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Simulation and Evaluation of Corrosion Effects on the Reduction of Column Capacity

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Abstract

Reinforcement inside the concrete is protected from corrosion and its damages until several years after the construction. After corrosion initiation, the Cross Section of Reinforcement begins to reduce and often load bearing of the reinforced concrete structure will be reduced significantly. Making an analytical model which considers the effects of corrosion that often occurs in reinforcement on concrete beams and columns and simulation of the accredited model for nonlinear finite element analysis with higher order solid element and advance shell element is one of the other objectives of this thesis, via in programs written in MATLAB software. In attachment we do it.

1. Introduction

Corrosion of longitudinal reinforcements is one of the main reasons for the destruction of reinforced concrete structure. Corrosion of reinforcement in RC members is one of the most important reasons for decreasing the shear capacity and the formation of concrete structures [1]. Corrosion also reduces the loading capacity of the members due to the reduction of the area of the steel, the reduction of the strength of the concrete and the reduction of the elasticity modulus and the tensile strength of the bars [2, 3]. In addition, a large number of concrete structures exposed to corrosion are of great importance and their behavior is important. Therefore, it is necessary to study the effect of corrosion of rebar on creep behavior of members of reinforced concrete structures [4]. Considering the corrosion effects on the strength of the concrete, the cross-section of the bars, the yield stress and the elasticity modulus of the steel, an anchor curve can be calculated proportional to the type and amount of corrosion, and in the end using these anchor curves, the behavior of the seismicity of the structure can be interpreted and evaluated [5]. The study of the anchor curvature curve was used to investigate the effect of corrosion of reinforcement on the behavior of members of concrete structures to about 25 years ago, which Mr. Ting and Novak used for concrete beams [6]. In recent years, due to the importance of corrosion, many scholars have done research in this field. Ma and colleagues examined the effect of corrosion of reinforcement on the seismic behavior of a column with a circular cross section under constant axial load combinations and lateral load cycles [7]. Patel and his colleagues studied the corrosion of the reinforcement and cracking of the reinforcing materials on the adhesion between the rebar and the concrete. Ghanooni-Bagha et al. have studied the effect of concrete cracking on the starting time of corrosion of bars in RC structures by simulating finite element [8]. The time to corrosion in clean, cracked concrete samples [9] was based on the methodology [10] in other studies of these researchers. De Carlo et al. have studied numerical effects of corrosion of reinforcement on the behavior of RC concrete pillars [11]. Mr. Andishi and colleagues have modeled and studied corrosion on mechanical properties of steel rails [12]. Inci et al. have studied corrosion effects of longitudinal corrosion reinforcements on the behavior of concrete structures. The effect of cavity corrosion on reducing the cross section of the reinforcement and also reducing the length of the plastic joint were

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considered in this study. The anchor-curvature analysis of different corrosion cavity scenarios showed a decrease in the final anchorage of the section due to the reduction of the cross-section of the reinforcement and the absence of a change in the final curvature of the section [13]. Yalciner et al., have obtained an anchor curvature curve for a rectangular column section under constant axial load with regard to the corrosion effects. Comparison of anchor curves for different corrosion values showed that with increasing corrosion, the cross sectional anchor capacity and energy absorption decreases and curvature is higher for lower anchor values [14].

In this study, the diagrams of the interference and anchor curves for the column sections are drawn and it is seen that taking into account the reduction of compressive strength, both the force and the balanced anchor decrease. Moreover, the cross sections of the skin will have a great effect in reducing the cross sectional capacity. On the other hand, according to studies of this paper, it can be seen that the increase in the axial force in the members of the column reduces the curvature and increases the anchor capacity.

2. Corrosion of Reinforcement on Steel and Concrete Properties

2.1. Change in the Mechanical Properties of the Steel and the Cross Section of the Reinforcement

One of the corrosion effects of reinforcement in concrete structures is the reduction of steel delivery and final stress by increasing corrosion [15].In addition, shaping and final shape of the steel decreases and abandons with increasing corrosion [16]. Laboratory results of Rodriguez et al. showed a decrease of 30% and 50% of the maximum strain to reduce the cross section of reinforcement 15% and 28% due to corrosion [17]. Lee and Cho, by conducting multiple experiments on a variety of laboratory samples, presented a model for defining the relationship between the corrosion rate of reinforcement and the mechanical properties of steel, in particular the yield strength and modulus of elasticity. The model presented by Lee and Chu was designed to evaluate and calculate the decrease in the yield resistance and the modulus of elasticity of steel which was based on the corrosion rate of the reinforcement in both types of uniform and hollow corrosion [18].

