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ESTIMATION OF IN-PLANE STIFFNESS OF HORIZONTAL STRUCTURE OF WOODEN BUILDING BASED ON MICROTREMOR MEASUREMENT

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ABSTRACT: The authors have conducted research on seismic performance evaluation of existing wooden buildings. In this study, the appropriate in-plane stiffness of wall and floor magnification was estimated from the results of micro tremor measurements.

The estimation was performed by finite element analysis using the in-plane stiffness of the vertical surface and the in-plane stiffness of the horizontal surface as parameters.

As a result of the research, it was confirmed that the fluctuation of the in-plane stiffness of the vertical surface has little influence on the natural vibration mode. In addition, the influence of the in-plane stiffness variation of the horizontal surface on the natural vibration mode was confirmed. The in-plane stiffness fluctuation of the horizontal surface affected the timing of the translation mode.

KEYWORDS: Wooden architecture, Microtremor measurement, Seismic performance

1 INTRODUCTION

In order to conduct seismic diagnosis and seismic reinforcement design of existing wooden buildings, it is necessary to evaluate seismic performance. One of the evaluation methods is a numerical analysis simulation by a finite element method. The element characteristics used for the numerical analysis simulation are determined based on actual measurement of member dimensions by field survey and visual degradation investigation. At that time, in order to make a more accurate evaluation, a micro-destructive test with minor damage may be performed in the investigation of the situation inside the wall. Non-destructive testing includes microtremor measurement, previous study that presumed vibrational characteristic from microtremor measurement date was reported so far,and from the measurement date, we can evaluate the number of vibrational characteristic, but cannot evaluate direct seismic performance.

Therefore, this study proposes a method for estimating the appropriate strength and floor magnification of a wall from the results of microtremor measurements on an existing wooden building (one-story un-anchor traditional building).

A parametric study using the in-plane stiffness of the vertical and horizontal planes of the analysis model as a parameter is performed, and is estimated from the results of continuous microtremor measurements and the matching evaluation values.

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2 TARGET BUILDING

2.1 OUTLINE OF THE BUILDING

The “shumaku” displayed in the ethnographic museum is a 1999 reproduction of a facility that was built around 1920 by a Korean Peninsula traveler to eat and sleep. During the xhibition, the original roof was changed from thatching to copper plate. The planar shape is L-shaped, and the floor plan is composed of accommodation rooms such as Japanese “Hatagoya” and “Uchiniwa” (cooking area).

Figure 1: *Appearance of the target building*

2.2 OUTLINE OF STRUCTURE

The frame by the wooden framework construction method is constructed with 150mm × 150mm columns, 150mm × 200mm beams, 90mm × 150mm rails, and walls are plywood Shinkabe(japanese traditional column-exposed wall). The wooden frame members are all made of pine, and the column base is Ishiba-date(Japanese traditional unanchored building), and the roof truss is copper roofing Japanese roof truss. Table.1 shows the building weight.

Table.1 *Building weight.*

Floor	height H (m)	weight W(kN)	area A(m^2)	W/A (kN/m^2)
1	3.270	114.61	61.76	1.85

