Modelling Issues for Old Reinforced Concrete Buildings

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Outline

- Objectives
- Definition of the study area
- Building typology
- Modelling issues
- Case study
- Future developments

Objectives

Main goal of this PhD Work:

- Vulnerability assessment of RC frame and RC wall frame buildings built between 1960 and 1980 in Lisbon;
- Identification and selection of strengthening solutions, accompanied by a quantification of costs for the reduction of the seismic vulnerability;
- Definition of fragility curves before and after strengthening;
- Development of a retrofitting plan to be employed at the city level using a GIS mapping application.

Definition of the study area

Alvalade district

Definition of the study area

Alvalade district

Definition of the study area

- Old RC frame buildings
- Other typologies

Definition of the study area

Av. Do Brasil

Av. dos Estados Unidos da America

Old RC frame buildings

Other typologies

Building typology

Av. Do Brasil

Av. dos Estados Unidos da America

■ Old RC frame buildings
■ Other typologies

A specific subcategory of buildings was selected and can be referred as **RC wall-frame buildings**.

They have the following characteristics:

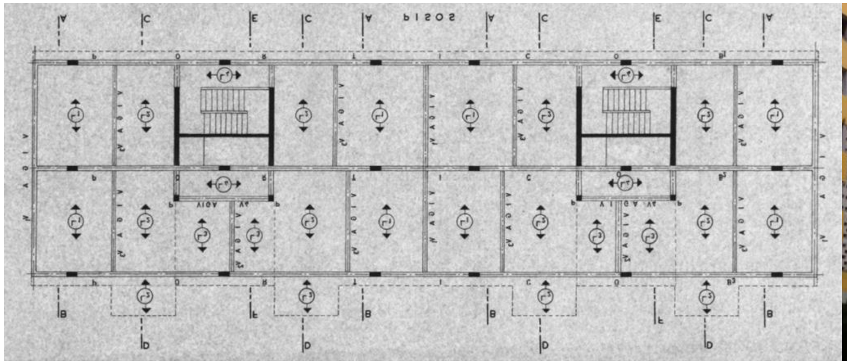
- Buildings with 8 to 12 storeys high
- “Soft-storey” irregularity (Ground Floor)
- Columns mainly oriented in one direction
- Eccentric RC core walls (stairs cores)
- Smooth reinforcement bars