Another corrosion effect of reinforcement in concrete structures is the reduction of the cross section of the reinforcement [19].Depending on the type of corrosion created in concrete structures, various relationships are presented to calculate the residual diameter of the reinforcement after corrosion. Rodriguez and colleagues have presented a relation (1) to a uniform type of corrosion. This model calculates the amount of reduction in the diameter of the armature based on the time elapsed from the beginning of the corrosion process and the corrosion rate of the reinforcement.

$$\varphi_t = \varphi_0 - \alpha P_x \tag{1}$$

The initial diameter of the armature is φ0 and φt the residual diameter of the armature after t years of corrosion and α is the coefficient determined by the type of corrosion. For wide corrosion (uniform), the value of α is equal to 2.Moreover, Px is the mean value of the depth of corrosion penetration in millimeters which is calculated from relation (2) [20].

$$P_x = 0.0116 i_{corr}(t - t_{in}) = 0.0116 i_{corr}(t_p) \tag{2}$$

In this regard, t_{in} is the time it takes to start corrosion in terms of year and t_p is the corrosion release time per year. i_{corr} is the average corrosion rate or corrosion density in μA / cm^2.To calculate the average corrosion rate, Wu et al. (Vu) [21] have provided relations.In a cavity corrosion, according to the model provided by Val & Melchers [22], the maximum corrosion penetration into the armature is between four and eight times the average level of corrosion in uniform type. In this model, the radius of the hemisphere due to the penetration of the corrosion hole is derived from relation (3).

$$P(T) = 0.0116 i_{corr} (t - t_{in}) R \tag{3}$$

R is the ratio between the maximum and the average corrosion influx into the armature, with Val and Melchers proposing a numerical value of 4 to 8.The amount of residual surface area of the reinforcement can be calculated after the penetration of the cavity corrosion according to the relations provided by Ghanooni-Bagha et al. [23].

2.2. Reduced Compressive Strength of Concrete

Another corrosion effect on concrete specification are concrete cracking and loss of concrete coating. Due to the increased volume caused by the products produced during the corrosion process (iron oxide), the radial compressive force is created across the reinforcement surfaces and causes tensile stresses in the concrete around the reinforcement. In the case of low and medium corrosion, cracking and then lamination and severe corrosion occurs, and the entire spalling coating is destroyed. In order to consider the reduction of compressive strength of concrete, Ghanooni-Bagha and Shayanfar have presented the following relation [24]:

$$\lambda = 2.288C_w - 1.733 \quad (4)$$

In this case, C_w is the percentage of steel corrosion and λ will be the percentage reduction in concrete compressive strength.

2.3. Reducing Structural Design and Deformation in Collapse Mechanism

As the corrosion rate increases, the structural formation decreases due to the reduction of cross-sectional area and the loss of continuity. Research shows that corrosion of 60% causes the same behavior of unmixed concrete [25]. In addition to reducing the strength and shape of the structure, corrosion of the reinforcement can cause large changes in the mechanism of failure. For instance, under certain conditions that the pillars of a floor are more exposed to corrosion than other structural members, the shaping failure mode (in which plastic joints are formed on the two ends of the beam) can become a crush failure mode (the formation of plastic joints in columns and the formation of soft floors).

3. Flexural and Axial Capacity of the Columns

One of the most important of these relationships is the effect of concrete compressive strength on the tensile strength of reinforced concrete columns.

$$N_r = A_c f_c^{'} + A_s f_y \quad (5)$$

In the above relationship, $f_c^{'}$ is directly effective, and its reduction in effective N_r decreases. Of course, it should be noted that the total compressive strength of the cross-section is not reduced, however, this decrease is noticeable in a region of the size of the coating on both sides of the corrosion-resistant reinforcements. The amount of balanced force and its corresponding anchor is also achievable by solving the horizontal and anchor equations of the cross section in accordance with the following relationships.

$$\sum F_x = N_r \quad (6)$$

$$\sum M_x = N_r e^{'} \quad (7)$$

The important point to be noted and considered is that, in calculating concrete structures with reinforced reinforcements, in addition to considering the amount of reduced compressive strength of concrete, the amount of ankle arm reduction that results from the horizontal equilibrium cross section should be taken into account.

4. Flexural and Shear Capacity of Beams

The effect of compressive strength of concrete on the flexural strength of arches without pressure reinforcement is obtained from the following relation.

$$M_r = A_s f_y \left(d - \frac{a}{2}\right) = \alpha f_c^{'} b_w a \left(d - \frac{a}{2}\right) \quad (8)$$

In this connection, which is usually investigated by the researchers, only the lower reinforcements are corroded and, given that the reinforcement is not high above, there is no harmful effect on the pressure concrete and its capacity is not diminished. However, due to the reduction of the tensile strength of the reinforcement (A_s and F_y), the equilibrium equation of the horizontal section of the neutral section is corrected (a decreases and the anchor arm increases). Based on these calculations, the tolerance of the section is calculated. Here too, it should be noted that if the carbonate corrosion is (uniform corrosion), the capacity of the tensile reinforcement is equal to $A_s \times f_y$, and if the type of corrosion is corrosion (perforation corrosion), the capacity of the tensile reinforcement is equal to $\gamma \times A_s \times f_y$.

