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DESIGN OF CONFINED MASONRY WALLS UNDER LATERAL LOADING

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ABSTRACT

The objective of this paper is to present models for the design of confined masonry structures based on the available experimental data. In particular, this study deals with in-plane response of masonry walls subjected to lateral forces, with emphasis on aspects of initial stiffness, strength and deformation capacity. The experimental information used in this work comprises tests performed at the Structures Laboratory of the Catholic University of Peru. Results indicate that stiffness can be calculated considering a wall cross section inertia using the transformed cross-section concept with the appropriate Young's moduli for concrete and masonry. Bending strength can be estimated reasonably well assuming for the cross-section (1) a rectangular compressive stress distribution, (2) zero strength under tension and (3) a linear strain distribution. Unit shear strength could be safely calculated as $0.5\sqrt{fm}$, where fm is the characteristic compressive strength of masonry. It is observed that confined masonry can develop drift values larger than 0.5% of wall height which is comparable to that of reinforced masonry. Deformation capacity is observed to increase for increasing (a) wall horizontal reinforcement ratio and (b) column horizontal and vertical reinforcement, and to be reduced with increasing axial load.

KEYWORDS

Confined masonry; experiments; stiffness; bending strength; shear strength; deformation capacity; models; code requirements.

GENERAL

Confined masonry consists of masonry panels, commonly made of clay units and portland cement mortar, and reinforced concrete beams and columns along lateral and top boundaries. Brick strength usually ranges from 50 to 150 kg/cm^2. Most structures are 1- or 2-story houses but 5-story buildings are also common.

Experimental information on confined masonry was primarily based on tests carried out at the Catholic University of Peru. This information includes studies dealing with parameters such as: (1) slenderness (height/depth ratio); (2) horizontal wall reinforcement; (3) axial load; (4) connection between the confining column and masonry wall; (5) dynamic loading; and (6) horizontal and vertical column reinforcement. Some unreinforced walls were also selected for the data base.

The literature reviewed consists generally of cyclic tests of square walls with approximate dimensions of 2.5 x 2.5 x 0.15 m. Monotonic tests were also considered. Masonry compressive strength ranged from 60 to 150 kg/cm^2, and concrete strength from 150 to 220 kg/cm^2.

Interpretation of the data was based on the following hypothesis: For monotonic tests, initial lateral stiffness of walls is the slope of the tangent to the load-displacement curve at the origin. For cyclic tests, the tangent was drawn to the virgin load-displacement curve at the origin.

The failure mechanism for walls subjected to lateral loading was classified as either flexural or shear. Flexural failure was associated with cases where (1) experimental evidence indicated that tensile reinforcement had yielded; and (2) lateral strength could be computed by calculations using Eq (1) described below. In such cases, inclined cracks may appear at some stage during the test. In other cases in which bending failure was not the controlling mechanism, and diagonal cracking caused a sudden drop in lateral strength, failure was defined as being of the shear type. All specimens fell in one of these categories, except one which clearly showed sliding-shear failure which was still included as a shear failure.

Deformation capacity was defined as the lateral drift ratio corresponding to a 20% drop in lateral strength.

COMPUTATION OF STRENGTH AND STIFFNESS

Shear strength was estimated using a formula described in the next Section. Flexural capacity was computed considering a rectangular compressive stress distribution, a linear strain distribution, and elastoplastic behavior for steel. For stiffness computation, walls were modelled as elastic cantilever beams using the moment of inertia of the transformed cross-section from strength of materials. All three materials: masonry, concrete and steel were considered. Deformations due to bending and shear were taken into account. In most cases the modulus of elasticity of concrete was computed as $Ec = 15000\sqrt{f'c}$. The exception was a 3-story specimen tested on a shaking table (Quiun, 1993) for which the measured value of Young's modulus was used since it differed appreciably from the above formula. For masonry, Young's modulus and shear modulus were assumed equal to 500f'm and 200f'm.

DISCUSSION

For computation of wall stiffness a cantilever beam model with a transformed cross section has been proposed. For the available experimental data this model gave acceptable results, as shown in Fig. 1. Specimens that best fit the calculated results had square wall panels with horizontal reinforcement and existing axial load.

