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STUDY OF THE EFECT OF SEISMIC REINFORCEMENT USING CFRTP STRANDS ON WOODEN BUILDINGS

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ABSTRACT: In this study, we conduct seismic reinforcement work using CFRTP (Carbon Fiber Reinforced Thermo-Plastics) strands on an actual wooden building, conduct microtremor measurement before and after the work, and grasp the change in natural vibration characteristics. Additionally, the numerical analysis before and after the work confirm that to what extent yield strength is raised by the seismic reinforcement. These results reveal that the effectiveness of the seismic reinforcement using CFRTP strands on wooden buildings is not a bad influence on the period of the actual building.

KEYWORDS: Wooden architecture, Microtremor measurement, Seismic performance

1. INTRODUCTION

We can raise yield strength by seismic reinforcement members as a result of conducting seismic reinforcement on wooden buildings. Moreover, we can raise stiffness. The rising of stiffness changes the natural period. In consequence, there is a possibility that the building resonates with seismic motion of the periodic band which used to not resonate before seismic reinforcement. Accordingly, in seismic reinforcement design, we need to grasp the possible spectral shape in the area as a result of surveys of the fault around the site and historical earthquake. On the other hand, if there are seismic reinforcement members raise yield strength and not change stiffness, we can keep resonance with the periodic band unchanged before and after the seismic reinforcement. However, conventional seismic reinforcement members of wooden buildings, for example, plywood, reinforcing bar brace, and diagonal brace, raise not only yield strength but also stiffness. Therefore, we developed a seismic reinforcement method for wooden buildings using CFRTP strands that having high yield strength, and moreover, low stiffness at large deformation. Carbon fiber composite materials are advanced materials used in a wide range of fields of engineering, and are also gathering attention in the field of construction [1]. In the previous study, the authors developed an end fixing structure for CFRTP strands having toughness [2][3][4]. We showed that CFRTP stands have high yield strength at large deformation, moreover, have low stiffness as a result of conducting an in-plane shear test on wooden frame reinforcement walls using CFRTP strands [5]. In this study, we conduct seismic reinforcement work using CFRTP strands on an actual wooden building, conduct microtremor measurement before and after the work, and grasp the change in the natural vibration characteristic. Additionally, the numerical analysis before and after the work confirm that to what extent yield strength is raised by the seismic reinforcement. The purpose of this study is that these results reveal the effectiveness of the seismic reinforcement using CFRTP strands on wooden buildings.

2. TARGET BUILDING

2.1 OUTLINE OF THE BUILDINGS

The “shumaku” displayed in Natural Museum of Ethnology since 1999 is a reproduction of a facility that was built around 1920 for Korean Peninsula travelers to eat and sleep. In order to exhibit, 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).

Photo 1: *Appearance of the target building (Before reinforcement)*

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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 bases are Ishibadate:Japanese traditional construction method, columns set up on stones instead of anchoring to the ground. The roof truss is copper roofing using Japanese roof truss. Table 1 shows the building weight. Figure 1 shows roof truss frame and framing elevation.

