Earthquake Resistant Performance of New Brace Fastener for Post-and-beam Wooden Houses

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SUMMARY:
A new type brace fastener which fastens the end of a diagonal wood brace to the end of column is developed for Post and Beam construction wooden houses. Since the brace fastener contains high damping rubber, it absorbs a displacement between the end of a wood brace and a column, damage of wood around wood screws is able to be prevented. On shake table test of a wood frame with a wood brace fastened by the new brace fasteners, the new brace fastener showed higher seismic performance in comparison with normal brace fastener especially under large earthquake motion. Moreover, by means of earthquake response analysis, it was confirmed that the new brace fastener showed good seismic performance under several earthquake motions.

Keywords: Wooden house, Brace fastener, High damping rubber, Shake table test, Earthquake response analysis

1. INTRODUCTION

Wooden houses play an important role to preserve human life and property. They need to bear repeated large earthquakes and to be in use even after the earthquakes. However, once wood is subjected to a force, a decline of stiffness occurs. Therefore, shear stiffness of shear walls subjected to an earthquake is considered to decline, which means wooden houses are hard to resist the repeated large earthquakes.

From the expressed reason, authors have been developed a new brace fastener which fastens the end of a diagonal wood brace to the end of column for Post and Beam construction wooden houses(Furuta, T. and NAKAO, M. (2009), Furuta, T. and Nakao, M. (2010)). Since the brace fastener contains high damping rubber, it absorbs a displacement between the end of a wood brace and a column, damage of wood around wood screws is able to be prevented. Therefore, the brace fastener minimizes the decline of stiffness, moreover high damping force by the high damping rubber is produced.

In this paper, to evaluate basic performance of the new type brace fastener, shake table test of a wood frame with a wood brace fastened by the new brace fasteners firstly. Wood braces fastened by the new type brace fastener presented in this paper is able to be considered as one of shear walls in Building Standard Law in Japan. Secondly, considering the result of the shake table test, earthquake response analysis is conducted to evaluate the performance of the new brace fastener in ordinary Post and Beam wooden houses.

2. OUTLINE OF THE NEW BRACE FASTENER

The new type brace fastener, as shown in Figure 1, consists of a L-shaped normal brace fastener, a steel plate and a high damping rubber with 5mm thick. The high damping rubber glues a L-shaped normal brace fastener and a steel plate together. The L-shaped normal brace fastener is fastened to the end of a column with nine 75mm wood screws and the steel plate is fastened to the end of a wood brace with six 45mm wood screws. In addition to the wood screws, four 45mm wood screws which fasten the L-shaped fastener and a wood brace directly are added for fail-safe considering exfoliate of high damping rubber. Picture 1 shows a wood frame with wood braces which are fastened by the new brace fastener at the ends of braces as shown in Picture 2. The new brace fastener is able to be used in place of a normal brace fastener to connect the end of a wood brace whose cross section is 90mm x 45mm to the end of a column.

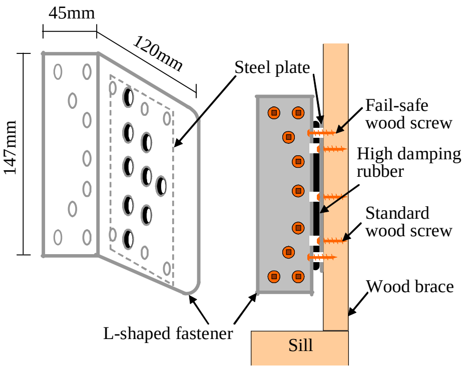


Figure 1. New developed brace fastener

Picture 1. Wood brace fastened by the new fastener

Picture 2. New brace fastener installed at the end of brace

3. SHAKE TABLE TEST

Shake table test of a wood frame specimen with a wood brace fastened by the new brace fasteners to evaluate its seismic performance. Figure 2 shows a wood frame for shake table test.

Three stages of excitation were performed, namely the specimen with fail-safe wood screws(Stage 1), the one without fail-safe wood screws(Stage 2) and the one with only fail-safe wood screws(Stage 3) as shown in Table 1. In each stage, one wood brace, whose cross section is 90mm x 45mm, was fastened by the brace fasteners at the both ends of the wood brace. In Stage 3, the high damping rubber did not glue a L-shaped normal brace fastener and a steel plate, and there was no wood screw which fasten the steel plate to wood brace.

Wood species of column, sill and brace of the specimen was Tsuga heterophylla and beam was Dugrus fur. Since weights on the top of the specimen were approximately 20kN, total weight of the upper half of the specimen was 24.5kN. On each stage, approximately 5%, 10% and 20% of JMA Kobe wave were input to the specimen in one direction. Before starting each stage, to have the natural period and the damping ratio, small random wave and impulse wave were input.

