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MASONRY PANELS WITH DIFFERENT MORTAR JOINTS UNDER COMPRESSION

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Abstract

In this paper the results obtained on masonry square panels by compression tests (i.e. compression normal to the bed mortar joints and diagonal compression) are analysed considering the influence of different types of mortar joints on the strength of masonry.
Polynomial formulas for constitutive diagrams of masonry built by perforated clay blocks are evaluated by compressive tests on masonry panels.
F.E. analysis of block masonry walls under diagonal compression is developed considering both macro-modelling and micro-modelling approach.

Key Words

Mortar joints, clay blocks, compression tests, F.E. analysis.

1 Introduction

The knowledge about the compressive behaviour of masonry has increased during the last decades due to significant theoretical and experimental works. Moreover the codes of practice adopted in many countries allow to design masonry structures on the base of well defined principles and rules. Nevertheless there is still a considerable lack of experimental data regarding the influence of different types of mortar joints on the strength of masonry. Few data are available in scientific literature to define the influence of *unfilled vertical joints*, *shell bedded joints* and *continuous joints* on the compressive and shear strength of masonry panels.
The strength of masonry panels built with clay perforated blocks and different mortar joints was analysed by Capozucca et al (2000) on the base of experimental compression tests both normally and diagonally respect to the bed mortar joints.
In this paper the experimental results obtained on masonry square panels are used defining polynomial formulas for constitutive stress-strain diagrams. Further it was developed F.E. analysis of panels considering both macro-modelling and micro-modelling approach. Finally, a comparison between the theoretical data and experimental results allows to recognise the better approach in the modelling of walls built with perforated clay blocks and different mortar joints.

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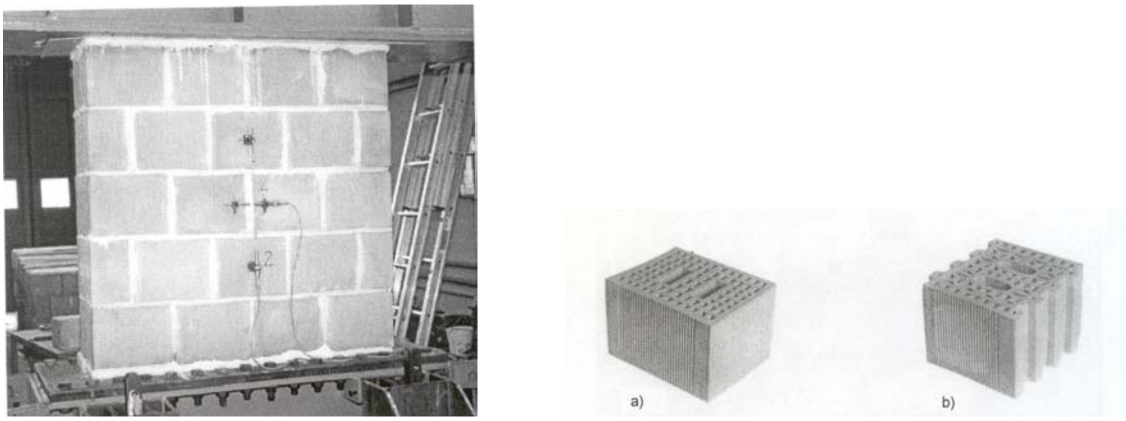
2 Experimental tests

The vertical compression and diagonal tests involved 38 specimens with different mortar joints: all joints filled, unfilled vertical joints and shell bedded joints. The experimental square panels with dimensions 1.0 m x 1.0 m and thickness 0.30 m were built with five layers of units (Fig. 1).



(a) (b)

Figure 1 – (a) Typical experimental wall and (b) perforated clay blocks.

The panels were built by clay blocks with smooth vertical surfaces and toothed vertical surfaces (Fig. 1). All units were characterised by 45% of holes on the gross area. The strength of the units and mortar are shown in Table 1.

