EN 1996 AND MASONRY PART OF EN 1998: ELABORATION OF NAs AND RESEARCH FOR DETERMINATION OF NDPs

Miha Tomaževič

Slovenian National Building and Civil Engineering Institute
miha.tomazevic@zag.si

CONTENTS

Introduction: implementation of Eurocodes in Slovenia and elaboration of NAs

Some examples of research for determination of NDPs in NAs:

- Shear resistance

- Behavior factor

- Robustness of units

Proposals for NDPs to be included in NAs

1991: Office for standards and metrology at the Ministry of Science and Higher Education

2001: Slovenian Institute for Standardization (SIST) was formed and established mirror TCs for Eurocodes. No funding for expert work in the committees available

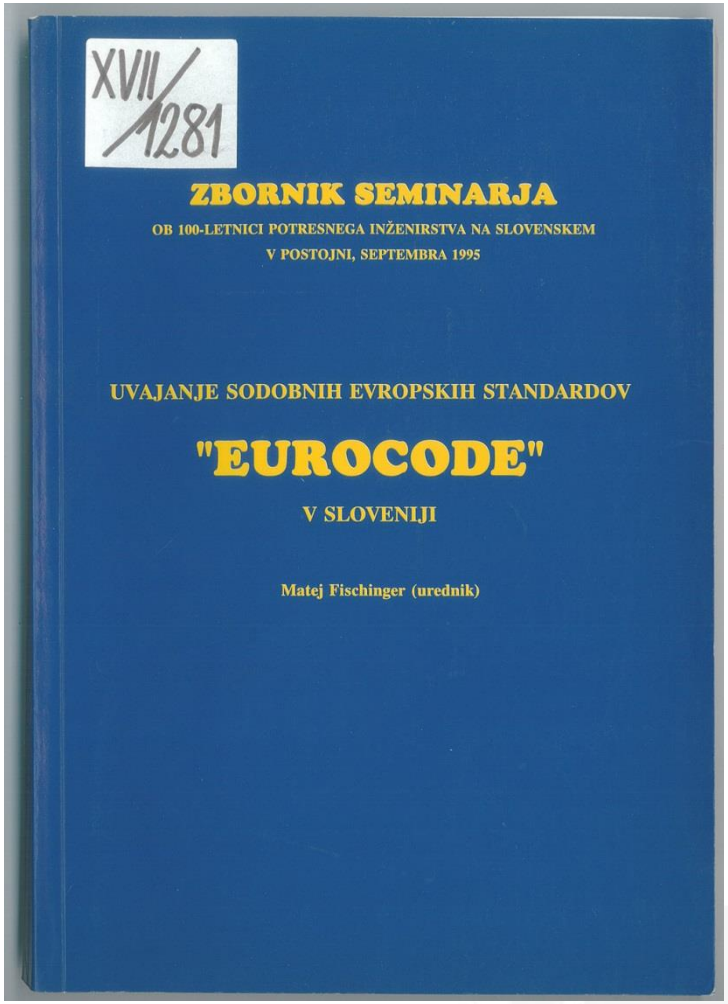
2004: SIST becomes full member of CEN and CENELEC

2005: Ministry of environment and planning passes Regulations for mechanical resistance and stability of buildings, which enables the official use of Eurocodes for the design of buildings in parallel to the existing Yugoslav codes and enforces the use of Eurocodes by the beginning of 2008. A general decision is made to translate the codes in Slovenian and temporarily use the recommended values of design parameters in National Annexes

Since the first drafts of ENVs were available, Eurocodes have been part of the teaching program for civil engineering students at the Faculty of Civil Engineering and Geodesy in Ljubljana

1994: at the Faculty of Civil Engineering, a manual for design of bridges by Eurocodes has been prepared for Motorway Company in the Republic of Slovenia (DARS). Since then, motorway bridges and viaducts in Slovenia are designed according to Eurocodes. The Carythia bridge in Maribor was the first bridge in Europe, designed and constructed in 1994/1995 according to EC 8-2.

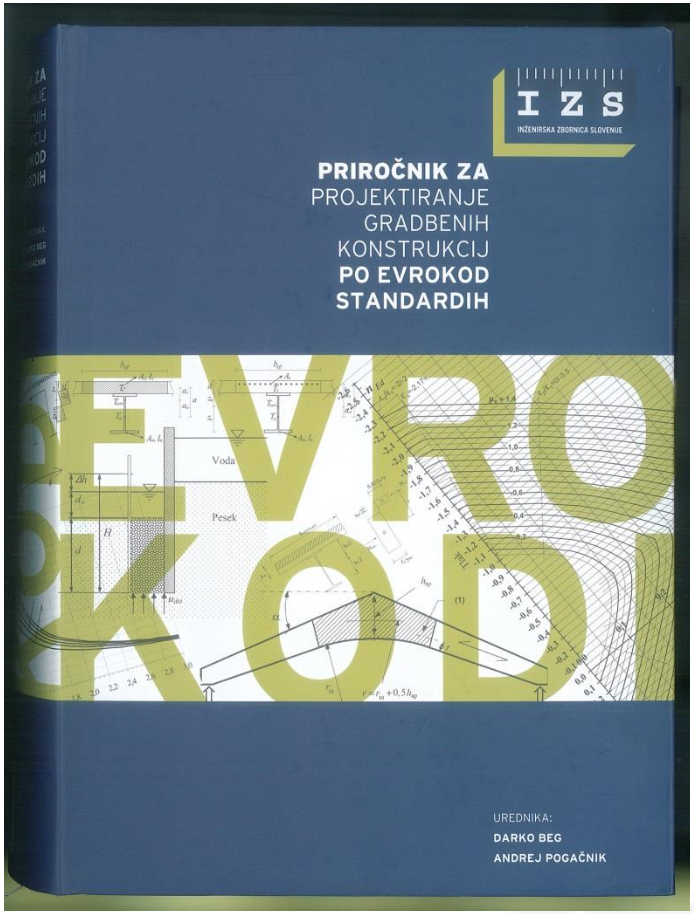
1995: at the occasion of the 100th Anniversary of earthquake engineering in Slovenia, a Seminar on implementation of Eurocodes was organized by the Institute of structures and earthquake engineering (IKPIR) of the Faculty of Civil Engineering



2005: Ministry of Environment and planning provides fundings for translation of Eurocodes to Slovenian. As a result of legal problems, SIST took over the action

2007: Chamber of engineers of Slovenia organizes a series of seminars for making civil engineers familiar with Eurocodes

2009: a publication of a manual (about 1000 pages) for the design of building structures according to Eurocodes was financed by the Chamber of engineers



National Annexes to EC 6 and masonry part of EC 8

In Slovenia, which is a seismic-prone country, the additional requirements of EC 8 in most cases over-rule the requirements of EC 6 and Eurocodes for other structural types. When preparing national annexes and proposing the values of NDPs, the attention has been given to seismic issues in masonry part of NA to EC 8.

