Numerical analysis of corrosion impact in seismic response in column and parametric model

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ABSTRACT

The structural vulnerability of RC buildings during major seismic events raised several concerns regarding structural design and behaviour, construction methods and existing building maintenance guidelines. Modern RC buildings are designed to achieve a global ductile failure mechanism, where plastic rotations are intended to occur in beams. This approach prevents shear collapse through the capacity design procedure and adherence to specific detailing and material requirements. Nevertheless, the reduction of the structural seismic performance of RC structures due to corrosion effects is often associated with the shift in the collapse modality. The corrosion effects on rebars and concrete (reduction of ductility, confinement, strength, among others.) can diminish strength and more critically reduce structural displacement capacity, often resulting in altered collapse mechanisms and unforeseen failures. This issue was emphasized in several numerical studies designed to capture the effect of corrosion on the seismic performance of the entire building.
This paper aims to contribute to that field by performing a numerical analysis of a parametric structure consistent with the most common building typology of South Europe. 0% and 20% of corrosion have been considered in the adaptative pushover analysis of that structure. To calibrate those models, it was considered a model of a column with 1.80 m of height tested experimentally. The structural response of that column demonstrated good adherence with the experimental tests, which led to the calibration of the model for the parametric study. According to the parametric model, corrosion considerably affects structural behaviour, reducing its capacity substantially.

Keywords: Corrosion; Structural response; Seismic performance; RC structures

1. INTRODUÇÃO

The structural vulnerability of RC buildings during major seismic events raised several concerns regarding structural design and behaviour, construction methods and existing building maintenance guidelines. Modern RC buildings are designed to establish a global ductile failure mechanism, allowing for anticipated plastic rotations in beams. This design approach mitigates shear collapse by implementing a capacity design procedure and adhering to specific requirements regarding construction details and material properties [1].

Corrosion´s impact on steel and concrete, including reduction in ductility, confinement and strength, can compromise structural performance. It is marked by the decline in strength and, more critically, a reduction of structural displacement capacity, often leading to the change of collapse modality and to

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unforeseen failures. This issue was highlighted in some numerical studies aimed at capturing the effect of corrosion on the seismic performance of the entire building [2,3]. Such a problem can be even higher in existing RC buildings characterized by the strong beam/weak column hierarchy typical of design performed only towards vertical loads, frequently exposed to brittle soft-storey collapses [4].

To assess the residual performance of corroded structures, comprehensive research has been conducted over the past few decades, leading to the development of numerous empirical and theoretical relationships between corrosion levels and various performance indicators, including corrosion-induced crack width, bond-slip behavior, mechanical properties of corroded reinforcement bars, and the load-carrying capacity of corroded elements. However, for these correlations to be applied in structural assessments, the corrosion level must first be accurately quantified, a task that presents significant challenges for in-service structures compared to laboratory specimens [5].

Recent experimental studies have demonstrated the significance of assessing the impact of corrosion on the strength and, particularly, the displacement capacity of RC columns. This is especially relevant for columns affected by pitting corrosion and those that are well-confined and designed to exhibit ductile behaviour [6]. Meda et al. [7] indicate that corroded elements experience a reduction in ultimate strength and a decline in overall ductility by as much as 50% when the corrosion level reaches around 20% mass loss, even when the loss of confinement from stirrup deterioration is disregarded.