However, in the case of girders in which pressure compressors are used, if the influx of attacking agents, such as chloride, or the effects of carbonation from above and corrosion occurs in the pressure regulator, the expansion of the corrosion products reduces the compressive strength of the concrete, and reduces the final flexural capacity.

$$M_r = \alpha f_c^{'} b_w a \left(d - \frac{a}{2}\right) + A_s^{'} f_y \left(d - d^{'}\right) \quad (9)$$

In addition to decreasing the load capacity of the pressure relief (due to the reduction of the area and the effects of the perforation), the maximum compressive strength of the concrete is also affected by the increase in the volume of corrosion products and reduced. In this case, the overall decrease is not affected by the entire section, which is why, in addition to the corrosion rate, the load and the profile of the sectional capacity (the location of the compression height and the amount of concrete coating), the capacity reduction is very effective.

For girders with pressurized reinforcements, it is clear that due to the presence of a pressure reinforcement, x (x) is always smaller than the equilibrium state (x_b). Considering the shape of the strain stress curve (the tiny amount of stress near the net), which is approximated and replaced by a squeezed rectangle (block) of Whitney equation, in the case of shorter beam height, the reduced compressive strength obtained from the calculations can be used for the entire compressive area in the beams. However, the reduction in the total compression strength can be approximated by doubling the ratio of the height of the coating to the height of the compression region in the coefficient of resistance reduction.

- Effect of concrete compressive strength the shear capacity of concrete sections is also calculated from the following relation.

$$V_C = 0.63\sqrt{f_c^{'}}b_w d \tag{10}$$

The reduction of maximum compressive strength under the influence of corrosion of the reinforcement reduces the compressive strength of the concrete and, as a result, affects the permeable shear strength of the concrete section.

- Effect of compressive strength of concrete shear capacity of all concrete sections with shear silts:

$$V_r = 0.63\sqrt{f_c^{'}}b_w d + A_{sv} f_{yv} \frac{d}{s} \tag{11}$$

In this regard, the corrosion of crumbs, in addition to reducing the area and the force of the reinforcements, also affects the maximum compressive strength of the concrete. It has previously been stated that the reduction of compressive strength due to corrosion of crumbs is more severe than the reduction of compressive strength due to corrosion of longitudinal reinforcements.

5. Case Study

In order to investigate, observe, and compare better corrosion effects on column bearing capacity, a program has been developed in MATLAB software for drawing an interference diagram (axial-flexural force). In these studies, the amount of corrosion and concrete coating for all the joints is assumed to be the same, in other words, the effects of the coating thickness on the start time of corrosion and the percentage of corrosion have been simplified and assuming that the above values are the same, studies have been done. Moreover, the percentage of compressive strength reduction of concrete has been calculated averaged, that is, in the case where the spalling section is corrosion-free. It is assumed that a zone with a thickness of twice the thickness of the coating from the outer surface of the section has a reduced resistance, and finally, based on the percentage participation of the area, the average compressive strength is calculated. Also, for a spalling-after-corrosion section, it is assumed that the cross-sectional coating is completely lost and that the area is equal to the thickness of the remaining surface of the surface of the cross-section.

In this paper, the section in the Tapan and Aboutaha articles [26] has been used, and the profile of the section is shown in Figure 1 The studied section has been studied for corrosion and corrosion conditions of 5%, 15% and 25%, and the curve of axial force flexural and their flexural have been drawn using MATLAB code, until the effect of each of the parameters of the compressive strength of the concrete, the thickness of the concrete coating, the stress of the steel sink and the percentage of cross section in the interaction curve of the columns are visible [27, 28]. Initially, the interaction curve of the initial section is analyzed for non-corrosion and corrosion states of 5%, 15% and 25% in cross-sections, and then in the following sections, the effect of the parameters mentioned above is investigated as follows:

1. Compressive strength of concrete: In addition to the initial strength of 27.6 MPa, the cross-section with concrete with a resistance of 20 MPa has also been studied.

2. Concrete Coating: The original coating is 5.8 cm in diameter, and in addition, the coating with thicknesses of 2.8 and 7 cm is considered and considered for the initial period.

3. Steel Delivery Stress: The delivery stress of 3000 and 5000 MPa has also been studied in addition to the initial yield tolerance of 4140 MPa.

4. Cross sectional steel: Also cross section for two percent of different fittings has been analyzed for 1.6 percent (12F25) and 2.6 percent (12F32).

Each of the above states has four different scenarios that, in the first scenario, the interaction curve of the column is obtained in a non-corrosion state. In the second scenario, it is assumed that only cross-sectional cores are corroded and lose a percentage of their area (5%, 15%, and 25%) assumed that they are often used for corrosion sections. It is noted that (except for minor corrosion) is very unsafe. In the third scenario, it is assumed that in addition to reducing the area of the reinforcement, the compressive strength of the section of the concrete is also reduced to a resistance, which is twice the thickness of the concrete surface to the center of the cross-section. In this scenario, in order to simplify, the cross-sectional resistance is calculated as an average, in which the average resistance of the product is obtained from the product of the ratio of area to its resistance.I n the fourth scenario, it is assumed that the spalling cross section and its coating disappear and the compressive strength of the cross section is also reduced. In this scenario, due to the fact that the amount of concrete damage in the reinforcement has been stopped a little earlier, the compressive strength of this region is a little less than the previous state calculations, also, because of the loss of the spalling coating, less area of the concrete has reduced the compressive strength, thus, in this scenario, the average compressive strength will be less than the third scenario. In general, since the fourth state the concrete coating is lost, thus, the lower stress in the compression area of the concrete is introduced as the coating remains, which will eventually reduce the compressive strength.

