Seismic vulnerability assessment of old frame-wall buildings in Lisbon

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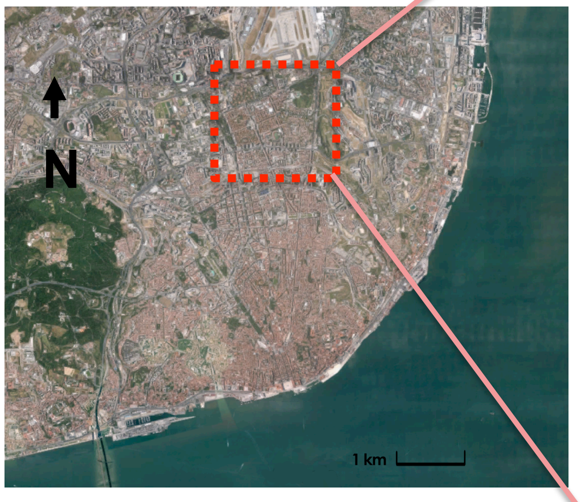
Motivation

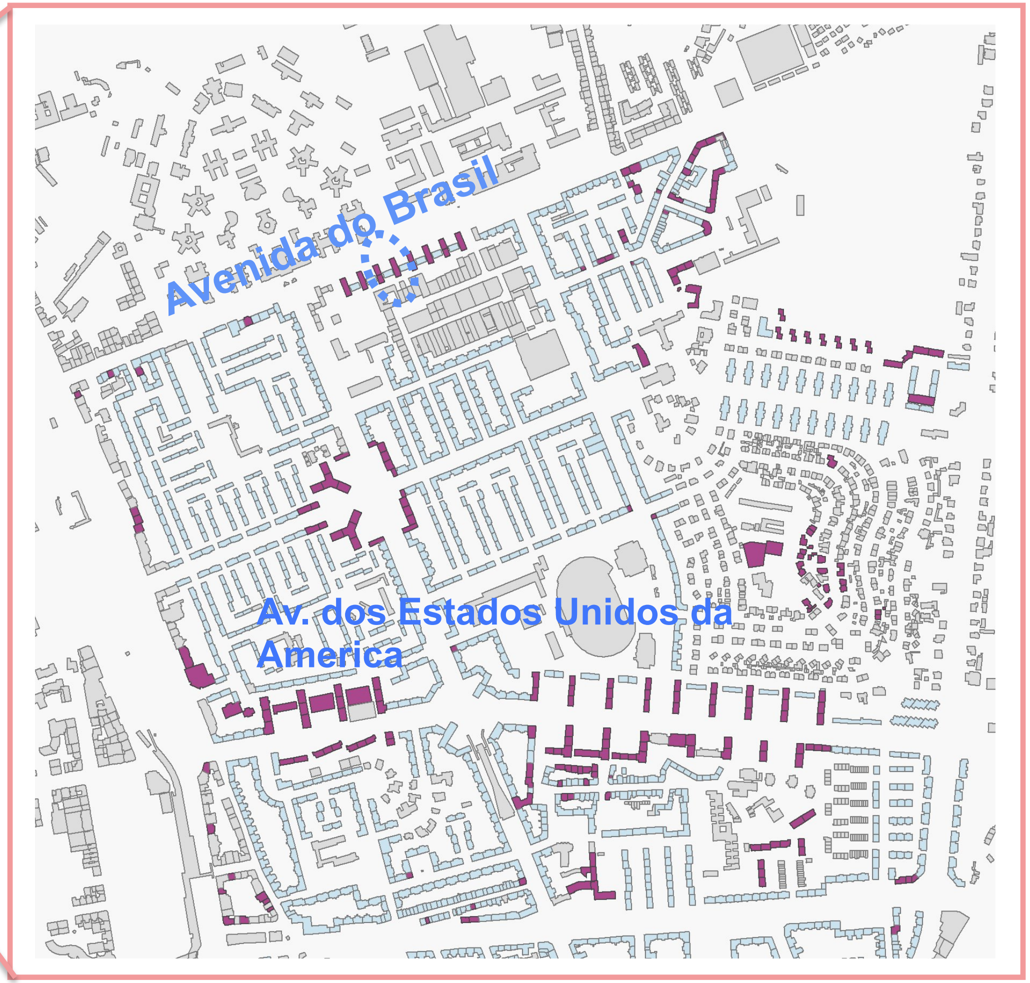
- Reinforced Concrete (RC) old frame and wall-frame structures represent a high percentage of building stock.
- They were Constructed before the introduction of modern seismic codeswithout considering appropriate seismic criteria.

Main goal of this PhD Work

- Vulnerability assessment of old RC wall-frame buildings built between 1960 and 1980 in Lisbon;
- Development of a model that can account for the main features of old RC frame-wall structures, such as
    - ✓infills walls
    - ✓reinforcement smooth bars
- Design of strengthening solutions, including quantification of costs;
- Definition of fragility curves before and after strengthening.

