Integrated Solutions for Infrastructure Development
Edited by Lau, H. H., Tang, F. E., Ng, C. K., and Singh, A.

ISBN: 978-0-9960437-3-1

STUDY ON RETROFIT EFFECTS FOR HORIZONTAL PLANE OF TRADITIONAL WOODEN HOUSES BASED ON FULL-SCALE TEST

MITSUHIRO MIYAMOTO and HARUKA OKUHIRO

Dept of Safety Systems Construction Eng., Kagawa University, Takamatsu, Japan

In the present study, few studies have focused on the horizontal plane of traditional wooden houses in Japan. This study aims to examine the retrofit effects for the horizontal plane of traditional wooden houses based on full-scale tests. The first part of this paper is devoted to the experimental study performed to determine the structural behavior and characteristics of full-scale roof specimens. A horizontal shear test was conducted to obtain the fracture mode and relationship between the applied load and deformation angle. The second part deals with a static pushover analysis of the full-scale roof specimens. The results between the experimental test and the static pushover analysis are presented and discussed. The analysis model used for the static pushover analysis is proposed; the results were in good agreement with the tests.

Keywords: Roof plane, Structural plywood, Structural characteristics, Static pushover analysis.

1 INTRODUCTION

Many large earthquakes have occurred in Japan since the Southern Hyōgo Prefecture earthquake in 1995. Therefore, ensuring the seismic resilience of traditional wooden houses has become very important for their preservation. A great number of studies in Japan focused on the vertical plane of traditional wooden houses (e.g., seismic walls and connections); however, only a few have focused on the horizontal plane of the houses (e.g., floor and roof plane).

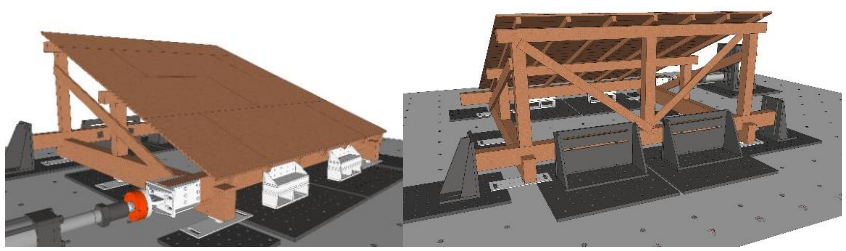
This paper aims to examine the retrofit effects for the horizontal plane of traditional wooden houses based on full-scale tests. The first part of this paper is devoted to the experimental study conducted to determine the structural behavior and characteristics of full-scale roof specimens. The test parameter is chosen to examine the retrofit effects for the roof plane. A horizontal shear test was performed to obtain the fracture mode and relationship between the applied load and deformation angle. The second part deals with a static pushover analysis of the full-scale roof specimens. The results between the experimental test and the static pushover analysis are presented and discussed in this paper.

2 FULL-SCALE TESTS

In the study, full-scale horizontal shear tests of roof specimens were conducted to examine the retrofit effects for the roof plane. The relationships between the lateral load and the deformation angle as well as the collapse mechanism were clarified. The test parameters were chosen to help examine the retrofit effect on the seismic performance of a roof plane. One specimen was used for each parameter.

2.1 Specimen Outline

A total of four specimens were used for the full-scale horizontal shear tests (Figure 1 and Table 1). The specimen lengths of the longitudinal and transverse directions were 2730 mm and 2730 mm, respectively. The beam dimensions to the longitudinal and transverse directions, vertical roof strut and purlin, brace for out-of-plane, rafter, roof board, structural plywood, and brace were 120 mm × 240 mm, 120 mm × 180 mm, 120 mm × 120 mm, 120 mm × 30 mm, 45 mm × 60 mm, 150 mm × 15 mm, 910 mm × 9 mm, and 13 mm × 104 mm, respectively. All wooden members were made of cedar from Kochi Prefecture, Japan. The specimen roof pitch was four. The beam was connected to each other with a cogged joint and a steel bolt. The vertical roof strut was connected to the beam or purlin using only a short tenon with height, width, and thickness of 50 mm, 90 mm, and 30 mm, respectively. The short tenon on specimen RA-4 was reinforced with steel plate to avoid the pull-out fracture of the connection. The other connections were connected with screws.



