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A STUDY ON MICROTREMOR MEASUREMENTS OF TIMBER STRUCTURE ON SEISMIC RETROFIT DWELLING HOUSES

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SUMMARY

The 1995 Hyogo-Ken Nambu Earthquake caused a large scale of damage on wooden dwelling houses in Japan. This damage showed us necessity of the new seismic design procedures considering the severe earthquake and investigation on dynamic behavior of wooden structures. Our research group conducted the field survey with microtremor measurement for seismic retrofitting Japanese timber dwelling houses on a part of Tokai district, which is afraid of damage by an expected Tokai earthquake or To-Nankai earthquake. We measured microtremor measurement to compare between before and after vibration characteristics on seismic retrofit effect.

As a result of these investigations, it was grasped that the natural frequency after seismic retrofit construction was higher than before.

1. INTRODUCTION

The location of our research group is in Mino City, Gifu Prefecture, JAPAN. This city has many Japanese traditional timber dwelling houses. This city is on a part of Tokai district, which is afraid of damage by an expected Tokai earthquake or To-Nankai earthquake in recent years. In the Mino city, our research group conducted a field survey with a microtremor measurement for these houses, and evaluated its vibration characteristics. It has started a seismic retrofitting works to these houses. In Japan, There are not seismic diagnosis and a legal system of the seismic retrofitting at the wooden building. Therefore, this purpose is to implementing seismic diagnosis and seismic retrofitting at the wooden houses which used microtremor measurement and confirming the effect of the microtremor measurement.

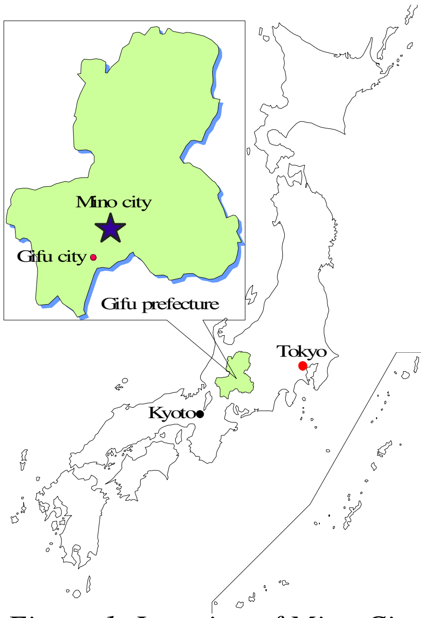

Figure 1 Location of Mino City

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2. LITERATURE RESEARCH

Relation between the constructed year and the natural frequency by microtremor measurment which was gathered from the literature [1]-[4] in the past is shown in figure 2.
It finds that the natural frequency of the recent wooden house is about 6.66 Hz. In other words, it finds that the natural period of the recent wooden house is about 0.15 seconds.

