SEISMIC-RESISTANT BEHAVIOR OF MINOR REINFORCED CONCRETE FRAMES WITH MASONRY INFILL WALLS

M LAFUENTE[1], A MOLINA[2] And C GENATIOS[3]

SUMMARY

An experimental research on the performance of masonry-infilled reinforced concrete (R/C) frames under in-plane cyclic loads is herein presented. Ten half-scale walls with masonry brick infills were tested. Three groups of walls with height-to-length ratios approximately equal, greater and lower to one, subjected to various levels of vertical load were studied. Each wall response in terms of lateral resistance and inelastic-energy dissipating qualities under lateral in-plane loads was assessed. Some recommendations to evaluate the lateral resistance and drift limits are proposed with design purposes. The tested walls showed an unexpectedly satisfactory behavior. Equivalent elasto-plastic ductilities varying between 3 and 8 were found. This feature was due to the early shear failure of the column concrete sections at the bottom of the walls and the final dowel mechanism developed at the vertical reinforcing steel bars.

INTRODUCTION

Despite the wide experimental research developed on the seismic performance of infilled frames [Abrams, 1994], [Angel et al., 1994], [Klingner et al., 1996], among many others, further investigation is still needed for the proper evaluation of the behavior of masonry walls confined by minor reinforced concrete frames [Buonopane and White, 1999].

In this kind of walls, some previous results [Lafuente et al., 1998] state that no separations or gaps between the masonry infills and the reinforced concrete frame elements should be expected. Strong lateral stiffness degradation and poor inelastic energy dissipating capacity usually characterize the behavior of these walls. Most of the published existing references limit the ductility of this kind of structural systems to values below two [Pauley and Priestley, 1992]. Nevertheless, the experiences presented below prove that particular resistant mechanisms can be developed in this kind of walls, providing fairly ductile responses with adequate levels of appropriate stable lateral strength.

First in this paper, a description of the experimental set-up and a brief characterization of the tested specimens are presented. Then, the main results of the experiences are discussed. Finally, some conclusions and design recommendations are resumed.

EXPERIMENTAL SET-UP AND SPECIMEN CHARACTERIZATION

Ten half-scale walls were tested against alternating lateral in-plane loads and constant vertical load. Solid bricks measuring 250x 60 x 120 mm with an average compressive resistance, $f_m = 9.28$ N/mm^2 were used in the infill

walls, with a 1: 1: 4 cement: lime: sand mortar. Diagonal tensile tests over five square 500 mm x 500 mm masonry specimens were carried out, giving an average shear resistance of Vx = Vy = 0.66 N/mm^2.

[1] *Instituto de Materiales y Modelos Estructurales, Universidad Central de Venezuela, Caracas.Email: mlafuen@reacciun.ve*
[2] *Instituto de Materiales y Modelos Estructurales, Universidad Central de Venezuela, Caracas*
[3] *Instituto de Materiales y Modelos Estructurales, Universidad Central de Venezuela, Caracas*

