13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 2885

# FULL SCALE ON LINE TEST ON TWO STORY MASONRY BUILDING USING HANDMADE BRICKS

Carlos ZAVALA[1], Claudia HONMA[2], Patricia GIBU[3], Jorge GALLARDO[4], Guillermo HUACO[5]

## SUMMARY

Masonry is the likely used material to build housing in developing countries. Most of bricks are not produced in factories, so handmade bricks don't have the appropriate resistance according with standards. In order to investigate the behavior of masonry under such conditions, a full scale on line test on two story masonry building using handmade bricks was carried out in the structure laboratory of CISMID/FIC/UNI. Three actuators under mix control drive the structure under prefixed displacement pattern. The actuators displacement reproduced a first mode configuration. 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

## INTRODUCTION

Peru is located in the central part of South America with mixture of cultures and cities with their own way for design and build a house. Since ancient times the masonry has been the most likely used material selected by the Peruvian Population. Stone block masonry and adobe block masonry has been used since Inka's times. Many historical buildings show good state in conservation due to the high wall density used by our old constructors. However after the experience of strong quakes in Cuzco and Lima, builders improved their technologies and rebuilt many of the historical buildings. Also in times of the Spanish colony, clay brick masonry started to be used in church construction and also in housing. Since that times many improvements have been developed in our culture. The first recommendation of quake considerations appears in the 60's and after the experience of 1966 Lima quake and 1970 quake, the first version of National Standards for earthquake resistant design appears in 1977. After 1996 Nazca quake, modification on the standards considering displacement control of the structure was a great improve in our code publish in 1997 [1]. The current standard was published in April 2003, including a modification in the reduction factors

[1] Chief Structural Lab, Associate Professor CISMID/ FIC/ UNI ,Lima Peru, Email: czavala@uni.edu.pe
[2] Assistant Researcher, Structural Lab, CISMID/ FIC/ UNI ,Lima Peru
[3] Assistant Professor CISMID/ FIC/ UNI ,Lima Peru
[4] Chief Earthquake Engineering Division, Associate Professor CISMID/ FIC/ UNI ,Lima Peru
[5] Graduate Student CISMID/ FIC/ UNI ,Lima Peru

The total shear force acting in the base of the structure, corresponding to the direction considered in the test, will be determined through the following expression:

$$V = \frac{ZUSC}{R} P$$

where Z is the zoning factor, U is the building category factor, S is the site condition factor, C is the seismic amplification factor, P is the weight of the structure and R is the reduction factor.
In this report a two story building designed using the above seismic demand and following the Peruvian confined masonry standards is tested against lateral cyclic loading using an on-line actuator system. The house was built on real soil and real interaction was monitored during the test execution. The house was built with handmade bricks where the comparison of behavior with factory brick is presented in wall cyclic test.
The construction process was monitoring and each stage of the construction follow the quality control standards. So it will show even a handmade brick is used (with not guarantee in quality control in fabrication and resistance) earthquake resistance building is reached to satisfied the quake demand.

## THE MASONRY STANDARDS

The construction and allowable stress of this structural system is rule by the Peruvian Standards E-70 SENCICO [2], of 1982. Minimum values of stress of walls and units are given in this code. More of the values has been affected by high security factors to prevent the poor quality control on handmade units, which are likely used in expansion areas of the urban zones, like shine towns. Table 1 presents the minimum values of allowable stresses of the Peruvian Standards.

**TABLE** 1: Allowable stresses in masonry

| Stress Type | Formula (Kg/cm2) |
|---|---|
| Compression due to axial load in Walls | Fa=0.20 f'm<br>f'm: compression resistance of masonry |
| Compression due to bending | Fm=0.40 f'm |
| Tension due to Bending<br>- Normal to horizontal joints | <br>Ft=1.00 |
| Shear | Vm=1.2+0.18fd < 2.7<br>fd: dead load normal stress |
| Crushing on Masonry<br>- In whole area<br>- In 1/ 3 of area | <br>Fca=0.25 f'm<br>Fca=0.37 f'm |
| Elastic Modulus<br>Shear Modulus | Em= 500 f'm<br>Ev=0.4 Em |

Actually a new Peruvian Standard E-070 [3] and [4] is under discussion. The proposal considers the verification of each of the icons critical stages of the behavior of each wall. These are the axial capacity, the initial cracking stage and finally the diagonal crack capacity of the wall. Also, two levels of quake must be verified for the masonry building under the new standard:

- Severe damage quake: design quake NT-030 (V)
- Moderate damage quake: likely occur quake with half of the shear demand of design quake(Ve = V/2).

According with the proposal masonry standards NTE-070 the maximum axial stress must be computed by:

$$\sigma_m = P_m / (L\ t) \leq 0.20\ f'_m\ [\ 1 - (h/35t)^2] \leq 0.15\ f'_m$$

where L = total lenght of wall including columns
t = thickness of the wall

$P_m$= gravity load including 100% of live load
h = free length between horizontal bracing elements
$f'_m$= compression stress of masonry

Cracking resistance depends on the diagonal craking capacity of the wall in the proposal of standards shear demands for a wall under a moderate quake(Ve) should verify the following equation:

$$Ve \leq 0.55\ Vm$$

Where Vm is shear capacity associated with diagonal cracking of the masonry wall.

