RELEVANT MASONRY PROYECTS CARRIED OUT IN THE STRUCTURES LABORATORY AT THE CATHOLIC UNIVERSITY OF PERU

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SUMMARY

This paper describes the most important projects covering the study of brick masonry structures carried out since 1980 in the Structures Laboratory at the Catholic University of Peru. One story square masonry walls corresponding to different types of masonry structural systems have been subjected to cyclic lateral pseudo-static displacements in cantilever tests. Comparative results are presented and related to results obtained in simpler standard tests of smaller specimens. Clay and sand-lime bricks were used.

INTRODUCTION

Brick masonry structures are one of the most common types of construction used in Peru's urban areas. They range from the unreinforced basically old buildings, to the more widespread structures where unreinforced masonry walls are confined or framed by reinforced concrete columns and beams casted after construction of the walls. Finally buildings with internally reinforced masonry walls are being used with increasing frequency.

Masonry research work in the Structures Laboratory at the Catholic University of Peru was initiated in 1980. Emphasis was placed on low-cost housing. The projects described have consisted of testing of full scale sub-assemblages of masonry buildings, which have been necessarily limited due to budgetary constraints. Further parametric studies varying the type of brick, type of mortar, type of brick suction treatment prior to lying, etc. have been conducted on smaller specimens.

This paper briefly describes the three most relevant projects carried out at the laboratory. One story, aproximately square, masonry walls have been subjected to cyclic lateral pseudo-static displacements in cantilever tests. In Project I (Ref.1) the effect of vertical load on the behavior of unreinforced walls was studied. Project II (Ref.2) investigated different types of materials and sought a correlation between the results of full-size framed walls and small specimens. The behavior of different types of masonry construction was examined in Project III (ref.3). No vertical load was applied in these two later cases.

CHARACTERISTICS OF THE WALLS TESTED

For each project the basic properties of the masonry used are presented in Table 1 and a description of the walls tested are summarized in Table 2. Reinforcement, when provided, was basically determined according to Peruvian

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practice and the amount necessary to resist bending tensile stresses due to overturning.

EXPERIMENTAL SET UP AND TEST PROCEDURE

The general test set up is illustrated in Fig.1. The lateral cyclic load was applied using a displacement-controlled dynamic actuator with a capacity of 500 kN. The testing sequence consisted of sets of wall displacement cycles with increasing amplitudes.

In Projects I vertical load was applied prior to cycling (see Fig.2). The test finished when diagonal cracking of the wall ocurred. Typical displacement histories in Projects II and III are shown in Figs. 4 and 9 respectively. In Project III the first wall of each type was tested monotonically.

RESPONSE BEHAVIOR

Typical modes of wall failure, all of a shear type, are illustrated in Figs. 2, 5 and 10 to 15. Usually, cracking of the wall was initiated by the development of an almost diagonal fissure. Further variations in the cracking pattern depended on the masonry structural system. Cracks usually crossed - the units for clay masonry and ran through the joints for sand-lime brick masonry. Following is a brief description of the response behavior observed in each of the projects:

Project I

Unreinforced clay masonry walls behaved in an almost linear elastic fashion until fragile diagonal cracking ocurred. The shear strength (v_R) at this point was linearly correlated to the vertical stress (f_v) as follows:

$$v_R \text{ (MPa)} = 0.4 + 0.35 \ (f_v) \text{ (MPa)} \quad ; \quad 0.6 \leq f_v \leq 1.1$$

The modulus of elasticity (Em) was obtained from the initial gradual aplication of the vertical load to the wall. The Peruvian code's ratio: $Em/f'_m = 500$ (Ref.4) was corroborated (See Table 1).

Project II

The general hysteretic behavior of clay brick framed walls was similar to that illustrated by Figs. 16 and 17 for sand-lime brick framed walls. An almost linear elastic behavior until diagonal cracking was observed. Usually, a sudden loss of strength and stiffness ocurred at this point. With increasing displacements, shear capacity was recuperated and maintained in most cases. Fig. 7 shows typical after diagonal cracking strength variations for the different types of clay masonry used in this project. Typical results for sand lime brick framed walls are also presented for comparison. Notice how cracking and spalling of the thin webs in type C hollow masonry accelerated deterioration.

