SeismicPRECAST - "Seismic performance Assessment of existing Precast Industrial buildings and development of Innovative Retrofitting sustainable solutions"

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Hugo Rodrigues, Fernanda Rodrigues, Aníbal Costa, Vitor Silva, Liana Ostetto, Hugo Vitorino – Universidade de Aveiro

Paulo Fernandes, Romain Sousa, João Veludo, Miguel Barreto – Instituto Politécnico de Leiria

Humberto Varum, António Arêde, Nádia Batalha, André Furtado – Faculdade de Engenharia da Universidade do Porto

universidade de aveiro

POLITÉCNICO DE LEIRIA | ESCOLA SUPERIOR DE TECNOLOGIA E GESTÃO

U.PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

SeismicPRECAST - “Seismic performance ASSessment of existing Precast Industrial buildings and development of Innovative Retrofitting sustainable solutions”

Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
Seminário de Encerramento do Projeto

SeismicPRECAST - “Seismic performance Assessment of existing Precast Industrial buildings and development of Innovative Retrofitting sustainable solutions”

- Task 1 | State-of-art review and initial studies
- Task 2 | Typical properties of the Portuguese precast industrial buildings
- Task 3 | Development of a Vulnerability Model
- Task 4 | Development and validation of retrofitting solutions
- Task 5 | Life-Cycle assessment of seismic retrofit strategies applied to existing precast RC Structures
- Task 6 | Integration of the data, development of guidelines and application to real case studies
- Task 7 | Project management and organization of scientific and technical meetings

Seismic Performance Assessment of Existing Precast Industrial Buildings and Development of Innovative Retrofitting Sustainable Solutions
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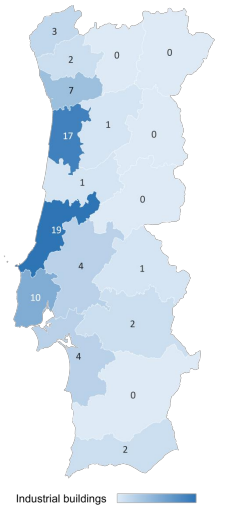
Characterization of the Portuguese Industrial Building Park

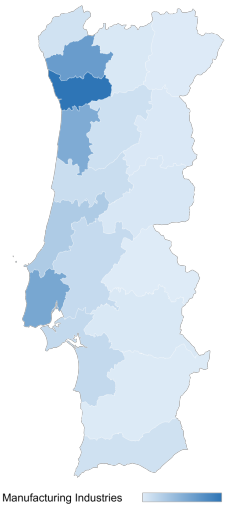
Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
Seminário de Encerramento do Projeto

Characterization of the Portuguese Industrial Building Park
Geographical distribution

- Comparison between the location of the collected projects and the actual manufacturing industry according with the data available in Pordata
- The buildings tend to be concentrated at the center and northern regions of the Portuguese coast side



Localization of the collected projects



Manufacturing industries in 2017 (Pordata)

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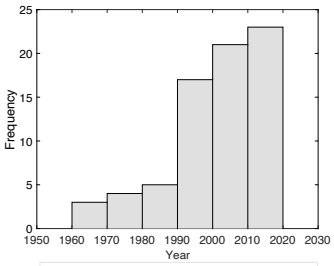
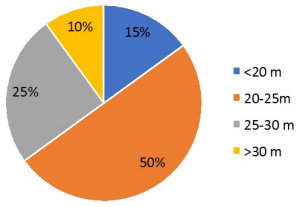
Characterization of the Portuguese Industrial Building Park

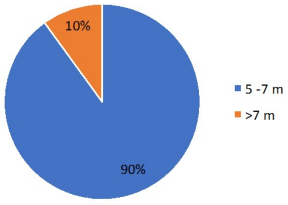
- Built over the last 50 years
- Clear concentration after 1990
- Very limited of information in the design project of older buildings
- Only during the 70's that an important grow in the precast systems



