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Cyclic loading tests of confined masonry wall elements for structural design development of apartment houses in the Third World

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ABSTRACT: The paper presents earthquake damage of masonry structures, feasibility study of apartment house construction with economic aspects in the Third World. Confined masonry structure is selected as appropriate apartment houses. We report static cyclic loading tests of confined masonry wall units to clarify confinement effects of reinforced concrete columns to brick walls, as a first step of our project. Axial reinforcement and shear reinforcement of columns are examined on the basis test results. It is pointed out that appropriate combination of axial reinforcement and shear reinforcement in confining frame, especially columns is crucially important.

1. INTRODUCTION

Urban areas of the Third World countries are subjected to excessive population concentration without sufficient infrastructure due to some social and economic conditions. One of the urgently overcoming problems in the areas is a housing problem. Development of economic and earthquake-resistant apartment house buildings is needed to supply massive housing in the urban areas.

Japanese Government has been and is carrying some technical cooperation programs, especially a few research center projects with some of the Third World countries. a few earthquake reconnaissance and technical consult in repair and retrofit of damaged buildings were also done in a few earthquakes. Through those experiences, We found something in common as well as some differences in structural engineering and construction technology between them and us. Our understanding on housing construction technology motivated us to develop structural design method of appropriate masonry-based construction method in urban areas on the Third World countries.

2. BACKGROUND AND PROBLEM DESCRIPTION

A preliminary study on appropriate construction technology of urban apartment houses was done on the following items; earthquake damage, traditional housing structures, prices of industrialized basic construction materials. The study included some comparison of earthquake damage to masonry structures in the Third World countries (H.Mizuno et al. 1990). Our understanding is as follows.

2.1 Earthquake damage

Damage patterns of masonry structure types are summarized as follows;

Adobe houses frequently suffered from severe damage, especially total collapse due to heavy mud roof, and a lot of human lives were lost , such as the Iran Manjil Earthquake of June 21, 1990. Unreinforced masonry also had severe damage. Damage patterns of these two types are overturning of walls in the out-of-plane direction and shear diagonal failure of walls.

Almost the same damage to brick masonry buildings is found in the 1891 Mino-Owari earthquake in Japan, as shown Figs. 1 and 2 (Nagoya city 1978). Japan transplanted brick masonry buildings in the second half of the nineteenth century from Europe as a token of modernization or industrialization. In the 1923 Kwanto earthquake, similar damage is reported.

Floors of these two types of masonry structure are usually wood floor slab, concrete joist slabs etc., whose in-plane stiffness and box effects of floors and walls are smaller than reinforced concrete slab.

Damage to confined masonry is found in the 1985 Chilean earthquake (E.Cruz et al. 1988). Confined masonry is composed of confining reinforced frame and confined masonry walls. After masonry walls are setup, reinforced concrete frame is constructed in confined masonry structure.

Typical damage patterns are 1) shear diagonal failure of walls, and 2) shear and bending failure of heads and feet of reinforced columns. The damage to confined masonry, however, is not severe, compared with adobe houses and unreinforced masonry.

Damage to masonry infilled wall is reported in the 1985 Mexican earthquake etc. After concrete frame is constructed, masonry units like bricks are infilled as walls. We have no data of damage to reinforced masonry, in which hollow bricks or concrete blocks are used as permanent forms for reinforced concrete casting.

2.2 Construction and economic aspects

1. Masonry structures prevail in many earthquake-prone countries of the Third World.
2. From building cost and dissemination viewpoints, however, masonry-based apartment houses are most appropriate to supply housing to the urban people, because masonry units like bricks are much cheaper than the other industrialized materials. Steel reinforcement bars and cement has a tendency to be international trade goods as well as crude oil, and the prices of these are expensive for people of lower GNP per capita. On the other hand, brick prices are about from one tenth to one twentieth of Japanese ones according to a survey of a few countries.
3. We concluded that confined masonry structure is most appropriate as standard version of an apartment building of the Third World, which may be applied to most countries of the Third World.
4. Confined masonry structure has been studied and is already used in some countries such as Chile, Peru, Indonesia, probably Mexico. Confined masonry is not a introduced or transplanted structure type from developed countries, and is utterly different from reinforced concrete structure and steel structure. Therefore, structural design data are not much accumulated. More studies, especially experimental and analytical ones are needed to improve structural design of the structure.

3. RESEARCH OBJECTIVES

Building Research Institute has begun a research project of housing construction technology transfer including this study since 1989 fiscal year. The objectives of the study are to analyze damage patterns of masonry structures, to examine improvement methods for minimizing earthquake damage, and to prepare guideline or data book of structural design with special emphasis to common aspects of confined masonry. Modification of the guideline to each country is supposed to be carried out in other research projects, because level of structural performance should be decided by each country, and local conditions, especially social economic conditions much differ.