Alvalade district





Old RC frame buildings

Other typologies

RC wall-frame buildings

Characteristics:

(i) from 8 to 12 floors;

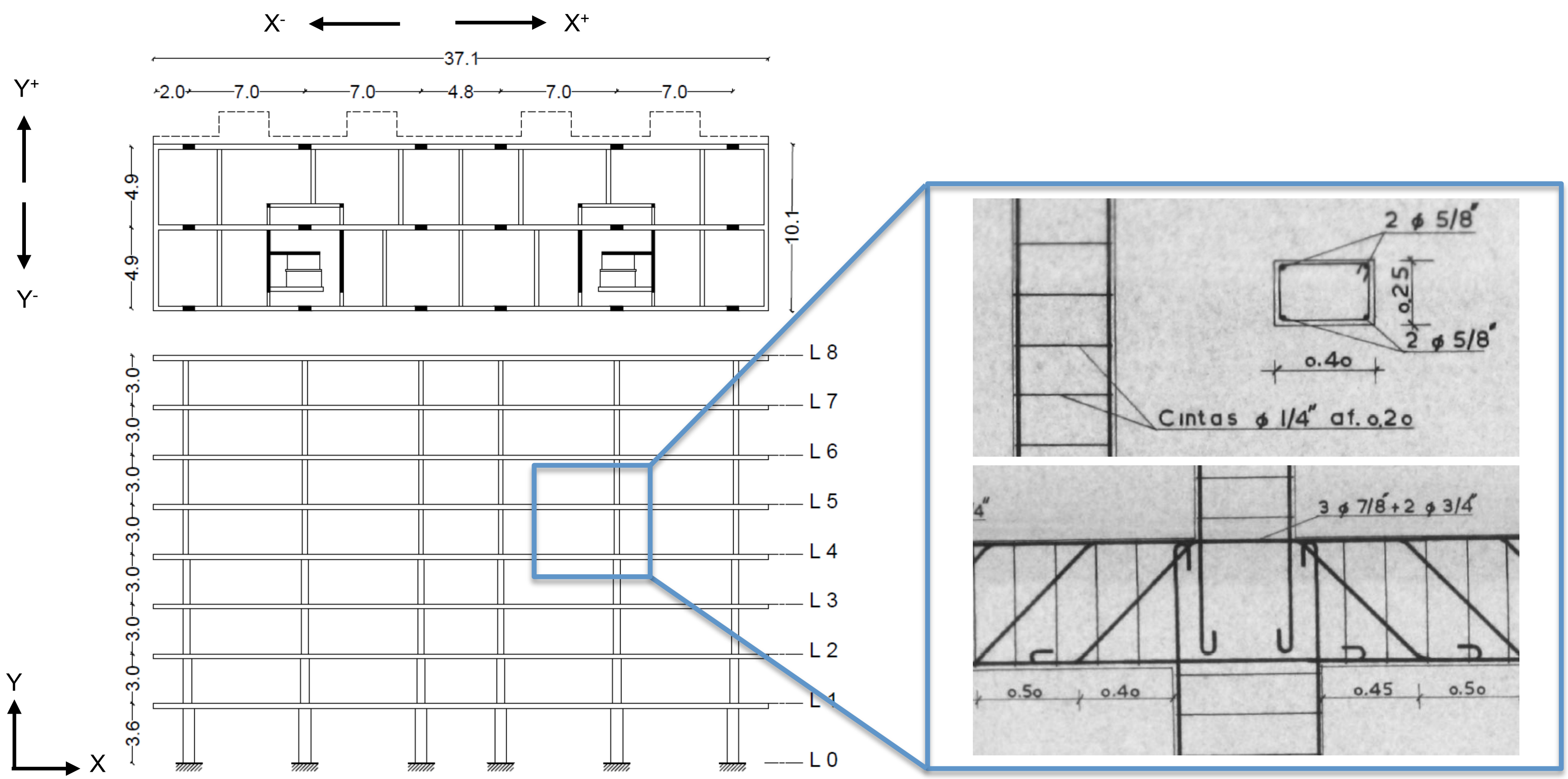
(ii) open ground storey and infills in the upper storeys (pilotis type building);

(iii) columns mainly oriented in one direction;

(iv) eccentric RC core walls (stair cases);

(v) smooth reinforcement bars.