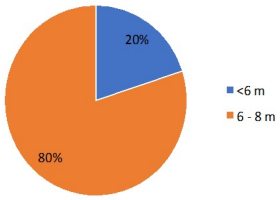
Distribution by the year of the project



Span length|Longitudinal direction



Span length|Transverse direction



Height of the columns

Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
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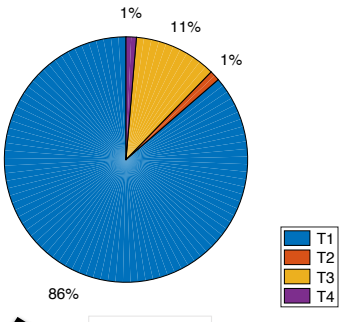
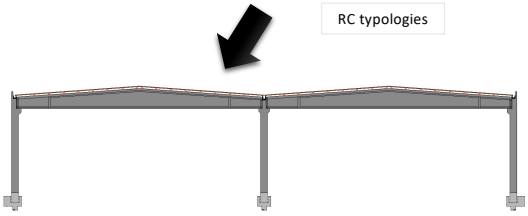
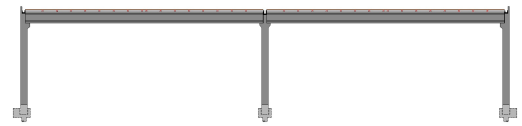
Characterization of the Portuguese Industrial Building Park

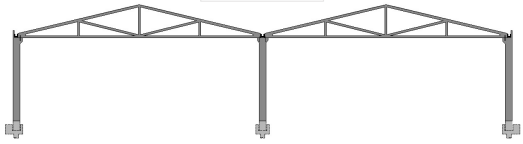
Common typology

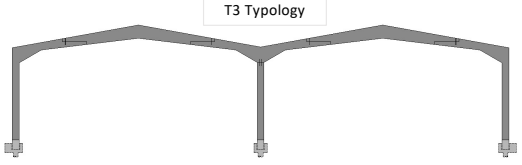


RC typologies


T1 Typology


T2 Typology


T3 Typology


T4 Typology

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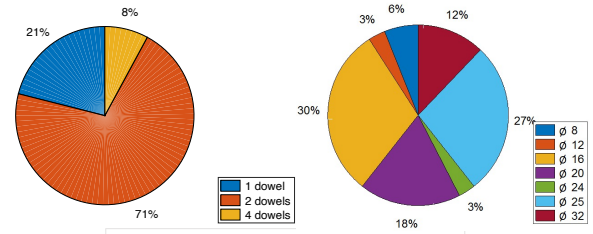
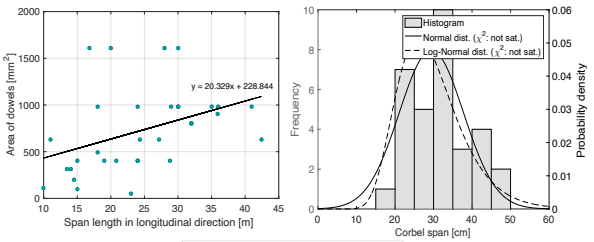
Characterization of the Portuguese Industrial Building Park

Beam-to-column connection

- In 60 % of the cases it was possible to access the details about the dowel connection
- Variability in terms of the number and diameter of the dowels
- The area of the dowels appears to be correlated with the beam span
- Regarding the corbel properties the results obtained from the data collected reveal values that vary between 10 and 50 cm
- The corbel span seems to be independent of the longitudinal beam span



Number and diameter of the connection dowels



Columns reinforcement ratio

Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
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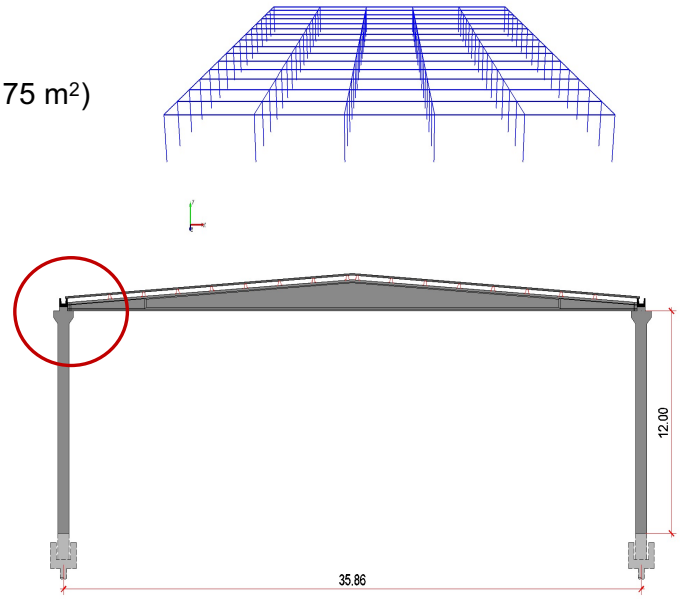
Seismic Assessment of Precast Buildings

