Wood Building Collapse Tests Using E-Defense

by

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ABSTRACT

This paper presents the wood building collapse tests of NIED E-Defense. In 2002, Ministry of Education, Culture, Sport, Science and Technology (MEXT) began “Special Project for Earthquake Disaster Mitigation in Urban Areas (Dai-Dai-Toku in Japanese)”. The test was conducted as one of the project. There were three stages in the test. First stage was “Base Isolated and Recovered Recent Wood House”. Second stage was “Traditional Wood Houses”. Third stage was “Retrofit and Non retrofit Conventional Wood Houses”. In first and second stages, the houses were experienced severe artificial quake on E-defense, and collapsed.

KEYWORDS: Base Isolation, Collapse Test, Seismic Retrofit, Shaking Table, Wood Building

1. INTRODUCTION

In !995, Hanshin Great Earthquake Disaster occurred. MEXT and NIED started the construction of three-dimensional and six-freedom shaking table for full-scale tests of structures. The table is called E-Defense. The table has scale of 20m by 15m and can move 2m, with velocity of 2m/s in X and Y horizontal directions, 1m with velocity of 0.7m/s in Z vertical direction. Maximum structure weight is 1200ton. Maximum accelerations are 2G in X and Y horizontal directions without structures. Vertical power of the table is 6300tonf.

E-Defense has completed in January 2005. Three types of structures were planned as DAI-DAI-Toku Project in 2002 for E-Defense. One is the test of piles in soil layer, another is concrete building, and the other is wood building.

This paper describes the wood building test. The wood building test had three stages. First stage was “Base Isolated and Recovered Recent Wood House”. Second stage was “Traditional Wood Houses”. Third stage was “Retrofit and Non retrofit Conventional Wood Houses”. At first and second stages, the houses were experienced severe artificial quake on E-defense, and collapsed. The test results of first and third stages are presented here.

2. FIRST STAGE TEST OF BASE ISOLATED AND RECOVERED RECENT WOOD HOUSE

At the opening ceremony of E-Defense, a test of recent style wood house was demonstrated, as shown in Fig. 1. The wood house was quaked by the use of JMA Kobe strong motion record. In the test, small cracks and small partial fracture of walls occurred. There was no heavy damage in the house. The base of the house was designed for the base isolation. When the base isolation system was locked, severe quakes was inputted. The damages of house at the opening ceremony were recovered for the First Stage Test.

Fig.1 Test Wood House at Opening Ceremony

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2.1 Outline of Recent Wood House

The wood house of two stories was built by Japanese post and beam methods. The house had floor spaces of 67.49 ㎡ in first floor, 62.93 ㎡ in second floor. Seismic resistance was provided by bracings. Seismic grade of the house in Quality Verification Law was second. Exterior wall was ceramic siding, and interior wall was gypsum board. The length of seismic resistance wall(LW) and the eccentric ratio(ER) in Quality Verification Law were as follows.

LW of 2nd FL X 49.01m(20.51m), ER 0.036
LW of 2nd FL Y 39.06m(20.51m), ER 0.349
LW of 1st FL X 61.50m(35.73m), ER 0.036
LW of 1st FL Y 46.50m(35.73m), ER 0.332

The length in bracket ( ) was the required seismic resistance wall. Mass above first floor was about 340KN. The plans of house are shown in Fig.2.

The base isolation system was installed between the house base and foundation, as shown in Fig.3. In the system, there were 17 slide bearings, 4 rubber bearrings (horizontal spring 0.5KN/cm) , 8 stainless wire stoppers(fracture strength. 75KN).Special slide plates of moving length 2m were set only for E-defense test.