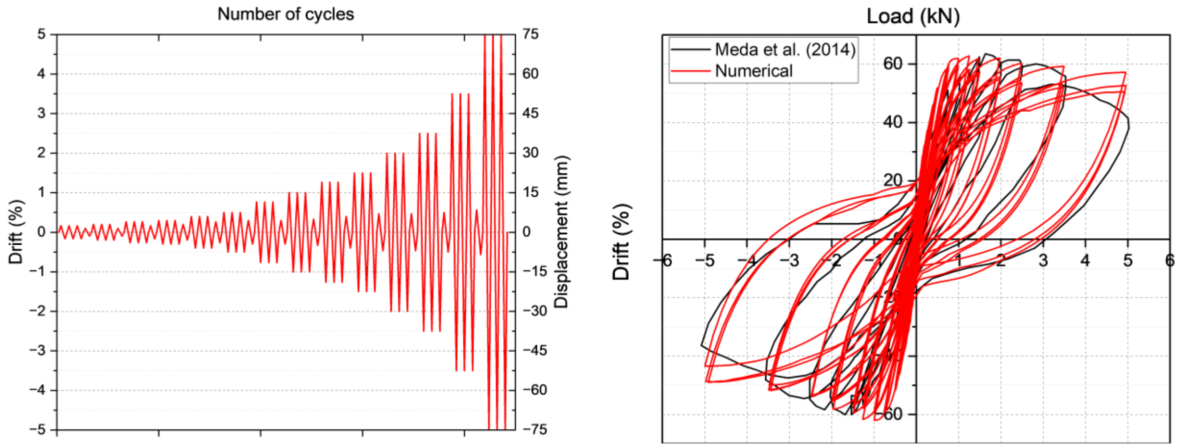
This work aims to contribute to that field by performing a numerical analysis of a parametric structure consistent with the most common building typology of South Europe. 0% and 20% corrosion have been considered in the pushover analysis of that structure. The reference structure is based in the five-storey MRF building proposed by Maranhão et al. [8]. The design calculations for DCM structures were performed following the guidelines outlined in Eurocode 8 [1] and the draft version of Eurocode 8 [9]. The method used is the force-based approach. The force-based approach includes the response spectrum method, a linear analysis incorporating overstrength and non-linear response through the behaviour factor (q). To calibrate those models, it was considered a model of a column with 1.80 m of height tested experimentally by Meda et al. study [7].

2. BUILDING GEOMETRY AND STRUCTURAL SYSTEM

2.1 Models calibration

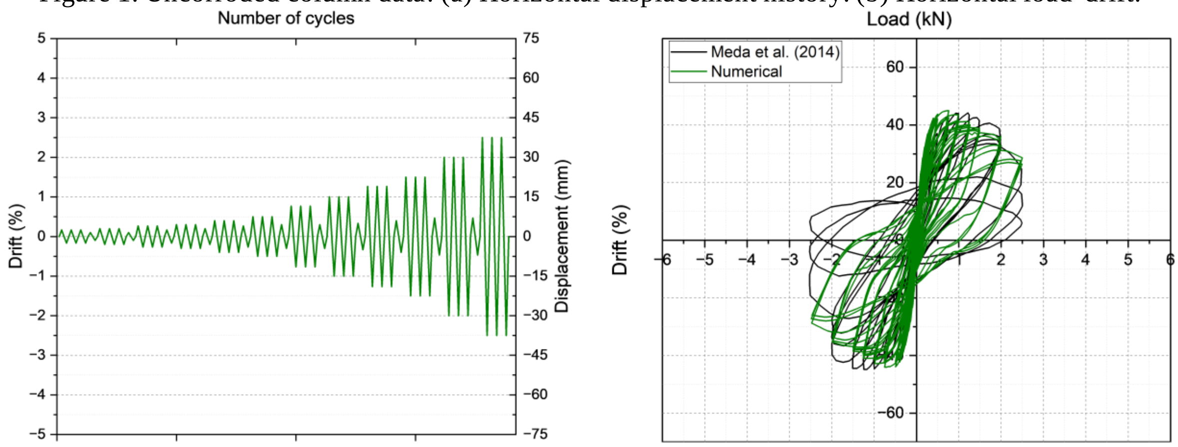
The column calibration is based on Meda et al. work [7]. Details of horizontal displacement history and load-drift of uncorroded column and column with 20% corrosion are presented in Figs. 1 and 2, respectively. The drift limit for the uncorroded column is 5%, representing, in the aforementioned work, the cover spalling and concrete crushing in the base of the column. For the column with 20% of corrosion, the limit is 2.5% which represents the complete concrete crushing.

As demonstrated in Figs 1 and 2, the proposed models simulate satisfactory the hysteric response of the experimental column specimens presented in Meda et al. [7] work.



(a) **(b)**

Figure 1. Uncorroded column data: (a) Horizontal displacement history. (b) Horizontal load-drift.



(a) **(b)**

Figure 2. 20% corroded column data: (a) Horizontal displacement history. (b) Horizontal load-drift.

2.2 Structural characterisation

The structures in this study consist of one five-storey building configuration, as shown in Fig. 3, which was developed from the structure studied by Maranhão et al. [8]. The structural system for the building consists of frames with a spacing of 6,0 m on the x-axis and 7,0 m on the y-axis, typical of residential buildings. The floor-to-floor height is 4,0 m in the ground storey and 3,0 m in all other storeys. All the structures were designed using Robot Structural Analysis Professional® [10], considering Eurocode criteria. Table 1 presents the main geometrical characteristics of the analysed structure.