Typical hysteresis loops are shown in Fig. 8. An important pinching effect, common to all walls tested, is observed due to the temporary loss of stiffness of the wall when the load is reversed and the cracks which just opened, gradually close.

In Fig. 6, the average of the minimum diagonal cracking shear strengths (v_R) for the framed walls tested in this projects have been linearly correlated to index properties defined in prisms ($\sqrt{f'm}$) and small square panels (v'_m). See Fig. 3 and Table 1. It should be noted that the expressions obtained refer to masonry with good brick-mortar adhesion which generally resulted in failure in the bricks themselves. Sand-lime brick framed walls cracked usually at the joints and did not fit the correlations.

Project III

Typical shear strength and normalized stiffness degradation envelopes obtained in sand-lime brick walls, corresponding to the different types of structural systems used, are illustrated in Fig. 16 and 17 respectively. Envelopes for the first and stabilized cycles are presented. An almost linear elastic behavior until diagonal cracking of the walls was observed. Further hysteretic behavior depended on the structural system.

The general behavior of the framed walls was described in project II. Usually a sudden loss of strength and stiffness of the wall ocurred at diagonal cracking but, with increasing displacements, the shear capacity was recuperated and maintained. This was specially true in the case of sand-lime brick masonry (See Fig.7).

Reinforced single-wythies with partial grouting kept increasing their strengths after diagonal cracking, which ocurred at smaller deformations and with a gradual loss of strength. After this, the spread and density of cracks increased rapidly. Soon the walls were completely fractured, specially around non-grouted unit holes, and finally, deterioration of strength was accelerated by fragile cracking due to indirect tensile stresses in critical regions (typically, compression toes). The danger of getting a failure due to lateral instability is recognized.

Cavity walls cracked at higher deformations and as long as the integrity of the grout in the cavity was preserved the strength of the wall was maintained. For higher deformations independent behavior of wall components was observed and strength deteriorated with cycling.

CONCLUDING REMARKS

Care should be exercized when analyzing the results presented because only a few one story high square masonry walls have been investigated and vertical loads have been applied on the walls in Project I only. This fact notwithstanding, the following conclusions can be drawn:

1) A shear type of failure was obtained in all walls tested. The walls behaved aproximately in a linear elastic way until diagonal cracking. An abrupt change in behavior was observed at this point. Strength but specially stiffness deterioration was accelerated (See Fig.17). Variations obtained depended on the structural system.

2) The average minimum diagonal cracking shear strength of clay masonry framed walls with good brick-mortar adhesion has been linearly correlated to index properties in smaller specimens ($\sqrt{f'_m}, v'_m$).

3) If adequate longitudinal and transverse reinforcement is provided in the columns and beams of square framed walls, the confinement developed allows to a certain extent the formation of a friction type of resisting system, capable of maintaining the load after diagonal cracking. Uncracked wall sections are kept sliding over each other (see Figs.5,10 and 11). The danger of a failure because of seismic action perpendicular to the plane of the walls should be noted.

4) Only sand-lime brick internally reinforced walls have been analyzed, so no general behavior of the structural system can be inferred. Fragile cracking, enhancing a rapid strength deterioration for high deformations, was observed. An additional limit state for design associated to wall repair criteria is thought to be appropiate.

ACKNOWLEDGEMENTS

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REFERENCES

(1) San Bartolomé, A., "Lateral Testing of Unreinforced Masonry Walls"; IVth. National Congress in Civil Engineering, Chiclayo, Perú, 1982 (In Spanish).

(2) San Bartolomé, A., "Lateral Testing of Clay Masonry Framed Walls"; COLLOQUIA '83; Santiago de Chile, 1983 (In Spanish).

(3) Svojsik de Beeck, M: "LEDI 113-82: Testing of Sand-Lime Brick Masonry Walls"; Catholic University; Lima, Perú, 1983(Internal report in Spanish and not published).

(4) Technical Building Regulation NTE-82; Masonry Standard E-070; Ministry of Construction, Lima, Perú, 1982 (In Spanish).

