and ties, the ultimate capacity and stiffness of the column was reduced, and the response was less ductile. For columns loaded at large eccentricities, a high corrosion level in both compression and tension zones resulted in a reduction in the ultimate capacity of the columns. There was greater reduction in ultimate capacity and ductility response for asymmetrical deterioration.

Li et al. [9] conducted experimental tests on 12 short columns (450 mm) subjected to an accelerated corrosion using a DC power supply followed by an axial compression test. The testing regime intended to corrode the ties only at various corrosion degrees. The results were assessed in terms of changes in material stress–strain curves, bearing capacity, failure mode, deformation and confinement effects. The current density of the test was set to a range of 200 to 500 $\mu A/cm^2$ for 10–50 days. Initially, load increments increased slowly but displacement increments increased at a faster rate, which led to bridging of existing corrosion-induced cracks. Afterwards, both the load and displacement increments increased at a similar rate and the cracks were not noticeable. At 80–100% of the peak load, new vertical cracks appeared in addition to spalling of the concrete cover. After peak, both corrosion-induced and newly formed cracks rapidly propagated leading to concrete spalling. The test ended when the longitudinal rebars buckled and the ties fractured at the corner side of the column. Reduction in the cross-section area of the ties resulted in reduction in column stiffness and ultimate bearing capacity. In addition, the mode of failure changed from ductile to brittle failure.

Azad and Al-Osta [2] conducted an extensive experimental work to test 48 specimens to estimate residual strength. The authors tested two groups (24 specimens each) of small-scale (1350-mm long) RC columns with different cross sections and reinforcement sizes. The compressive load was applied at three eccentricity values: 30, 60 and 95 mm for one group and 35, 65 and 115 mm for another one. To corrode the middle section of the columns, the authors utilized an accelerated corrosion method using a constant current of 250 $\mu A/cm^2$ for 7, 10 and 11.5 days. The authors proposed a reduction factor established from a multi-regression analysis of test data to account for the effects of corrosion damage. It is a function of member size and diameter reduction, and it accounts for bond degradation, crack damage and possible variation in yield strength of the reinforcement. The reduction factor was validated with experimental tests from [23]. The residual strength value was then calculated by multiplying the reduction factor with the undamaged value. In conclusion, for a compression-controlled column (with an eccentricity over height ratio of e/h $\leq$0.17), the entire section remains in compression; hence, the reduced cross-sectional area of the corroded steel has a minimum effect on the ultimate capacity reduction. The ultimate capacity of the column is governed by the reduction of the compressive strength of the concrete cover due to crack growth. The failure of columns with e/h = 0.16 occurred on the side that experienced high compressive stresses. For cases with e/h > 0.16, transverse cracks appeared on the tension side of the column. It was found that as the corrosion period is increased, the corrosion damage is more extensive. Also, the flexural rigidity of the corroded columns is reduced compared to non-corroded ones.

Tapan [17] conducted experimental work on 12 small-scale (350 mm long) columns to investigate the effect of tie corrosion on confinement strength. The 12-mm diameter longitudinal bars were enveloped by ties with a diameter size of 8 mm spaced at 10 mm. The columns were corroded using an accelerated corrosion regime with a DC power supply with a current output of 6 A, while being submerged in 5% NaCl solution to produce different levels of tie section loss (5, 10, 15, 20, 25, 30, 35, 40, 45 and 50%). The RC columns were then subjected to an axial compressive load until failure. The deterioration of the ties had very significant effects on the structural response. The ultimate capacity of the columns was reduced as the rate of the corrosion level was increased. The author found evidence of tie debonding and concrete cover cracking. According to the author, pitting corrosion was not considered for simplicity, hence, section loss was estimated by measuring the average weight loss of the damaged tie. The author found that cross-sectional loss is non-uniform along the tie length. From the experimental results, the author concluded that confinement effects are reduced due to tie corrosion. The author recommended a detailed and full-scale testing program to determine the effect of tie corrosion on the confinement strength, ultimate capacity and failure mode.

