"THE CURRENT STATE-OF-THE-ART OF MASONRY AND ADOBE BUILDINGS IN PERU"

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ABSTRACT

Masonry is extensively used to build houses and small buildings in urban areas, and when built with reinforcing elements has demonstrated good behavior to resist earthquake forces. This is reported in experimental and analytical work carried out at UNI and CISMID in research projects with government agencies like ININVI, SENCICO (in charge of specific standards for building construction) or with the support of JICA. Aim of studies ranges from material (unit, mortar) to full-scale models going through prisms and walls, studying different parameters that affect its resistance and obtaining experimental curves for masonry behavior.

Because of its low resistance and brittle behavior, adobe houses has shown poor performance when subjected to seismic loads, as observed in 2001 Atico Earthquake (South of Peru). Even this fact is well known, adobe is commonly used in countryside, especially in small cities and rural areas. Here is reported a brief view of research in adobe, focusing on improvement of material and reinforcing methods for existing buildings..

STANDARDS

Masonry and Adobe specific standards are part of the National Standard for Construction (RNC). Others standards related to design and building are those of Loads (NTE-E020), Earthquake Resistant Design (NTE-E030), Soils and Foundations (NTE-E050)

Masonry Standard NTE E-070

Current standard for masonry NTE-E070 (1982) considers elastic design method under service conditions. Considering a simple analysis with seismic equivalent lateral forces, and permanent gravity loads, working stresses values of material should be verified to be lower than specified allowable stress, which are presented in Table 1

Table 1: Peruvian confined masonry stresses

Stress Type	Formula (Kg/cm^2)
Compression due to axial load in Walls	Fa=0.20 f'm f'm: compression strength of masonry
Compression due to bending	Fb=0.40 f'm
Tension due to Bending - Normal to horizontal joints	 Ft=1.00
Shear	Vm=1.2+0.18fd < 2.7 fd: dead load normal stress
Crushing on Masonry - In whole area - In 1/ 3 of area	 Fca=0.25 f'm Fca=0.37 f'm
Elastic Modulus Shear Modulus	Em= 500 f'm Ev=0.4 Em

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Besides values of stress, this code describes general recommendations for construction and defines types of masonry units. Two kinds of masonry are used: with hollow units and reinforced distributed inside them and with solids units where reinforcement is concentrated in "confining" elements, beams and columns.
A new standard using capacity design approach has been proposed (2004) and is on discussion stage, but is not approved yet. This proposal shows a more comprehensive focus of design, specifying general aspects as structural planning, wall density, and more detailed procedures for designing confinement elements.

Adobe Standard NTE E-080
Standard for adobe NTE-E080 (1999) describes elements of adobe construction and specifies need of reinforcing elements as orthogonal walls, columns or collar beams and vertical reinforcement inside walls made of cane or wood. On the basis of compression strength of adobe unit and piles, it is determined allowable stresses for compression and shear effects. Current code is an updated version from its original of 1985, and changes are referred to requirements for adobe units, seismic lateral forces and the possible use of wire mesh or concrete elements for reinforcing walls.

