Workshop SERIES – Istanbul, February 8-9, 2012

Contribution of the spandrels and of the perpendicular walls to the seismic performance of masonry walls

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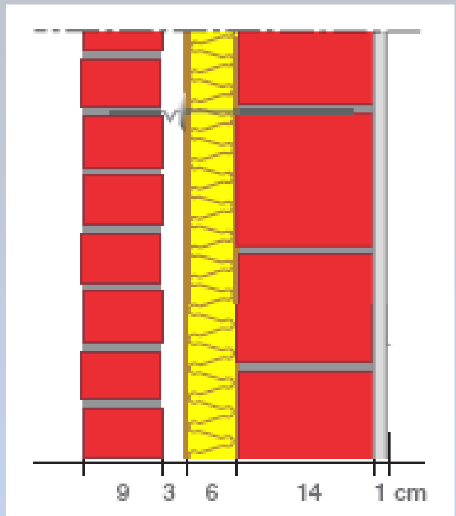
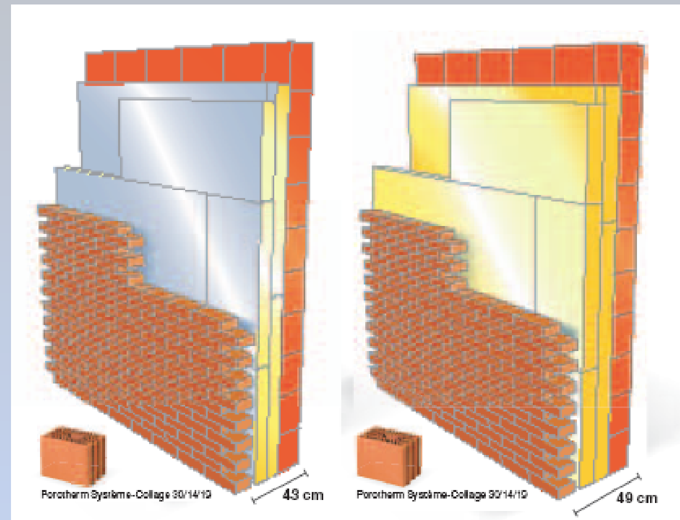
Université de Liège

Wienerberger

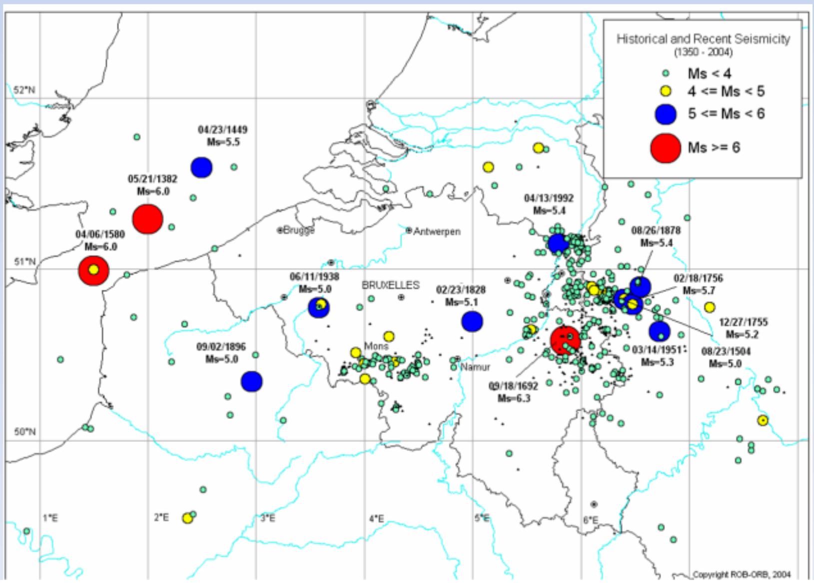
1. Context and introduction

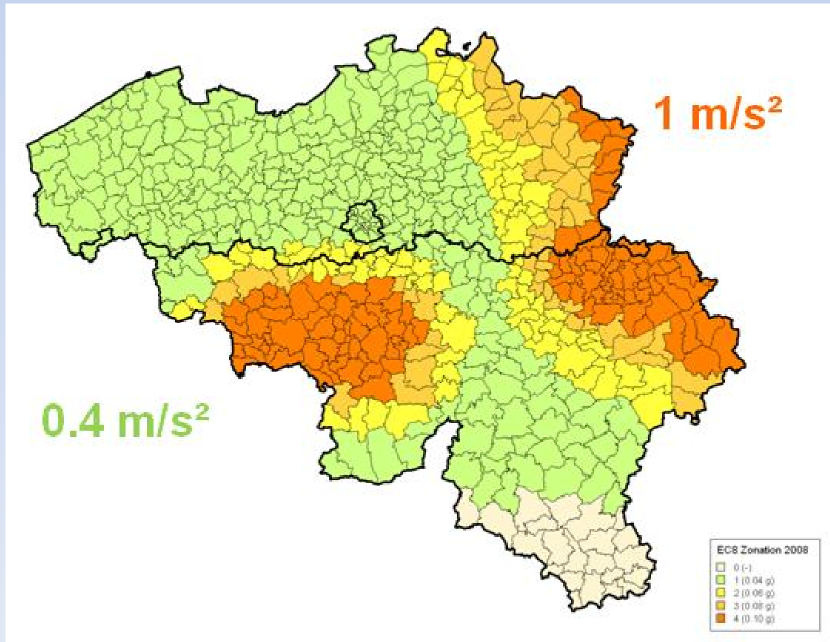
- **Typical Belgian masonry construction (like UK and NL)**



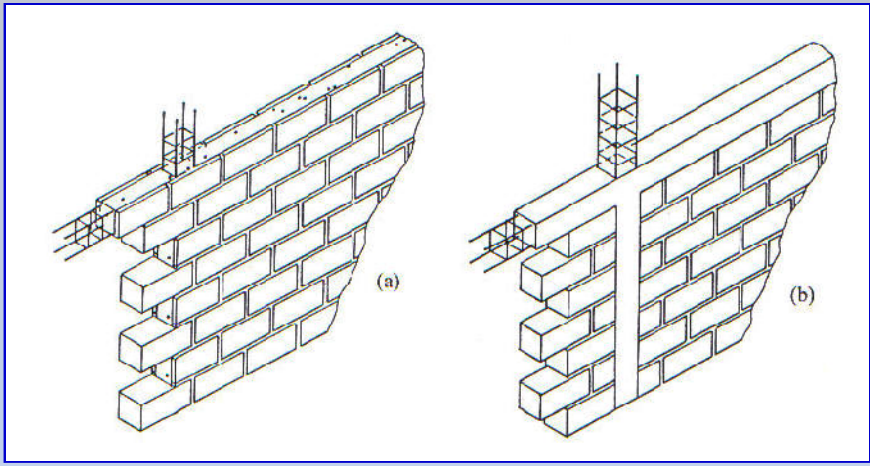


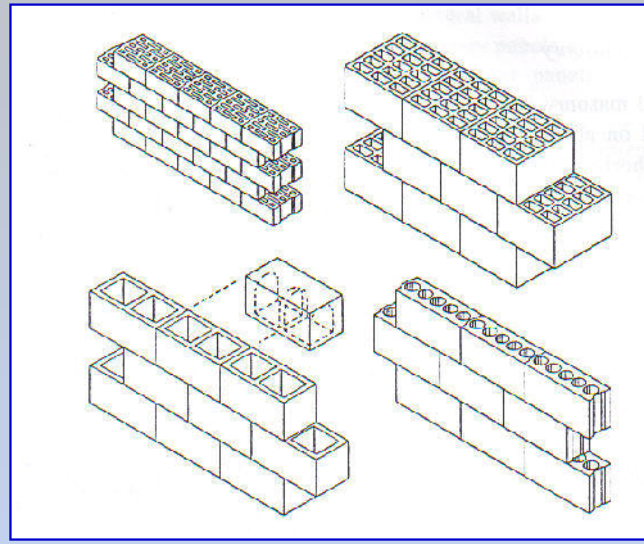
- **Seismicity level of Belgium**





1. Context and introduction





Confined masonry

(Common in seismic regions)

↔

Unreinforced masonry

(Standard in Belgium)

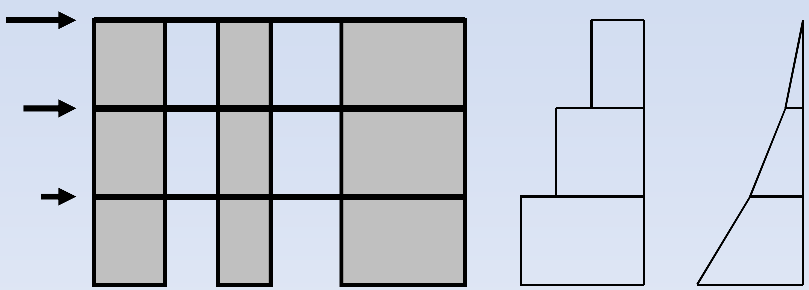
1. Context and introduction

Eurocode 8 verification methodology (version from Belgian National Annex)

