Evaluation of the resistant behaviour of concrete block masonry bearing walls subjected to flexo-compression transverse to their plane, with and without reinforcement, by testing prism specimens

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Abstract
This research shows a theoretical-experimental study of resistant behaviour of concrete block masonry bearing walls, with and without reinforcement, subjected to flexo-compression transverse to their plane.
In order to carry out this investigation 21 masonry walls were tested, each of them had a height of 2.6m and (0.14 x 1.00) m^2 cross section, submitted to a scheme of equal eccentricities of load and of the same sense in the top and bottom part of the wall. The analyzed eccentricities were: e=0, e=t/6; e=t/3 and e=t/2. Likewise 6 "prisms" were tested, with and without grout, which are the test specimens that the American Society for Testing and Materials "ASTM" [3] proposes to evaluate the compressive strength masonry.
The results of the resistant behaviour of the walls, obtained experimentally, have been compared with those proposed of the design codes Europeans: Eurocode EC6 [7, 8], the British Standards Institution "BSI" [4, 5], as well as with the proposals of the design codes Americans: National Masonry Association "NCMA" [9] and the American Concrete Institute "ACI" [1]. In the same way, the experimental results have been compared with the proposition made for this type of walls by the researchers Yokel, F.Y.; Mathey, R.G. and Dikkers, R.S. [14, 15]; who may possibly be those who most tested these types of walls to international level.

1 Reach of the investigation

The fundamental objectives that correspond to this investigation are the following ones:

- Determine the break loads experimentally, with different eccentricities, of concrete block masonry bearing walls (with and without reinforcement): of 2.6 m of height and (0.14 x 1.00) m^2 of cross section; that is to say, with a geometric slenderness (λ) of 18.6. The results of these tests will be confronted with the theoretical proposals that keep in mind the unfavourable effects of the eccentricities and of the slenderness, in the behaviour of the wall.
- Obtain "coefficients of step" of the resistance of "Prisms" [3] (simple specimens of executing, to transport and relatively economic), to that of the masonry walls of the previous paragraph. It is sought with it, using the analytic existent formulations, to arrive to realistic previsions of the loads resisted by masonry subjected to flexo-compression transverse to their plane.

The model experimental elect, for the introduction of the loads, is a scheme of same eccentricities and of the same sense (single curvature).

In order to complete the objectives of this investigation, in their experimental part, the plan of tests of the Table 1 have been programmed.

Table 1: Plan of tests

Tests	Investigated variables
Constituent materials	- All (Blocks, Mortars, Grout and Reinforcements).
Walls (Of 1 x 2.6 m^2): 21 elements. (*) Thickness of the block, t=14 cm	- Eccentricity of the load. - Influences of the grout.

2 Experimental investigation realized

2.1 Properties of the basic materials

The block type and the batching of the mortar and grout, used in the present investigation, they are indicated in Fig. 1 and Tables of the 2 at the 4.

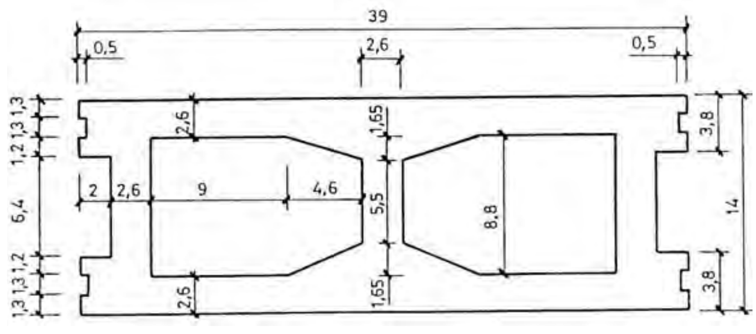

Figure 1: Dimensions of the block used in the investigation

As for the reinforced masonry, the reinforcement has been distributed vertical as horizontally. For the vertical reinforcement, it has been opted to use a steel of 10 mm of diameter for each alveolus of the block. This steel, distributed throughout the axis of the wall, leads to a geometric quantity of 0.28%; bigger in 40% of the minimum settled down in the design codes (0.2%). The steel type has been AEH-500S, with a nominal elastic limit of 616.15 N/mm^2.

In what concerns to the horizontal reinforcement, a jealousy (type Murfor RND) has been placed in each bed joint mortar. The elected diameter has been of 4 mm, being obtained this way a geometric reinforcement ratio of 0.07% (minimum settled down by the design codes). See you Table 5.

