# Influence of infill masonry walls on RC buildings

João Mário

Humberto Varum
Panagiotis Asteris

# Influence of infill masonry walls on RC buildings

Motivation

Literature review

Research plan

# Research field

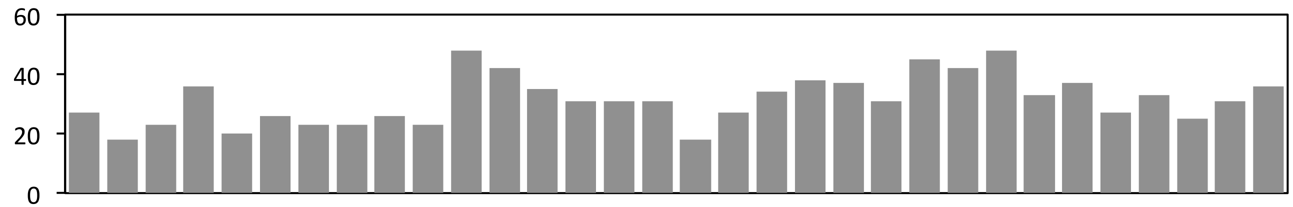
Seismic engineering

Mitigation of seimic risk

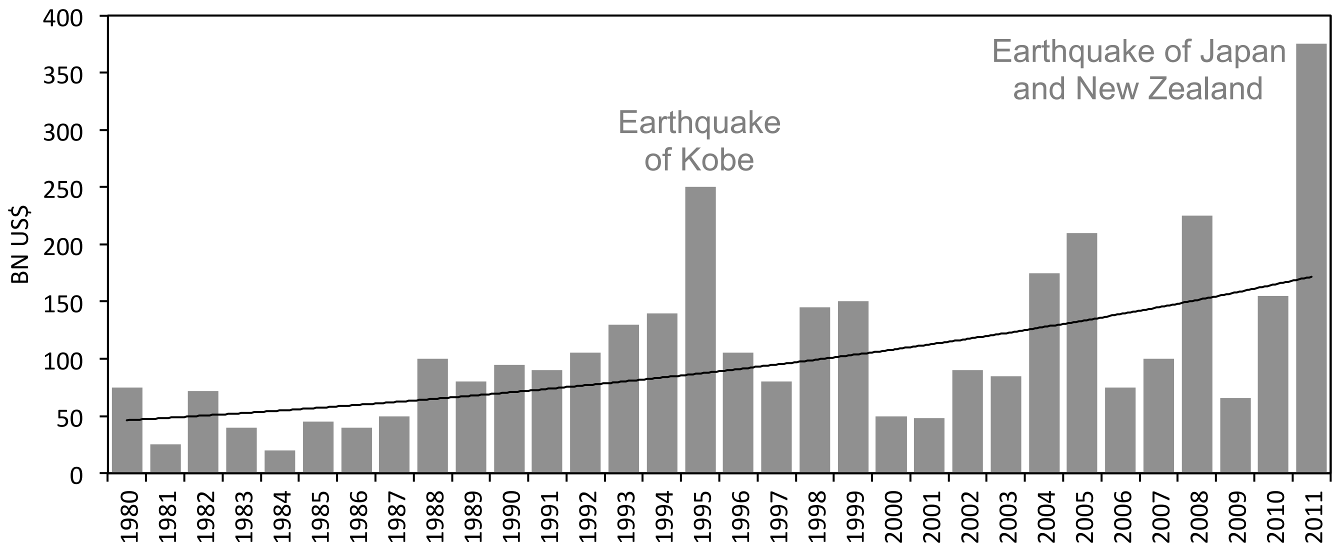
Numerical modelling

# Motivation – Natural disasters

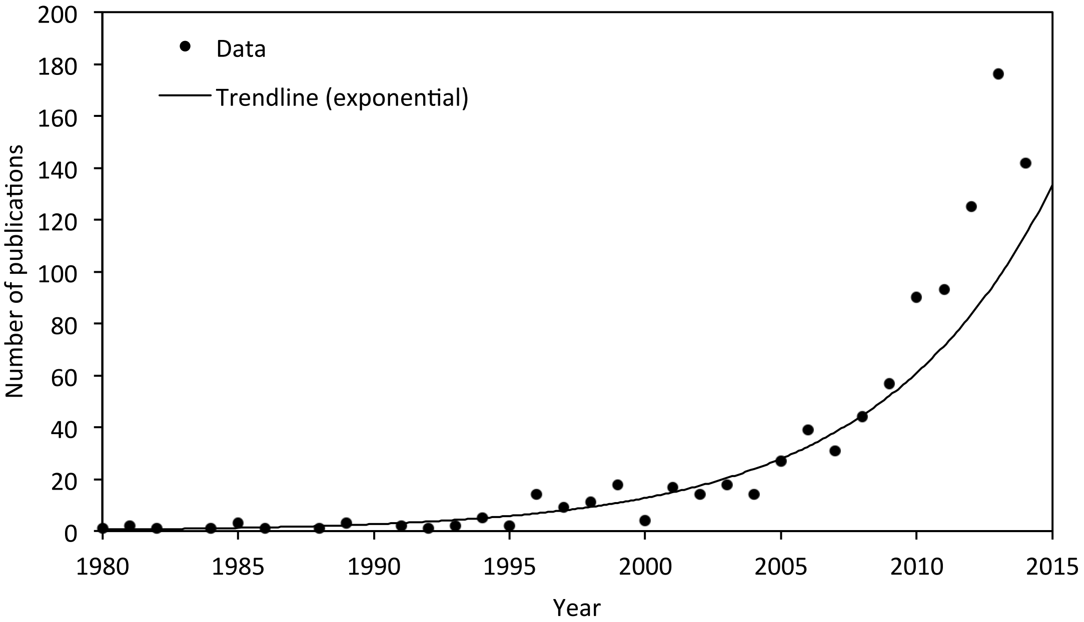
## Geophysical disasters




## Economical impact



# Motivation – Scientific attention



# Seismic Risk

Hazard “x” Vulnerability “x” Exposure

Low Risk

High Risk

Thierry Legault, 2012 (legault.perso.sfr.fr). Dabarti CGI (www.shutterstock.com). Unknown. AP Photo/Itsuo Inouye, 2009. Unknown. Unknown.

# Seismic risk = Hazard x **Vulnerability** x Exposure

Structural elements

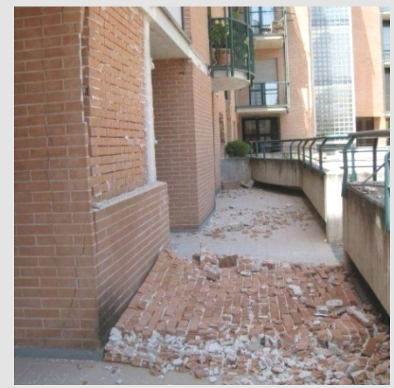
Non-structural elements

Boundary (foundation, soil, pounding,…)