Shear strength of reinforced masonry walls is normally expressed in terms of $\sqrt{f'm}$ and the M/VL ratio, where M is the bending moment, V, shear force, and, L, length of the wall. The intent is to allow calculated shear to increase with decreasing M/VL ratios, for M/VL < 1 (e.g. short walls). For all M/VL > 1 (tall walls) strength is kept constant (Bariola, 1994). The calculation of shear strength for confined masonry walls is not simple because there are no models that distinguish between the individual contributions of the confining frame and masonry wall. Therefore it is convenient to adopt a conservative value of unit shear strength expressed as

$$v_u = 0.5\sqrt{f'_m} \tag{1}$$

considering the experimental data shown in Fig. 2. As can be observed (Fig. 2) this formula gives conservative estimates for all available experimental data in which shear failure was observed, including unreinforced masonry. The beneficial effect of axial load has been neglected as suggested in the literature (Blondet, 1990).

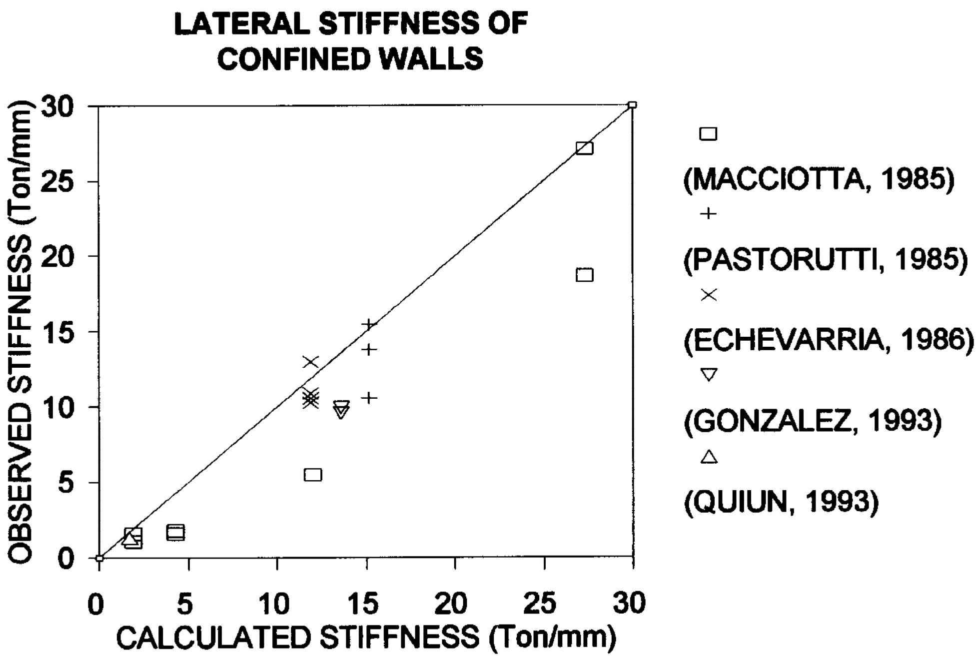

Fig. 1. Lateral stiffness of confined walls

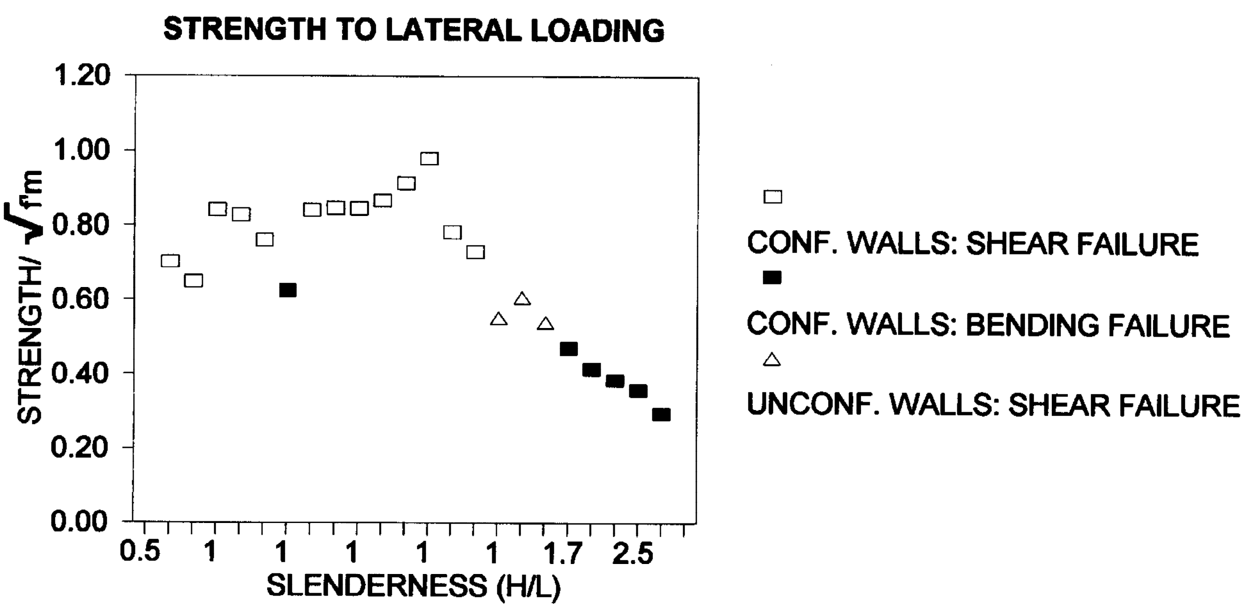

Fig. 2. Lateral strength vs. wall slenderness

Calculated flexural strength was compared with observed results indicating good agreement (Fig. 3).

Calculated lateral strength of walls was obtained as the minimum value of (calculated) flexural strength and shear strength (Fig. 4). Values of the ratio between observed and calculated strength were in the range 0.96 to 1.96 and, in all cases calculations indicated the failure type (flexure or shear) that was observed in the experiment.