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

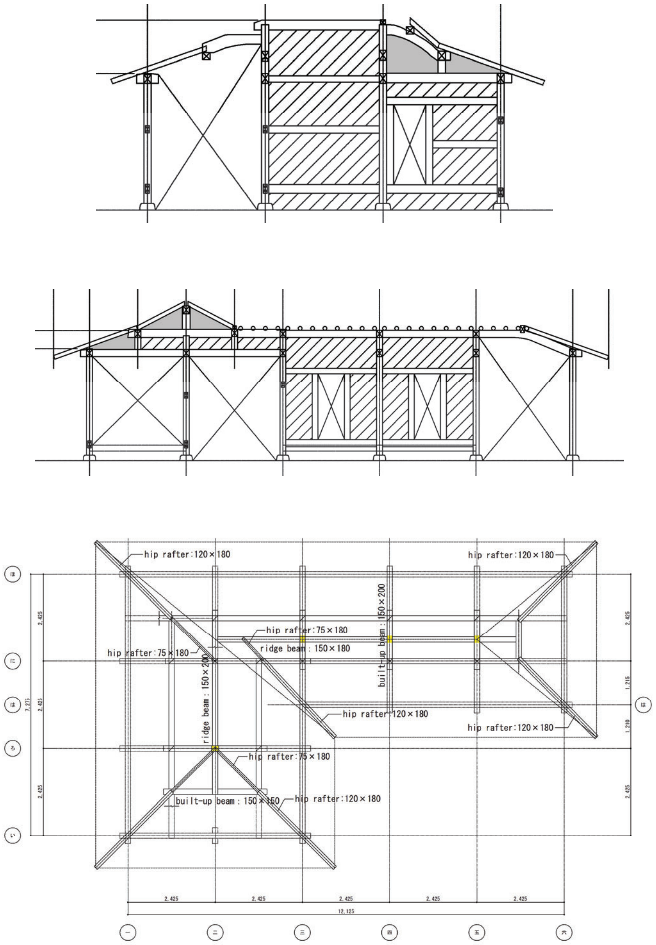


Figure 1: *roof truss flame plan, framing elevation*

2.3 OUTLINE OF REINFORCEMENT

We needed to conduct a reinforcement to maintain the exterior and the interior of the building. Therefore, we selected reinforcement members installed on the current wall. We adopted CFRTP strands made of carbon fiber composites as seismic reinforcement members and conduct seismic reinforcement. CfRTP strands were arranged in well balanced manner on the structure of each frame (top and bottom of girts), and the entire building was considered so that there was no behavior of twisting. The seismic reinforcement work was completed at the end of March 2022.

Photo 2: *Appearance of the target building (After reinforcement)*

Photo 3: *Appearance of the target building (After reinforcement)*

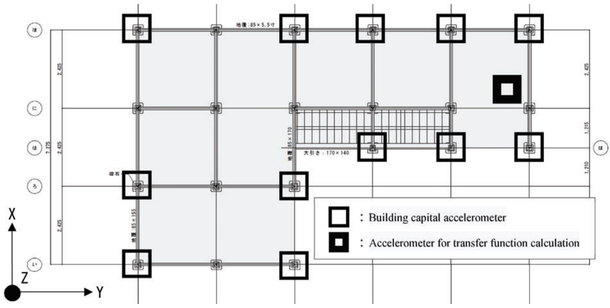
Photo 4: *Control of tightening torque*

Photo 5: *Control of tightening torque*

3. MICROTREMOR MEASUREMENT

3.1 OUTLINE OF THE MEASUREMENT

The eigenfrequency and vibration mode shape are estimated by measurement. Figure 2 shows the measurement position. The measurement was performed at the capital and ground level using a 3-axis accelerometer:RS-ONE.
Data for 180 seconds was sampled at a sampling frequency of 100 Hz.



Height of the accelerometer installed on the column

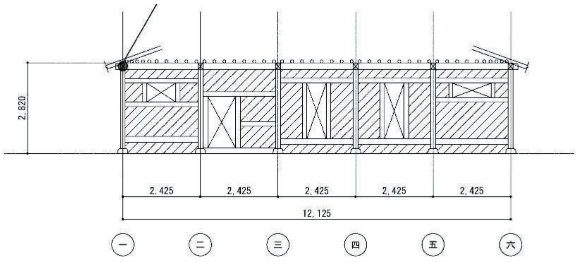


Figure 2: *measurement position*

3.2 MEASUREMENT RESULT

Figure 3, 4 (Before reinforcement) and Figure 5, 6 (After reinforcement) show analysis results.