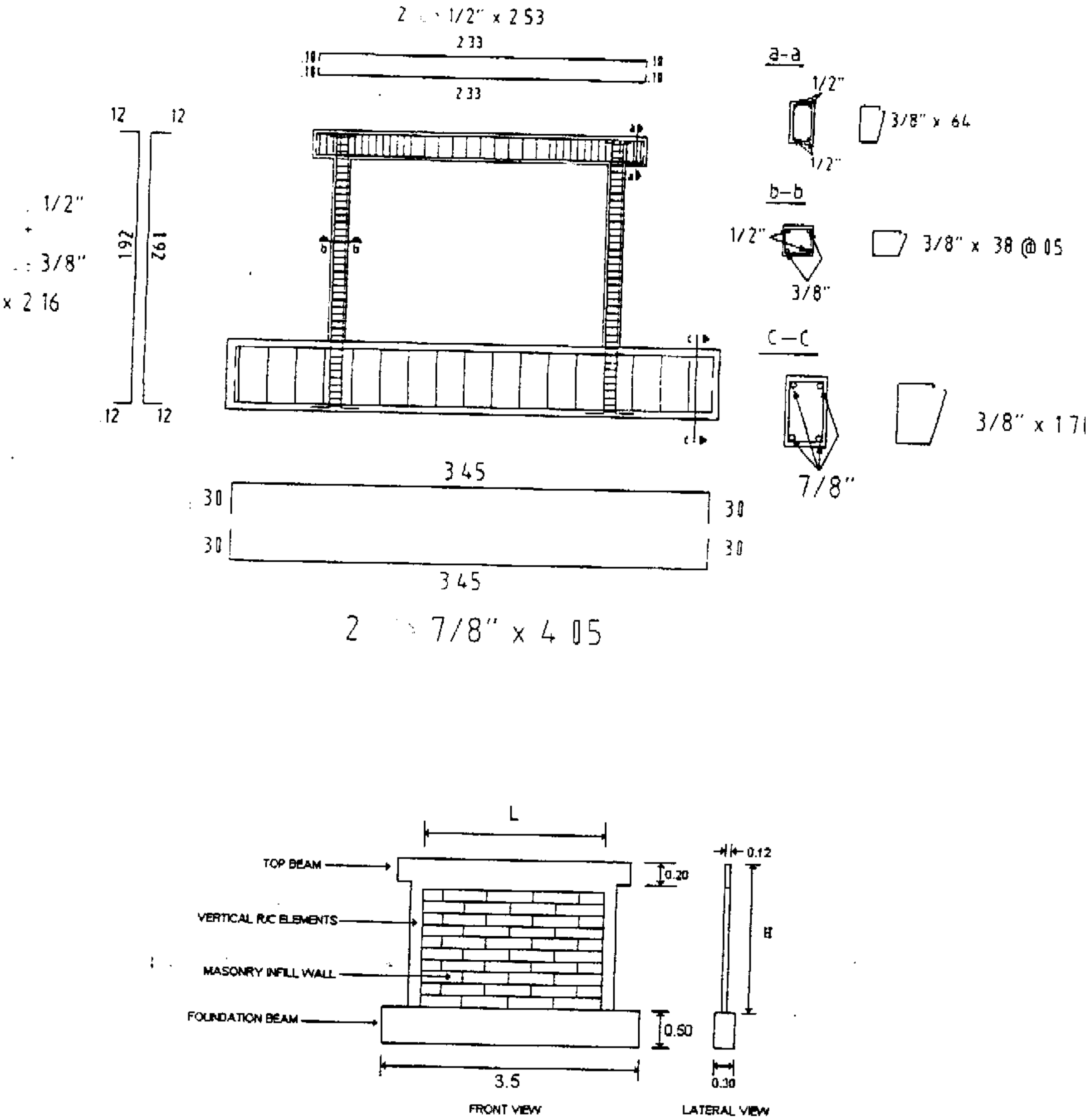

Figure 1. Characteristics of the walls

Three walls had an aspect ratio of 0.70 (<1), three had a ratio of 1.13 (>1) and the remaining four, of 0.95 (≅ 1). The height of the ten walls was 1.38 m. (figure 1). The upper vertical load applied on the walls by means of hydraulic actuators was maintained constant during tests to provide an average vertical compressive stress of 0%, 5%, 7.5%, or 15% of fm, depending on each case.

The vertical steel reinforcement in columns consisted on two 12.7 mm. diameter bars and two 9.5 mm. bars, and transversal reinforcement of 9.5 mm bars with spacing of 50 mm., excepting for one of the walls, where the vertical reinforcement consisted on four 9.5 mm diameter bars. At the top beam, the main reinforcement was four 12.7 mm bars and 9.5mm diameter stirrups with spacing of 50 mm close to the beam-column joints and of 100 mm. in the middle of the span. The dimensions of the concrete element sections were 12 x 12 cm in columns and 12 x 20 cm in top beams. The steel bars yielding resistance was equal to F_y = 420 N/mm^2 and the concrete had a nominal compressive strength of f'c = 18 N/mm^2.

