An experimental study on full scale shaking table test of conventional wood house by E-defense

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ABSTRACT :

The objectives of this study are to evaluate the dynamic performance of Japanese conventional post & beam wooden dwelling house, and to compare the estimated dynamic response with the results of the static shear wall tests. This conventional house was provided by the house manufacturer.
The static shear walls tests, which were 22 types, were completed to prepare fundamental data for estimating dynamic response. The shear walls tested were, brace type that were single and double brace, nailed-on sheathing type using "MOISS" that was made of silica-calusium with vermiculite, and bare frame type. The hysteresis curves were modeled by using data taken from the static shear walls tests. And the dynamic response of full scale two story test house of 8,000 mm X-direction and 10,000 mm Y-direction was analyzed by taking the hysteretic curve of each static shear walls located in each places in the test house into consideration.
It was obvious from this comparison that the modern wooden residential house, which was designed so as to meet with required design criterion, was stronger and tougher than this prediction. Thus it was thought that the non-structural members might have large influence on the structural performance. It was recognized that the base shear coefficient was about 1.4 times higher than that of the standard plan.

KEYWORDS: Static shear wall test, Shaking table test, E-defense, Full scale, External wall, Non-structural member

1. INTRODUCTION

Recently, some full-scale shaking table tests of the wooden residential house were done for to grasp seismic performance. On 8th and 10th January in 2008, a series of full-scale shaking table tests was done on a two-story modern wooden residential house at E-defense, which is well-known as the largest 3D shaking table test facility in the world. Using the same wooden residential house, we changed their specifications into two different grade, those are, the level three and the level two, in accordance with "Bill for Ensuring the Quality of Public Works", when they suffered same earthquake waves. In addition to this, we clarified the influence of external sheathing material and non-structural members on the seismic performance of the house. There were some reports about comparison of level two and level three of Bill for Ensuring the Quality of Public Works on the shaking table test, but there were few of reports on the non-structural members. Incidentally on the level of Bill for Ensuring the Quality of Public Works, high number was better than low one.
In this paper, we described the seismic performance evaluation of the wooden residential house including the non-structure members. At first shear resistance performances were described not only formal shear walls but also such special elements as hanging walls by the static loading test. And the behavior of the whole house was

predicted based on the performance of all resisting elements involving in the test specimen. Lastly, the experimental data observed by acceleration measuring devise on the shaking table at E-defense and predicted behavior of the whole house was compared.

2. STATIC PERFORMANCE FROM SHEAR RESISTING TEST

2.1. Specimens

Before this full-scale shaking table test, a series of static push-pull cyclic lateral loading tests was conducted on every shear resistant element, which thought to give any contributions to the seismic resisting performance of whole house. Static loading tests were done by using the common use facilities. It was 22 types and 46 specimens. All specimens were same size 2,925mm height and 2,000mm width. Main members were all the same species, namely column, sills, beams and brace were Japanese cedar, Cypress, Douglas fir and Douglas fir, respectively. Two types panels used in specimens; one was a “MOISS (9mm thickness)” that was made of silica-calusium with vermiculite, another one was a Gypsum board (12.5mm thickness). Fig.1 showed two examples of specimens.