Beam-to-column connection – Influence at the buildings level

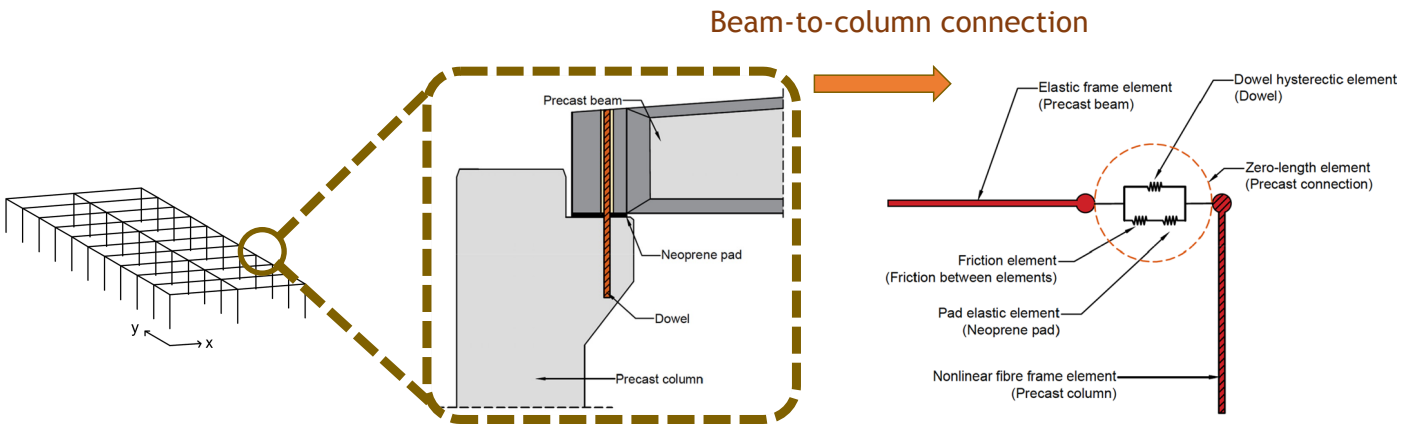
- Existing Precast Industrial framed structure (180 ×175 m²)
- Height: 12 m
- 5 Spans in the X direction with 35 m of length
- 15 Spans in the Y direction with 12 m of length
- Concrete C40/50
- Steel S500 NR-SD



Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
Seminário de Encerramento do Projeto

Seismic Assessment of Precast Buildings

Beam-to-column connection – Influence at the buildings level



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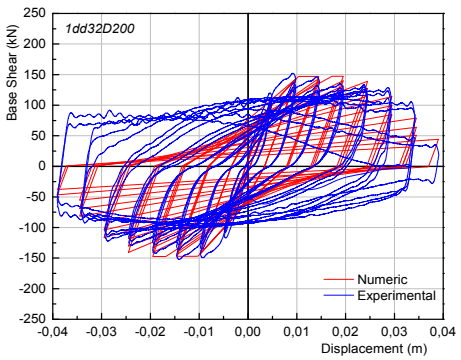
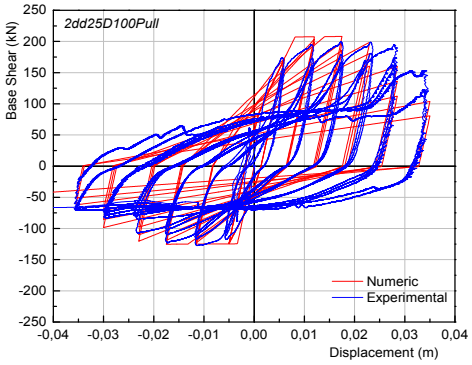
Seismic Assessment of Precast Buildings

Beam-to-column connection

- To access the accuracy of the numerical model, each experimental test was simulated considering the set of parameters previously defined





Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
Seminário de Encerramento do Projeto

Seismic Assessment of Precast Buildings

Beam-to-column connection – Influence at the buildings level

Parametric Study

- 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

Model	Number/Diameter of Dowels [mm]		Friction	Neoprene Pad [mm]
	X Direction	Y Direction		
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

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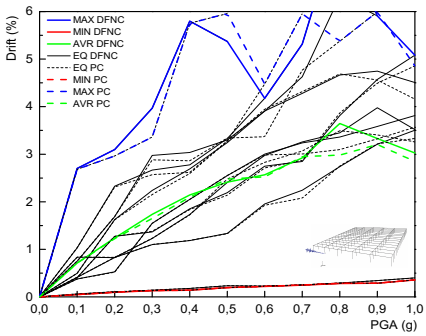
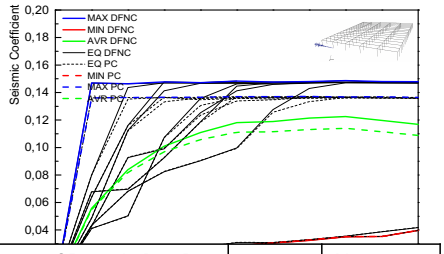
Seismic Assessment of Precast Buildings

