SHAKING TABLE TEST OF MODEL HOUSE OF BRICK MASONRY FOR SEISMIC CONSTRUCTION

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ABSTRACT :
In under-developing countries, many devastating earthquake damages occurred. In order to mitigate the damage of under-developing countries, Japanese research group has initiated cooperative studies with Asian countries, such as Pakistan, Indonesia, and so on. In under-developing countries, there are many masonry structures. The structures were damaged in earthquakes. In order to provide the study and dissemination materials for countermeasure against earthquake damages, the dynamic collapse test of a masonry house 3m x 3m x 3m which was made of Pakistan bricks was conducted, using a one-direction horizontal shaking table and video graphic measurements. The test results indicated that the careful and manual construction would induced no damages. In order to estimate the seismic performance of masonry structures, a new numerical simulating method was developed using the Extended Distinct Element Method (EDEM) and carried out the collapsing process simulations of real size brick masonry houses which were used at the shaking table tests.

KEYWORDS:
Brick masonry, Shaking table test, Numerical simulation, EDEM

1. INTRODUCTION

For earthquake disaster mitigation in developing countries in earthquake-prone area in Asia, we have studied seismic and affordable seismic construction of non-engineered masonry houses as an international collaborative study-Japan, Pakistan, Indonesia, Nepal and Turkey. It has been essential to record the actual behaviors of the non-engineered structure subjected to the strong motions. For such purpose, the shaking table test of a model of masonry brick house was carried out to understand the actual behavior until the structure collapsed, as well as, to verify the analysis methods to evaluate the seismic resistance. In particular, the bricks produced in Pakistan were imported to fabricate the model structure as a proto-type house in South Asia, because it was considered that the seismic resistance might depend on the mechanical properties of bricks. The model house with openings was designed through discussion between Japanese and Pakistan's experts.
One- direction horizontal shaking table of NIED Tsukuba was used, in cooperation with BRI and Mie University, on a small masonry house of imaging a brick house of mountainous region in Pakistan. Many shaking table tests of masonry structures were already conducted in Portugal, Italy, Greece, Macedonia, US, and useful results were provided. Main purpose of test is an understanding dynamic collapse characteristic of masonry.
A new numerical simulating method based on the Extended Distinct Element Method (EDEM) was developed and the numerical collapsing process simulations carryout for the shaking table test results. Bricks were assumed as rigid body, and mortar was modelled by mortar spring. .

2. SHAKING TABLE TEST

NIED has two shaking tables. One is E-Defence which completed in 2005. The other is one-direction horizontal Tsukuba Shaking Table which completed in 1970 and improved in 1988. Tsukuba Shaking Table was used for the test. Tsukuba table has the performances of displacement ±22cm (44cm of stroke), velocity 100cm/s, exciting force 3.6MN. Test weight is 500ton, and table dimension is 14.5m by 15m.

2.1. Test House

As a first step of dynamic tests on masonry structures, a plain brick masonry structure was chosen as test house. The test house was designed by Mie University and NWFP University at Peshawar, Pakistan. Test house has roof of steel folded-plates with wood beams, a plan of 3m by 3m, and height of 3m, approximately. East wall, south wall and north wall have opening, but west wall without an opening. Walls were built up with English bond brickwork. Bricks of 230mm x 110mm x 70mm and 2.92kg were imported from Pakistan. Before brickwork, bricks soaked in water. Mortar of compounding ratio; early-strength cement 1 and sand 8, early-strength cement 1 and water 1, was used as bond for bricks. The compressive strengths were 0.15MPa of brick, 0.1MPa of mortar, approximately. Lintels were installed on openings. Weight of test house was about 10.23ton (bricks: 7.74ton, mortar: 1.79ton, lintels: 0.37ton, roof: 0.25ton). In the test, there is no test weight. Base of test house was assembled by H steel (H300 x 300 x 15 x 10) at the centre of one-direction horizontal shaking table 14.5m x 15m of hydraulic electric control, and, on the trench of H steel base, test house was built up in a week. It took two weeks to get mortar strength. In Figure 1, the outline of test house is shown.