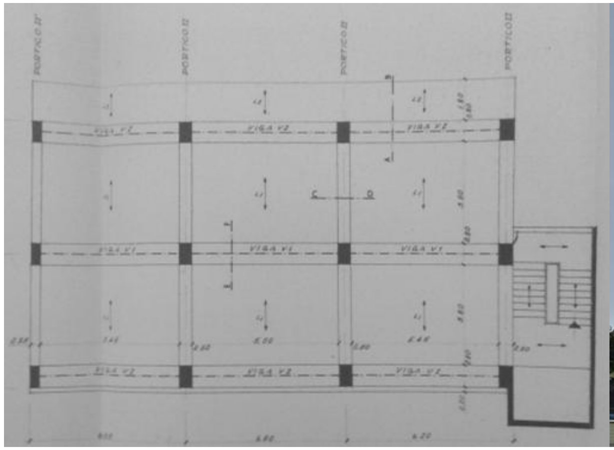
Building typology

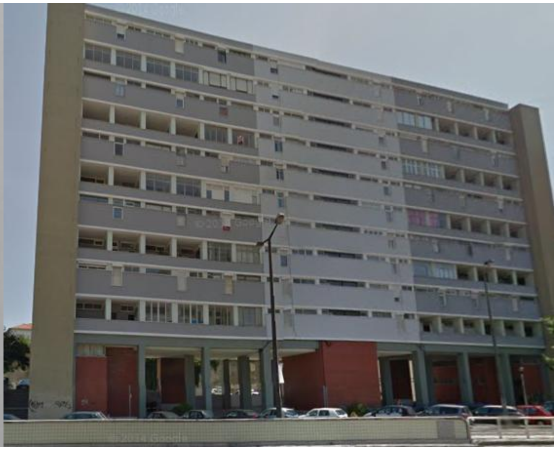
Av. Do Brasil

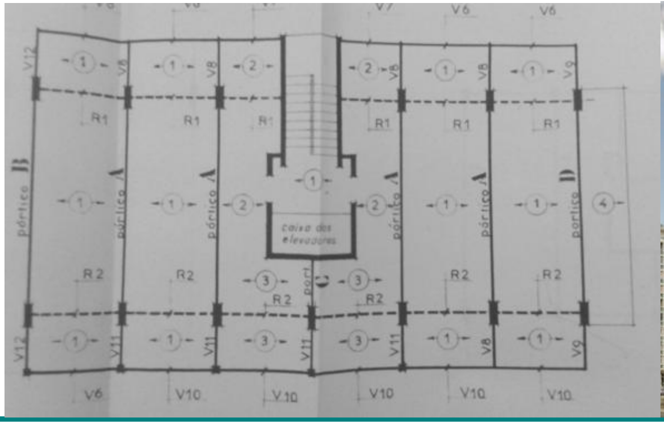
Av. dos Estados Unidos da America

- Old RC frame buildings
- Other typologies







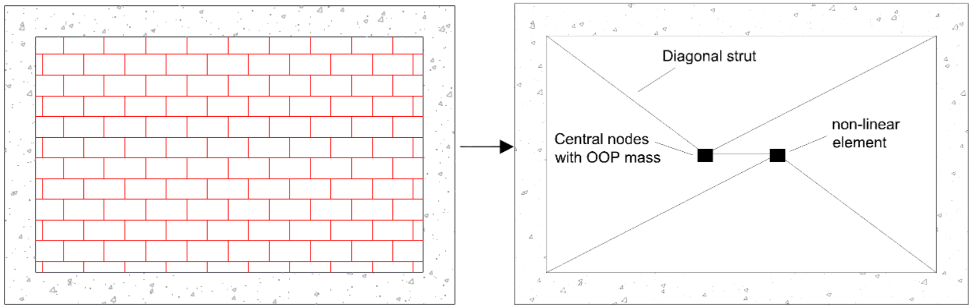


Modelling issues

- OpenSees program is used to perform the seismic analysis and the non-linear models of the building.
- In the framework of finite element method, a study regarding some modelling approach was conduct:
  - **RC walls**: Almeida et al. (2014) (more to follow);
  - **Reinforcement (plain) bars**:

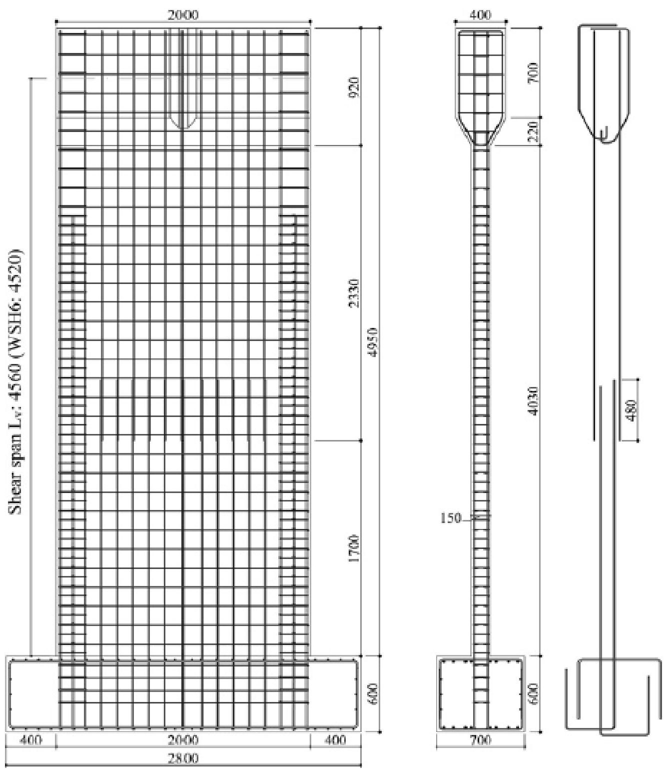
    Varum (2003) - correction of the steel reinforcement constitutive law;

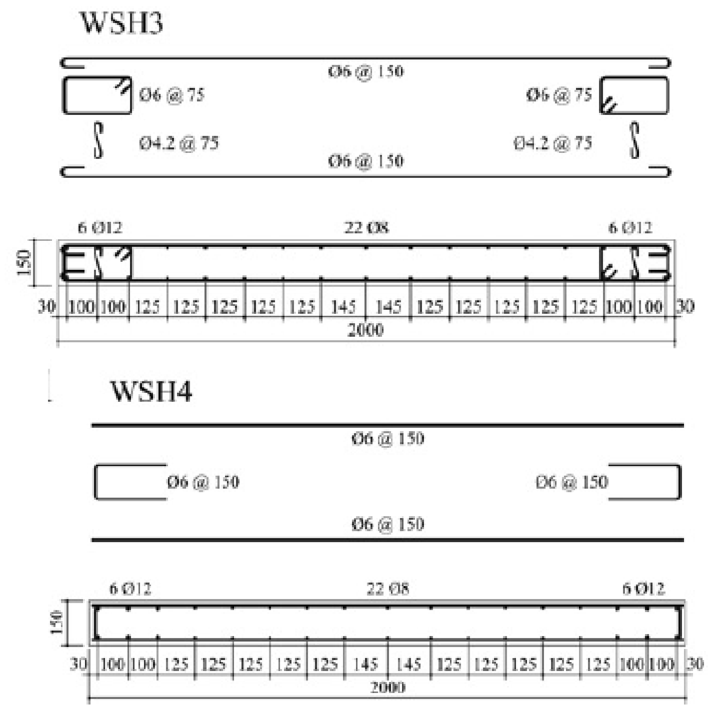
    Sousa et al. (2016) - explicit bond-slip relation to use with a fiber-based beam-column element through a zero-length link element
  - **Infill Masonry walls**: Furtado et al. (2016) Model based on the bi-diagonal strut model approach proposed by Rodrigues et al. (2010), characterized by four rigid support strut and a central element where the non linear behaviour is concentrated.