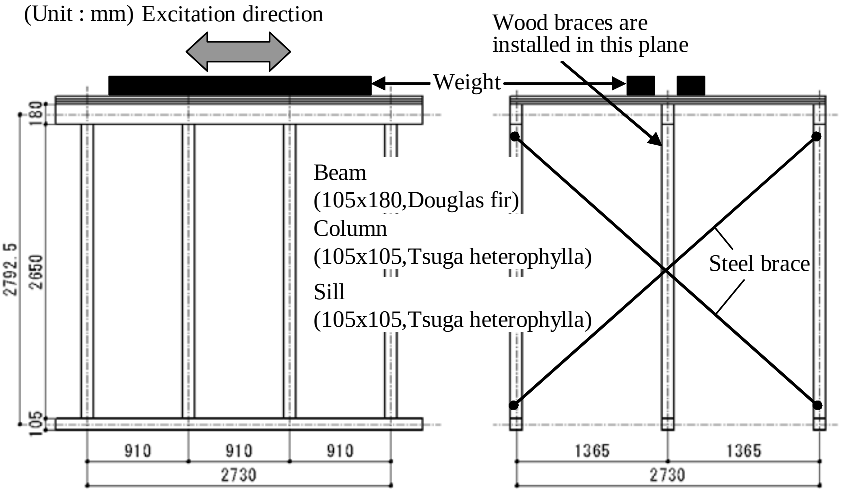
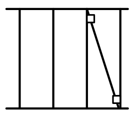
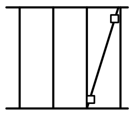
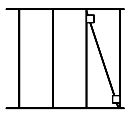
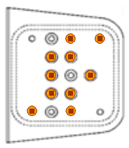
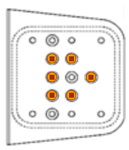
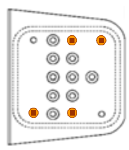


Figure 2. Wood frame for shake table test

Table 1. Arrangement of wood brace on each stage

Stage1	Stage2	Stage3
		
		

Stage1: 6 standard screws and 4 fail-safe screws
Stage2: 6 standard screws
Stage3: 4 fail-safe screws only

In the case of the new brace fastener with fail-safe wood screws(Stage 1), a maximum response drift under approximately 20% of JMA Kobe wave was 3.4%, where principal motion of the JMA Kobe wave was input to the wood brace as tensile force. Figure 3 shows the shear force-drift relation ship. Though deformation at the corner of the L-shaped fastener and embedment on the surface of the column were observed, fatal damage to the fastener was not detected.

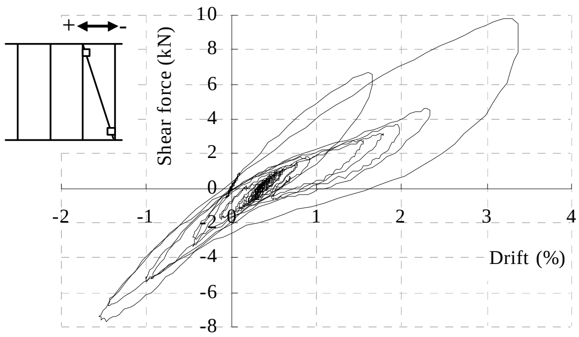


Figure 3. Shear force-drift relationship under 20% of JMA Kobe wave on Stage 1

In the case of the fastener without fail-safe wood screws(Stage 2), the principal motion of JMA Kobe wave was input to the wood brace as compressive force. Figure 4 shows the shear force-drift relationship under approximately 20% of JMA Kobe wave. Maximum response drift was 2.4%, compressive buckling of the wood brace occurred. Slight bending deformation of the fastener due to the buckling of the wood brace was observed. Little difference of the result of the specimen with and without the fail-safe wood screws was detected as shown in Figure 5 with respect to shear force-drift relationship when the wood braces were subjected to tensile force. More over, additional wood screws as fail-safe caused no brittle failure on the wood brace such as splitting failure.