(a) Front side (b) Back side

Figure 1. Specimen RA-4.

Figure 2. Photograph of the loading instrument.

Figure 3. Photograph of the bearing.

Table 1. Specimen specification.

Specimen	Rafter	Roof board	Structural plywood	Brace
RA-1	○			
RA-2	○	○		
RA-3	○	○	○	
RA-4	○	○	○	○

2.2 Test Method

Figure 2 shows a photograph of the loading instrument. One side of the specimen beam was fixed with anchor bolts. The other side was subjected to lateral loads through a servo actuator with six bearings under the specimen beam (Figure 3). The specimen was subjected to cyclic lateral loads, with the real shear deformation angle γ_0 gradually increased symmetrically from 1/600, 1/450, 1/300, 1/200, 1/150, 1/100, 1/75, 1/50, and 1/30 to 1/15 rad. One cyclic loading was applied. The specimen was finally deformed to 1/10 rad at one end. The plus and minus directions are defined in this experiment (Figure 2). The lateral loads applied to the specimen were measured using a load cell attached to the edge of the servo actuator.

2.3 Results and Discussion

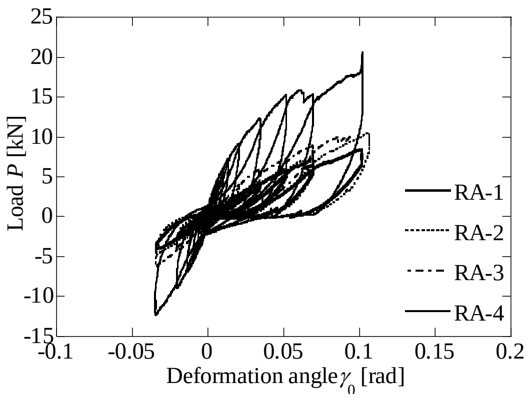


Figure 4. Relationship between the load and the deformation angle.

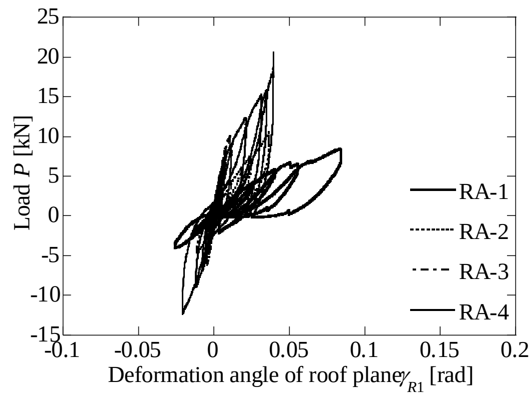


Figure 5. Relationship between the load and the deformation angle of the roof plane.

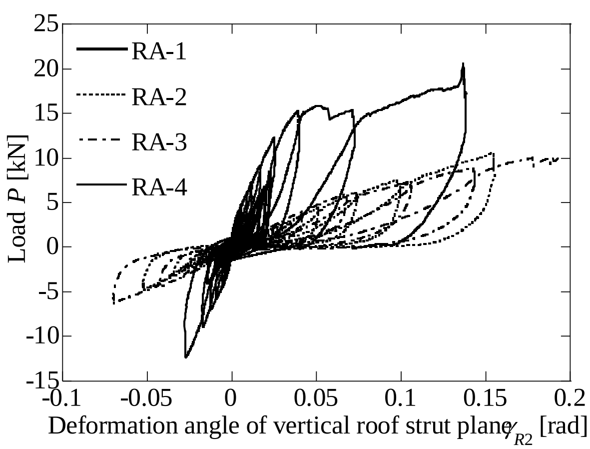


Figure 6. Relationship between the load and the deformation angle of the vertical roof strut plane.

Figure 7. Buckling of brace (RA-4).