Table 2: Compression strength of saturated blocks rehearsed according to UNE 41-172 [12]

Age (days)	Average breaking load (KN)	Average compressive strength (KN/mm^2)	
		S/ Gross area	S / Net area
193	439	8.04	14.95

Note: Gross area = 546 cm^2 // Net area = 293.62 cm^2 (value according to geometry).

Table 3: Batching of the used mortar

Batching (M-80)	Water-cement ratio	Half slump cone (cm)
Cement = 1 Lime = 0.5 Sand = 4	1.18 - 1.24	18

Table 4: Batching of the used grout

Batching	Water-cement ratio	Half slump cone (cm)
I cement = 1 Sand = 2.25 Coarse aggregate= 1	0.83 - 0.86	20.5

Table 5. Characteristic geometric of the bed joint reinforcement

Type	Wide (mm)	Diameter wires longitudinal (mm)	Diameter wires diagonal (mm)	Distance between weldings (mm)	Section of 2 longitudinal wires (mm^2)
RND / Z	100	4	3.75	406	25

2.2 Investigation elements

Based on the specifications of CEN/TC 125 N163 [6], NCMA-TEK 108 [10] and ASTM-E72 [2], it has been opted to tested walls of 1 m of longitude and 2.6 m of height.

3 Analysis results masonry walls. Confrontation theoretical-experimental

3.1 Unreinforced masonry walls subjected to centered load

The relationship between the experimental and theoretical values of the breaking axial loads, for the proposals discussed, is quantified in Table 6.

Table 6: Relationship between the experimental and theoretical values of the breaking axial loads of unreinforced masonry walls

Proposal of calculate	Experimental break load (KN)	Theoretical break load (KN)	Relationship "Exp./Theo."
EC-6: Pu=.ϕPo	1001	742	1.35
BS: Pu=ß Po	1001	788	1.27
YOKEL: $Pcr=.\pi^2*Ei*I/(3.5h^2)$	1001	1007	0.99

3.1.1 Coefficient of step "Wall / Prism simples" (MS/P3), for centered load

The coefficient of step between the resistance to compression of the walls, for the slenderness in study (λ=18.6), on its effective or gross area, and the corresponding to prisms [3] simple of three units, is equal to 0.75 (see you Table 7).

Table 7: Coefficient of step, in average compressive strength, between Unreinforced walls (MS) and single prisms of three units (P3)

Type of transverse area	Experimental average strength (N/mm2)		Coefficient of step: MS/P3
	MS	P3	
Effective	13.5	17.98	0.75
Gross	7.22	9.67	

Note: Gross area MS = 99 x 14 cm2. // Effective area MS = Σ Net area of blocks.

3.2 Unreinforced masonry walls subjected to eccentric loading

3.2.1 Dimensional interaction diagrams, for unreinforced walls, starting from the compressive strength of ungrout prisms.

In the Figs. 2 to 4 have been drawn interaction diagrams "P # e" for unreinforced walls, with and without effect of slenderness, as well as its break loads obtained experimentally.

3.3 Reinforced masonry walls subjected to eccentric loading

3.3.1 Dimensional interaction diagrams, for reinforced walls, starting from the compressive strength of grouted prisms

In the Fig. 5 have been drawn interaction diagrams "P #e" for reinforced walls, with and without effect of slenderness; as well as their break loads obtained experimentally. To elaborate these diagrams it has been

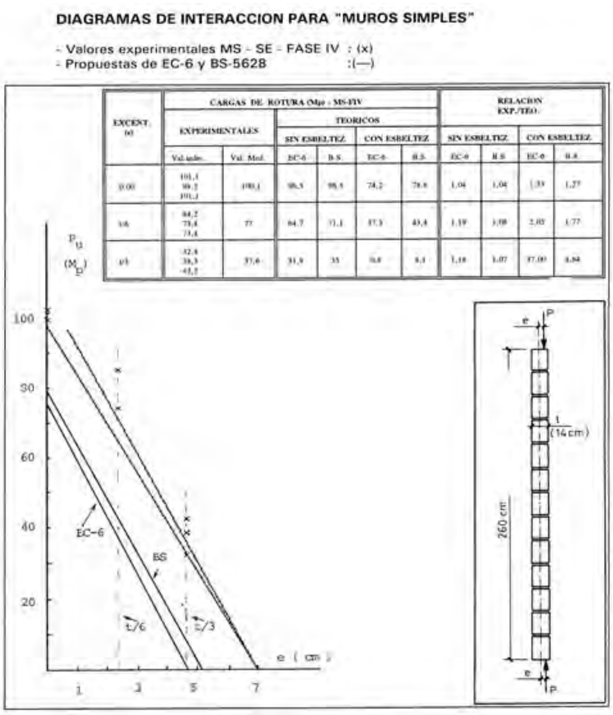

Figure 2: Values (Pu), experimental and theoretical, for different eccentricities (e) of the load on "walls simple" (1.0 x 2.6) m2 tested in dry [f 'm=0.72 f 'm(P3)]