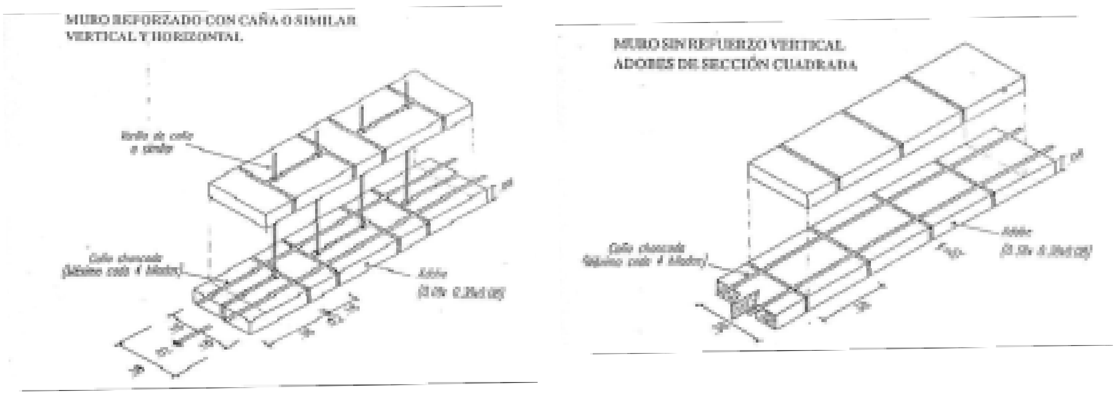
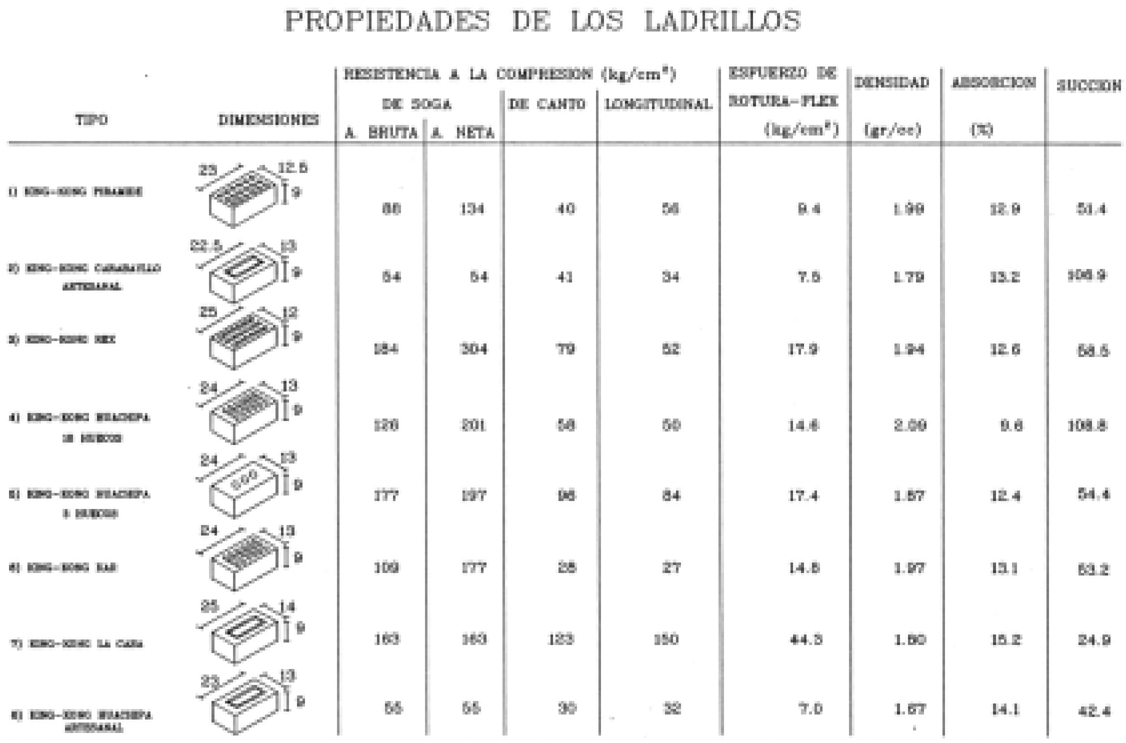


Figure 1: Reinforcement in adobe walls: cane rods used horizontally or vertically

EXPERIMENTAL RESEARCH AT CISMID. CISMID-ININVI-JICA PROJECT (ref. 2,3)
A first level of research was carry out on CISMID-UNI under the support of JICA and in joint research with ININVI, institution in charge of standardization in building at that time. Between 1988-1990, just after implementation of equipments at CISMID, different kinds of bricks units and arrangements (prisms) were tested to find average mechanical properties. A series of test with factory made and hand made clay brick were carried out. Tests of compression strength, flexion, and absorption were made on masonry units, and in masonry arrangements or piles, compression, shear, adherence and diagonal compression tests were executed, in order to obtain comparison parameters and proposal formulas for masonry standards. In the theoretical part of this study, analytical models and elastic lineal analysis of wall were made, and some examples of masonry buildings (existing projects) were analyzed with a proposed computational program. Also construction cost items and work aspects were studied. Experimental aspects of this project was presented also as a thesis at UNI (ref 4). Figure 2 shows table of results for brick unit tested



