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Seismic Behavior of Reinforced Brick Masonry Cavity Walls

Comportement aux séismes de murs de briques renforcés en béton armé

Das seismische Verhalten von bewehrter hohler Ziegelwand

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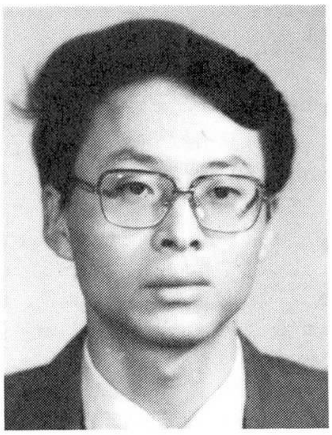

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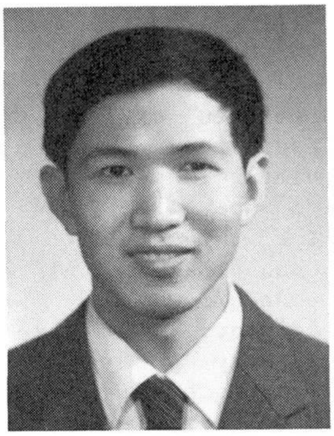

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SUMMARY

Fourteen brick cavity wall specimens and two normal brick wall specimens with reinforced concrete columns under lateral cyclic loading have been tested. The effects of reinforced concrete columns, ties and other factors on the seismic behavior of cavity walls are studied.

RÉSUMÉ

Quatorze murs creux en briques et deux murs normaux en briques avec poteaux en béton armé ont été testés sous charge latérale cyclique. On a étudié les effets des poteaux en béton armé, de chaînages et d'autres facteurs sur le comportement aux séismes des murs creux.

ZUSAMMENFASSUNG

Versuche an Backsteinwänden mit Stahlbetonstützen und unter zyklischer Seitenbelastung wurden durchgeführt. Der Einfluss der Stahlbetonstütze, der Anschlussbewehrungen und anderer Faktoren auf das seismische Verhalten von Backsteinwänden wird erörtert.

1. INTRODUCTION

Brick masonry building is one kind of structures widely used for civil building in China. The necessity of reducing the heat loss in external wall of the building has resulted in a demand for brick masonry cavity walls to accommodate isolation. By now, a lot of studies have been conducted on behavior of brick masonry cavity walls and most of them were focused on the performance requirements for ties and the practice of construction and that a little attention, however, has been paid to the aseismic behavior of brick masonry cavity walls [1,2]. During strong earthquake brick masonry buildings may suffer serious damages. In general, under earthquake loading the brick masonry wall as the major lateral force resistance member should damage at first and this may lead up to the collapse of the whole building. In this paper experimental results of fourteen brick masonry cavity wall and two normal brick wall specimens with reinforced concrete columns under lateral cyclic loading up to failure are described.

2. OUTLINE OF TESTS

Fourteen cavity walls consisting of two brick leaves with a layer of heat isolation and two normal brick walls specimens have been tested. The dimension of specimen is 2880 mm in length, 1440 mm in height, 420 mm in width (370 mm as to normal wall specimen). The thicker leaf of the wall is 240 mm in width and the thinner one is 120 mm. A layer of heat isolation is between two leaves. Connecting bar ties of diameter 8 mm and vertical or lateral rigid brick connections have been slected in the specimens to bridge the two leaves. Reinforced concrete column has a great effect on improving the ductility of masonry wall, but heat can be easily transimitted through the column, so in 12 specimens the reinforced concrete column only encirles in the thicker leaf. Four specimens with 1100 x 500 mm opening have been designed to study the influence of opening on the behavior of the walls. All specimens detail is shown in table 1. Shear strength of the brick masonry wall is about 0.32 MPa.

