Paper No. 13. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

EXPERIMENTAL ANALYSIS REFERRED TO INCLUSION OF MASONRY INTO REINFORCED CONCRETE FRAMES

R.J.MICHELINI, N.G. MALDONADO and L.A. OLIVENCIA

CEREDETEC Center -Universidad Tecnológica Nacional
Rodríguez 273 - 5500 - Mendoza, República Argentina

ABSTRACT

The aim of this paper is to evaluate the different seismic design alternatives for the inclusion of masonry into reinforced concrete framed structures. The reason for this is that the constructive system of the western provinces of Argentina have adopted this type of construction.

In this work, the behaviour of reinforced concrete structures with and without infill masonry is evaluated. The infill masonry is of two types. The models are subjected to equivalent seismic loads at the top of wall. The type of models are: one level and one span, two levels and one span and two levels and two spans. The experimental results are obtained from 1:1 laboratory tests under monotonic and cyclic loads. The factors under consideration are: relation height/length of panel, type and reinforcement of concrete frame tie and different types of masonry units.

In this paper the results are compared to theoretical and code criteria. The alternatives of theoretical design present notable differences with experimental results. The resulting expressions for seismic included masonry design must be adequated to amount of tie masonry reinforcement, to its localization into the structure, to regional technology and to quality of the materials used to obtain a correct correlation between codes and tests.

KEYWORDS

Experimental Masonry; Seismic-resistant Masonry, Infill Masonry Panels, Reinforced Concrete Infill Frames; Modelation of Masonry; Equivalent Diagonal Strut

INTRODUCTION

The ultimate capacity seismic resistant design requieres a great knowledge about its behaviour. Up to now, this experimental knowledge is limited only to the study of reinforced concrete, steel or masonry elements, but the interaction between materials isn´t known or, is extrapolated.

The constructive system of the western provinces of Argentine have adopted the inclusion of masonry as an structural support element or not under gravitatory loads, seismic loads, wind loads, etc. and in the particular way of state of art of building for this great western region of Argentine, where the masonry has been included into the reinforced concrete structure, as a whole, although there are other proposals to separate the masonry from the frame structure to keep in this way, the ductile behaviour of reinforced concrete structure.

The inclusion of masonry is presented in the seismic-resistant structural modelation; a problem which not only is present in the quantization of stiffness and strength but also affects the deformability, and of course, the ultimate capacity of the structure.

The aim of this research is to evaluate the different seismic design alternatives for the inclusion of masonry into reinforced concrete framed structures.

METHODOLOGY OF RESEARCH

Theoretical Scheme

The masonry is idealized by one equivalent diagonal strut. This strut is made up as a bar biarticulated element of reinforced concrete.

Stafford-Smith devised this concept for steel frames and monotonic loads. Other authors included this same concept for modelation of masonry (Priestley et al, 1992 and Decanini et al, 1993). Regulations INPRES-CIRSCOC 103 (1983-91) of Argentine introduces the concept of the strut for modelation of strength and stiffness design in the structural calculus.

The Seismic-Resistant Building Code of the Province of Mendoza, (Di. 5.1.3.2) includes the concept of the strut for strength and deformability for isolated masonry panels.

The equivalent diagonal strut analyzed in this paper is:

$$A = 0{,}4 \,.\, e \,.\, Em / E \,.\, (l^2 + h^2)^{1{,}5} \; / (h.l)$$

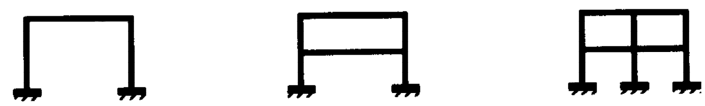
where:
A : area of equivalent diagonal strut
e : thickness of masonry panel
Em : elasticity module of masonry
E : elasticity module of material structure
l : length of masonry panel
h : height of masonry panel

Models

Three models of frames were analyzed: one level and one span (5 tests), two levels and one span (5 tests) and two levels and two spans (3 tests). The infill masonry was on the second level in two-level-frames.