Table 1- Experimental data for units and mortar

Type of unit	**Dimensions** (mm)	**Strength of unit*** (N/mm^2)	**Strength of mortar**
			Compression f_m=24.5N/mm^2
smooth	300x240x190	21	Bending f_f = 4.6N/mm^2
toothed	300x270x190	24	

*Direction of compression load parallel to the holes

2.1. Results by compression normal to the bed joints

Geometric parameters and different mortar joints are indicated in the Table 2 considering 36 experimental panels subjected to compression tests. For all the groups 3 specimens regarded panels built with smooth and toothed units. In the Table 2, average experimental values of the compressive strength σ_y and the Young's modulus E_y evaluated for the panels subjected to the load applied normally to the bed mortar joints, are shown. The strain measures were recorded during the compression tests by the electronic inductive instruments laid on the surfaces of the walls.
Further simply compression tests with load parallel to the bed mortar joints regarded also 2 panels of $\mathbf{A_s}$ group.
The experimental results of compressive stress values allow to carry out some considerations linked to the type of mortar joints:

- the presence of continuous bed mortar joints guaranties a higher compressive strength both in the case of units with smooth lateral surface, $\mathbf{A_s}$, and toothed lateral surface, $\mathbf{A_t}$;
- lower average values of failure compressive stress are recorded for the groups $\mathbf{B2_s}$ and $\mathbf{C_s}$ - $\mathbf{C_t}$, respectively, characterised by shell bedded mortar joints with

central strip of 150 mm, equal to ½ of thickness of panels, and unfilled mortar joints;
- the presence of shell bedded mortar of joints with central strip equal to 50 mm has a limited influence on the response under compressive load in the case of **$B1_s$** group.

Table 2 - Experimental results by compression tests

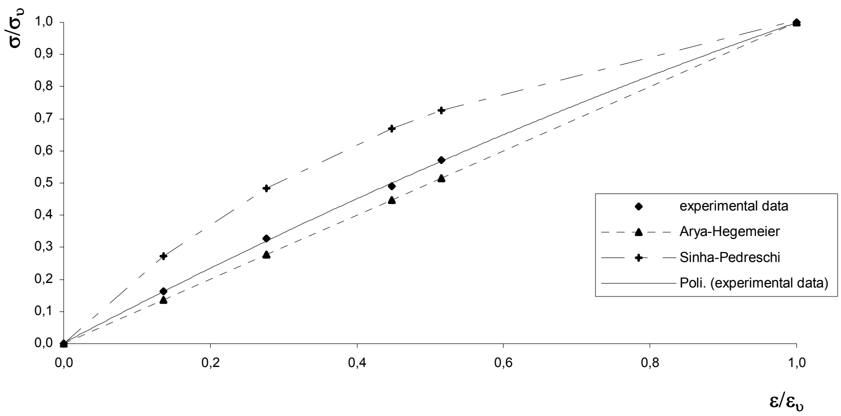
Type of panels	Bed mortar joints	Vertical mortar joints	Unit	No.	specimen	Average value σ_u (N/mm^2)	Average value E_y (kN/mm^2)
As	continuous	continuous	smooth	6	As 4 As 5 As 6	**9.9**	**10.0**
B1s	shell bedding (1) central strip 50mm	shell bedding (1) central strip 50mm	smooth	6	B1s 3 B1s 5 B1s 6	**7.9**	**9.7**
B2s	shell bedding central strip 150mm	shell bedding central strip 150mm	smooth	6	B2s 1 B2s 2 B2s 3	**4.6**	**6.5**
Cs	shell bedding central strip 150mm	absent	smooth	6	Cs 4 Cs 5 Cs 6	**4.1**	**4.8**
At	continuous	absent	toothed	6	At 3 At 4 At 5	**8.7**	**11.1**
Ct	shell bedding central strip 150mm	absent	toothed	6	Ct 2 Ct 4 Ct 6	**4.9**	**6.1**

(1) The term shell bedding applies to masonry indicates two equal strips of mortar at the outside edges of unit.