In this regard, the idea to correct a few inconsistencies, occurring in EC 6 and EC 8, has been also followed. For example, simple buildings in EC 6, in the case of which simplified methods of calculations are required, are not simple buildings by EC 8, in the case of which no seismic resistance verification by calculation is required.

National Annexes to EC 6 and masonry part of EC 8

Design equations, given in EC 6, were not prepared by taking into consideration seismic loads. For example, equation for shear resistance of walls, based on the sliding shear (friction) mechanism does not reflect seismic situations. Similarly, equations for the design of reinforced masonry, same to be used in the case of all various reinforced masonry construction systems, do not take into consideration brittleness of masonry units and the effects of poor bond and anchorage . The values of seismic force reduction factors have been proposed without having available sufficient experimental background.

New technologies are introduced without knowing the possible difference in the behavior with regard to traditional masonry construction systems.

National Annexes to EC 6 and masonry part of EC 8

In Slovenia, the decision was made to include some traditionally used values of parameters, like minimum thickness of walls and compressive strength of units, whereas in most other cases, values of parameters as recommended in the main documents, have been adopted as the values of NDPs in both, NA to EC 6 and NA to EC 8.

Based on the results of several decades long experimental research and earthquake damage observations, Slovenian National Building and Civil Engineering Institute suggested modifications of EC 8 recommended values. The results of the recently carried out research projects have been also used to support the proposals.

EC 6: shear strength of masonry

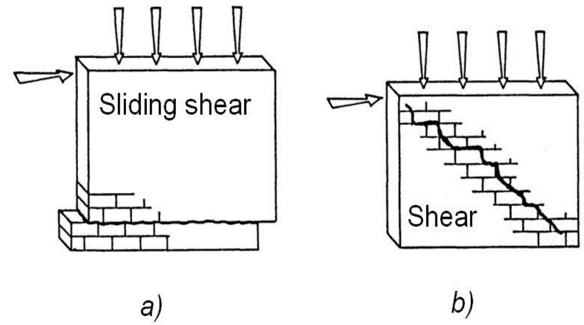
$$f_{vk} = f_{vko} + \mu_c \, \sigma_d$$

f_{vko} = the shear strength under zero compressive stress

μ_c = the constant defining the contribution of compression stresses

σ_d = the design compression stress, perpendicular to shear

Shear failure mechanisms

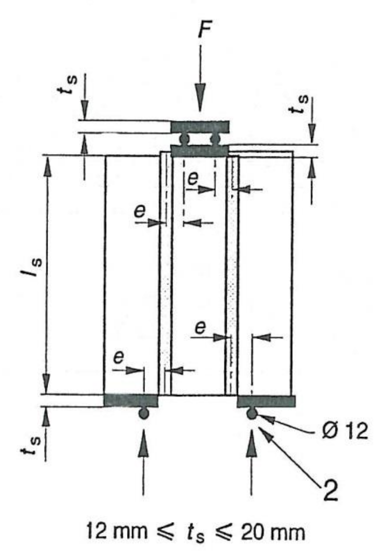


Tensile strength of masonry

$$f_t = \sigma_t = \sqrt{\left(\frac{\sigma_o}{2}\right)^2 + (b\tau_{max})^2} - \frac{\sigma_o}{2}$$

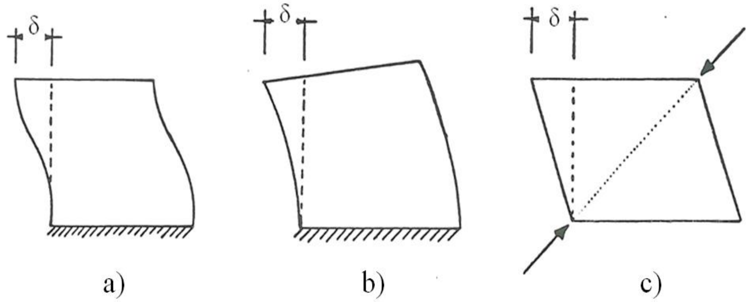
f_t = the tensile strength of masonry
σ_t = the principal tensile stress in the middle section
σ_o = working stress due to axial load N
τ_{Hmax} = the average shear stress in the wall at the attained maximum resistance

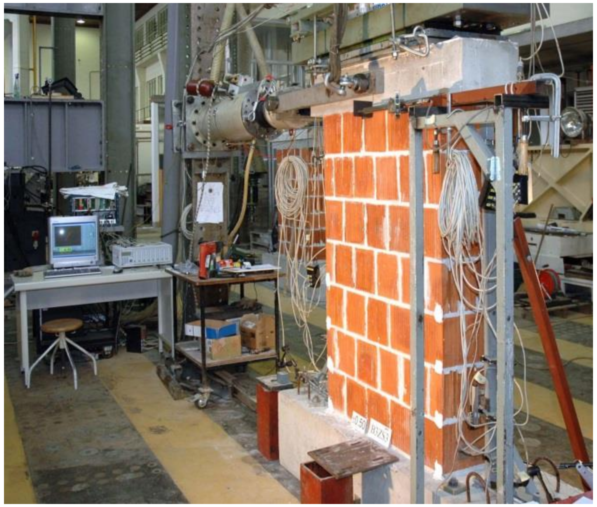
Initial shear strength of masonry

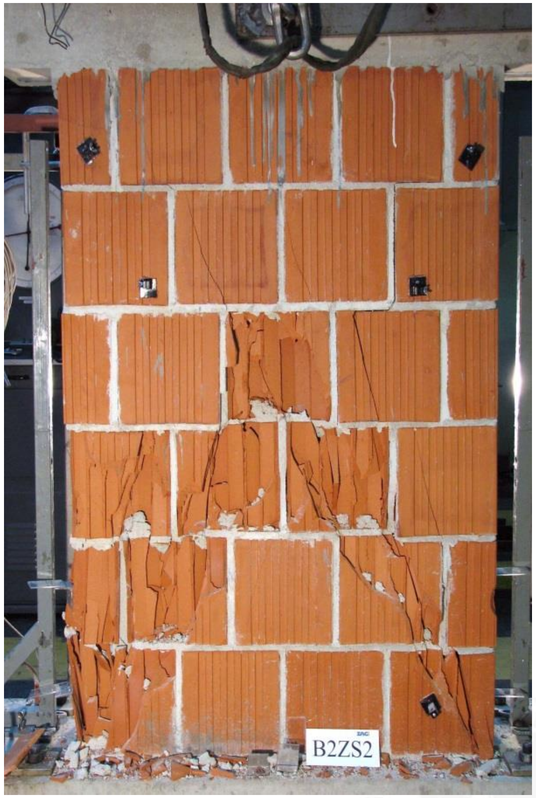


EN 1052-3

Tensile strength of masonry







Is there a correlation between shear and tensile strength of masonry?