The value of Vm is a function of the slenderness reduction factor "α" of the wall, the wall dimensions (thickness "t" and length "L") and the gravity load "Pg" (with reduced live load NTE-030) and the resistance to diagonal tension "v'm". In the case of brick masonry blocks of clay or concrete, Vm is computed as:

$$Vm = 0.5\ v'm\ \alpha\ t\ L + 0.23\ Pg$$

Here v'm could be approximate as: $v'm = \sqrt{f'_m}$

The slenderness reduction factor is computed as: $\alpha = Ve\ L / Me$ where Ve is the shear demand of the wall and Me is the bending moment of the wall as a result of an static analysis.

Also must satisfied: $0.33 \leq \alpha \leq 1.00$

## THE TESTED BUILDING

Figure 1 presents the architectural drawing of two stories testing building. This house represents a likely used distribution for six family members and have all facilities for living. The house was built using handmade clay bricks taken from a representative sample from common informal sellers in surroundings north Lima's suburbs. Story height of the house is 2500 mm.. Samples of the material were taken and piles of 4 clay bricks were subjected to compression test for determine the resistance of masonry. Table 2 show the results for the used handmade bricks and also the factory bricks for comparison

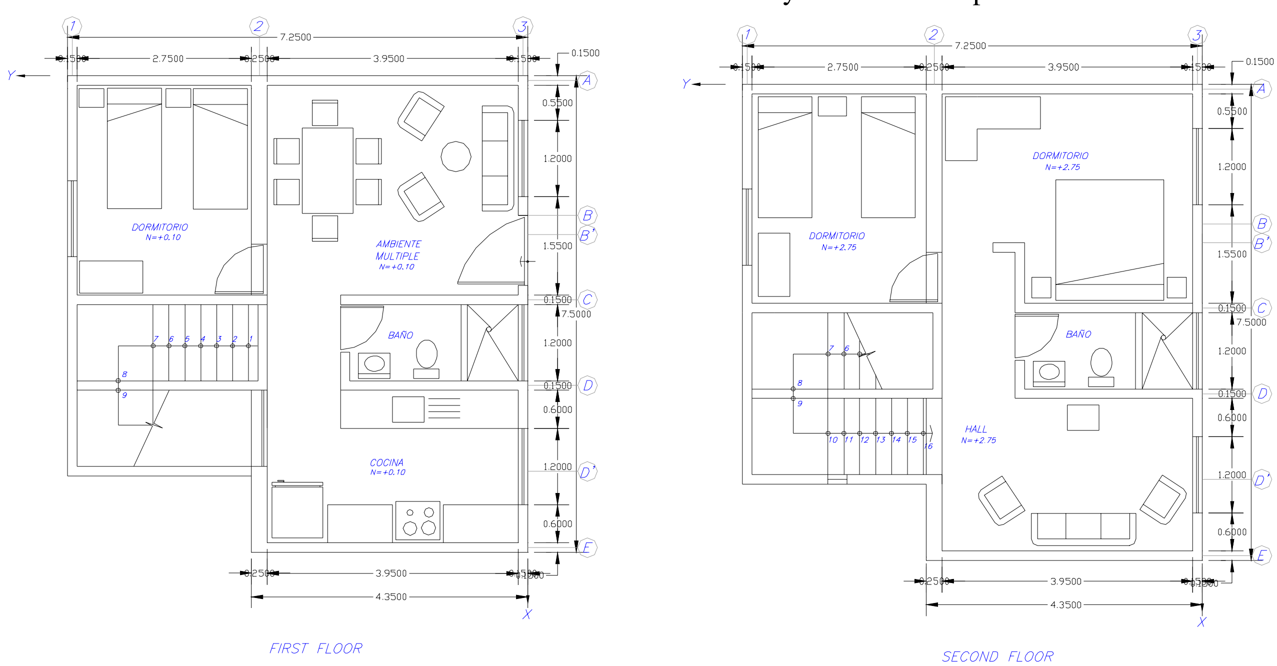


**FIGURE 1:** Architectural distribution of testing house (←North South→)

**TABLE 2:** Masonry compression strength of clay bricks

| 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 | |

The building was designed following the Peruvian earthquake design Standards NT-E030 and the masonry standards NT-E070. Under these standards Table 3 presents the computed design quake demand for the building where design quake acceleration was 267 gals. Table 3 presents the results for the demand of the quake in each of the directions of the building. Test forces application was in direction X-X, which is parallel to the longest length of the building as is presented in Figure 1.

**TABLE 3:** Design Quake demand for each axis

| Story | Height (m.) | Weight (t.) | Weight x Height | Fi (t.)= Static Equivalent Force XX |
|---|---|---|---|---|
| 2 | 5.30 | 51 | 270.3 | 18.5 |
| 1 | 2.50 | 51 | 127.5 | 8.7 |
| | | | 397.8 | 27.3t. |

| Story | Height (m.) | Weight (t.) | Weight x Height | Fi (t.)= Static Equivalent Force YY |
|---|---|---|---|---|
| 2 | 5.30 | 51 | 270.3 | 37.1 |
| 1 | 2.50 | 51 | 127.5 | 17.5 |
| | | | 397.8 | 54.6t. |

**FIGURE 2:** The building under construction

It can be read that in direction Y-Y the base shear force is bigger than X-X direction. This is because in Y-Y direction the reduction factor is R=2.25 because only masonry walls are presented. In direction X-X R=4.5 because masonry walls and one concrete shear wall were used. The concrete shear wall was included because according to masonry standards NT-E070, the minimum wall density for seismic safety building is 4%. Therefore because this ratio was not satisfied, additional concrete element was considered to reach an appropriate stiffness and minimum wall density.