Modelling of RC Walls

- To investigate the suitability of different numerical models for the seismic analysis of RC walls, simple pushover analyses were performed on single column and the numerical results were compared with experimental results
- Two test units were considered: WSH3 and WSH4 (reduced ductility properties)
- The length of the shear span Lv of the test units was 4.56 m for a shear span ratios of 2.28. Axial force ratio 0.056.

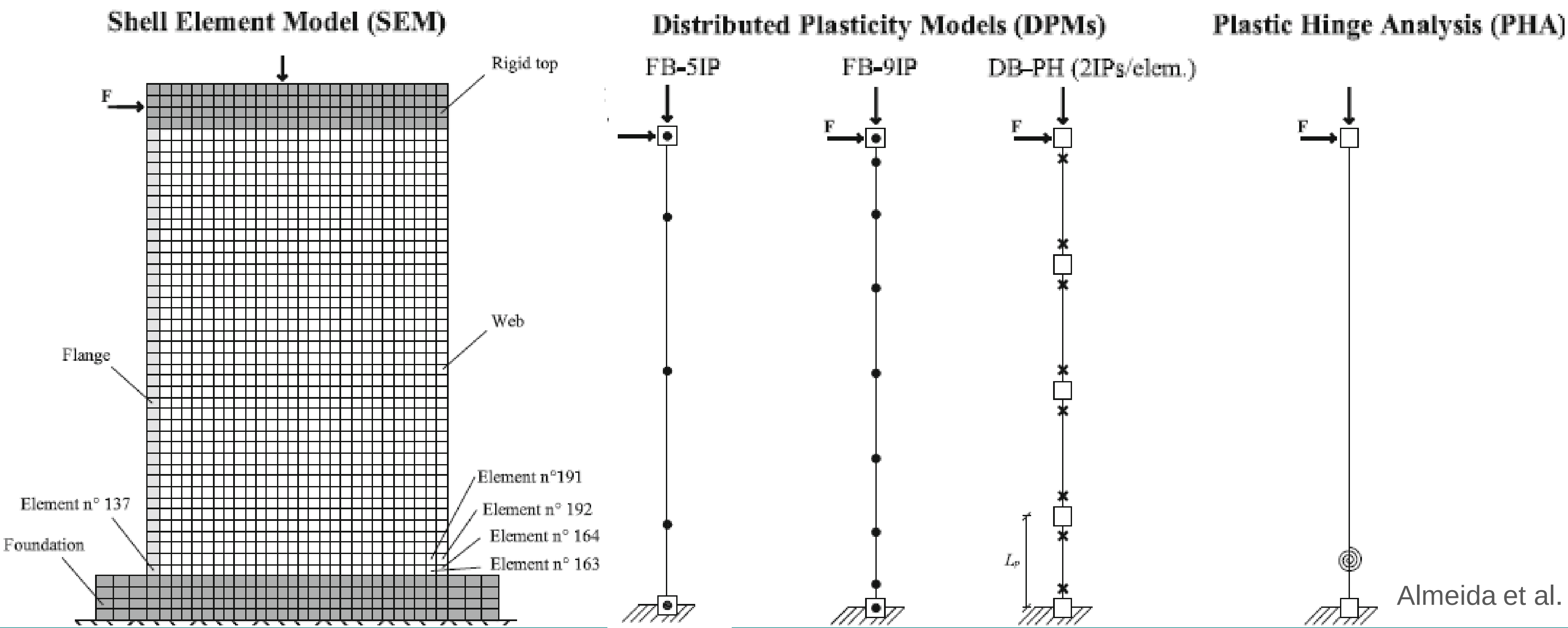




Dazio et al.

Modelling of RC Walls

- Existing modeling approach are divided into
  - Shell Element Models (SEMs)
  - Distributed Plasticity Models (DPMs)
    - Displacement-based (DB)
    - Force-based (FB) – 5 Integration Points (5 IPs); 9 IPs
  - Plastic Hinge Analysis (PHAs)



Almeida et al.

Modelling of RC Walls

- Existing modeling approach are divided into
  - Shell Element Models (SEMs)
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  - Plastic Hinge Analysis (PHAs)