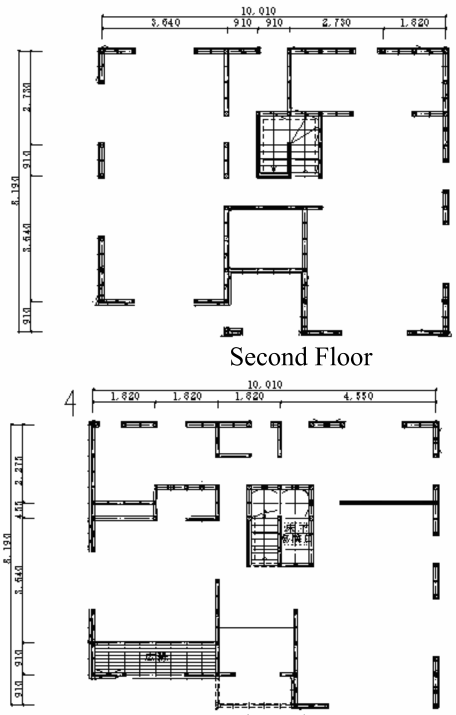
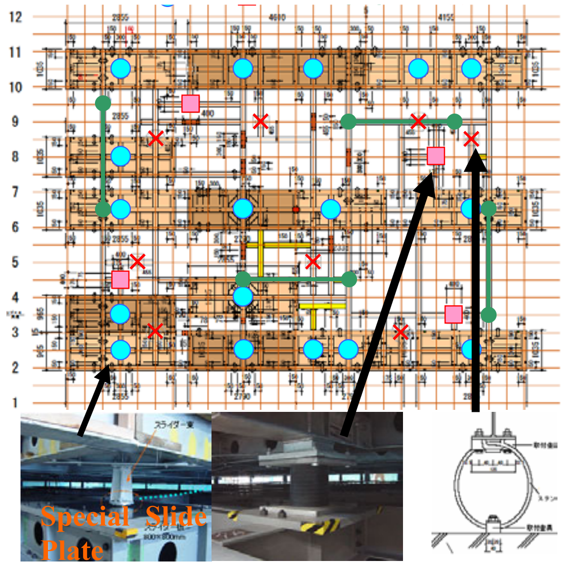


Fig.2 Floor Plans of First Stage Test House

2.2 Test Results

2.2.1 Tests of over design input to Base Isolation

Large displacement and long period input motions were applied to the house with base isolation system. Fig.4 is the response deformation spectra of input waves used in the tests. The damping 25% and natural period 2 second were roughly estimated the characteristics of the system,



Slider Rubber bearing Stopper

Fig.3 Base Isolation System

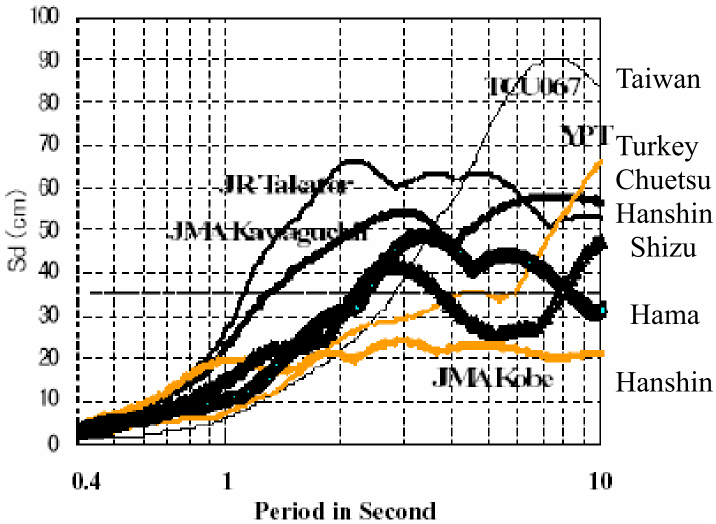


Fig.4 Response Deformation Spectra

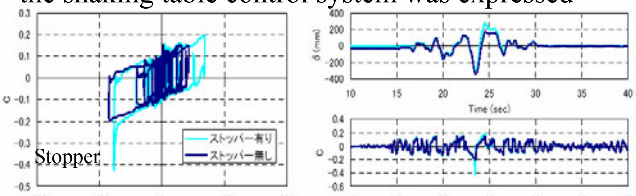
Fig.5 presents the base shear coefficient and deformations waves of base isolation layer in shakings of proposal motion Hamamatsu SI(Hama) and 2004 Niigata Chuetsu JMA Kawaguchi inputs. Limit deformation of stopper was 30cm approximately. Stoppers were effective to proposal motion Hamamatsu SI, in which the maximum response deformation was 34cm. However, in the case of JMA Kawaguchi input, stoppers cut by severe motions. The maximum response deformations to JMA Kawaguchi were 62cm without stoppers, 61cm with stoppers.