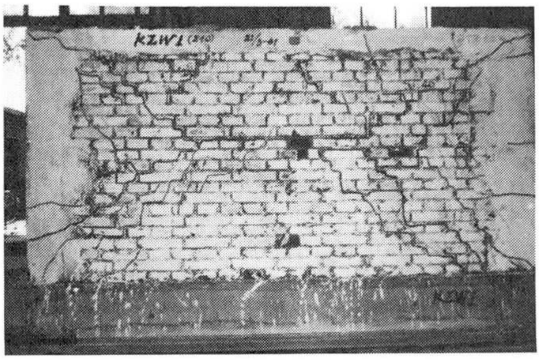
Table 1 Classification of specimens

Specimen	Type	Connection	Girth	R/C column	Opening
SZW 1,2	normal	no	in whole	in whole	no
BGW 1,2	cavity	ties	as above	as above	no
QGW 1,2	as above	as above	as above	in thicker leaf	no
KGW 1,2	as above	as above	separate	as above	no
KZW 1,2	as above	vertical brick	in whole	as above	no
KZW 3,4	as above	lateral brick	as above	as above	no
DZW 1,2	as above	as above	as above	as above	1100x700
DZW 3,4	as above	ties	as above	as above	1100x700

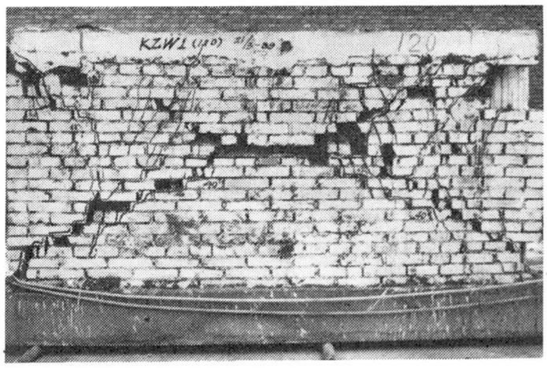
The tests were performed on a pseudo-static loading equipments. The specimen was built on a reinforced concrete beam which was fixed on the loading platform. The amplitude of the lateral cyclic loading was increased stage by stage before cracking. After cracking the applied loading was controlled by displacement at the top of the specimen. The vertical loads were applied to the top of specimen by hydraulic jacks and were kept constant during the test. The jack can move freely in the horizontal direction when the top of specimen is displaced.

3. TEST RESULTS

3.1 Cracking Pattern and Damage



Thicker Leaf



Thinner Leaf

Fig.1 Crack Pattern of Specimen KZW1

The observed crack pattern of specimen KZW 1 following test is shown in Figure 1. The visible cracks are observed in the central portion of specimens when the applied lateral load is about 70-75% ultimate load. However, the visible cracks of specimen with the opening appear in the coner of the opening. As increasing of loading and displacement the cracks develope toward the corner of the wall and connecte to form major X shape diagonal crack. At the about 90% ultimate load the diagonal cracks are extended through the wall. At the ultimate state the wall is divided into four blocks by the extending diagonal cracks. With increasing cycles of the loading the blocks slide along the surface of cracks. Finally, some broken parts of the wall are splitted and the specimen is failed. Comparing with normal specimen, the cracking pattern of the cavity wall speciemn is almost identical. The failure pattern of the specimen is similar to that of post earthquake damage surveys of the walls.

3.2 Hysteresis Characteristic and Ductility

The brick masonry buildings subjected to earthquake loading are usually in the inelastic range. Response of a structure subjected to strong ground motion is

Table 2 Experimental and Analytical Results

Specimen	Cracking load (kN)			Ultimate load (kN)			Ductility
	Measured	calculated	error(%)	Measured	calculated	error(%)	factor
SZW1	405.00	459.75	13.5	536.30	520.51	2.9	8.3
SZW2	393.80	448.44	13.8	577.50	520.51	9.8	8.2
BGW1	381.70	430.26	12.7	561.00	499.40	11.0	7.1
BGW2	390.50	430.26	10.2	476.25	499.40	4.8	6.1
QGW1	362.50	397.35	9.6	468.75	453.54	3.2	4.0
QGW2	346.25	359.68	3.9	435.00	453.54	4.1	4.3
KGW1	343.75	366.35	6.6	418.75	453.54	8.3	4.0
KGW2	350.00	359.68	2.7	409.57	453.54	10.0	4.4
KZW1	356.50	359.68	0.9	412.50	453.54	9.9	4.0
KZW2	359.50	359.68	0.0	437.50	453.54	3.6	4.4
KZW3	312.50	352.22	12.7	402.50	453.54	11.2	3.4
KZW4	356.50	366.35	2.8	456.25	453.54	0.7	5.7
DZW1	165.00	167.47	1.4	251.25	270.30	7.5	4.9
DZW2	167.50	167.47	0.0	247.50	270.30	9.3	3.3
DZW3	157.50	159.82	1.4	255.00	270.30	6.0	3.3
DZW4	157.50	154.72	1.7	261.25	270.30	3.4	3.1