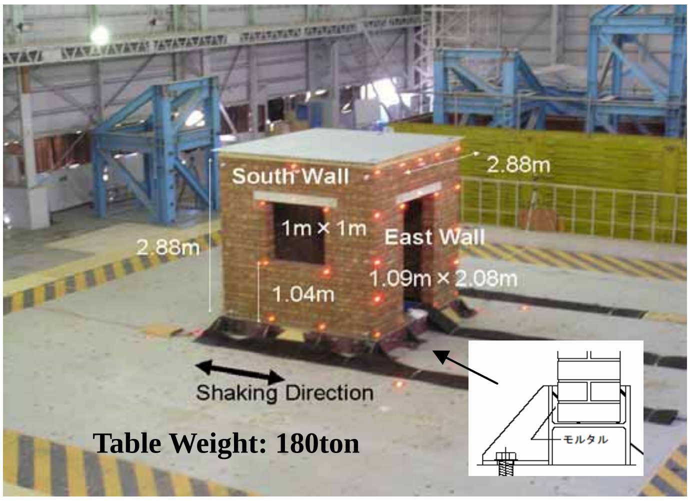


Figure 1. Outline of South and East Walls
Base of Test House and Anchorage.

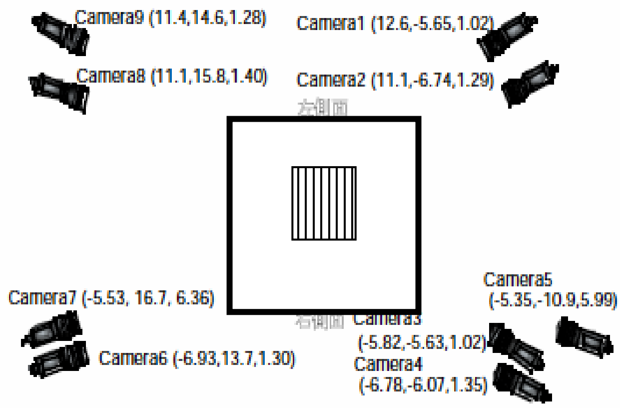


Figure 2. Schematic Distribution of Video Cameras
for Image Processing

2.2. Instrumentation

In the test, acceleration and displacement were measured. Servo and strain-gage-type acceleration sensors were installed. Response displacements were measured by the use of image processing. In image processing, movement of test house was recorded by video cameras as shown in Figure 2. Red lamps of Figure 1 were displacement measure points. Three X, Y, Z components of red lamp movement were obtained by computing process of continual video images, sampled in 100Hz. Test house responses, table data and synchronizing signal for image processing were recorded in hard a disk through 24 bits AD converter.

2.3. Shaking

At first, in order to check the vibration characteristics of the test house, amplitude 1mm rectangular wave of period 10sec were inputted into the shaking table. There was no natural frequency in the region of less than 20Hz. Table 1 is the input wave list of shaking table tests. In Bam(No.1 and 2) and JMA KOBE(No. 3) excitations, no damges occurred in the test house. The actual amplitude of time-scale reduced Bam excitation 94cm/s was less than the expecting amplitude 100cm/s. However, the actual amplitude of JMA KOBE 104cm/s was stronger than the expecting; 100cm/s as shown in Figure 3. The response accelerations of the test house at the roof

amplified to about 110%. Amplification ratio was very little. The test house of brick masonry under controlled construction was rigid and strong to ever recorded strong earthquake motions.
Aim of the shaking table test is to obtain the data on the collapse process of brick masonry structures in developing countries. Therefore, the test house must be collapsed in the shaking table test. However, No cracks occurred in the planned excitations. So, the excitations for making cracks in masonry walls were carried out additionally. There were no cracks in first two sinusoidal(No.4 and 5) excitations. Next, amplitude 20mm rectangular waves(No. 6,7 and 8) of period 10sec. were inputted. Three velocity 40cm/s pulse shocks applied. 1.7G acceleration was observed in the pulse shocks. Figure 4 presented the shaking table motions of additional excitations. By the shocks, walls displayed cracks. By crack initiations, the test of aiming collapse would be possible. After the pulse shocks, Bam motion was inputted. Cracks grew large in Bam excitation. At last, JMA KOBE motion collapsed the test house.