2.2.2 Collapse Tests of Recent Wood House

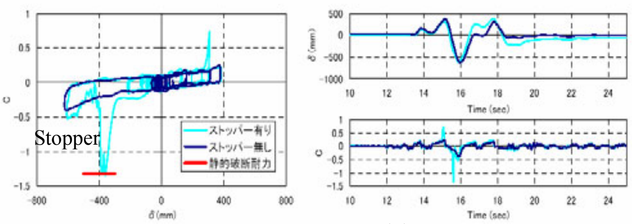
After the base isolation tests., the base isolation layer was anchored. The house experienced strong motions before the collapse test. The strong motions made the house soft. At first, the natural frequencies of house were more than 6Hz in X direction, about 5Hz in Y direction. The frequencies right before a collapse test were 2.7Hz in X direction, 2.6Hz in Y direction, approximately. Hanshin great earthquake three dimensional record of JR Takatori, shown in Fig.6, was used for the inputs. The strongest axis motion was adjusted to Y direction input. The maximum input velocities were about 170cm/s in Y direction, 60cm/s in X direction, as 20cm/s in Z direction. The input motion to E-Defense was displacement. The E-Defense performances in displacement inputs were not tuned up.

Therefore, the displacement inputs were compensated by the simple methods, in which the shaking table control system was expressed as two degree differential equation. The Fig.7 were velocity response spectra comparisons of shaking table inputs (black) and outputs (red). Long period component more than 0.3 second three direction outputs shows good agreements to inputs. However, the output components of less than 0.3 second in X and Y directions are bigger than input. In Z direction, the output components of less than 0.3 second are smaller than input. The small response of Z direction is supposed to bring from the large flow estimation of servo valves. The peaks of 0.2 second (5Hz) in responses were estimated to be the yawing motion of table.

It took three times of shakings to collapse the house. At first shaking of JR Takatori, a few pieces of wall panel fell down. Permanent deformations were scarcely observed. The photo after first shaking is shown in Fig.8. At second shaking of JR Takatori, big damages occurred. However, the house was standing. Large permanent deformations, shown in Fig.9, were observed. At the third shaking of JR Takatori, the first story of house was completely collapsed, as shown in Fig.10.

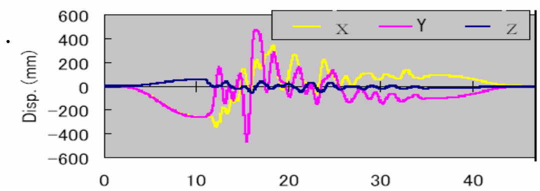


Proposal motion Hamamatsu SI

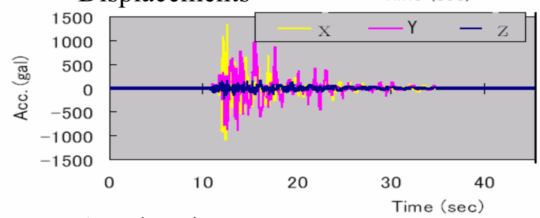


JMA Kawaguchi

Fig.5 Responses of Base Isolation Layer

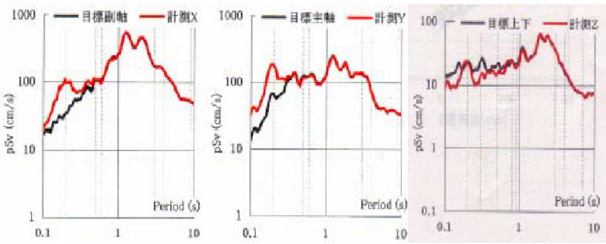


Displacements



Acceleration

Fig.6 JR Takatori Input Waves



X Direction Y Direction Z Direction

Fig. 7 Comparisons of table inputs and outputs

Fig.8 After First Shaking of JR Takatori

Fig.9 After Second Shaking of JR Takatori

Fig.10 After Third Shaking of JR Takatori

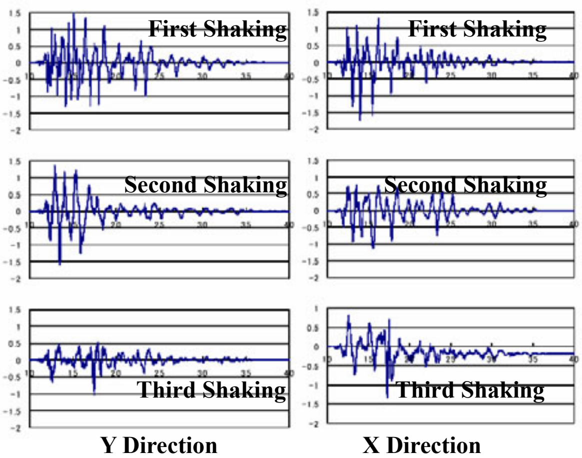


Fig.11 Roof Accel. Responses to JR Takatori

Fig.11 is the roof acceleration responses to three JR Takatori shakings. The response acceleration went down with progress of shakings.