The test specimens were built in 1:1 scale. The physical characteristics, type of partial infill masonry, quantity of reinforcement and details are presented in Table 1 and Table 2.

Table 1. Physical Characteristics of Reinforced Concrete Frames



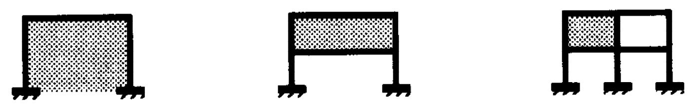
Items		Model I-1	Model II-1	Model III-1
Total Height	(m)	2,93	2,93	2,91
Total Length	(m)	2,36	2,31	2,30
Height Media Beam	(m)	-	1,53	1,51
Length 1o.Span	(m)	-	-	1,17
Modulus E	(MPa)	200	200	200
Modulus G	(MPa)	80	80	80
Size of	b(m)	0,180	0,180	0,180
Column	d(m)	0,310	0,305	0,170
Size of	b(m)	0,180	0,180	0,170
Upper Beam	d(m)	0,310	0,328	0,175
Size of	b(m)	-	0,180	0,170
Media Beam	d(m)	-	0,310	0,175
Lateral	Fe=Fé 2° Level	-	7 ϕ 8 mm	2 ϕ 12 mm
Column	Fe=Fé 1° Level	6 ϕ 16 mm	7 ϕ 8 mm	3 ϕ 12mm
Reinforcement	Stirrups 2°Level	-	ϕ4,2mm each 5,5cm	ϕ6 mm each 14cm
	Stirrups 1°Level	ϕ6 mm each 11,5cm	ϕ4,2mm each 5,5cm	ϕ6 mm each 9cm
Central	Fe=Fé 2° Level	-	-	4 ϕ 12 mm
Column	Fe=Fé 1° Level	-	-	4 ϕ 12mm
Reinforcement	Stirrups 2° Level	-	-	ϕ6 mm each 6cm
	Stirrups 1° Level	-	-	ϕ6 mm each 7cm
Upper	Fe=Fé	6 ϕ 16 mm	7 ϕ 8 mm	2 ϕ 12 mm
Beam	Fe Support	6 ϕ16 mm	-	2ϕ12 mm+2ϕ 8mm
Reinforcement	Stirrups	ϕ6 mm each 11,5cm	ϕ4,2mm each 9 cm	ϕ6 mm each 9 cm
Intermediate	Fe=Fé	-	9 ϕ 8 mm	4 ϕ 12 mm
Beam	Central Bond	-	-	3 ϕ 12 mm+1 ϕ 8mm
Reinforcement	Stirrups	-	ϕ4,2mm each 5 cm	ϕ6 mm each 5 cm

Materials

The mechanical characteristics of the constitutive materials of models were analyzed. The characteristic constants were determinated by standarized tests.

The used materials were: reinforced concrete (H13), steel reinforcement (ADN 420) and masonry (LCM-B, BCV-B and BCH-B).