It should be noted that in the studies of this paper, the duration of corrosion and the time when the bars are being eaten are considered for all the same sections, and corrosion in all sections is considered as reducing the area of the reinforcement. Furthermore, the slip of the rebar is ignored.

The final values of the concrete (ε_u) and the strain (ε_y) were 0.003 and 0.002, the coefficient of height of the Whitney block (α) was 0.85, and all parameters were considered according to the values given in the paper.All sections 61 through 61 cm used in the analysis of these researchers are presented in the following figure.

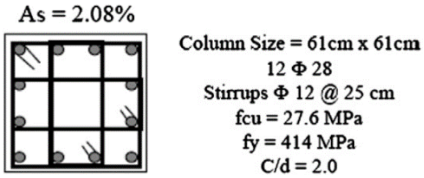
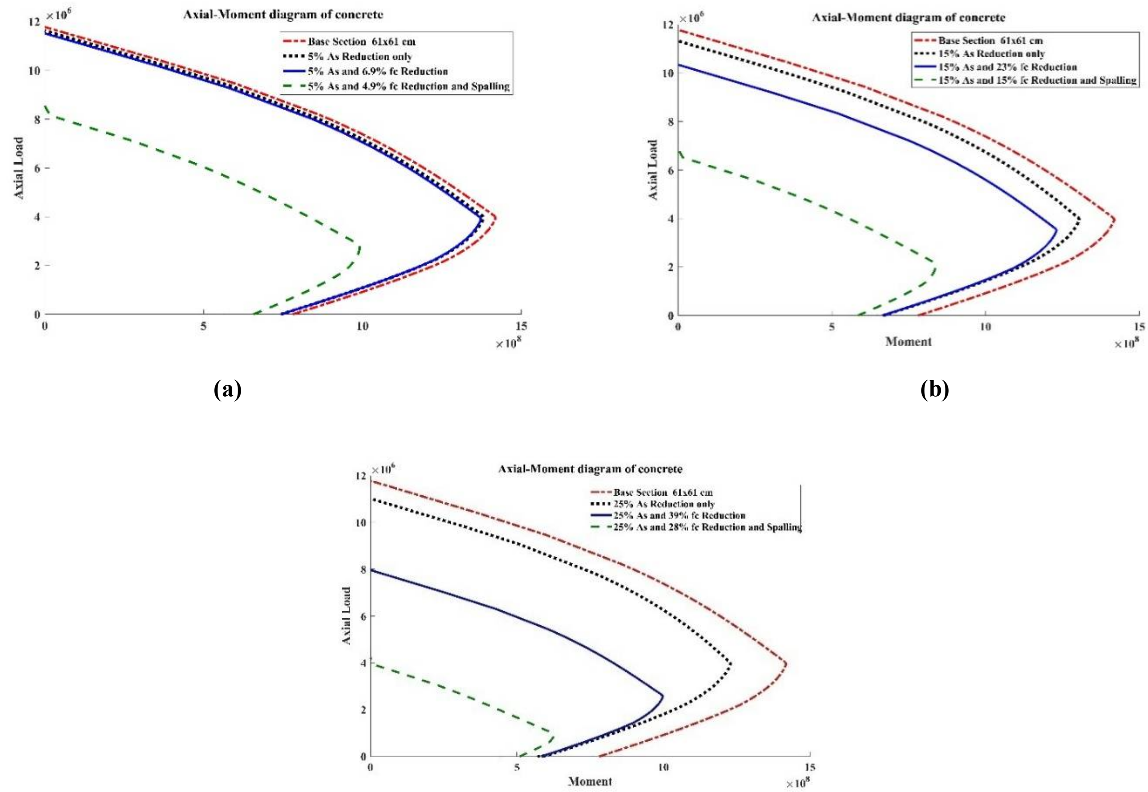


Figure 1. Base Section Details [26]

5.1.1. Primary Section Analysis under the Influence of Various Corrosion Rates:

In this section, the initial section with the characteristics listed in Figure 1 for the four scenarios mentioned above is analyzed and the results of this study have been studied under the influence of different corrosion rates (5, 15 and 25%).