(5) Valle, E.; "Clay Masonry Framed Walls", Civil Engineering Thesis, Catholic University; Lima, Perú, 1982 (In Spanish and not published).

Project ID	MASONRY UNIT								MORTAR	INDEX PROPERTIES	
	Brick Type	Material	Plan View	Dimensions (mm)			Net Area / Gross Area (%)	Compressive Strength f_b (MPa) ①	Parts by volume cem:lime:sand	Prism Compressive strength f_m (MPa) ①,②	Diagonal Shear strength v_m (MPa) ①,③
				width	length	height					
I		Clay④	○○○	135	240	90	94	12.8	1:0:4	6.5	0.85
II	A	Clay④	▭	135	240	90	100	4.1	1:0:5	4.0	0.55
									1:1:5	3.6	0.48
	B	Clay④	(multi-perforated)	130	240	90	79	12.1	1:0:5	6.8	0.94
									1:1:5	6.2	0.84
	C	Clay④	(multi-perforated)	120	250	95	65	11.2	1:0:5	9.6	0.96
									1:1:5	7.8	1.00
III	D	Sand-Lime	▭	90	290	90	100	30.0	1:½:4	22.7	1.43
	E	Sand-Lime	○○○	90	290	90	76	18.6	1:½:4	13.2	0.56

① Strength was calculated as the average value of the ultimate loads divided by the gross area minus one standard deviation.

② Masonry prisms had a slenderness ratio equal to 5.

③ Strength was obtained in square wall panels 500mm x 500mm subjected to diagonal compression.

④ Because of high suction clay bricks were wetted prior to laying.

TABLE. 1.- MASONRY BASIC PROPERTIES

Project ID	Plan View of Half Wall Dimensions (mm)	Type of Wall	Number of Walls	Brick Type	Amount and Position of Main Reinforcement (mm)				Additional Characteristics *
					Vertical Edges	Transverse (Stirrups)	Vertical Interior	Horizontal	
I	135; 895; 760	Unreinforced Wall	12	–	–	–	–	–	–
II	135, 130, 120; 1000; 200; 170	Framed Wall	12	A B C	4ø 12.7	5@100 4@250 5@100	–	–	Concrete Compressive Strength f'_c = 14.5 MPa
III	90; 850; 150; 170	Framed Wall	3	D	4ø 12.7	◻ø 5.0 13@40, 5@150 and 14@40	–	–	Concrete Compressive Strength f'_c = 17.5 MPa
	90; 1000	Reinforced single whythe with partial grouting	3	E	4ø 12.7 (grouted)	–	ø 5.0 @ 300 (grouted)	ø5.0 joint reinforcement @200 (every 2 layers)	Brick holes grout cem:lime:sand (parts by volume) 1:½:3 slump(mm) = 250–280
	250; 90, 70, 90; 1000	Reinforced Grouted Cavity Wall	3	D	4ø 25.4 @ 80	–	ø 9.5 @ 320	ø 9.5 @ 200	Cavity grout cem:sand: 9.5mm stone (parts by volume) 1: 2½ : 1½ slump (mm) = 250–280

* f_y = Nominal yield strength of reinforcement = 420 MPa

TABLE. 2.- DESCRIPTION OF MASONRY WALLS

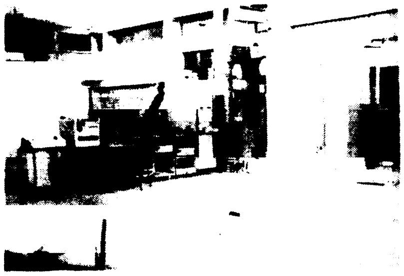

Fig.1 General Test Set Up

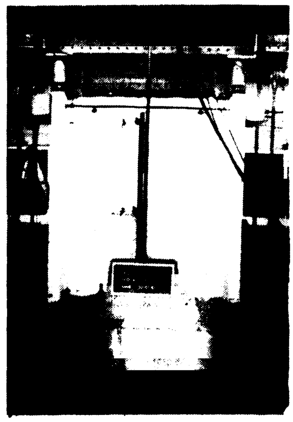

Fig.2
Unreinforced Wall
After Testing
(Project I)

