Assessment of Seismic behavior of a RC Precast building

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Abstract. Past earthquakes brought attention to the poor performance of precast reinforced concrete structures. One of the problems observed in those structures is related to the beam-to-column connections. The evaluation of different methodologies for the analysis of beam-to-column connections in industrial buildings is an important aspect that should be studied. The numerical analyses developed allowed the study of the effect that different connection properties have on the frequencies of vibration, members drifts and seismic coefficients. The connection properties were modelled through a macro-element that considers the friction (between concrete-concrete and concrete-neoprene) and the steel dowels. The results showed that the friction between concrete elements and the consideration of the neoprene in the connection have a small impact on the drifts demands in the columns and seismic coefficient of the analyzed structure; on the other hand, the effect of the steel dowel on the drift demand and seismic coefficient is significant. The comparison of the models with different properties and connections allowed a better understanding of the factors with a higher impact on the results.

Keywords: Industrial Buildings, Precast Reinforced Concrete, Beam-to-Column Connections, Seismic Performance, Numerical Analysis.

1 Introduction

Precast reinforced concrete (RC) structures have shown in several cases a poor seismic performance presenting damages on structural and non-structural elements, highlighting the vulnerability of industrial buildings [1]–[4]. An important part of these buildings was not designed with seismic provisions. Most of the observed damages are related to structural elements, namely in the beam-to-column connections. In several buildings were observed significant failures and collapses. For example, after the 2011 earthquake in Emilia Romagna, more than half of the existing precast structures exhibited significant damages [5]. Even in moderate and short duration earthquakes events, RC structures exhibit high levels of structural damages as Romão et al. described after field observations of the 2011 Lorca earthquake [6]. The unceasing reports of damages on precast structures derived from seismic events pointed to a need for consistent methodologies for analysis, modeling and assessment of existing constructions. Those models need to account for the interaction between structural elements (e.g. beam-to-columns connections) and structural and non-structural elements in order to describe the non-linear dynamic behavior of this type of structures [7]. In the precast topic, Sacks et al. [8] presented a parametric work with 3D modeling with examples from precast concrete, analyzing the requirements, features and performance of a CAD platform. The need to assess the seismic vulnerability of existing buildings led different authors to develop new modeling solutions following both macro (e.g., [9]–[12]) and refined numerical models (e.g., [13]–[15]). The use of refined models tends to offer more precise results given the ability to consider the different mechanisms involved. However, these models are computationally demanding and, therefore, unsuitable for common engineering applications or seismic risk analyses at a large building scale. Since the beam-to-column connections were identified as one of the most critical elements in precast structures under seismic loads, some works were developed in this field in the last years. It should be highlighted the works of Casotto et al. [11] and Magliulo et al. [12] that are focused on the behavior connections without dowels, others, e.g. Clementi et al. [9], account only for the contribution of the dowels. The macro-element adopted in the present work follows the model proposed by Sousa et al. [16], which explicitly simulate the contribution of both friction and dowel action.

2 Parametric Study

2.1 Description of the Case Study

The RC precast building under study represents an industrial framed structure (Fig. 1.) constituted by one floor with an area of 180 × 175 m^2 and a height of 12 m. The structure has 5 spans in the X direction (Fig. 2.) with 35 m of length each and 15 spans in the Y direction with 12 m of length each. The columns of the structure have a height of 12 m (the height of the building) and a rectangular section of 0,70 × 0,50 m (**Error! Reference source not found.** 3.) with a 40 mm cover. The concrete used was the C40/50 and the steel was the S500 NR-SD. The beams are pre-stressed with an I variable section, with a length of 35 m and a 30 mm cover. The columns are assumed fix to the foundation. In Europe, the most common type of beam-to-column connection in precast RC industrial buildings is the dowel beam-to-column connection [17]. In this system, the beam is mechanically connected to the column through vertical steel dowels. These dowels, usually one or two, protruding from the column's corbel, fit into sleeves left in the edge of the beams, which are later filled with a proper grout. In several cases, a steel or neoprene pad is placed between the column and the beam. These connections do not restrain the rotations between both members, while the transfer of horizontal forces between the beam and column is essentially ensured by friction and dowels (if present). In this type of connection, the transfer of the horizontal forces between the beams and columns is essentially ensured by the dowel action and friction between the beam and column [18].