(a) (b)

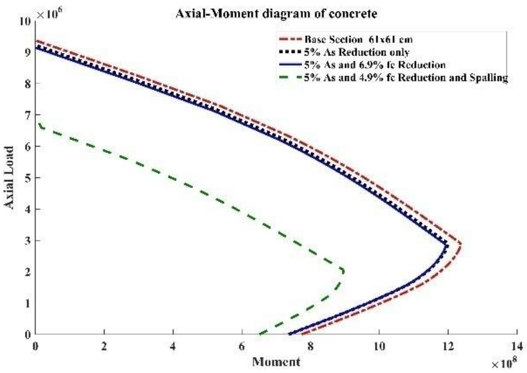
(c)

Figure 2. Interaction of the Primary Section Curve under a) 5% Corrosion b) 15% Corrosion c) 25%Corrosion

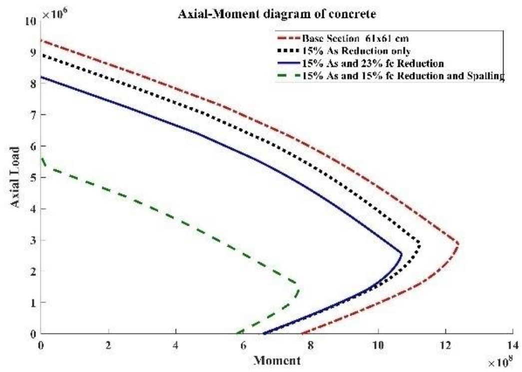
According to the calculated and drawn figures, if we consider the decrease in the area under corrosion, the balanced axial force will not be reduced due to the cross sectional symmetry. However, the balanced anchor is low. With regard to reducing compressive strength, both the force and the balanced anchorage are reduced. It is observed that the reduction of compressive strength does not have much effect on reducing cross-sectional capacity with flexural behavior and is more effective in the compression region (the upper region of the balanced state). It is also noticeable that the skin of the section will have a great effect in reducing the cross sectional capacity. Furthermore, the results obtained from the initial analysis can be deduced that the corrosion of the meshes alone (Scenario 2) has a very small effect on the axial capacity of the cross section, and only reduces the flexural capacity of the cross section. It can also be seen that increasing the corrosion rate of the bars reduces the axial and flexural strength of the cross section.

5.2. The Effect of Concrete Strength:

In this section, in order to study the effect of the concrete compressive strength parameter on the column interaction curve, it is assumed that the initial cross-section concrete has a resistance of 20 MPa.



(a)



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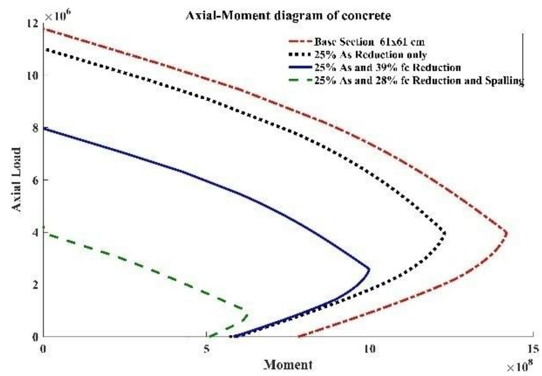


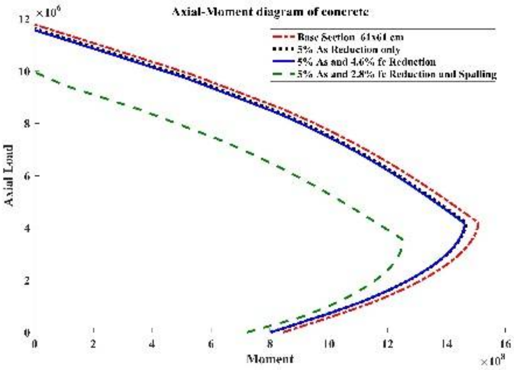
(c)

Figure 3. Interaction of the Primary Section Curve with 20 MPa concrete under a) 5% Corrosion b) 15% Corrosion c) 25%Corrosion

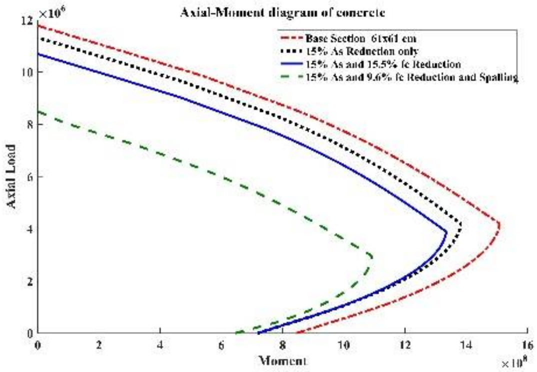
The results of the analysis of the cross-section and its comparison with the results obtained from the first scenario (the initial phase with a non-corrosion 20 MPa compressive strength) can be pointed out that the reduction of the initial compressive strength of the concrete has little effect on the axial and anchor force reduction ratio in different situations, and only reduces the axial and flexural capacity of the section.

5.3. Effect of Cross-Sectional Coating

In this section, the initial concrete cross section was analyzed with the assumption of 2.8 cm (c / d = 1) and 7 cm (c / d = 2.5) coatings for the four scenarios under different corrosion rates, so that the effect of this parameter on the corrosion of the section is investigated.