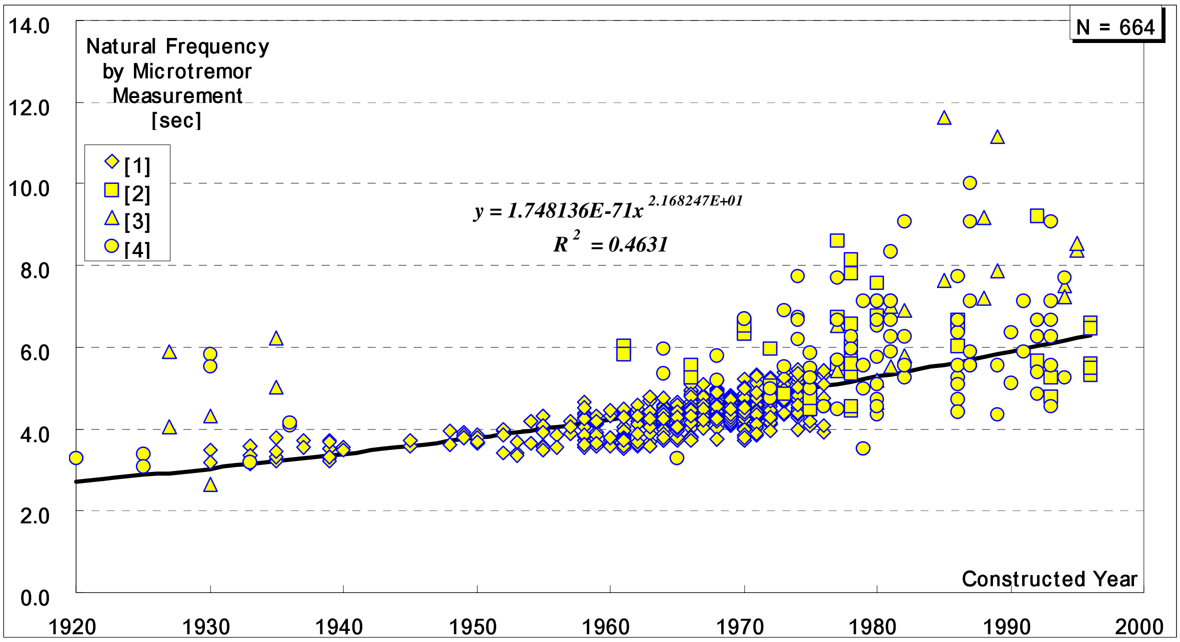


Figure 2 Natural Frequency by Microtremor Measurement and Constructed Year

The one to have gathered a natural frequency and a destruction overview in experiment by the microtremor measurement in case of full scale shaking table tests on the recent house is shown in table 1. Incidentally, this full scale shaking table tests, it enters the earthquake wave of JMA-Kobe-1995 which was observed at Japan Meteorological Agency by the Hyogo-ken Nanbu Earthquake in 1995. The maximum acceleration is 818 gal of the horizontal direction and 630 gal of the vertical direction.
It finds that a recently timber house is destroyed (similar collapsed) on about 3-4 Hz of the natural frequency by the microtremor measurement and had slight damage on about 6 Hz of one.

3. VIBRATION CAHARACTERISTICS OF TIMBER HOUSES

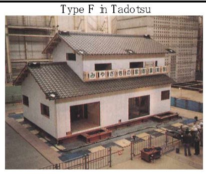
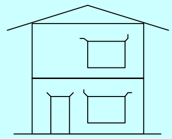
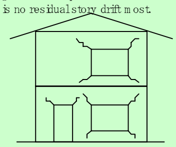
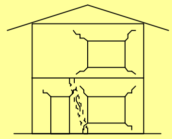
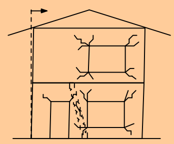
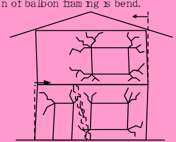
Relation between the natural frequency by microtremor measurment and effective wall length ratio
is shown in figure 3. It is shown by the following approximate curve. The correlation coefficient is 0.6628.

$$y = 5.5242\ x^{0.29} \qquad (1)$$

Relation between the damping ratio by microtremor measurment and effective wall length ratio is shown in figure 4. It is shown by the following approximate curve. The correlation coefficient is 0.4488.

$$y = 0.0269\ x^{-0.2424} \qquad (2)$$

Table 1 Natural Frequency by the Microtremor Measurement and the Destruction Overview of Full-scale Shaking Table Tests