3. THIRD STAGE OF RETROFIT AND NON -RETROFIT CONVETIONAL WOOD HOUSE

In 2002, the Defense test plan of Retrofit and Non retrofit Conventional Wood Houses" was made. The tests were conducted according to the plan.

3.1 Moving of Existing Houses and Retrofit

In February 2005, the offerings of two conventional wood houses were called around Kobe city, by public media. There were 200 applications approximately. Two conventional wood houses shown in Fig. 12, which built in 1974 at Akashi City in accordance with same drawing, were selected as E-Defense test structures. There were small differences in the houses. The houses were divided into 4 blocks, and moved to E-defense as shown in Fig.13, and rebuilt .The divide lines of moved houses were

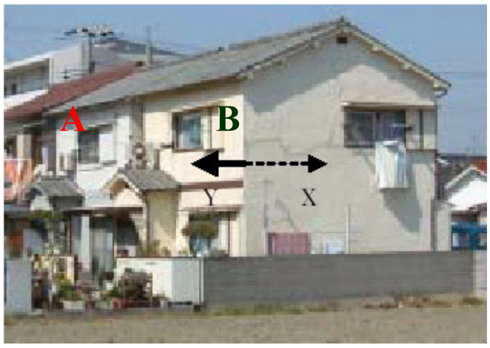
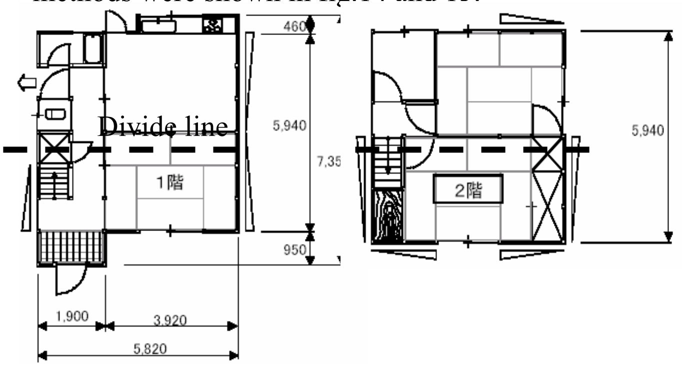


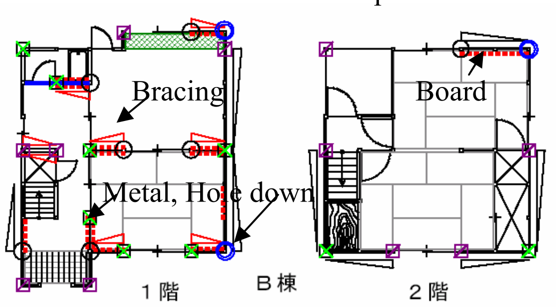
Fig.12 Selected Houses at Akashi City

Fig.13 Moving Works

reinforced with steel plates, steel angles, and additional timber members According to the seismic diagnosis, the houses have the seismic strengths of 22KN in Y axis of A house, 15KN in Y axis of B house, approximately. The required seismic strengths for two houses were same 50KN. The B house was decided to retrofit. According to the publication of "Japan Building Disaster Prevention Association", general retrofit methods of adding structure boards, metal joints and braces were employed. The dimensions, reinforced position and retrofit methods were shown in fig.14 and 15.



The dimensions of house plan



Reinforcement Positions

Fig. 14 Outline of Houses

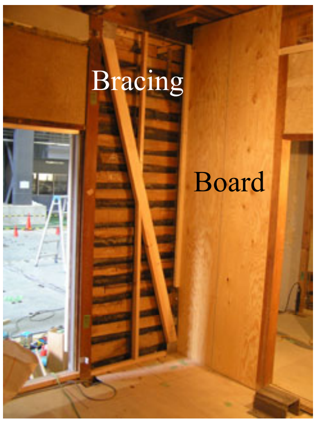


Fig.15 Retrofit Methods

The seismic strength of House B increases to 79KN by the retrofit. The weights were 11ton in roof level, and 15ton in 2nd floor level. Fig.16 shows two houses on the table of E-defense. Micro tremors of two houses were measured for investigating rigidities. Dominant frequencies were estimated as follows.