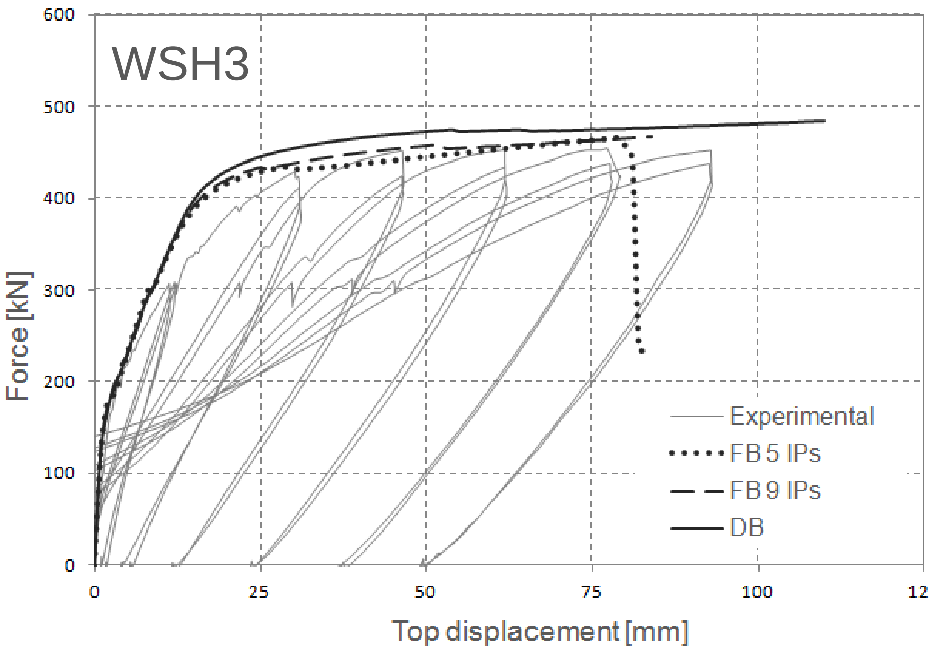
- Shear deformations in wall-type structures can be a significant portion of the total deformation and thus should in general be modeled.

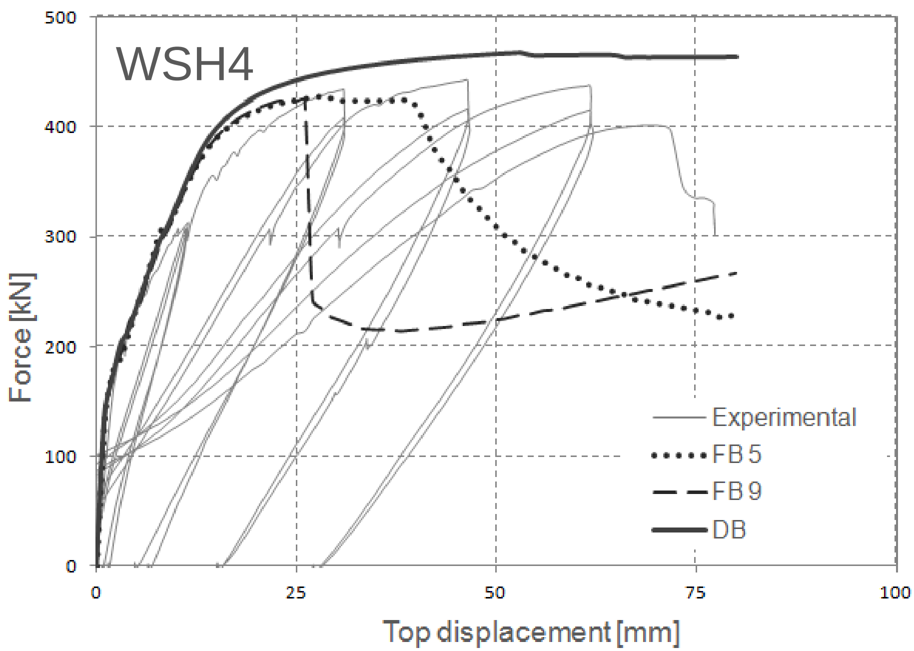
  For walls subjected to in-plane loading with shear span ratios larger than 2.0, the impact of shear deformations on global demand parameters will be typically small and can possibly be neglected (Almeida et al. (2014)).

Modelling of RC Walls

Conclusions:

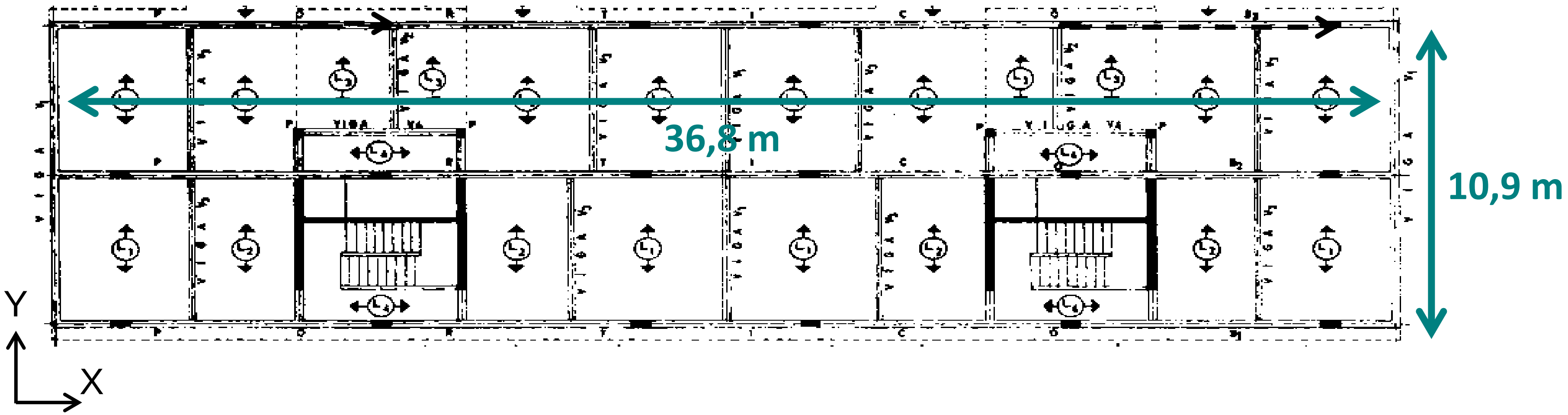
- Acceptable results were obtained in terms of lateral force capacity and stiffness evolution.
- DB approach deviates from the other models in terms of simulation of ductility and lateral strength prediction.
- From the literature review and the results obtained it can be concluded that **FB are preferable to DB elements**.