Beam-to-column connection – Influence at the buildings level

DFNC And Pinned connection

- Comparing the model with a connection with dowel, friction and neoprene and a model with pinned connections (usually considered in the common design stage)
  - The difference is very low, which shows that developing a detailed connection model might not be necessary to study the drifts and seismic coefficients of the structure
  - Most of the time, the DFNC model leads to slightly higher results when compared with the PC model





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	X Direction	Y Direction		
PC	Pinned Connection			
DFNC	2 Ø24	2 Ø20	Yes	20

Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
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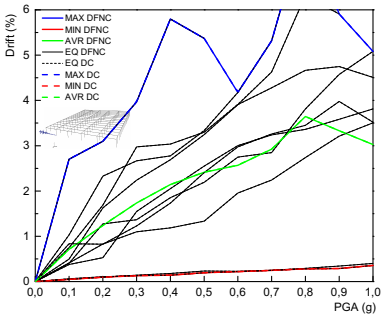
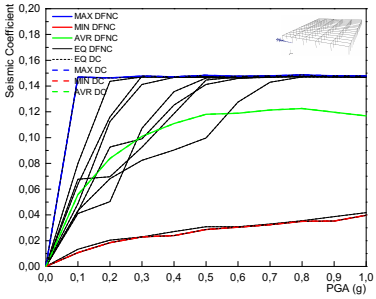
Seismic Assessment of Precast Buildings

Beam-to-column connection – Influence at the buildings level

Effect of the neoprene and friction

- Evaluate the effect of the connection only with the dowel (DC) and the connection considering the dowel, friction and neoprene (DFNC)
  - Difference between these model connections is inexistent | Low influence of the friction and neoprene in the drift and seismic coefficient of the structure
  - For buildings with higher demands at the connection level, the contribution of the friction and neoprene pad may not be so insignificant



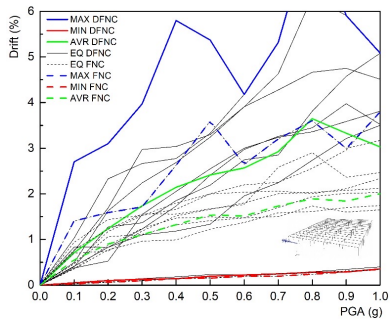


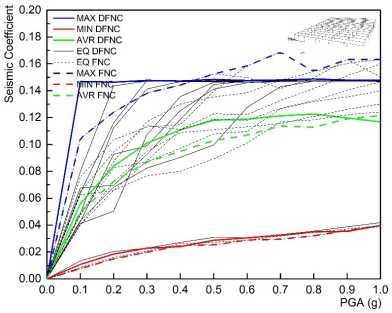
Model	Number/Diameter of Dowels [mm]		Friction	Neoprene Pad [mm]
	X Direction	Y Direction		
DFNC	2 Ø24	2 Ø20	Yes	20
DC	2 Ø24	2 Ø20	NC	NC

Seismic Assessment of Precast Buildings

Beam-to-column connection – Influence at the buildings level

Effect of the dowels





- Significant difference between considering FNC and DFNC connections
  - 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

Model	Number/Diameter of Dowels [mm]		Friction	Neoprene Pad [mm]
	X Direction	Y Direction		
DFNC	2 Ø24	2 Ø20	Yes	20
FNC	NC	NC	Yes	20

Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
Seminário de Encerramento do Projeto

Seismic Assessment of Precast Buildings

Beam-to-column connection – Influence at the buildings level

- The results showed the importance of the beam-to-column connections to the seismic behaviour of the entire structure
- If the dowels are well designed, 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, while 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

Assessment of existing RC precast industrial buildings according with Eurocode 8 – Part 3

Objectives:

Seismic assessment using nonlinear static (pushover) and dynamic analyses, following the recommendations presented on Eurocode 8 – Part 3.

Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
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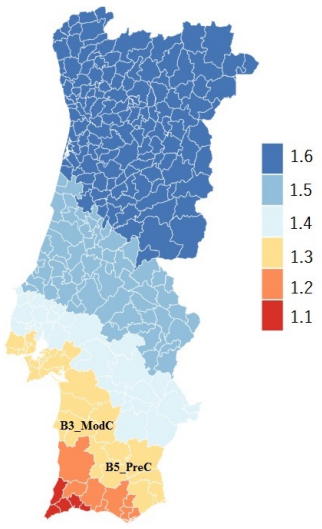
Assessment of existing RC precast industrial buildings according with Eurocode 8 – Part 3

Structures information

	Structure ID	Year	Seismic Zone
Mid code	B3_ModC	1997	1.3
Pre code	B5_PreC	1979	

- The existing PRC **buildings** considered to perform the **seismic assessment**, following the prescriptions of the **Eurocode 8 – Part 3** were **collected from the database**
- The **buildings were chosen** with the objective of reflecting the **typical properties** on **each period**
- It was decided to define **three sub-classes** based on the **year of construction**, as an important fraction of the **mechanical and geometric properties** depend on the year of construction
- The sub-classes were defined as:
  - '***Pre code***': 1960 to 1980
  - '***Moderate code***': 1980 to 2000
  - '***Post code***': 2000 to 2020

Buildings distribution vs Type 1 seismic zonation



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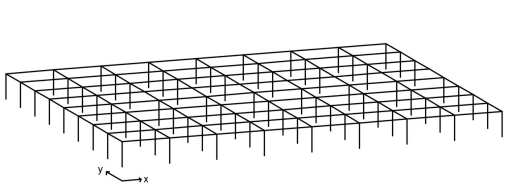
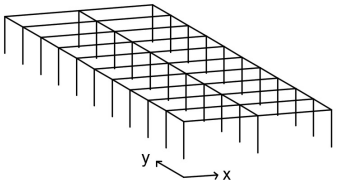
Assessment of existing RC precast industrial buildings according with Eurocode 8 – Part 3



B3_ModC



B5_PreC

Geometric characteristics of the buildings in studying

Structure ID	Number of spans		Span length		Height [m]	Columns Slenderness	
	x	y	x [m]	y [m]		x	y
B3_ModC	8	8	17.0	6.0	9.0	69	89
B5_PreC	2	10	15.0	4.2	7.5	65	65

Material and reinforcement detailing characterization

Building ID	Concrete f_{cm} [MPa]	Steel f_{ym} [MPa]	Column bxh [m]	% Steel		Dowel Ø [mm]
				Longitudinal	Transversal	
B3_ModC	33	440	0.45x0.35	1.60	0.17	2Ø16
B5_PreC	24	440	0.40x0.40	0.79	0.16	-

Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado Seminário de Encerramento do Projeto

Assessment of existing RC precast industrial buildings according with Eurocode 8 – Part 3

Nonlinear static analysis

- The **assessment of the buildings** was firstly carried out through nonlinear static (**pushover**) **analyses**
- These analyses were carried out **along the two main directions** of the buildings adopting a **distribution** of incremental horizontal forces **proportional to the shape of the fundamental modes** and a **uniform distribution proportional to the mass**, according with the Eurocode 8 recommendations
- The effects of the **accidental eccentricity** was also considered in order to account for possible **variations** in the **distribution of masses** in the structures
- The **normative resistance** for the **flexural** and **shear mechanisms** was calculated, along with the appliance of the N2 method, as defined in the Eurocode 8
- The determination of the **target displacement** associated with the seismic hazard at the building location was based on the procedure presented on the **Annex B of Eurocode 8 – Part 1**

Seismic Performance Assessment of Existing Precast Industrial Buildings and Development of Innovative Retrofitting Sustainable Solutions
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Assessment of existing RC precast industrial buildings according with Eurocode 8 – Part 3

Building assessment – Structural capacity

- **Capacity of the buildings → Eurocode 8 – Part 3**
- Significant damage (**SD**) **limit state**
- **Chord rotation** (deformation) $$\theta_{um} = \frac{3}{4}\frac{1}{\gamma_{el}} 0,016 \cdot (0,3^{\nu}) \left[\frac{\max(0,01;\omega')}{\max(0,01;\omega)} f_c\right]^{0,225} \left(\min\left(9;\frac{L_V}{h}\right)\right)^{0,35} 25^{\left(\alpha\rho_{SX}\frac{f_{yw}}{f_c}\right)} \left(1,25^{100\rho d}\right)$$
- **Shear strength** $$V_R = \frac{1}{\gamma_{el}}\left[\frac{h-x}{2L_V}\min\left(N;0,55A_c f_c\right) + \left(1-0,05\min\left(5;\mu_{\Delta}^{pl}\right)\right)\cdot\left[0,16\max\left(0,5;100\rho_{tot}\right)\left(1-0,16\min\left(5;\frac{L_v}{h}\right)\right)\sqrt{f_c}A_c + V_w\right]\right]$$