All primary seismic members (beams and columns) of the assessed structures are considered using C30/37 concrete and B500 steel reinforcement. The nominal concrete cover considered is 30 mm. It was calculated by adding to the minimum cover the allowance in design for deviation according to EN 1992-1-1 [11]. Additionally, it was considered Exposure Class XC1, related to environmental conditions following EN 206-1 [12], as specified in En 1992-1-1 [11].

Table 1. Geometry of the MRF structure.

<table>
<tr><th>Storey</th><th>Columns</th><th>Beams</th><th>Slabs thickness</th></tr>
<tr><td>Up to storey 2</td><td>55x55 cm</td><td>40x55 cm</td><td rowspan="3">15 cm</td></tr>
<tr><td>Storey 2 to 4</td><td>50x50 cm</td><td rowspan="2">40x50 cm</td></tr>
<tr><td>Storey 4 to 5</td><td>45x45 cm</td></tr>
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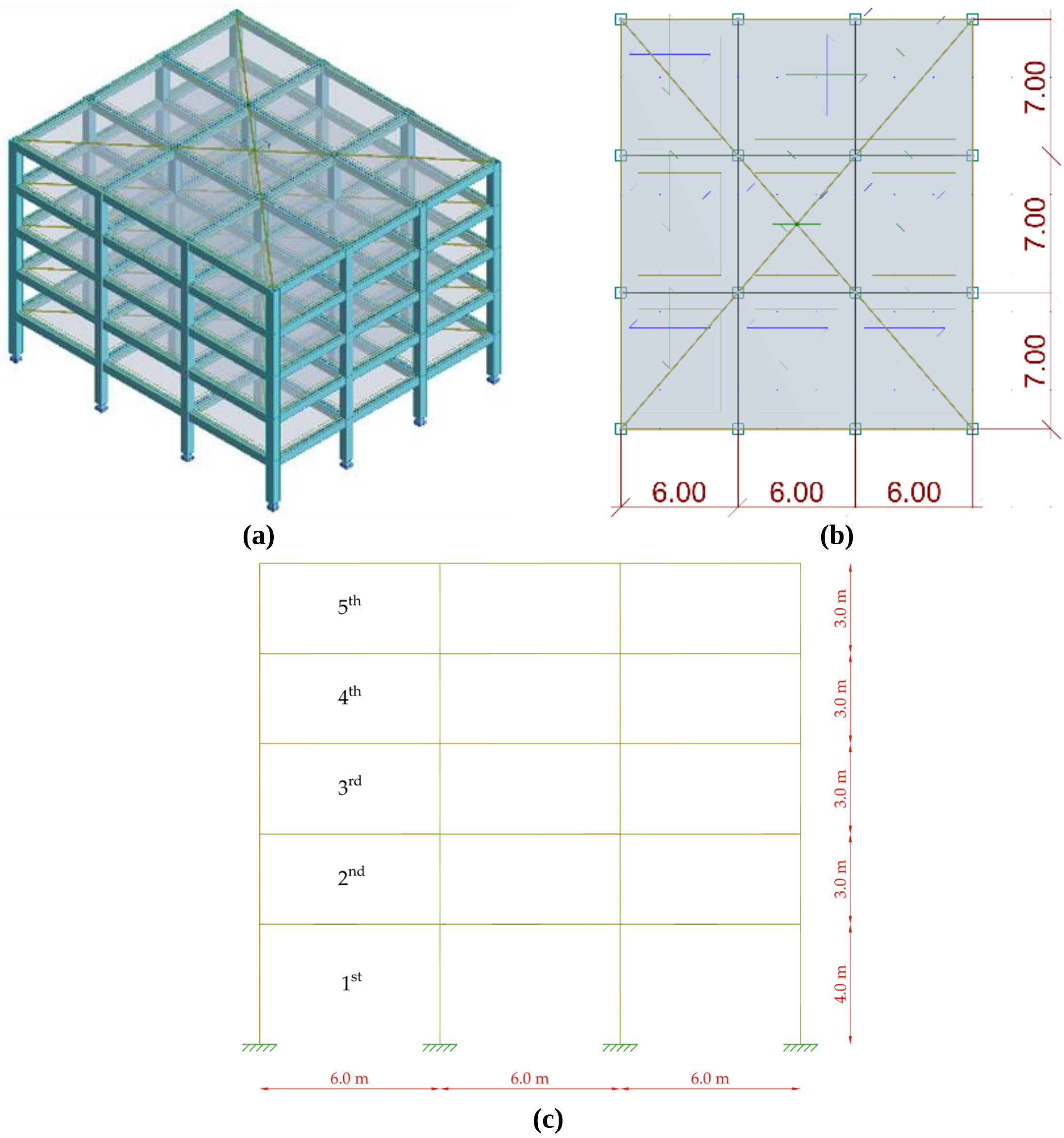