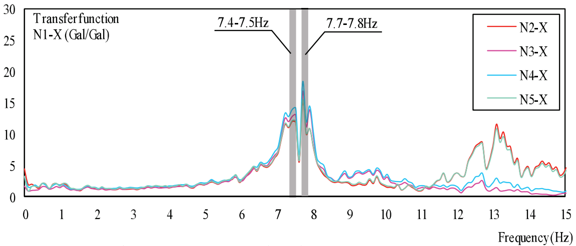


Figure 3: *X direction Transfer function*

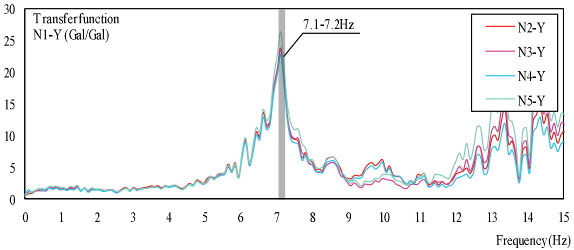


Figure 4: *Y direction Transfer function*

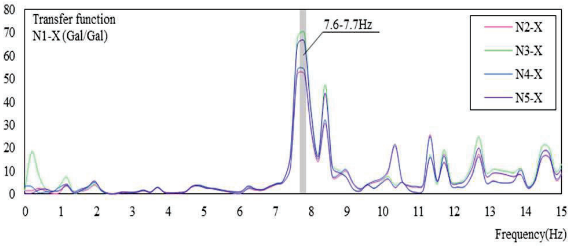


Figure 5: *X direction Transfer function*

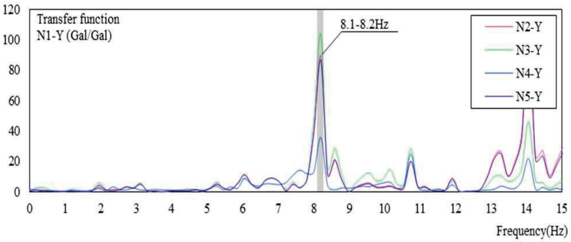


Figure 6: *Y direction Transfer function*

Before reinforcement, it had a natural vibration mode of X component around 7.4 - 7.5 Hz and Y component around 7.1 – 7.3 Hz. After reinforcement, it had a natural vibration mode of X component around 7.6 - 7.7 Hz and Y component around 8.1 – 8.2 Hz. There is almost no change in the periodic band before and after reinforcement.

4. ESTIMATION OF STIFFNESS AND YIELD STRENGTH

We calculated stiffness and ultimate horizontal yield strength before and after seismic reinforcement by numerical analysis, and compared the change of stiffness before and after seismic reinforcement.

4.1 OUTLINE OF THE ANALYSIS MODEL

This analysis model express horizontal diaphragm stiffness in pole plate level contributed by roof truss. We replaced seismic reinforcement members arranged on the wall with wire braces. Figure 7 shows analysis model.

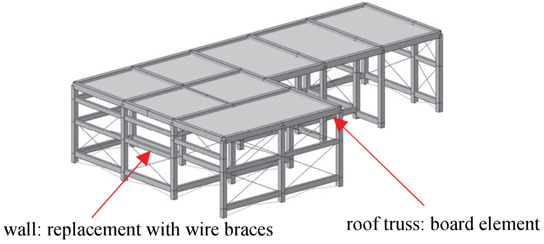


Figure 7: *analysis model*

4.2 EIGENVALUE ANALYSIS

We conducted eigenvalue analysis before and after seismic reinforcement. Table 2 is comparative table of analysis result and microtremor measurement result. Figure 8 and 9 show primary mode.

Table 2: *Eigenfrequency (Hz)*

	Microtremor measurement		Analysis result	
	X direction	Y direction	X direction	Y direction
Before reinforce -ment	7.40	7.10	0.001	0.005
After reinforce -ment	7.60	8.10	2.535	2.805

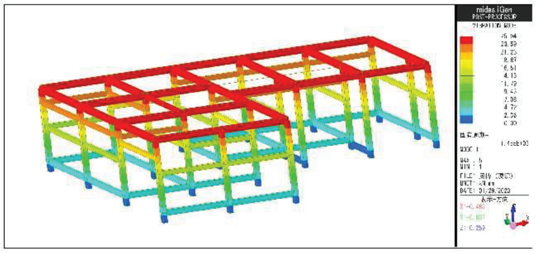


Figure 8: *Primary mode chart (Y direction before reinforcement)*

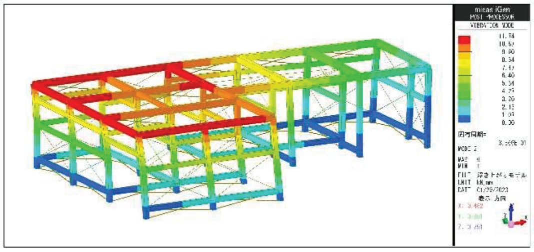


Figure 9: *Primary mode chart (Y direction after reinforcement)*

4.3 STATIC ELASTIC ANALYSIS

We conducted static elastic analysis before and after seismic reinforcement, and compared horizontal stiffness and ultimate horizontal yield strength. We adopted ultimate horizontal yield strength in 1/15 rad. Figure 10 and 11 show load-deformation relationship. Table 3 shows ultimate horizontal yield strength.