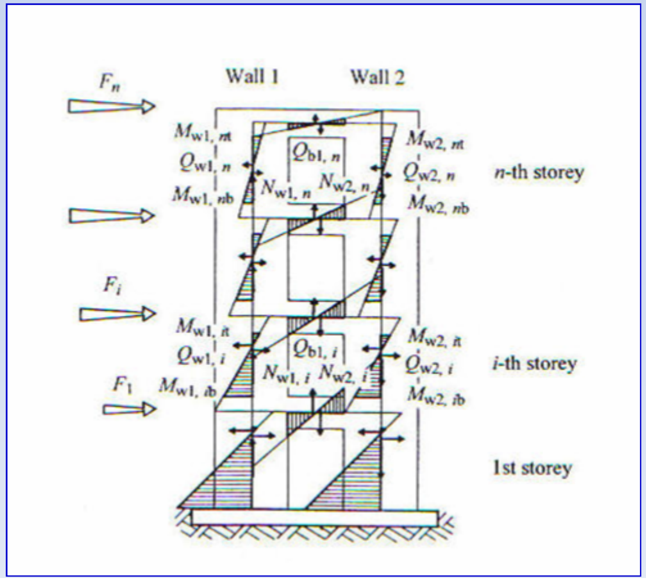
- **Simple masonry buildings (independent of configuration in elevation)**

Acceleration $\gamma_I a_g S$	≤ 0.075 g	≤ 0.09 g	≤ 0.12 g	≤ 0.15 g	≤ 0.18 g
Number of levels	Minimal cross-sectional area of shear walls (percentage of the total floor area)				
1	**1,0** (*2,0*) %	**1,0** (*2,0*) %	**1,5** (*2,0*) %		**3,0** (*n/a*) %
2	**2,0** (*2,0*) %	**2,0** (*2,5*) %	**2,5** (*2,5*) %		**7,5** (*n/a*) %
3	**3,0** (*3,0*) %	**3,5** (*5,0*) %	**5,5** (*5,0*) %		**n/a** (*n/a*)
4	**5,0** (*5,0*) %	**5,5** (*n/a*) %	**8,5** (*n/a*) %		**n/a** (*n/a*)
5	**6,5** (*n/a*) %	**8,0** (*n/a*) %	**n/a** (*n/a*)		**n/a** (*n/a*)

- **Set of cantilevers coupled by floor diaphragms**



- **Equivalent frame model**



1. Context and introduction

Example

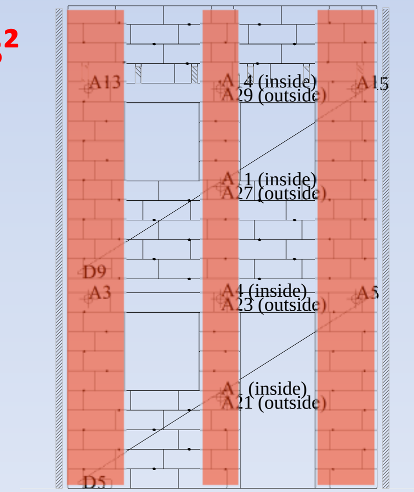
"EC8 simple building" n/a

= not applicable

• **Simple analysis model as from EC8**

cantilever walls:

=> ag,max = 0.5 m/s²

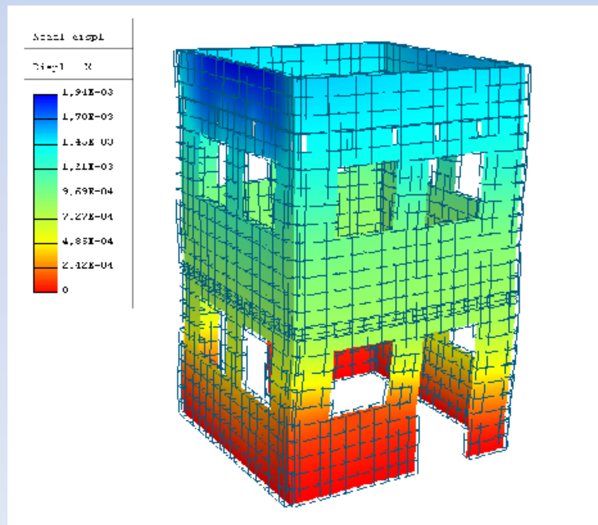


ELEVATION SIDE 1
(North)

Refined model:

•**FE model: Calibrated on frequency analysis (No facing bricks // E* = E/2)**

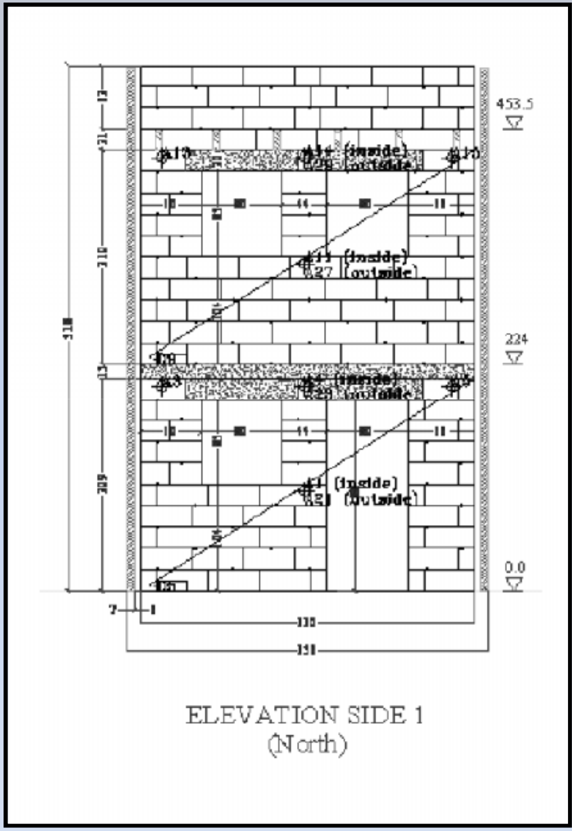
+ EC6 verification: => ag,max = 3.0 m/s²