Based on the preliminary surveys, possible damage patterns of confined masonry are classified as follows; 1) Shear failure of masonry walls, 2) bending and shear failure of confining reinforced column ends, 3) collapse of wood slabs, hollow brick joist slabs and brick jack arch slabs, 4) separation of columns from walls.

We planned a series of static cyclic loading and shaking table tests to clarify basic mechanical characteristics of con-

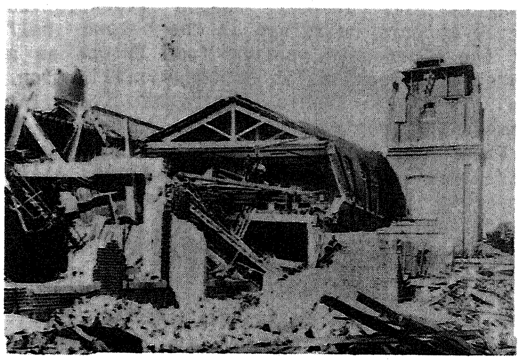


Figure 1. Damage of Mino-Owari earthquake, 1891 to unreinforced brick masonry building (spinning factory)

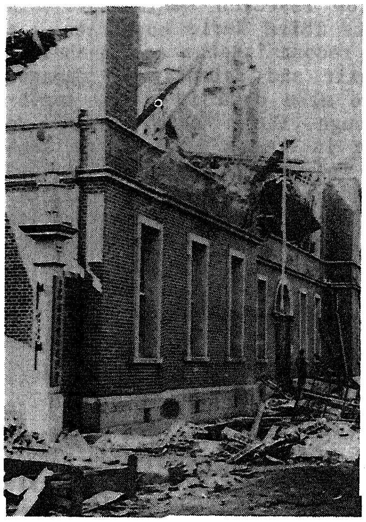


Figure 2. Damage of Mino-Owari earthquake, 1891 to unreinforced brick masonry building (Nagoya post office)

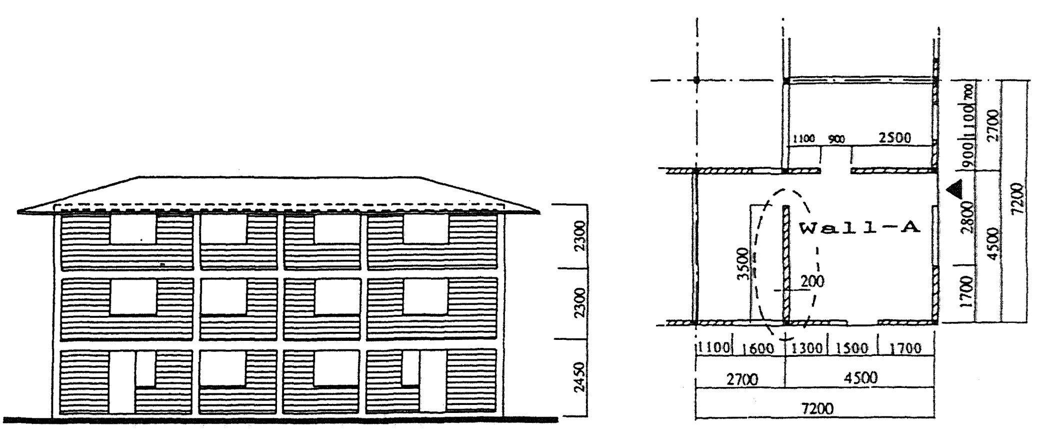
fined masonry structures. In the experimental study, following factors which affect structural performance are selected.
1) confinement effect of reinforced concrete frame to wall
2) horizontal reinforcement effect in brick wall
3) diaphragm effect of floor slab

4. STATIC LOADING TEST ON CONFINED MASONRY WALLS

As the first step of the project, wall elements of confined masonry structures were selected, and static loading tests of the elements were carried out. It is intended to examine confinement effects of columns to brick walls, and reinforcement effects of columns to walls.