Capacity values calculated according Eurocode 8 – Part 3

Building ID	Chord rotation [rad]		Shear strength [kN]	
	x	y	x	y
B3_ModC	0.038	0.039	5316	5733
B5_PreC	0.037	0.037	1691	1691

- KL1 – **Limited knowledge level** → Reduction factor of 1.35
- **Expressions** applied **only in the column** (beams should remain essentially undamaged)
- **Beam-to-column connection**: limit of **6 cm** of relative displacement (Cornali *et al.*)

Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
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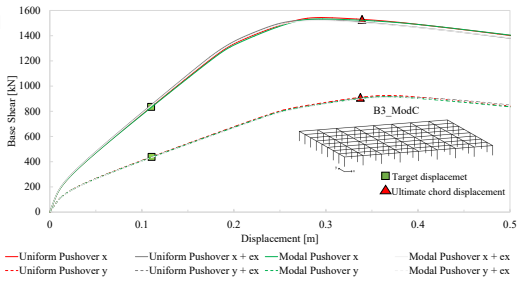
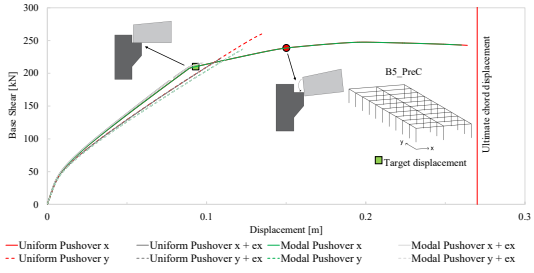
Assessment of existing RC precast industrial buildings according with Eu

Building assessment – Static analysis

- Almost **perfect overlapping** of the pushover curves associated with the uniform and modal distributions → **single-story buildings and regular in plan**
- **Both building** appear to **fulfil the code requirements** given that the **target displacement** associated with the seismic zone 1.3 is **lower** than the displacement associated with the exceedance of the elements **chord rotation** and **shear capacity**
- The **latter mechanism (ultimate chord)** is very unlikely to occur given the large slenderness of the columns
- **Building** could be **classified** as **seismically safe**



Pushover curves for B3_ModC



Pushover curves for B5_PreC

Seismic Performance Assessment of Existing Precast Industrial Buildings and Development of Innovative Retrofitting Sustainable Solutions
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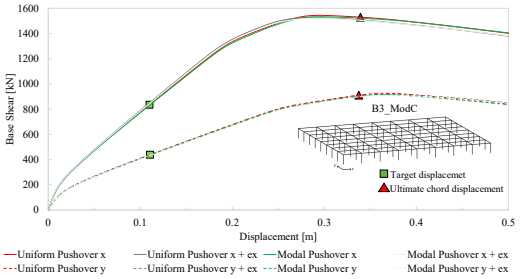
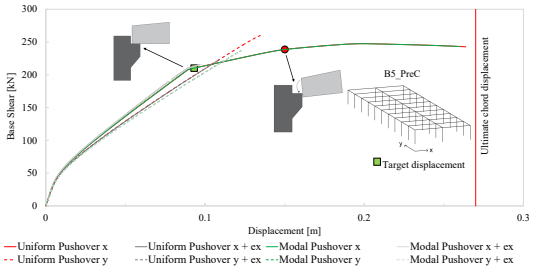
Assessment of existing RC precast industrial buildings according with Eurocode 8 – Part 3

Building assessment – Static analysis

- **Similar results** were attained considering the **behaviour at the beam-to-column connection** → **presence of steel dowels** that **prevent the connection to fail** under seismic loads
- **Connection** ensured by **friction** → potential failures under moderate to high seismic loads
- Based on a limit **differential displacement** at the beam-to-column connections of **6 cm** for severely damaged connections, it was possible to verify that for the model *B5_PreC* (pre code design) the **connection fail** for a **global displacement lower than the one associated with the ultimate chord rotation**
- Although the connection limit state occurs for a global displacement larger than the target displacement the results points for a **potentially vulnerable seismic behaviour**



Pushover curves for B3_ModC



Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
Seminário de Encerramento do Projeto