## FRICTION TEST AND FULL SCALE TEST SETUP

**Investigation of the Reaction Force on the Basement of the Building**

To investigate the friction coefficient between foundation and soil, a block of 100 cm length and 60 cm. width was build in a position beside the house as is presented in Figure 3. The block weight is 2500 kg. and extra weight of 350 kg. was set. The total height of the block is170cm. which consider the top side to apply the jack.

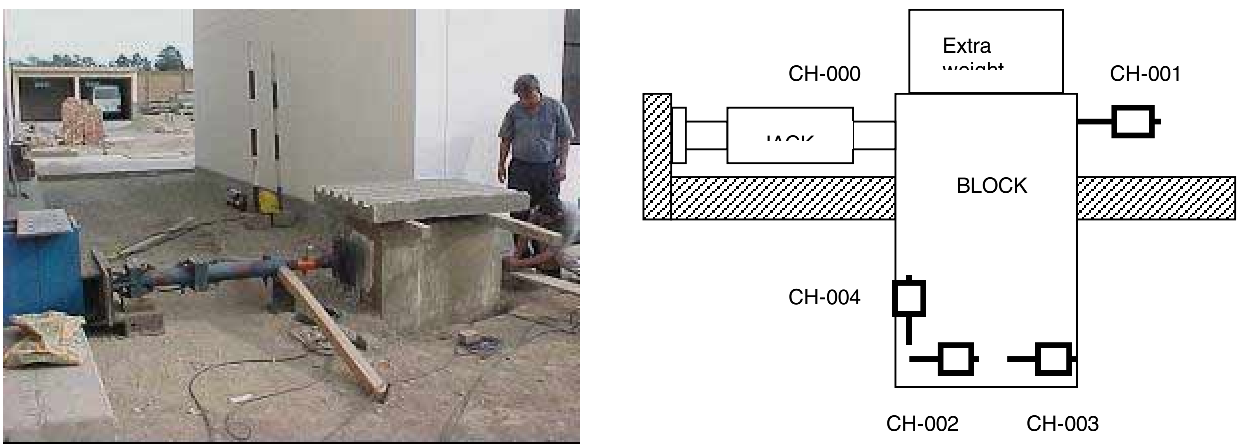


**FIGURE 3:** Block test

The load was applied with a 20 t. Static Jack and 4 displacement transducers were set according with Figure 3. Ch-000 is the load channel and Ch-001 to Ch-004 corresponds to displacement channels.

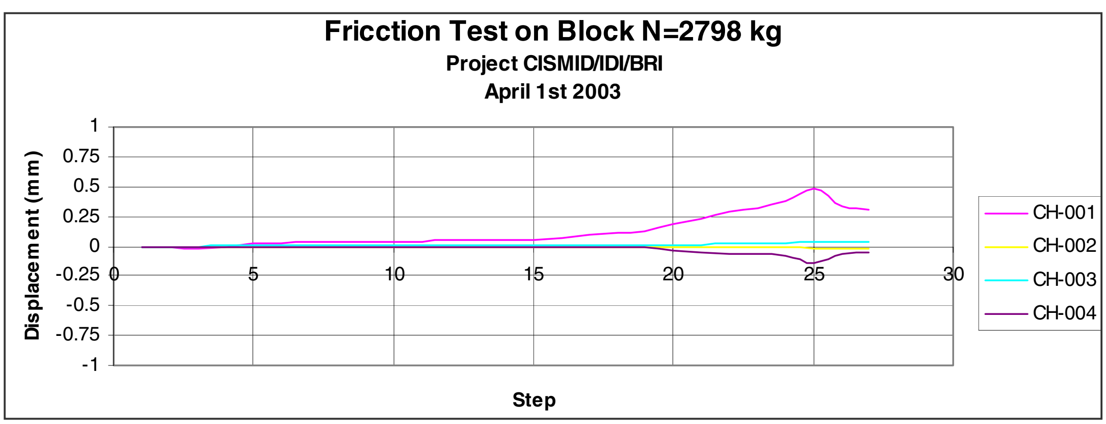


**FIGURE 4:** History of displacements

If the behavior of channel 4 is observed, for a load of 1.073 t. the block started to move vertically as is shown in Figure 5. Therefore the static friction coefficient is computed as the ratio between the start load and the normal load. Then friction coefficient is $\mu = 1.073/2.798 = 0.3834$.

If the normal load of the masonry house including the footing is 175 t., the load to produce the lift of the building is Vmax = μ  x 175 = 67.1 t. as a base shear. According with the analysis presented above maximum shear load of 54.6 t. is demand for the design quake. However the resistance of the building is 61.82 t.
After the block investigation is possible to assure a threshold load of 67 t as a base shear will not produce displacement or lift on the building. After this threshold value, a correction in the lateral displacement should be performing in order to have the real behavior of the house without influence of the footing displacement.