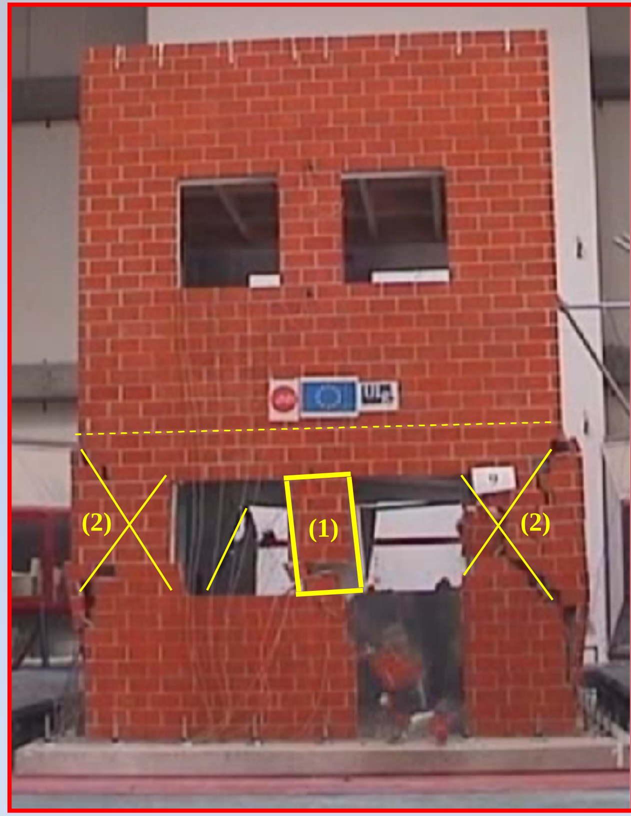


1. Context and introduction

Reality !! *Frame behaviour, not cantilever*

but not easy to quantify

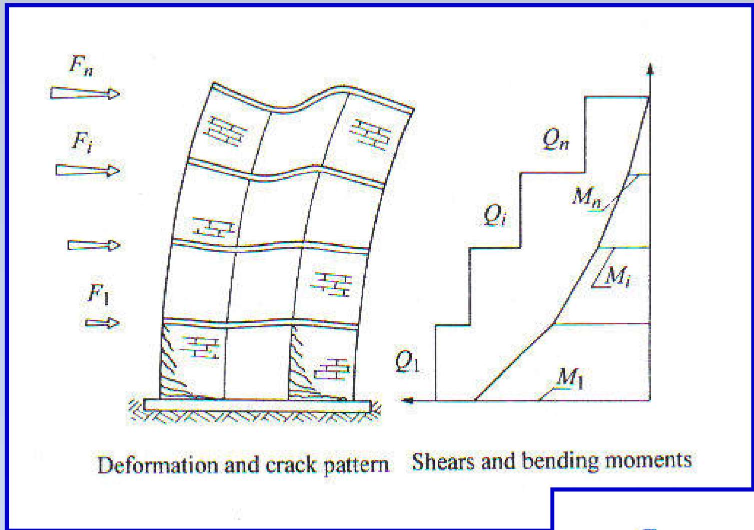




Tests indicate: ag,max > 4.5 m/s² => Research needs

Full scale tests

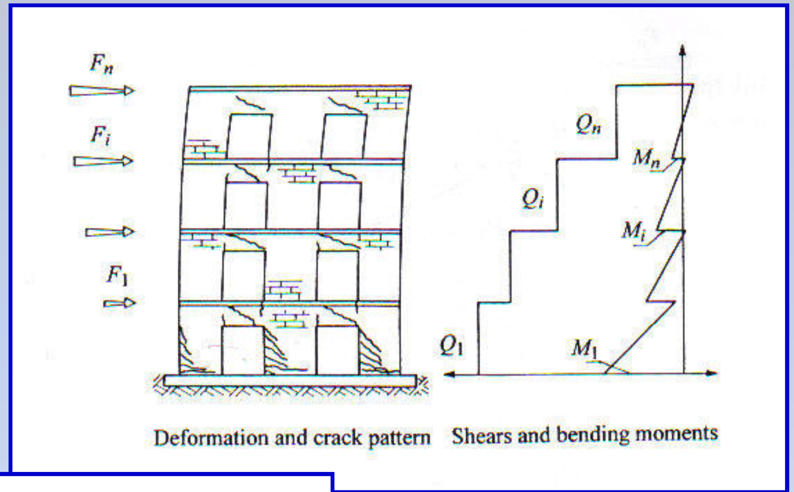
- Questions to be investigated by the test program:
  - Effect of horizontal spanning elements



Coupled by «ties »

No effect on bending

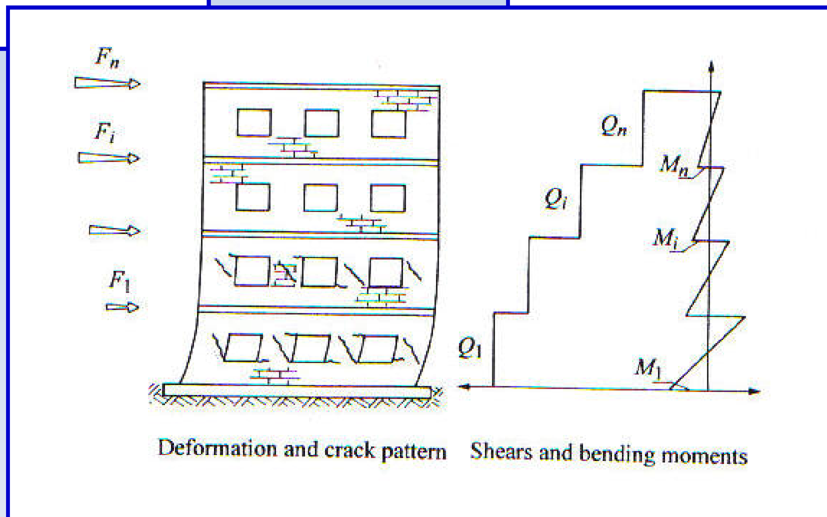
Lower bound



Intermediate

realistic

situation

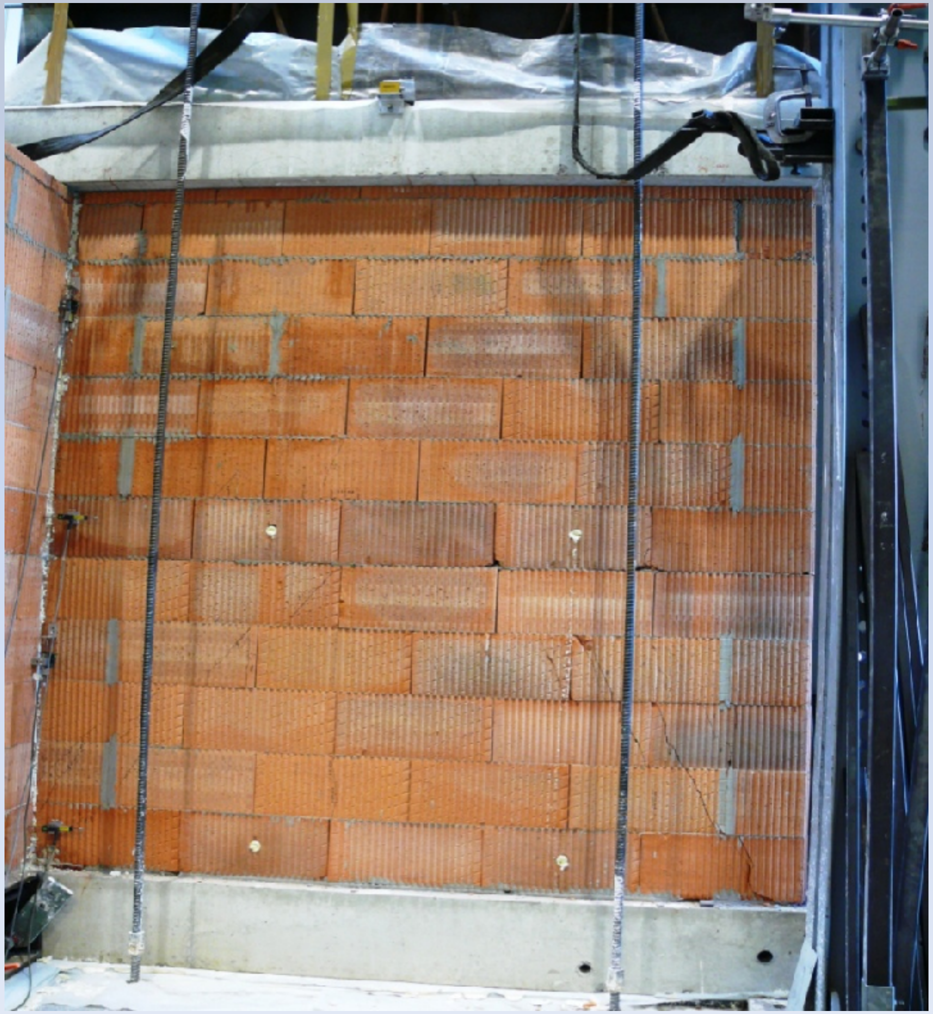


Infinitely rigid spandrels Upper bound

2. Characterization of material and structural properties

Full scale tests

- **Questions investigated by the test program:**
    1. **Effect of horizontal spanning elements**
    2. **Influence of a prefabrication process**



prefab panels

5 brick layers (for 12 t crane max load)

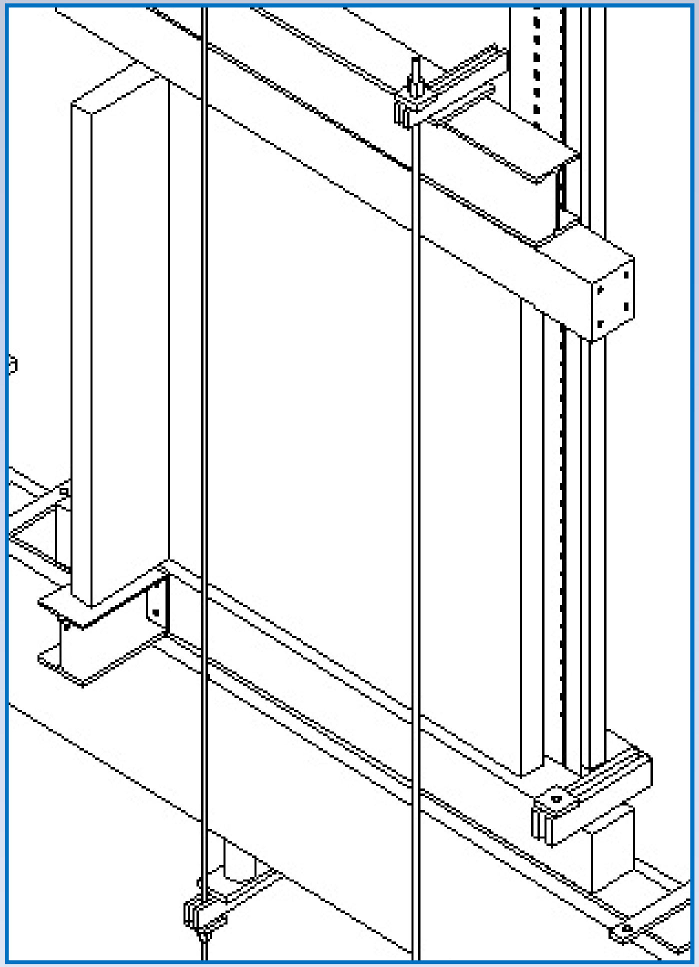
glued on site

2. Characterization of material and structural properties

Full scale tests

- **Questions investigated by the testing program:**
  3. **Effect of perpendicular wall on the stability of shear walls**