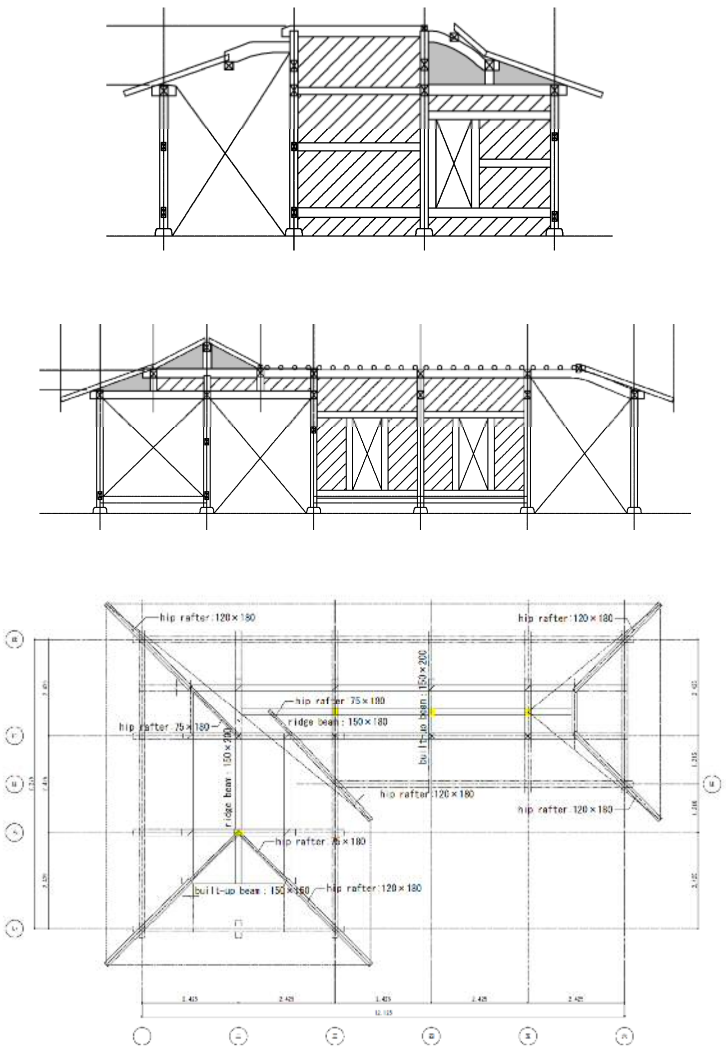


Figure 2:*roof truss flame plan, framing elevation*

3 MICROTREMOR MEASUREMENT

3.1 OUTLINE OF THE MEASUREMENT

The natural frequency and vibration mode shape are estimated by measurement. Fig.3 shows the measurement position. The measurement was performed at the stigma and ground level using a 3-axis accelerometer (RS-ONE).
Data for 180 seconds was sampled at a sampling frequency of 100 Hz.

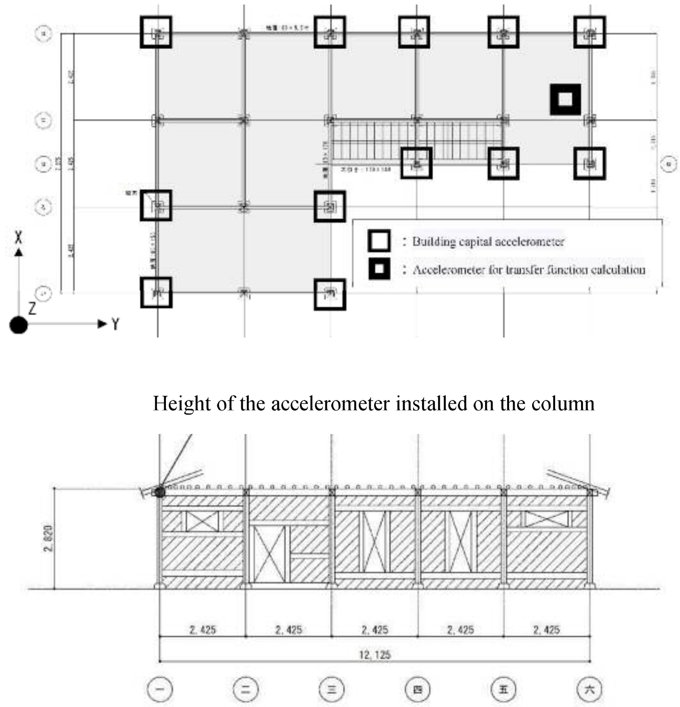


Figure 3:*measurement position*

3.2 MEASUREMENT RESULT

The target building has natural vibration mode of X component near 7.4-7.5Hz and 7.7-7.8Hz, and natural vibration mode in Y direction near 7.1-7.3Hz. Fig.4 and Fig.5 show the analysis results.

