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Experimental Study for Developing a Seismic Confined Brick Masonry Walls
Part 1: Effect of confining columns, connecting bars and horizontal wall reinforcements.

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1. INTRODUCTION

Confined masonry walls, which are defined as brick or concrete masonry walls confined by reinforced concrete (R/C) columns and beams, are widely accepted as seismic structural walls in Latin American countries as low- and medium-rise residential building structures and also in the People's Republic of China. Confined masonry walls are composed of brick or hollow concrete-block masonry units, which are confined by cast-in-place R/C small columns and beams (and/or floor slabs) along the perimeter of each masonry wall. These structural wall systems are very popular and have been frequently designed and constructed in those earthquake countries. It is noted, however, that any wall-reinforcing bars (Re-bars) are usually not provided in the masonry wall panels in this wall system.

Quindio Earthquake in Colombia on January 25th 1999 [Ref.4], which caused thousands of death toll and totally collapsed buildings, indicate the necessity to develop additional experimental studies of seismic masonry building structures. In order to develop more seismic confined concrete masonry walls, some authors have conducted various experimental studies including several parameters [Ref.1-3]. Main objective of the first phase of this study is to develop much more seismic confined brick masonry walls. Four confined brick masonry wall specimens with different parameters are tested under the condition of constant vertical compression and alternately repeated lateral forces. All the test results obtained from the four specimens are compared each other in the present paper.

2. SPECIMENS

Four different confined and unconfined masonry wall specimens listed in Table 1 and Figure 1 were designed and constructed. Thickness of all the masonry walls is 105mm, and except for 2D-L0-H0V0-LC Specimen, all other three masonry walls are confined by R/C confining columns with 105mm x 105mm cross-sections in the extreme edges of each wall. Each of the specimens is designated by six symbol code, such as 2D-L1-H42V0-LC, with exception of 2D-L1-H0V0-LC-CB Specimen which has seven symbol code. The first symbol "2D" represents two-dimensional specimens. The second letter "L" represent the location of the applied lateral forces (or height of the inflection point of the wall) is "low". The third numeral "1" after the letter L represents that only one longitudinal Re-bar with bar-size of D19 (#6) is provided in each of the confining R/C column-section, which is transversely reinforced by circular spiral hoops of D6 (#2) as shown in Figure 1. The fourth symbol "H42" indicates that the horizontal Re-bars are provided in the spacing of 42cm and "H0" means that there is no horizontal Re-bars provided, and also the fifth symbol "V0" indicates that vertical Re-bars are not used. The sixth letters "LC" represents that the constant low axial compression load is applied to the specimens. The seventh symbol "CB" indicates that U-shaped connecting steel Re-bars with bar-size of D6 (#2) are placed every 21cm between masonry wall-edges and attached R/C column sections. In case when the specimen's name does not have this symbol there is no connecting bars provided in the masonry wall panel. Mechanical properties of materials used for specimens are shown in Tables 2 and 3.