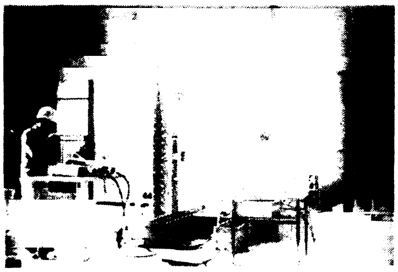

Fig.3 Diagonal Compression
of Small Wall Panels

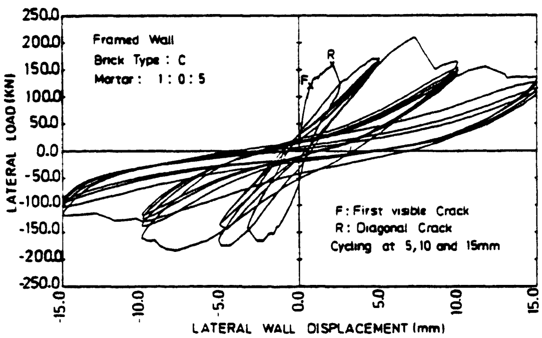

FIG. 4.-TYPICAL LOAD WALL DISPLACEMENT HISTORY
IN PROJECT II

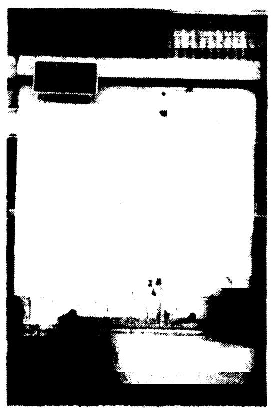

Fig.5
Framed Clay Brick Wall
After Testing
(Project II)

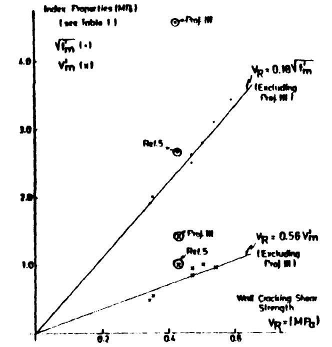

FIG. 6.- Correlations between Wall Cracking Shear Strength (v_R) and Index Masonry Properties ($\sqrt{f'_m}$, v'_m) for clay Masonry Framed Walls With Good Brick-Mortar Adhesion.

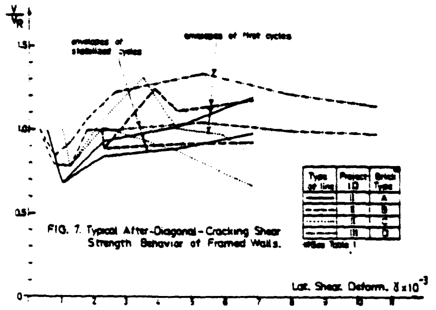

FIG. 7. Typical After-Diagonal-Cracking Shear Strength Behavior of Framed Walls.

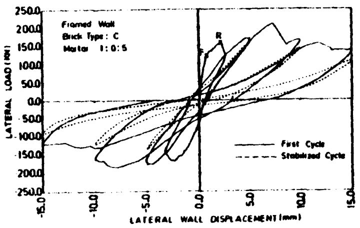

FIG. 8.-HYSTERESIS LOOPS

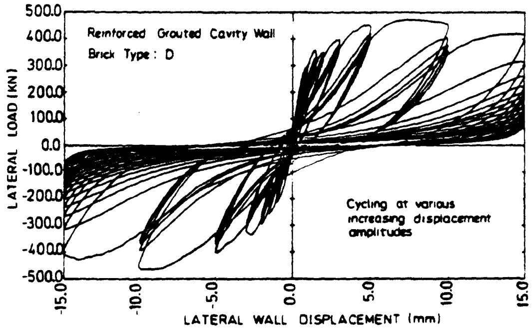

FIG. 9 TYPICAL CYCLIC LOAD WALL DISPLACEMENT HISTORY IN PROJECT III

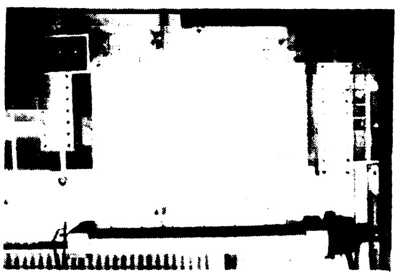

Fig.10
Sand-Lime Brick Framed Wall
After Monotonic Testing
(Project III)