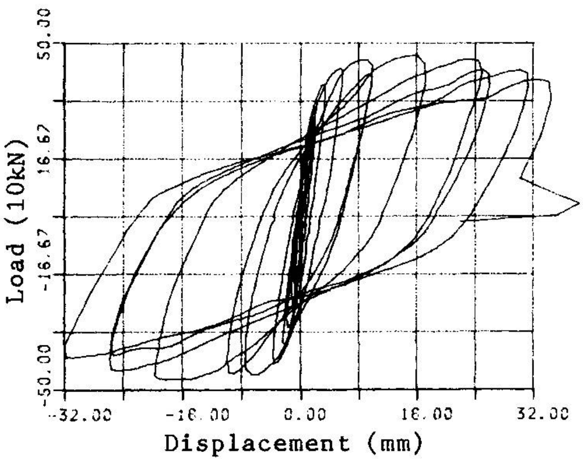


Fig.2 Speciemn BGW2

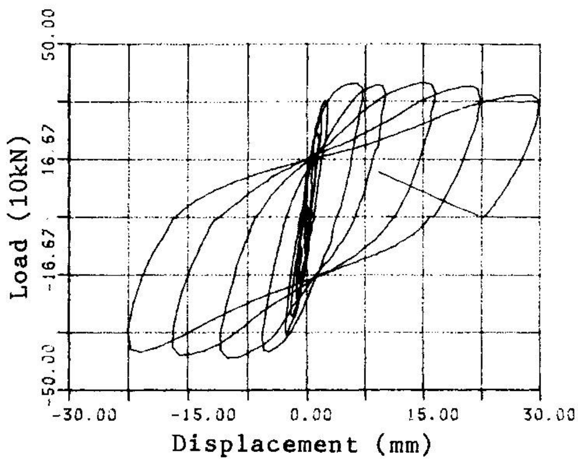


Fig.3 Specimen KZW3

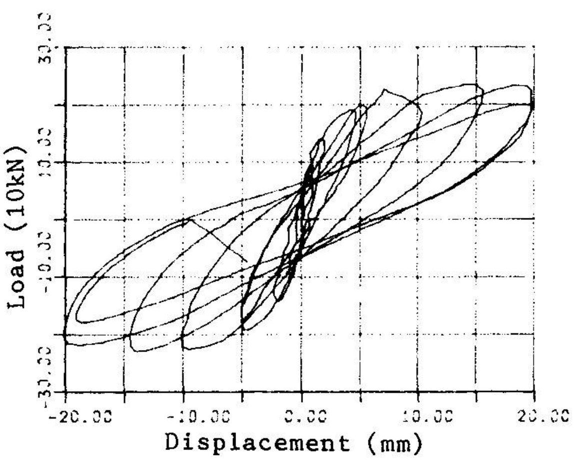


Fig.4 Specimen DZW2

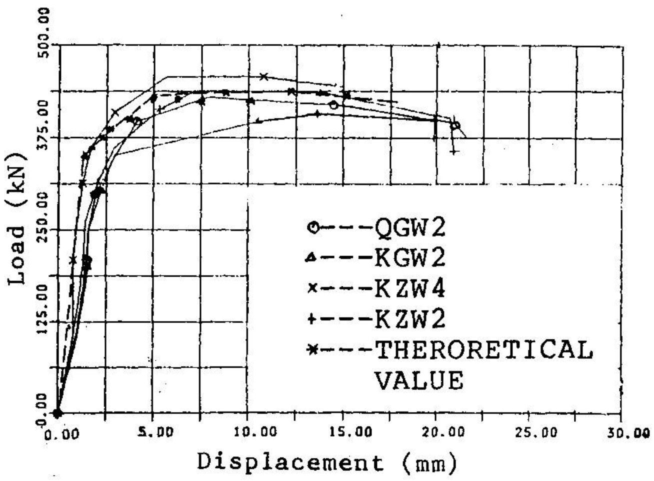


Fig.5 Load-Displacement Curves

obviously influenced by inelastic deformation. Therefore, the inelastic behavior of brick masonry cavity wall should be considered in a reasonable and economic structural design and the inelastic deformation, especially the ability of absorbing energy should be utilized in practice. It is emphasized that in the aseismic design the horizontal loads recommended by most building codes are such that structures will be able to resist only moderate earthquake without structurl damage. Most severe earthquake can only be survived if the structures are sufficiently ductile.

Hysteresis curves of lateral load P versus to displacement Δ of specimens BGW, KZW and DZW are shown in Figure 2-4 respectively. Obviously, the hysteresis loop of brick masonry wall with reinforced concrete columns is much different from perfect elasto-plastic behavior and shows rounding and pinching behavior due to the closing of cracks with increasing the numbers of cycle. In the stage of reloading the considerable