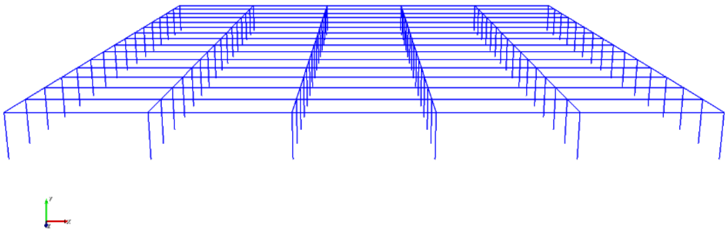


Fig. 1. A 3D overview of the building under study.

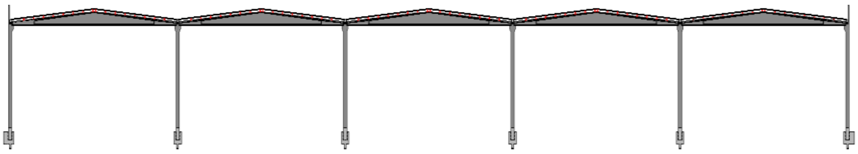


Fig. 2. Principal direction (X) of the framed structure.

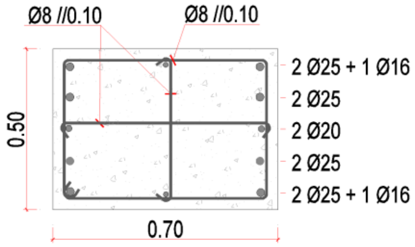


Fig. 3. Column section.

For the numerical analysis, constant vertical loads distributed on beams were considered to simulate the dead load of the self-weight of roof and RC elements, and the corresponding quasi-permanent value of live loads, giving a total value of 0.65 kN/m^2. The 3D models were subjected to incremental dynamic analysis (IDA). A total of 10 ground motion record were selected from real previous seismic events according to the Araújo et al. [19] method. The average of the earthquake records fit the Eurocode 8 spectrum according to Type 1, for Lisbon, soil type A and were progressively scaled.

2.2 Sensitivity Parameters

To understand the seismic performance of the structure a parametric study was developed. Several cases were considered in a 3D model to better understand the impact that certain parameters have on the response of the building. The parameters considered are focused on the response of the beam-to-column connections, namely regarding the relative importance of the contribution of the dowels, neoprene and friction. Each case was named according to the properties considered in the model, for example, the case DFNC corresponds to a Dowel, Friction and Neoprene Connection considered in the model, in the same way, the case DC corresponds to a Dowel Connection and the case FNC corresponds to a Friction and Neoprene Connection considered in the model. The model PC corresponds to Pinned Connections considered in the model. In Table 1 is the list of properties adopted in the different models.

Table 1. List of properties adopted in the different models.

Model	Number/Diameter of Dowels [mm]		Friction	Neoprene Pad [mm]
	X Dir.	Y Dir.		
PC	Pinned Connection			
DFNC	2 ø24	2 ø20	Yes	20
DC	2 ø24	2 ø20	NC	NC
FNC	NC	NC	Yes	20