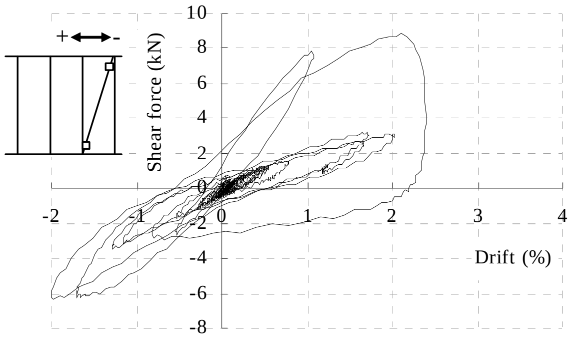


Figure 4. Shear force-drift relationship under 20% of JMA Kobe wave on Stage 2

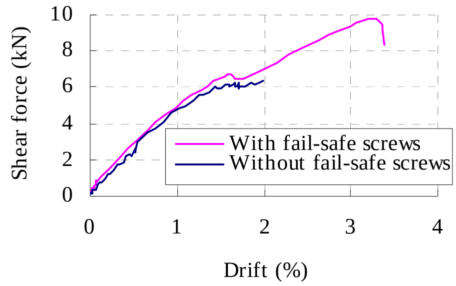


Figure 5. Skeleton curves of shear force-drift relationships under 20% of JMA Kobe wave on Stage 1 and Stage 2

Figure 6 shows the results of a wood frame with the brace fasteners whose high damping rubber did not glue a L-shaped fastener and a steel plate under approximately 10% of JMA Kobe wave(Stage 3). Only four fail-safe wood screws fasten the L-shaped fasteners and the end of brace.

Initial shear stiffness of the specimen with only fail-safe wood screws(Stage 3) was approximately 50% of the one with fail-safe wood screws(Stage 1) as shown in Figure 7. It is considered that friction force between the surfaces of the high damping rubber and the two steel parts, namely the L-shaped fastener and the steel plate was produced due to a compressive force by the wood screws. It was confirmed that the fail-safe wood screws show moderate performance even the exfoliation of the high damping rubber occurs.

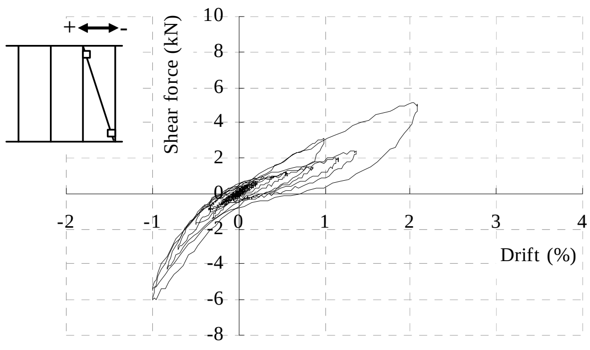


Figure 6. Shear force-drift relationship under 10% of JMA Kobe on Stage 3

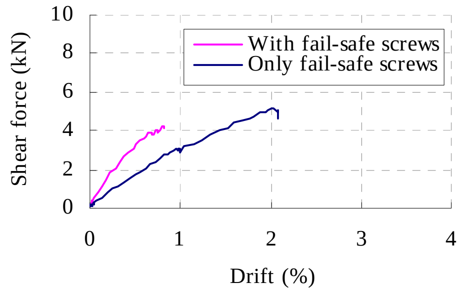


Figure 7. Skeleton curves of shear force-drift relationships under 10% of JMA Kobe on Stage 1 and Stage 3

An additional test of a wood frame with two wood braces fastened by the new brace fasteners was conducted. The fastener was attached using six standard wood screws and four fail-safe wood screws the same as Stage 1. In this test, 10%, 30% and 50% of JMA Kobe waves were input to the specimen. Maximum drift and shear force under 50% of JMA Kobe were 3% and 13kN, respectively as shown in Figure 8. In a series of this test, a test of a wood frame with two wood braces fastened by normal brace fasteners was also performed. Figure 9 shows the result under 50% of JMA Kobe wave. The maximum drift was 5.6%, it is 1.9 times as much as the drift with the new brace fastener. Figure 10 shows maximum drift of the tests with the new fastener and with normal fastener. In the tests under 10% and 30% of JMA Kobe wave, the maximum drifts of the two kinds of fasteners were almost the same. Therefore, the use of the new brace fastener is effective especially under relatively large earthquake motion.

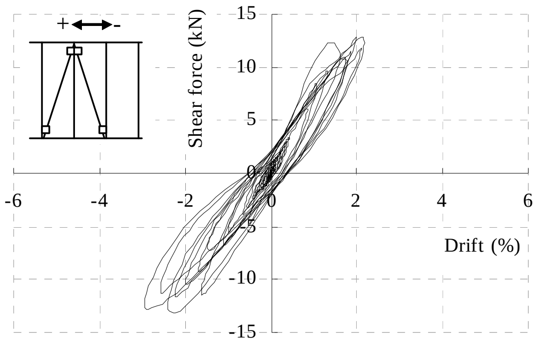


Figure 8. Shear force-drift relationship with two wood braces under 50% of JMA Kobe wave
under 50% of JMA Kobe wave