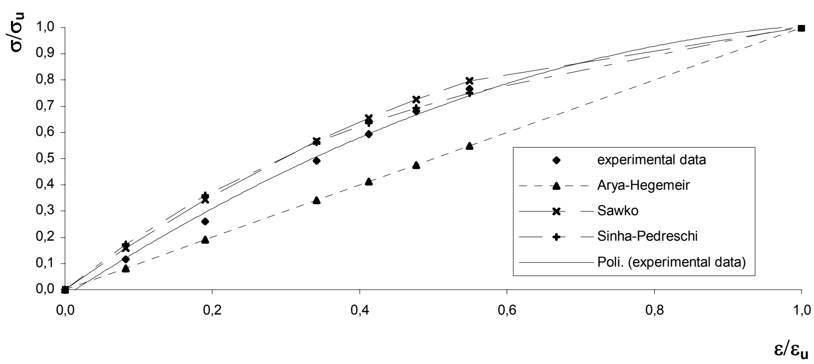
The experimental stress vs. strain diagrams for the walls subjected to compression permit to evaluate polynomial formulas which can be used to describe the behaviour of block masonry with different mortar joints under compression (Capozucca 2002).
The polynomial formulas may be also compared with some laws suggested by some Authors. The following cubic polynomial formula is generally adequate to describe a constitutive stress vs. strain diagram for masonry:

$$\frac{\sigma}{\sigma_u} = a\left(\frac{\varepsilon}{\varepsilon_u}\right)^3 + b\left(\frac{\varepsilon}{\varepsilon_u}\right)^2 + c\left(\frac{\varepsilon}{\varepsilon_u}\right) + d \qquad (1)$$

The coefficients are determinate by theoretical laws obtained analysing the experimental data using the minimum quadratic method.
In the Figures 2 a, b and c diagrams deduced by experimental data are compared with theoretical laws proposed by Turnesec and Cacovic (1970), Arya and Hegemeir (1978), Sawko (1982), Sinha and Pedreschi (1982;1983) and Binda et al (1988).



a)



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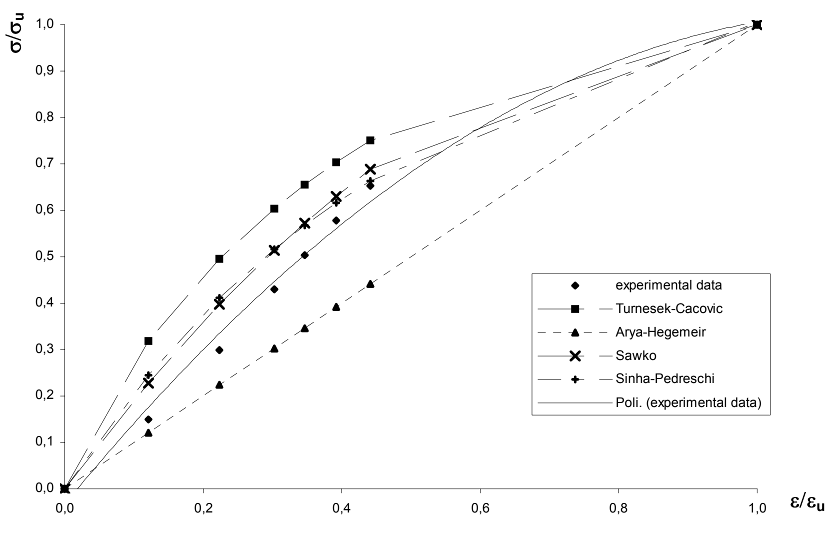


c)

Figure 2 – Experimental diagrams and comparison with theoretical laws for a) B1s 6, b) As 5, c) At 5