Table 1. The Input Wave List of Shaking Table Tests

Number	Input wave	Damage of the specimen	
No. 1	2003 Iran Bam Eq. L (EW) TS=0.79 75cm/s	No Damage	
No. 2	2003 Iran Bam Eq. L (EW) TS=0.79 100cm/s	No Damage	
No. 3	1995 JMA KOBE (NS) 100cm/s (110%)	No Damage	
No. 4	Sin 15Hz 1G 50 second	No Damage	
No. 5	Sin 1Hz 10cm 0.4G 20 second	No Damage	
No. 6	Pulse Shock 1 40cm/s	Cracks Occurred	Single string
No. 7	Pulse Shock 2 -40cm/s	Cracks Grown	
No. 8	Pulse Shock 3 30cm/s	No Growth of Cracks	
No. 9	2003 Iran Bam Eq. L (EW) TS=0.79 100cm/s	Crack Grown	
No. 10	1995 JMA KOBE (NS) 100cm/s (110%)	Collapsed	

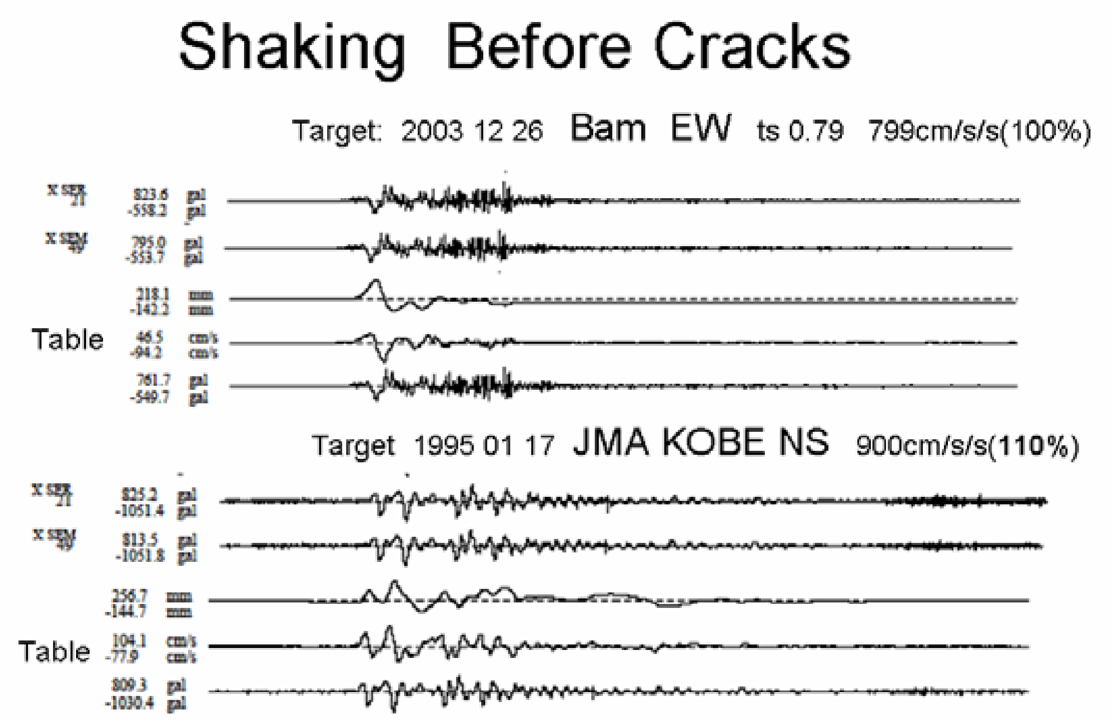


Figure 3. Responses of Bam No.2 and JMA KOBE No.3

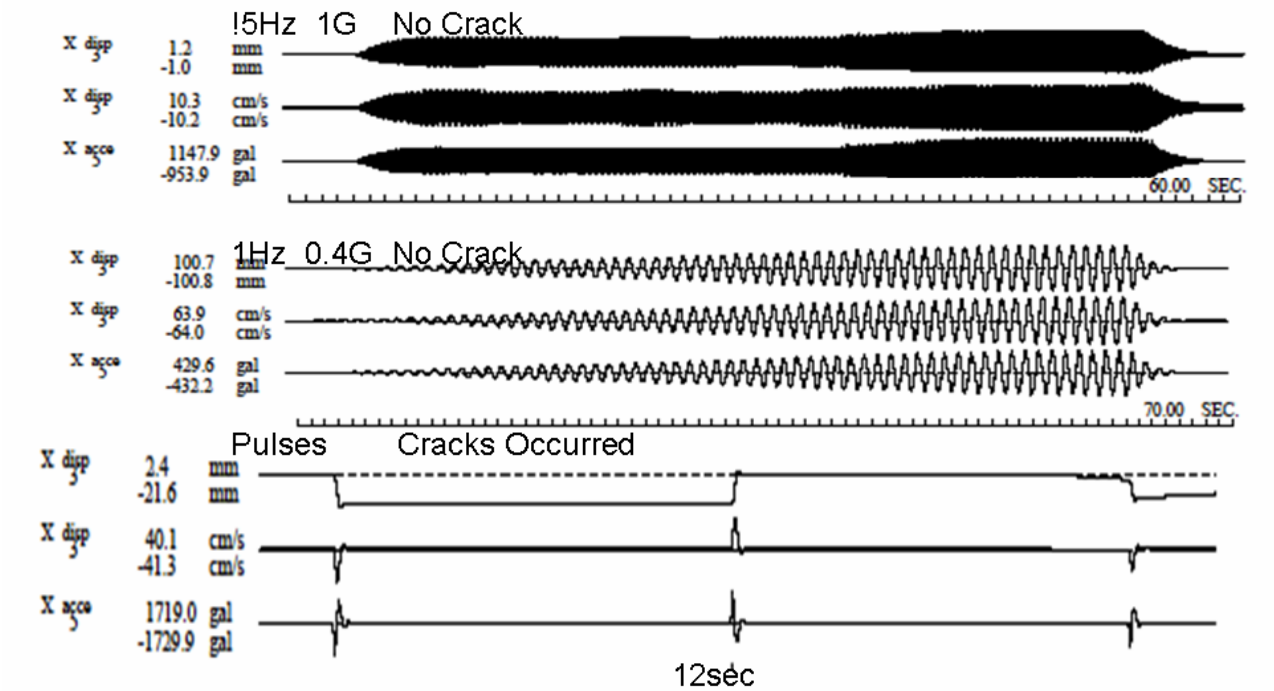


Figure 4. Additional Excitations No.4, 5, 6, 7, 8

2.4. Cracks Initating by Pulse Shocks

The test house collapsed finally. Walls of the test house were considered to fracture along the existing cracks. Cracks initiated in Pulse shocks No.6,7, acceleration 1.7G and velocity 40cm/s. Figure 5, shows the cracks and response accelerations in Pulse shocks excitations. The cracks was checked by the use of video analysis. The initiating position of cracks close to window in the south wall, agreed with FEM analysis of author Prof. Qaisar Ali. The dislocations of bricks above lintels in No. 7 excitation were observed. Cracks of walls occurred along masonry joint lines. South and North walls; in-plane walls toward the excite direction displayed many cracks..