$$f_{tk}' = \sqrt{\left(\frac{\sigma_d}{2}\right)^2 + (bf_{vk})^2} - \frac{\sigma_d}{2}$$

σ_d	$0.1\, f_k^*$	$0.2\, f_k^*$	$0.3\, f_k^*$	$0.4\, f_k^*$	$0.5\, f_k^*$
f_{vko}	f_{tk}’	f_{tk}’	f_{tk}’	f_{tk}’	f_{tk}’
0.20	0.400	0.530	0.665	0.803	0.941
0.30	0.541	0.663	0.794	0.929	1.066

Note: * - f_k = 5.0 MPa

Shear resistance

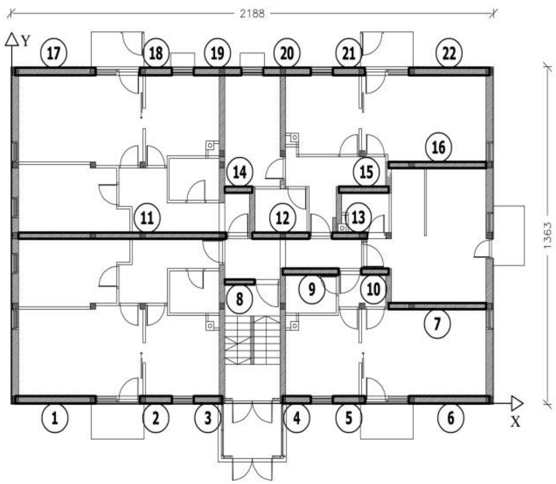
$$R_{\mathrm{ds,w}} = \frac{f_{\mathrm{vk}}}{\gamma_{\mathrm{M}}} t\, l_{\mathrm{c}}$$

$$R_{\mathrm{ds,w}} = A_{\mathrm{w}} \frac{f_{\mathrm{tk}}}{\gamma_{\mathrm{M}}} \frac{1}{b} \sqrt{\frac{\gamma_{\mathrm{M}}}{f_{\mathrm{tk}}} \sigma_{\mathrm{d}} + 1}$$

l_c – compressed part of the wall's length:

$$l_{\mathrm{c}} = 3\left(\frac{l}{2} - e\right)$$

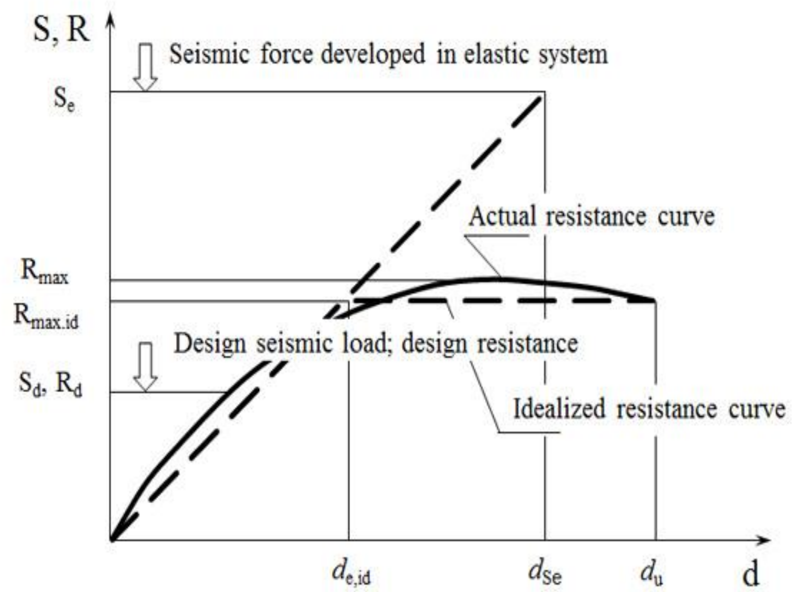
Shear resistance



a_g	F_{Bd} (kN)	$\Sigma R_{ds\text{-}EC6}$ (kN)		$\Sigma R_{ds\text{-}ft}$ (kN)
		$K_{e\text{-}test}$	$K_{e\text{-}EC6}$	
0.10 g	1928	3788	3677	2500
0.15 g	2892	3352	3007	2500
0.175 g	3374	3191	3026	2500
0.20 g	3856	2670	2572	2500
0.225 g	4337	2433	2111	2500
0.25 g	4819	428	1135	2500

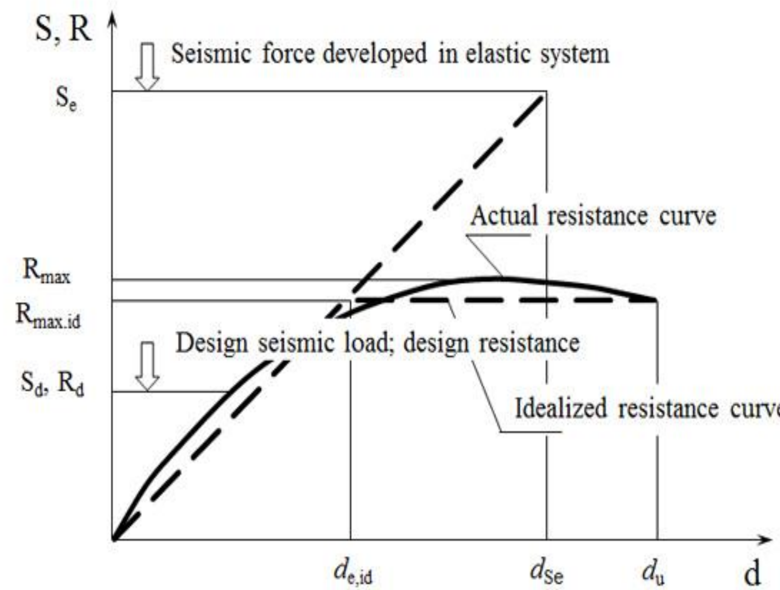
Structural behavior factor q

- ***The capacity of structural system to resist seismic actions in the non-linear range generally permits the design for forces smaller than those corresponding to a linear elastic response***
- ***To avoid explicit inelastic structural analysis in the design, the capacity of the structure to dissipate energy is taken into account by performing an elastic analysis based on a response spectrum reduced by the behaviour factor q***