# Seismic risk = Hazard x **Vulnerability** x Exposure

Structural elements

Interaction

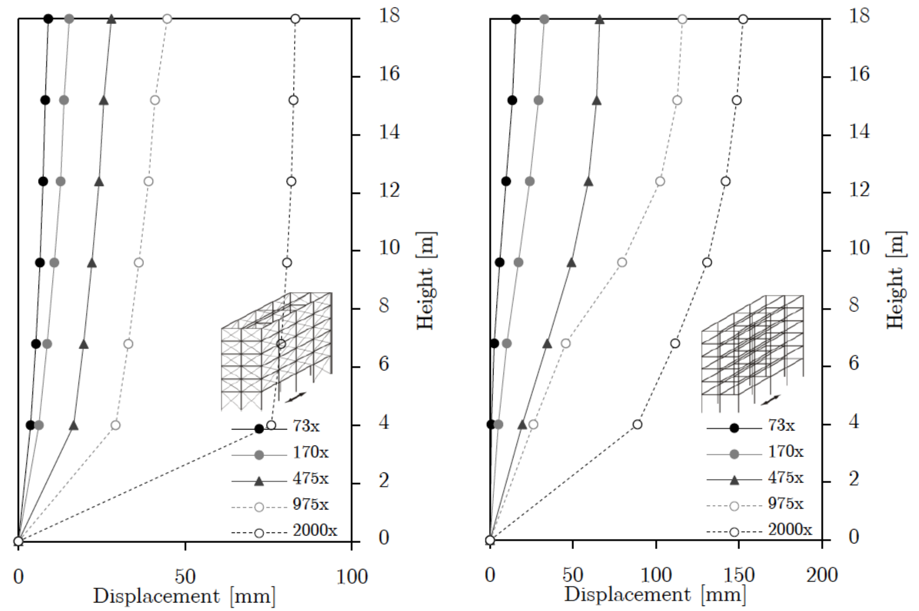


Non-structural elements

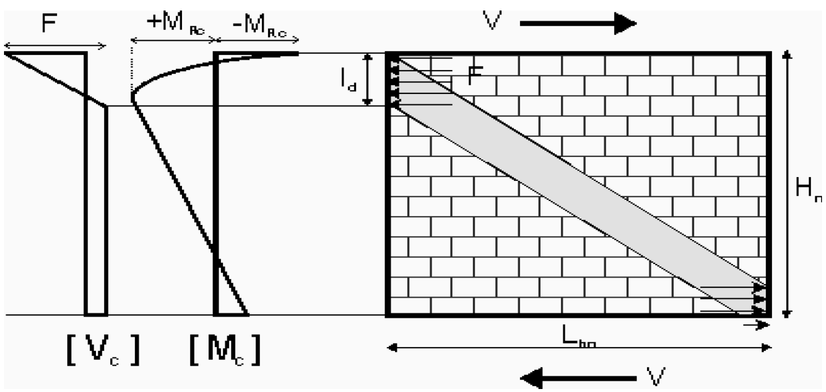
Boundary (foundation, soil, pounding,…)

# Influence of infill walls

Globally




Locally



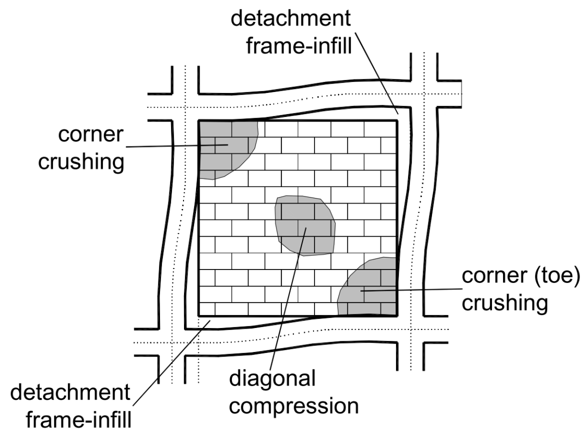
# Influence of infill walls

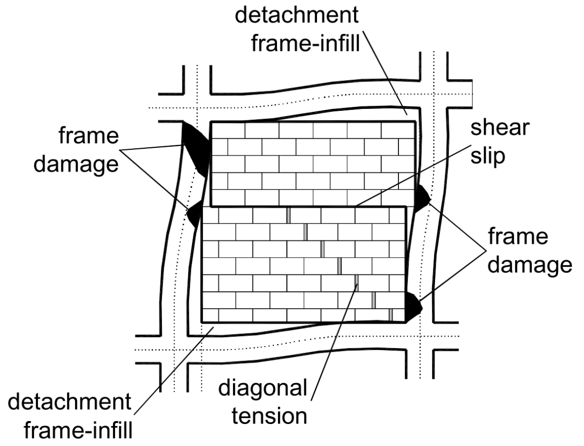
| Advantages | Disadvantages |
|---|---|
| Structure protection for low and medium earthquakes | Degradation of stiffness, strength and energy dissipation capacity |
| Higher stiffness | Stiffness irregularity in height (soft-storey) and in plan (torsion) |
| Higher strength | Strength irregularity in height (weak-storey) |
| Reduction of lateral resisting contribution from the columns | Concentration of shear in columns beams and joints |
| Reduction of deformations on the structure | Increase of axial loads on columns |
| Higher energy dissipation capacity | Higher stress demand due to higher frequencies, especially on the foundations |

# Failure modes

## In-plane

| | Weak infill | Strong infill |
|---|---|---|
| Weak Frame | | Shear Sliding<br>Diagonal Cracking<br>Frame Failure |
| Strong Members<br>Weak Joints | Corner crushing | Shear Sliding<br>Diagonal Cracking<br>Frame Failure |
| Strong frame | Corner crushing | |