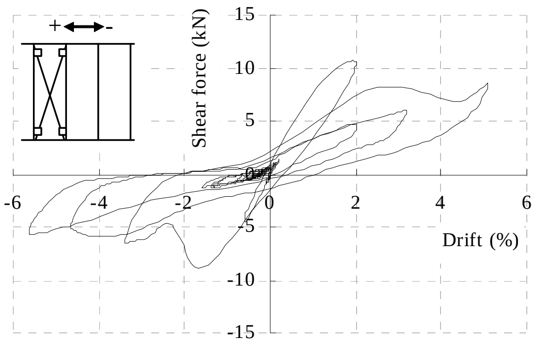


Figure 9. Shear force-drift relation ship with two wood braces fastened by normal fastener

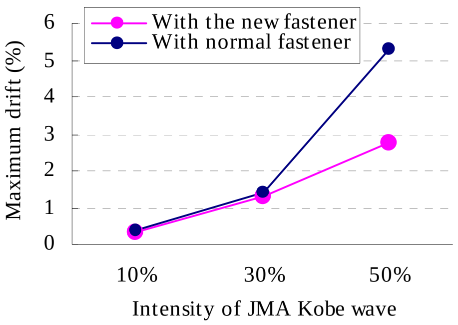
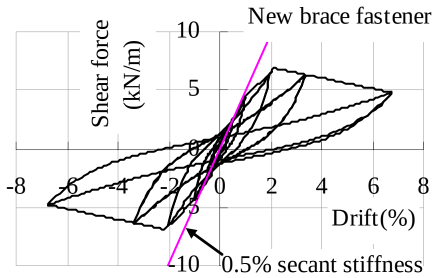


Figure 10. Maximum drifts of the specimen with two braces under 10%, 30% and 50% of JMA Kobe

4. EARTHQUAKE RESPONSE ANALYSIS

Earthquake response analysis was carried out to examine the seismic performance of the new brace fastener under several earthquake motions.

NCL model(Matsunaga, H., Miyazu, Y. and Soda, S. (2009)) was adopted for hysteresis model of a wood frame with a wood brace fastened by the new brace fasteners. Figure 11 shows the hysteresis model calibrated by the test results. A wood frame with a wood brace fastened by normal brace fasteners and the one with nailed plywood were also modeled as shown in Figure 12 and Figure 13, respectively. Shear forces presented here are shear force per wall length.



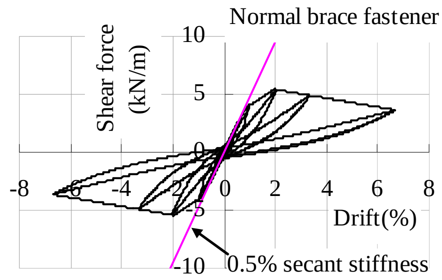


Figure 11. Hysteresis model of wood frame with wood brace fastened by the new brace fastener

Figure 12. Hysteresis model of wood frame with wood brace fastened by normal brace fastener

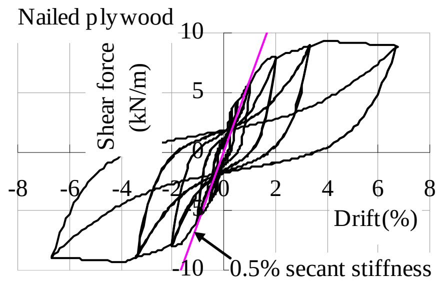


Figure 13. Hysteresis model of wood frame with nailed plywood

Three amounts of shear wall, minimum amount of required wall length in the Building Standard Law in Japan(100% wall quantity), 1.5 times of the minimum(150% wall quantity) and 2 times of the minimum(200% wall quantity) were set to the analysis model.

Input earthquake to the analysis models were El-Centro NS and BCJ L2(Level 2 simulated earthquake wave for structural design by The Building Center of Japan) in addition to JMA Kobe NS. Figure 14 shows the unscaled response spectra of the three earthquake waves. They were scaled to 980 gal(1G) on peak acceleration of elastic response as listed in Table 2. To calculate the input level, 0.5% drift secant shear stiffness of 100% wall quantity model was regard as elastic shear stiffness.