The constitutive equations for masonry panels built with smooth and toothed blocks are shown below. For panels built with horizontal and continuous joints (type $\mathbf{A_s}$ and $\mathbf{A_t}$) the constitutive equation is:

$$\frac{\sigma}{\sigma_u} = -0{,}47\left(\frac{\varepsilon}{\varepsilon_u}\right)^2 + 1{,}47\left(\frac{\varepsilon}{\varepsilon_u}\right) \qquad (2)$$

with value of strain under monotonic load increasing equal to ε_u = 0.127%o.
The presence or not of the vertical joint does not influence the equation but it increases the ultimate strain. For panels of type $\mathbf{B1_s}$ (or $\mathbf{B2_s}$) where horizontal and vertical joints have been made uninterrupted for 50 (or 150mm), the obtained constitutive equation is:

$$\frac{\sigma}{\sigma_u} = 0{,}98\left(\frac{\varepsilon}{\varepsilon_u}\right) \qquad (3)$$

with a strain at ultimate load equal to ε_u = 0.855%o.

2.2. Results by compression parallel to bed joints

In the Table 3 there are shown the values of Young's modulus E_x , the Poisson's coefficient ν_{xy} and strength σ_u evaluated in the direction parallel to the mortar beds (direction x) related to two panel of type $\mathbf{A_s}$ with continuous joint of mortar.
In Figure 2 it has shown a panel in the condition of collapse. The values of mechanical parameters for panel $\mathbf{A_s}$ are utilised for the theoretic analysis of panel by F.E.M. considering the orthotropic behaviour of masonry.

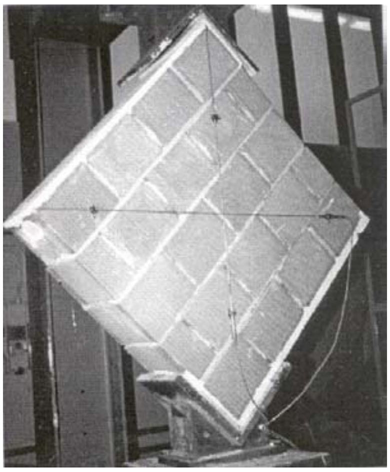
Table 3 – Exp. values obtained by compression parallel to the bed mortar joints

Type	σ_u (N/mm^2)	E_x (N/mm^2)	ν_{xy}
As	3,69	2654	0,0992

Figure 3 – Compression failure by loading parallel to the bed mortar joints

2.3. Results by diagonal compression tests

The tests of diagonal compression have been conducted with referring to the standard ASTM E 519-81. This type of test is often wrongly considered as a test of pure shear.
In fact, the results of Frocht (1931), based on photoelastic solution, and those obtained by Yokel and Fatal (1976) evidence that the tensional state is complex in the panel. In the centre of the panel the values of principle stresses are equal to $\sigma_1 = 0{,}7336\ \tau$ and $\sigma_2 = -2{,}380\ \tau$ being τ the average shear stress along the diagonal $\tau = P / bt\sqrt{2}$.
The instrument of measurement of strain used in the diagonal compression tests consists in 2 inductive transducers apply to the panel surface (Fig. 4).



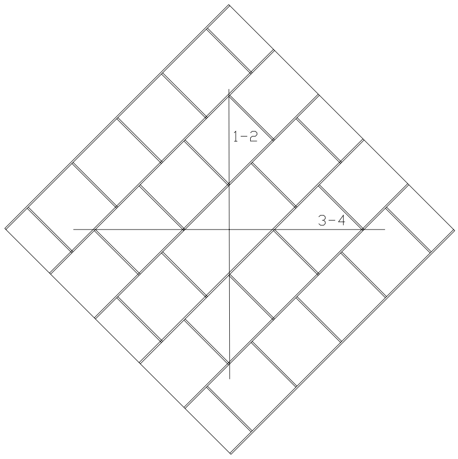


Figure 4 – Transducer displacement instruments for diagonal compression.