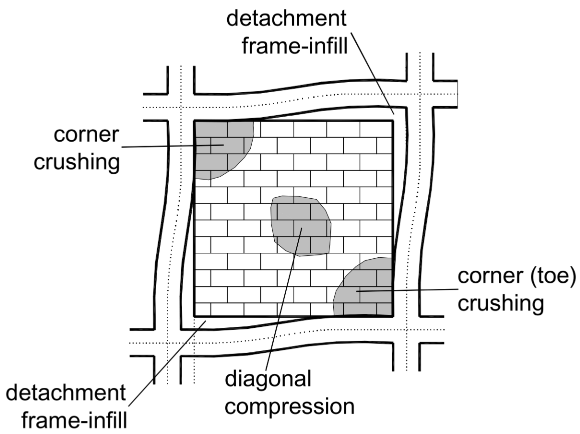



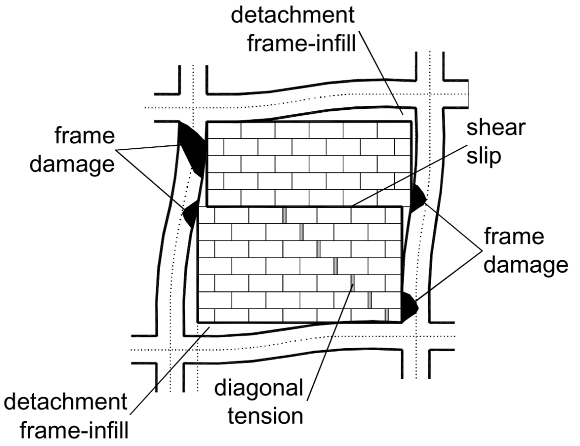

## Out-of-plane

# Failure modes

## In-plane

| | Weak infill | Strong infill |
|---|---|---|
| Weak Frame | | Shear Sliding<br>Diagonal Cracking<br>Frame Failure |
| Strong Members<br>Weak Joints | Corner crushing | Shear Sliding<br>Diagonal Cracking<br>Frame Failure |
| Strong frame | Corner crushing | |




## Out-of-plane

## Combined

# Literature review

| | |
|---|---|
| Lessons from earthquakes | ~20 |
| Seismic standards | ~20 |
| Experimental work | ~125 |
| Numerical modelling | ~70 |
| Macro-modelling | ~40 |
| Micro-modelling | ~30 |

Example

Google fusion tables beta

# Lessons from earthquakes

Earthquakes in study

World 16

Europe 4

Low quality of materials

Insufficient constructive detailing

Insufficient shear strength

Vulnerability of infill walls

Collapses:

Due to irregularities on the distribution of the infill walls

| City, Country | Year | $M_w$ | Deaths | Losses |
|---|---|---|---|---|
| San Francisco, USA | 1906 | 7.8 | 3,425 | |
| Guatemala City, Guatemala | 1976 | 7.5 | 23,000 | |
| Loma Prieta, USA | 1989 | 6.9 | 63 | >US1,000$M |
| Northridge, USA | 1994 | 6.7 | 58 | >US$50,000M |
| Kobe, Japan | 1995 | 6.8 | 6,434 | >US$100,000M |
| Dinar, Turkey | 1995 | 6.2 | 90 | US$250M |
| Jabalpur, India | 1997 | 6 | 39 | |
| Adana-Ceyhan, Turkey | 1998 | 5.9 | 145 | US$1,000M |
| Athens, Greece | 1999 | 6 | 143 | US$3,000M |
| Kocaeli, Turkey | 1999 | 7.5 | 17,127 | US$23,000M |
| Duzce, Turkey | 1999 | 7.2 | 894 | US$40M |
| Chi-Chi, Taiwan | 1999 | 7.6 | 2,416 | US$9,200M |
| Gujarat, India | 2001 | 7.7 | 20,000 | >US$10,000M |
| Bingöl, Turkey | 2003 | 6.4 | 176 | |
| Sumatra, Indonesia | 2004 | 9.2 | 280,000 | >US$10,000M |
| Sichuan, China | 2008 | 8 | 62,664 | >US$100,000M |
| L'Aquila, Italy | 2009 | 6.3 | 308 | US$10,000M |
| Maule, Chile | 2010 | 8.8 | 525 | US$30,000M |
| Haiti | 2010 | 7 | 300,000 | US$8,000M |
| Christchurch, New Zealand | 2011 | 6.3 | 181 | US$20,000M |
| Tohoku, Japan | 2011 | 9 | 15,800 | US$300,000M |
| Van, Turkey | 2011 | 7.1 | 604 | US$2,000M |
| Lorca, Spain | 2011 | 5.1 | 9 | US$99M |
| Bologna, Italy | 2012 | 6.1 | 26 | US$13,000M |
| Iquique, Chile | 2014 | 8.2 | 7 | US$100M |

# Seismic recommendations

Philosophies Standards ~20

1 – Isolation of infill masonry walls

2 – Allow the use of infill walls on the designing

3 – Connection between infill walls and structure is mandatory

Formulations of different natural frequencies

Irregularities in height and plan (structural and non-structural elements)