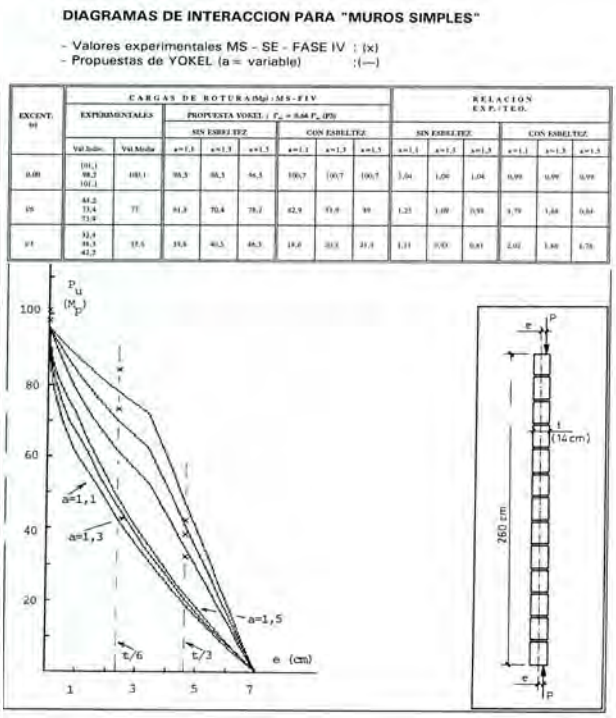

Figure 3: Values (Pu), experimental and theoretical, for different eccentricities (e) of the load on "walls simple" (1.0 x 2.6) m2 tested in dry [f 'm=0.66 f 'm(P3)]

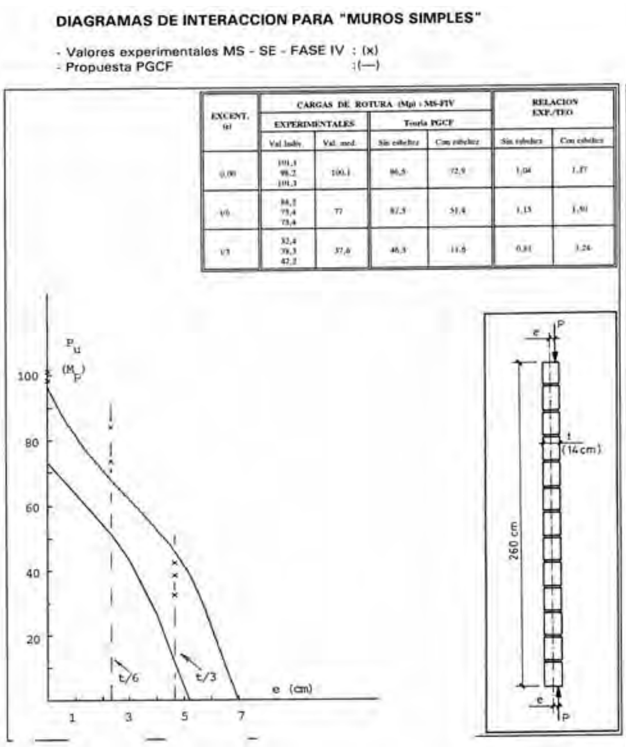

Figure 4: Values (Pu), experimental and theoretical, for different eccentricities (e) of the load on "walls simple" (1.0 x 2.6) m2 tested in dry [f 'm=0.66 f 'm(P3)]