PROPIEDADES DE LOS LADRILLOS

TIPO	DIMENSIONES	RESISTENCIA A LA COMPRESION (kg/cm^2) DE SOGA A. BRUTA	DE SOGA A. NETA	DE CANTO	LONGITUDINAL	ESFUERZO DE ROTURA-FLEX (kg/cm^2)	DENSIDAD (gr/cc)	ABSORCION (%)	SUCCION
1) KING-KONG PIRAMIDE	23 x 12.5 x 9	88	134	40	56	9.4	1.99	12.9	51.4
2) KING-KONG CARABAYLLO ARTESANAL	22.5 x 13 x 9	54	54	41	34	7.5	1.79	13.2	106.9
3) KING-KONG REX	25 x 12 x 9	184	304	79	52	17.9	1.94	12.6	58.5
4) KING-KONG HUACHIPA 18 HUECOS	24 x 13 x 9	120	201	58	50	14.6	2.09	9.6	108.8
5) KING-KONG HUACHIPA 3 HUECOS	24 x 13 x 9	177	197	96	84	17.4	1.87	12.4	54.4
6) KING-KONG BAR	24 x 13 x 9	109	177	28	27	14.8	1.97	13.1	53.2
7) KING-KONG LA CAJA	25 x 14 x 9	163	163	123	150	44.3	1.80	15.2	24.9
8) KING-KONG HUACHIPA ARTESANAL	23 x 13 x 9	55	55	30	32	7.0	1.67	14.1	42.4

Figure 2: Results of tests for factory-made and handmade bricks

CICLIC LOADING TEST ON CONFINED MASONRY WALLS (Eng. Patricia Gibu, Eng. César Serida & Dr Javier Pique – 1990-1992, ref 5)

Walls without and with confining element (beam, columns) were tested to study some parameters affecting wall in-plane behaviour. Some studied variables were type of confining (beams-columns at the edge, smalls columns distributed, orthogonal walls, effect of slab) amount of reinforcement (longitudinal and transversal) in the confining elements, axial load. Eight types of walls were subjected to lateral cyclic loading involving masonry behavior and interaction with its confining elements.

Table 2: Geometry and parameters of walls

Wall ID	Confined Beam dimension (cmxcm)	Confined Columns dimension (cmxcm)	Wall Thicknes s (cm)	Wall Masonry Length (cm)	Wall Height Dimension (cm)	Confined Elements
MCST1	30x20	15x25	15	190	220	Footing, Beam and 2 Columns
MCST2	30x20	15x25	15	190	220	Footing, Beam and 2 Columns
MC4C1	30x20	15x12.5	15	@ 63	220	Footing, Beam and 4 Columns
MC4C2	30x20	15x12.5	15	@ 63	220	Footing, Beam and 4 Columns
MLCC1	200x20 (slab)	15x25	15	190	220	Footing, Slab and 2 Columns
M-H	30x20	220x25 (Wall)	15	220	220	Footing, Beams and Lateral Walls

Cyclic control displacement test was performed on the mentioned specimens. On Figure 3 is shown hysteretic curve and final state of MCST1 specimen tested.

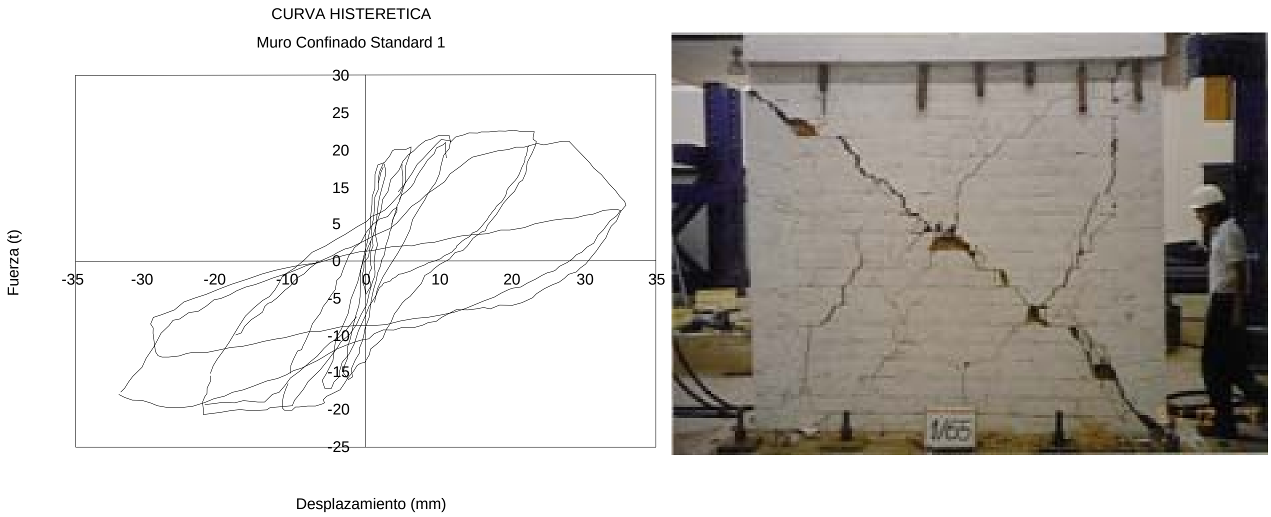


Figure 3: Hysteresis curve (left) and final state of wall MCST-1 (right)