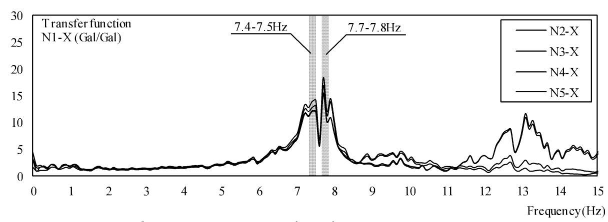


Figure 4:*X direction transfer function*

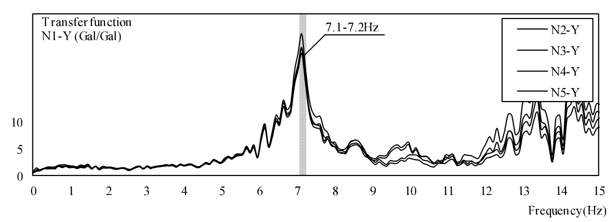
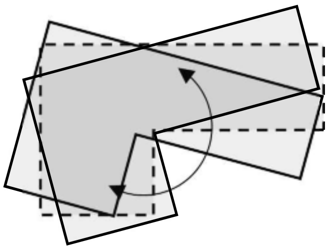


Figure 5:*Y direction transfer function*

The X component of 7.4-7.5Hz is estimated to be a natural vibration mode due to the torsion of the entire building because superiority has been confirmed near the natural frequency in the Y direction. The 7.7-7.8Hz X component is a natural vibration mode that vibrates mainly in the X direction near the 6-axis and is estimated to be caused by the amount of 6-axis (gable plane) and other road walls. The reason for these natural vibration modes is that the shape of the building is L-shaped.



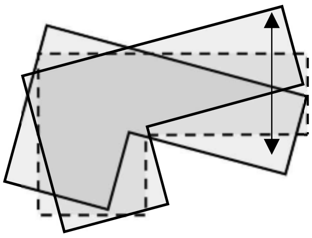


Figure 6:*Mode 7.4-7.5Hz* ***Figure 7:****Mode 7.7-7.8Hz objectives, the tools, and the conclusions.*

About the behavior of each room,translational components toward horizontal direction occurs in 7.1-7.9Hz. But natural vibration mode such as each frame act on independently[2],[3] not occurs. It is possible that horizontal diaphragm stiffness and vertical plane of structure rigidity are well balanced. In this study, we analyse and confirm whether if the same mode excel.

4 ESTIMATION OF IN-PLANE STIFFNESS OF HORIZONTAL

4.1 EXAMINATION OF APPARENT HORIZONTAL STIFFNESS

From the building weight and the eigenfrequency thought by microtremor measurement, we supposed that whole building is equivalence one mass system, we culculated the apparent horizontal stiffness.Tabble 2 shows the result.

Direction	Building weight (kN)	Eigenfrequency (HZ)	Horizontal stiffness (kN/mm)
X	114.61	7.6	26.13
Y	114.61	7.2	23.45

Table.2 *: apparent horizontal stiffness, eigenfrequency, building weight*

We supposed the effect by the variation of horizontal plane of structure (roof truss) and vertical plane of structure (columns, walls) that is considerd to contribute to horizontal stiffness of the building. And we proposed to look at by the parameter study as discussed below.

4.2 OUTLINE OF ANALYSIS MODEL

The analysis model expressed the horizontal stiffness of the pole plate level as the roof truss contribute to it. We conveniently considered the modulus of elasticity of board element to parameter from floor magnification. Thererore, we did parameter study targeted at the horizontal plane of structure as the roof truss contribute, and verified the floor magnification in accord with the actual measurement value. Then, by the floor magnification in accord with the actual measurement value, we replaced the wall of the analysis model with wire braces.A parameter study was conducted for the in-plane rigidity of the horizontal structure contributed by the cabin by setting the wall magnification to 0.2 to 2.5 times (increment by 0.5 times) to 5.0 times and 7.0 times. 0.2 to 2.5 times is the extent presumed that the effect is clearly. Figure 8 shows the analysis model.