Table 2. Physical Characteristics of Infill Panel Masonry Frames



Items		Models I-i	Models II-i	Models III-i
Total Height	(m)	2,96	2,93	2,91
Total Length	(m)	2,33	2,31	2,30
Height Media Beam	(m)	-	1,55	1,51
Length 1o. Span	(m)	-	-	1,17
Infill Panel Modulus E				
Ladrillón	35 MPa	I-4, I-5	II-2	III-2
Hollow Brick	50 Mpa	I-2, I-3	II-3, II-4, II-5	III-3
Size of	b(m)	0,180	0,180	0,170
Column	d(m)	0,300	0,300	0,175
Size of	b(m)	0,180	0,180	0,170
Upper Beam	d(m)	0,300	0,310	0,175
Size of	b(m)	-	0,180	0,170
Media Beam	d(m)	-	0,300	0,175
Lateral	Fe=Fé 2° Level	-	7 ϕ 8 mm	2 ϕ 12 mm
Column	Fe=Fé 1° Level	6 ϕ 16 mm	7 ϕ 8 mm	3 ϕ 12mm
Reinforcement	Stirrups 2° Level	-	ϕ4,2mm each 5,5cm	ϕ6 mm each 14cm
	Stirrups 1° Level	ϕ6 mm each 11,5cm	ϕ4,2mm each 5,5cm	ϕ6 mm each 9cm
Central	Fe=Fé 2° Level	-	-	4 ϕ 12 mm
Column	Fe=Fé 1° Level	-	-	4 ϕ 12mm
Reinforcement	Stirrups 2° Level	-	-	ϕ6 mm each 6cm
	Stirrups 1° level	-	-	ϕ6 mm each 7cm
Upper	Fe=Fé	6 ϕ 16 mm	7 ϕ 8 mm	2 ϕ 12 mm
Beam	Fe Support	6 ϕ16 mm	8 ϕ 8 mm	2ϕ12 mm+2ϕ 8mm
Reinforcement	Stirrups	ϕ6 mm each 11,5cm	ϕ4,2mm each 9 cm	ϕ6 mm each 9 cm
Intermediate	Fe=Fé	-	9 ϕ 8 mm	4 ϕ 12 mm
Beam	Central Bond	-	-	3 ϕ 12 mm+1 ϕ 8mm
Reinforcement	Stirrups	-	ϕ4,2mm each 5 cm	ϕ6 mm each 5 cm

Mathematical Design of the Structure

The structures in elastic state (section without cracking) and in ultimate state were calculated analytically.

The masonry was included as a bar biarticulated element, taking account of regional technologies of building.

The sections were calculated up to maximum collapse load. These loads didn´t overcome the maximum capacity of test equipment. The criteria of design of reinforcement took into account the guidelines of present codes.

Program of Testing

The test structure were subjected to quasistatic tests. The cyclic load was applied by an hydraulic jack on the top of the structure and the specimens were fixed to the base (cantilever beam test). The loads were applied in load-unload cycles increasing up to failure.
During test, the loads were measured in the model and the measurement instruments were installed for displacements in different points of the structure. The evolution of cracking was also drawn.

RESULTS

The analyzed variables from the tests were: applied load, displacements, stiffness, strength, ductility and mode of failure.
The diagrams of loads-top displacements of models are shown in Fig. 1. The crack patterns of test are shown in Fig. 2.

Analysis of Results

The behaviour of reinforced concrete frames with horizontal load was analyzed with respect to the behaviour of reinforced concrete with partial infill masonry frames under the same conditions. The results of theoretical and experimental stiffness are presented in Table 3.

Table 3. Results of Theoretical and Experimental Tests

Item	Test	Model 1	Model 2	Model 3	Model 4	Model 5
Theoretic	I	74790	990090	956940	655740	743490
Elastic Stiffness	II	383140	493827	472813	473933	486618
1° Level (N/m)	III	126103	152827	210378	-	-
Theoretic	I	-	-	-	-	-
Elastic Stiffness	II	346020	2150537	1129943	1818181	1785714
2° Level (N/m)	III	16160	610873	710900	-	-
Experimental	I	49314	1056951	853178	463886	649595
Stiffness	II	217634	466019	320000	452830	473373
1° Level (N/m)	III	31350	62080	103940	-	-
Experimental	I	-	-	-	-	-
Stiffness	II	145887	623376	1371429	923077	1030043
2° Level (N/m)	III	22150	45180	54870	-	-
Ultimate	I	1200	2060	1320	2000	2000
Capacity	II	1360	1950	1720	2000	2000
Load (N)	III	680	1200	1000	-	-
Wide of Diagonal	I	-	0,69	0,70	0,48	0,45
Strut by Mendoza	II	-	0,34	0,18	0,45	0,44
Code (m)	III	-	0,27	0,37	-	-
Adjustment of	I	-	0,35	0,28	0,31	0,65
Diagonal Strut by	II	-	0,20	0,19	0,47	0,26
Mendoza Code (m	III	-	0,05	0,04	-	-