ADOBE AND QUINCHA SCALE STRUCTURES SHAKING TABLE TEST (Eng. Francisco Ríos & Msc.Julio Kuroiwa (1991)

Test on one floor scale models (1:6) were developed in Cismid shake table at structural laboratory. A series of harmonic load with different type of amplitude and acceleration ranges were applied to the model in order to assess the effect of adding reinforcement to the simple adobe model. Reinforcement adopted was bamboo bars and also wood belt on the top of each floor. One floor and two floor specimens were tested. Two floor specimen was first floor of adobe and the second one made of quincha.

MASONRY MODELS FROM TEST RESULTS

An Analytical Study Of Behavior Of Confined Masonry Structures Under Lateral Loads (Eng. Victor Rojas, 1994)

There are many different kinds of models for numerical modeling of structural walls. Models could be classified into two main groups: macro models and micro models. Macro models intend to model the overall behavior of a structural wall cross section over certain height. Micro models are based on the constitutive laws of the mechanics of solids and finite elements methodology. A good discussion of this two major categories is provided by Vulcano and Bertero (1987) for the R/C shear walls. Also Linde (1993) showed a description of the current likely used micro models. Rojas (1994) predict the behavior of masonry wall through an adaptation of a micro-model application proposed by Noguchi (1986) for concrete walls.

Micro models are quite accurate and it could be showed by the results presented by Rojas, comparing the failure pattern and results with real standard masonry wall test, Figure 4 compares the results of Gibu et.al (1993) with the simulation performed by Rojas (1994). It is shown the good agreement between this refined model and the real test results. Unfortunately practical applicability of such kind of models are quite difficult for daily engineering work, and it is limited to research job on developing countries.

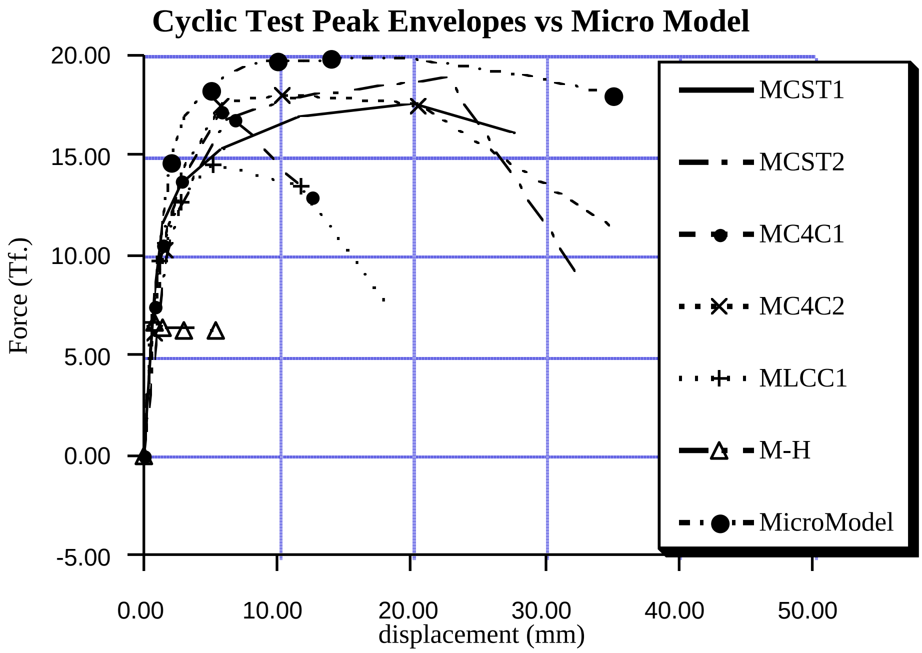


Figure 4: Analitical Micromodel and test results

Aseismic Masonry Building Model for Urban Areas (Dr. Carlos Zavala, Dr. Rafael Torres, Eng. Jorge Gallardo, 1998)

On the other side, macro models are easy to implement and apply to practical applications and computational work is quite few. This motivated the authors to implement a practical macro model considering a simple strut, using the behavior characteristics of the walls failure pattern. Masonry walls behave as a shear beam during the elastic range, where the stiffness of the wall is provided by the masonry itself and the confining columns. After the first crack occurs on masonry, stiffness decrease gradually and crack propagation spread into the wall on different ways. The most likely is the X spreading due to shear cracks. It will decrease the stiffness of the masonry panel starting the action of the strut. It will behaves as a brace that confine the frame with stiffness, considering the action width for the section of one quarter of the diagonal length. Figure 5 explains the actions and configuration of the strut model used.