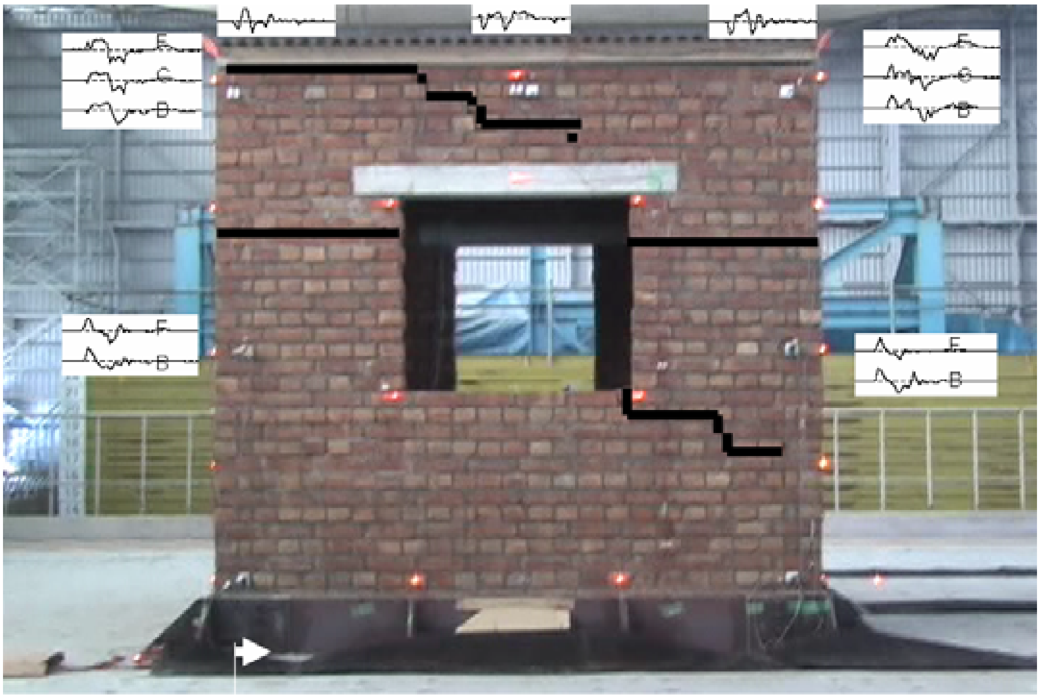


Figure 5. Initial Cracks and Responses of South Wall in Pulse Shock No.7

In Bam excitation No.9, the growth and opening of cracks was observed. The accelerations 1.5G – 2G were measured at roof position. The displacement measurement of the Image processing was carried out for Bam excitation No.9. Deformation in exciting direction at roof position was shown in Figure 6.