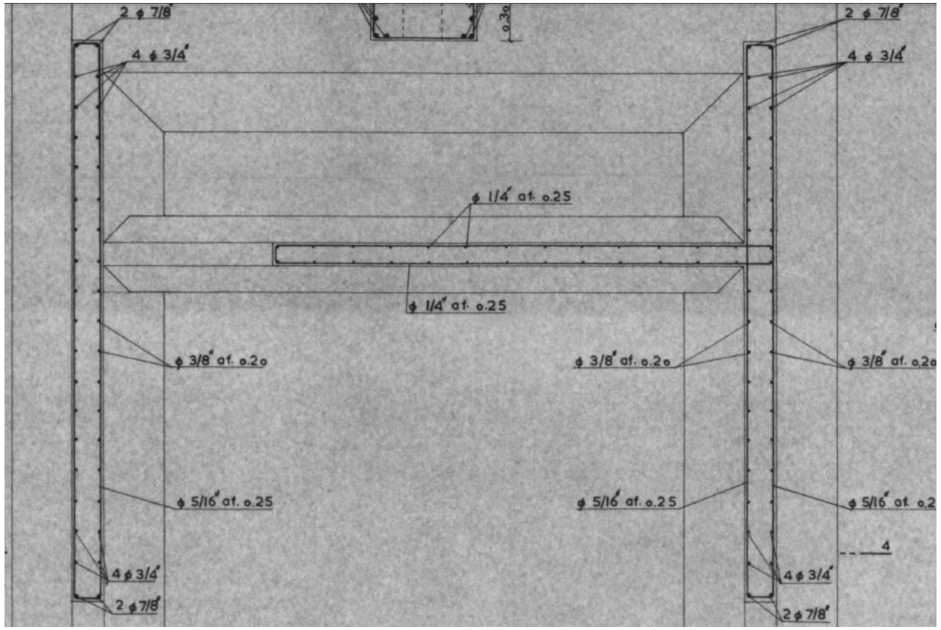
Case study

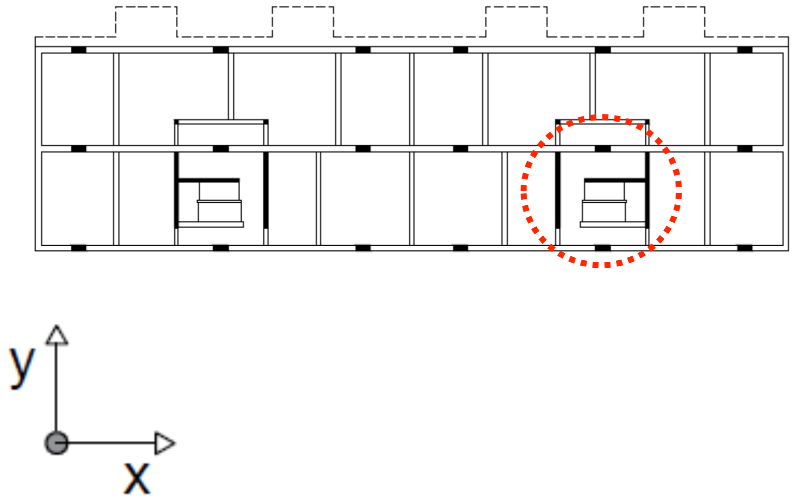


Inadeguate reinforcement detailing

- Insufficient reinforcement ties
- Size and reinforcement of columns varies in each floor
- Smooth longitudinal reinforcing bars

RC walls





		Dimension (m)	Longitudinal Reinforcement	Horizontal Reinforcement	ρ_{tot} (%)	ρ_h (%)
T-flange	Level 0 - 1	0.25 x 4.00	38 Φ 3/8" + 4 Φ 7/8" + 8 Φ 3/4"	Φ 5/16"@0.25	0.65	0.16
	Level 1 - 2	0.25 x 4.00	38 Φ 5/16" + 4 Φ 5/8"+ 12Φ3/8"	Φ 5/16"@0.25	0.35	0.16
	Level 2 - 8	0.25 x 4.00	38 Φ 5/16" + 4 Φ 5/8"	Φ 5/16"@0.25	0.27	0.16
T-web	Level 0 - 1	0.15 x 3.00	26 Φ 1/4"	Φ 1/4"@0.25	0.18	0.10
	Floor 1 - 8	0.15 x 3.00	26 Φ 1/4"	Φ 1/4"@0.25	0.18	0.10

Numerical modelling – RC members

3D Modelling
Force based beam- column elements and fibre modelling approach are employed

Uniaxial material models
Concrete 04' (Popovics model)
Steel 02' (Menegotto e Pinto)

Development of a model that can account for the main features of old RC frame-wall structures