Structural behavior factor q

Behavior factor q is defined as "an approximation of the ratio of the seismic forces that the structure would experience if its response was completely elastic with 5 % viscous damping to the minimum seismic forces that may be used in the design - with a conventional elastic analysis model - still ensuring a satisfactory response of the structure"



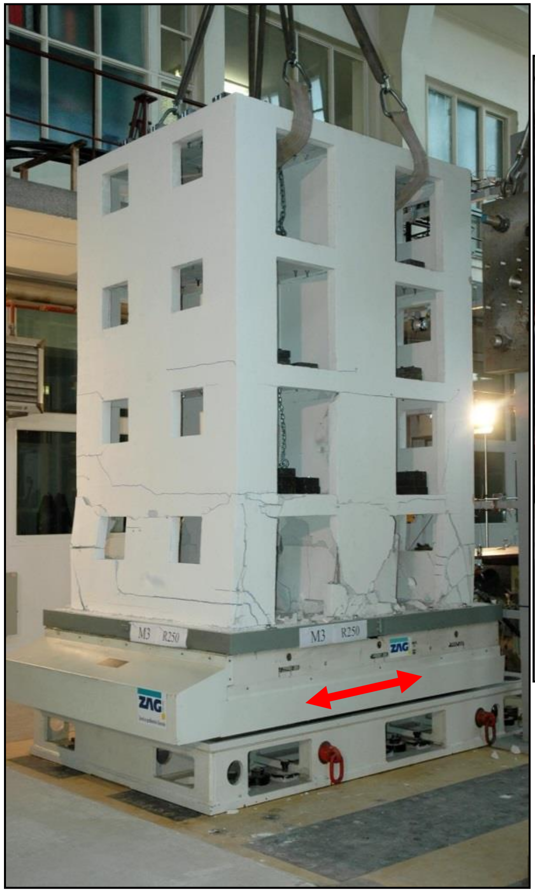
Equality of displacements:
$q = S_e/S_d$

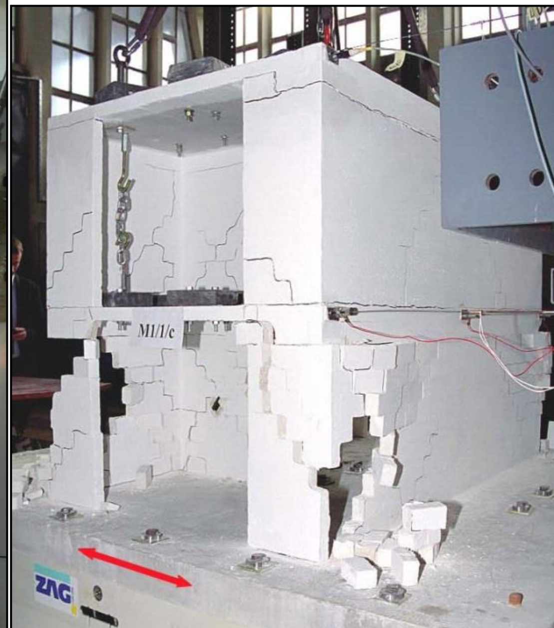
Equality of energies:
$q = (2\,\mu_u - 1)^{1/2}$

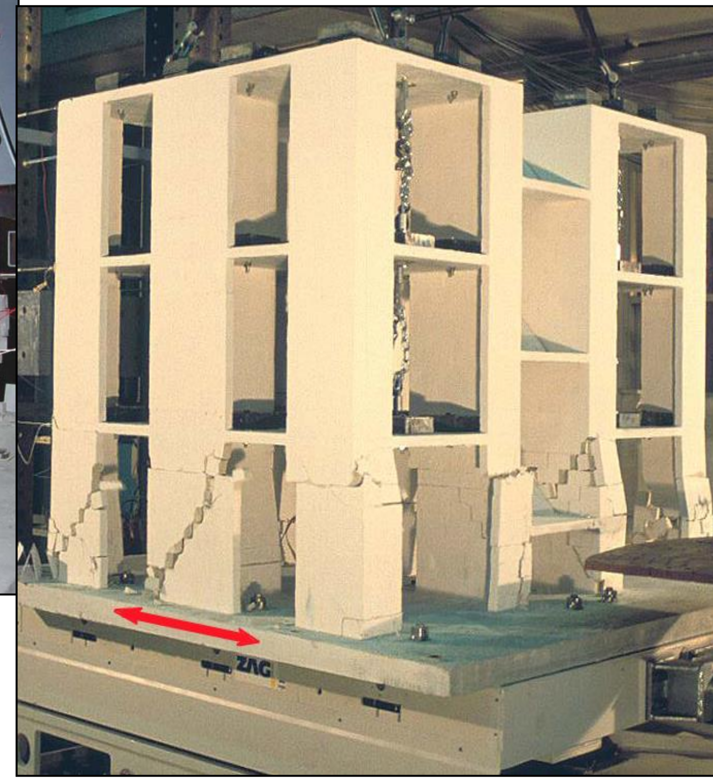
EC 8: Types of masonry construction and behavior factors q

plain masonry (EC 6)	<u>1.5</u>
plain masonry (EC 8)	<u>1.5</u> - 2.5
confined masonry	<u>2.0</u> - 3.0
reinforced masonry	<u>2.5</u> - 3.0

Note: The values ascribed to q use in a Country may be found in its National Annex. The recommended values are underlined







European Commission

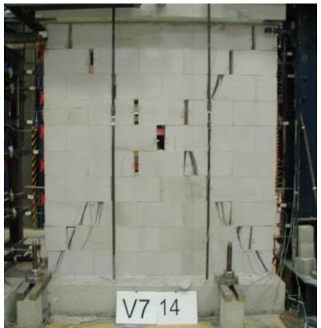
Model shaking table tests:

Similitude in dynamic behavior (mass, stiffness distribution)
Similitude in failure mechanims (preloading ratio)

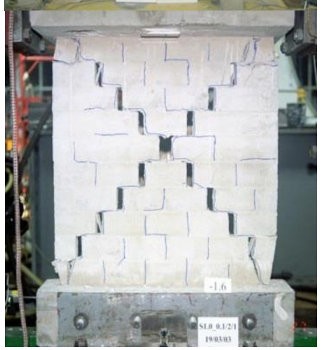
Similitude in failure mechanisms

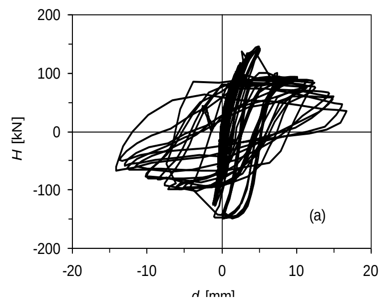
Montenegro earthquake of 1979, N-S component of Petrovac record, compressed