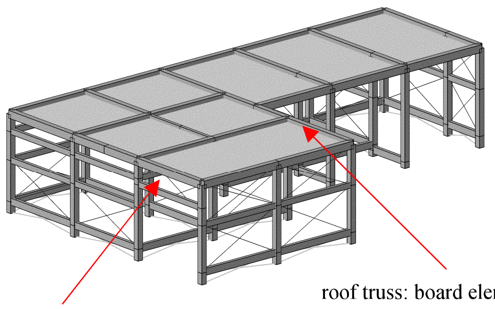
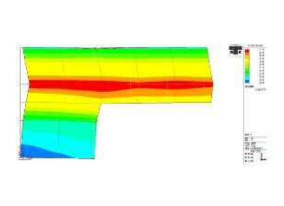
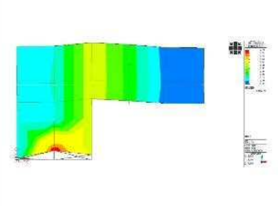
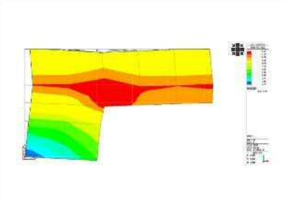
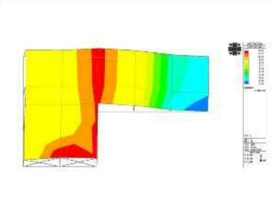
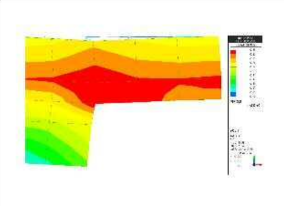
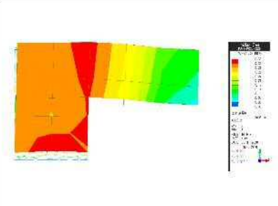
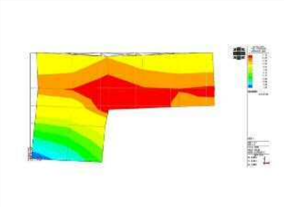
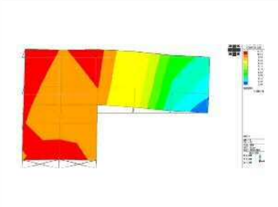
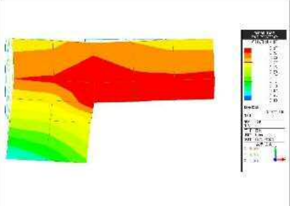
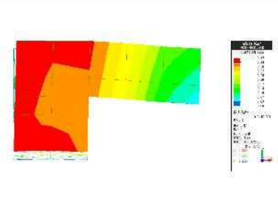
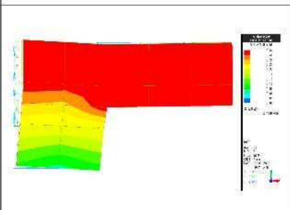
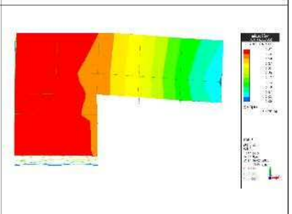
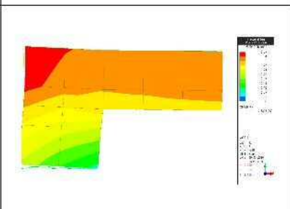
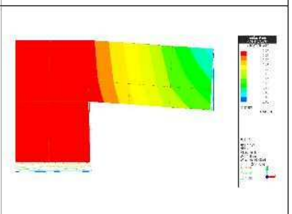
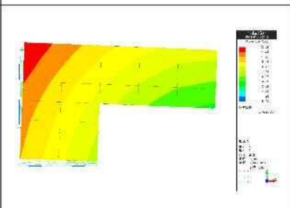
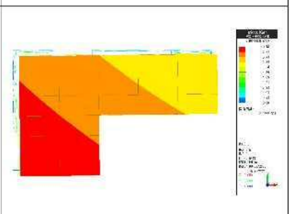


Figure.8 *: analysis model*

4.3 EIGENVALUE ANALYSIS

By varying the in-plane stiffness of the vertical and horizontal structure of the analysis model as parameters, repeated eigenvalue analysis yielded values that matched the measured values.Table 3 shows the eigenvalue analysis results with varying floor magnification.