Infills walls
Reinforcement smooth bars

Infill walls

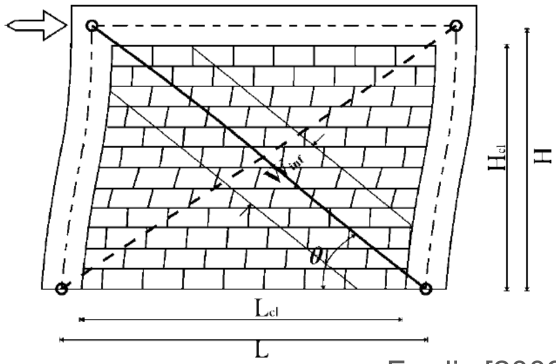
Force displacement relation

$$K_{el} = \frac{G_w A_w}{h_w}$$

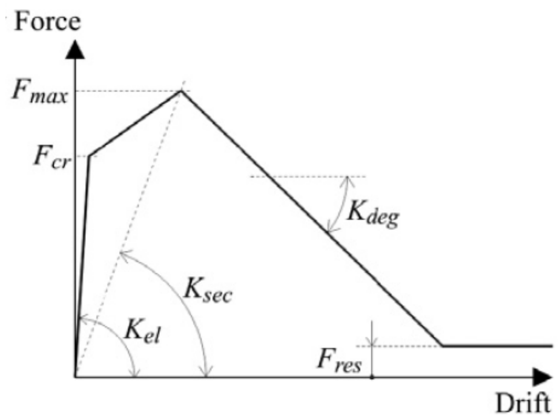
$$F_{cr} = \tau_{cr} A_w$$

$$K_{\sec} = \frac{E_w b_w t_w}{\sqrt{L^2 + H^2}} \cos^2 \theta.$$

$$F_{max} = 1.30 \cdot F_{cr}$$



Fardis [2009]

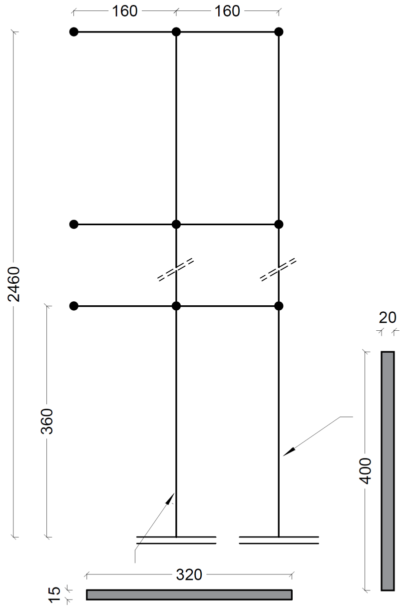


Celarec et al. [2011]

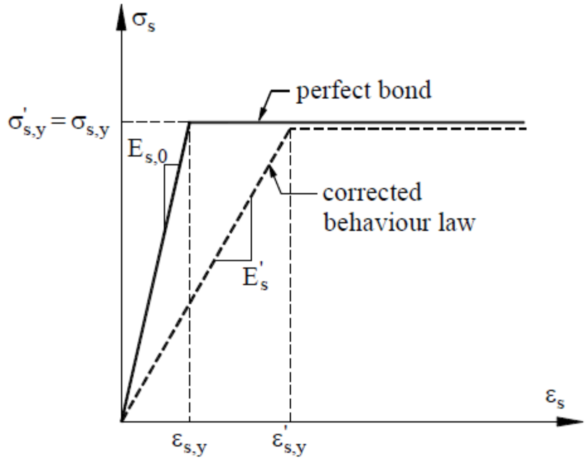
Reduction coefficient that considers the influence of openings (Dawe and Seah [1988])

$$\lambda_o = 1 - \frac{1.5 L_o}{L_{in}} \geqslant 0,$$

RC walls with smooth rebars



All dimensions in [cm].



Varum [2003]

Modelled as force-based nonlinear beam elements, with each element located at the centre of the wall axis

Connection within flange and web in the T-shaped walls and with the frame is simulated with rigid elements located at the floor level

Strain penetration effects simulated through the reduction of the Young's Modulus and maximum strength of rebars (Varum, 2003)

Seismic assessment – Nonlinear static (pushover) analyses

Significant damage (SD) limit state –National Annex of EC8-3

Chord rotation (EC8- 3)

$$\theta_{um} = \frac{1}{\gamma_{el}} 0.016 \cdot (0.30^{\nu}) \left[\frac{\max(0.01;\omega')}{\max(0.01;\omega)} f_c\right]^{0.225} \left(\min\left(9;\frac{L_v}{h}\right)\right)^{0.35} 25^{\left(\frac{\alpha\rho_{sx} f_{yw}}{f_c}\right)} (1.25^{100\rho_d})$$

Shear resistance calculated by means of shear resistance to web crushing, $V_{Rd,max}$, and shear resistance as controlled by the stirrups, $V_{Rd,s}$ (EC2- 1).

$$V_{Rd,sy} = \frac{A_{sw}}{s} z\, f_{ywd} \cot\theta \qquad V_{Rd,max} = b_w\, z\, \nu\, f_{cd}/(\cot\theta + \tan\theta)$$

Target displacement (dt) determined through the N2 method.

Seismic action

EC8 elastic response spectrum for soil type B.