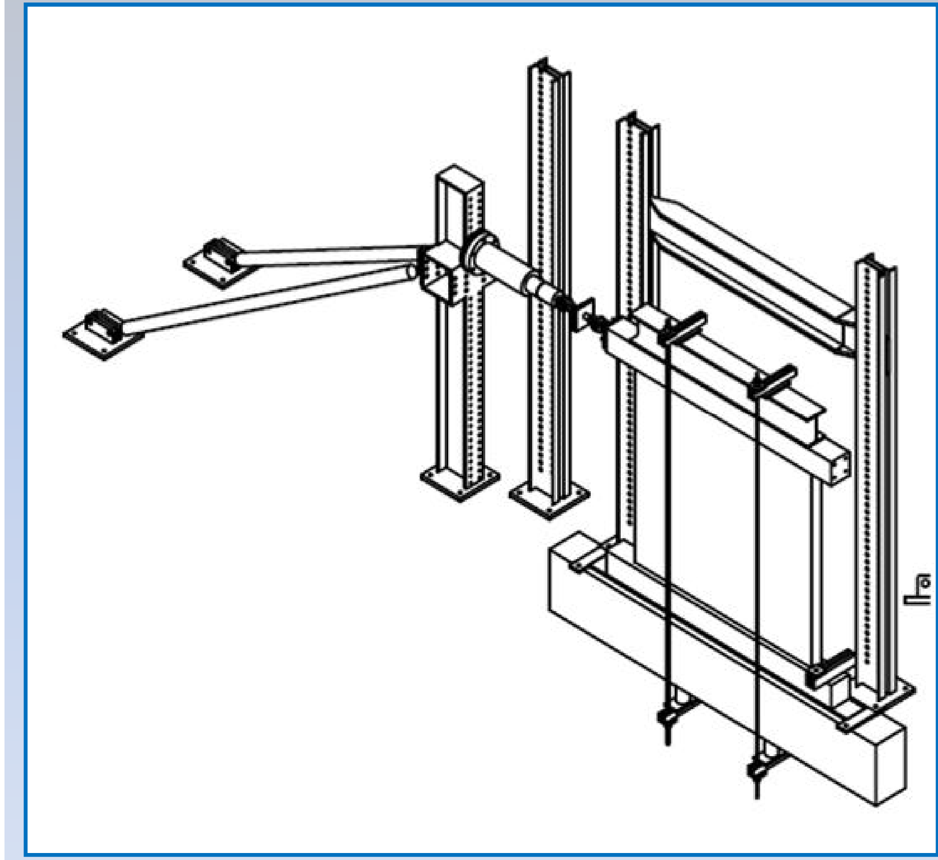
     = T shape wall

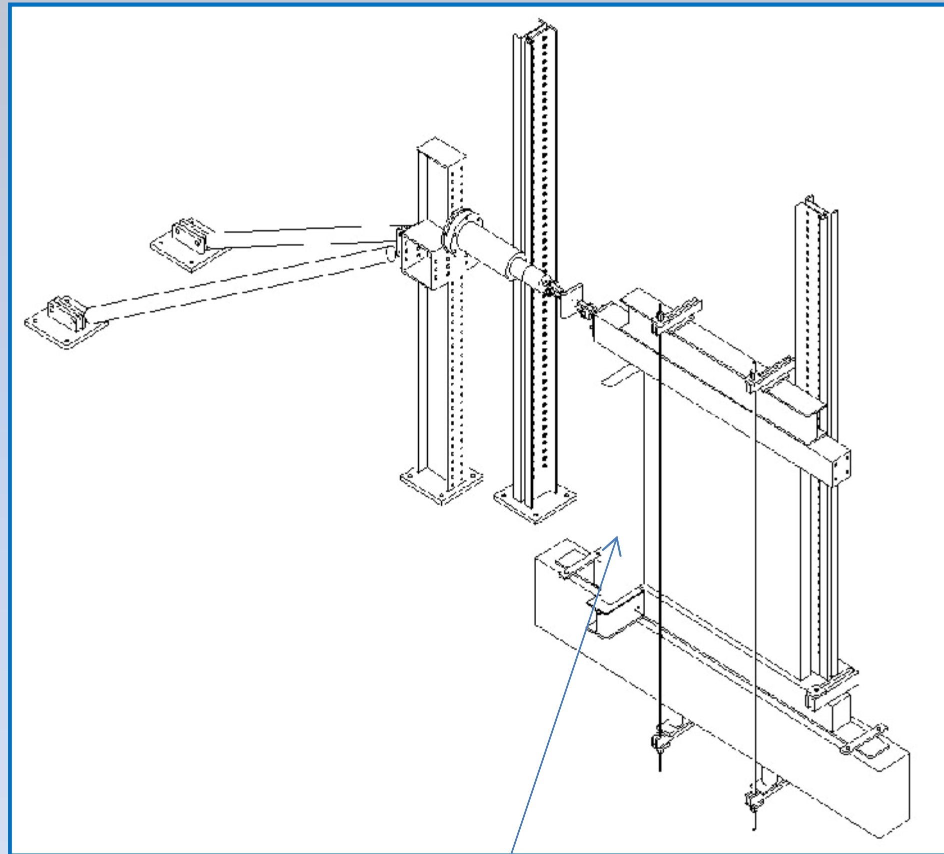


2. Characterization of material and structural properties

Full scale tests

- **Test set-up**





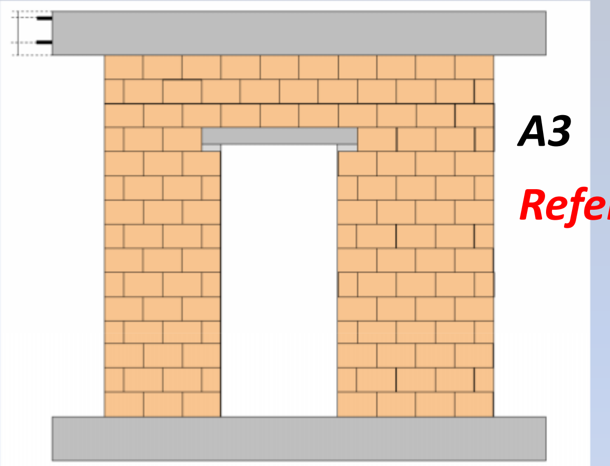
T shape wall

2. Characterization of material and structural properties

Full scale tests at University of Liege

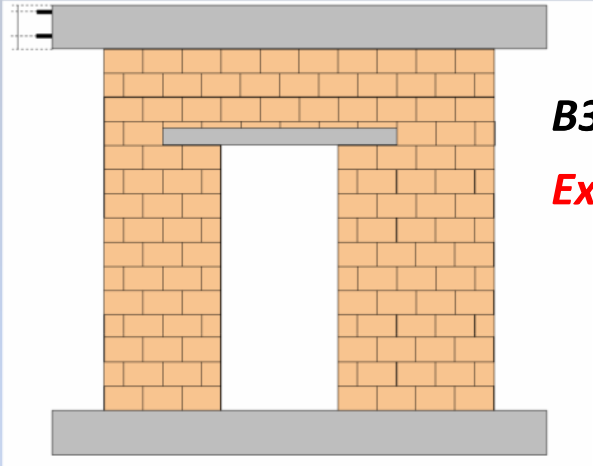
- **Definition of the test specimens**

SPECIMENS WITH DOOR OPENING



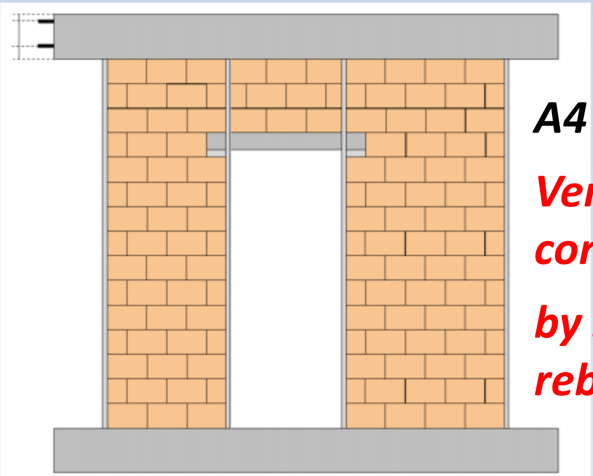
A3

Reference



B3

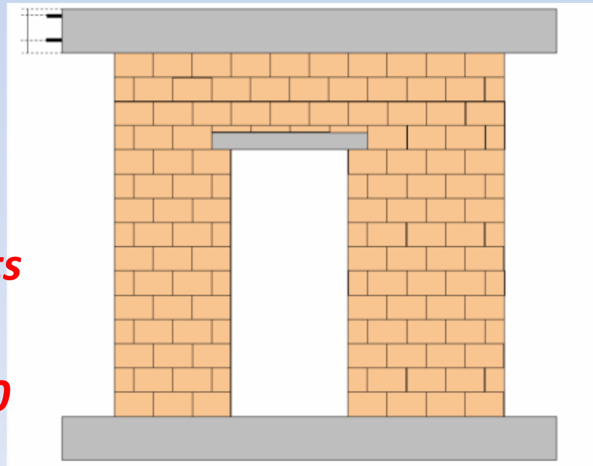
Extended lintels

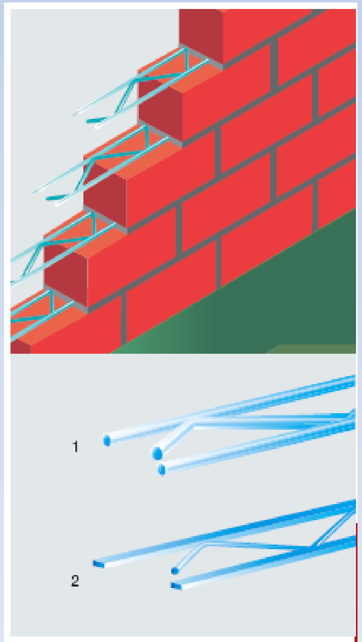


A4

Vertical confinements

by standard rebars 4T10