The tests were carried out with controlled, alternating and increasing displacement cycles. Hydraulic actuators at both sides of the top beam applied the required lateral load. Displacement transducers mounted on an external reference frame measured the displacement at three levels of the columns, including the top. Additional transducers were placed to measure the relative displacement between the infill wall and the frame. Complete details on the experimental set-up, the data acquisition and the test control systems appear in [Carrillo and Molina, 1997].

TEST RESULTS.

The non-linear behavior of the tested walls was typically initiated by diagonal cracking of the infill, first observed at the cycles corresponding to 2 or 3 mm of top lateral displacement, combined with horizontal failure of the bed mortar joints. Walls' failure was mostly dominated by the shear capacity of the R/C columns. Since the early stages of the tests, both at the bottom and at the top of these elements, shear cracking was noticed, followed by the spalling of the recovering concrete at the bottom of the columns and by the progressive severe degradation of these concrete sections, leading to a final dowel action resistant mechanism developed by the vertical steel bars. Separations between the masonry infill and the columns were observed, while the top beams showed no separation at all during the whole tests. The early shear failure of the columns was surely due to the poor quality of the concrete and some detected construction defaults, related to the small size of the R/C sections.

Table 1. Equivalent systems and ductilities

Wall	Δy(mm)	F_y(N)	μ_d	μ
M1	1.1	160.	19.	5
M2	0.9	220.	4.	4
M3	1.1	160.	10.	8
M4	1.9	110.	4.	3
M5	2.1	78.	5.	3
M6	2.5	135.	4.	3
M7	0.3	152.	7.	5
M8	1.4	66.	3.	2
M9	1.3	128.	7.	4
M10	0.7	86.	7.	3

Figure 2 presents the drift-shear relations for each test. Sliding shear failures of bed joints as well as diagonal stepped cracking in the masonry infill occurred, producing large local forces on frame members. Mostly in all cases, as a result of the early shear failure of the R/C columns, the dowel mechanism described above could be observed. This effect, together with the friction action associated to bed-joint failures, produced a fairly ductile response with substantial hysteretic energy dissipation. The significance of the axial load could also be confirmed. The lateral strength of the walls increased in 60% to 80%, depending on the axial load level, when compared to similar walls with no vertical load.

Equivalent elasto-plastic systems were proposed for each wall. The resistance to yielding (F_y) was approximated from the envelope of the hysteresis loops and the corresponding displacement (Δy) found through an iterative process, equating the areas of the envelope below and under the F_y level (see Table 1). From these systems, the μ equivalent ductility was calculated as:

$$\mu = 1 + E / (4 F_y \Delta_y) \tag{1}$$

where E is the dissipating energy of the equivalent elastoplastic system. The obtained μ values are presented in table 1, as well as the displacement ductility μ_d. It was found that the equivalent ductility increases linearly with the displacement ductility. Equivalent ductility values showed to be remarkably higher than those found in similar previous experiences with other kinds of masonry infills [Lafuente et al., 1998], due to the particular resistant mechanism commented before.