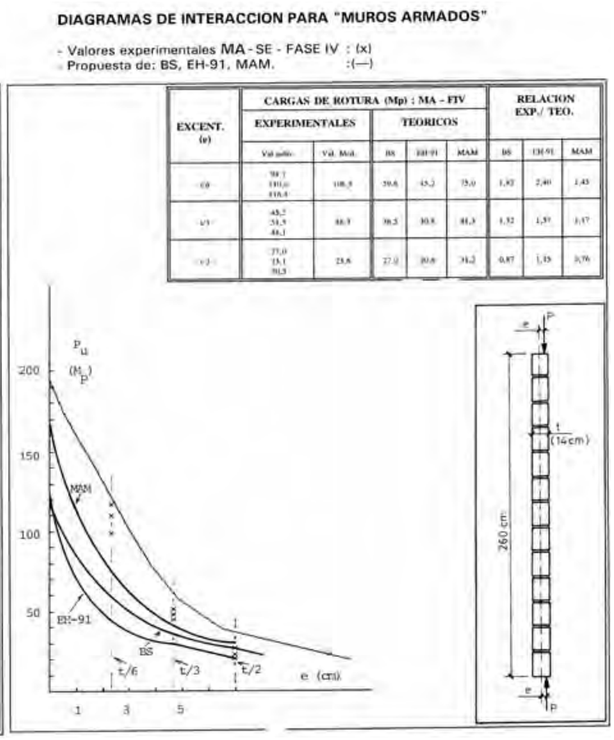

Figure 5: Values (Pu), experimental and theoretical, for different eccentricities (e) of the load on "armed walls" (1.0 x 2.6) m2 tested in dry [f 'm(PR2)=12.88 N/mm2]

considered as resistance to compression of the masonry, the resistance to compression of grouted prisms of three units. For the case of the interaction diagrams that consider the effect of slenderness, they have been obtained starting from increasing, to the values "e" of the diagram of interaction of the section of the reinforced walls, the “additional eccentricities” that consider the analyzed proposals.

4 Conclusions

4.1 With regard to the analysis of the results of unreinforced masonry walls

4.1.1 Unreinforced masonry walls subjected to centered load

The theoretic analyzed values of compressive strength, for the unreinforced masonry walls, are conservative in their majority; it is so that:

- The value obtained experimentally, is greater: in a 27% the proposed by BS [4], and in a 35% the EC-6 [7]. The proposal that best fits, 1% greater than the obtained in the tests, is that of Yokel [14].

The experimental value of the coefficient of step that relates the compressive strengths: "unreinforced masonry wall (λ=18.6) / ungrout prism of three units", on the effective or gross areas of both, it is equal to 0.75.

4.1.2 Unreinforced masonry walls subjected to eccentric load

It is very conservative to evaluate the eccentric breaking loads of the unreinforced masonry walls (for the analyzed proposals), from cross-section interaction diagram that take into account the effect of slenderness. The relations obtained between the experimental and theoretic breaking loads, they are over 1.5

It is reasonable to evaluate the eccentric breaking loads of the tested unreinforced masonry walls, to exception of PGCF [13] (for e=t/3), based on the cross-section interaction diagram of their effective area. Under this context, if are analyzed the proposals that better approach to the experimental values, it is had than:

- The experimental values (of the wall) are bigger than the theoretical (of the section): between 8% (B.S.) [4] and 9% (Yokel: a=1.3) [14] for the t/6 eccentricity, and between 7% (B.S.) [4] and 11% (Yokel: a=1.1) [14] for the t/3 eccentricity.

The interaction diagrams of the effective area of the unreinforced masonry wall (λ=18.6) that best are close to their eccentric breaking loads, are those that are obtained from reducing the compressive strength of ungrout prisms of three units: In a 65% for eccentricities between 0 and t/6, and in one 50% for eccentricities between t/6 and t/3.

4.2 With regard to the analysis of the results of reinforced masonry walls subjected to eccentric loads

Should not be evaluated the eccentric breaking loads of the reinforced masonry walls (λ=18.6) from cross-section interaction diagram, when it takes as its compression strength of grouted prisms of three units. The diagram provides values higher than the experimental; it is as that relations that are obtained, between the values experimental and theoretical (of its section), are: 0.90 for e = t/6; 0.77 for e = t/3; and 0.64 for e = t/2

It is conservative analyze the eccentric breaking loads of the reinforced masonry walls (λ=18.6), from the proposals of interaction diagrams with effect of slenderness. The most reasonable relations between the experimental values and those who are obtained of the mentioned diagrams, are: 1.45 for e=t/6 and 1.17 for e=t/3, for the method of ampliation moments (MAM); and 1.15 for e=t/2, for the proposal called EH-91.

The cross-section interaction diagram of the reinforced masonry walls (λ=18.6) that best are close to their eccentric breaking loads, are those that are obtained from reducing the compression strength of grouted prisms of three units: In a 75 % for eccentricities between t/6 and t/3, and in a 55 % for eccentricities between t/3 and t/2.

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