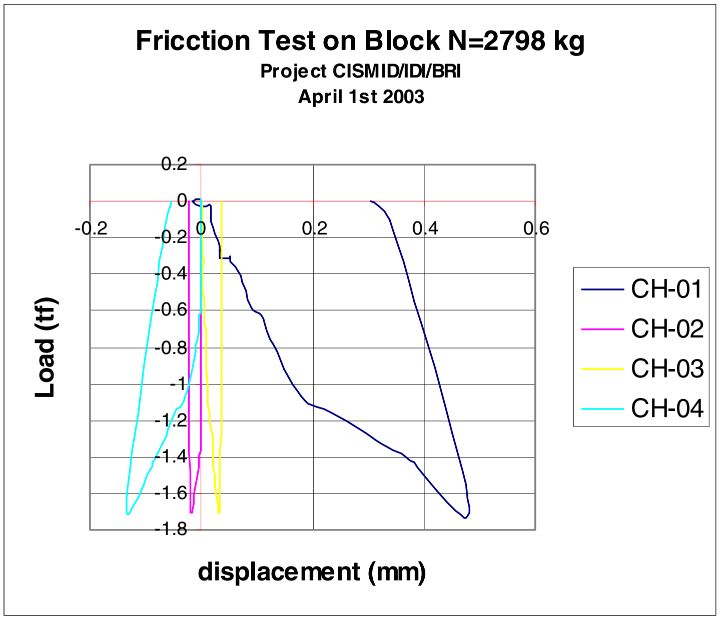


**FIGURE 5:** Load – displacements on block

**Loading Mechanism for Full scale house test**
In order to develop a cyclic test on the full scale confined masonry house, the procedure proposed by the standard ASTM E564-00e1 Standard Practice for Static Load Test for Shear Resistance of Framed Walls for Buildings have been adapted for this experiment. Considering the possibility of torsion on the house and mitigation the problems for the loading on the experiment using an external support structure as shows in Figure 6.

**Control load Equipment and Measuring s**
To develop the test, three actuators of 25 t. of capacity were used. Two actuators on the second floor and one actuator on the first floor were in position to push and pull the full-scale specimen. The actuators were working under a mix control; this is one actuator on the second floor under displacement control (let's name it command actuator) and the others two actuators under load control using the signal from the command actuator. All the actuators work under a stroke range of 200 mm. A computer through a servopulser controlled the actuators. Signal conditioner was used for the acquisition of the signals of each sensor. A set of 45 sensors were set and two measuring systems were used: first a signal conditioner with 16 channels and UCAM 5BT static measuring system using 29 channels.
The command actuator is driven to produce the following drift values: 1/3200, 1/1600,1/800,1/400,1/200, 1/100, 1/75.

**FIGURE 6:** Test setup of the testing house

## TEST RESULTS

Using three actuators, a command actuator with stroke control and two actuators under load control, the test was performed successfully. For each of the story drift ratio measured on the top, the specimen was drive in cyclically producing deterioration on the walls and confinement under high drift ratios.

It was observed that the structure behaves elastically till 1/1600 drift is reached. After drift 1/800 cracking on walls started. High deterioration occurs under a drift of 1/200 and the maximum deterioration happens at a drift of 1/75.