(a)



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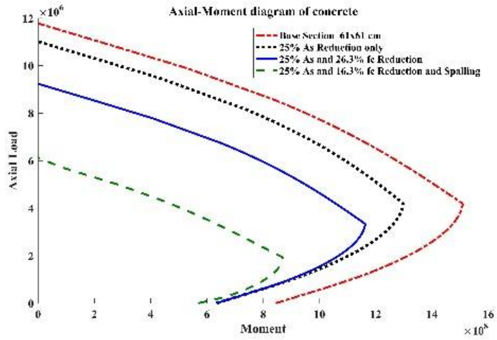
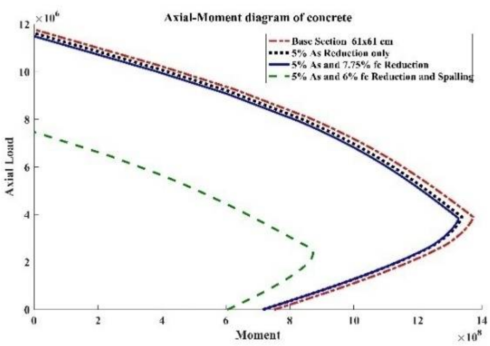
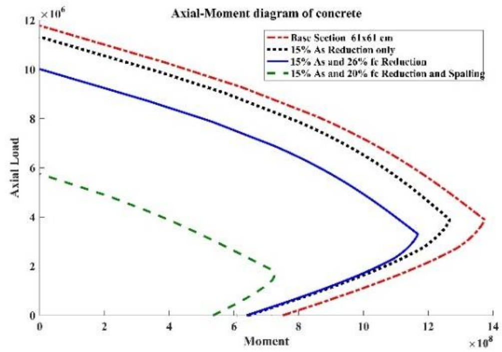


(c)

Figure 4. Interaction Curve with a Coating of 2.8 cm under a) 5% Corrosion b) 15% Corrosion c) 25% Corrosion



(a)



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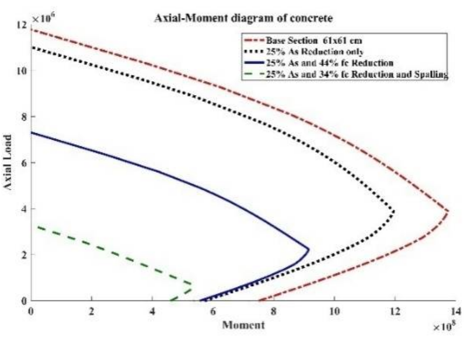


(c)

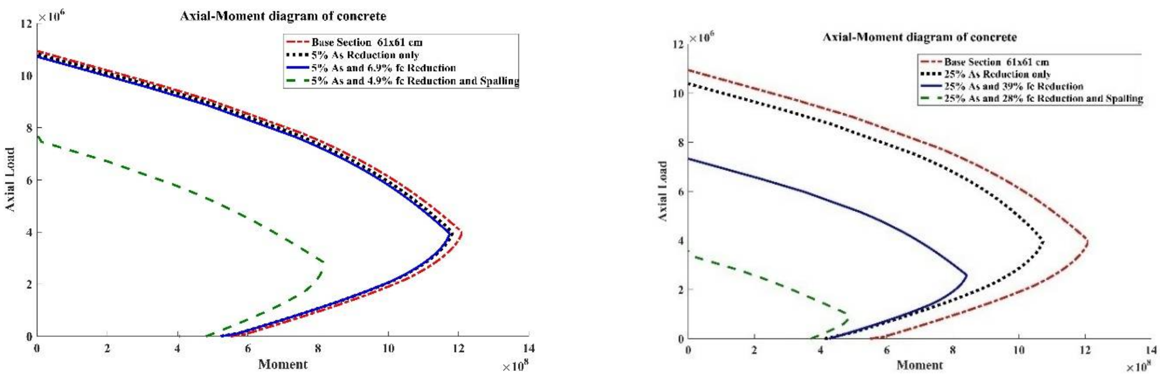
Figure 5. Interaction Curve of the Cross Section with a Coating of 7 cm under a) 5% Corrosion b) 15% Corrosion c) 25% Corrosion

Comparing the shape of cross-sectional diagrams with the same conditions however with different coatings, we conclude that the thickness changes of the concrete coating in the non-corrosion and corrosion-free mode have a very small effect on the axial capacity of the cross section, and only affects the flexural capacity of the cross section, however with corrosion more than 5% for scenario 1 (corrosion-free section) and scenario 2 (corrosion-5%), the impact on the flexural and axial strength of the column also increases. Now, if the interaction diagrams of the sections with different coatings that are under the same corrosion ratio are compared, we conclude that with the increase of the concrete coating, the area of the area will suffer a decrease in resistance, as a result, the cross-sectional capacity will be further reduced.It should be noted, however, that with the increase of the concrete coating and the increase in the distance between the bars, the probability of the occurrence of the spalling phenomenon will be less.

Generally, with the increase of concrete coating at the cross section, corrosion will have a significant effect on reducing the cross-sectional capacity under corrosion of more than 5%, and also the spalling phenomenon will reduce much more cross-sectional capacity.