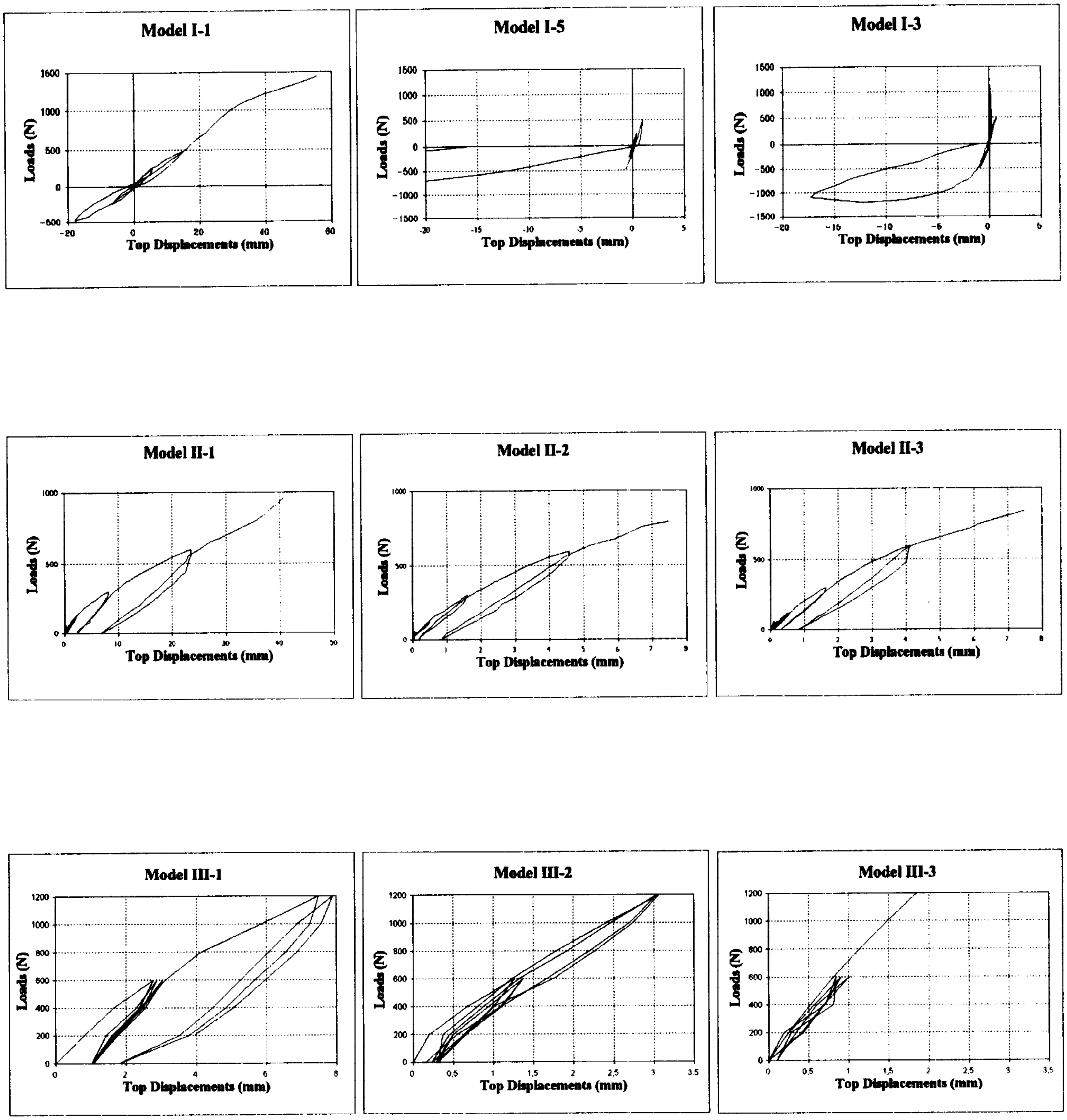
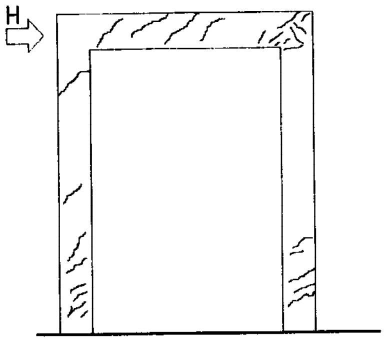
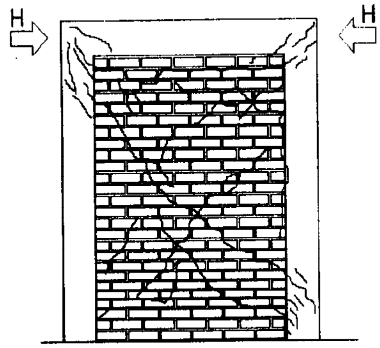