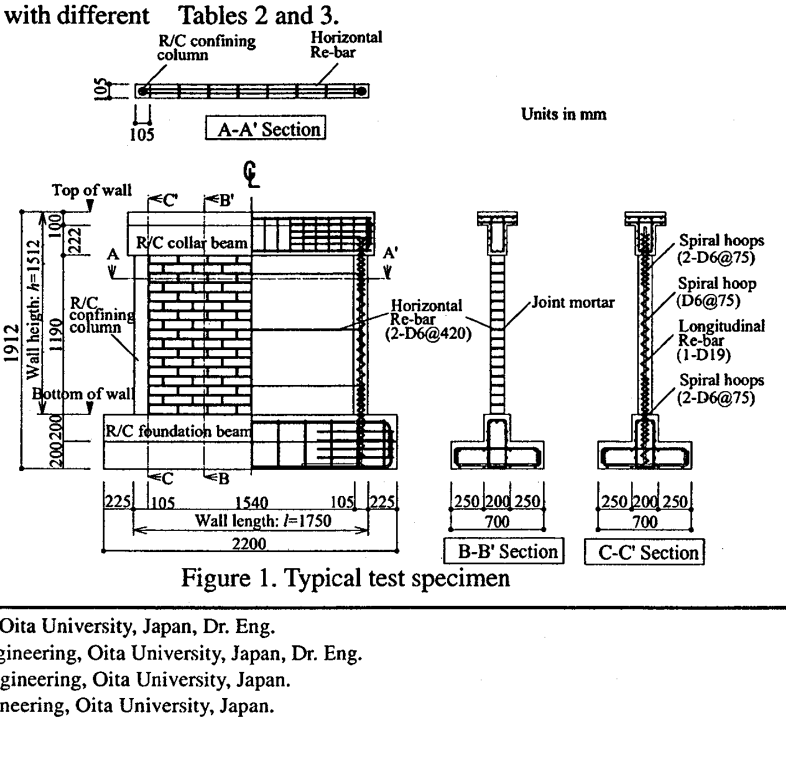

Figure 1. Typical test specimen

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3. TEST SETUP

The test setup adopted in the present study is shown in Figure 2, where height of the longitudinal axis of the lateral forces applied to the specimens (or height of the inflection point induced in the wall) is approximately 0.67 times of the wall height. A hydraulic jack applied corresponding constant vertical axial load with a capacity of 490kN (50tf), and another double-acting hydraulic jack applied alternately repeated lateral forces with 980kN (100tf) capacity. An auxiliary jack installed between loading- and reaction- frame is for counterbalancing and setting the test specimens. Displacement transducers and strain gages measured important displacements and strains in reinforcing bars, and all the measured information were processed simultaneously by a personal computer.

Table 1. List of test specimens

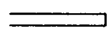
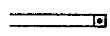
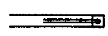
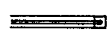
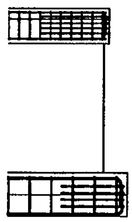
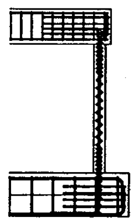
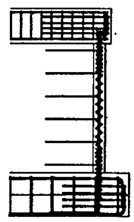
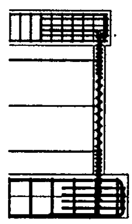
Specimen	2D-L0-H0V0-LC	2D-L1-H0V0-LC	2D-L1-H0V0-LC-CB	2D-L1-H42V0-LC
Heigth of applied lateral force	0.67x*h* (*h*:Wall height)			
Axial stress σ (MPa)	0.84			
Horizontal Wall Re-bars	None	None	None	2-D6(#2)@420
Vertical Wall Re-bars	None	None	None	None
Connection Re-bars	None	None	D6(#2)@210	None
Longitudinal Column Re-bars	None	1-D19(#6)	1-D19(#6)	1-D19(#6)
Column Hoop	None	D6(#2)@75	D6(#2)@75	D6(#2)@75
Horizontal Cross-section				
Details of Reinforcement				

Table 2. Mechanical properties of reinforcing bars

Bar size	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
D6(#2)	448	565	10
D19(#6)	335	480	20

Table 3. Compressive strength of concrete, prism and mortar

Specimen	Concrete (MPa)		Prism (MPa)	Joint Mortar (MPa)
	Column	Beam		
2D-L1-H0V0-LC	30.5	28.6	18.9	25.7
2D-L0-H0V0-LC	none	29.8	20.8	22.7
2D-L1-H0V0-LC-CB	28.8	28.6	19.4	24.6
2D-L1-H42V0-L	27.4	29.4	18.5	21.5

4. RESULTS AND DISCUSSIONS

Complete hysteresis loops between applied lateral force (Q) versus story drift (R) relations obtains from the present test are shown in Figures 3(a) through 3(d), where story drift (R) is defined as an interstory displacement divided by the story-height of the specimen. In all the Q-R curves shown in Figure 3, crack and strain information are also presented by using five different symbols shown in Table 4. Dashed lines in the figures represent the theoretical values determined by the ultimate flexural moment capacity at the bottom of each wall, while dotted lines are the ultimate lateral strengths determined in shear failure mode of the masonry wall with flexural reinforcement in its wall-edges (or R/C confining columns). In addition, final