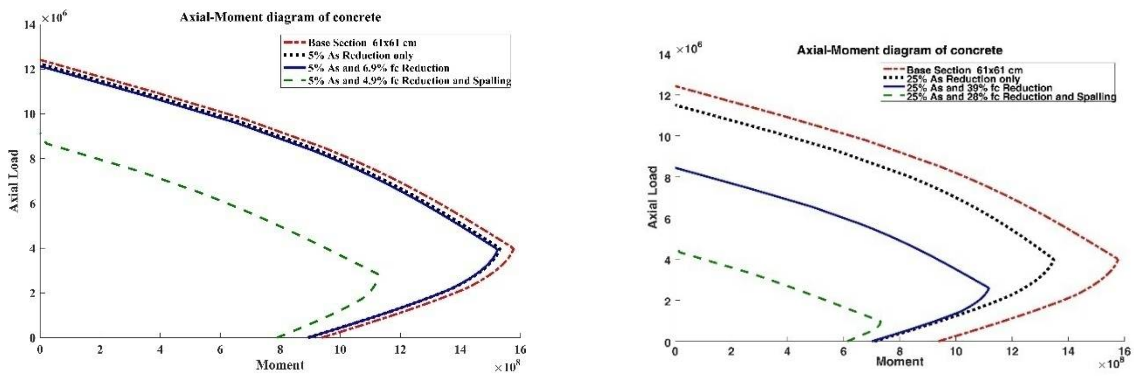
5.4. Evaluation of the Effect of Yield Stress on Sectional Sections

In this part of the paper, to analyze the effects of changing the steel stress transfer parameter on cross sectional corrosion, the initial cross section with two stresses of 3000 and 5,000 MPa was analyzed. In both cases, all cross sectional characteristics are the same as the specification of the primary section, and only the stress of cross sections has changed.



(a)Corrosion 5% **(b) Corrosion 25%**

Figure 6. Interaction Curve of the Cross Section with a Yield Stress of 3000 MPa under Corrosion



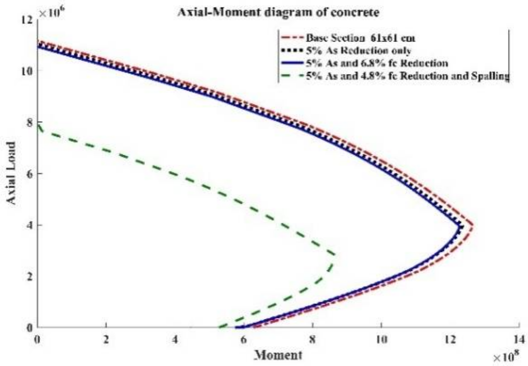
(a) **(b)**

Figure 7. Interaction Curve of the Cross Section with a Yield Stress of 5000 MPa under a) 5% corrosion b) 25% corrosion

Observing the above diagrams and comparing the interaction curve of the cross section under corrosion of 5% and 25%, we conclude that the variation of the stress tolerance does not affect the ratio of reduction of cross-sectional capacity. In other words, the corrosion rate is independent of the tensile strength of the cross-section bars, and the impact of the corrosion on the sinks is different for each other. Obviously, with decreasing stress, the axial and flexural capacity of the cross section also decreases.

5.5. Effect of Cross-Sectional Bars

In this section, changes in the percentage of cross stitch (with the same arrangement) are examined to see its effects on corrosion cross-section.



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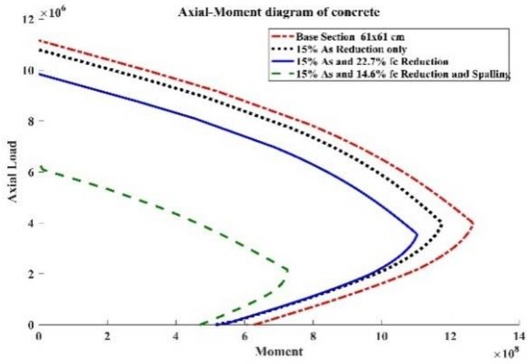