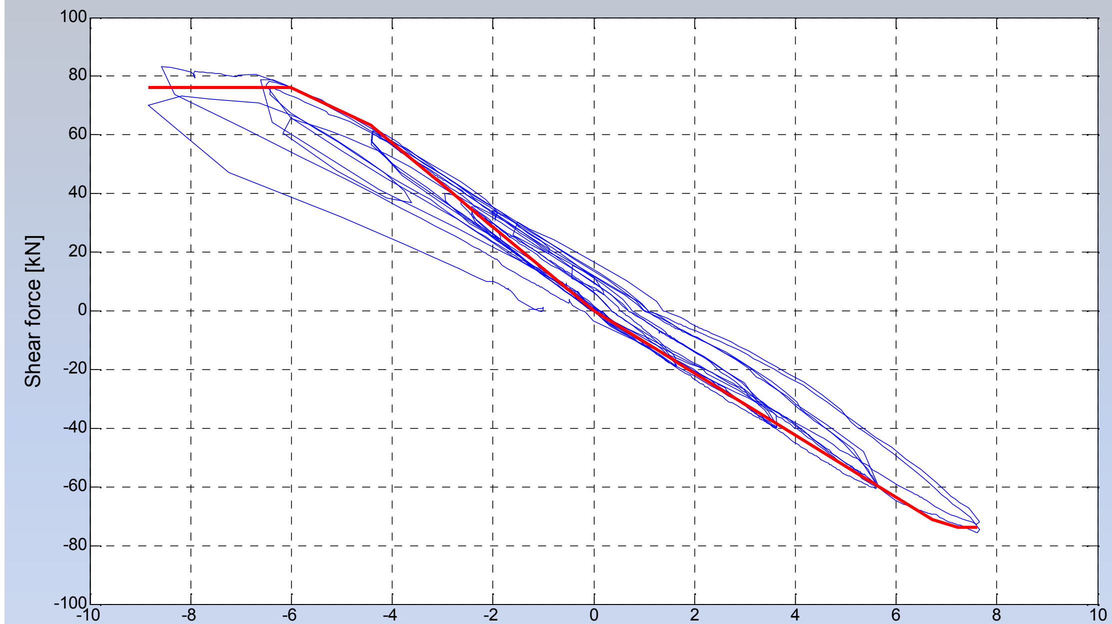


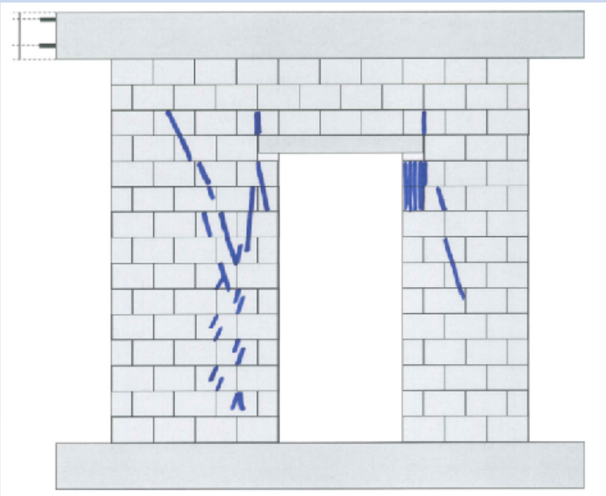
B4 =A3 + Murfor

2. Characterization of material and structural properties

Full scale tests SPECIMENS WITH DOOR OPENING

- **Main results**





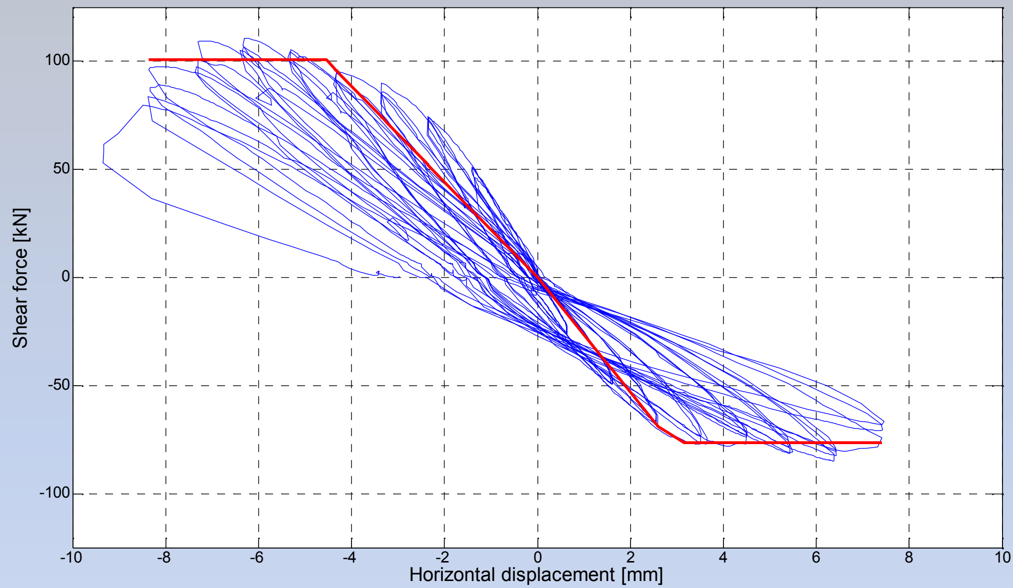
A3 = reference

- **End of test:** **Crushing of lintel supports**
- **No ductility**

2. Characterization of material and structural properties

Full scale tests **SPECIMENS WITH DOOR OPENING**

- **Main test results**

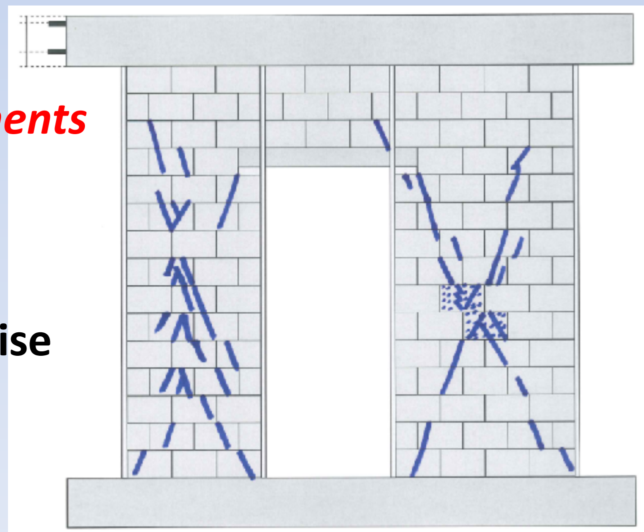


A4

Vertical confinements

by rebars

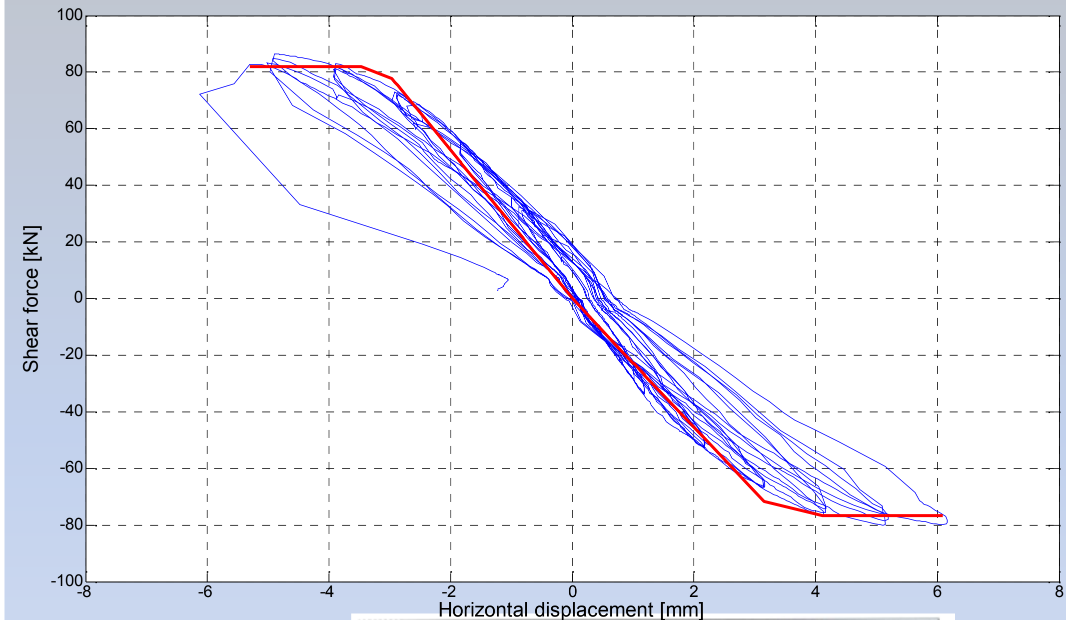
- **Good ductility**
- **Difficult to realise**