Case study

Avenida do Brasil



Case study

Inadequate reinforcement detailing conditions

- Columns’ transverse reinforcement ties is insufficient.

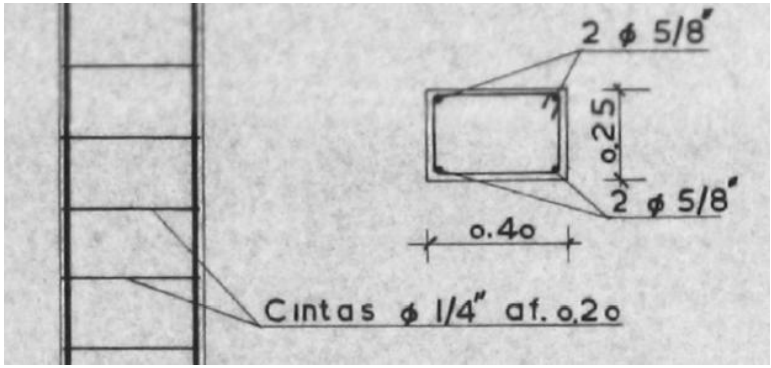
  Distance between longitudinal restrained bars exceeds the EC8-1 limits (200 mm).

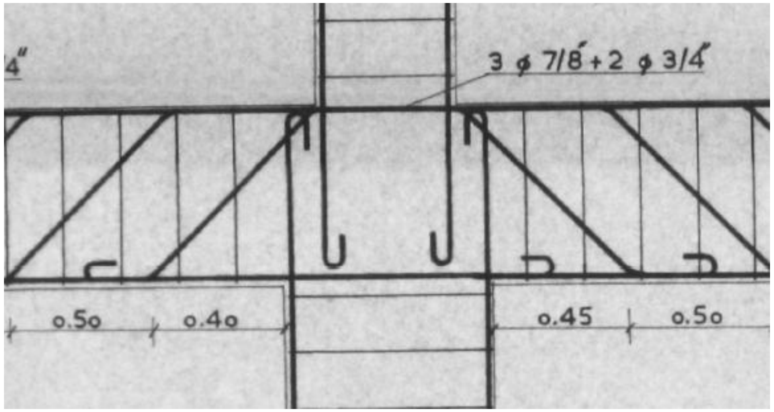
- The size and reinforcement of columns varies in each floor.

  Consequent reduction in stiffness in the upper storeys.

- Columns’ bars are spliced inside the beam-column joint.

  Lap splice are very short and not well confined.





Computational modelling of the building

Non-linear modelling

- For **cover and core concrete** were modeled using the library uniaxial material ‘Concrete 04’, based on the model proposed by Popovics (1973).
- For the **steel** it was considered the material model ‘Steel 02’ that correspond to the behavior law proposed by Menegotto and Pinto (1973).

Mechanical properties:

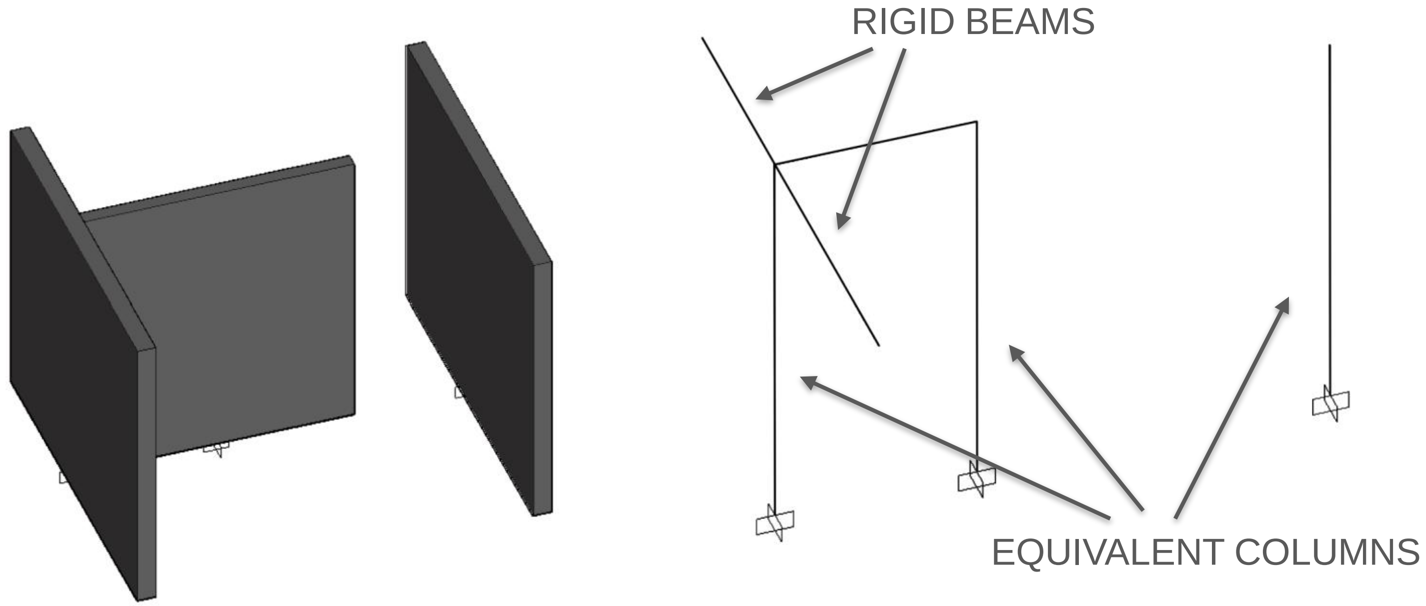
Concrete	f_c (MPa)	ε_c (‰)	ε_{cu} (‰)	E_c (GPa)
	28000	2	4	30.0