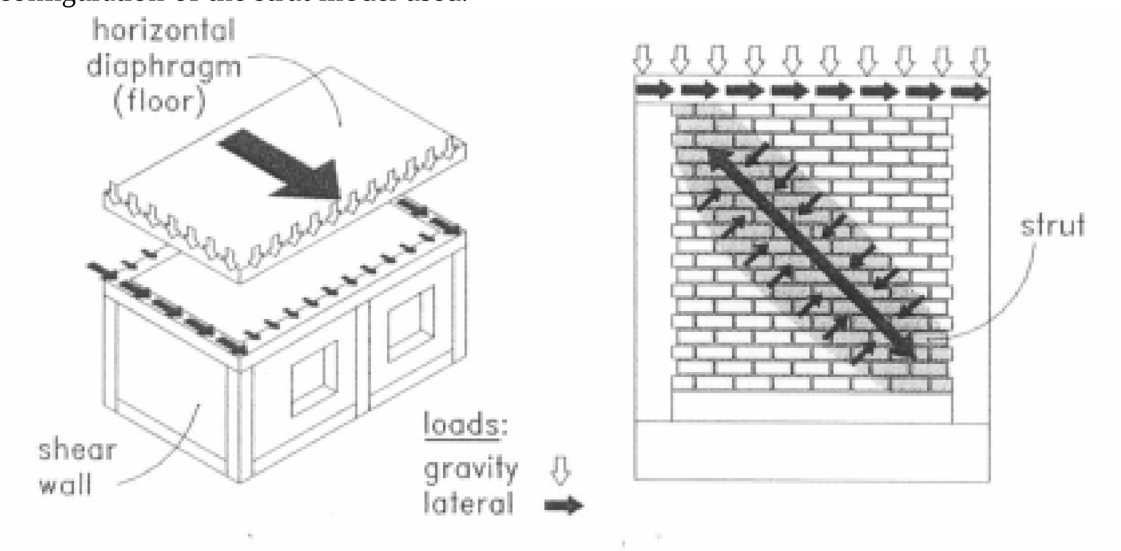


Figure 5: Strut Modelling

Using the strut model for masonry it is possible to simulate the behavior of the real wall. Test results of Gibu et.al. (1993) micro model and strut model are presented on Figure 6. It could be observed the good agreement between the push over analytical curves and the cyclic peaks results. It shows with a simple modeling it is possible to simulate the real behavior of a wall.

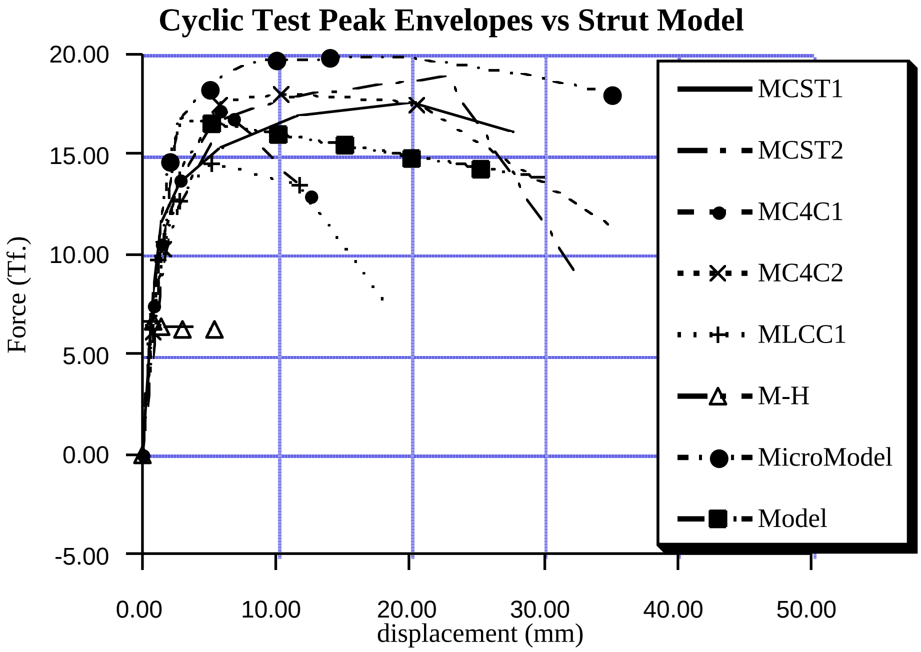


Figure 6: Analitical Strut model , micromodel and test results

PSEUDO DYNAMIC TEST OF CONFINED MASONRY BUILDINGS (Eng. Gladys Cuadros, Dr. Tsunehisa Tsugawa, Dr. Hugo Scaletti- 1991)

An online test on a 1/2 scale two floor masonry building model was developed in CISMID in a joint cooperation research with Catholic University under the support of JICA. Two specimens were tested: one in 1/2 scale on the shaking table of Catholic University and other in the Structural lab of CISMID. Comparison of the results of both models and also the calibration of the online test system was carried out. Figure 7 shows the response of specimen tested on CISMID.