degradation of the specimen stiffness can be observed. In the stage of unloading the degradatin of stiffness is existed but not so significant. It is shown that the hysteresis loop behavior of brick masonry cavity wall is almost the same as the normal brick masonry wall. The hysteresis loop behavior of specimens with opening is poorer than that of specimen without opening. From the tests, the different type of connection has little influence on the hystersis characteristics of the specimens.

The ductility factor is defined as the ratio of ultimate displacement Δ_u to cracking displacement Δ_c. Measured cracking and ultimate loads and ductility

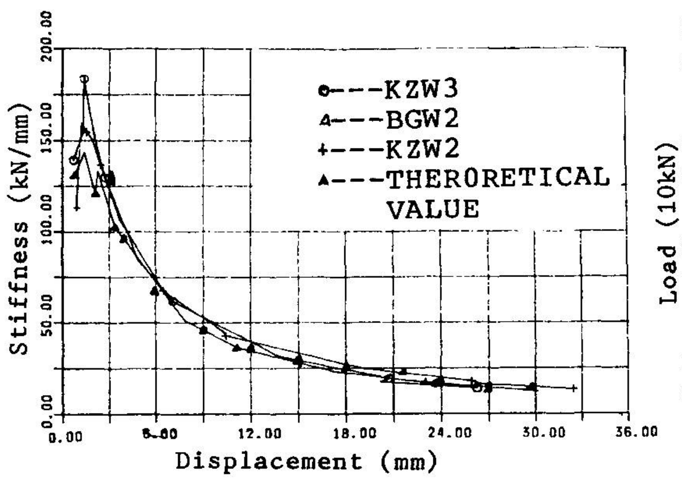


Fig.6 Stiffness Degradation

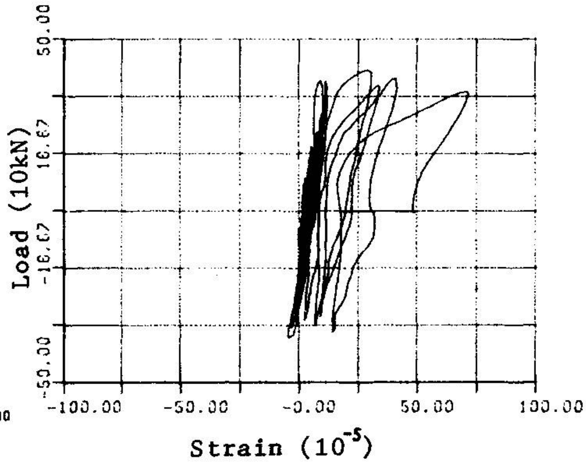


Fig.7 Load-Strain loops for Tie

factors of the specimens are summerized in Table 2. It can be seen that the ductility factor of the cavity wall specimens with reinforced concrete column encirling in two leaves is almost equal to that of the normal wall specimens. The ductility factor of the cavity wall specimens with column encirling only in the thicker brick leaf is about 50-60% of the former. The capacity of deformation of the cavity wall specimen with opening is obviously inferior.