Xia et al. [25] tested 24 small-scale (1500 mm long) RC columns to determine their structural performance and evaluate the relationship between reinforcement cross-sectional loss and maximum crack width of the concrete cover. The specimens were corroded using an accelerated corrosion method at a current density of 200 $\mu A/cm^2$ while exposed to wet and dry conditions. A compressive load was applied at two eccentricity values of 50 and 90 mm for two sets of columns that have different tie spacings (200 and 100 mm). The relationship between cross-sectional area loss of steel, maximum crack width of the concrete cover and strength loss of the RC column was analyzed. The residual compressive strength of the column was estimated from measured crack widths of the concrete cover. The authors found that increasing the level of corrosion leads to adverse effects on column strength, stiffness, and mechanical properties of both steel and concrete materials. Also, the crack opening increased as the corrosion level increased. The column stiffness and strength decreased as the loading eccentricity and corrosion level was increased.

Vu et al. [22] investigated the effect of corroded transverse reinforcement on the stress–strain curve of confined concrete. The authors tested 36 columns with a length of 600 mm and 200 mm, either square or circular cross-sections, with three different transverse reinforcement layout at different corrosion levels. Transverse reinforcement was subjected to an accelerated corrosion method using a DC power supply with current density of 500 $\mu A/cm^2$ while immersed in 5% NaCl solution. Three methods were used to estimate the corrosion degree: mass loss, average cross-section, and residual cross-section loss.

To measure the effect of crack width on the stress–strain relations of confined concrete, the average crack width (W_{cr}) was defined as the total crack width measured on the four sides of the specimen along the length (L) of the specimen (Eq. 2):

$$\mathrm{W_{cr}} = \frac{\sum W_{cri} L_i}{L} \tag{2}$$

where L_i is the crack length, and W_{cri} is the width of the crack.

The reduction of the concrete compressive strength (f_r) was estimated according to Eq. 3:

$$f_r = \frac{0.9}{\sqrt{1 + 600\varepsilon_r}} \tag{3}$$

where the tensile strain induced by cracks ε_r was estimated as follows (Eq. 4):

$$\varepsilon_r = \frac{\mathrm{W_{cr}}}{\mathrm{p_0}} \tag{4}$$

where p_0 is the perimeter of the cross section.

For corrosion levels of 15–30%, the transverse ties were fractured due to severe pitting. This resulted in a significant reduction in the concrete confinement strength followed by buckling of the longitudinal bars. Furthermore, these specimens exhibited a brittle response with significant reduction in ultimate strength. Specimens with corrosion levels lower than 10% failed by buckling of the longitudinal bars, while they exhibited a more ductile response. Furthermore, it was found that for low volumetric ratios of transverse reinforcement, the ultimate strength, peak stress, and strain values were reduced, and the specimens had a brittle mode of failure. For example, for a square section with volumetric ratio of 2.51 and 0.97% and corrosion levels of 16.7 and 17.5%, there is 10 and 22.3% reduction in peak stress, respectively, compared to non-corroded sections. Furthermore, there is 13.8 and 31.3% reduction in ultimate strain, respectively, compared to non-corroded sections. From the experimental results, [22] proposed an analytical stress–strain model based on Mander's model [10] for confined concrete that is applicable to both square and circular cross section with different transverse volumetric ratios. The results of this model were verified with the experimental tests from both square and circular cross sections and three different reinforcement layouts.

2.2 Analytical Studies

Rodríguez et al. [15] calculated the axial force of RC columns tested by [16] using conventional models. To account for corrosion, the cross-sectional area of the steel was reduced, and the concrete cover was removed in one side or in all sides. The authors developed four axial load-moment curves that consider non-deteriorated case, removal of two or three ties, and complete removal of concrete in all sides. Experimental data were fitted within the curves and aligned with the curve that considers tie failure. It was found that the structural behaviour of the analyzed columns (eccentricity values of 0 and 20 mm) is mainly controlled by: concrete cover degradation, increased load eccentricities due to irregular damage associated with reinforcement corrosion, and premature buckling of steel.