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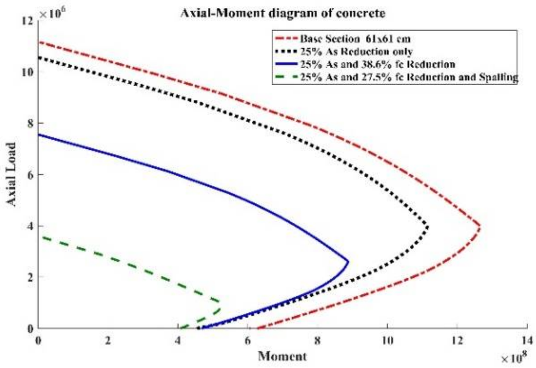
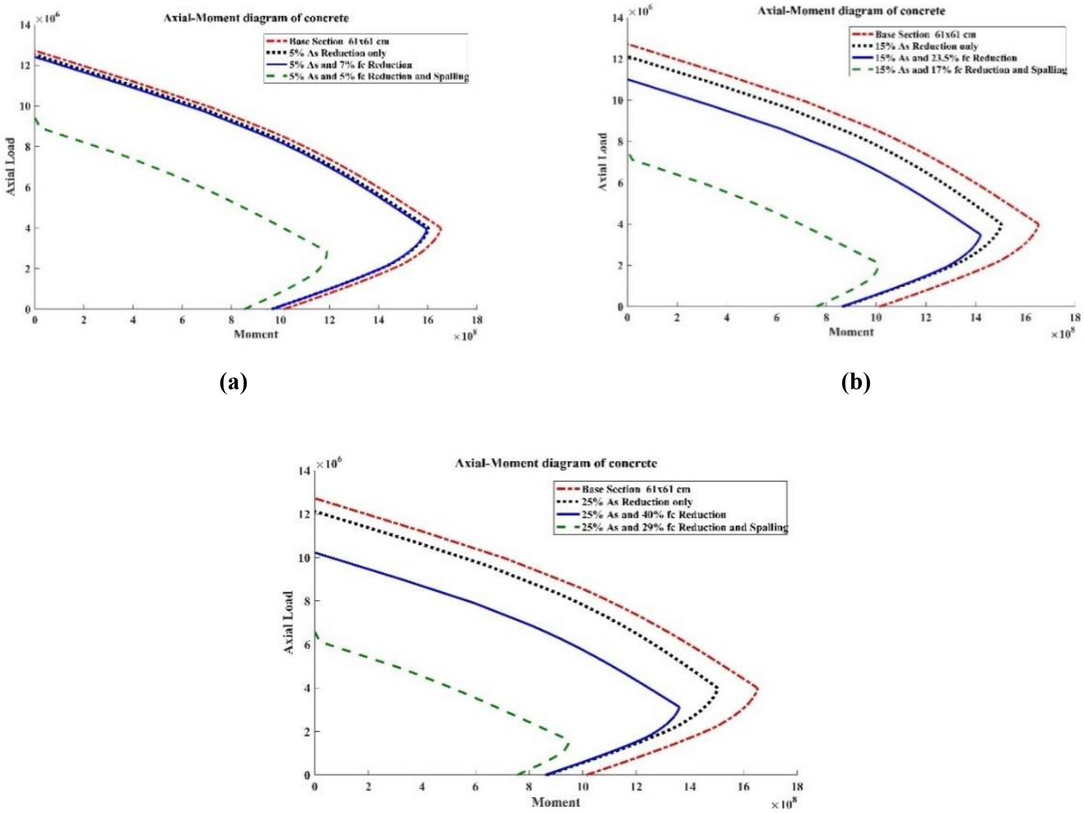


(c)

Figure 8: Interaction Cross-Sectional Curve with 0.016 (12F25) under a) 5% corrosion b) 15 %corrosion c) 25 % corrosion

By observing the interaction curves we conclude that the change in the percentage of cross section reinforcements has a small effect on the ratio of the axial and flexural capacity reduction and, in high corrosion rates, this effect is also increased. In other words, the corrosion of the rebar and the changes in the cross sectional strength percentage have a low degree of dependence on each other and, with increasing corrosion rates, this dependence will be slightly increased, however in general, the ratio of reduction of cross-sectional capacity to the corrosion percentage for the different milling profiles is approximately the same. Obviously, with the increase in the number of sections, the flexural and pivotal capacity of the section also increases.



(a) **(b)**

Figure 9. Interaction Curve with Cross-Section Ratio 0.026 (12F32) under a) 5% Corrosion b) 15%Corrosion c) 25%Corrosion

6. Conclusions

In the current study, the effects of corrosion of reinforcement on the behavior of the curvature of the column with the development of code is considered. Moreover, the effect of concrete compressive strength, concrete coating thickness, cross-section steel surrender stress and cross-sectional weight on the interference curve have been investigated. Based on the analysis, the following results are obtained:

- Reducing compressive strength does not have much effect on decreasing cross-sectional capacity with flexural behavior and is more effective in the compression region (the upper region of the balanced state).
- Skin formation in the section will have a great effect in reducing the cross sectional capacity.
- Reducing the initial compressive strength of concrete does not affect the axial and anchor force reduction ratio in different situations.
- The thickness changes of the concrete coating in a non-corrosive state with a corrosion of 5% have a very small effect on the axial capacity of the section and only affects the flexural capacity of the cross section. However, with corrosion more than 5% for scenario 1 (corrosion-free section) and scenario 2 (corrosion cross-section 5%), the impact on the flexural and axial strength of the column also increases.
- As the concrete coating rises, the area will suffer from a decrease in resistance, resulting in greater cross-sectional capacity. However, it should be noted that with the increase of the concrete coating and the increase in the distance between the bars, the probability of the occurrence of the spalling phenomenon will be less.
- Tangential variations do not affect the ratio of capacity reduction. Obviously, with decreasing stress, the axial and flexural capacity of the cross section also decreases.
- The change in the percentage of cross-section reinforcements has a small effect on the ratio of the axial and flexural capacity reduction, and the percentage of corrosion increases this effect.

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