3.3 Stiffness Degradation

Envelopes of the hysteresis loops of the measured top displacement of specimens are shown in Figure 5. It is indicated that in the initial stage the load-displacement relationship is linear and after cracking the displacement increases significantly with appeared and developed cracks. The measured post-cracking stiffness K is illustrated in Figure 6. It can be seen that as increasing displacement the stiffness of specimen decreases obviously. The stiffness K may be calculated from the following empirical formula:

$$K=0.0017(\Delta/H)^{-0.91} K_0 \quad (\Delta/H > 1/1000) \qquad (1)$$

where K_0--the initial stiffness of wall; Δ --the top displacement of wall; H--the height of wall.

3.4 Effect of Reinforced Concrete Column and Connection

The first cracks of reinforced concrete column are observed at the section at distance h/3 from the bottom of the column under about 70% lateral ultimate loading level. The second cracks appear at the column middle. The measured maximum width of crack of the column at the ultimate state is 3 mm. Due to confined effect of reinforced concrete column the accumulated deformation of the wall is decreased and the fall off of the wall is prevented. In the process of cyclic loading the top displacement at the thicker wall leaf with reinforced concrete column is gradually different from that of the thinner leaf without the column. At ultimate state the top displacement difference in the plane of the cavity wall is about 30-40 mm. The thinner leaf of the cavity wall cracks seriously as shown in Figure 1.

The load-strain curve of connecting tie in the cavity wall is shown in Figure 7. It is shown that the connecting ties in the cavity wall have little influence on the behavior of the wall under lateral loading, especially as the ties are used at the upper and lower part of the wall. As viewed from the stiffness, the effect of the vertical or lateral brick connection on the behavior of the cavity wall is much greater than that of the connecting ties. On the other hand, however, the existence of brick connection may easily destroy the continuity of the cavity wall, it is not suitable to subjected earthquake loading.

4. COMPARISON BETWEEN EXPERIMENTAL AND ANALYTICAL RESULTS

The cracking load of the cavity wall with reinforced concrete columns can be calculated by following formula:

$$Pc = 0.24nkfv(1+\sigma_0/fv)^{\frac{1}{2}}Am \qquad (2)$$

in which k = 1 + GcAc/GmAm,
where Am, Ac -- area of the wall and the column respectively; Gm, Gc -- shear modulus of the wall and the column respectively; fv -- shear strength of the brick masonry wall; n -- affecting coefficient of the opening and is 1.0 and 0.6 for the wall with and without opening respectively; σ_0--compressive stress of wall.

According to the method of limit analysis the ultimate load of the cavity wall without opening can be given by following formula:

$$Pu = 2.5Mu/H + (f\sigma_0+2/3fv)Am \qquad (3)$$

where Mu -- the ultimate moment of concrete column; f -- friction coefficient. The calculated results of the cracking and ultimate load are given in Table 2. It is shown that the calculated results are in a good agreement with the measured values. In Figure 5 the corresponding calculated load -- displacement cuve is also shown. From the comparison the calculated complete curves are in good agreement with that from the test.

5. CONCLUSIONS

1. The brick masonry cavity wall with reinforced concrete columns significantly increases the ductility, deformation capacity and energy of dissipation. The brick masonry cavity walls used in seismic area should arrange the reinforced concrete columns to improve the aseismic capacity of the wall.

2. Under lateral cyclic loading the connections, especially the ties, have little effect on the integrality of the cavity wall after cracking. However, the connections may effctively aviod the fall off of the thinner brick leaf out of the wall plane.

3. Due to the existence of opening the aseismic behavior of the cavity wall obviously deteriorates. More attention should be devoted to strengthing the opening surrounding in aseismic design.

4. According to proposed method the calculated results of the the strength and displacement are in good agreement with the measured results.

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