Tapan and Aboutaha [18, 19] investigated the effect of reinforcement corrosion and loss of concrete cover on the structural response of RC columns using interaction diagrams. Six different cases of reinforcement corrosion patterns with different corrosion levels were investigated for a cover-to-diameter (c/d) ratio of 1 (Fig. 1). This was established using a modified analytical approach. The authors proposed a modified procedure to calculate interaction diagrams by taking into account material degradation in both concrete and steel due to section and bond loss and asymmetry. A bilinear stress–strain curve for corroded reinforcement was used taking into account strength reduction of the reinforcement. The strength reduction (f) of the reinforcement was

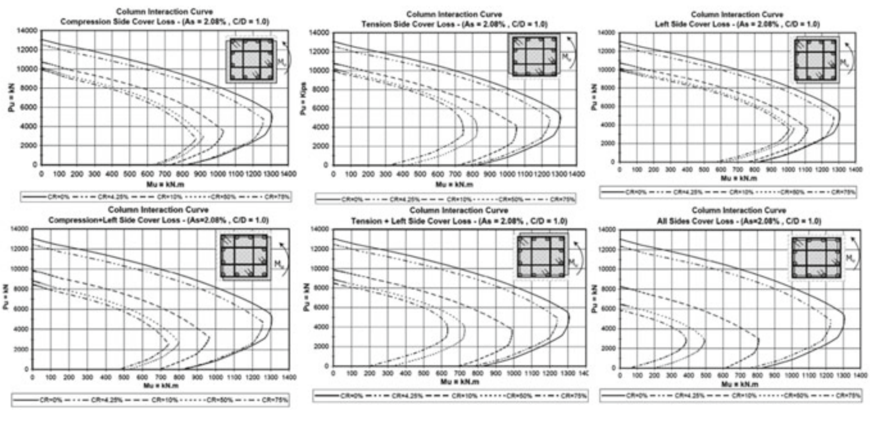

Fig. 1 Interaction diagrams for six different cases of corrosion patterns with different corrosion rates (Reproduced from [19])

estimated based on equations proposed by [7] (Eqs. 5–7).

$$f = (1 - 0.005.Q_{corr})f_y \tag{5}$$

$$A_s = A_{s0}(1 - 0.01.Q_{corr}) \tag{6}$$

where Q_{corr} is the amount of corrosion (%) given by:

$$Q_{corr} = \left(0.046.\frac{I_{corr}}{d}\right)t \tag{7}$$

where f, f_y are the yield strength of corroded and non-corroded steel, respectively,A_{s0} is the initial cross-sectional area of non-corroded steel, A_s is the average cross-sectional area of corroded steel, d is the diameter of non-corroded steel, I_{corr} is the corrosion rate in the reinforcement (μA/cm^2), and t is the time elapsed since the initiation of corrosion (years).

Tapan and Aboutaha [19] accounted for the strain change along the corroded region of the longitudinal bar as follows (Eq. 8):

$$\varepsilon_s = \frac{1}{L}\int_0^L \Delta\varepsilon_c.dx \tag{8}$$

where ε_c is the strain in the concrete, ε_s is the strain in the longitudinal bar, and L is the length of exposed corroded bar.

Furthermore, longitudinal bars are more vulnerable to buckling due to loss of concrete cover and the affected bars are exposed. Also, corrosion of the ties increases the unsupported length of the longitudinal bars. Tapan and Aboutaha [19] used Eqs. 9–12 to estimate the buckling strength of compression members subjected to concentric loading according to AISC Spec E2 [1]:

$$P_n = A_g.f_{cr} \tag{9}$$

$$f_{cr} = (0.658)^{\lambda_c^2} f_y for \lambda_c \le 1.5 \tag{10}$$

$$f_{cr} = \left(\frac{0.877}{\lambda_c^2}\right) f_y for \lambda_c > 1.5 \tag{11}$$

$$\lambda_c = \frac{kL}{r.\pi}\sqrt{\frac{f_y}{E}} \tag{12}$$

where A_g is the gross area of the bar, f_{cr} is the critical buckling stress of corroded reinforcement, A_s is the average cross-sectional area of corroded reinforcement, L_{exp} is the exposed length of corroded reinforcement, E_s is the steel modulus of elasticity, f_y is the yield stress, L is the laterally unbraced length of the bar, k is the effective length factor, and r is the governing radius of gyration about the axis of buckling.