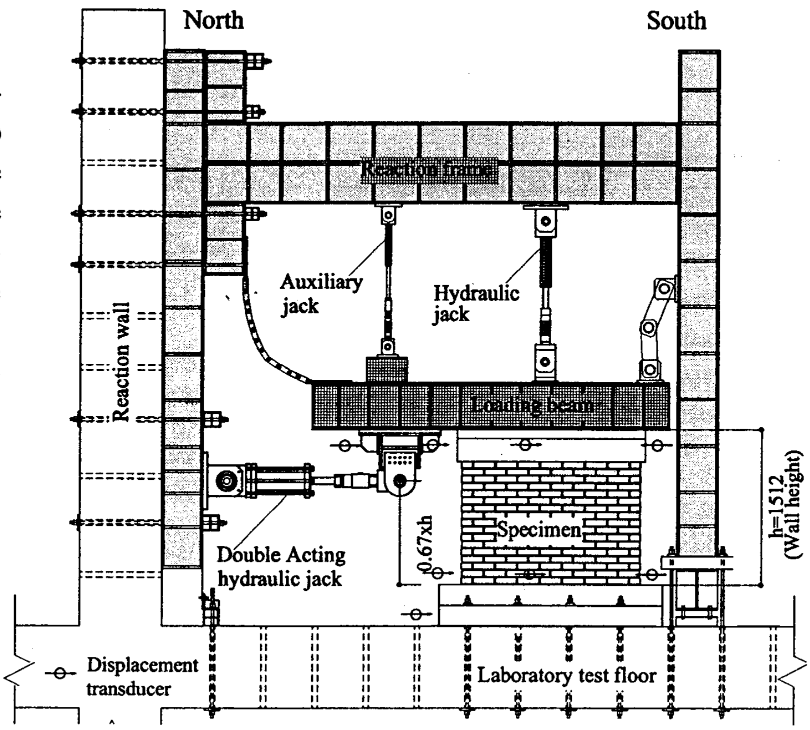


Figure 2. Test setup

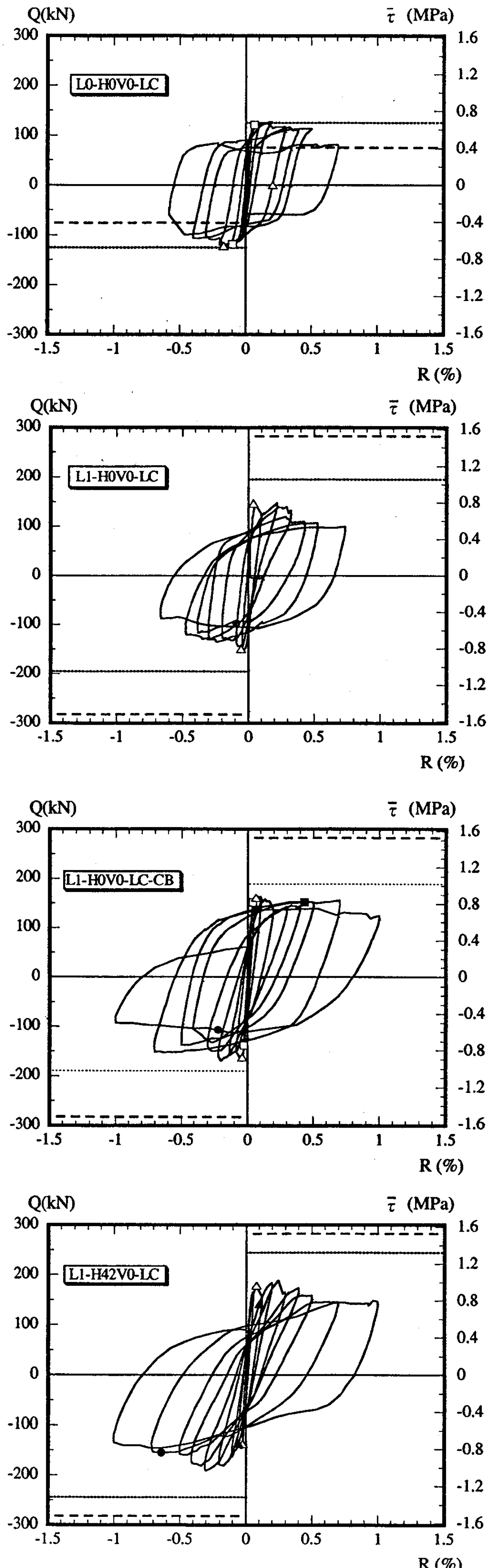


Figure 3. Q-R Hysteresis loops

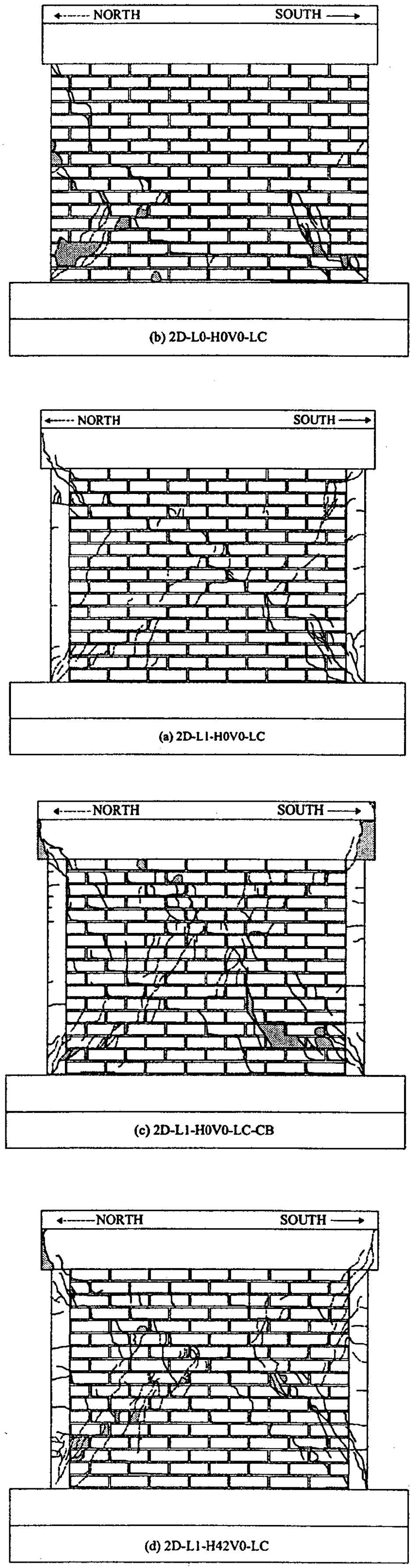


Figure 4. Final crack patterns

Table 5. Predicted and observed ultimate lateral strengths and failure modes

Specimen	Evaluation	Theorical prediction			Test Results	
		Ultimate lateral strength		Predicted Failure Mode*	Ultimate lateral strength Q(kN)	Observed Failure Modes*
		Flexural mode Q_u(kN)	Shear mode Q_u(kN)			
2D-L0-H0V0-LC	Colombia		22	S	125	F, S
	China	76	125	F		
2D-L1-H0V0-LC	Japan	282	195	S	149	S
2D-L1-H0V0-LC-CB	Japan	282	189	S	167	S
2D-L1-H42V0-LC	Japan	282	244	S	190	S

* F=Flexural Failure Mode, S=Shear Failure Mode

Table 4. Symbol used in Figure 3

□ :	Initial flexural crack in masonry wall
△ :	Initial shear crack in masonry wall
● :	Initial yield* in longitudinal Re-bar in south column
■ :	Initial yield* in longitudinal Re-bar in north column
▲ :	Initial yield* in horizontal Re-bar in masonry wall

*Yield in tension

crack patterns observed on the West surface of all the specimens are shown in Figures 4(a) through 4(d).

For all the specimens, theoretical ultimate lateral strengths determined by the existing equations to predict the ultimate flexural and shear strengths of the masonry walls, are shown in Table 5, together with the expected failure modes and observed test results.

By summarizing the test results obtained:

In Specimen (2D-L0-H0V0-LC), initial flexural crack in the brick masonry wall occurred at R=+0.069%, after this the ultimate flexural strength is presented at R=+0.199%, then the specimen starts to failure by shear and the ultimate strength occurred at R=-0.166%.