Minimal strength capacity for the infill walls

Deformation limitation to control damages

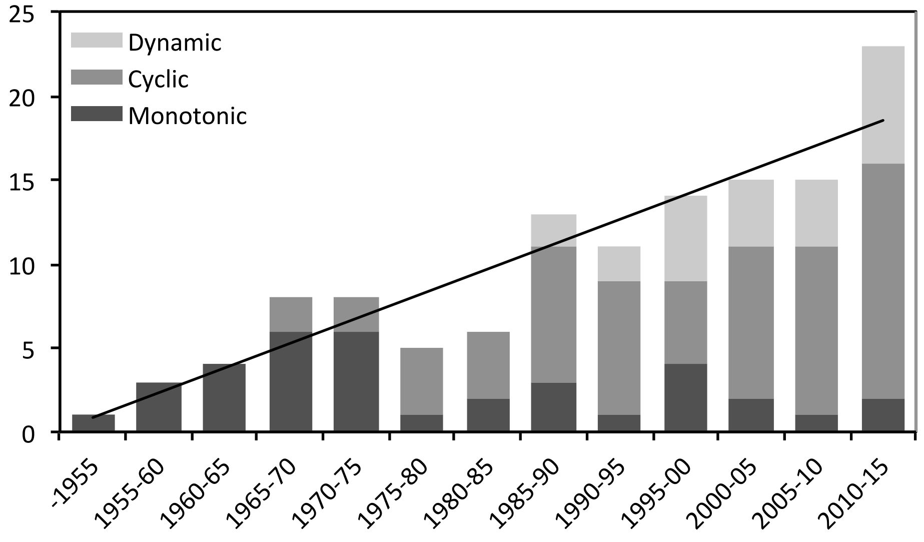
Recommendations regarding positioning of openings on infill walls

# Experimental work

Number of experimental campaigns ~125

Linear growth with time

Monotonic testing dropped and cyclic testing



# Experimental work

Decrease of aspect-ratio (h/l) leads to an increase of the ultimate capacity

Gaps on infill-frame interface decreases considerably the horizontal strength

Building's stiffness do not increase linearly with the number of walls

Openings close to edges reduce more the capacity of the wall than centred

Openings usually increase the ductility of the system

Vertical loading on columns increase of stiffness and resistance of the system due to increase of confinement of the wall

Eccentricity of the wall relative to the frame plane centre-line leads to out-of-plane bending effects, reducing both initial stiffness and ultimate capacity

Horizontal bond beam increase the ductility of the system

| Author, Year | Scale | Type | Wall | Frame | Wall | Tests |
|---|---|---|---|---|---|---|
| [Thomas, 1953] | | M | IP | Steel | B,C | |
| [Ockleston, 1955] | 1 | M | IP | RC | B | |
| [Benjamin and Williams, 1958, 1959] | 1-1/8 | M | IP | RC | C | 20 |
| [Wood, 1958] | | M | IP | Steel | | |
| [Sachanski, 1960] | 1 | M | IP,O | RC | B,C | 31 |
| [Holmes, 1961] | 1 | M | IP | RC | B,C | |

...

# Refined models *vs* Simplified models

Micro-modelling (refined) ~ 30

Macro-modelling (simplified/analytical) ~40

| | Micro-modelling | Macro-modelling |
|---|---|---|
| 1 | Higher detailed modelling | Simplified models compared |
| 2 | Allow interpretation of the behaviour at local level and to obtain cracking patterns, ultimate load, and collapse mechanisms | Allow a representation of the global behaviour of the infill masonry panels and of their influence in the buildings response |
| 3 | Need a large number of parameters | Usually modelled as an equivalent strut |
| 4 | Higher computational effort | Lower computational effort |
| 5 | Useful for the calibration of global models | |

# Numerical limitations

Models with combined in-plane and out-of-plane's behaviour

- Failure curve of infill masonry walls for actions in both directions

Parametric studies (and experimental) of double-leaf walls

Calibration of simplified models for retrofitting interventions

# Research plan

Parametric study with a semi-refined model

- Abaqus

Development of a macro-model

- OpenSees

# Parametric study

Volume elements

Continuum element for infill wall

Study:

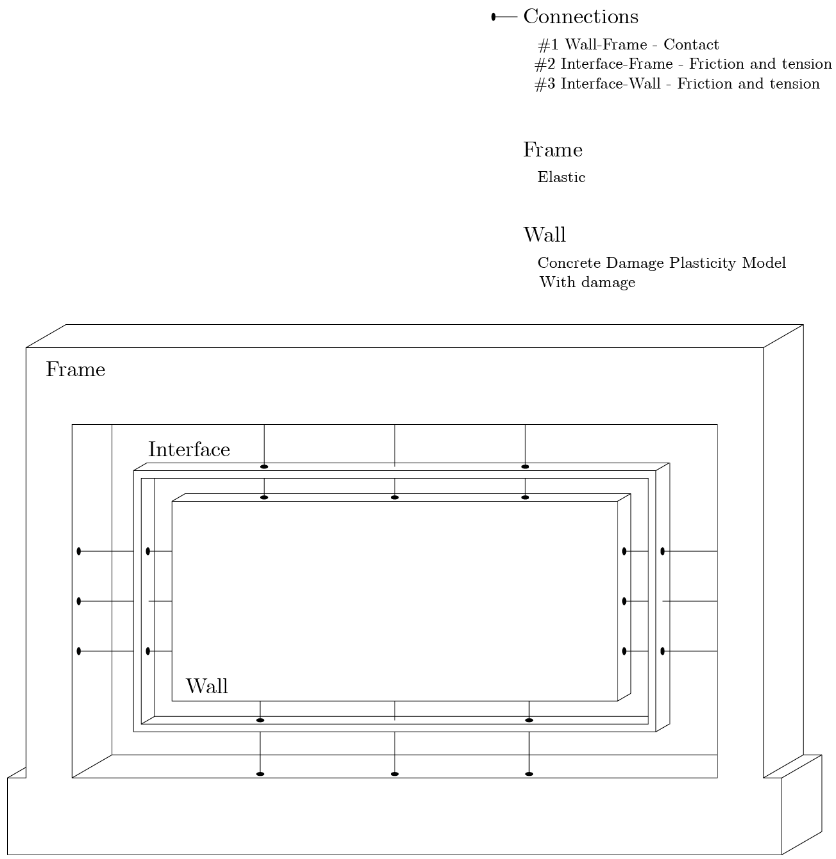
Dimensions

Properties of materials

Infill-frame interface conditions

Eccentricities

Single- and double-leaf walls



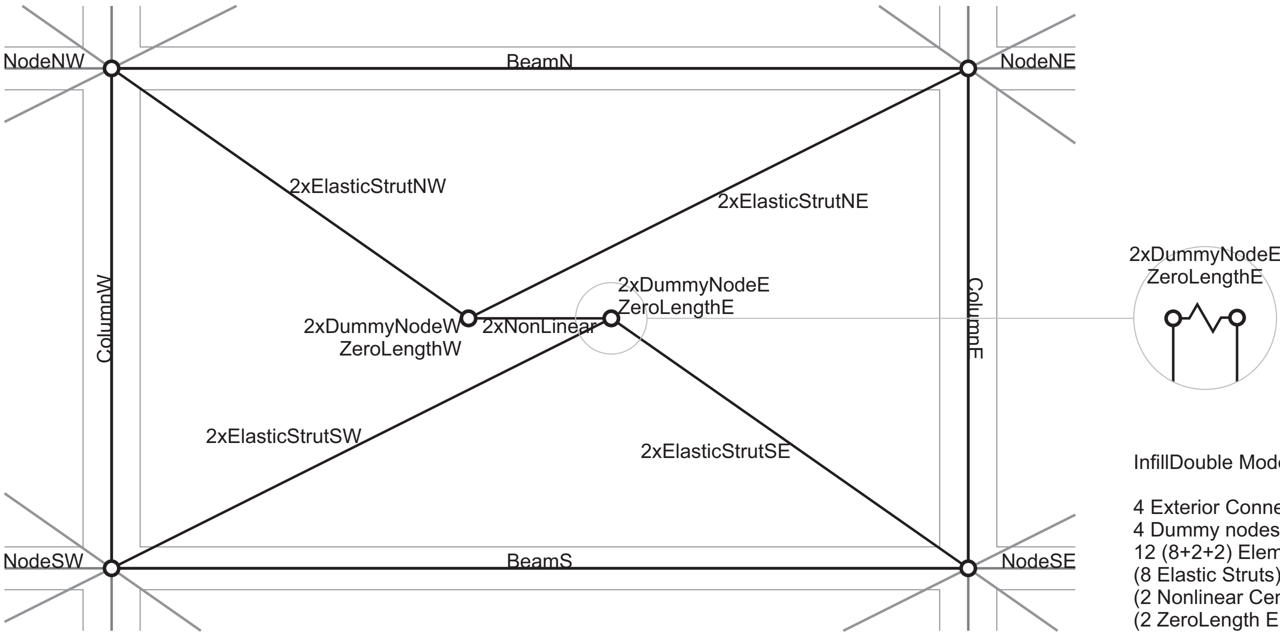

Used on the calibrations of the simplified model

# Simplified models

(Limitations of models with single-struts)