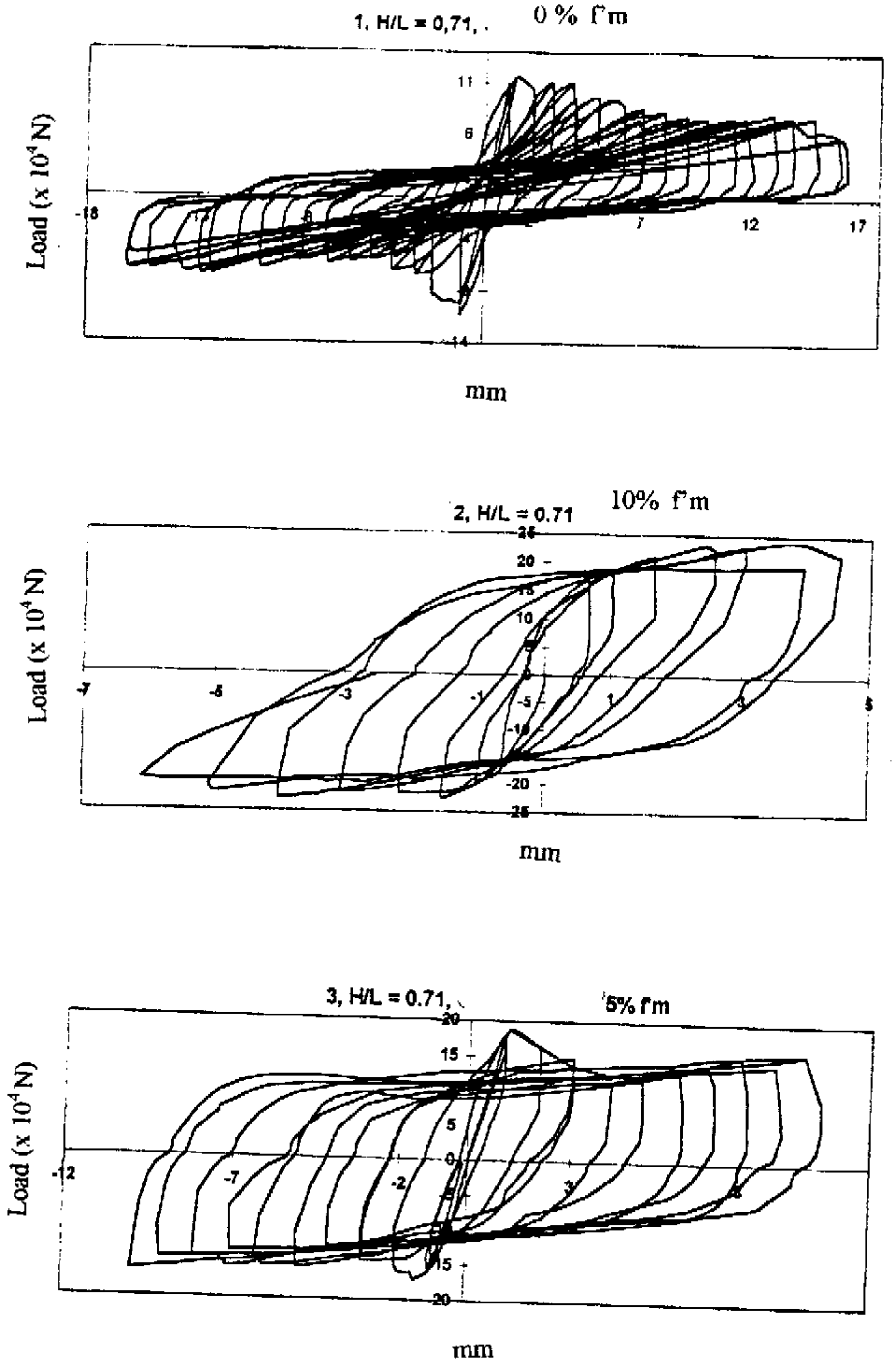

Figure 2a. Hysteresis Loops (H / L = 0.71)

Severe lateral stiffness degradation was observed in the walls since the first early cycles. In all cases, a significant stiffness reduction was found after the 2mm-displacement cycle. Based on the performed tests, in order to limit damage to confined masonry walls and to reach and acceptable resistance against lateral loads, it is recommended that drift shall be limited according to:

$$\Delta / H < e / 700 \qquad (2)$$

where H is the wall height and e the aspect ratio (e = H / L, with L being the length)

With design purposes in mind, an expression was adjusted from the tests' results to evaluate the lateral resistant capacity of confined brick walls:

$$V_m = 3.22\ (f / f_m) + 3.14\ (H / L) \qquad (3)$$

Where f is the compressive stress produced by the vertical loads. The test results and the proposed expression are plotted in figure 3.