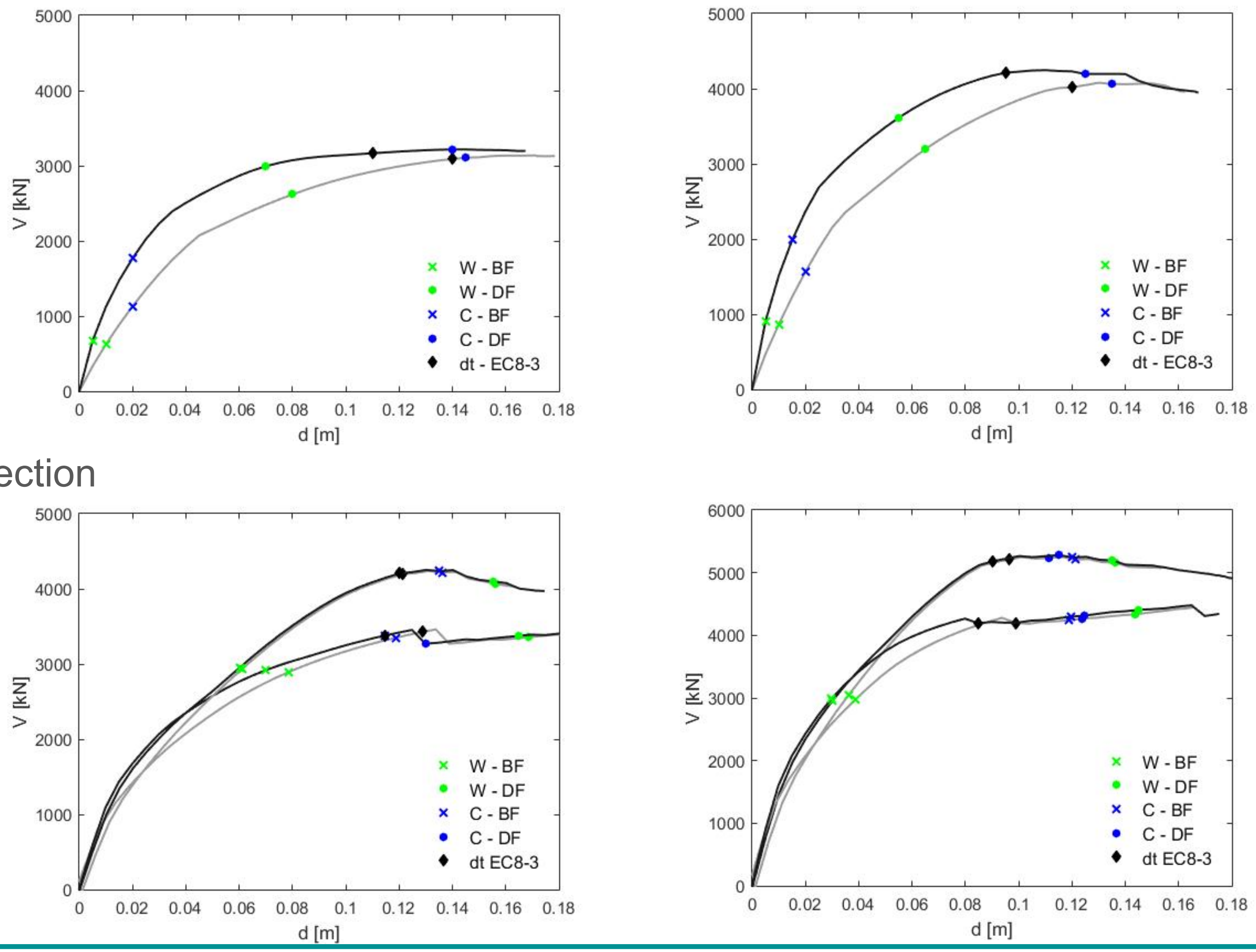
Return period of 475 years and a peak ground acceleration (PGA) of 0.153 g.

Pushover curves

modal load pattern | uniform load pattern

X direction

Y direction



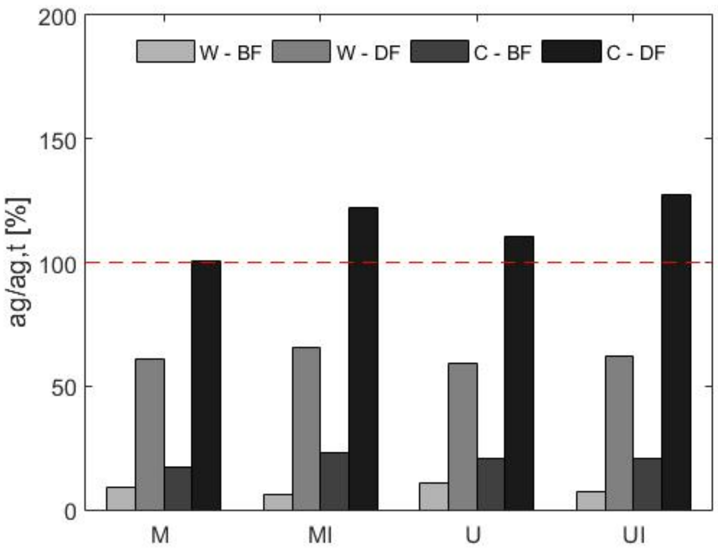
Brittle failure (BF)
Ductile failure (DF)
Wall (W)
Column (C)