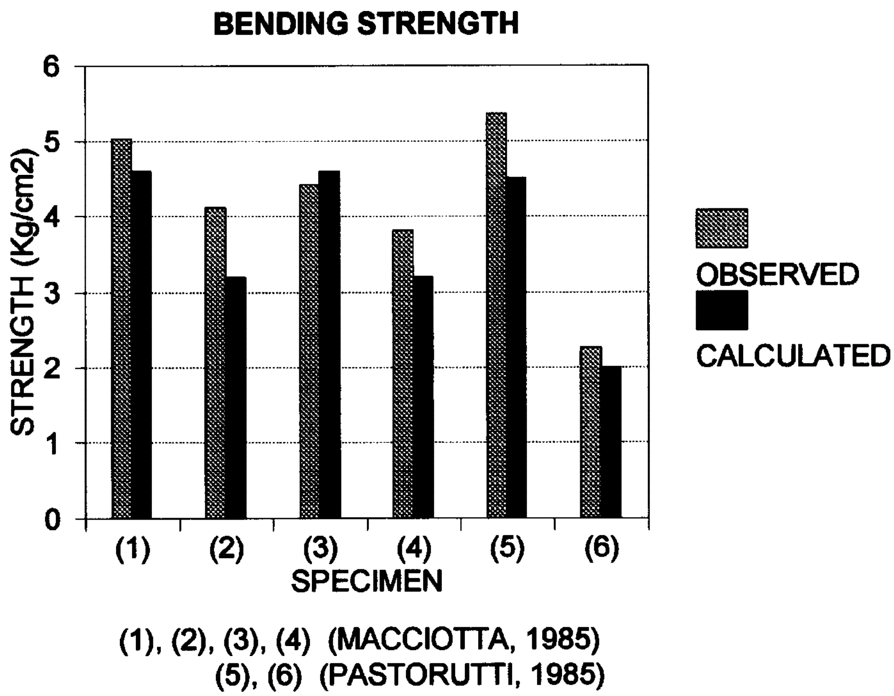

Fig. 3. Flexural strength

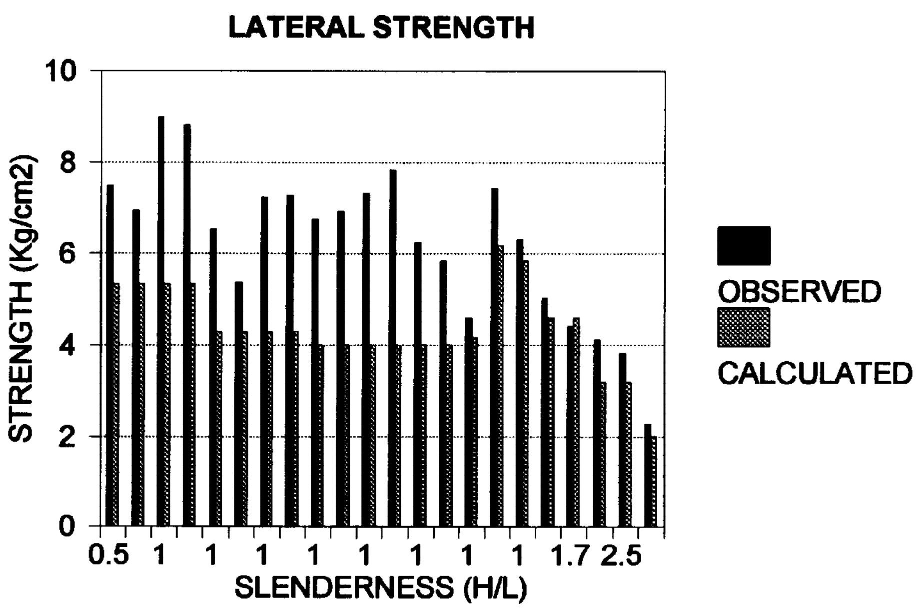

Fig. 4. Lateral strength

Horizontal reinforcement in the wall and vertical and horizontal reinforcement in confining columns have a beneficial effect on deformation capacity as indicated in Table 1 (Kato et al, 1992). Limited data in Table 2 indicates that axial load above P/f'mLt = 0.08 causes a reduction in deformation capacity. The experimental data from (Macciotta, 1985) in which influence of slenderness was studied are presented in Table 3. As can be seen the slenderness ratio H/L did not seen to influence deformation capacity .

Table 1. Influence of Column Reinforcement on Deformation Capacity

Specimen	Vertical Reinforcement (%)	Horizontal Reinforcement (%)	Max. Drift ratio (%)
KA[1]	3.81	1.28	1.4
KB[1]	3.81	0.30	0.5
KC[1]	0.99	1.28	0.7
KD[1]	0.99	0.30	0.3

[1] (Kato et al, 1992)

Table 2. Influence of Axial Load on Deformation Capacity

Specimen	P/f'mLt	Max. Drift ratio (%)
A2[2]	0.00	0.9
B2[2]	0.03	0.8
C2[2]	0.08	0.9
D2[2]	0.13	0.6

[2] (Macciotta, 1985)

Table 3. Influence of Slenderness on Deformation Capacity

Specimen	Wall Height/Length	Max. Drift ratio (%)
A1[2]	0.5	2.0
B1[2]	1.0	0.96
C1[2]	1.7	1.2
D1[2]	2.5	2.0
A2[2]	0.5	1.3
B2[2]	1.0	1.1
C2[2]	1.7	0.9
D2[2]	2.5	1.2

[2] (Macciotta, 1985)

SUMMARY AND CONCLUSIONS

The research objective of this paper was to study experimental results of confined masonry walls under lateral loading with the aim of obtaining models for design.

Results indicate that stiffness can be estimated adequately idealizing the wall as a cantilever beam with a cross section defined by the transformed section. Because of the large difference between moduli of elasticity of concrete and steel in comparison with masonry, confining columns contribute considerably to the moment of inertia of the cross section.

It was found that bending strength of walls, calculated assuming for the cross section: (1) a rectangular compressive stress distribution and (2) a linear strain distribution coincides satisfactorily with experimental values.

Unit shear strength was assumed conservatively as $0.5\sqrt{fm}$, where fm is the characteristic compressive strength of masonry. Based on the available data it was not possible to develop a model to compute shear strength that includes contributions of the masonry wall and the confining columns. Therefore only the contribution of masonry was considered.

Computing lateral strength as the smaller of bending and shear strengths, it was possible to estimate experimental results and anticipate the mode of failure (flexural or shear).

Experiments indicated that deformation capacity of confined masonry walls can be safely assumed to exceed chord rotations of 0.5%. This deformation capacity is comparable to that of reinforced masonry. Deformation capacity was observed to increase with increasing (a) horizontal reinforcement ratio in the wall and (b) horizontal and vertical reinforcement ratios in confining columns. Limited data presented here indicated that axial load reduces deformation capacity for P/fmLt values larger than 0.08.

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