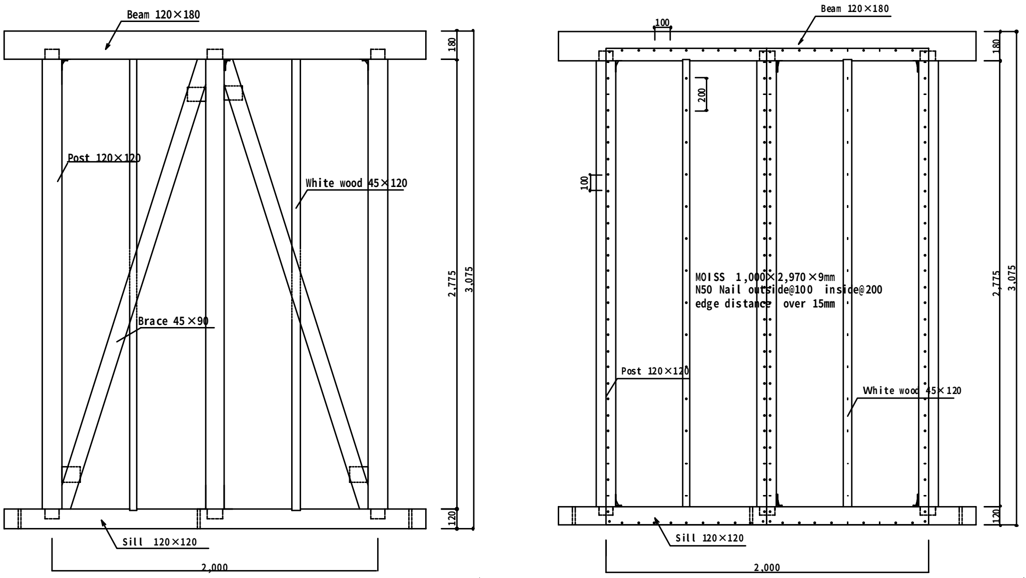

Figure 1 Two examples of specimens (Left: Single brace type, Right: MOISS) unit:mm

2.2. Results of shear resisting tests

Table 1 showed the results of some important seismic walls. Figure 2 showed two examples of load-story drift angle curves. Based on these cyclic results, the load-deformation relations of all seismic elements were evaluated, and the seismic performance of the house was examined.

Table 1 Results of some important seismic walls

Type of shear seismic wall	P_{max} kN	Initial stiffness kN/rad	Shear Resistance Factor
Frame	1.69	97.29	0.19
Single brace	16.71	1510.31	2.19
Double brace	31.89	2354.05	3.20
Gypsum board	5.96	2633.13	0.92
External wall	7.12	74.18	0.35
MOISS	27.52	5967.83	3.53
MOISS (hanging wall)	3.92	155.38	0.37
MOISS (hanging + lower partial wall)	7.41	526.18	1.07

Note: Initial stiffness was calculated with secant of $0.1P_{max}$ and $0.4P_{max}$.

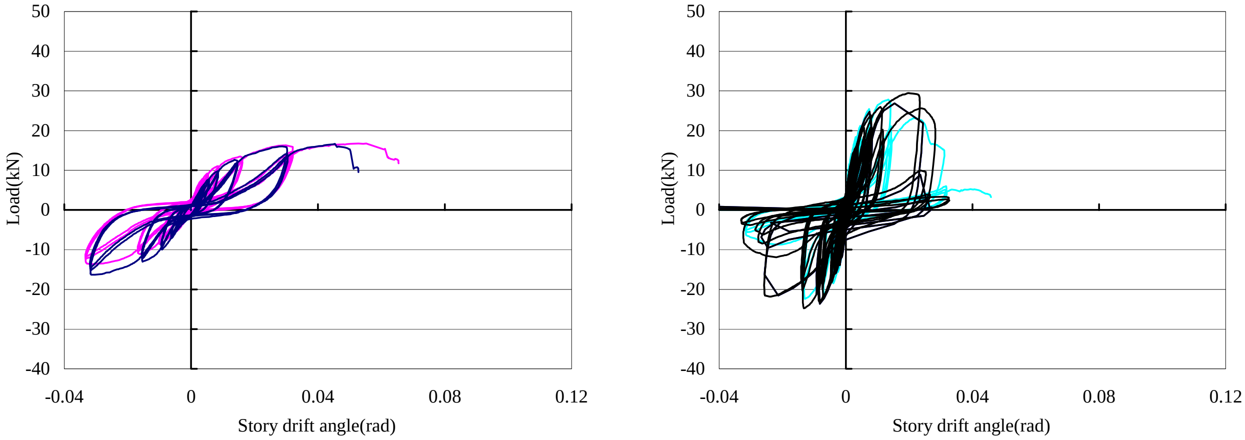

Figure 2 Relationships between Load and Story drift angle (Left: Single brace, Right: MOISS)

Photo 1 Failure mode (Left: Single brace, Right: MOISS)

3. Prediction of whole house

Folz model was used as Prediction model. As the results for high seismic performance plan, Folz model predicted that the story drift of first floor should be 1/42 rad by subjecting to JMA Kobe 100% input, and also should be 1/9 rad by JMA Kobe 150% input, if non-structural members did not affect on seismic performance of whole house.