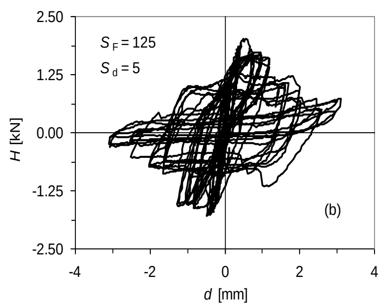
Prototype

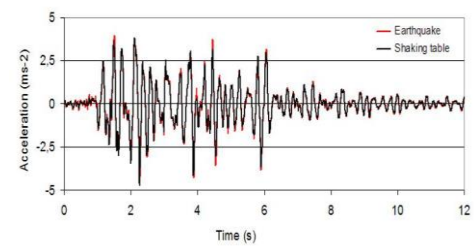


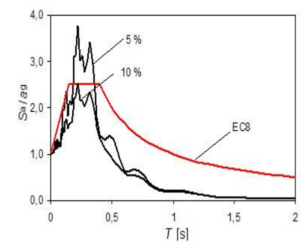
Model









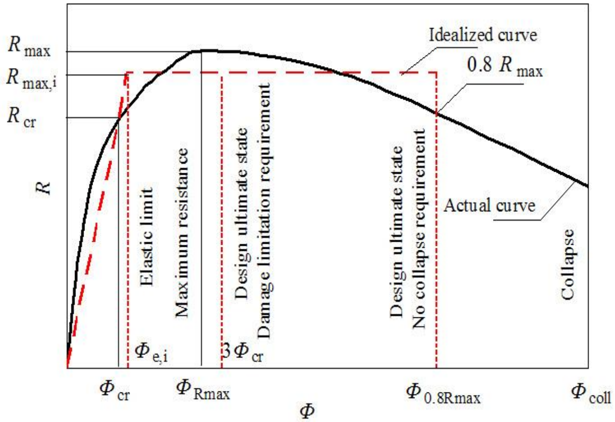


Model shaking table tests:

Similitude in dynamic behavior (mass, stiffness distribution)

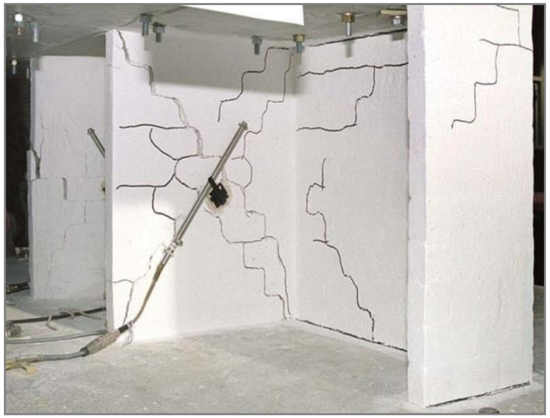
Similitude in failure mechanims (preloading ratio)

Acceptable damage and story drift



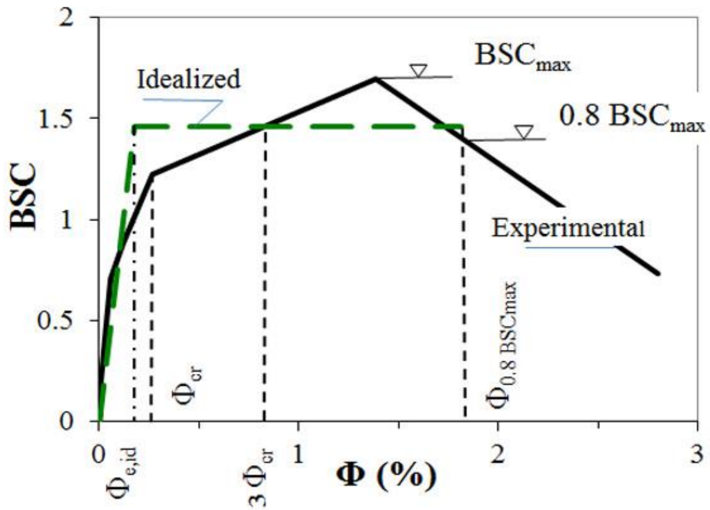
$\Phi_{cr} \approx 0.2 - 0.3$ %
$\Phi_{Rmax} \approx 0.4 - 0.5$ %
$\Phi_{u} \approx 1.0$ %

Damage grade 4: at 0.8 Rmax
(Model M2-2, R100/3, Φ_u = 1,77 %)



Damage grade 3: at maximum resistance
(Model M1-1c, R050, Φ_u = 0,9 %)

Evaluation of q-factor



System	No. of stories	Materials	$\Phi_{e,id}$ (in %)	Φ_{cr} (in %)	$\Phi_{0.8BSCmax}$ (in %)	$3\Phi_{cr}$ (in %)	$\mu_u = 3\Phi_{cr} / \Phi_{ei,d}$	
							μ_u	q
Confined	3	Clay block	0.17	0.28	2.60	0.84	4.94	2.98
	3		0.17	0.27	1.81	0.81	4.76	2.92
	3	AAC block	0.23	0.28	2.46	0.84	3.65	2.51
	3		0.36	0.48	2.27	1.44	4.00	2.65
	4		0.30	0.44	2.33	1.32	4.40	2.79
	3	Clay block	0.14	0.42	1.36	1.26	9.00	4.12
	3		0.23	0.55	3.16	1.65	7.17	3.65
Plain	3	Calcium silicate	0.07	0.20	0.42	0.16	8.57	4.02
	3	Clay block	0.16	0.33	1.65	0.99	6.18	3.37

Robustness of units

- Masonry units should have sufficient robustness in order to prevent local brittle failure
- National Annex may select the type of masonry units from EN 1996-1, Table 3.1, that satisfy this requirement