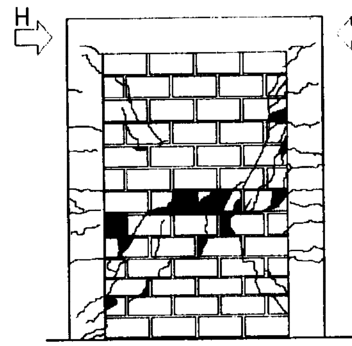
Fig. 1. Diagrams of Loads-Top Displacements of Testing Models



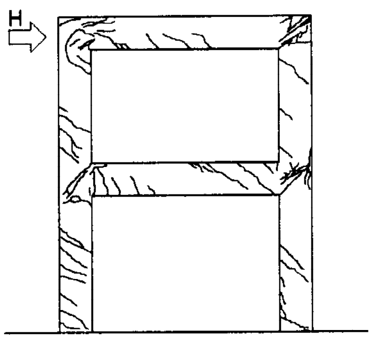
Scale Model I-1



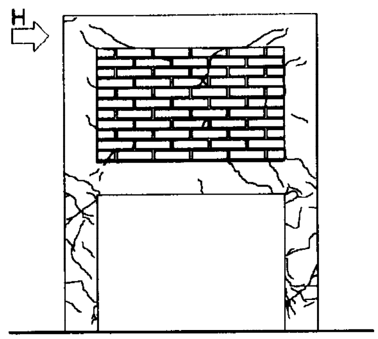
Scale Model I-5



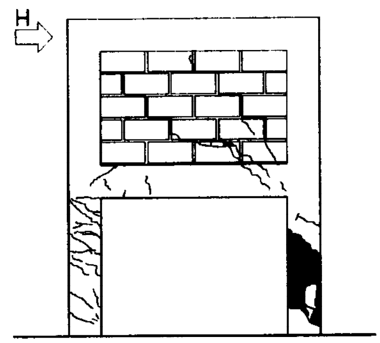
Scale Model I-3



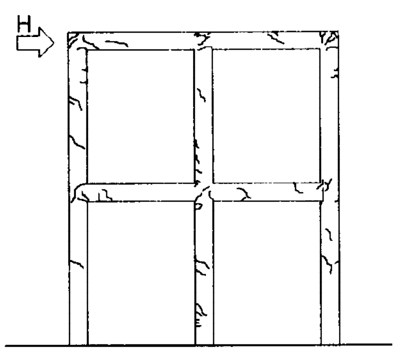
Scale Model II-1



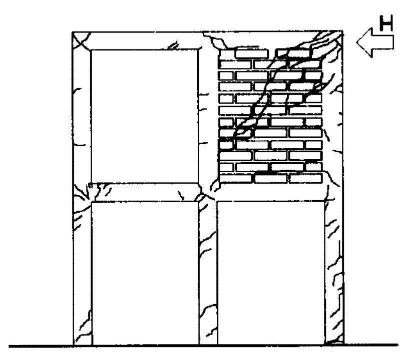
Scale Model II-2



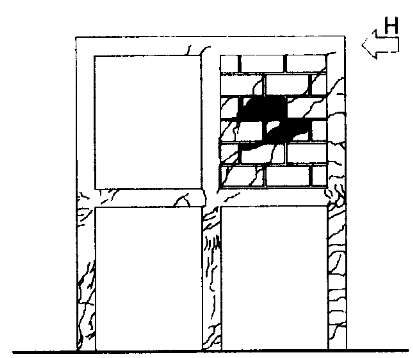
Scale Model II-3



Scale Model III-1



Scale Model III-2



Scale Model III-3

Fig.2. Crack Patterns of Tests

CONCLUSIONS

The damage in all the models was controlled by diagonal cracking, with an extension into the interface mortar-brick and pulling-out hollow ceramic bricks.

The theoretical stiffness is influenced by the variation of modelation of the equivalent diagonal strut into the reinforced concrete frame. The results show that the inclusion of pains of masonry, elastically joint to structural planes in reinforced concrete frames produces a great stiffness under horizontal actions at the level where the infill masonry panel is found.

The experimental results show that the mathematical model stiffened by a strut is adequate, taking account of the mechanic characteristics of brick and masonry applying the factors of compatibility proposed in Table 3 .

The resulting expressions for seismic included masonry design must be adequated to amount tie-masonry reinforcement, to its localization into the structure, to regional technology and to quality of the materials used to obtain a correctly correlation between codes and tests.

The perform tests show that the subject isn't in any way finished and it is neccessary to continue with the research, analyzing or studying new variables which would allow us to come to a closer and closer theoretic modelation which will be able to compatibilize with the real structure when this one is subjected to a seismic action.