Natural Frequency before the Excitation			Natural Period before the Excitation			Type A in Tadotsu	Type B in Tadotsu 	Type F in Tadotsu 	Results of the full-scale shaking tests of two story wodden dwelling houses
Hz			sec						
6.5	~		0.154	~					
6.0	~	6.5	0.167	~	0.154		There is no damage of body most. In the 1st and the 2nd floor, gypsum boards around opening have slight crack. On the 1st floor north and south surface, bearing walls have shear crack.		There is no damage of body most. The interior and exterior materials around opening have slight crack. There is no residual story drift most. 
5.5	~	6.0	0.182	~	0.167		There is no body damage most. Cracks of gypsum board and mortars develop. Wrinkles are seen by the cross of the living room.	There is no damage of body most. Gypsum boards and siding boards have a minute crack. Roofing tiles move. There is no residual story drift most.	
5.0	~	5.5	0.200	~	0.182	At three points on the north side, gypsum boards have crack. Sidings have a minute crack. On the south side, a half of roofing tiles drop. There is no residual story drift most.	There is no damage of body most. A crack doesn't develop. There is no residual story drift most.		
4.5	~	5.0	0.222	~	0.200		On the north side, brace hardware float. On the south side of living room, the hardware fixed bottom of column deformation and sink. At the nail of base, there are cracks. Mortars have cracks increase. The connection around the ceiling on north side in the living room side are damaged.	Cracks of gypsum board and mortars develop. Roofing tiles falls partly to the east. There is no residual story drift most.	There is damage of body. The interior and exterior materials around opening have developed crack. There is no residual story drift most. 
4.0	~	4.5	0.250	~	0.222				
3.5	~	4.0	0.3	~	0.3	The hold-down hardwares are deformed. The nail of brace's edge float. Gypsum boards have crack Siding boards have developed crack. There is residual story drift of 4mm to the east. The 14 braces of X direction in the 1st floor. : The one of them on the south is bend. The one of them on the north is buckling. The one of them on the north is tencil destruction. The one of them on middle street is como off a nail On the north of the 1st floor, the gypsum boards of the three places have crack. There are many base fractures. There is residual story drift of 7mm.	In the 1st floor, 2/4 braces have a buckling deformation. On the north side in the 1rst floor, 2/6 braces have a buckling destruction. On the north side in the 2nd floor, a brace have the buckling deformation and joint destruction. The entrance side HD hardware, of which a nut has been loosened, have a deformation. The washer of anchor bolt washer sinks to base. There is no residual story drift most.	The base at bottom of column fractures on four corners in the 1st floor. The column float 9mm on the northwestern corner. There is no residual story drift most. The nail of hardware fixed bottom of column pull out 2mm. At the east side on the south surface, The nail of brace's edge coming off 3-8mm There is no residual story drift most.	The braces have buckling destruction. The joints of brace have tencil destruction. There are many base fractures. The nails of joint hardware float. There is residual story drift about 1/350 radian. 
3.0	~	3.5	0.333	~	0.286	On the southwestern corner, hold-down hardware loose. A bolt of hold down hardware curves a little. Gypsum boards develop crack. There is residual story drift of 6mm.	The 2/4 braces in the 1st floor are buckling deformation The 1/6 brase on the northside in the 1st floor is buckling destruction. One of braces have tencil destruction at the its top edge after the its buckling deformation. On the north side in the 2nd floor, 1/2 braces are buckling destruction. The hardwares of bottom of column have a deformation and the nail float. The hut bundle on the east in the 2nd floor float.	The nail of the plywood comes out in the excitation direction greatly. All the four hold-down hardwares turn a little with tension. There is residual story drift of 1/33 radian to the east.	There is heavy damage of body. There are joint destruction and a member crack. There is residual story drift about 1/50 radian. 
2.5	~	3.0	0.4	~	0.3		Two braces have buckling deformation on the south side in the 1st floor. Two braces have buckling deformation, and the nail of the joint of one brace floats on the north side in the 1st floor. There is residual story drift about 1/900 radian. The nail of 17/ 20 sheets of plywood for the reinforcement came out, and 4 sheets on them fell. The nail of the plywood on the north surface comes out greatly. Acceleration isn't so big as that. All the CP-L hardware is transformed. Two places VP hardware of the south side and six places that of the north side transform. There is residual story drift about 1/80 radian.	Most brace is buckling by the compressive force, and it is coming off of the nail by the tractive force in the EW direction of the 1st floor. Four columns of balloon framing fractures in the girt part. There is residual story drift about 1/46 radian to the east.	
	~	2.5		~	0.400	Brace does buckling, and that joint is destroyed. 3/6 braces of the south side, 2/ 2 braces of the middle side and 5/6 braces of the north side destroy in the excitation direction on the 1st floor. 4/4 braces of the south side and 4/4 braces of the north side destroy in the excitation direction on the 2nd floor. Story drift is antiphase in the 1st floor and the 2nd floor. 4/4 column of balloon framing is bend. There is residual story drift of 24mm.			There is heavy damage of body. Each story is transformed in the antiphase. Column of balloon framing is bend. 