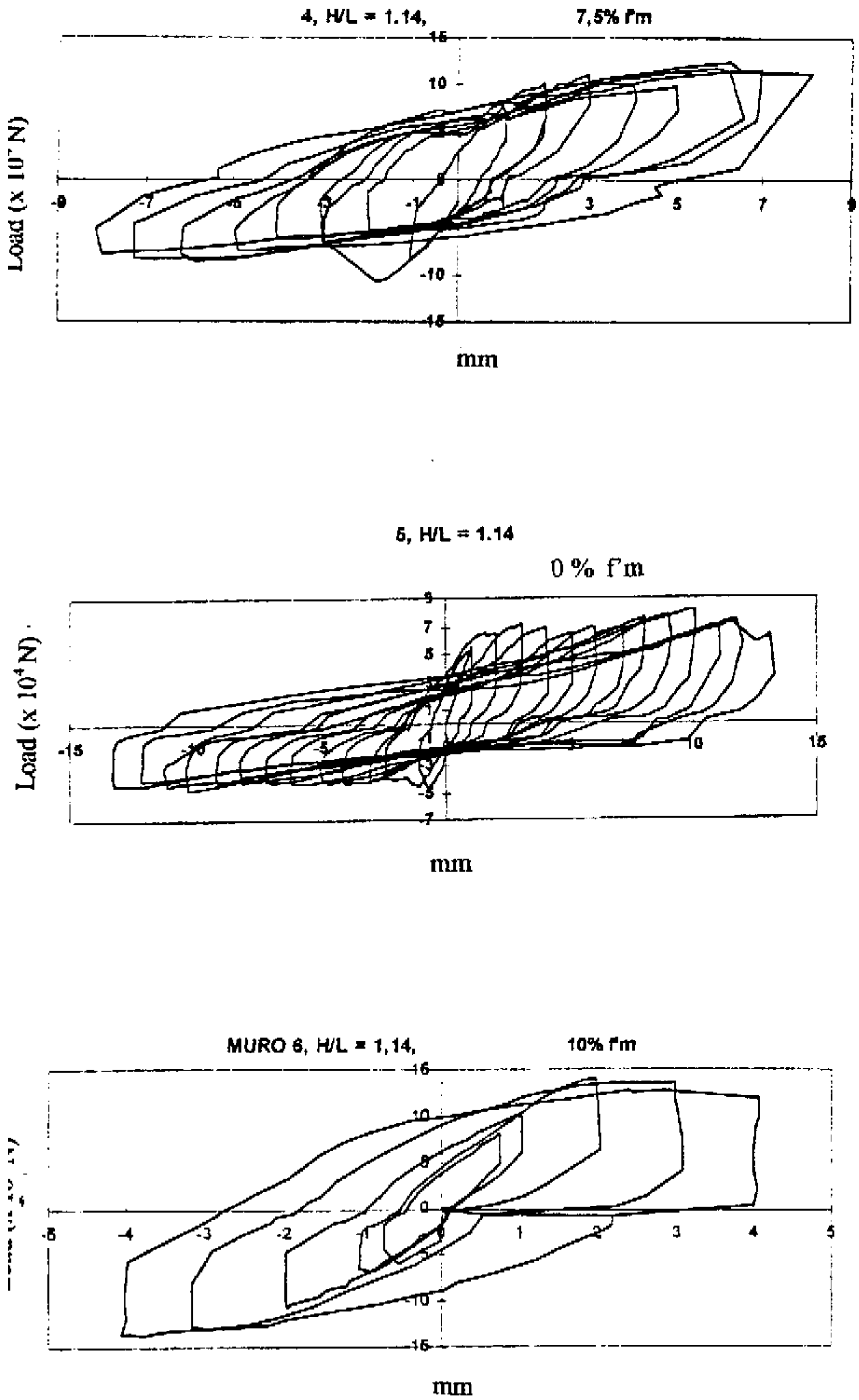

Figure 2b. Hysteresis Loops (H / L = 1.14)