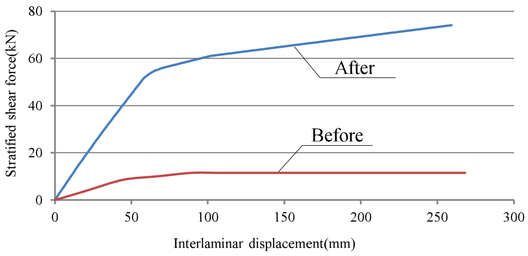


Figure 10: *X direction Load-deformation relationship*

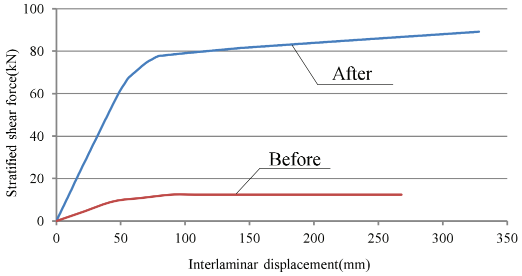


Figure 11: *Y direction Load-deformation relationship*

Table 3: *ultimate horizontal yield strength*

	Horizontal Stiffness (kN/mm)		Ultimate horizontal yield strength (kN)	
	X direction	Y direction	X direction	Y direction
Before reinforce -ment	0.083	0.090	11.5	12.50
After reinforce -ment	1.010	1.236	70.42	78.87

According to analysis results, we can see that stiffness and ultimate horizontal yield strength increased greatly from before reinforcement. By contrast, according to results of microtremor measurement, we can see that eigenfrequency is about the same. Therefore, we suggest that initial stiffness is almost unchanged.

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5. EFFECT ON THE BUILDING BY CHANGE OF STIFFNESS

There's a wide variety of seismic reinforcement from high-stiffness members to low-stiffness members. We need to grasp the period of the building, to attenuate the effect on the building by the change of stiffness.

5.1 SEISMIC REINFORCEMENT WITH DIFFERENT STIFFNESS REINFORCEMENT MEMBERS

In the case of seismic reinforcement using high-stiffness members, the natural period fluctuates due to increasing stiffness. In consequence, there is a possibility that the building resonates with seismic motion of the periodic band which used to not resonate before seismic reinforcement.

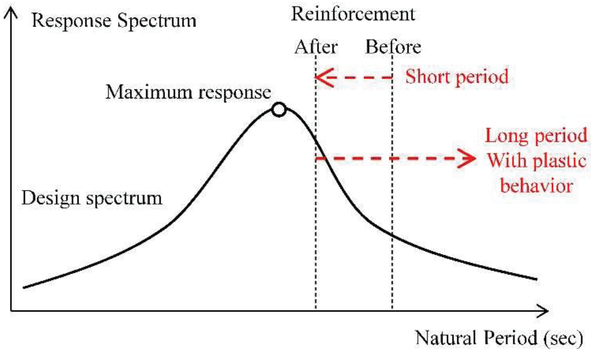

Figure 12: *Seismic reinforcement using high-stiffness members (Steel material brace, plywood, diagonal brace etc.)*

By contrast, seismic reinforcement using low-stiffness members raise yield strength without change of stiffness. In consequence, we can keep the same periodic band which the building resonates before and after seismic reinforcement.