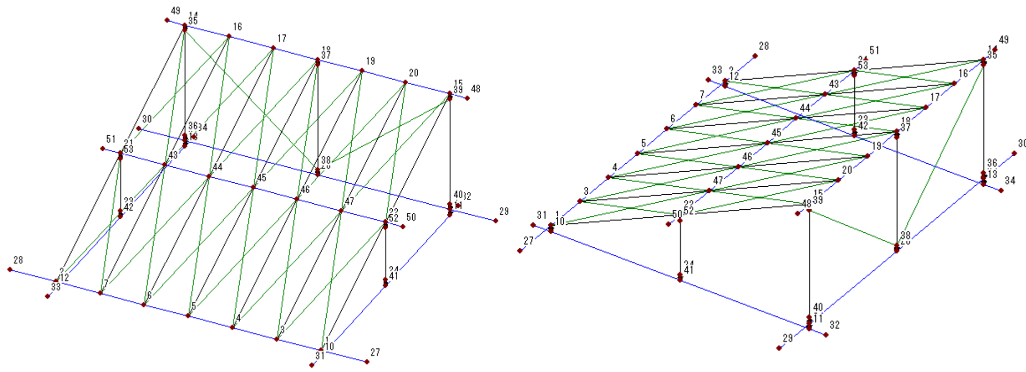
Figure 4 shows the relationship between the load and the deformation angle. Figure 5 illustrates the relationship between the load and the deformation angle of the roof plane. Figure 6 presents the relationship between the load and the deformation angle of the vertical roof strut plane of each specimen. Figure 7 shows the fracture mode of the RA-4 specimen. The loads on specimens RA-1–3 in both directions are almost similar; hence, the retrofit effect of the structural plywood without brace on the vertical roof strut plane is very small. However, a large difference is found between the deformation angles of the other planes. The deformation angle of the roof plane on specimen RA-1 is larger than that of the vertical roof strut plane. Meanwhile, the deformation angle of the roof plane on specimens RA-2 and 3 is smaller than that of the vertical roof strut plane because of the retrofit effect of the structural plywood. The maximum load on specimen RA-4 is approximately twice as large as that on the other specimens because of the retrofit effect of brace on the vertical roof strut plane in addition to the structural plywood on the roof plane. The load on specimen RA-4 becomes almost constant after 1/20 rad because of the buckling of the brace (Figure 7). The initial stiffness on all specimen during the second cycle is much smaller than during the first cycle because of the embedment deformation at each connection.

3 SIMULATION ANALYSIS

The simulation analysis was executed using a 3D model to estimate the relationship between the load and the deformation angle of each specimen.

3.1 Analysis Model Outline

Figure 8 shows the analysis model used for the static pushover analysis. The cogged joint and the connection of the short tenon were expressed as a rotation spring. The rood board and structural plywood were expressed as a brace. The connections between the beam and the rafter and the rafter and the purlin were assumed to be pin joints. The hysteresis model of each rotation spring and roof board brace is a bi-linear model. The initial stiffness and yield moment were calculated from the previous study (Architectural Institute of Japan, 2006, Isoda et al., 2007, Architectural Institute of Japan, 2009, Takino et al., 2014). The mechanical property of cedar was estimated from the results of non-destructive tests for each wooden member. The hysteresis model of the structural plywood brace was a tri-linear model (Japan Housing and Wood Technology Center, 2008). The unit multiplier of the structural plywood was assumed to be 2.5.



(a) Front side (b) Back side

Figure 8. Analysis model of specimen RA-4

3.2 Comparison of Test and Analysis Results

The static pushover analysis was performed using a general purpose analysis software, SNAP (Ver. 6). Figure 9 shows the comparison of the relationship between the load and the deformation angle of each specimen as obtained from the test and analysis results. The analysis results were in good agreement with the tests for each specimen. The initial stiffness on specimens RA-1 and 2 obtained by the analysis was larger than that obtained by the tests because of the gap at the connections or between wooden boards, such as the roof board and the structural plywood. The load on specimens RA-4 after 1/50 rad obtained from the analysis was larger than that from the tests because the brace edge was expressed as a pin joint without considering the brace’s embedment deformation.