The loss of concrete cover was estimated based on a numerical model which analyzes the effect of volume increase of the corrosive products on the cover cracking [13, 24]. Based on the above, [19] concluded that corrosion of the reinforcement reduces the ultimate strength of the column depending on the location and exposed length of the corrosion. The authors reported a 7–17% reduction in ultimate capacity for corroded longitudinal bars on the compression zone, while a 16–41% reduction for corroded longitudinal bars on the tension zone. This is because corrosion of the reinforcement on the compression side reduces the effective depth and leads to more ultimate reduction in capacity for compression-controlled columns. However, corrosion of the tension reinforcement causes more strength reduction for tension-controlled columns subjected to load eccentricity. It was reported that reinforcement corrosion on all sides of the column causes the most severe reduction in ultimate strength.

Campione et al. [4] proposed a simple analytical model to estimate the moment-axial force curves for corroded columns. The model takes into account material deteriorations, concrete cover spalling, loss of bond, rebar buckling and reduction in confinement effects due to tie corrosion. The analytical model estimates only specific points on the interaction diagram: pure bending, pure axial load, balanced point, and a point having some pure moment and axial force to be determined. In the development of the model, the compressive strength for confined concrete was calculated according to [14]. The reduction in the compressive strength of the concrete cover due to cracks induced by rust expansion was estimated according to a study by [5]. Coronelli and Gambarova [5] suggested utilizing a crack width model of [12] into the model developed by [21] (Eq. 13).

$$f_r = \frac{f_c}{1 + k.\frac{2\pi.n_{bars}(1-v_{rs}).X}{b_0\varepsilon_0}} \tag{13}$$

where f_r is the reduced compressive strength of the concrete, f_c is the compressive strength of concrete, ε_0 is equal to 0.002 for normal weight and strength concrete, K is 0.1 as suggested by [5], X is the thickness penetration calculated from Faraday's law, v_{rs} is the ratio of volumetric expansion of the oxides with respect to the virgin material, and n_{bars} is the number of bars in the compressed zone.

For compression-controlled columns, it was found that under severe conditions of reinforcement corrosion, there is about 20–30% reduction in the ultimate capacity, which was mainly affected by the significant reduction in the compressive strength of the concrete cover and not by reinforcement mass loss. On the contrary, the ultimate capacity of flexure-controlled columns is mainly reduced by mass loss of the reinforcement and bond loss, with about 40% decrease in ultimate strength associated with a 15–20% mass loss of reinforcement. The developed model had a good agreement with experimental and analytical results established from previous research work.

Xin et al. [27] proposed an analytical model to evaluate the bearing capacity of corroded RC columns under eccentric loads based on Hermite interpolation and Fourier function. The first step of the model estimates the degradation of concrete and steel properties due to reinforcement corrosion. The model accounts for reduction in bond strength, confinement effects, cross-section reduction of the steel, buckling of the longitudinal bars and concrete cover cracking for three points on the column interaction diagram (axial load point, balanced load point and pure bending point). The interpolation points were then determined through piecewise cubic Hermite interpolating polynomials, and curve fitting was conducted through the trigonometric Fourier series model. The cross-section of the RC column was divided into different regions: unconfined concrete, cracked confined concrete, uncracked confined concrete and the area of the longitudinal reinforcement considering buckling mechanism. The model was verified with data collected from experimental work on 45 RC columns conducted by different researchers. In addition, the interaction diagrams estimated using this method agreed well with the ones estimated using the analytical model proposed by both [19] and [4].