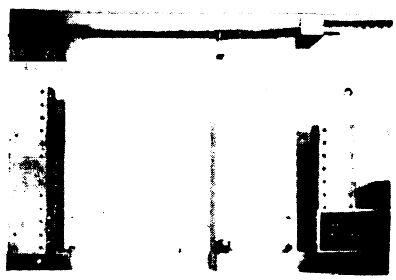

Fig.11
Sand-Lime Brick Framed Wall
After Cyclic Testing
(Project III)

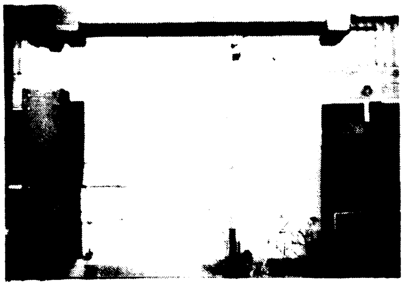

Fig.12 Reinforced Single-Wythies After Monotonic Testing (Project III)

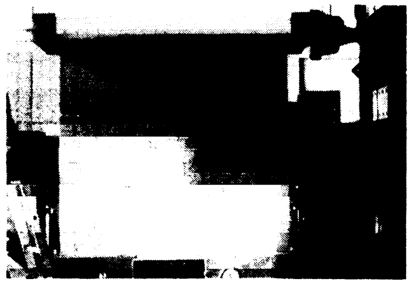

Fig.13 Reinforced Single-Wythies After Cyclic Testing (Project III)

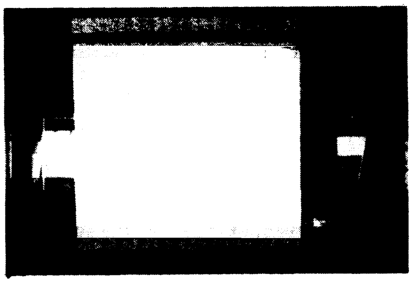

Fig.14 Reinforced Cavity Wall After Monotonic Testing (Project III)

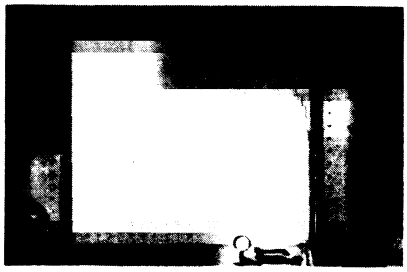

Fig.15 Reinforced Cavity Wall After Cyclic Testing (Project III)

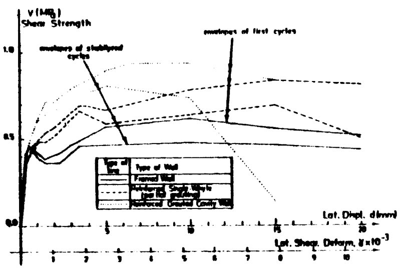

FIG. 16.- Comparison of Typical Shear Strength Envelopes for Sand-Lime Brick Masonry Walls varying the Structural System.

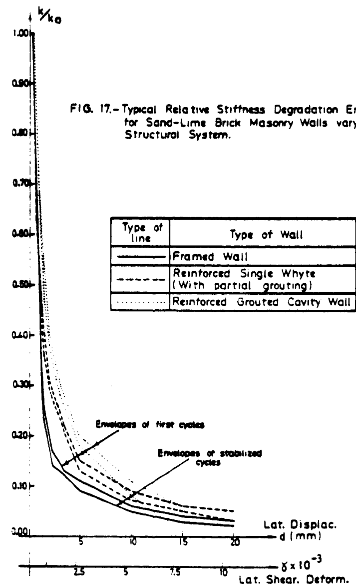

FIG. 17.- Typical Relative Stiffness Degradation Envelopes for Sand-Lime Brick Masonry Walls varying the Structural System.