Figure 3. Frame building system configuration: (a) 3D Model. (b) Planview. (c) Cutaway.

2.3 Seismic response assessment

The software employed for the particular purpose in this research was SeismoStruct [13]. The software has been extensively quality-checked and validated. It is a Finite Element package designed to predict the large displacement behaviour of space frames under static or dynamic loadings, accounting for both geometric nonlinearities and material inelasticity [14].

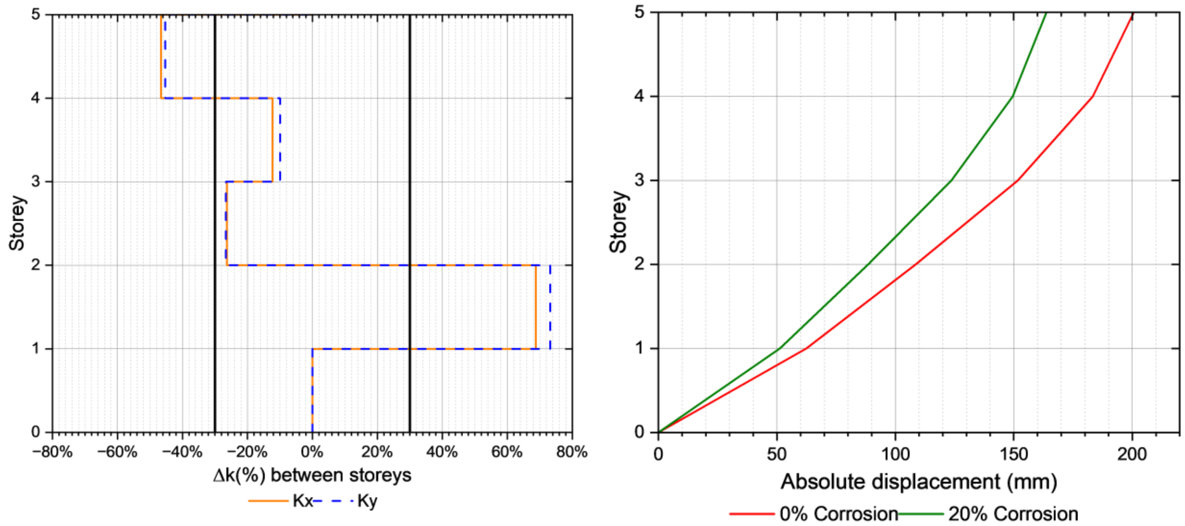
SeismoStruct accommodates both static (forces and displacements) and dynamic (accelerations) loads and offers a range of analytical capabilities including eigenvalue analysis, nonlinear static pushover, nonlinear static time-history analysis, response spectrum analysis, among others [14].

Adaptative pushover analysis was carried out as a modelling approach. It is one of the methods available for evaluating buildings against earthquake loads. Despite other types of analysis such as the dynamic time-history analysis are more precise, the preliminary assessment nature of this paper would allow an adaptative pushover analysis to be used. Numerous studies have also considered this type of analysis in studying regular and irregular buildings [15–21].