NC- not considered in the model

3 Results

3.1 Contribution of the Connection to the global behavior

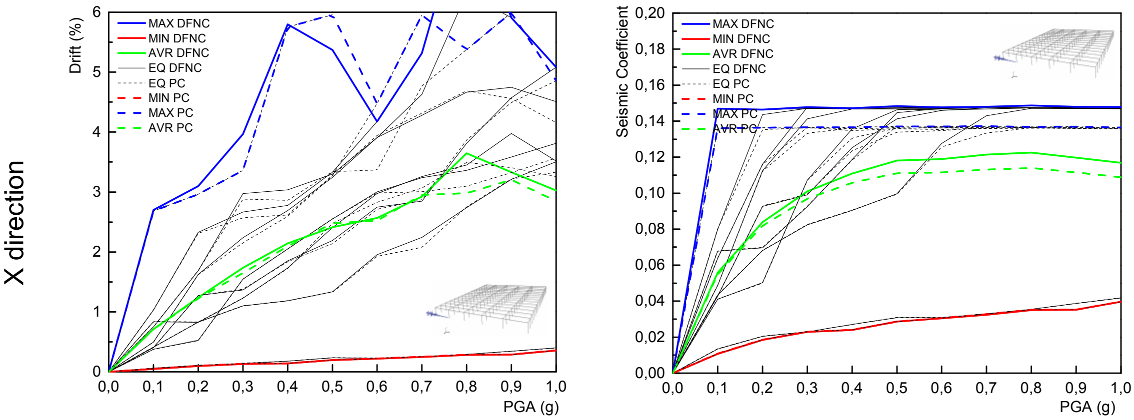
One of the main aims of the present study is to assess the effects of the connection in the global behavior of the building under study. In Table 2 are presented the 1st and 2nd frequency of the different structures with different connections. The models with pinned connections (PC) and DFNC connections have the same frequencies. This situation shows that, for this model, when analyzing the frequencies, considering a detailed connection with dowel, neoprene and friction is the same as considering a pinned connection. The models with DFNC and DC connections have the same frequencies, which shows the very low impact of the neoprene and friction on the structure frequency. On the other hand, the models with DFNC and FNC connections have different contributions to the global stiffness of the structure, which shows that the dowels may have a significant impact on structure behavior in terms of strength, as expected, but also in the global stiffness.

Table 2. Frequency comparison between the models with different connections.

Model	Frequency 1 (Hz)	Frequency 2 (Hz)
PC	0.44	0.65
DFNC	0.44	0.65
DC	0.44	0.65
FNC	0.44	0.48

3.2 DFNC connection and Pinned connection

In the present section, the DFNC model is compared with the PC model to find the difference between considering a model with a connection with dowel, friction and neoprene and a model with pinned connections, usually considered in the common design stage. In Figure 4 are represented the drifts and seismic coefficients for the DFNC and PC models in the X direction. The difference between the DFNC and PC models is very low, which shows that developing a connection model with dowels, friction and neoprene might not be necessary to study the drifts and seismic coefficients of the structure. Considering a pinned connection leads to a relatively simpler model that has practically the same results as considering a model with dowel, friction and neoprene connections. Most of the time, the DFNC model leads to slightly higher results when compared with the PC model.

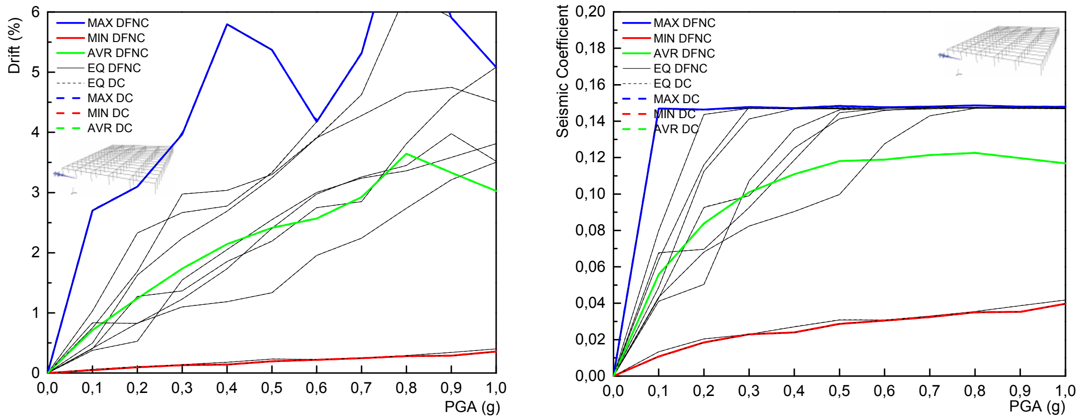


a) Drift comparison **b)** Seismic coefficient comparison

Fig. 4. Model with pinned and DFNC connections.

3.3 Effect of the neoprene and friction

In the present section is discussed the comparisons of the drift and seismic coefficient with DC and DFNC connections, to evaluate the effect of the connection only with the dowel and the connection considering the dowel, friction and neoprene. For the building under study this effect seems to not play a significant role. Figure 5 shows that the difference between considering a DC and DFNC connection is inexistent, leading to a low influence of the friction and neoprene in the drift and seismic coefficient of the structure. In fact, in other studies [16], only focused in the connection level, the contribution of the friction and neoprene are evaluated around 25% of the global connection response. Both cases can be true, once in the building under study the connection does not experience a huge demand, like observed in the previous studies. For buildings with higher demands at the connection level, the contribution of the friction and neoprene pad may not be so insignificant.