Out-of-plane behaviour

Interaction between two masonry walls and its connections



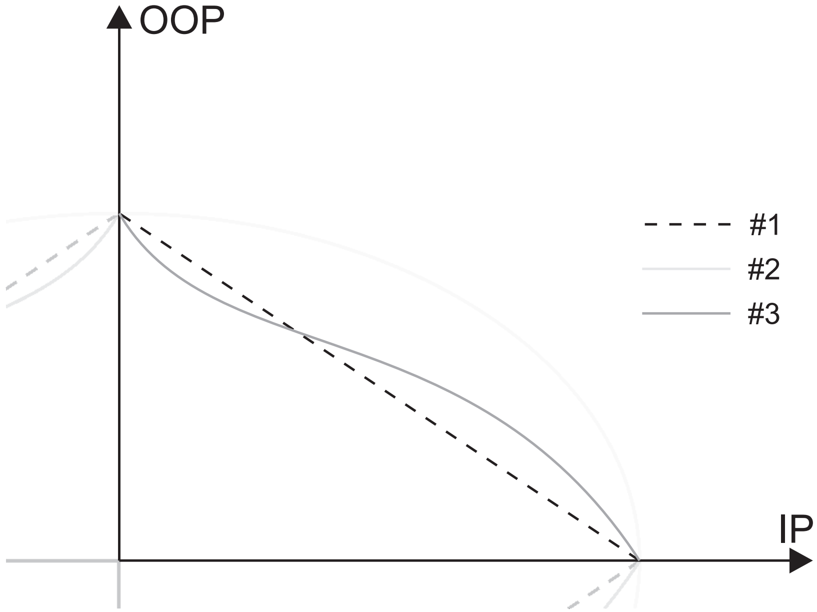

InfillDouble Model

4 Exterior Connections (nodes)
4 Dummy nodes
12 (8+2+2) Elements
(8 Elastic Struts)
(2 Nonlinear Central Elements)
(2 ZeroLength Elements)

# Interaction curve

Simplified approach for assessment of failure's strength for actions combined in both directions: in-plane and out-of-plane