In the Table 3 the average experimental data obtained by the response of 3 panels - $\mathbf{A_s}$ and $\mathbf{A_t}$ type - under diagonal compression are shown. The average diagonal failure load P_u for $\mathbf{A_s}$ and $\mathbf{A_t}$ is, respectively, equal to 403kN and 169kN.

Table 3 – Results by diagonal tests for As and At specimens

$\mathbf{A_s}$ Diagonal Load (kN)	ε_o Horizontal Strain(10^{-6})	ε_v Vertical Strain(10^{-6})	$\mathbf{A_t}$ Diagonal Load (kN)	ε_o Horizontal Strain(10^{-6})	ε_v Vertical Strain(10^{-6})
0.0	0	0	0.0	0	0
19.0	4	-14	19.0	1	-26
64.3	11	-56	40.0	6	-54
127.7	25	-114	80.3	18	-109
183.7	37	-166	117.6	30	-160
227.0	49	-205	144.5	47	-202
274.3	61	-251	-	-	-

3 Analysis of panels under diagonal compression by FEM

Masonry is a material which exhibits distinct directional properties due to the mortar joints. In general, the approach towards its numerical representation can focus on the micro-modelling of the individual components, unit and mortar, or the macro-modelling of masonry as a composite. In the first approach, Young's modulus, Poisson's ratio and, optionally, inelastic properties of both unit and mortar are taken into account.
However an accurate micro or macro-modelling of masonry requires experimental knowledge of the material.

3.1. Macro-modelling

Considering $\mathbf{A_s}$ panels the masonry was assumed both as an orthotropic and isotropic material. As isotropic material we assumed the following Young's modulus E=10.0 kN/mm^2 and Poisson's coefficient ν = 0.1. As orthotropic material the moduli were E_x=2657 N/mm^2, E_y=10018 N/mm^2, G_{xy} = 2016 N/mm^2, ν_{xy} = 0.0992. In the Figure 5 the theoretical results are compared with the average experimental diagrams - diagonal load, P, vs. vertical strain ε_v (and horizontal strain ε_o) - obtained by diagonal tests. An orthotropic modelling describes the real behaviour in a better way.