4. SHAKING TABLE TEST

4.1. Experimental specimen

On 8th and 10th January in 2008, a series of full-scale shaking table tests was done on a two-story modern wooden residential house at E-defense. On the first day, high seismic performance plan which was level three of Bill for Ensuring the Quality of Public Works was tested. The second day, standard seismic performance plan (level two) that was achieved by removing some wooden braces from high seismic performance plan was tested. Photo 2 showed the specimen. Fig.4 showed those floor plans. Table 2 showed the existing wall-length ratio and the eccentricity ratio. The dimension of specimen was 10,000 x 8,000mm for both 1st and 2nd floors. In this experimental specimen, all sashes, all glass, stairs, and some furniture were set up, but the bathtub was not placed. The seismic load was 322.9kN for the whole house, 165.6kN on the 1st floor and 157.3kN on the 2nd floor. In addition, the measured weight of this specimen was 359.5kN that included the live load.

Photo 2 Specimen set up on shaking table (Left: View of Southwest, Right: View of Northeast)

Table 2. Existing wall-length ratio and Eccentricity ratio

Floor	Direction	First day		Second day	
		Existing wall-length ratio	Eccentricity ratio	Existing wall-length ratio	Eccentricity ratio
2	X	2.24	0.00	2.24	0.00
	Y	2.59	0.15	2.33	0.15
1	X	1.81	0.00	1.35	0.03
	Y	1.81	0.02	1.58	0.14

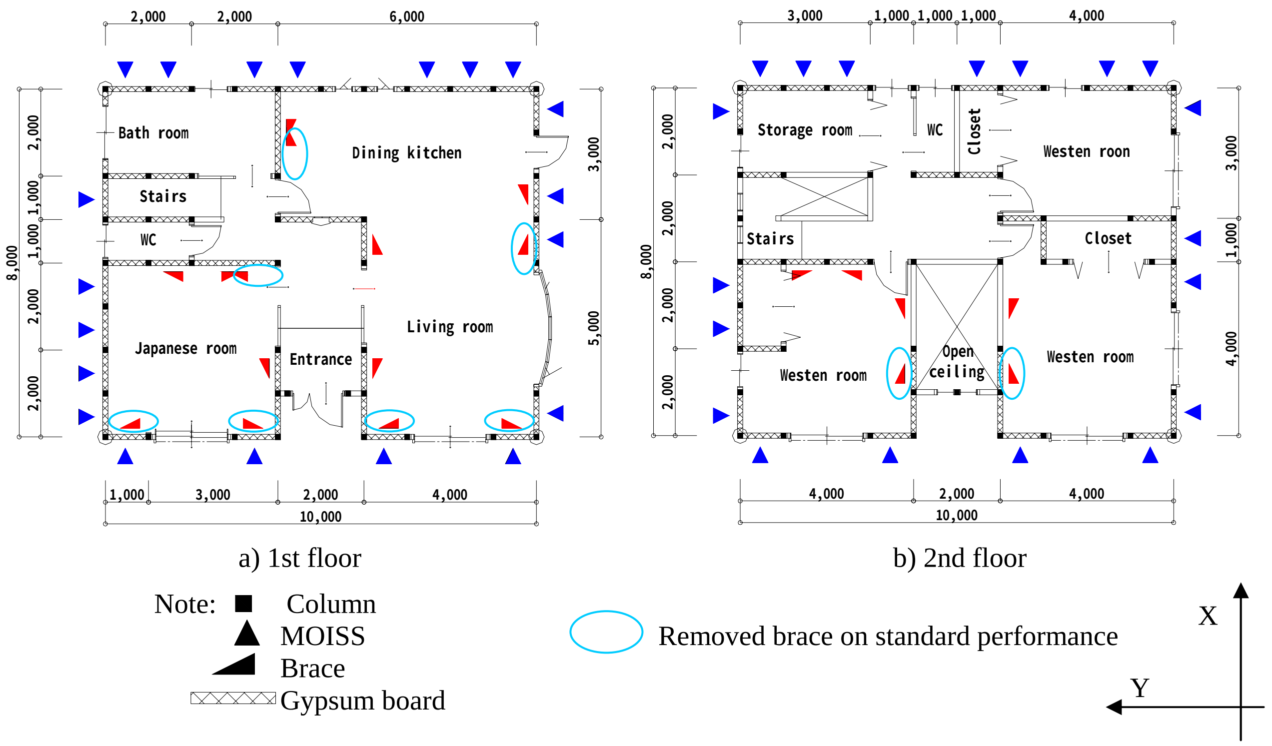

Figure 4 Floor plan of specimen (high performance plan) unit:mm

4.2. Waves of shaking test

In paste, many earthquakes gave devastating damages on the conventional wooden houses in Japan. Therefore these earthquake waves, which were 1995 Kobe, 2004 Kawaguchi, 2007 Wajima and 2008 Kashiwazaki, were used to shake the table. The wave schedule was shown in Table 3.