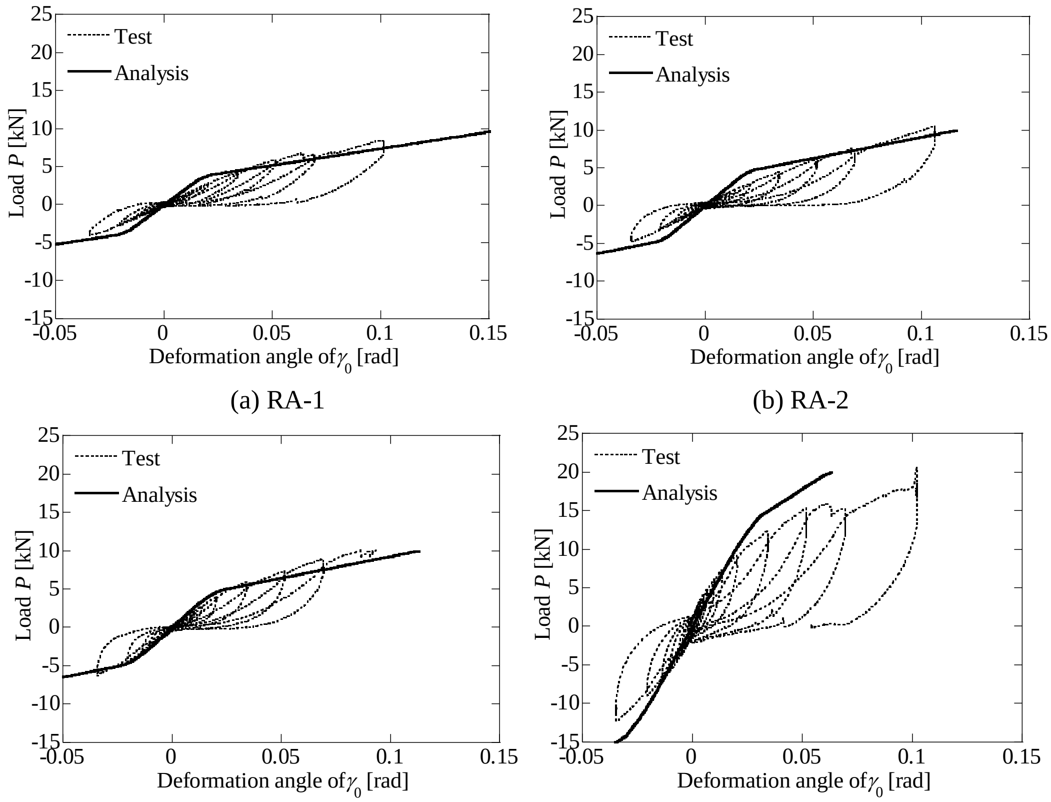
4 CONCLUSIONS

We performed horizontal shear tests to obtain the fracture mode and relationship between the applied load and deformation angle. Furthermore, the static pushover analysis of the full-scale roof specimens was executed. The results between the experimental test and the static pushover analysis were compared. The main findings of this study are as follows:

1) The retrofit effect of the structural plywood without brace on the vertical roof strut plane was very small. However, the deformation angle of the roof plane was smaller than that of the vertical roof strut plane because of the retrofit effect of the structural plywood.

2) The maximum load was approximately twice larger than that of the other specimens because of the retrofit effect of the brace on the vertical roof strut plane in addition to the structural plywood on the roof plane. The load became almost constant after 1/20 rad because of the buckling of the brace.

3) The analysis model used for the static pushover analysis was proposed. The analysis results were in good agreement with the tests for all specimens.



(a) RA-1 (b) RA-2

(c) RA-3 (d) RA-4

Figure 9. Comparison of test and analysis results.

Acknowledgments

This research was supported by the Maeda Engineering Foundation and the Forest Technology Center of Kochi Prefecture. We gratefully acknowledge this support.

References

Architectural Institute of Japan (edited), *Design Manual for Engineered Timber Joints*, Maruzen, Japan, 2009.

Architectural Institute of Japan (edited), *Standard for Structural Design of Timber Structures*, Maruzen, Japan, 2006.

Isoda, H., and Kawai, N., Hysteresis Model of Walls on Japanese Conventional Construction: Study on seismic behavior of wooden construction, *AIJ Journal of Structural and Construction Engineering*, Architectural Institute of Japan, 72(616), 157-163, June, 2007.

Japan Housing and Wood Technology Center (edited), *The Allowable Stress Design of Conventional Wooden Houses*, Japan Housing and Wood Technology Center, Japan, 2008.

Takino, A., Azumi, Y., Okamoto, S., Nakagawa, T., Shibutani, T., and Murakami, M., Formula to Predict the Shear Performance of Floor Construction of Traditional Wooden Structures Considering the Increasing Strength Based on Friction, *AIJ Journal of Structural and Construction Engineering*, Architectural Institute of Japan, 79(703), 1329-1336, September, 2014.