HOUSE	AXIS	On-site	On-table	Retrofitted
A	X	8.1Hz	7.3Hz	---
A	Y	5.8Hz	4.6Hz	---
B	X	7.1Hz	6.7Hz	7.2Hz
B	Y	5.1Hz	3.9Hz	4.7Hz

3.2 E-Defense Test and Computer Simulation

The three directional strong motions of JR Takator in Hanshin Earthquake, shown in Fig.17, were used as shaking table Inputs. In Fig.17, table response waves and target waves in acceleration were presented. In third stage, displacement wave inputs were adopted, just the same as first stage. Table yawing motion of 5Hz was estimated to occur, and made differences of to two waves.

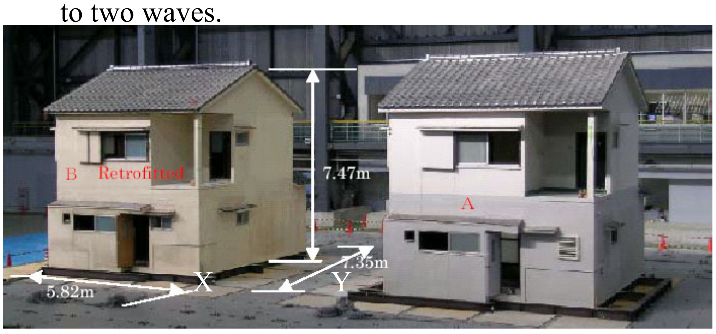


Fig.16 Two rebuilt houses on the table

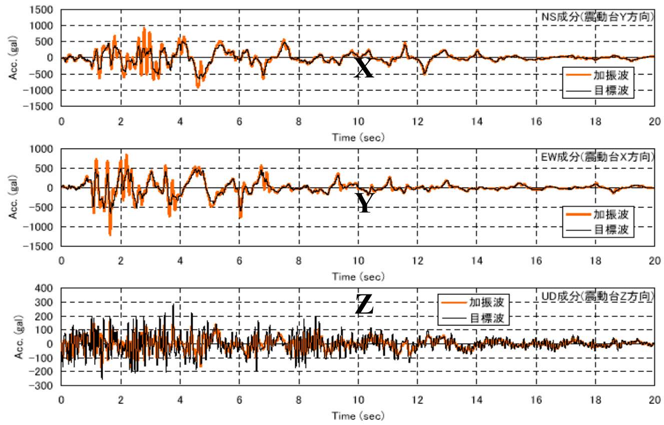


Fig.17 Measured waves(Red) and target waves (Black) of JR Takatori Accelerations.

Maximum velocities of target waves were 149cm/s, 117cm/s, 16.5cm/s in X, Y, Z directions.

In 2003 and 2004, preliminary tests were carried out in the use of middle size 3D shaking table. According to the preliminary test results, computer simulation program was developed, and the computer predictions for E-defense test responses were tried. Computer model of the house is Fig.18. There are 421 analysis points, about 1170 freedoms in the models. Restoring force models are Fig.19 for structure elements, In the model, bracings, mortal walls, mud walls, nailed boards, metal joints were considered.
There were incredible values in the model and the houses. Ratios for house weight mass R=1.0, 0.95, 0.9, 0.75 were used as parameters.