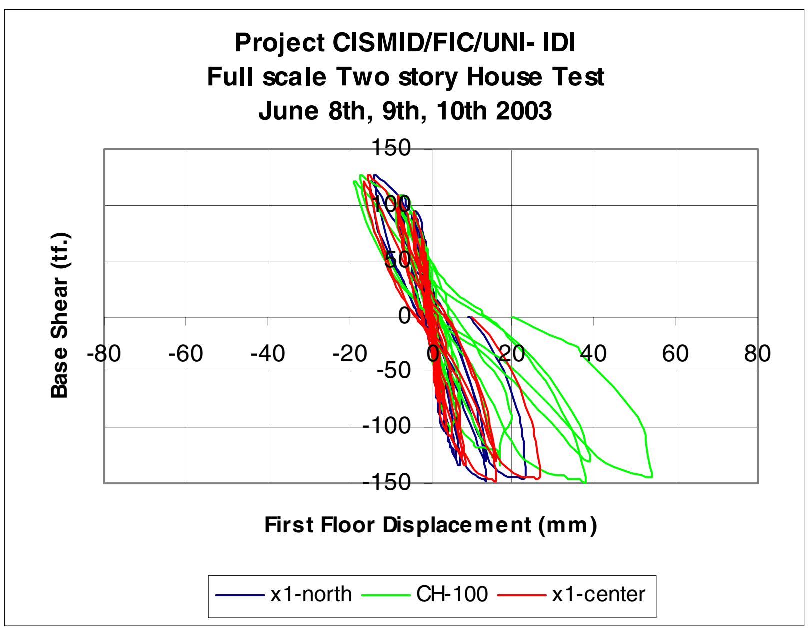


**FIGURE 7:** First Floor displacement versus Base shear

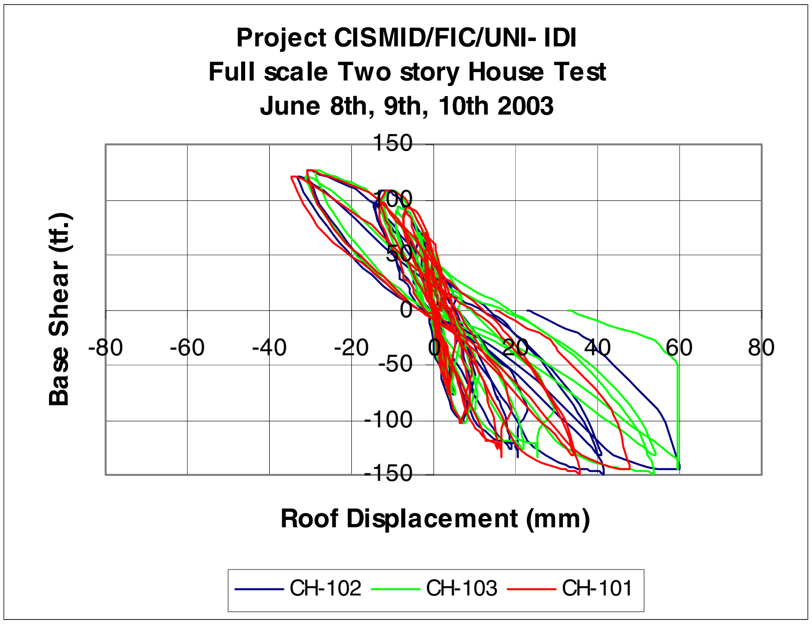


**FIGURE 8:** First floor displacement history

Figure 7 and Figure 8 shows displacement - shear relations on the first and second floors. Here each of the sensors is related with the main axis for walls in the direction of the test. It is possible to read that small torsion is induced because there are difference between each of the sensors on this direction. This is confirmed in Figure 9 where measure rotation is presented. The rotation angle on the top floor has maximum value of 0.0035 radians that was reached for the maximum drift

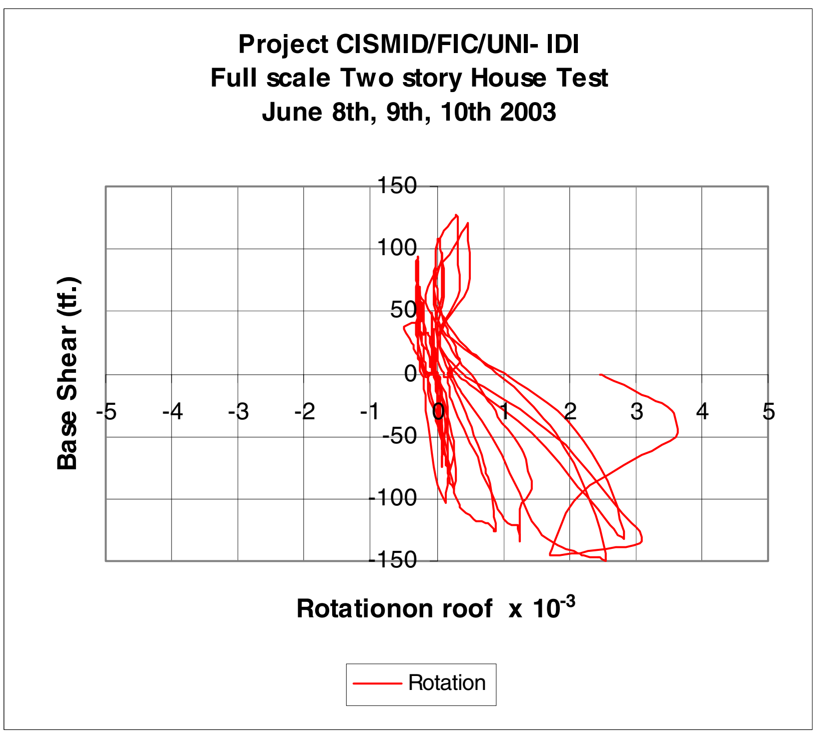


**FIGURE 9:** measured rotation on roof

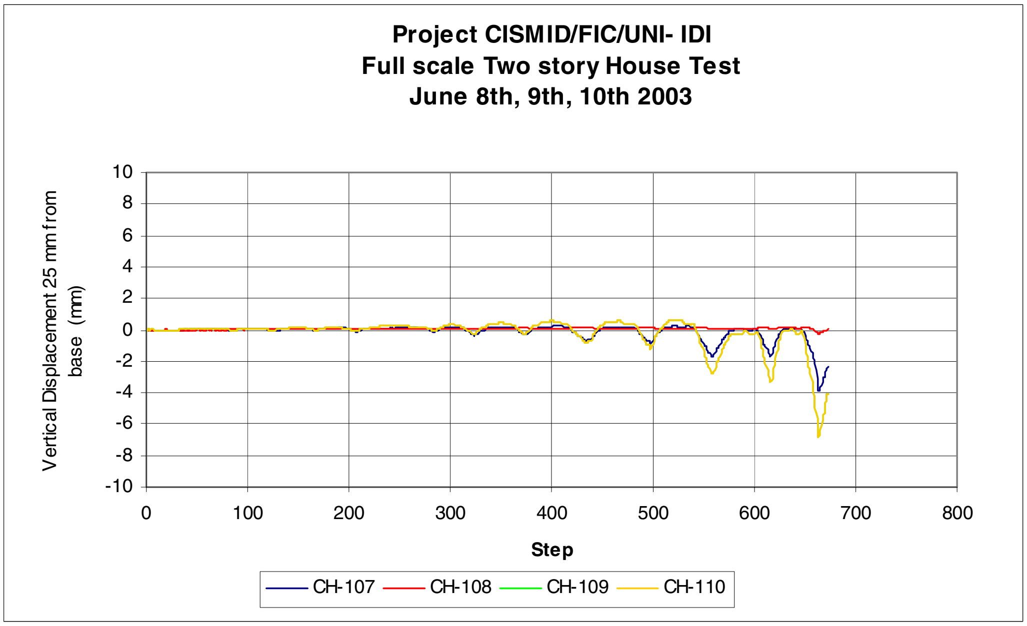


**FIGURE 10:** Vertical displacement at level 25 mm. from basement

Figure 10 presents the vertical displacement at level 25 mm. from basement. By observation of Figure 10 is possible to read that after step 250, the base shear of the house reach the friction resistance value and the lateral displacement will include the displacement of the basement due to resistance of soil is overpassed. Therefore, a correction on the displacement was performed on the curves presented in Figure 7 and 8. The results of the test after this correction are presented in Figure 11 and 12.