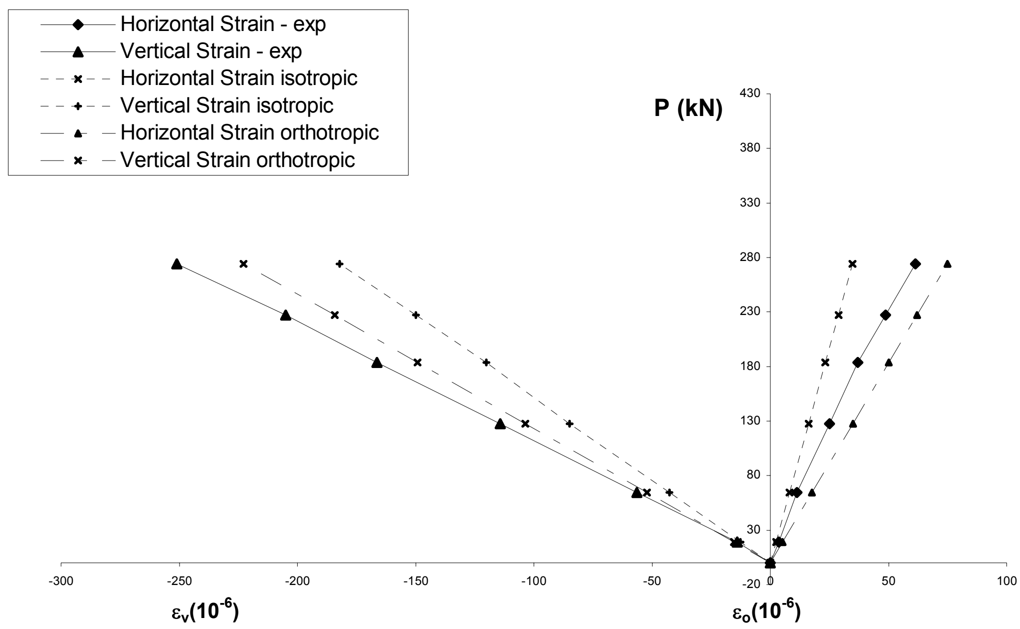


*Figure 5 – Comparison between average exp. and theor. data (**As** panels).*

In the analysis of $\mathbf{A_t}$ panels only an isotropic material has been considered: E = 11.1 kN/mm^2, ν = 0.1. That modelling underestimates the real strain of the panel and the average error of the vertical strain is 57% and the one of the horizontal strain is 54%. Also in this case, an analysis, which considers the material as an orthotropic one, can be more suitable.

3.2. Micro-modelling analysis

In the simplified micro-modelling the masonry is modelled considering the blocks connected to elements of interface which describes the behaviour of the mortar joints. Each block has been modelled by 69 plate-shell elements. The mechanical parameter obtained by the experimental tests of every block are the following (y is the direction of the holes of block): E_x = 5800 N/mm^2, E_y = 8910 N/mm^2, ν_{xy} = 0.117, G_{xy} = 3077 N/mm^2. Concerning the mortar it has been defined a beam cut off – bar element. The following mechanical parameters have been assigned to the mortar joints: horizontal joint E = 15.0 kN/mm^2, ν = 0,198; vertical joint E = 0.3 kN/mm^2, ν = 0.198. It has been assumed the following values of strength of the mortar: 25 N/mm^2 and 3.9 N/mm^2, respectively for the compression and tensile one. The results of the analysis with micro-modelling and the one with macro-modelling assuming the orthotropic material concerning the **As** panels are shown in Figure 6. They show that the analysis with the micro-modelling gives results closer than the experimental ones.

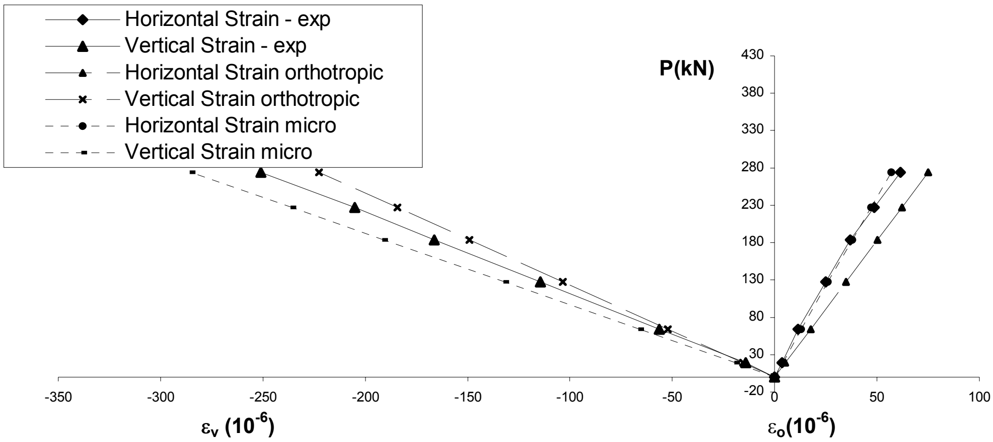


*Figure 6 – Comparison between average exp. and theor. data (**As** panels)*

4 Conclusions

The above experimental and theoretical analysis permits to underline the following conclusions:

i) the behaviour of panels with different mortar joints is very different especially under diagonal compressive load;

ii) in the case of panels with continuous joints the constitutive law may be a quadratic polynomial formula while in the case of masonry with shell bedded joints the law is quite linear;

iii) in the theoretical analysis by macro-modelling the assumption of masonry as orthotropic material is necessary to obtain adequate results.

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