Steel	f_y *(MPa)*	f_u *(MPa)*	E_s *(GPa)*	ε_{su} *(‰)*
	235.0	360.0	210.0	240

Computational modelling of the building

Non-linear modelling

- Fiber-section finite elements were considered.
- The concrete element (**beams and columns**) were modeled as **Force-based non linear BeamColumns elements** available in the OpenSees library.
- **RC walls** are modeled as equivalent beamcolumn element located at the centre of wall axis with rigid beams at floor level.

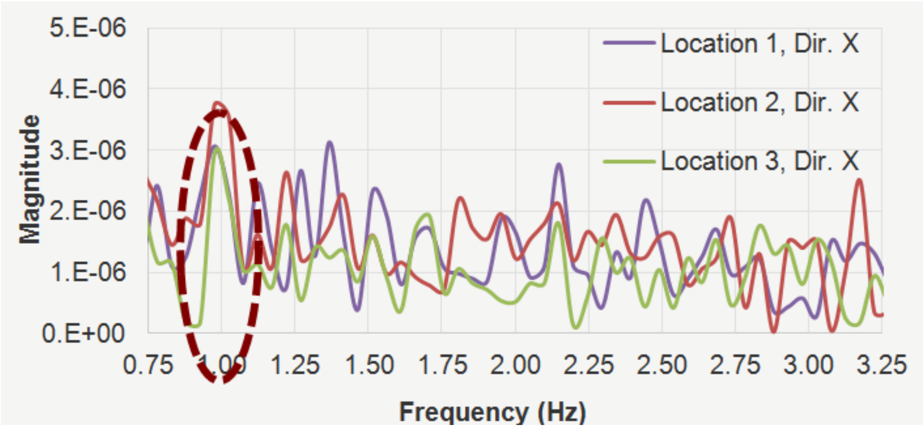


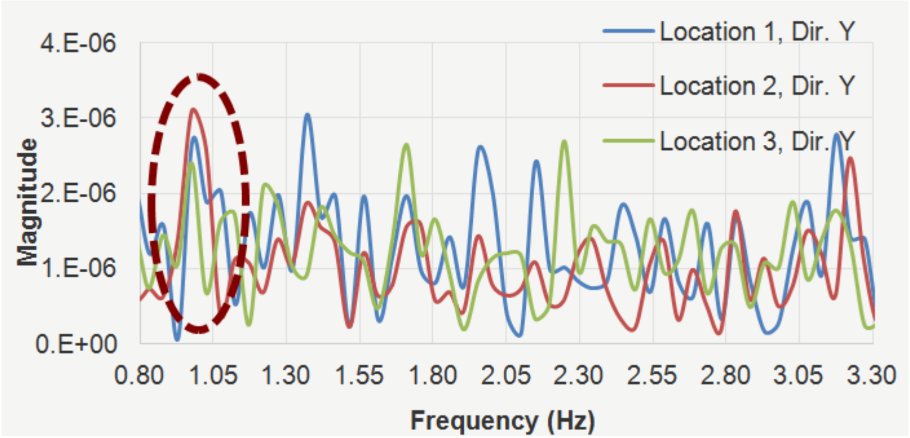
Seismic Assessment

Modal analysis

- The **natural frequencies and vibration modes** corresponding to modal analysis were obtained (verify influence of infill walls).
- Field ambient vibration tests (Santos, 2016) were performed and results compared with the analytical results.