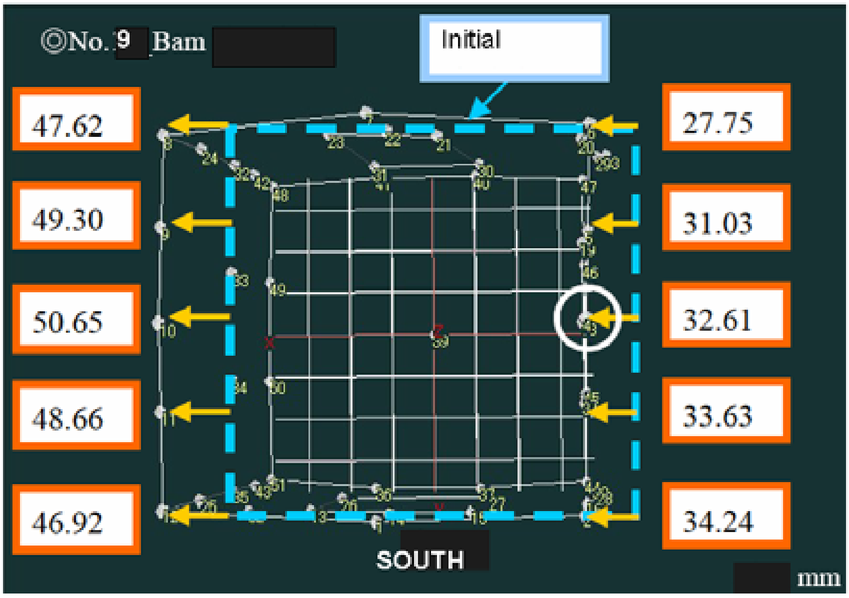


Figure 6. Horizontal Deformation of Test House at Roof Position of No.9 in mm

2.5. Collapse Process by Video Analysis

Next, the shaking table was excited by JMA KOBE No.10. In less than 10 second, the test house collapsed. Figure 7 are video copies of west and south walls, and the close video copies of south wall cracks. The collapse pattern of the shaking table test was similar to the collapse of Japanese brick building heritage in 2007 Niigata Off Chuetsu Earthquake.. Adhesion Tests indicated that the bond of cement mortar had the adhesive strength of 0.32MPa.

1.5s 4.0s 5.5s

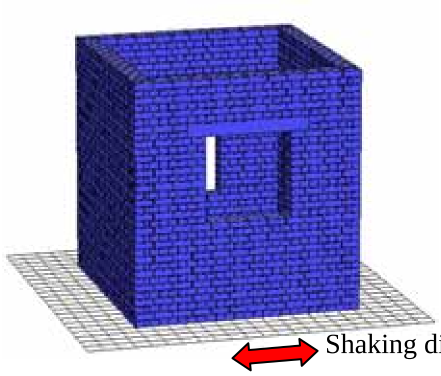
1.5s 4.0s 5.5s

Figure 7. Continual Video Copies in JMA KOBE Excitation No.10

3. NUMERICAL SIMULATION OF SHAKING TABLE TESTS

A new simulating method based on the Extended Distinct Element Method (EDEM). Trial simulations were made for wooden houses, and the calculating method was turned out to be useful for collapsing process analysis of wooden houses. The numerical models used here were depicted in Figure 8. The bricks were modelled by the rigid body (brick element). The configurations of bricks elements were same as test specimen (English bond brick work). The total number of brick elements for numerical models is 2,600. The number of degree-of-freedoms is 15,600. The simulation was carried out by T. Nakagawa.

(a) Test specimen



(b) Analytical Model

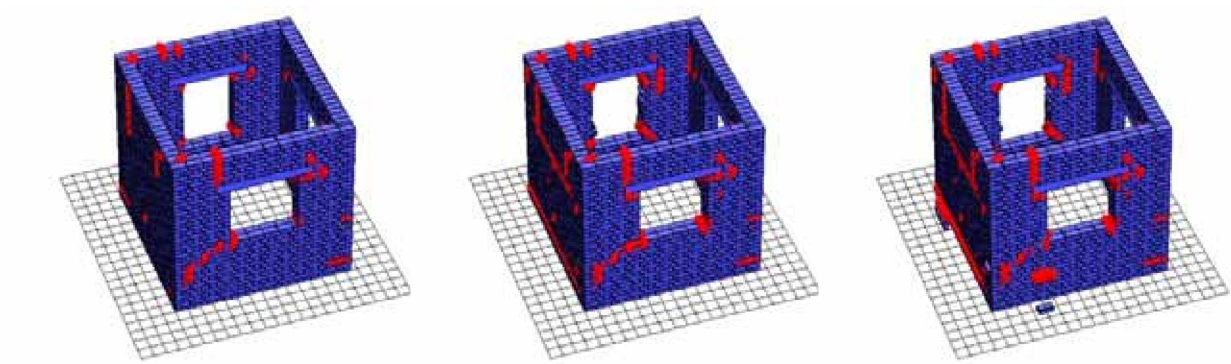
Figure 8. The Test Specimen and the Analytical Model

3.1. Simulation Result of Pulse Shocks

Figure 9 shows the simulation result of pulse shocks (No. 6-8). At the first pulse shock, the cracks occurred around the window opening area. At the second pulse shock, the cracks expanded and some bricks fell down. At the third pulse shock, the small crack expanding was observed. Figure 10 shows the crack position of the analytical model and shaking table test. The similar type of crack pattern was observed in the shaking table test.