4.1 Determination of specimens and test procedures

Confined masonry structures are utterly unfamiliar structural system in Japan as previously described. In determination of the specimens, we surveyed some actually designed buildings in Chile, Mexico and Peru. Of course, characteristics of those buildings were different respectively depending on plans, number of stories and classification of buildings, etc. We picked up a plan of Chilean confined masonry apartment house shown in Fig. 3, as a prototype building. The confining frames consisted of reinforced concrete columns and beams in the selected building were a little bigger than that of ordinary confined masonry buildings in other Third World countries. The reasons of selecting the apartment house as a prototype are as follows; 1)The building considering in this project is three-four story apartment house, therefore appropriate confining frames are required. 2)Though there are requests of minimizing industrial material use, the improvement of earthquake-resistant capacity depends on use of industrial materials. 3)It will be expected that the use of those expensive materials will become easy with economic growth.
Therefore we set up the technical target in advanced stage compared with current situation.
The schemed specimens and reinforcements of columns are illustrated in Figs. 4 and 5. The specimens are half scaled model of the wall-A in the building shown in Fig. 3. Dimensions of the specimens were 1270mm x 1330mm x 100mm in width, height and thickness, respectively. In design of specimen width of column was 200mm to avoid rapid shear failure in loading test. Four specimens were designed by combination of two kinds of parameters, that are two ratios of reinforcing of column, 3.81 and 0.99 percents, and two ratios of shear reinforcement(ties) in column, 1.28 and 0.3 percents. The properties of specimens are summarized in Table 1. Namely, the Specimen-A is of rich axial reinforcement of columns, and rich shear reinforcement of columns; The Specimen-B is of rich axial reinforcement and poor shear reinforcement; The Specimen-C is of poor axial reinforcement and rich shear reinforcement; The Specimen-D is of poor axial reinforcement and poor shear reinforcement. The specimens were fabricated using Japanese domestic materials. Table 2 presents mechanical properties of material used.



(a) elevation (b) plan

Figure 3. Prototype of confined masonry building (confined masonry apartment house in Chile)

In the test, cyclic side sway loading was performed to the specimen keeping stubs of the specimen in parallel. And axial load was applied to the specimen in order to simulate the vertical load in the prototype building. Some displacement transducers and strain gages were attached to the specimens.

4.2. Outlines of test results

Figure 6 presents relationships between horizontal load and horizontal deflection, with those between average shear stress and drift angles in the wall element. And Fig. 7 shows final crack patterns of the Specimen- A, B, C and D, respectively.

The Specimen-A showed stable hysteretic loops before drift angle of 1% without remarkable load drops, the maximum horizontal load was 230 kN. After that load carrying capacities of the specimen were deteriorated gradually, but the shapes of hysteretic loop were stable enough until drift angle of 2%. In case of Specimen-B, sudden shear failure occurred at drift angle of 0.25%, thereafter load carrying capacities of the specimen was declined severely. The maximum horizontal load was 235 kN. Comparing fail-

Table 1. Properties of test specimens

Parameter / Specimen	*1 Ag(mm²)	*2 Pg(%)	*3	*4 Pw(%)
A	6-D13 (762mm²)	3.81	D6-@50	1.28
B			D6-@220	0.3
C	4-D8 (198mm²)	0.99	D6-@50	1.28
D			D6-@220	0.3

*1 Axial Reinforcement of Column
*2 Ratio of Axial Reinforcement
*3 Shear Reinforcement of Column
*4 Ratio of Shear Reinforcement

Table 2. Mechanical properties of material used

Prism		$\sigma_p = 40.3$ MPa , $E_p = 12\times10^3$ MPa
Concrete		$\sigma_c = 20.3$ MPa , $E_c = 20\times10^3$ MPa
Reinforcing Bar	D6	$\sigma_y = 370$ MPa , $E_s = 199\times10^3$ MPa
	D8	$\sigma_y = 406$ MPa , $E_s = 252\times10^3$ MPa
	D13	$\sigma_y = 348$ MPa , $E_s = 205\times10^3$ MPa