Mode	*Frequency* (Hz)	*In-situ*
1st mode (X direction)	0.97	0.95
2nd mode (rotation)	1.05	----------
3rd mode (Y direction)	1.11	1.00



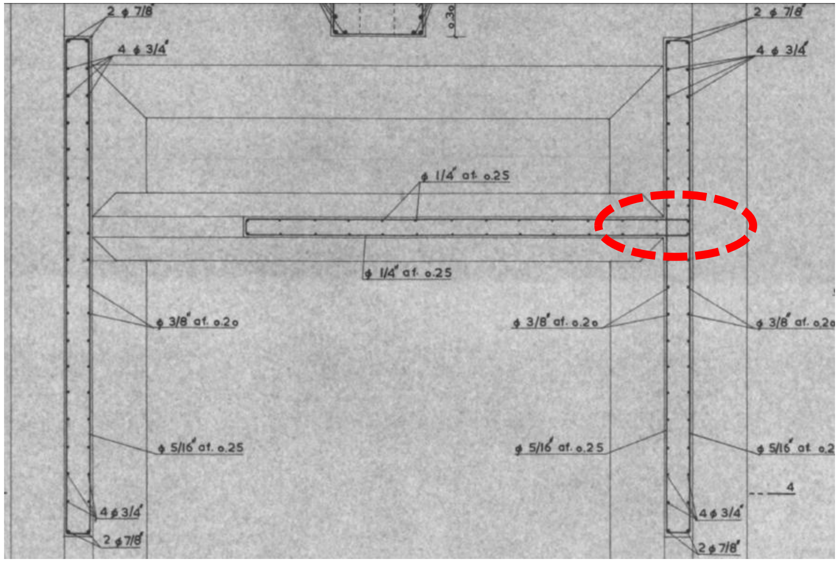


Seismic Assessment

Epistemic (knowledge-based) uncertainty

Model uncertainty:

- on the **connection between perpendicular walls**, due to the inadequate horizontal reinforcement of the interlocking.



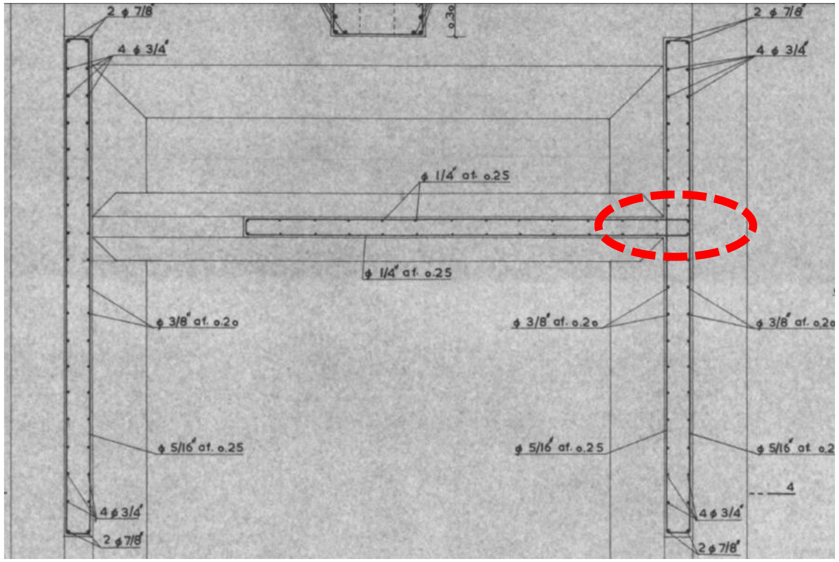
Seismic Assessment

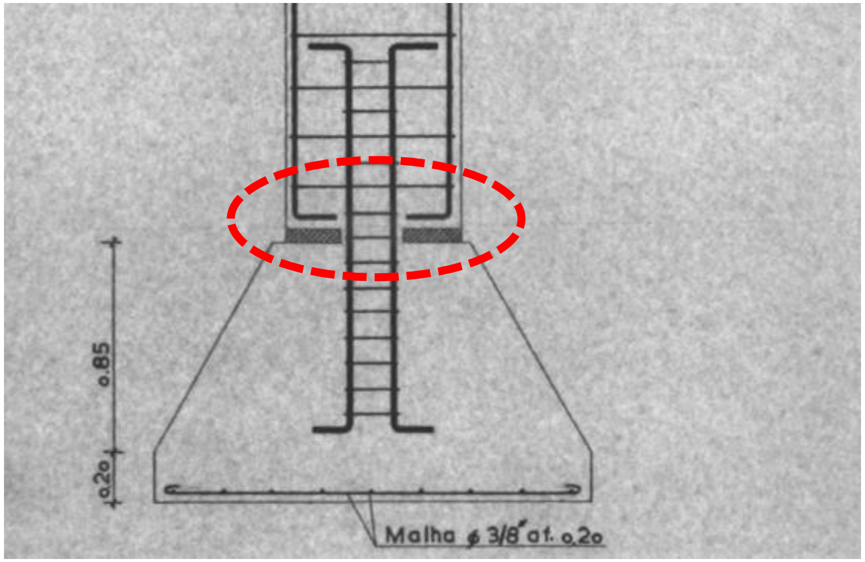
Epistemic (knowledge-based) uncertainty

Model uncertainty:

- on the **connection between perpendicular walls**, due to the inadequate horizontal reinforcement of the interlocking.
- on the **foundation modelling of the columns**.