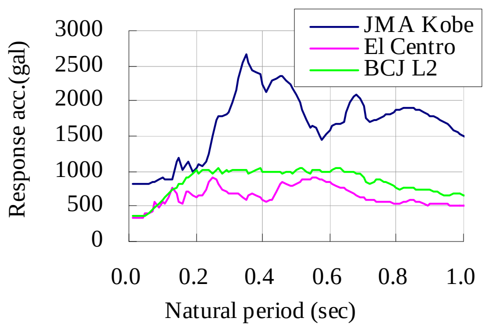


Figure 14. Unscaled response spectra with 5% damping

Table 2. Input intensities on earthquake response analysis

Sh (0.5% Secant stiffness per wall length (kN/mm/m))	Wall length to the law reqired	Natural period (sec)	JMA Kobe	El Centro	BCJ L2
Normal brace fasener (0.175)	100%	0.67	47%	145%	100%
	150%	0.55			
	200%	0.48			
New brace fastener (0.179)	100%	0.66	49%	142%	99%
	150%	0.54			
	200%	0.47			
Nailed plywood (0.301)	100%	0.57	66%	111%	97%
	150%	0.47			
	200%	0.40			

From the analysis result, as shown in Figure 15, the maximum drifts of a wood frame with wood braces fastened by the new brace fasteners are conservative in comparison with the one fastened by normal brace fasteners. Especially in the result under BCJ L2 wave, the response drift with the new brace damper was approximately 40% of the one with normal brace fastener. The new brace fastener showed relatively good seismic performance especially under large earthquake motion. It is considered that the high damping rubber enhanced deformation capacity of the brace fastener.

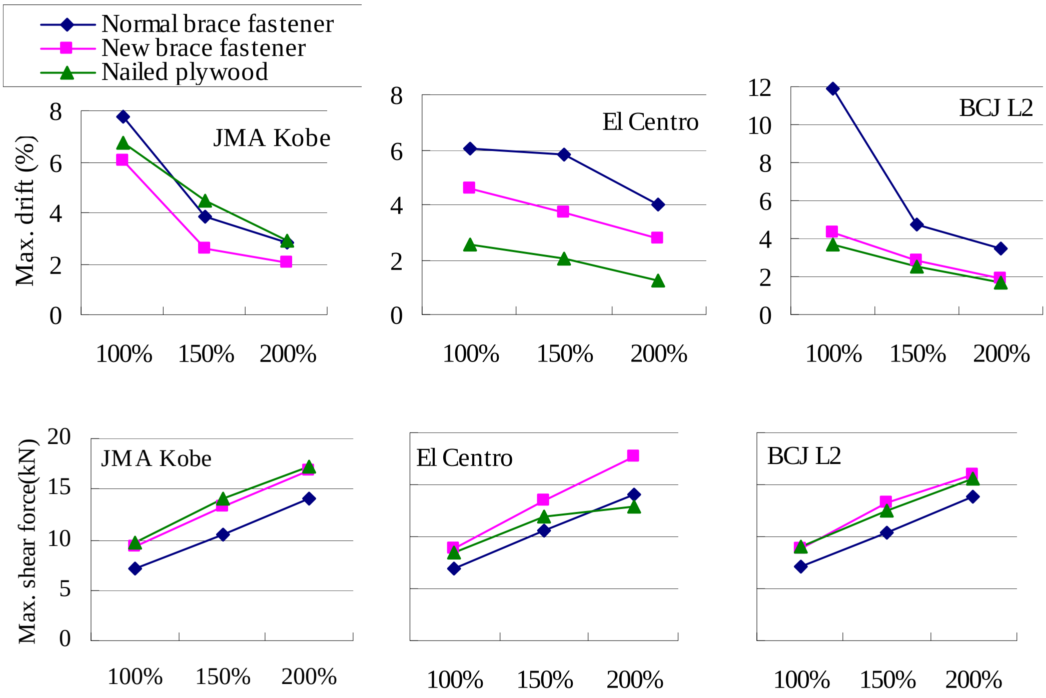


Figure 15. Maximum drifts and shear forces of analysis models with 100%, 150% and 200% wall quantity

5. CONCLUSIONS

A new type brace fastener which fastens the end of a diagonal wood brace to the end of column is developed for Post and Beam construction wooden houses.

On shake table test of a wood frame with a wood brace fastened by the new brace fasteners, it was found that fail-safe wood screws cause no brittle failure on wood braces such as splitting failure. In the case of the specimen with only fail-safe wood screws, even if the high damping rubber did not glue a L-shaped fastener and a steel plate, a decline of shear stiffness was approximately 50%. From the additional test, the new type brace fastener showed higher seismic performance in comparison with normal brace fastener especially under large earthquake motion.

Moreover, by means of earthquake response analysis, it was confirmed that the new brace fastener showed good seismic performance under several earthquake motions. Especially in the result under BCJ L2 wave, the response drift with the new brace damper was approximately 40% of the one with normal brace fastener.

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