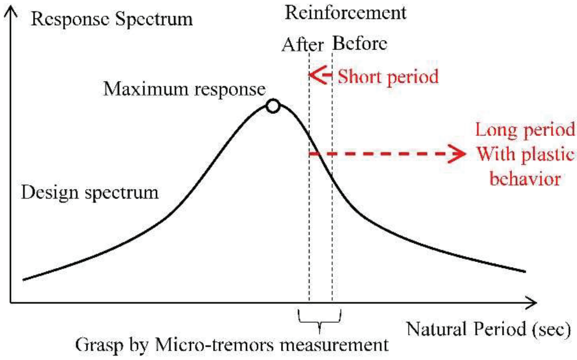

Figure 13: *Seismic reinforcement using low-stiffness members (CFRTP strand proposed by this study)*

5.2 COMPARATION WITH HIGH STIFFNESS MEMBERS

We compared by analysis seismic reinforcement with high-stiffness against low-stiffness members, and considered the change of eigenfrequency after reinforcement. We employed high-stiffness wire braces as high-stiffness members, and CFRTP strands as low-stiffness members. We calculated eigenfrequency and horizontal stiffness in 1/120 rad. Figure 14 and 15 show load-deformation relationship. Table 4 is comparative table of eigenfrequency and stiffness.

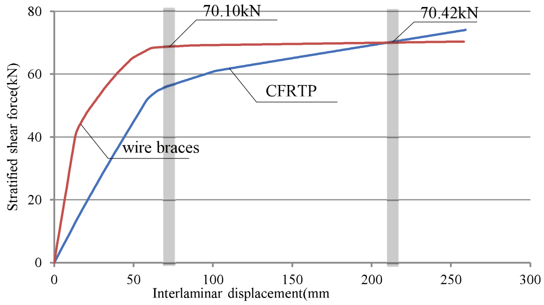

Figure 14: *X direction Load-deformation relationship*

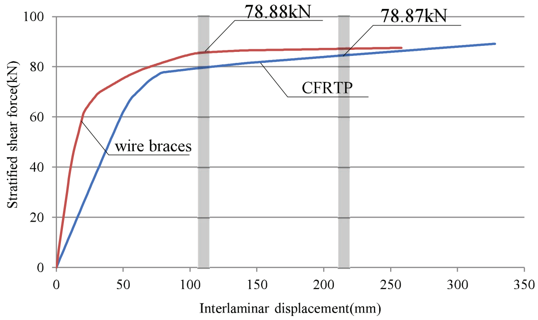

Figure 15: *X direction Load – deformation relationship*

Table 4: *Comparative table of eigenfrequency*

Reinforceme-nt members	CFRTP strand		Wire brace	
Direction	X direction	Y direction	X direction	Y direction
Horizontal stiffness	0.945	1.236	1.963	2.403
Eigenfreque-ncy	2.535	2.805	2.776	3.112

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Figure 16 shows mode chart after seismic reinforcement with high-stiffness members.

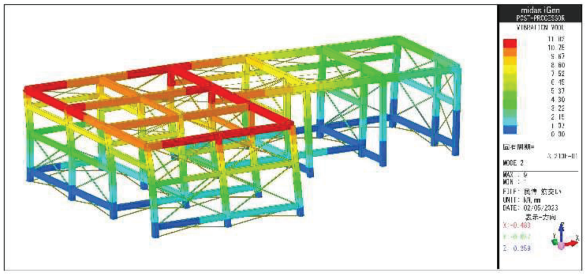

Figure 16: Primary mode chart (Y direction after reinforcement)

Analysis results demonstrated that eigenfrequency of high-stiffness members is up 1.10 times in X direction, and 1.11 times in Y direction than low-stiffness members. We confirmed that horizontal stiffness of high-stiffness members is up around 2 times in both direction than low-stiffness members.

6. CONCLUSIONS

We confirmed that horizontal stiffness calculated by actual measurement value of microtremor measurement is almost unchanged before and after reinforcement. Numerical analysis demonstrated that yield strength after reinforcement is up than before reinforcement. We employed high-stiffness wire braces and low-stiffness CFRTP strands as seismic reinforcement members, and confirmed differences in stiffness between the two by numerical analysis. According to the result, we confirmed that eigenfrequency of using wire braces is higher than using CFRTP strands in the case that each ultimate horizontal yield strength is almost the same. We presume that CFRTP strands employed as seismic reinforcement members in this study are high-yield strength and low-stiffness members. The building reinforced with these seismic reinforcement members function as fail safe in large deformation. Moreover, we confirmed that seismic reinforcement with CFRTP strands have no negative effect on periodic characteristic of the existing building.

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