  In fact, there is no evidence that were designed to withstand bending moments and restrain rotations.





Seismic Assessment

Model uncertainty:

The following modelling options were considered:

- **Model 1_1**: RC walls with fully hinged connection;
- **Model 1_2**: RC walls with fully hinged connection and pinned foundations;
- **Model 2_1**: RC walls with stiff connection;
- **Model 2_2**: RC walls with stiff connection and pinned foundations.

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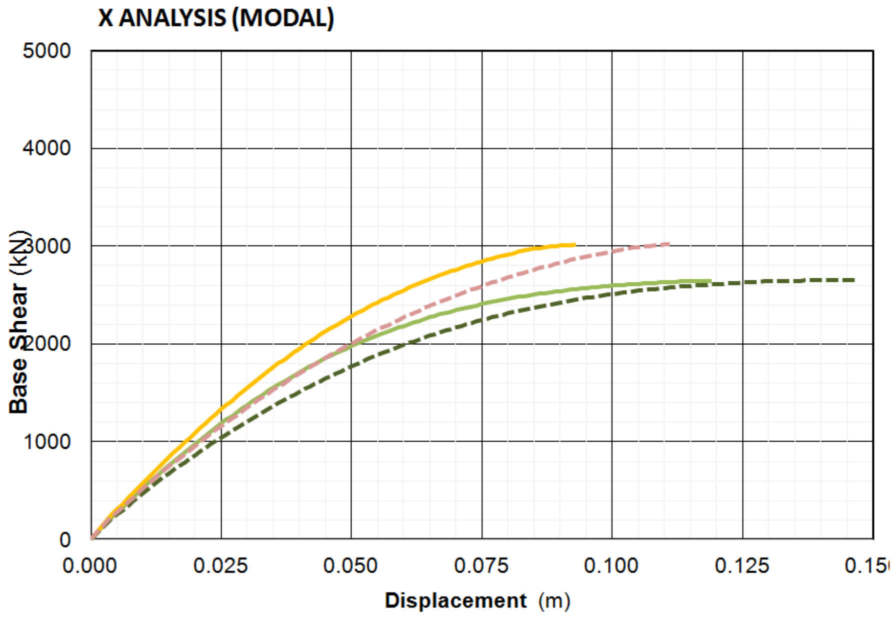
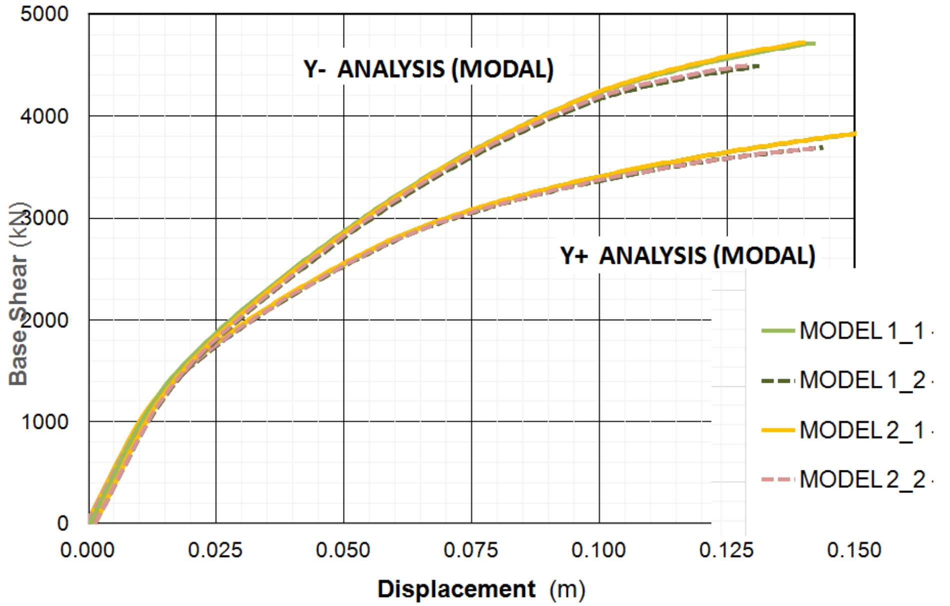
Seismic Assessment

The in-plane capacity curves of the buildings were obtained by **non-linear static (pushover) analyses considering the uniform and the modal load patterns.**





It is noticed a reduction of the initial stiffness in the X direction for model 1_2 caused by the higher rotation capacity of the RC wall and of the columns' foundations.

The behaviour of the building in the Y direction is almost indifferent to the modelling options, as the response is mainly governed by the RC walls in that direction.

Future Developments

- The current state of the research involves the main modelling issues regarding old RC frame and wall-frame buildings and the definition of a case study.
- The next step will be to derive fragility curves for the case study to deeply characterize the seismic performance of the structure.
- It is also suggested the study of strengthening techniques to reduce the seismic vulnerability of these buildings. Structural safety of the RC buildings is accounted in future intervention works.

Thank you!

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