BARE

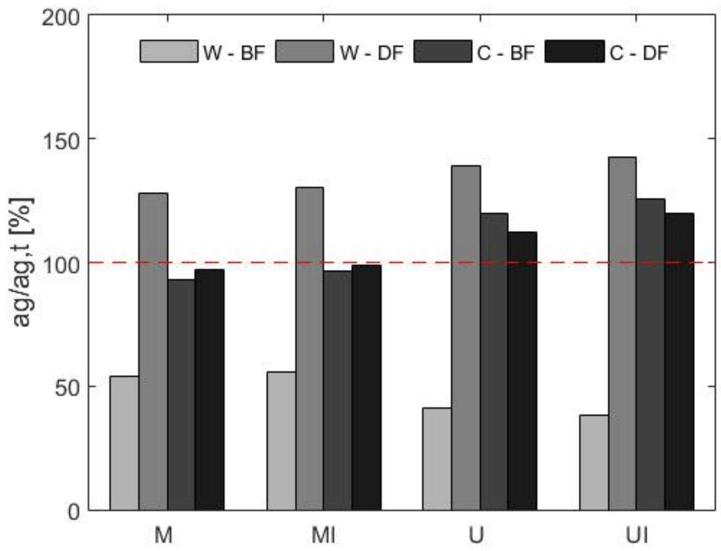
INFILLED

Normalized peak ground acceleration

X direction



Y direction



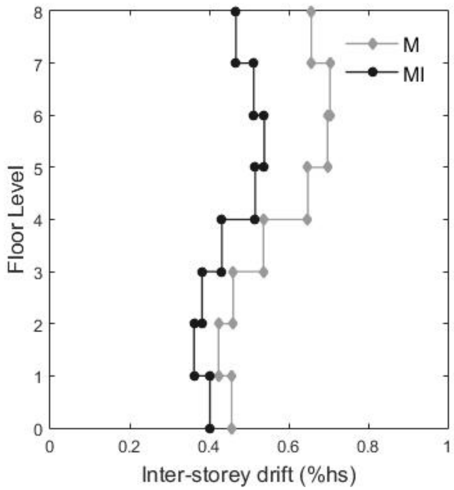
- X direction: brittle failure of the RC walls oriented in the X direction at 6% of PGA
- Y direction: first brittle failure of the RC walls is reached at 37% PGA