Table.3 :Eigenvalue analysis results

α*	Mode. 1	Mode. 2
0. 2		
1. 0		
1. 5		
2. 0		
2. 5		
5. 0		
7. 0		
Rigid		

※α ：Floor magnification（α=1.0：1.96kN/m）

We confirmed that floor magnification in accord with the actual measurement value has twist component at 2.0, after that it be same mode. Figure 9 shows the natural vibration mode of the actual measurement value.

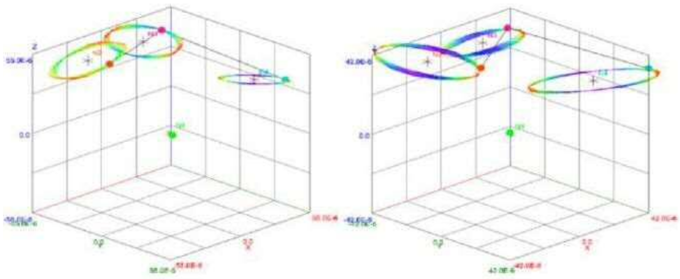


Figure.9:*natural vibration mode of actual measurement value*

Table 4 shows the in-plane stiffness that we varied the parameter of the roof truss floor magnification and calculated by static elastic analysis .

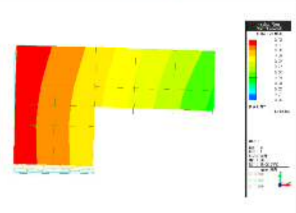
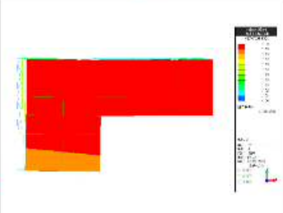
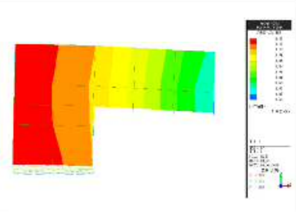
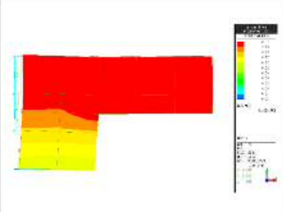
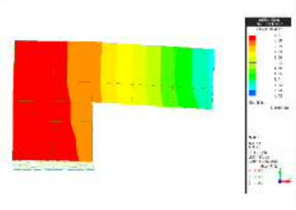
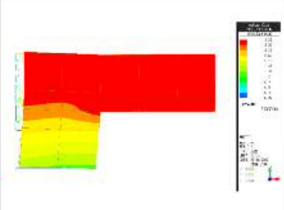
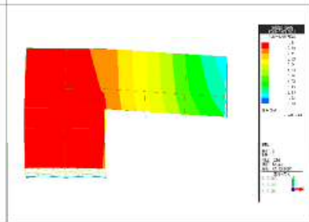
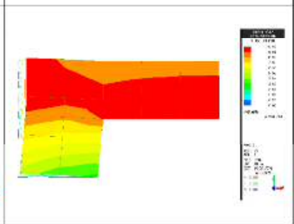
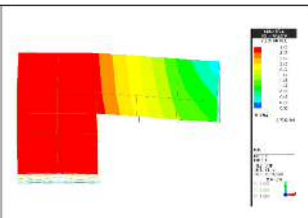
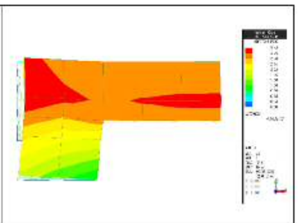
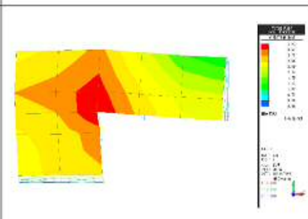
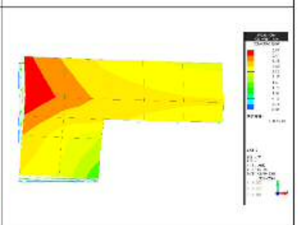
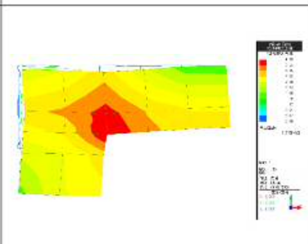
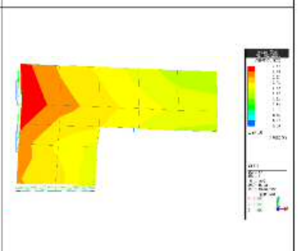
Table.4 *:Horizontal stiffness by variation of floor magnification*