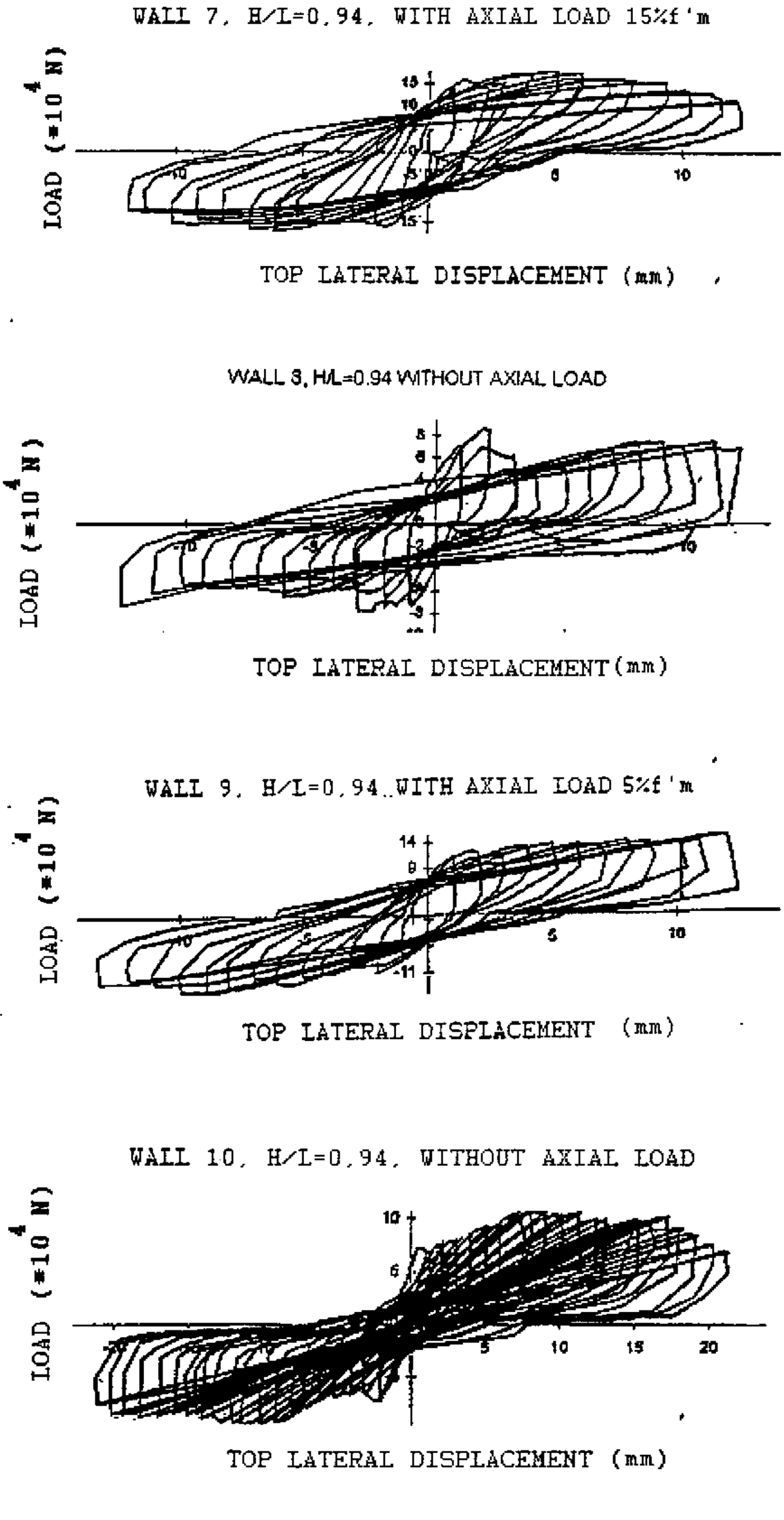

Figure 2c. Hysteresis Loops (H / L = 0.94)

CONCLUSIONS

Based on the results of this experimental research, several recommendations were proposed for design of brick masonry, infilled minor concrete frames,subjected to seismic loads. Drift limits were introduced to guaranty an adequate controlled damage of the masonry infill under service conditions. An expression was found to evaluate the lateral load capacity of the walls, taking into account its geometry and the level of the applied vertical load.