2. Characterization of material and structural properties

Full scale tests SPECIMENS WITH DOOR OPENING

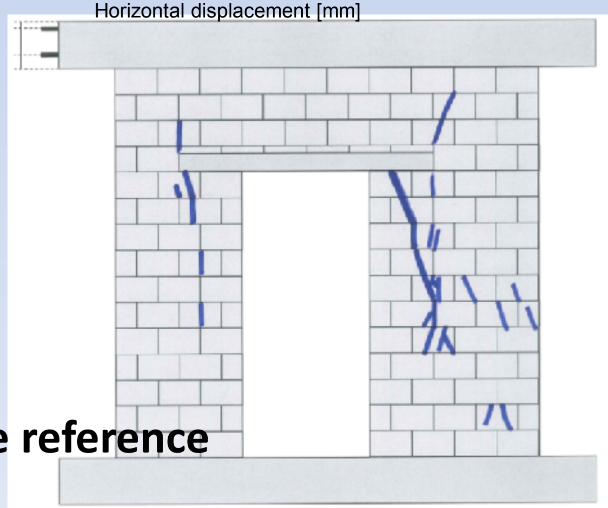
- **Main test results**



B3

Extended lintels

- **Low ductility**
- **Cracking at supports**
- **Resistance like reference**



2. Characterization of material and structural properties

Full scale tests **SPECIMENS WITH DOOR OPENING**

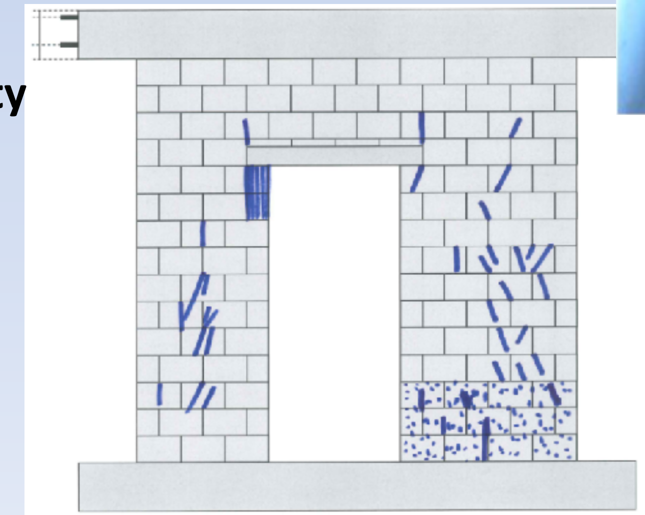
- **Main test results**

Murfor holds

Brick walls together

B4 ***Murfor***

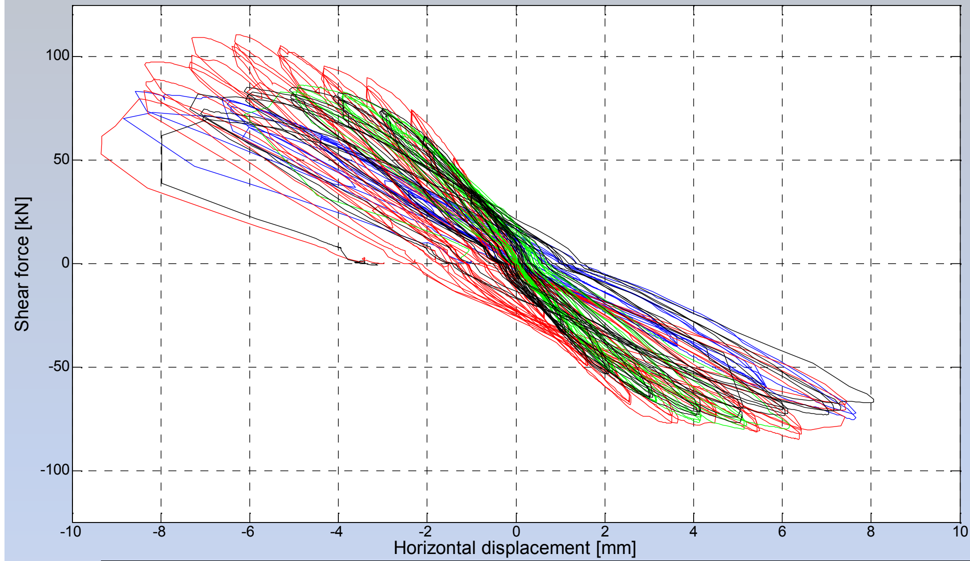
- **Good ductility**
- **Resistance governed by crushing at supports ≠ collapse**

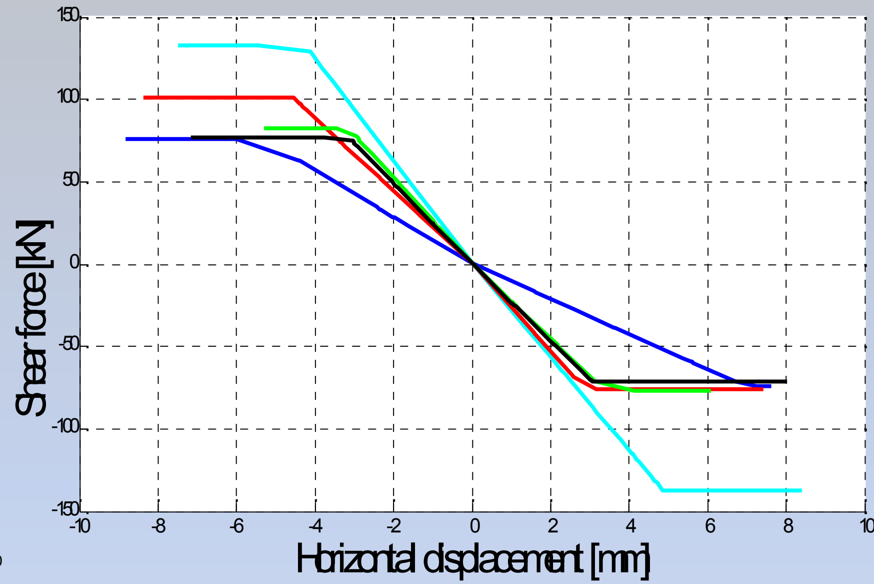


2. Characterization of material and structural properties

Full scale tests SPECIMENS WITH DOOR OPENING

Main test results





Test	Ultimate load + (kN)	Ultimate load – (kN)	Ultimate drift + (mm/%)	Ultimate drift – (mm/%)	Ductility +	Ductility -
A1	133.0	137.1	7.5 / 0.27	8.4 / 0.30	1.8	1.7
A3 Ref	76.1	*73.8*	8.8 / 0.32	*7.6 / 0.27*	1.7	*1.1*
A4 Vertic bars	100.8	76.3	8.4 / 0.30	7.4 / 0.26	1.8	2.6
B3 Ext. Lintels	82.0	76.6	5.3 / 0.19	6.1 / 0.22	1.7	1.8
B4 Murfor	76.9	71.2	7.2 / 0.26	8.0 / 0.29	2.3	2.6

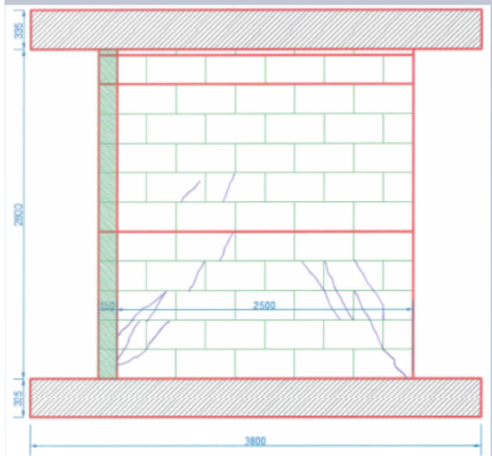
2. Characterization of material and structural properties

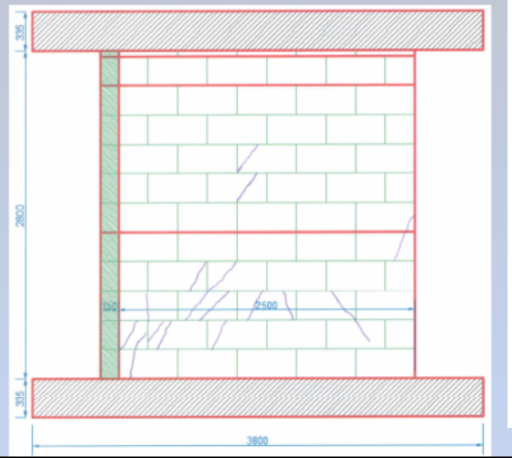
Full scale tests TESTS ON PREFABRICATED T-SHAPED WALLS