* Each Shaking Table Test is referred to the [4]

Relation between the damping ratio by microtremor measurment and natural frequency by microtremor measurment is shown in figure 5. It is shown by the following approximate curve. The correlation coefficient is 0.7363.

$$y = 0.1139\ x^{-0.8855} \qquad (3)$$

Relation between the damping ratio of torque by microtremor measurment and natural frequency of torque by microtremor measurment is shown in figure 6. It is shown by the following approximate curve. The correlation coefficient is 0.6962.

$$y = 0.1237\ x^{-0.9361} \qquad (4)$$

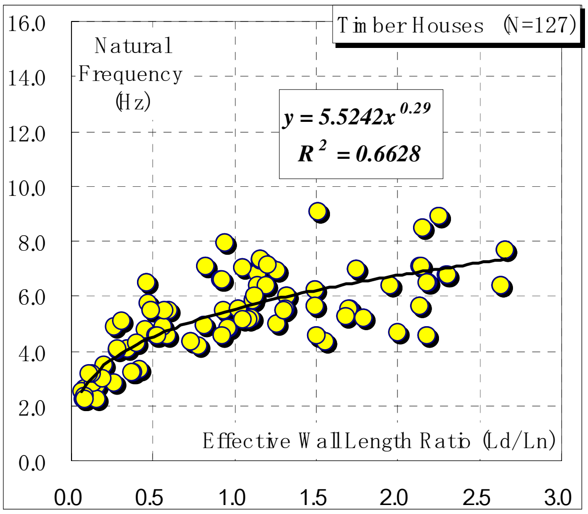


Figure 3 Natural Frequency and Effective Wall Length Ratio

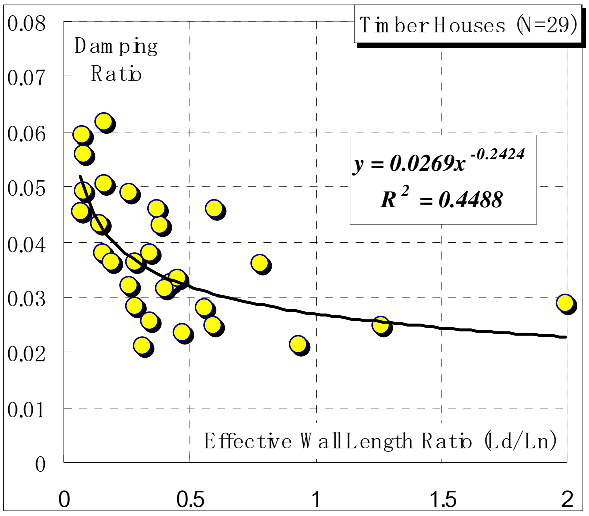


Figure 4 Damping Ratio and Effective Wall Length Ratio

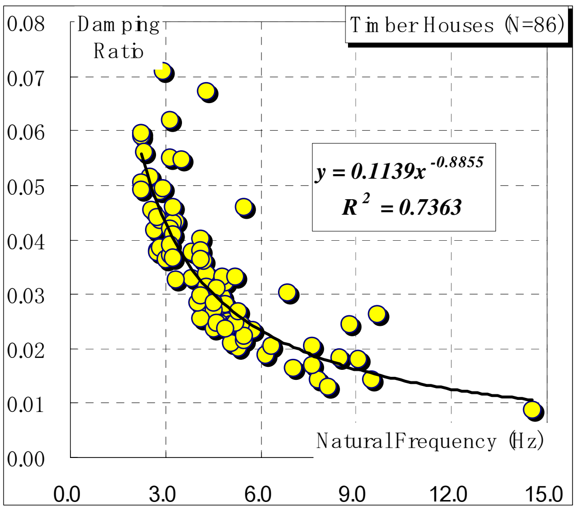


Figure 5 Damping Ratio and Natural Frequency

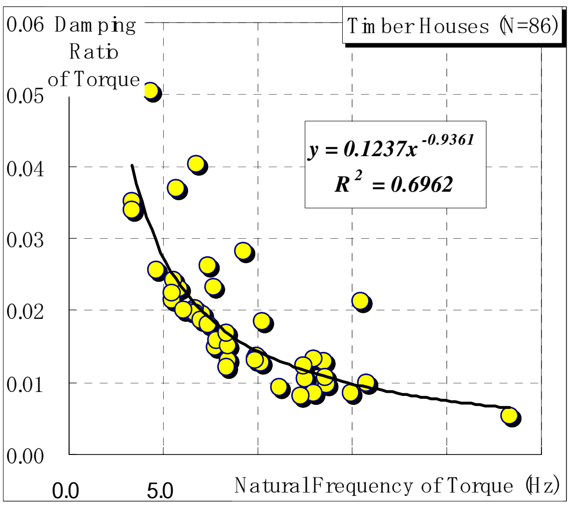


Figure 6 Damping Ratio of Torque and Natural Frequency of Torque

3. SEISMIC DIAGNOSIS WAY

It proposes our seismic diagnosis way which is shown in figure 7.

The first step, we made drawings in on-site survey, which were consisted of each story plan, elevations, and framing elevations. Simultaneously, we investigated a condition of foundation, joints of frame, bearing walls, and horizontal diaphragm. The state of the work is shown in photograph 1 - 5. And we measured microtremor measurement to grasp natural frequency.

The second step, we made a proposal for seismic retrofitting of the timber dwelling house, for filling the client's demands, which is handy in their life, for economics in their income, for seismic effective of their house and etc. We analyzed natural frequency, damping ratio, and other vibration characteristics by fast Fourier transform of value of microtremor measurement.

The third step, the house was retrofitted in our proposed way. We supervised the construction work and the management of work progress.

The fourth step, we measured microtremor measurement to compare between before and after vibration characteristics on seismic retrofit effect.