3.2. Simulation Result of Earthquake Input

Figure 11 shows the simulation result of the second input of Iran Bam earthquake wave (No. 9). By the first movement from left to right, the diagonal cracks expand bottom left to top right, and then the part of the analytical model fell down. Because the specimen didn't collapsed at the shaking table test, this numerical result was different from shaking table test.



(a) First Pulse (a) Second Pulse (a) Third Pulse

Figure 9. Cracking Process of Numerical Model at the Pulse Shock Input.

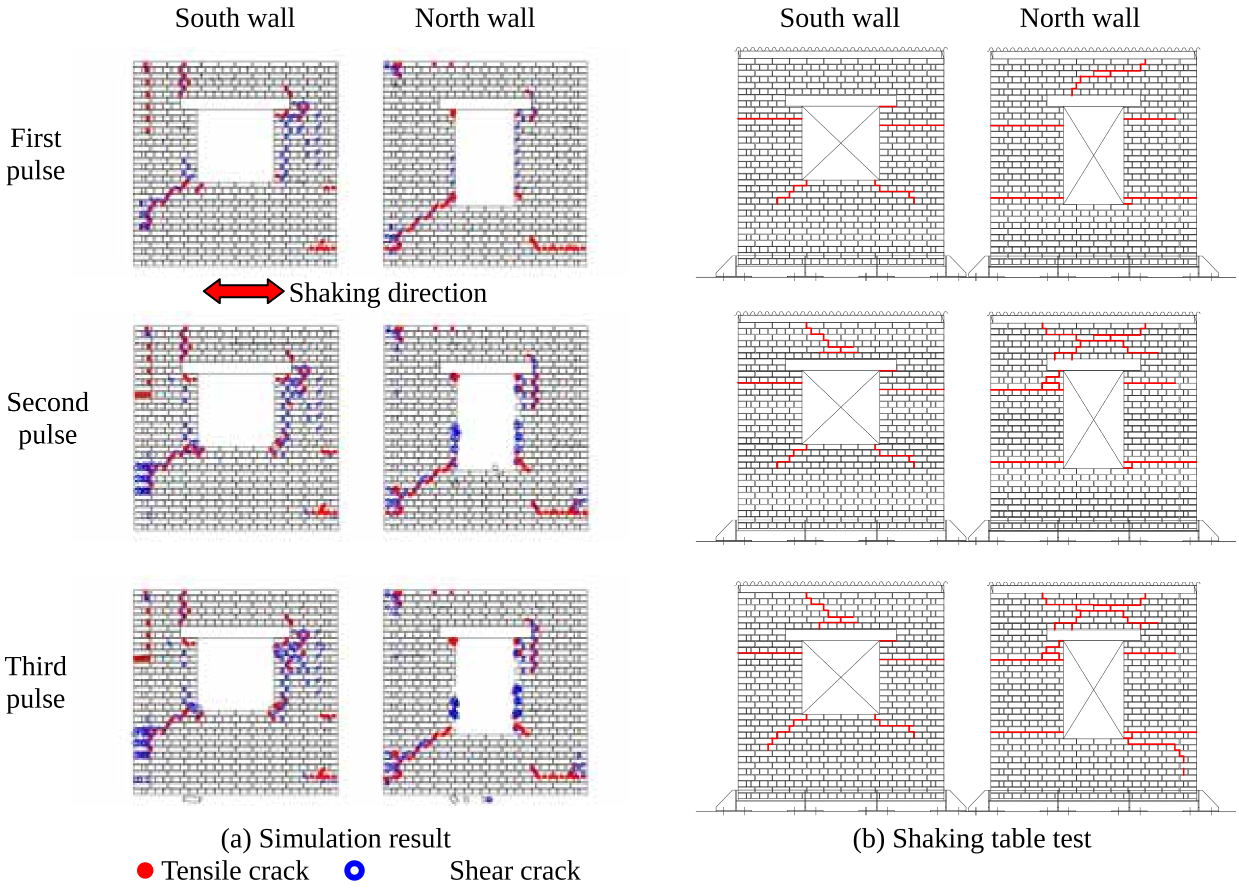


Figure 10. The Crack Pattern of Numerical Simulation and Shaking Table Test

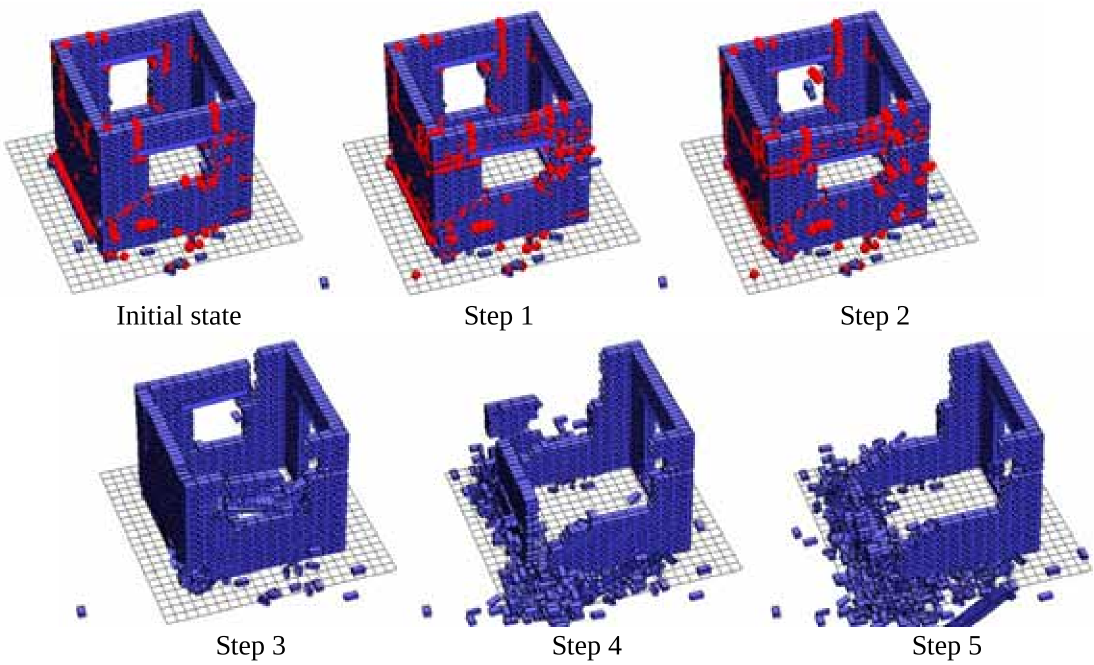


Figure 11. Collapsing Process of Numerical Model at the Bam Earthquake Wave

4. CONCLUSION

In this shaking table test, one of outlines of masonry house collapse process was shown. Careful construction work would make a strong house. We carried out the collapsing process simulations of brick masonry structure that has tested at the shaking table tests by using newly developed DEM program. Our analysis program is under development, but the crack pattern of the numerical analysis was similar to the shaking table results qualitatively. By improving our analytical method, it proved to be promising for measuring seismic design of masonry structure. Collapse modes of shaking table test and numerical simulation are something different from actual collapse modes as shown Figure 12. Further study on masonry structures is necessary.

ACKNOWLEDGEMENTS

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Figure 12. Collapsed Test House