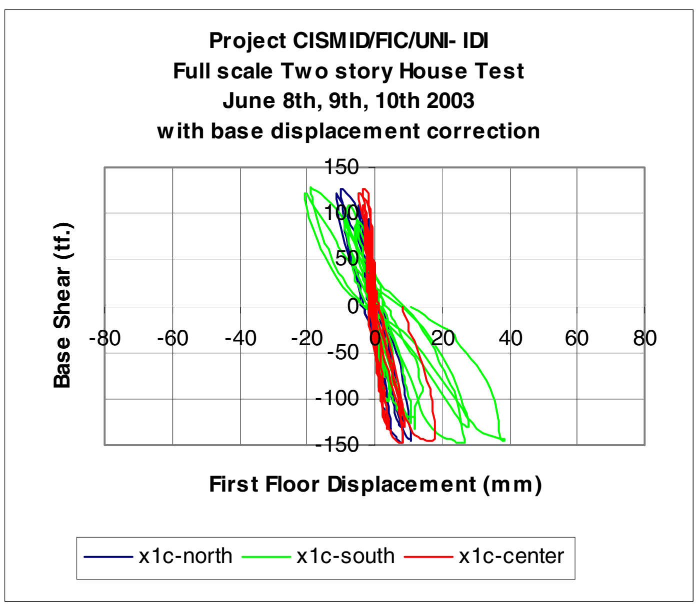


**FIGURE 11:** First Floor displacement versus base shear
with base displacement correction

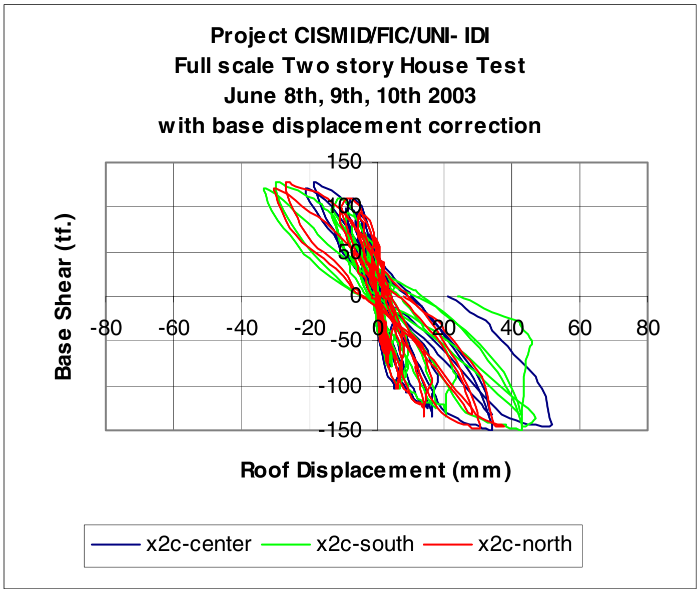


**FIGURE 12:** Second floor load - displacement corrected

Using the peak values for each of the applied loading cycles of Figure 11 and Figure 12, the behavior curves of each floor is built. Figure 13 and Figure 14 presents the behavior curves for first and second floor respectively. It is possible to read from Figure13; Then, the displacement of the central part of the structure became smaller than the south and north sides. However the south side have bigger displacement because the torsion effect (irregularity in plan of the structure). Then the building has more displacement in the south side than in the north one, as is expected. A maximum drift of 1/140 in the south side was reach on the first floor and 1/250 on north side when actuator pulls the specimen. By the other side when actuator push the specimen maximum drift of 1/65 and 1/250 was reach for south and north sides

Because security of our equipment's we decide to push the specimen on the last step because the loading beam for 1/100 drift had a displacement near 40 mm. We imagine if pull condition could damage the loading frame an accident will occur so under this consideration the specimen was pushed with the actuators and reach its failure for a drift of 1/65 under a base shear of 147.86 t.