Seismic Performance Assessment of Existing Precast Industrial Buildings and Development of Innovative Retrofitting Sustainable Solutions
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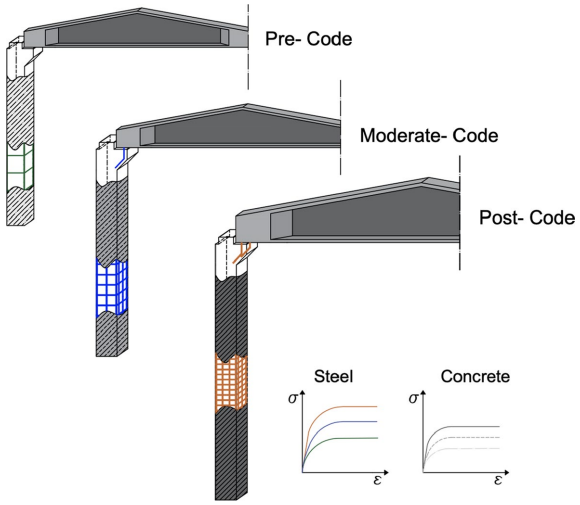
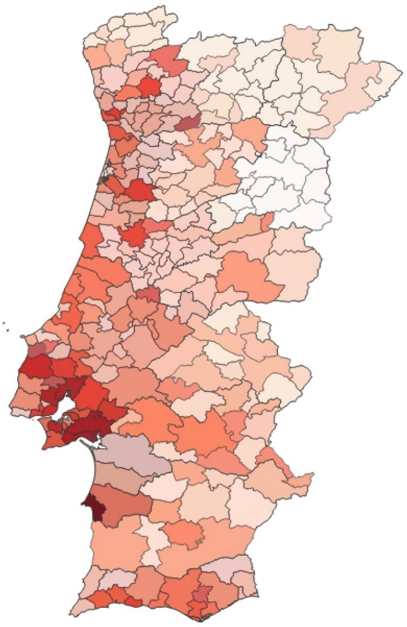
Seismic Fragility of Precast Buildings





Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
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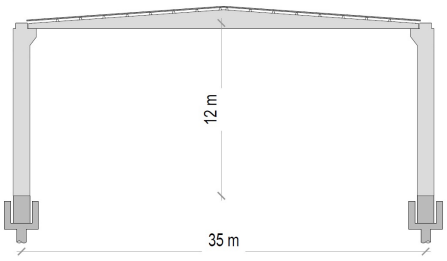
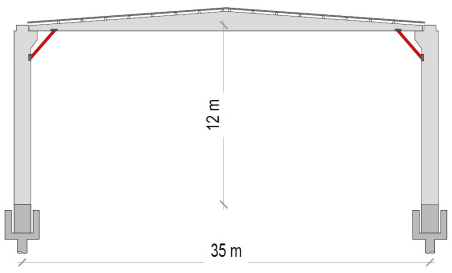
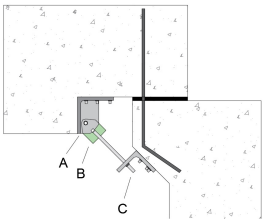
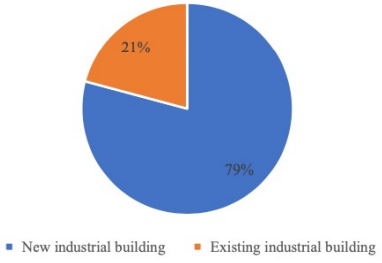
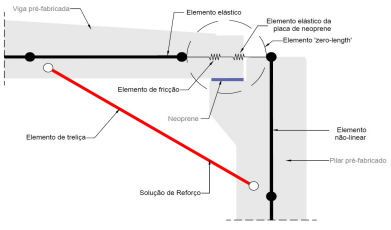
Strengthening











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Influence of cladding panels in the seismic behaviour of a PRC Industrial Building

Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
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Influence of cladding panels in the seismic behaviour of a PRC Industrial Building

- Critical problems in the connections of cladding panels on industrial PRC structures in Italy and Turkey during recent earthquakes;
- Non-structural damages and collapse related with high economic losses;
- Making use of a simplified macro element;
- Assesses the seismic capacity of common claddings-to-structure connections and interaction with main structure;
- Study of a representative building of the Portuguese industrial park.

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Influence of cladding panels in the seismic behaviour of a PRC Industrial Building

Precast buildings in Portugal

- Horizontal cladding panels are the most current layout.
- Typical commercial connections in use in Portugal;
- Isostatic Sliding-Frame system for horizontal panels.

Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
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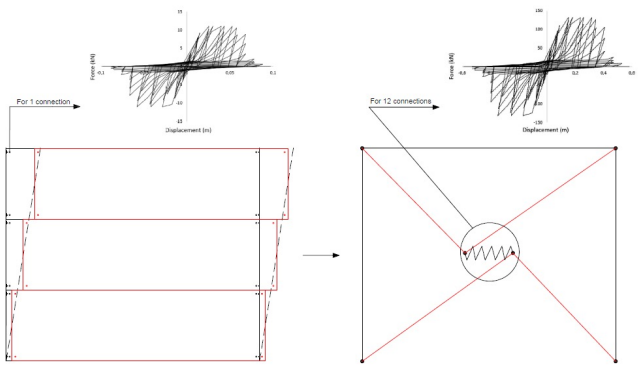
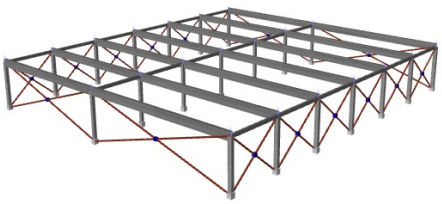
Influence of cladding panels in the seismic behaviour of a PRC Industrial Building

Cladding panels Modelling

- A macro element proposed to simulated the global behaviour at the centre of the frame and connected to the column edges through four diagonal truss elements, with rigid behaviour.





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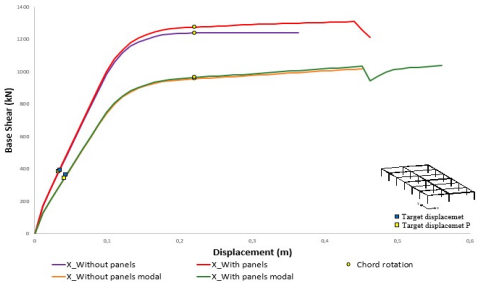
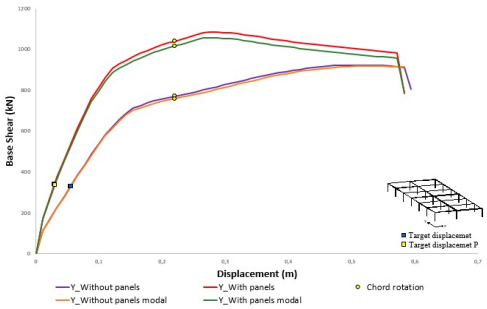
Influence of cladding panels in the seismic behaviour of a PRC Industrial Building

Cladding panels Modelling - Non-linear static analysis

- Different load distributions were applied in the pushover analysis, a uniform and modal distribution;
- In X direction it is apparent that the presence of the cladding panels has a minor contribution;
- In Y direction the strength and stiffness increases significantly - only one of the three frames does not include the panels.





Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado
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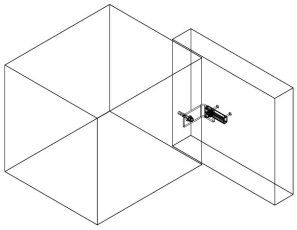
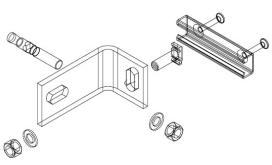
Seismic Assessment of Precast Buildings

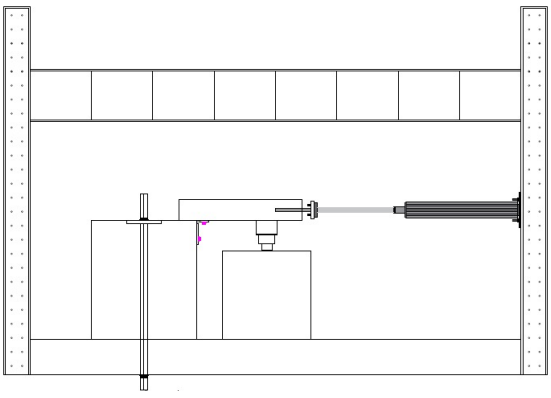
Cladding-to-column connection

- The planning of the experimental campaign focuses on cladding-structure connection of horizontal panels.
- A better understanding on the behavior of the connection between precast cladding panels and the main structure used in Portugal.
- The results more reliable to calibrate the numerical models.
- Explore the solutions for connections retrofitting.





Instrumentation Setup



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It is acknowledge the support provided by the following municipalities, to access dozens of existing design projects, enabling the characterization of the existing precast reinforced concrete building stock: Câmara Municipal de Agueda, Câmara Municipal de Aveiro, Câmara Municipal de Leiria, Câmara Municipal de Mafra, Câmara Municipal da Marinha Grande, Câmara Municipal do Montijo, Câmara Municipal de Ourém,
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VEconcept

Avaliação sísmica de estruturas existentes pré-fabricadas de betão armado Seminário de Encerramento do Projeto

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