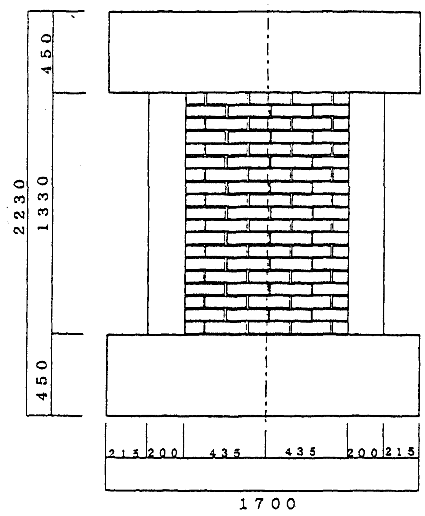


Figure 4. Specimen of confined masonry wall

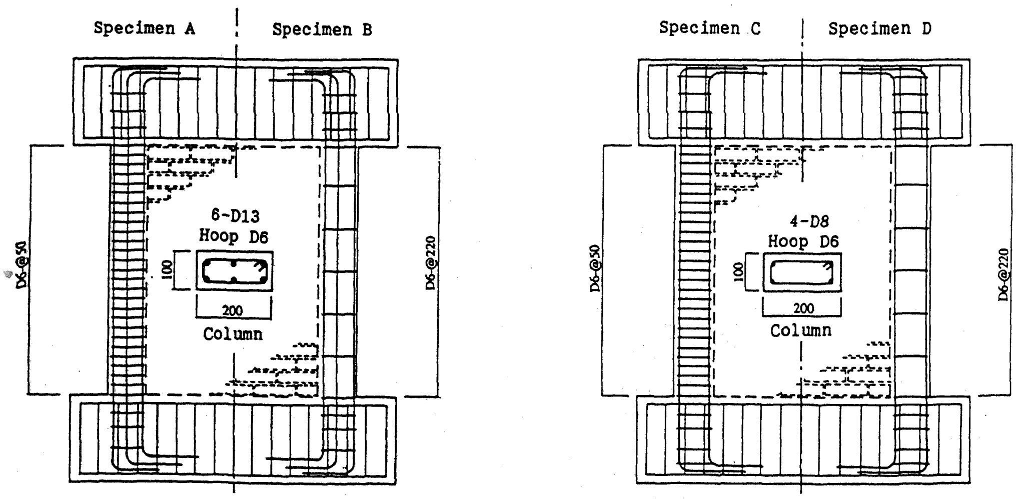
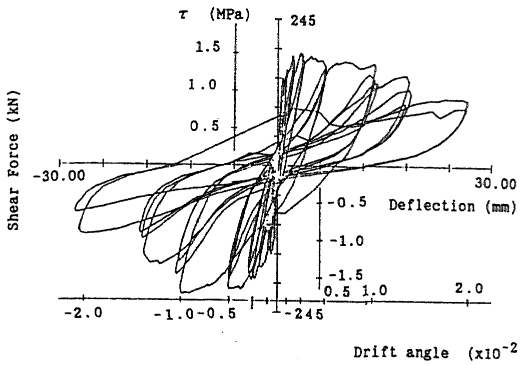
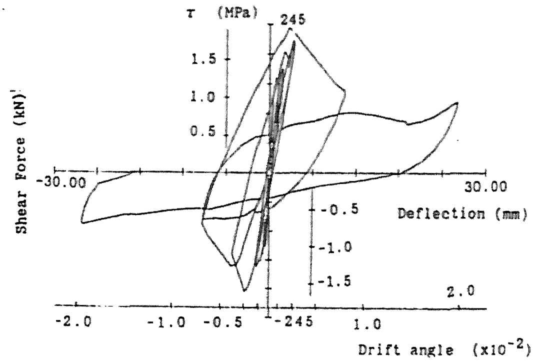


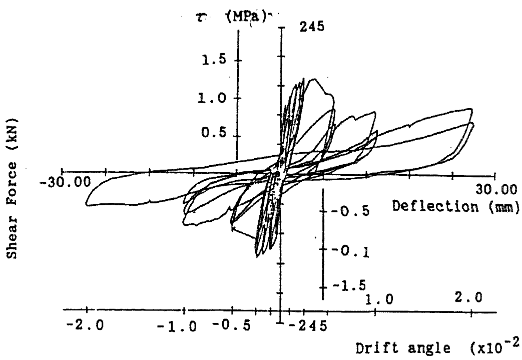
Figure 5. Bar arrangement of column



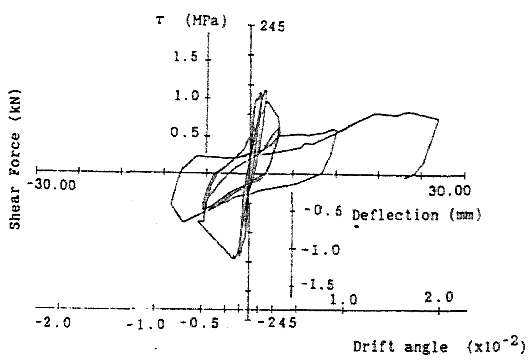
(a) Specimen-A



(b) Specimen-B



(c) Specimen-C



(d) Specimen-D

Figure 6. Relationship of lateral load versus deflection

ure patterns between Specimen-A and B in Fig. 7, there are many bending cracks in both columns and no diagonal crack in brick wall in Specimen-A. On the other hand in Specimen-B there are big diagonal cracks in brick wall, the diagonal cracks dominate the behavior of the specimen.