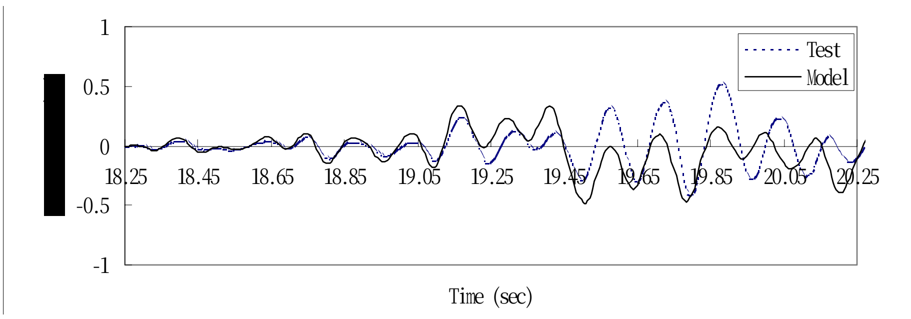


Figure 7: Comparison between PSD Test results and strut model

ENERGY DISSIPATION LIGHT STEEL PANEL ON MASONRY WALLS (Dr. Carlos Zavala & Msc Aerls de la Rosa Toro – 1999)

Since 80's decade research about energy dissipation devices had been concentrated in steel honey dampers and passive rubber dampers. Since most of these devices are quite expensive systems for developing countries, the authors proposed the combination of two economical materials like masonry and cold formed shapes of light gauges to generate a energy dissipation panel infill a masonry wall.

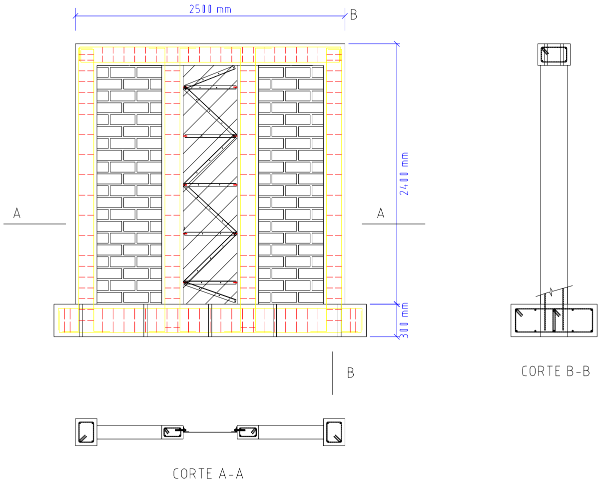


Figure 8: Prototype specimen

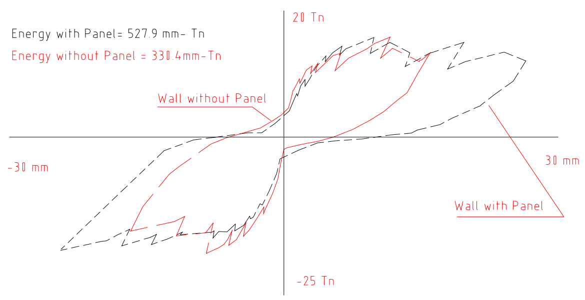


Figure 9: Energy dissipated on both specimens

A prototype specimen of 2400 mm. height by 2500 mm. length confined masonry wall with 125 mm. thickness is considered; an opening of 2200 mm. height by 500 mm. on the wall is filled by the Light Steel Panel, where Energy dissipation is expected. Cyclic test was performed under displacement control and on-line actuator system for two levels of deformation: nor visible cracks on masonry and visible cracks on masonry. The research presents the levels of energy dissipation on the panel during an elastic range on the masonry and no-linear behavior on both materials. Buckling on the panel appears prior the yielding on it for a visible crack level. Comparison between test results using Light Steel Panel and test without energy dissipation device is presented showing the improve on the behavior of the wall (Figure 9).