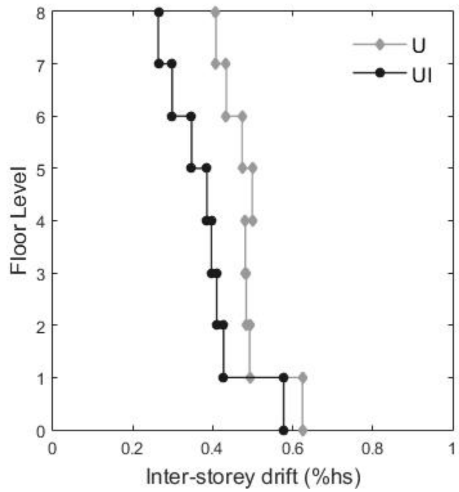
Inter-storey drift ratios

modal load pattern

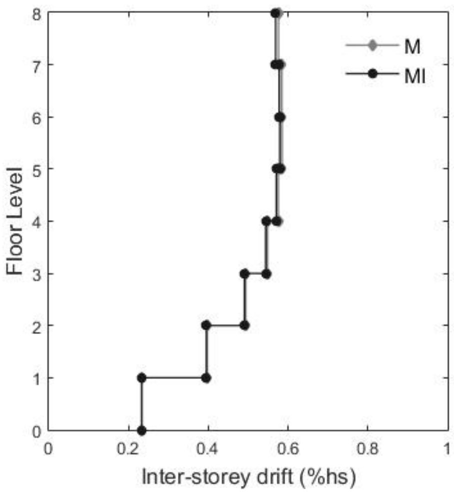
uniform load pattern

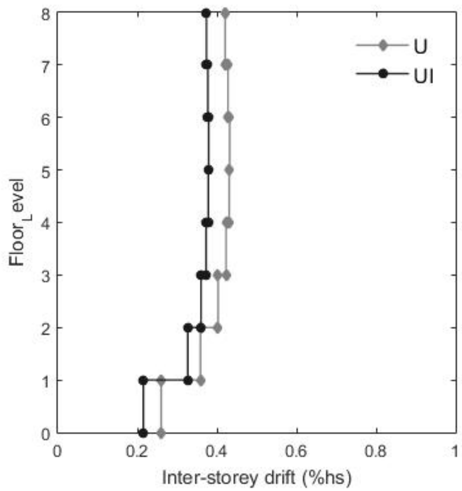
X direction





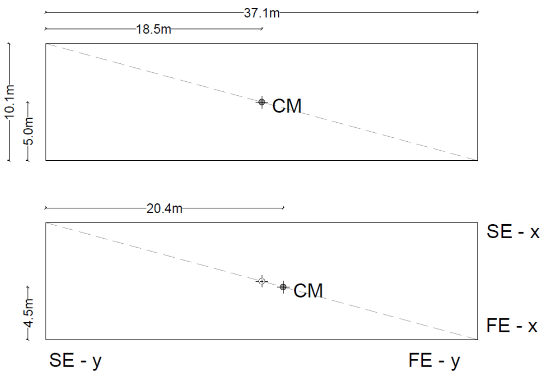
Y direction



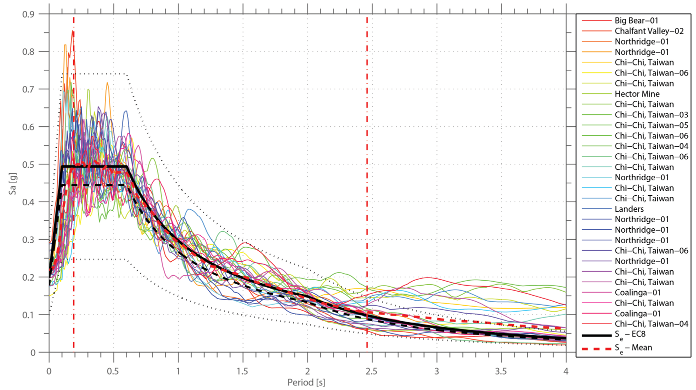


Assessment of torsional behaviour – Extended N2 method

Accidental eccentricity equal to 5%

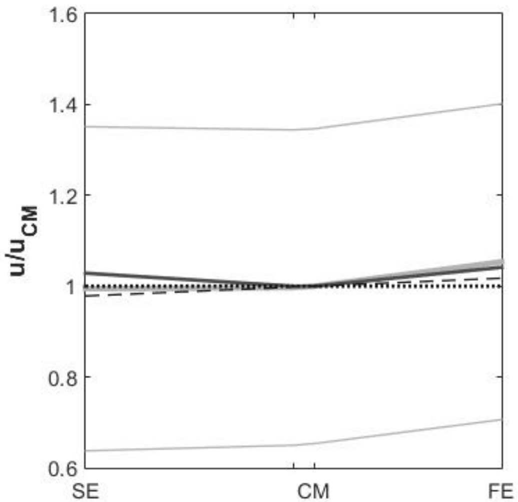


Nonlinear *Time-History* analysis

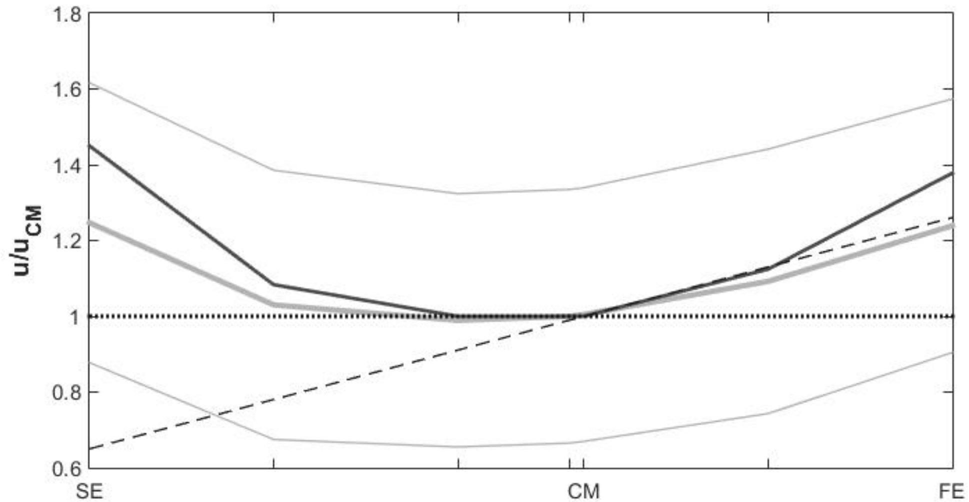


Roof displacement

X direction

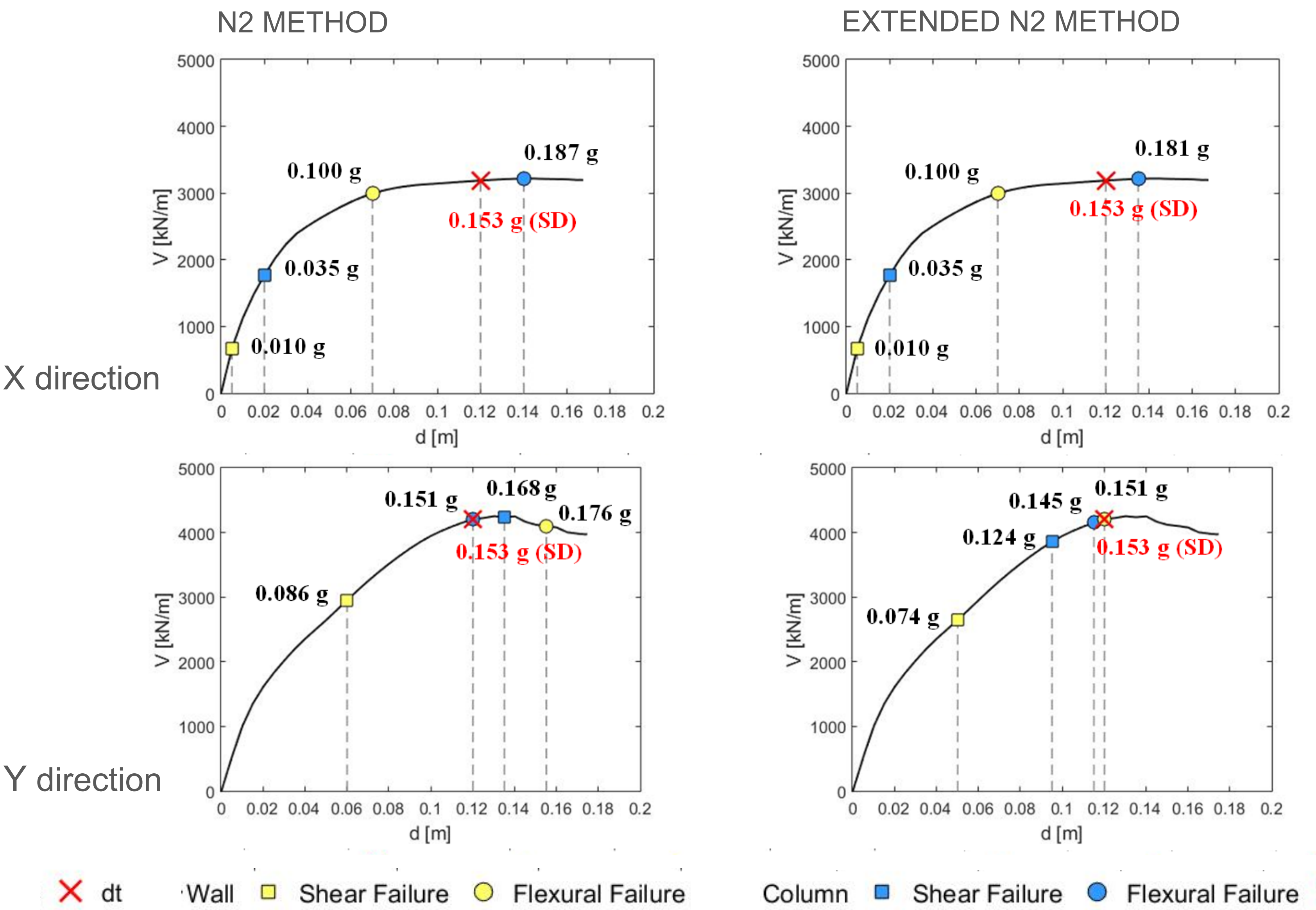


Y direction



TH(+) TH(+sd) TH(-sd) Extended N2

Assessment of torsional behaviour



Use of Sensitivity analysis for probabilistic-based seismic assessment

Fragility curves

$$p_{LS} = P(d > D_{LS}|im) = P(im_{LS} < im) = \Phi\left(\frac{\log\left(\frac{im}{IM_{LS}}\right)}{\beta_{LS}}\right)$$

Computation of partial (β_i) and total (β_{LS}) dispersions

$$\beta i = (\breve{Z}^{T} Z)^{-1} \dot{Z}^{T} Y$$

$$\beta_{LS} = \sqrt{\boldsymbol{\beta i}^{T} \boldsymbol{\beta i}}$$

Parameters	Median Value	Distribution	CoV
fcm	28.0 MPa	Lognormal	0.31
fsy	322 MPa	Lognormal	0.08
Gw	1240 MPa	Lognormal	0.30

Work done

- Overview about procedures for the seismic assessment of old RC wall-frame buildings, including the assessment of the torsional response.
- The main modelling issues regarding old RC wall-frame buildings have been addressed, including infill walls and smooth reinforcing bars.

Future developments

- Derivation of fragility curves.
- Definition of techniques for seismic retrofitting to reduce the seismic vulnerability of these buildings.

Thank you!

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