REFERENCES

J.Axley and V.Bertero (1979). Infill Panels: Their Influence on Seismic Responses of Building. *Report 79/28.* University of California. Earthquake Engineering Research Center.

Decanini L. et al. (1993). Telai Tamponati Soggetti ad Azione Sismiche. Un Modello Semplificato Confronto Sperimentale e Numerico. Dipartamento di Ingegneria Strutturale e Geotecnia. Università degli studi di Roma "La Sapienza".

I.N.T.I. Regulations *CIRSOC 201* (1983) & Regulations *INPRES-CIRSOC 103* (1983-1991). Argentina.

Ishibashi K. et al. (1992). Experimental study on earthquake-resistant design of confined masonry structures. 10th World Conference on Earthquake Engineering (Balkema Ed.). Vol. VI -pp 3469-3474

Michelini R et al. (1995). Influencia de los ganchos en las armaduras de estructuras aporticadas de hormigón armado. XXVII Jornadas Sudamericanas de Ingeniería Estructural, Argentina. Vol. II. pp 381-391.

Michelini R et al. (1994). Informe Académico "Comportamiento de estructuras de hormigón armado interactuando con mampostería de ladrillo". Consejo Nacional de Investigaciones Científicas y Técnicas PID 30-81900/88. Argentina. 76pp.

Michelini R. et al. (1991). Influence of Masonry in Reinforced Concrete Frame Structures Subjected to Horizontal Loads. 9a. International Conference of Masonry Block, Berlín, Alemania. Vol.1.

Park P & Priestley N.(1992). *Seismic Design of Reinforced Concrete and Masonry Buildings*. John Wiley & Sons, Inc. New York.

Seismic-Resistant Building Code of the Province of Mendoza (1987). Argentina

ACKNOWLEDGMENTS

The present paper is one of the projects done at Facultad Regional Mendoza, Universidad Tecnológica Nacional. We thank the sponsorship of federal state authorities of the UTN, CONICET (PID *30-81900/88*), private local enterprises and the invaluable collaboration of the Anteseismic Construction Group staff.