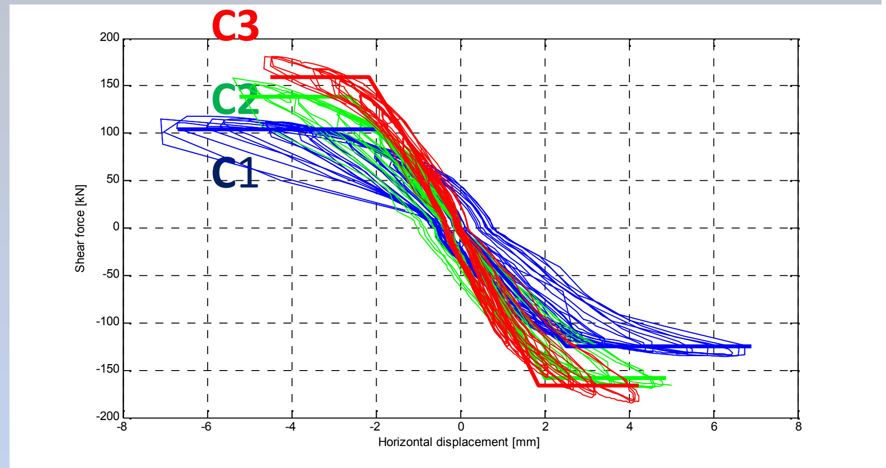
≠ compression stress C1 0,75MPa C2 1,00MPa C3 1,25MPa

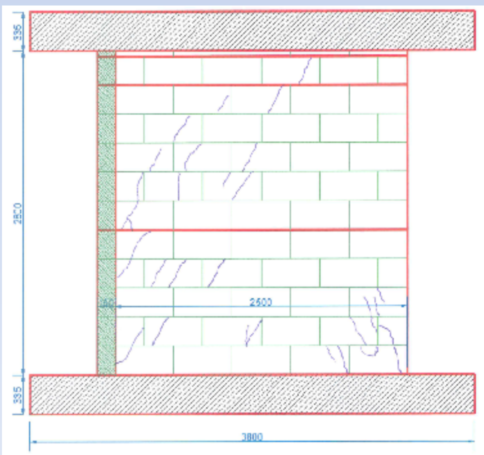
- **Main test results**

Global behaviour









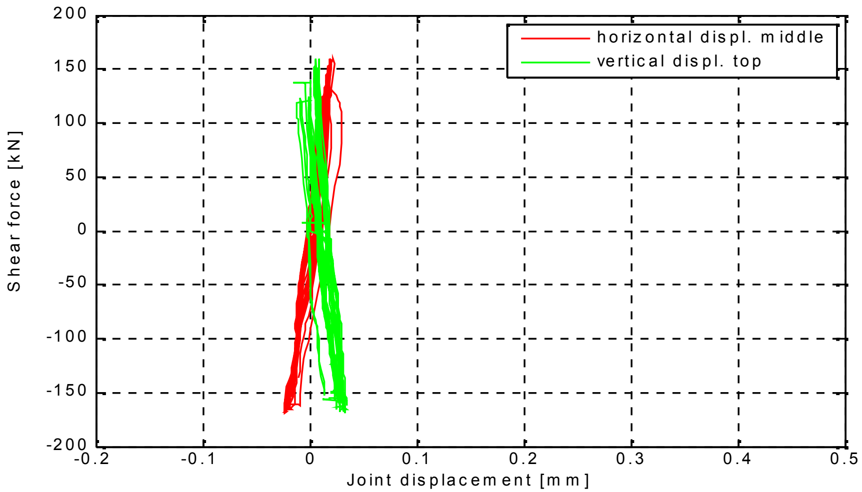
Characteristics values	C 1		C2		C3	
	Positive loading	Negative loading	Positive loading	Negative loading	Positive loading	Negative loading
Maximum load(bi-linearized curve)/ Maximum load from cyclic curve	104.4 kN / 118.3 kN	125.6 kN / 135.2 kN	138.8 kN / 158.3 kN	158.1 kN / 167.8 kN	161.7 kN / 180.8 kN	172.5 kN / 189.8 kN
Maximum displacement / Maximum Drift	6.71 mm / 0.24 %	7.71 mm / 0.27 %	5.22 mm / 0.19 %	4.88 mm / 0.17 %	4.91 mm / 0.17 %	5.33 mm / 0.19 %
Maximum theoretical shear resistance according to EC6	104.4 kN	104.4 kN	128.3 kN	128.3 kN	148.6 kN	148.6 kN
Ductility(based on the bi-linear curve)	3.43	3.06	1.99	2.43	1.84	2.27

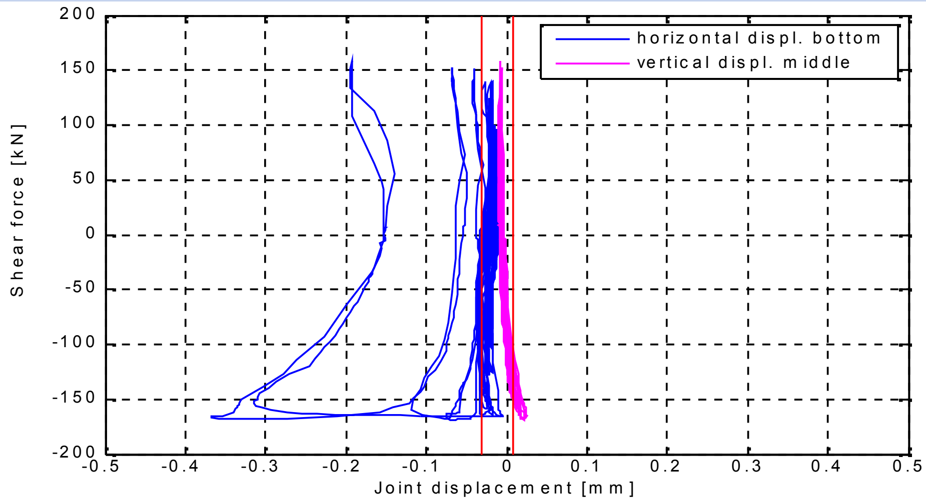
2. Characterization of material and structural properties

Full scale tests **TESTS ON PREFABRICATED T-SHAPED WALLS**

- **Main test results** ***Vertical Joint behaviour***

Joint displacement						
	C 1		C2		C3	
Characteristics values	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
Compression stage	0.012 mm	0.001 mm	0.009 mm	0.010 mm	0.015 mm	0.005 mm
Yield strength	0.062 mm	0.061 mm	0.009 mm	0.032 mm	0.004 mm	0.051 mm
Collapse	0.010 mm	0.410 mm	0.025 mm	0.360 mm	0.018 mm	0.071 mm





Vertical displacement from longitudinal shear

Horizontal displacement Joint opening

Elastic until shear cracking in main wall

2. Characterization of material and structural properties

Full scale tests

General conclusions of the 2 cyclic test series

1. **Specimens with door opening**
   1. **In the standard configuration, brittle failure at the lintel support**
   2. **Situations improved with longer lintel supports: same failure mode, but less brittle**
   3. **Sub-vertical cracking → failure in compression rather than in shear**
   4. **Both reinforcement systems (Vertical confinement, Murfor)are efficient mainly on the deformation capacity**

      BUT ● vertical confinement is not easy to implement in practice

      ● Murfor are too thick for thin-bed mortar layers

2. Characterization of material and structural properties

Full scale tests

2. Tests on T-shaped wallsGeneral conclusions of the 3 test series:

1. **Prefabrication character of specimens does not influence the cracking pattern**
2. **No significant joint shear or opening until significant shear cracking of the wall**
3. **Ultimate drift governed by shear (similar to the case without flange)**
4. **Ductility significantly increased (higher elastic stiffness for a similar ultimate drift)**

→ Suggestions for practice

- **Use longer lintel supports**
- **Target flexural failure modes (more ductile in case of high initial compression level)**
- **Higher q-factor could be used if transverse walls are considered in the analysis**