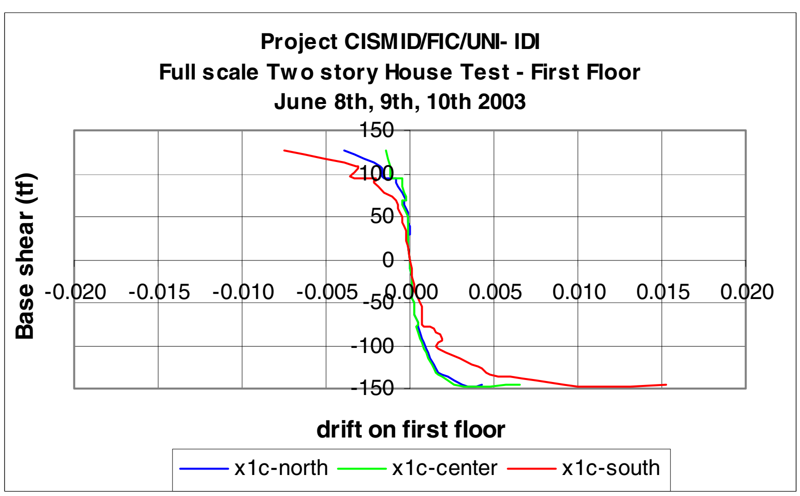


**FIGURE 13:** Behavior curve on first floor

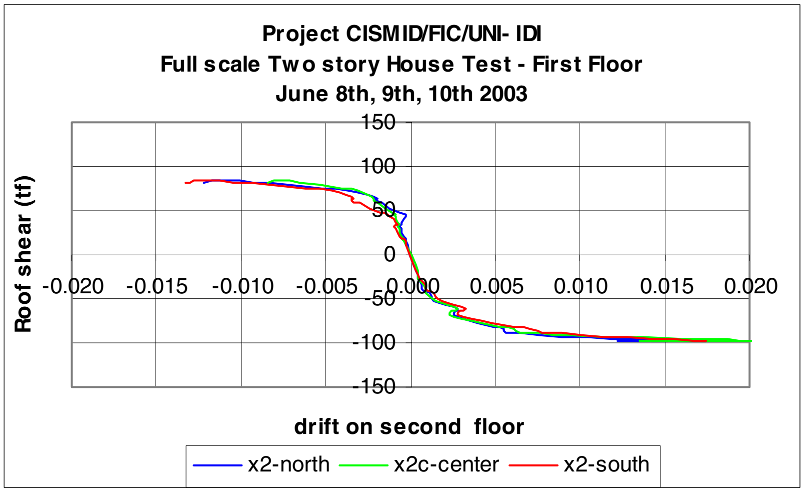


**FIGURE 14:** Behavior curve on second floor

## CONCLUSIONS

- For application of displacement to the specimen a three-actuator system of CISMID Structural Lab was used. Two actuators were set on the second floor and one actuator on the first floor level. One actuator was set under displacement control and the signal of the feedback load was by passed to the others to actuators. By this method a load of 2P was applied on the second level and a load of P was applied on the first floor. This configuration simulated a displacement pattern similar to the first mode of vibration of the structure.
- The displacement was applied to the specimen and a data acquisition system scanned measurements from transducers, load cells and strain gauges. Cyclic displacement was applied under the defined pattern of inter-story drift.
- Initial cracking of the specimen starts for a drift of 1/1600 with cracks of 0.05~0.10 mm. and become notorious after 1/800 when cracks of 1.2 mm. appeared. A maximum base shear 147.86 t. was the failure load of the specimen under a drift of 1/65 with cracks from side between 5~10 mm. in thickness.
- After a base shear of 67 t., the specimen a translation on the specimen base ocurred. Then, correction on lateral displacement is performed in order to find the appropriated behavior curves.
- Behavior curves are presented in Figure 13 and Figure 14 for first and second floor of the building. Here it is possible to read how the displacement in the south side of the specimen is bigger than the dsiplacement of north side. Is obvious influence of the torsion effect was verified in Figure 9 where rotation on roof was reported. Then specimen rotates to the south side because north side has bigger stiffness than the south side.

**Table 4:** Maximum Drift on capacity of initial cracking

| | Vx(kg) | δx i (cm) | Δxi /h |
|---|---|---|---|
| Story 1 | 23457.07 | 0.516367 | 0.00207 |

**Table 5:** Maximum Drift on the capacity of diagonal cracking

| | Vx(kg) | δx i (cm) | Δxi/h |
|---|---|---|---|
| Story 1 | 42649.23 | 0.687300 | 0.00275 |

- Considering that the actuator pushing behavior curve represents the performance of the structural system, the required demand for severe quake and the required demand for moderate quake is presented in Figure 15. Considering the diagnosis by capacity design values from Table 4 and 5 we found the values of the standards are in a safety range.

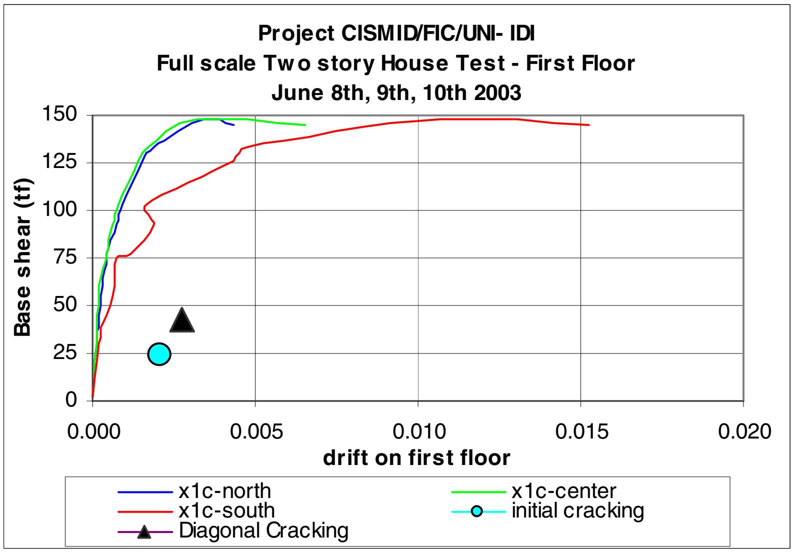


**Figure 15:** Design require demand points and cyclic behavior on full scale house

- Cracking pattern performed during the test is presented in [5]. Figure 16 shows some cracking patterns in south wing of the building. Here its is possible to understand the meaning of each of the drift values and verify that with 1/200 value the structure could be repair even a considerable cracking appears on walls.