Table 3. Schedule of shaking table test

	No.	Input Wave		No.	Input Wave
First day	1	BCJ-L2 20% Y	Second day	1	BCJ-L2 20% Y
	2	BCJ-L2 20% X		Check damage (Fourth)	
	Check damage (First)			2	BCJ-L2 20% X
	3	BCJ-L2 100% X,Y		3	BCJ-L2 100% X,Y
	4	JMA Kobe 100% X,Y,Z		4	BCJ-L2 100% X,Y
	5	JMA Kawaguchi 100% X,Y,Z		5	JMA Kobe 100% X,Y,Z
	Check damage (Second)			6	JMA Kobe 100% X,Y,Z
	6	JMA Wajima 100% X,Y,Z		7	JMA Kawaguchi 100% X,Y,Z
	7	K-NET Kashiwazaki 100% X,Y,Z		Check damage (Fifth)	
	8	JMA Kobe 100% X,Y,Z		8	JMA Wajima 100% X,Y,Z
	9	JMA Kobe 100% X,Y,Z		9	K-NET Kashiwazaki 100% X,Y,Z
	Check damage (Third)			10	JMA Kobe 100% X,Y,Z
	Changing the quakeproof level and repair			Check damage (Sixth)	

4.3. Damage level

The damage of the specimen observed in each step situation was follows;
For the high performance plan (Level 3);
Check damage Second: The response story drift angle showed 1/100rad. But small cracks and ripped wall crosses on the inside were slightly recognized.
Check damage Third (Photo 3): The response story drift angle showed 1/50rad on the final wave. Both outside and inside had some amounts of damages. The external sheathing board slightly came off and the inside wall had large damage.

For the standard performance plan (Level 2);
Check damage Fifth: The natural frequency was dropped down from 7.9Hz X-direction 7.2Hz Y-direction to 2.9Hz for both directions. And there were much damages on such structural elements as shear walls or/and inside gypsum boards.
Check damage Sixth (Photo 4): As well as the damage of Fifth, there were fairly large damages on column at the 1st floor having large crack and the shear walls moved greatly.

Photo 3 Damage of check third (Left: Inside, Right: Outside)

Photo 4 Damage of check sixth (Left: Column, Right: Inside)

4.4. Performance of seismic resistance

Figure 5 and 6 showed relationship between load and story drift angle for comparison of 1st and 3rd wave inputs of JMA Kobe. Maximum story drift and angle of each wave was shown in Table 4. The high performance plan showed a high natural frequency of 8.0Hz. And it was obvious from this comparison that the modern wooden residential house, which was designed so as to meet with required design criterion, was stronger and tougher than the prediction. For example, for the shaking JMA Kobe 100% input, the prediction value was 1/42rad but the experimental value was 1/145rad. The base shear coefficient showed about 1.4 times that of the standard plan. This conventional house had good seismic performance. Two reasons why actual response was higher than that of prediction were deduced. One reason might be the weight. As there were, however, not big deference between measured weight and calculated weight, we thought that other reason such as non-structural members might affect on the higher performance. In this study, we examined the shear resisting performance of all elements by static loading test including the external walls, but did not include stairs and a sash. We thought that this point was important to predict more precisely the performance of the whole house.