2.3 Numerical Studies

Mohammed [11] proposed a simplified Nonlinear Finite Element Analysis (NFEA) to asses the residual capacity of corroded aged beam-columns. The NLFEA evaluates structural performance of corroded slab-on-girder bridge columns under the application of external loads. The NLFEA determines the instantaneous stiffness through the transfer of axial and flexural rigidities from the section level to the member level. The effects of reinforcement corrosion on material degradations of both concrete cover, reinforcement strength reduction and bond loss are incorporated into the model. The model was verified with four cases from previous experimental and analytical work conducted by different researchers.

Dabas [6] developed a 3D Nonlinear Finite Element Model (NFEM) using ABAQUS software to determine the structural response of large-scale (2200-mm) corroded RC columns. The columns were subjected to a small eccentric load of 30 mm atop the column. In the development of the numerical model, concrete response in compression for unconfined concrete was defined using Hognestad's parabola, while the model proposed by [14] was used for confined concrete. An elastoplastic model was used to simulate the stress–strain relationship of the steel reinforcement. Reinforcement corrosion was simulated by reducing the reinforcement cross section or by removing corroded ties. In addition, the stiffness of the concrete cover was reduced by 50% to account for severe corrosion-induced cracking. Furthermore, Euler's equation was used to calculate the critical buckling stress for the longitudinal bars along the exposed length. The 3D numerical model evaluated the RC structural behaviour

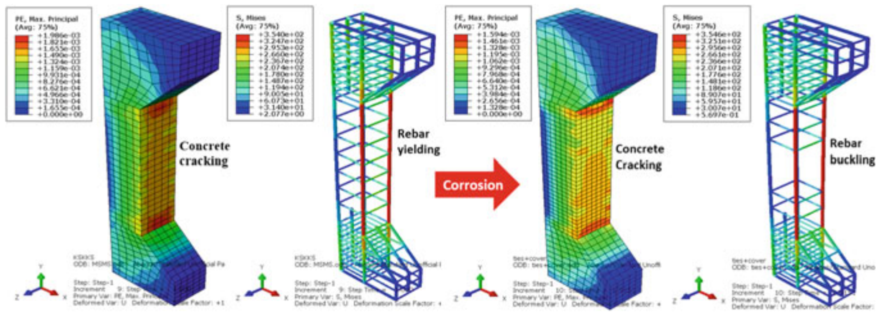

Fig. 2 Comparison between failure of non-corroded and corroded columns [6]

for two different patterns of corrosion exposure: (i) corrosion of two ties at the mid-section of the column with cover stiffness reduction, (ii) corrosion in the compression rebars and cover stiffness reduction. The numerical model was validated with experimental work reported by [25]. The numerical results of the model indicated that for high-corrosion levels (50% of steel area reduction), the ultimate capacity of the RC column was reduced and the column had a brittle failure mode. When mid-ties were compromised, the exposed and unsupported length of the longitudinal rebars was increased, and confinement effects were reduced, both leading to buckling of the longitudinal bars (Fig. 2).

3 Estimation of Concrete Cover Loss

The loss of the concrete cover due to severe cracking and spalling leads to reduction in concrete strength and subsequently ultimate RC column capacity. Xia et al. [25] examined the pattern and amount of both tie and longitudinal corrosion on the concrete cover loss. Subsequently, equations were developed to determine the effective cross section of the concrete based on tie spacing and cover depth. Xia et al. [25] modified the equation proposed by [8] to account for various angles of wedge spalling-off (ϕ or β) due to transverse or longitudinal reinforcement corrosion. The authors estimated the effective cross-section of the column (b_{eff} and h_{eff}) damaged by corrosion of the ties in Eqs. 14 and 15:

$$b_{eff} = \begin{cases} (b - 2(c + d_v) + \frac{stan\phi}{2}s < 2ccot\phi \\ b - \frac{2}{stan\phi}(c + d_v)^2 s \geq 2ccot\phi \end{cases} \tag{14}$$

$$h_{eff} = \begin{cases} ((h - 2(c + d_v) + \frac{stan\phi}{2}s < 2ccot\phi \\ (h - \frac{2}{stan\phi}(c + d_v)^2 s \geq 2ccot\phi \end{cases} \tag{15}$$

where b and h are the original width and height of the undamaged column, respectively, s is the tie spacing, c is the concrete cover, d_v is the tie diameter, and ϕ is the angle for corrosion-induced spalling at tie locations (determined from test measurements).