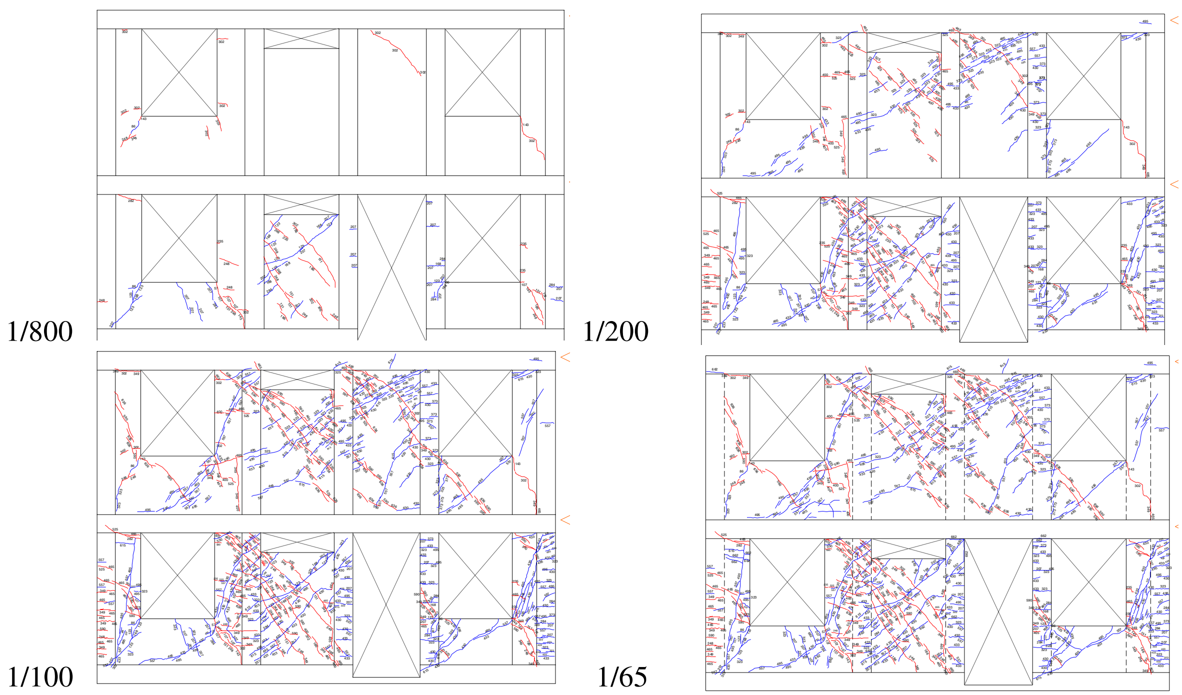


**FIGURE 16:** Crack Pattern during test

**FIGURE 17:** North wing of the house in final state

**FIGURE 18:** South wing of the house in final state

- Figure 17 and Figure 18 shows the final state of the house in north and south wings of the house. It can be seen that at final stage some parts of the covering surface falled down and cracks has been open from face to face on the falls.


## AKNOLEDGEMENTS

The authors would like to express our infinite gratitude to the Infrastructure Development Institute of Japan for the financial support to this project. Our gratitude in the persons of the person of Ryokichi Ebizuka former director of Study Department-IDI and Dr. Satoshi Nomura Senior Counselor Dpt.1-IDI for the advice in the development of the project. Our gratitude to Dr. Takashi Kaminosono Research Coordinator for Disaster Mitigation of Buildings of National Institute for Land and Infrastructure Management Ministry of Land Infrastructure and Transport of Japan and member of the Japanese advisor committee for all the advice and support from the beginning of the project and his supports in the execution of the full-scale test. Out gratitude to all the Japanese Committee members specially to Dr. Hiroto Kato from Building Research Institute of Japan, for his valuable recommendations and advice prior and during the test. Our gratitude to Dr. Yutaka Yamasaki from Yokohama National University with the support and advice in the generation of the project and find the route for the development of it. Our thanks to CISMID/FIC/UNI authorities for the support in the management of this project specially to Professor Roberto Morales Principal of UNI to trust in our group for execution of this research..


## REFERENCES


1. Pique J, Martel P, Seismic Code Improvement in Building Response, Congreso Nacional de Ingenieria Civil, Iquitos, Peru Octubre 2003(in Spanish)
2. SENCICO - Masonry Standards -E070, Ministry of Construction (Norma de Edificacion E-070 - Albañileria; Ministerio de Vivienda y Construccion ) Lima 1982. (in Spanish)
3. San Bartolome A, Documento base: Diseno por Capacidad en Albanileria , SENCICO,Ministerio de Vivienda y Construccion. Lima 2001(in Spanish).
4. SENCICO – Proposal of Masonry Standards -E070, Ministry of Construction (Norma de Edificacion E-070 - Albañileria; Ministerio de Vivienda y Construccion ) Lima Noviembre 2003. (in Spanish)
5. Zavala C, Honma C, Gibu P, Gallardo J, Salinas R, Huaco G, et.al, Construction Monitoring And Improvement Techniques For Masonry Housing / CISMID/FIC/UNI - On Going Research Report – February 2004.