From Figs. 6(c) and (d) the maximum horizontal loads of Specimen-C and D were 167 and 147 kN, respectively. The load carrying capacities of two specimens were almost same. However, the shapes of hysteretic loops were obviously different. The Specimen-C shows more ductile behavior than the Specimen-D does. Those characteristics of hysteretic loops correspond to failure patterns of the specimens shown in Figs. 7(c) and (d).

The differences between Specimen-A and B, and between Specimen-C and D in horizontal load versus deflection relationships results from shear reinforcement ratio of columns. In other words, the columns confined by enough shear reinforcements are effective to bind unreinforced masonry wall adequately and to avoid brittle shear failure.

In comparison between Specimen-A and C and between Specimen-B and D, the load carrying capacities increase with axial reinforcements of column. The rates of increase are 38 and 60 percents, it is pointed out that the effects of axial reinforcements on the load carrying capacities are remarkable.

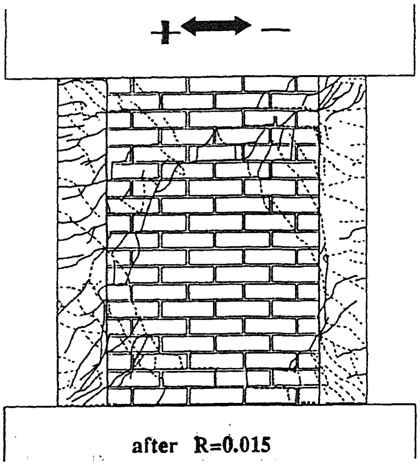
The results obtained from these pilot tests show that adequate reinforcements in confined frames are indispensable to improve the earthquake-resistant capacity of confined masonry building, the subjects in seismic design are to find better combinations of two factors, i.e. the ratio of axial reinforcement and that of shear reinforcement.

5. CONCLUSIONS AND FUTURE WORKS

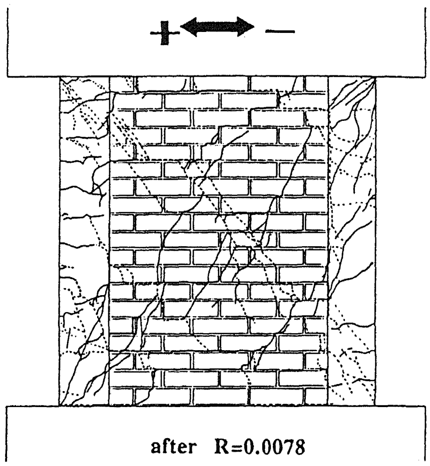
Major findings obtained from static loading tests are summarized as follows;

1)Sufficient axial reinforcements in column can improve load carrying capacities of the confined masonry walls.

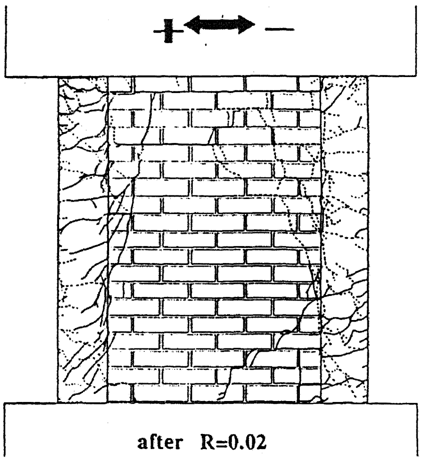
2)The columns confined by enough shear reinforcements are effective to bind unreinforced masonry wall adequately and to avoid



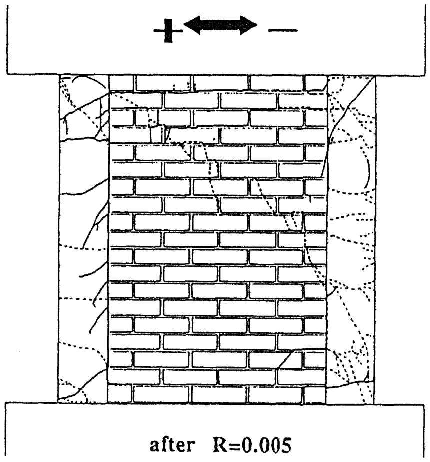
(a) Specimen-A



(b) Specimen-B



(c) Specimen-C



(d) Specimen-D

Figure 7. Final crack patterns

brittle shear failure.

3)The subjects in seismic design are to find better combinations of the ratio of axial reinforcement and that of shear reinforcement.

We are carrying out series of axial force effects and horizontal reinforcement of brick walls in similar cyclic loading tests. As the next steps of the project, we are planing to analyze effects of slab stiffness on total structural performance, and to carry out shaking table testing for grasping ultimate failure modes of confined masonry structures.

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