Units’ properties

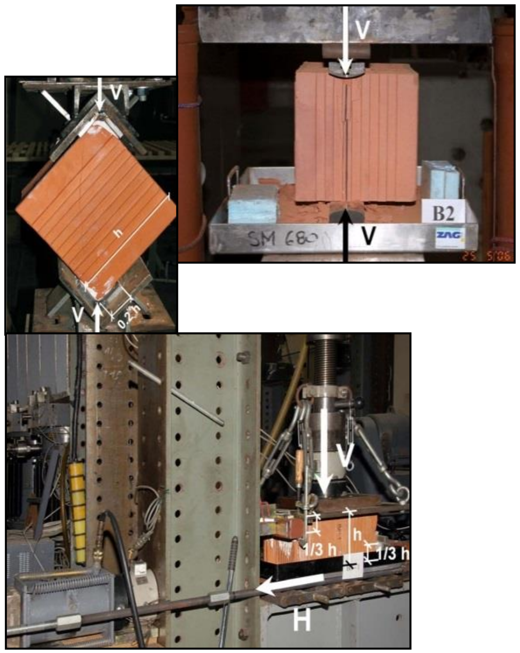
Designation of unit	B1	B2	B3	B4	B5	B6
Mean compressive strength of unit, $f_{b,m}$ (MPa)	18.2	11.4	12.8	11.4	10.2	29.1
Shape factor, δ	1.14	1.14	1.14	1.07	1.13	1.04
Normalized compressive strength of unit, f_b (MPa)	20.7	13.0	14.6	12.2	11.5	30.3
Compressive strength of unit parallel to bed joints, $f_{b,h}$ (MPa)	5.0	3.0	3.5	3.8	5.9	16.0
Ratio $f_{b,h}/f_b$	0.24	0.23	0.24	0.31	0.51	0.52
Gross density (kg/m^3)	806	811	880	863	860	1446
Net density (kg/m^3)	1941	1798	1860	1866	1756	1925
Water absorption coefficient (%)	11.0%	11.6%	14.2%	13.4%	13.8%	11.4%

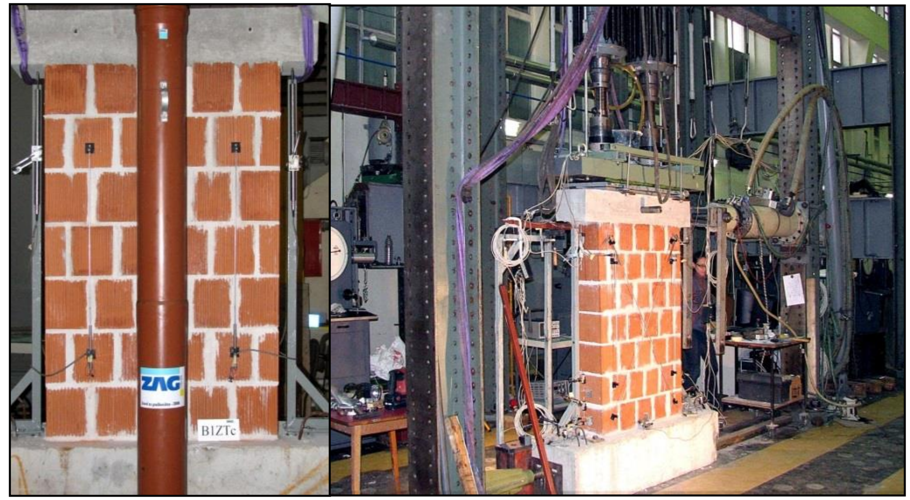
Designation of unit	B1	B2	B3	B4	B5	B6
Length, l (mm)	188	238	189	331	244	254
Width*, w (mm)	288	282	292	292	297	122
Height, h (mm)	189	234	188	189	236	121
Volume of holes (%)	58	55	53	54	51	25
Thickness of shells (mm)	9.8	10.8	11.4	11.7	11.8	21.6
Thickness of webs (mm)	6.5	6.7	7.2	7.4	6.8	7.3
Combined thickness of shells and webs - transversal (% of width)	20	41	35	33	35	46
Combined thickness of shells and webs - longitudinal (% of length)	24	18	24	21	24	48

* width of the units is equal to thickness of the walls.

Testing

Units





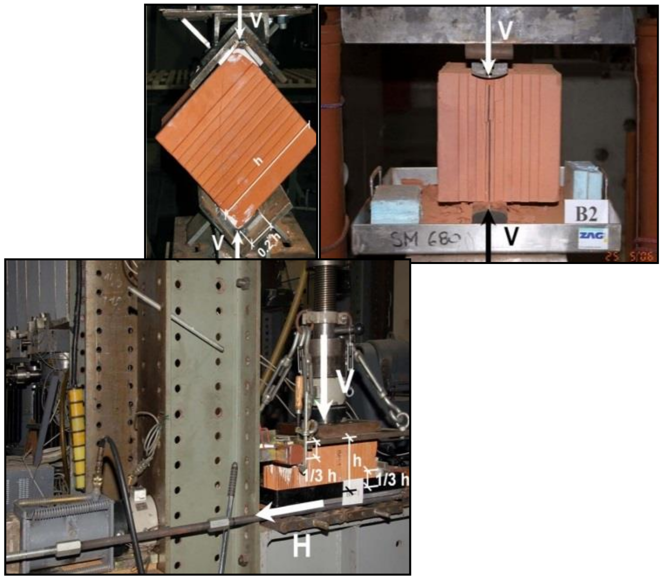
Unit	Cyclic shear tests			Compression tests
	Precompression level (σ_o/f_c)			
	0.30	0.20	0.15	
B1	2 walls	-	2 walls	2 walls
B2	2 walls	1 wall	1 wall	2 walls
B3	2 walls	-	2 walls	2 walls
B4	2 walls	2 walls	-	2 walls
B5	3 walls	-	3 walls	2 walls
B6*	2 walls	-	2 walls	1 wall
B6t**	1 wall	-	1 wall	1 wall

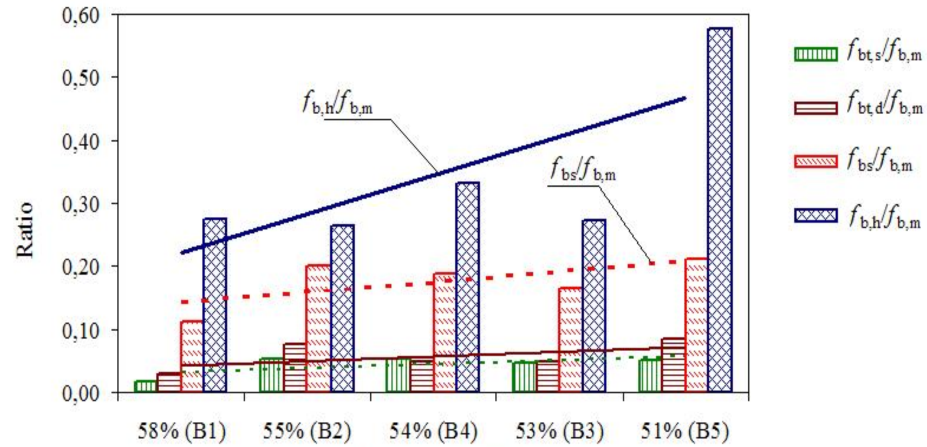
* Units type B6 are laid transversally, thickness of walls 24.9 cm