CYCLIC TEST ON MASONRY WALLS USING NON STRUCTURAL BRICKS

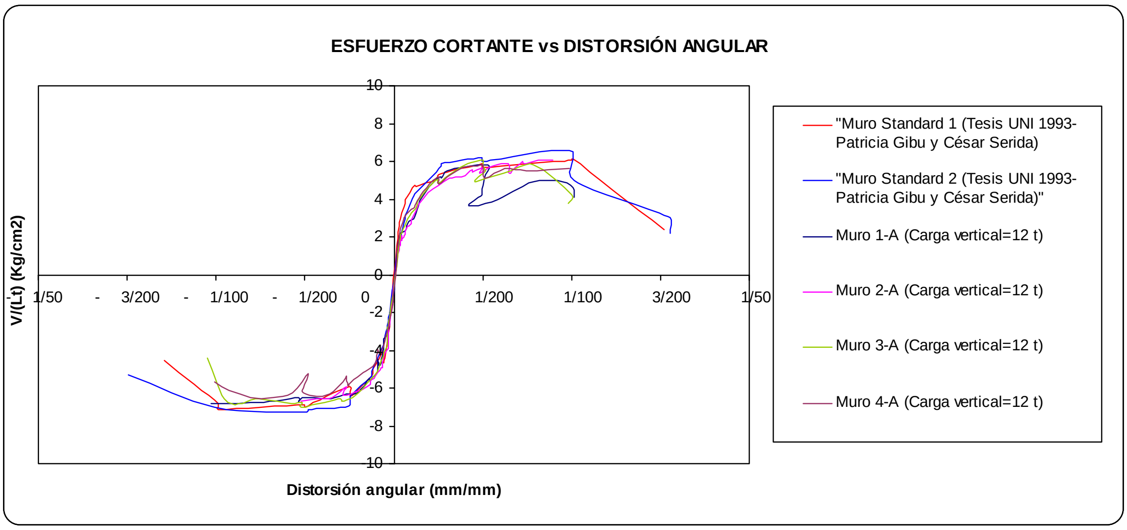
(Eng. Monica Ramirez & Dr. Carlos Zavala, 2001. Ref. 6)

According with our masonry Standards, an standard brick must have less than 25% of area of wholes to be consider an structural brick. However in the last decade, many of the factories increase the number of wholes in the brick, producing non structural bricks because they are out of the standards. A series of wall test using non structural bricks were carried out. Three were the objetive of this research work:

- Find the mechanical properties of three types of non structural bricks.
- Study the bahavior of walls by testing 8 samples and compare it with an standard wall who used structural blocks.
- Provides a proposal values for this kind of brick

A comparison with the standard wall test (Gibu, Serida & Pique 1990) was carried out to show the decrease of the resistance by using this kind of non structural block

Figure 10: Comparison of non structural bricks and structural bricks on walls



It can be read form Figure 10, a decrease of ductility on the samples who are using non structural walls. Also the stress capacity is lower than in the standard wall.

FULL SCALE ON LINE TEST ON TWO STORY MASONRY BUILDING USING HANDMADE BRICKS (Dr. Carlos Zavala, Eng. Claudia Honma, Ms. Eng. Patricia Gibu, Eng. Jorge Gallardo, Eng. Guillermo Huaco)

Under the advisor support of the Ministry of Land, Infrastructure and Transport of Japan by an experts committee of Building Research Institute, National Institute for Land, Infrastructure and Management, Yokohama National University, Center for Better Living Tsukuba Building Test Laboratory and of and financial support of the Infrastructure Development Institute, behavior of full-scale two-story masonry building using handmade bricks was investigated.

Photo 1: Construction Process

The key of this project was the monitoring of the construction process under real conditions and investigate behavior of a sample of masonry blocks of bad quality. A design following the allowable stress design standards and using this material must produce a good behavior structure, even the material have a bad quality.
The walls and building were built using handmade clay bricks. Samples using handmade bricks were taken to prepare piles of 4 clay bricks for compression test for determine the resistance of masonry. Table 3 shows the results of some samples of the used material..

Brick Type	Sample	Pmax (kg)	Area (cm2)	Stress (kg/cm2)	Average F'm (kg/cm2)
Handmade	M1	9500.00	238.05	39.91	47.41
	M2	9500.00	253.20	37.52	
	M3	13225.00	228.00	58.00	
	M4	13225.00	235.75	56.10	
	M5	10375.00	228.00	45.50	
Factory made	M6	20975.00	303.15	69.19	70.24
	M7	17325.00	312.84	55.38	
	M8	20575.00	300.80	68.40	
	M9	27000.00	306.80	88.01	

Table 3: Material Samples for full scale test

A series of wall tested to investigated the stiffness properties, cracking points and maximum capacity of different configuration of walls (walls with openings and without openings) were developed. On Figure 11 the comparison of the behavior of a wall made with handmade block and another built with factory blocks is presented.