The tested walls showed a fairly ductile response with important hysteretic energy dissipation and appropriate stable resistance to lateral loads. This behavior is not usually observed in minor reinforced concrete frames with masonry infills. The results suggest further research pointing to obtain methods to enforce the dowel resistant mechanism, here reported, in a controlled manner.

REFERENCES

Abrams D. P., ed. (1994), “ Proceedings from the NCEER Workshop on Seismic Response of Masonry Infills”, Technical report NCEER-94-0004, Buffalo, NY 14261.

Angel, R., Abrams D.P., Shapiro D., Uzarski J. and Webster M. (1994), “Behavior of reinforced concrete frames with masonry infills”, *Structural research series repport*, 589, Dept. of Civ. Eng., Univ.of Illinois.

Buonopane S. G. and White R. N. (1999), “Seismic Evaluation of a Masonry Infilled Reinforced Concrete Frame by Pseudodynamic Testing”, *Tech. Report MCEER-99-0001*, Buffalo, NY 14261.

Carrillo V. and Molina A. (1997), “ Evaluación del Comportamiento de Muros Confinados de Bloques Macizos de Arcilla con Diferentes Relaciones de Aspecto ante Cargas Laterales Alternantes”, *Civil Eng. Dissertation,* U.C.V., Caracas, Venezuela.

Klingner R. E., Rubiano N. R., Bashandy T., Sweeney S. (1996), “Evaluation and Analytical Verification of Infilled frame test data: part 1, part 2”, *Proceedings of 7th North American Masonry Conf.*, University of Notre Dame.

Lafuente M., Castilla E. and Genatios C. (1998), “Experimental and Analytical Evaluation of the Seismic Resistant Behavior of Masonry Walls”, *Journal of the British Masonry Society*, 11, 3, pp 65-101.

Pauley, T. and Priestley M. J. N. (1992), *Seismic Design of Reinforced Concrete and Masonry Buildings*, John Wiley & Sons, New York.

$$V'_m = 3.22 * \left(f / f'_m \right) + 3.14 * a$$

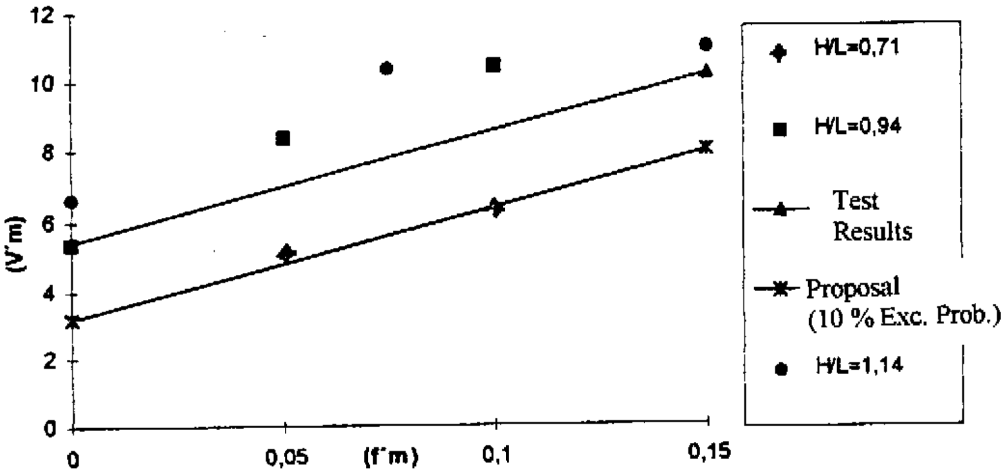

Figure 3. Lateral Resistance : Test Values and Proposal.