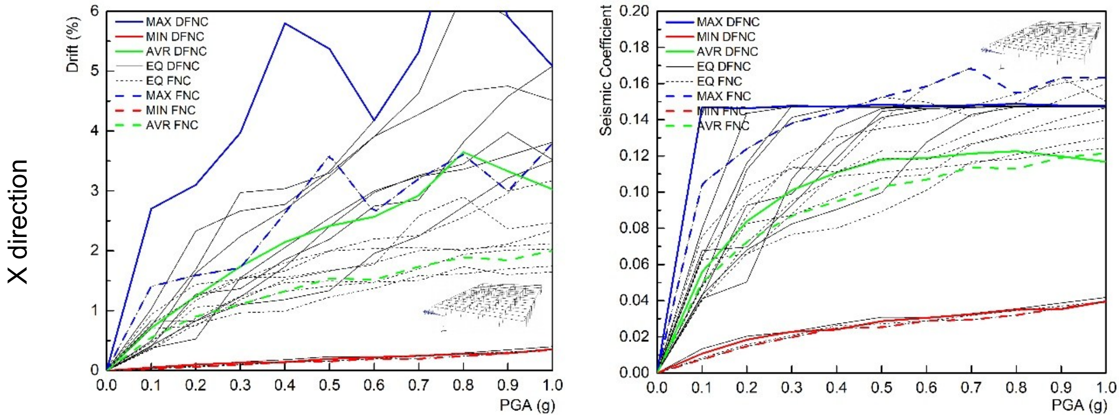


a) Drift comparison **b)** Seismic coefficient comparison

Fig. 5. Model with DC and DFNC connections.

3.4 Effect of the dowels

In this section is presented the comparative analysis of the models with FNC and DFNC connections. Figure 6 shows a significant difference between considering FNC and DFNC connections, which shows that the dowel is a connection parameter with influence in the drift and seismic coefficient of the structure. For the same PGA, the model without dowel presents a lower drift demand in the columns when compared with the model with dowels.



a) Drift comparison b) Seismic coefficient comparison

Fig. 6. Model with DFNC and FNC connections.

4 Concluding Remarks

Several comparisons between models featuring different beam-to-column connections were developed to assess its contribution and impact to the global behavior of general RC precast structures. The comparison between the models DFNC and PC showed that the models have the same frequencies and equivalent results of the drift and the seismic coefficient. This situation shows that considering a detailed connection with dowels, neoprene and friction may not be necessary to study the drifts and seismic coefficients of the structure. Comparing the models DFNC and DC allows the evaluation of the effect of the neoprene and friction on the structure. The frequencies of the models DFNC and DC are the same. The drift and seismic coefficient in the X direction of the DFNC and DC models are similar which shows that there is no contribution of the neoprene and friction on the drift and seismic coefficient of the structure. The comparison between the models DFNC and FNC allowed the evaluation of the effect of the dowels on the structure. The dowels, contrary to the friction and neoprene, have a significant impact on the drift and seismic coefficient of the structure. For the same PGA, the FNC model has lower drift demand when compared with the DFNC model. For lower PGA, the seismic coefficient in the model FNC is lower than in the model DFNC. For higher PGA, it is the contrary, the seismic coefficient in the model FNC is higher than in the model DFNC. From a general point of view, the results showed the importance of the beam-to-column connections to the seismic behavior of the entire structure. In the presence of adequately design dowels, small deformations are expected at the connections level and, therefore, the response of the structures is controlled by the properties of the vertical elements. For these cases, the consideration of simple pinned connection appears as an efficient and accurate numerical approach. On the other hand, in the absence of dowels, or in cases where these are not properly designed, a concentration of damage is expected to occur at the connection level, whilst the columns remains essentially undeformed. Hence, whenever the relative horizontal strength between the columns and the adjacent connections is unknown, the consideration of the different connection mechanisms is recommended in order to obtain a reliable estimation of the seismic behavior of the building.

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