In Specimen (2D-L1-H0V0-LC), initial shear crack in the brick masonry wall occurred at R=+0.039%. Additional, diagonal crack occurred in the bottom and top of both columns. The ultimate strength occurred at R=-0.051 and R=+0.196. Additional, the longitudinal Re-bar in the south columns yielded at R=-0.086%.

In Specimen (2D-L1-H0V0-LC - CB), initial flexural crack occurred at R=-0.025% and R=+0.041% between the bottom of the masonry wall and the top surface of the foundation-beam. Then initial shear cracks are observed at R=-0.039% and R=+0.063%. Diagonal cracks occurred in the brick masonry wall propagated into top and bottom of both columns and passed completely into the top of each columns and beam-column connections. The ultimate strength occurred at R=+0.08% and R=-0.199%. The longitudinal Re-bar in the south and north columns yielded at R=-0.221% and R=+0.266%, respectively.

In Specimen (2D-L1-H42V0-LC), initial shear crack occurred at R=-0.025% and R=+0.079% and the ultimate strength occurred from R=+0.245% to R=-0.303. Both columns were damaged by the propagation of the wall-diagonal cracks into the bottom and top of each columns and transversal cracks in the center of both columns. Finally, the south column in the bottom part yielded at R=-0.637.

5. CONCLUSION

To develop much more seismic masonry walls, the horizontal reinforcements in masonry wall play an important role for expecting higher ultimate lateral strength and better ductility.

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