The effective concrete cover depth c_{eff} affected by tie corrosion can be obtained from (Eq. 16):

$$c_{eff} = \begin{cases} (c + d_v) - \frac{s\tan\phi}{4}s < 2c\cot\phi \\ \frac{1}{s\tan\phi}(c + d_v)^2 s \geq 2c\cot\phi \end{cases} \tag{16}$$

Xia et al. [25] found that the location and number of corroded reinforcing bars have significant effects on the damage of the concrete cross section. The effective concrete cross-section affected by corroded ties and longitudinal bars can be obtained in Eqs. 17–18, while the effective loss of cover length is estimated in Eq. 19:

$$\overline{b}_{eff} = b_{eff} - (2 + \cot\beta)\left(c_{eff} + d\right) \tag{17}$$

$$\overline{h}_{eff} = h_{eff} - (2 + \cot\beta)\left(c_{eff} + d\right) \tag{18}$$

$$\overline{t}_{eff} = \left(1 + \frac{\cot\beta}{2}\right)\left(c_{eff} + d\right) \tag{19}$$

where d is the diameter of the longitudinal bar, β is the angle of the spalling wedge caused by corrosion of the longitudinal bars, $\overline{b}_{eff} x \overline{h}_{eff}$ is associated to the instant when the concrete section no longer resists the applied load, and $\overline{t}_{eff}$ is the length of cover that is lost.

Xia et al. [25] proposed an analytical model to estimate the ultimate load capacity for corroded columns, which takes into account bond degradation and concrete cover loss based on the affected reinforcement as shown in Fig. 3.

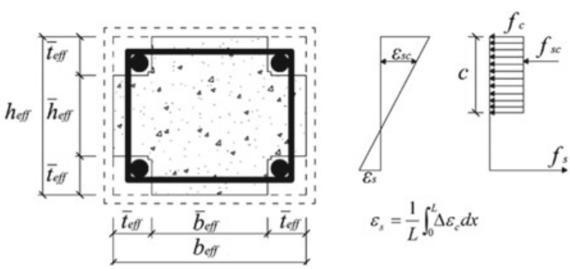

Fig. 3 Equivalent cross-section damaged by corroded ties (Reproduced from [25])

4 Concluding Remarks

Currently there is limited research on the structural behaviour, residual strength, material degradations and failure mode of corroded RC columns subject to eccentric load. All recent work is limited to small-scale corroded columns [23], Wang et al. 2012, [2, 17, 22]. Wang and Liang [23] and Wang et al. (2012) conducted the most extensive experimental work on the effect of partial length and location of reinforcement corrosion on the structural performance of columns subjected to load at small and large eccentricity levels. Azad and Al-Osta [2] evaluated the residual strength of corroded columns with different reinforcement layouts. For both Wang et al. (2012) and [2], the corrosion level of the experiment is limited to mass losses lower than 10–15%. Therefore, it is necessary to investigate the effect of higher corrosion levels on columns, as the structural response becomes more critical along with the increase in load eccentricity value. There is a significant need to evaluate the residual strength of corroded columns with different corrosion patterns and degrees while monitoring crack evolution before and after failure. Furthermore, it is important to investigate the reduction in confinement strength due to tie corrosion in large-scale columns.

To address this need, an experimental work on large-scale (2200-mm) columns was conducted to investigate the effect of different steel corrosion patterns due to chloride-induced corrosion under cyclic exposure to wet and dry conditions on the structural performance of columns. The columns were tested under an eccentric load. Crack evolution was monitored and recorded periodically. Experimental work is complemented with 3D nonlinear numerical modelling using Diana software. The model takes into account steel and concrete degradations due to corrosion. It takes into account confinement effects of the core concrete, buckling of the longitudinal bars and bond-slip behaviour. Using both methods of analysis, it is aimed to derive simplified expressions to evaluate and predict the structural response of large-scale columns affected by corrosion.

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