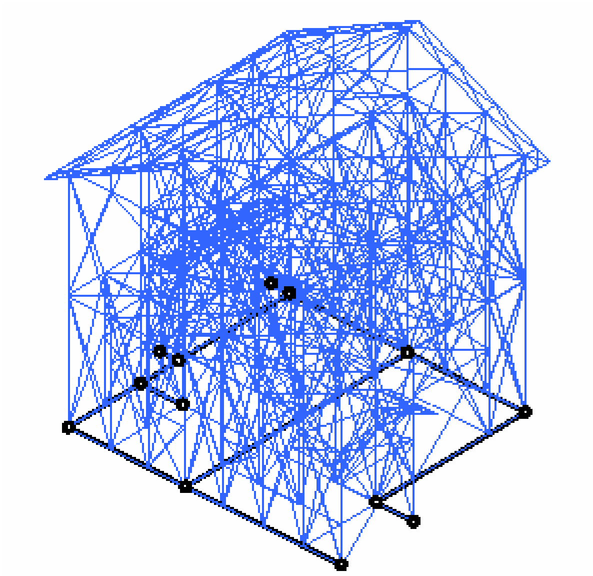


Fig.18 Computer Simulation Model

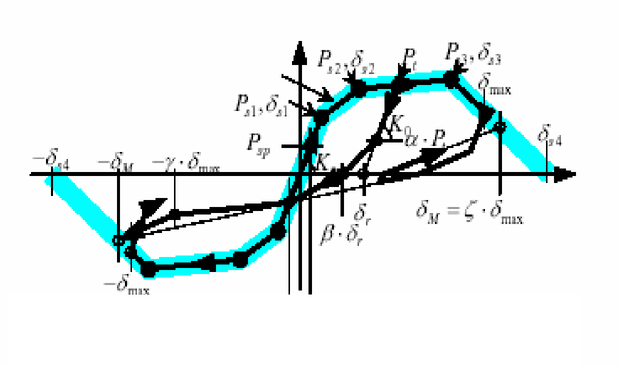


Fig.19 Restoring Force Model

The predicted computer simulations and measured story deformations of two houses are shown in Fig.21. According to the predicted results, there were the possibilities of non-collapse in non-retrofit house A, and the possibilities of collapse in retrofit house B
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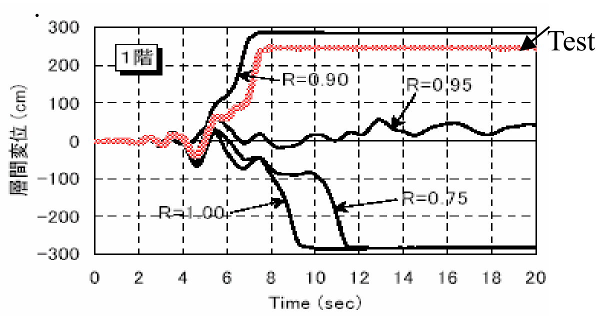
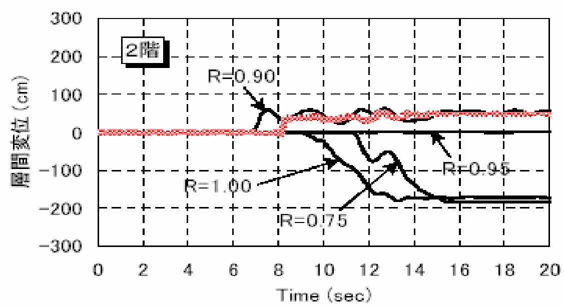
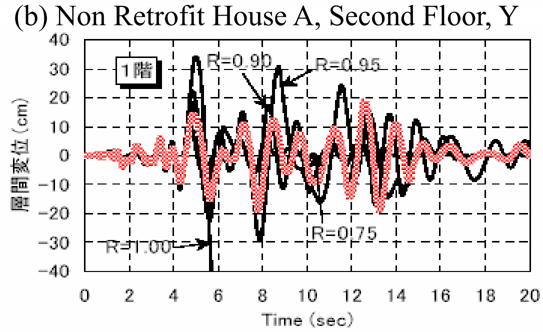


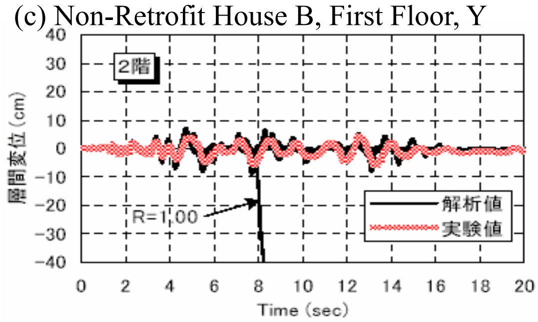
(a) Non Retrofit House A, First Floor, Y



(b) Non Retrofit House A, Second Floor, Y



(c) Non-Retrofit House B, First Floor, Y



(d) Non-Retrofit House B, First Floor, Y

Fig.20 Story Deformations of Shaking Table Test and Computer Simulations

As test results, the retrofit house B withstand to JR Takatori shakings, and non-retrofit house A collapsed in accord to computer prediction R=0.9. The corrected computer simulation carried out with the use of measured weight data of the house, after tests. Fig.21 is the recorded video and computer simulation graphic. The collapse modes were similar to Hanshin Earthquake damage modes.