3. RESULTS AND DISCUSSION

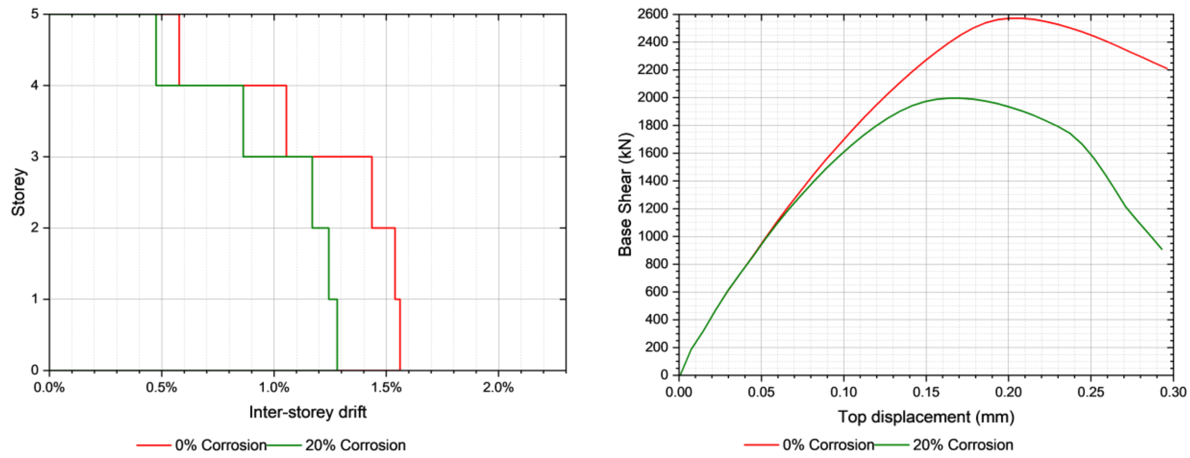
Fig. 4a presents the lateral stiffness in both axis X and Y directions and Fig. 4b demonstrates the comparison of absolute displacement of each storey in 0% and 20% corroded structures. Fig. 5 shows the comparison of inter-storey drift (a) and capacity curves (b) of each storey in 0% and 20% corroded structures.

The lateral stiffness of the structure was obtained by applying unitary displacements on the peripheral column nodes of the storey under assessment and fixing the column nodes of the stories below. The obtained slope of the force-displacement relationship is the lateral stiffness of the storey. This procedure was performed on all storeys, with lateral stiffness being the sum of all calculated forces that generate a unitary displacement.



(a) (b)

Figure 4. (a) Lateral stiffness in the X and Y axis. (b) Absolute displacement of 0% and 20% corroded structures.



(a) (b)

Figure 5. Comparison between 0% and 20% corroded structures: (a) Inter-storey drifts. (b) Capacity curves.

It can be drawn the following discussion:

a) From Fig. 4a, the structures present a shift higher than 30% in lateral stiffness between the first and second floors. According to the new draft of Eurocode 8 [9], those structures would be classified as irregular in elevation due to this criterium. Additionally, despite the fact that the top floor also presents a shift of lateral stiffness higher than 30%, the aforementioned code allows that condition only on the top floor.

b) Regarding Fig. 4b, the 20% corroded building presents lower displacements in comparison to the uncorroded model in all storeys. The variation is between 17.9% and 18.5%.

c) From Fig. 5a, the 20% corroded model presents lower inter-storey drift in comparison with the uncorroded structure in all floors. In Fig. 5b, it is demonstrated a substantial reduction in base shear and the correspondent top displacement in the 20% corroded structure in comparison with the uncorroded one. The base shear reduction is 27.3% and the top displacement reduction is 19.9%. That corroborates with the lower absolute displacement observed in Fig. 4b. Additionally, it can be observed that there is an abrupt loss of capacity in the 20% corroded structure after maximum base-shear.

d) Several experimental and analytical studies need to be performed for further generalizations, considering different concrete resistance; levels of corrosion (5% - 20%); different geometries, considering irregularities in plan and elevation, columns and beams cross-section variation, among other parameters.

CONCLUSIONS

In this paper, it was carried out an assessment of seismic response of uncorroded and 20% corroded models. Firstly, experimental tests and analytical analysis of Meda et al. (2024) [7] was considered. The proposed model for nonlinear dynamic analysis of RC columns and frames was presented. Finally, using this model, an adaptative pushover analysis was conducted on a hypothetical RC frame.

It can be drawn the following conclusions:

1. The hysteric response of the experimental column specimens demonstrated good adherence with the proposed models for uncorroded and 20% corroded structures, which led to the calibration for the parametric study.

2. According to the parametric model, corrosion considerably affects structural behaviour. The 20% corroded structure presents considerable reduction in structural capacity due to their strength and ductility.

3. Further experimental and analytical studies in that field are necessary to better comprehension of corrosion impact in seismic response. Specifically, considering high number existing old buildings in Europe and several current seismic events.

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