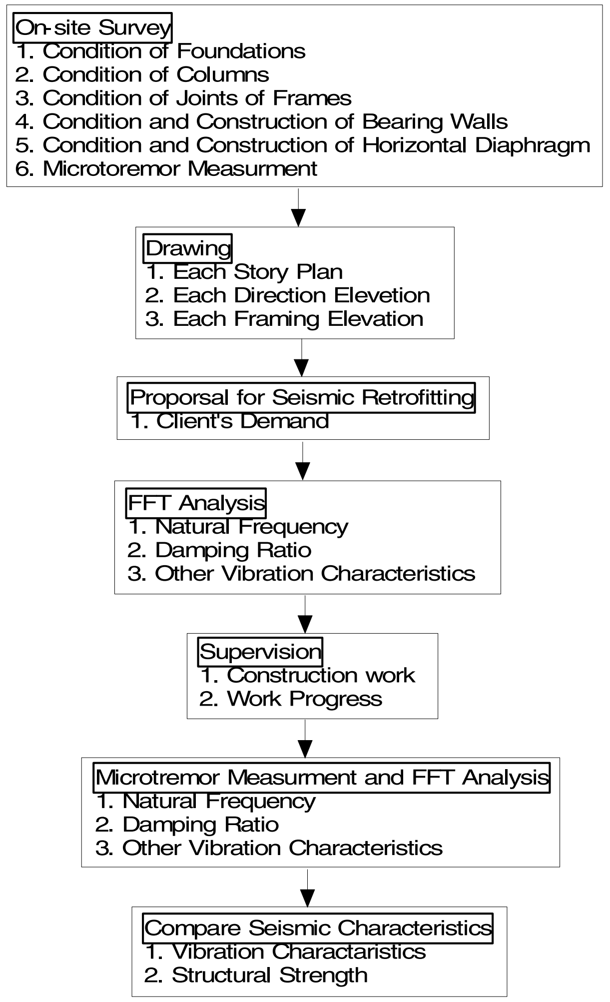


Figure 7 Outline of Seismic diagnosis


Photo. 1 Hangar Back


Photo. 2 Hangar Back


Photo. 3 Under Floor


Photo. 4 Under Floor


Photo. 5 Under Floor

4. EXAMPLES SEISMIC RETROFIT OF JAPANESE DWELLING HOUSE

It gives the case of the seismic retrofitting which used microtremor measurement. It considers about the usability of that.

4.1 A-HOUSE

This one-storied house, which is shown in photograph 6, is a typical traditional house in Japan, and has built 100 years before. In the hangar back, a sericulture has been done ever, and a straw and soil are spread. These total weight is about 85kN.

It disposed all of these and there was to make the weight light, and it implemented to increase a effective bearing wall ratio.

The characteristics of vibration before and after seismic retrofitting is shown table 2. This seismic retroffiting change 3.2 Hz of the natural frequency into 4.7 Hz of one. This seismic retroffiting change 0.046 of the damping ratio on width direction into 0.029 of one.

Table 2 Characteristics of Vibration

	Direction	Before	After
Effective bearing wall ratio (Ld/ Ln)	Width	0.370	1.580
	Length	1.012	3.960
Natural Frequency (Hz)	Width	3.223	4.688
	Length	3.223	4.980
	Torque	5.468	10.156
Damping Ratio	Width	0.046	0.029
	Length	0.037	0.024
	Torque	0.023	0.013

Before

After

Photo. 6 Before and After Seismic Retrofitting A-House

4.2 S-HOUSE

This two-storied house, which is shown in photograph 7, is a typical traditional house in Japan. It implemented to increase a effective bearing wall ratio. This seismic retroffiting changes 3.0 Hz of the natural frequency on width direction into 3.2 Hz of one. This seismic retroffiting changes 0.036 of the damping ratio on width direction into 0.043 of one.

Table 3 Characteristics of Vibration

	Direction	Before	After
Effective bearing wall ratio (Ld/ Ln)	Width	0.190	0.280
	Length	0.380	0.280
Natural Frequency (Hz)	Width	3.027	3.222
	Length	4.003	4.100
	Torque	7.617	14.063
Damping Ratio	Width	0.036	0.043
	Length	0.028	0.036
	Torque	0.023	0.030

Outside of Entrance, Before

Inside of Entrance, Before

Inside of Entrance, After

Outside of Entrance, After

Overview of Outside on the South Side, After

Photo. 7 Before and After Seismic Retrofitting S-House

6. CONCLUSIONS

In this report, it implemented the way of increasing wall quantity and the way of decreasing weight in a seismic retroffiting. The rise of the natural frequency could be confirmed after seismic retrofitting in the both way. Because the client could be shown value after seismic retrofitting by the microtremor measurement, it was possible to have consented to a client in any case. We were able to propose effective seismic retrofit based on microtremor measurement of timber structure.

ACKOWLEDGEMENTS

We appreciate the client who has been provided the microtremor measurement, the seismic diagnosis and the seismic retroffiting.

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