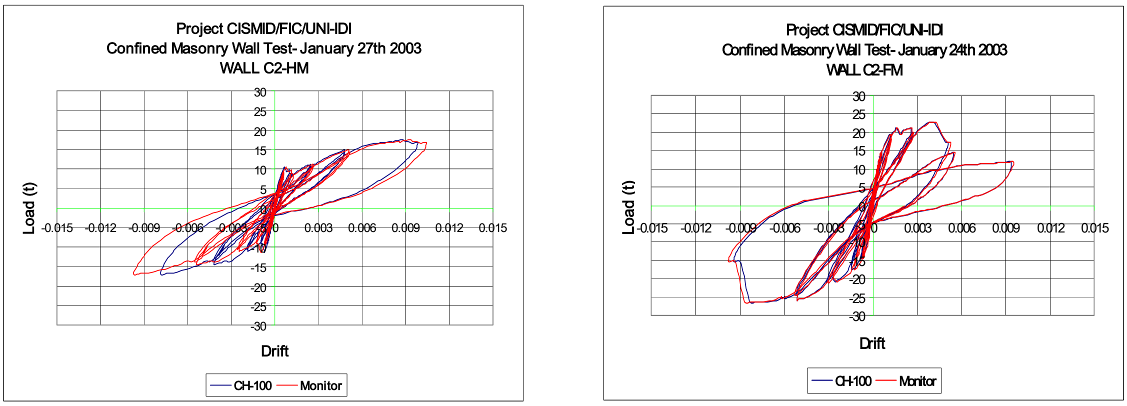
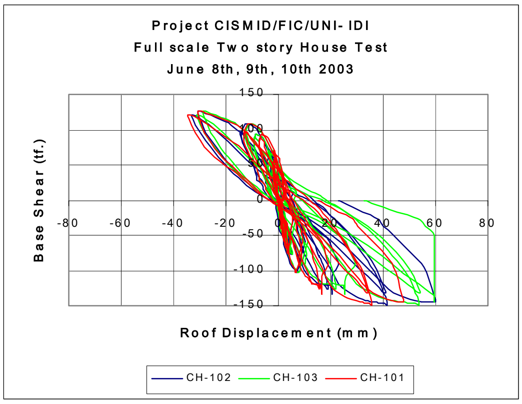


Figure 11: Comparison of factory made and handmade brick on walls

Three actuators under mix control drive the structure under prefix displacement pattern. The testing experiment torsion during its performance and good behavior even handmade bricks was used. Final stage of the building was found under story drift of 1/65 for a base shear of 147.86 t. Cracking pattern related with drift response is presented for this kind of building. Figure 12 shows the cyclic behavior of the specimen under lateral forces for the roof and first story of the two stories house.



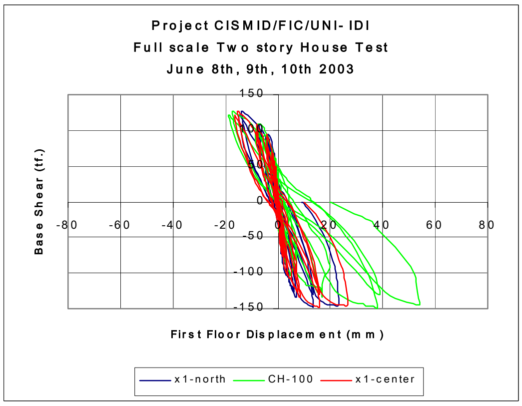


Figure 12: Hysteresis response to lateral forces

Photo 2: Final state of the specimen

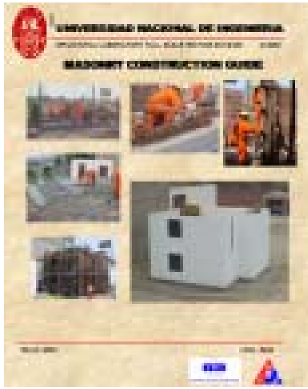


Figure 13: Guide for construction

The final state of the specimen is presented in Photo 2. Some of the walls failures in very string maner after reach the 1/200 interstory drift. However the house reach its maximum capacity for 1/65 drift.

As a result of this project a construction guide for masonry buildings was printed and now it can be download from our web site (www.cismid-uni.org) to be download for anyone who is interested in masonry structures and its construction process.

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