α*	1st mode	2nd mode	Horizontal stiffness (kN/mm)	
			X direction	Y direction
0.2	1.872	2.362	1.58	2.52
1.0	2.368	2.728	2.53	3.36
1.5	2.468	2.777	2.75	3.48
2.0	2.535	2.804	2.91	3.55
2.5	2.585	2.821	3.02	3.60
5.0	2.735	2.838	3.38	3.64
7.0	2.791	2.903	3.52	3.81
Rigid	2.863	3.371	3.71	5.14

※α ：Floor magnification（α=1.0：1.96kN/m）

As compared with the actual measurement value, natural frequency and the shape of vibration mode were varied by the variation of floor magnification. But the horizontal stiffness sliped from the actual measurement value,roughly to be consistent. Then, we supposed that the in-plane stiffness of wall is floor magnification,varied as parameter, analyzed the eigenvalue analysis. Table 5 shows the result of the eigenvalue analysis.

Table.5 *:Eigenvalue analysis results*

β*	Mode. 1	Mode. 2
0.2		
1.0		
1.5		
2.0		
2.5		
5.0		
7.0		

※β ：Wall magnification（β=1.0：1.96kN/m）

Table 6 shows the horizontal stiffness calculated by static elastic analysis and eigenvalue analysis as variation of wall magnification parameter.

Table.6 *: Horizontal stiffness by the variation of wall magnification*

β*	1st mode	2nd mode	Horizontal stiffness (kN/mm)	
			X direction	Y direction
0.2	0.677	0.724	0.207	0.237
1.0	1.416	1.520	0.907	1.045
1.5	1.705	1.814	1.315	1.488
2.0	1.908	2.027	1.647	1.859
2.5	2.096	2.219	1.987	2.227
5.0	2.276	2.873	3.362	3.734
7.0	3.053	3.238	4.217	4.743

※β ：Wall magnification（β=1.0：1.96kN/m）

5 CONCLUSIONS

As a result of this study, the apparent horizontal stiffness that found from natural frequency provided by the microtremor measurement, it was around 4.5times as larger as the equivalent rigidity when we consider the horizontal plane of structure as rigid floor.This result and the result [4]as equivalent rigidity that found from microtremor measurement was 2~4times as larger as cumulative rigidity of wall quantity calculation roughly agree.Herewith, we confirm about validity of the eigen frequency evaluated by microtremor measurement in this study as well as the solution of numerical analysis .

Thus, foe the reason of that microtremor measurement is the measurement in infinitesimal deformation range, it is difficult that we measure equivalent rigidity, we showed that presuming of the floor magnification of horizontal plane of structure of the existing wooden building with numerical analysis.And, by the numerical analysis model of the floor magnification (in this case 2.0 times),we did parametric study as we varied the wall magnification by eigenvalue analysis. As a result, in case of that wall magnification is low magnification (2.5 times and under) ,we could confirm the natural vibration like a rigid floor. But in case of that wall magnification is high magnification (5.0 times and upper) , we could confirm the natural vibration like a flexible floor. This result shows that is caused by balance of the rigidity of horizontal plane of structure and vertical plane of structure if we can measure the structural performance evaluation in wall quantity calculation. In most cases, the rigidity of existing wooden building is uncertainty, therefore, it is necessary that we did the structural performance evaluation by the spatial analysis. At that time, we can gain a great deal of informations by microtremor measurements, they should be together.

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