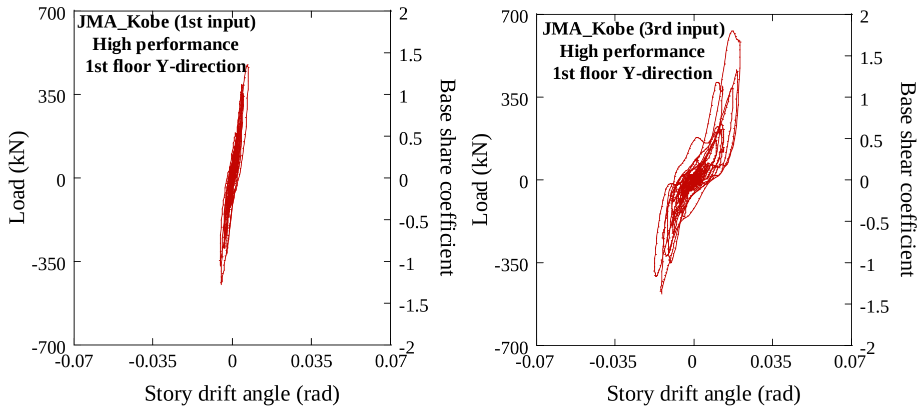

Figure 5 Comparison of 1st and 3rd times JMA Kobe of first day (High performance plan)

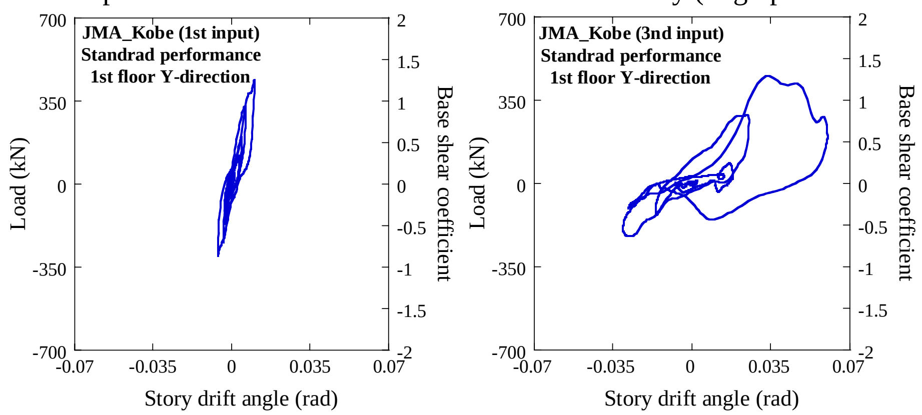

Figure 6 Comparison of 1st and 3rd times JMA Kobe of second day (Standard performance plan)

Table 4 Maximum story drift and angle of each wave

	No.	Direciton	Maximum story drift (mm)		Maximum story drift angle (rad.)			No.	Direciton	Maximum story drift (mm)		Maximum story drift angle (rad.)	
			Plus	Minus	Plus	Minus				Plus	Minus	Plus	Minus
First day	4	Y	20.33	-16.17	1/146	1/183	Second day	5	Y	30.22	-18.68	1/98	-1/158
		X	14.60	-13.62	1/203	-1/217			X	9.78	-18.50	1/303	-1/160
	5	Y	20.54	-17.99	1/144	-1/165		6	Y	58.03	-64.86	1/51	-1/46
		X	25.47	-29.96	1/116	-1/99			X	30.38	-54.29	1/97	-1/55
	6	Y	15.09	-14.16	1/196	-1/209		7	Y	42.65	-37.87	1/69	-1/78
		X	21.12	-17.84	1/140	-1/166			X	35.33	-40.26	1/84	-1/74
	7	Y	17.02	-17.91	1/174	-1/165		8	Y	56.50	-37.10	1/52	-1/80
		X	20.30	-19.54	1/146	-1/151			X	51.83	-44.39	1/57	-1/67
	8	Y	35.18	-37.49	1/84	-1/79		9	Y	60.35	-53.68	1/49	-1/55
		X	36.55	-40.40	1/81	-1/73			X	47.80	-51.57	1/62	-1/57
	9	Y	60.77	-51.68	1/49	-1/57		10	Y	177.70	-91.26	1/17	-1/32
		X	37.55	-55.50	1/79	-1/53			X	100.58	-113.01	1/29	-1/26

5. CONCLUSIONS

At first, shear resistance performances were evaluated not only formal shear walls but also such special elements as hanging walls by the static loading test. Then the behavior of the whole house was predicted with the performance of all seismic resisting elements involving in the test specimen. At last, the experimental data observed by acceleration measuring devise on the shaking table and predicted behavior of the whole house were compared. Followings might be concluded;

1. The base shear coefficient showed high value that was about 1.4 times of that of the standard plan.
2. It was deduced that the non-structural members might have large influence on the structural performance of whole house.

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