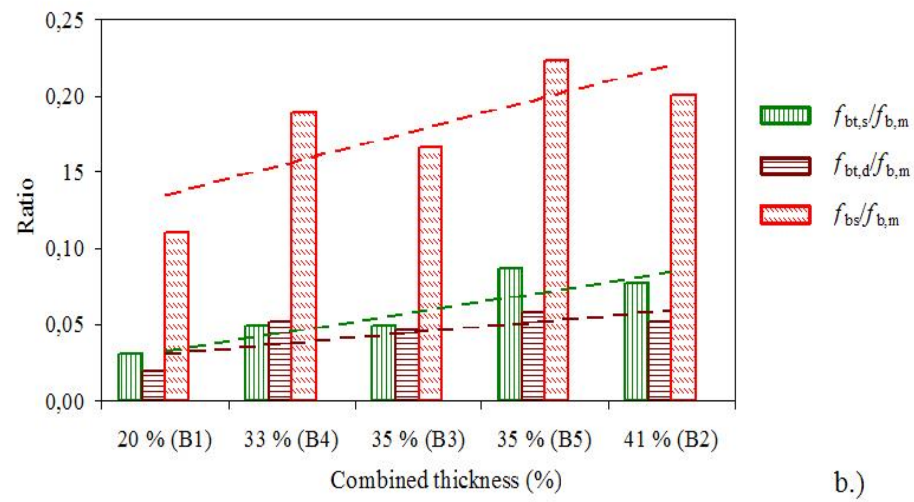
** Units type B6 are laid longitudinally, thickness of walls 12.3 cm.