Considering after shocks, JR Takatori of 60% amplitude was applied to House B. Mortal walls fell off, however the House B was standing. Next, JR Takatori of 100% amplitude was applied, the house B collapsed.

4. CONCLUSIONS

The base isolation of house is useful to decrease the usual seismic responses of houses. However, safety methods against the earthquake motions of large velocities and large displacements must be developed.

The recent Japanese houses of post-and-beam wood structures were verified to provide enough seismic strength.

E-defense exhibited the efficiency of retrofit, and proved the recommendation of Japan Building Disaster Prevention Association to be correct.

The computer simulation program to be developed in the project was useful to explain the collapse of wood houses.

5. ACKNOLEDGEMENTS

The tests were conducted with NIED, BRI, FRI, Tokyo Denki University, and Nihon System Design. President, Dr. Miyake developed the computer simulation program. We appreciate the cooperation of many peoples, especially Associate Professor Isoda in Shimshu University, Associate Professor Koshihara in University of Tokyo, Mr. Toyoshima of Tokyu Construction.

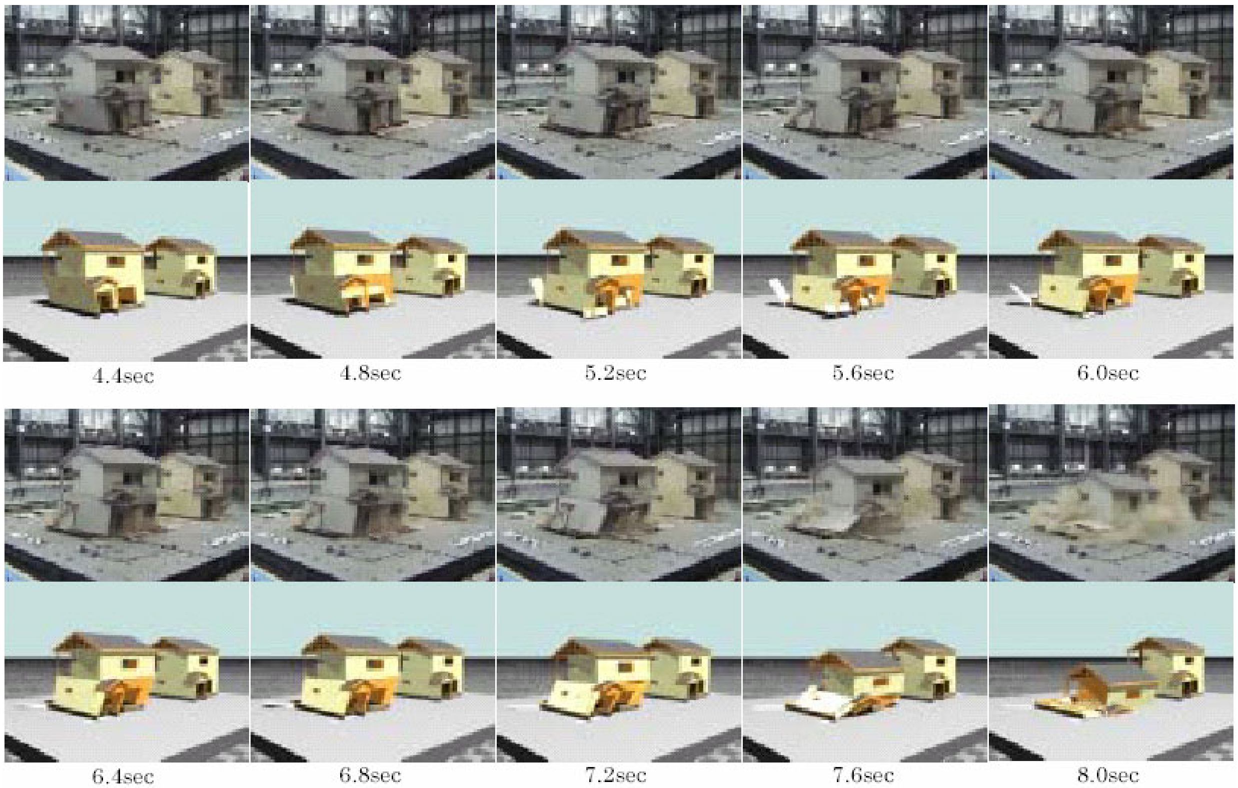


Fig.21 Video Records and Computer Simulation