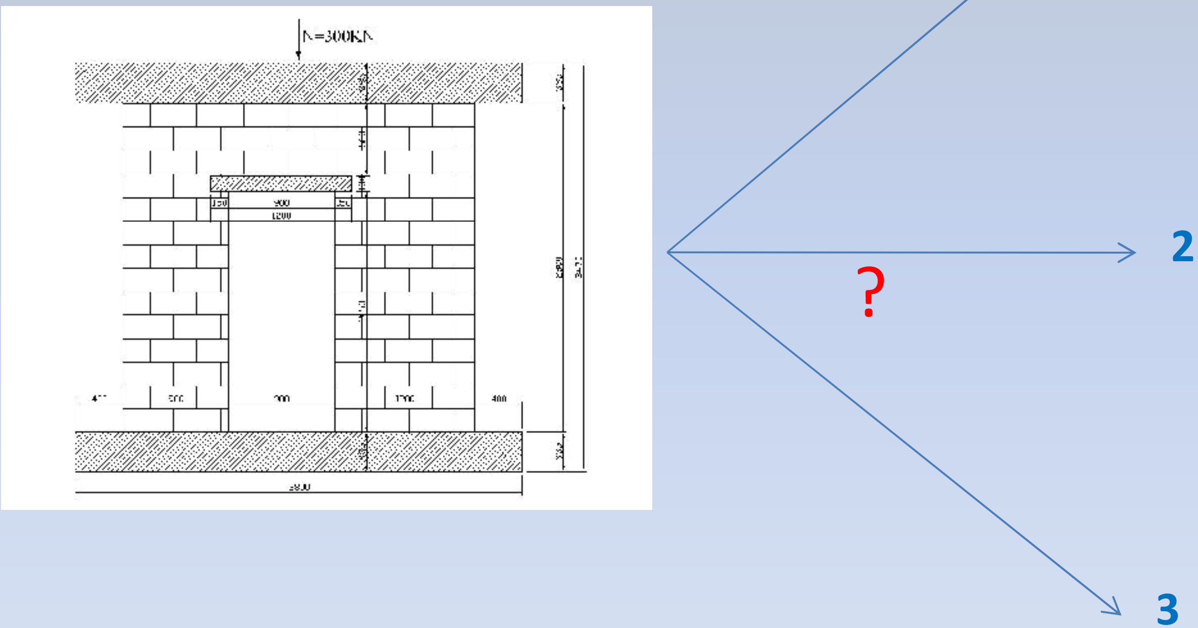
3. Seismic analysis

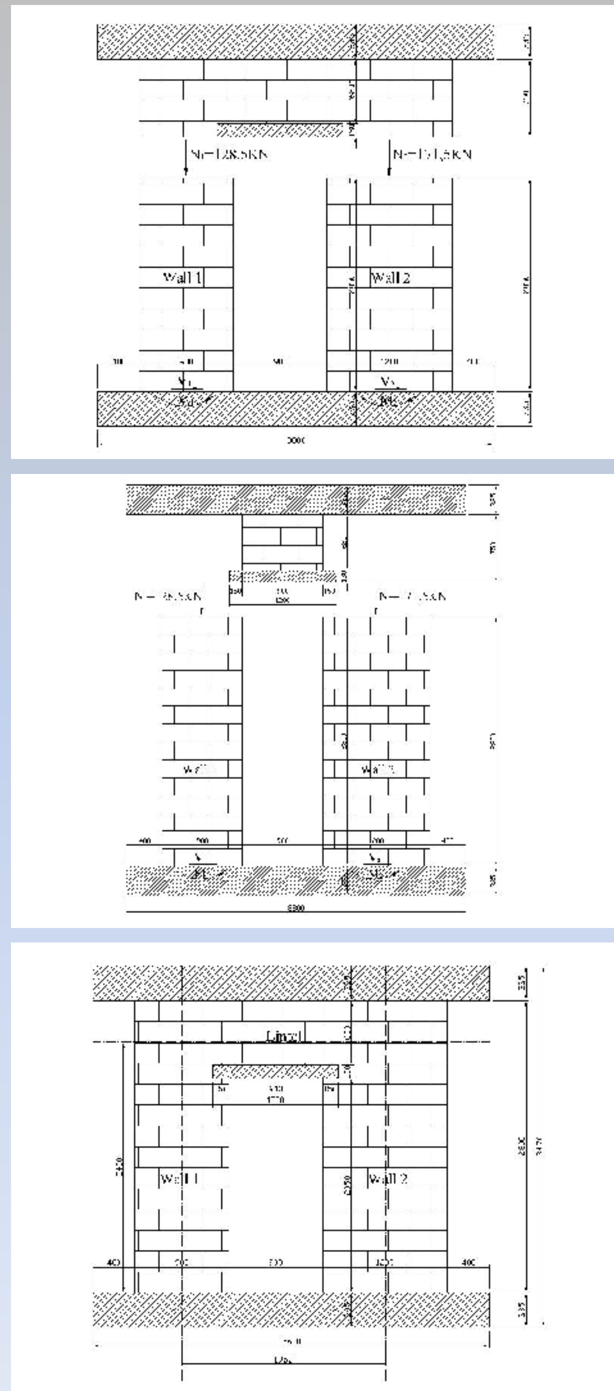
Wall with door opening

Problem of model for the framing elements

Problem of load redistribution

plastic redistribution or not?





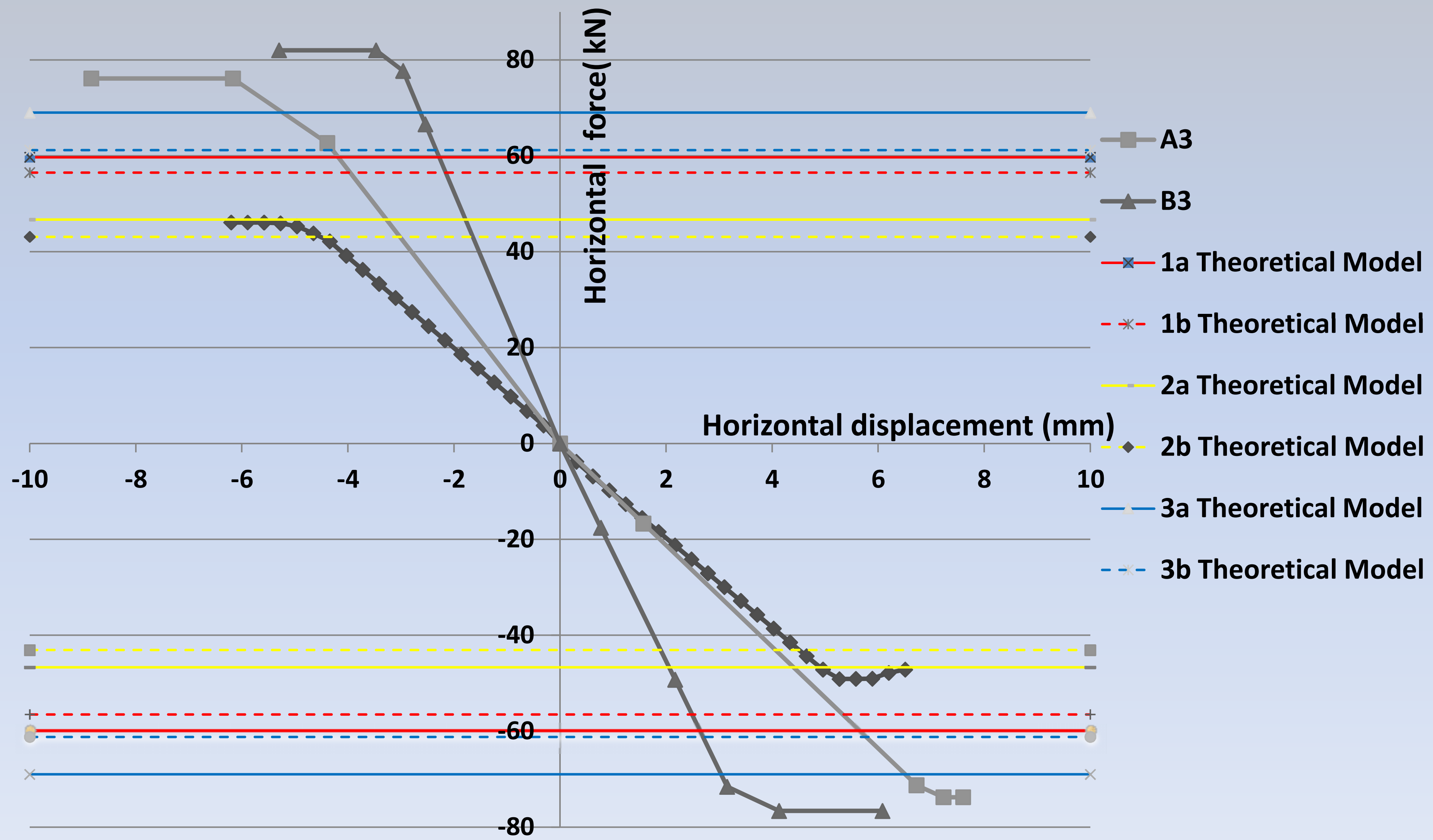
3. Seismic analysis

Wall with door opening – Influence of the framing elements

Computed or theoretical pushover curve

- - - - - - no redistribution

——— with redistribution



FUTURE SHORT TERM ACTIONS

► **Preparation of SERIES dynamic cyclic tests on shake table in Bristol**

● **4 in-plane shear/bending tests of isolated glued clay-block walls April 2012**

2 of those tests are made on walls includings acoustic isolation devices by 10 mm rubber mats in order to investigate the capacity of such rubber mats to achieve seismic isolation

● **2 tests on T-shaped walls coupled by a spandrel June 2012**

► **SERIES Shake table tests on full-scale models in LNEC (to be scheduled)**

Objective: validation of theroretical/numerical model of masonry structures in real conditions, including coupling by floor slabs and/or spandrels

► **Re-assessment of all available test results for calibration of the frame effect**

PERSPECTIVES

► **Evaluation of typical Belgian real cases**

► **Development of simple code rules**