Walls

Test results



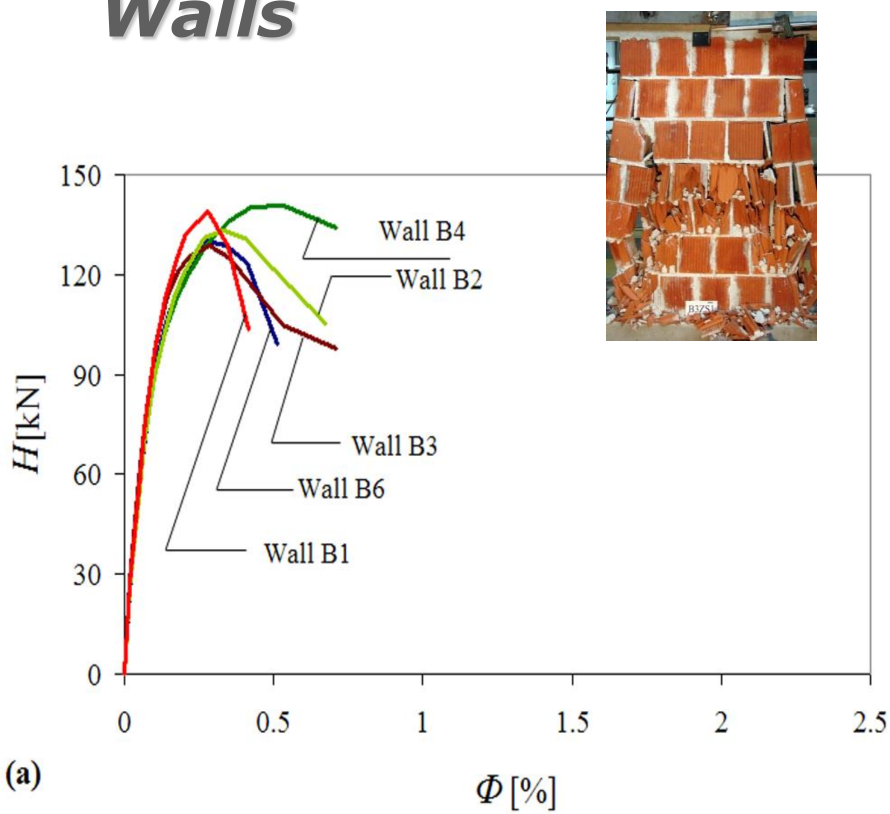


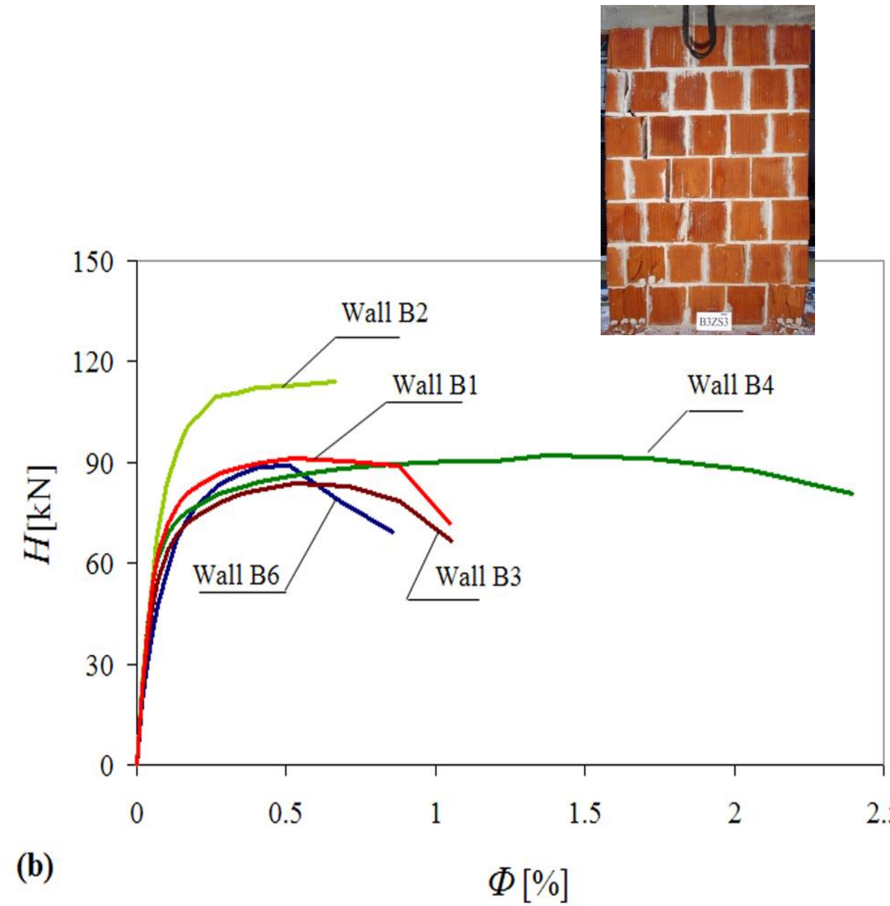


Units

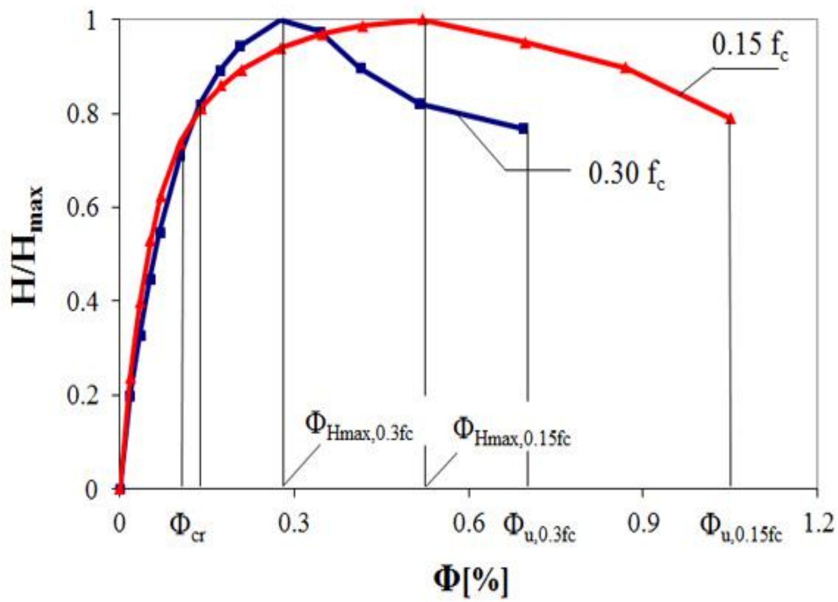
Test results

Walls





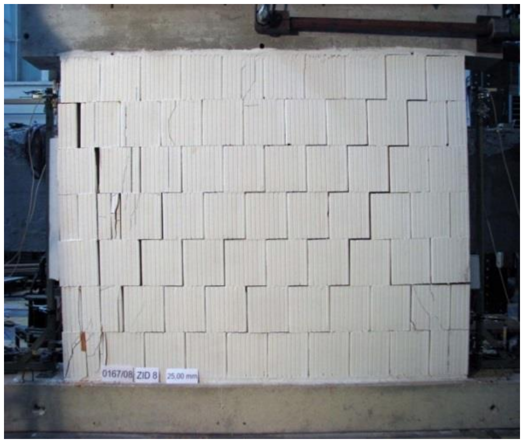
Test results: in-plane shear

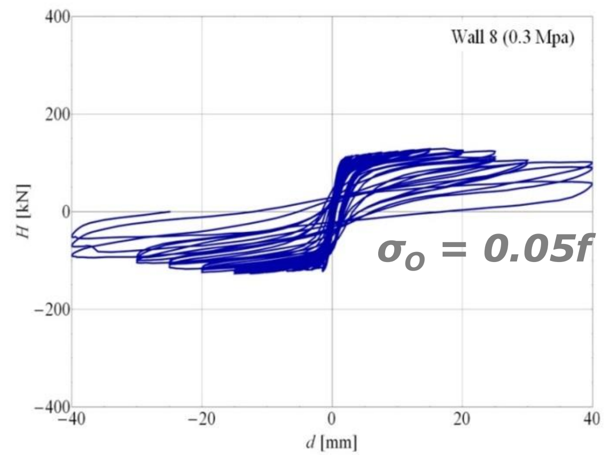


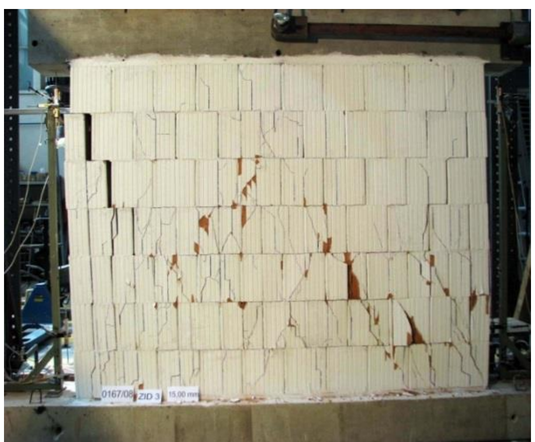
$\Phi_{cr} \approx 0.2 - 0.3$ %
$\Phi_{Hmax} \approx 0.4 - 0.5$ %
$\Phi_{u} \approx 1.0$ %

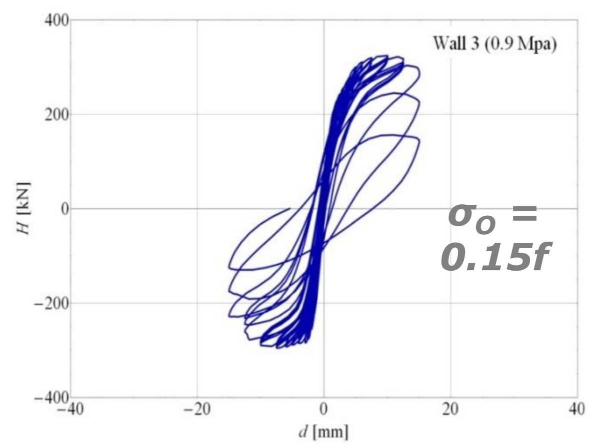
σ_o/f_c	Φ_{cr} (%)	Φ_{Hmax} (%)	$\frac{\Phi_{Hmax}}{\Phi_{cr}}$	Φ_u (%)	$\frac{\Phi_u}{\Phi_{cr}}$
0.30	0.27	0.34	1.26	0.60	2.22
0.15	0.44	0.62	1.41	1.12	2.54

“Robustness” depends on precompresion ratio









Conclusions and proposals for NAs

- ***Replace shear-friction formula for shear resistance of masonry walls with diagonal tension formula: not accepted***
- ***Use q-factors values at the upper limit of ranges, recommended in Eurocode 8, instead of recommended lower limit values. Upper limit values are adequate if verification methods are used which yield little overstrength, otherwise, even higher values may be used. Proposal not accepted.***

Conclusions and proposals

- ***Robustness of hollow clay blocks only partly depends on the units' type. The same units exhibit brittle local failure at high but adequate behavior at low level of preloading. Proposal: the use of Group 2 units should be limited by precompression ratio of 0,15-0,20 (compressive stresses in the walls should not exceed 15-20 % of the characteristic compressive strength of masonry). Accepted, but not yet implemented***

THANK YOU!