Applicability on the simulation of real (and complex) study cases



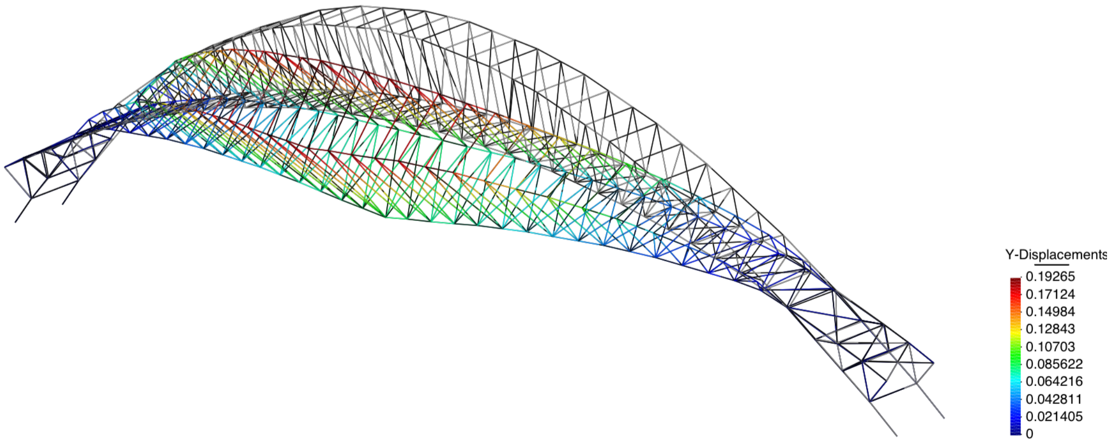
# FEMuA++

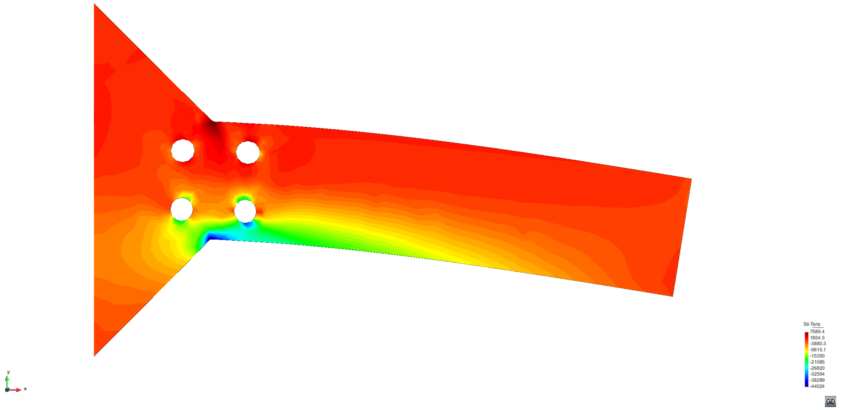
Software for structural analysis

Programming language: C++ (used in OpenSees)

(Pre- e post-processing in GiD)

"Testing platform"

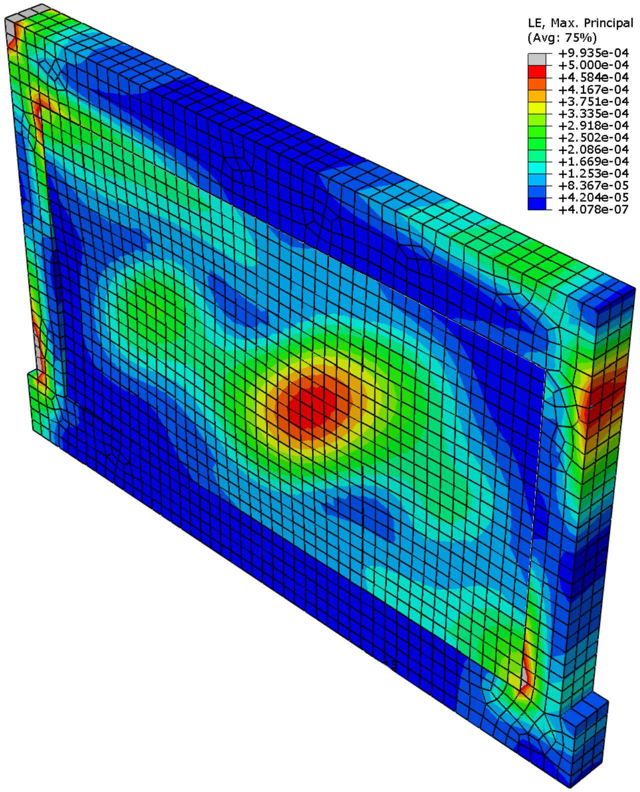


# Numerical developments

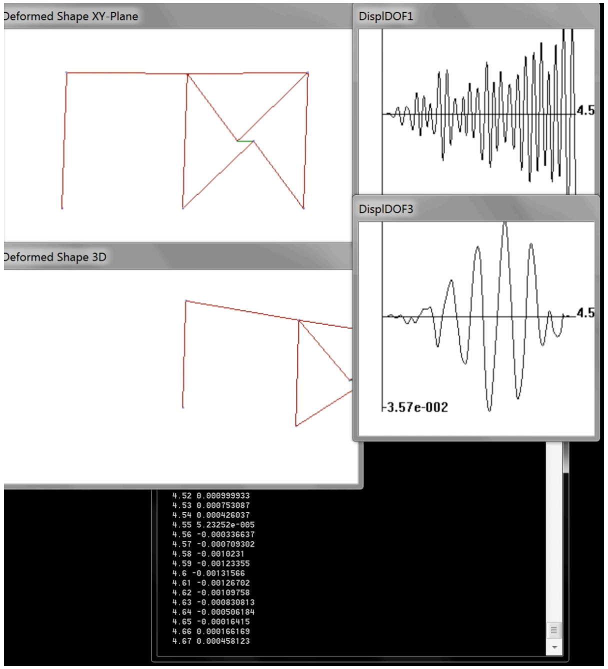
## Semi-refined modelling

Abaqus




## Macro modelling

OpenSees



# ~~Conclusions~~ Objectives

Compilation and organization of the state-of-the-art in a database

Development of a parametric study

Development of a macro-model able to describe the behaviour of infill masonry walls with combined in-plane and out-of-plane actions

Improve the knowledge regarding the influence of infill masonry walls on the behaviour of reinforced concrete buildings

Creation of new methodologies for the designing and assessment of reinforced concrete structures with infill masonry walls

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