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DEVELOPMENT OF SIMPLE REPAIRING HARDWARE FOR DAMAGED ENDS OF WOODEN BEARING WALLS

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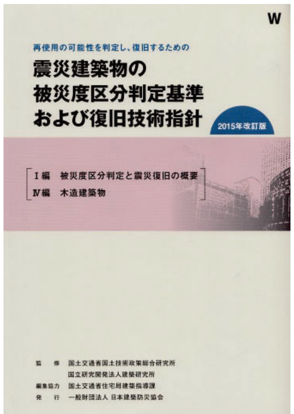
ABSTRACT: This study investigated the repairing effect for wooden bearing walls (which wall length was 910 or 1820mm) which are repaired by developed hardware. The study found that the repair was effective in increasing the maximum load and energy by more than 100% and 120%, respectively, but not very effective in increasing stiffness, which was often less than half. Additionally, the structural performance of the load-bearing walls with only the repair hardware was found to be equivalent to that with only the joint hardware, suggesting that these performances contribute to the overall structural performance of the repaired specimens.

KEYWORDS: Bearing wall, Repairing hardware for brace-ends, Structural performance

1 INTRODUCTION

This study examines repair methods for braces in wooden bearing walls, specifically in the case of horizontal forces acting on bearing walls due to earthquakes or other causes. Conventional frame construction is the most common type of wooden house construction in Japan and in case of an earthquake, an emergency hazard assessment is made to evaluate the need for repair or reinforcement [1](***Fig. 1***). Repair techniques are used to restore the structural performance of damaged buildings to its pre-damage state, and reinforcement techniques are used to make it higher than the pre-damage state.

This study proposes a new steel hardware repair method, which is simple enough to be installed by DIY hobbyists using tools such as impact wrenches. The study aims to investigate the effect of this repair hardware on the structural performance of 1P and 2P wall-length, bearing walls under monotonic and cyclic loading. The repair hardware will be installed after a horizontal force test, and the structural performance will be compared before and after the repair. Additionally, a separate test will be conducted on a load-bearing wall with only the repair hardware installed to determine the basic structural performance when the repair hardware is used.



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再使用の可能性を判定し、復旧するための

震災建築物の
被災度区分判定基準
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Ⅰ編　被災度区分判定と震災復旧の概要
Ⅳ編　木造建築物

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Figure 1: *Documentation*

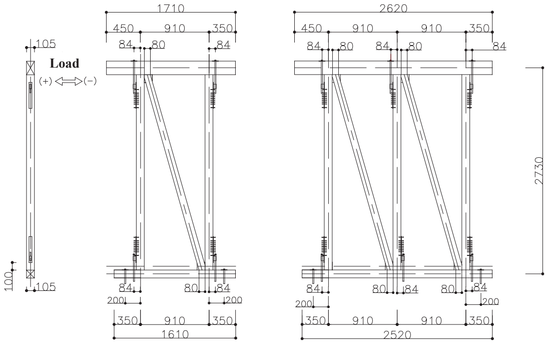

Figure 2: *Geometry of specimens(Unit:mm)*

2 SPECIMENS AND REPAIRING HARDWARE

2.1 SPECIMENS

In this study, horizontal load tests on 1P or 2P wall-length (indicated in ***Fig. 2***) with single-brace which were made of laminated veneer laminate (LVL) were conducted. The species of the LVL members was larch, grade 100E-1 (graded in Japan Agricultural Standard [2]), and the cross-sectional dimensions were 45 x 90 mm. The foundation, columns, and beams were made of laminated timbers of different grade compositions, grade E105-F300 (graded in

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Japan Agricultural Standard [3]) with cross-sectional dimensions of 105 x 105 mm for the foundation and columns, and 105 x 180 mm for the beams. The hardware used for the column legs was the screw-fastening type for Hold-down U 35 kN and "Justy Gusset Lite" were used for the joint hardware at the end of the brace. Monotonic and cyclic forces were applied to the specimens before and after repair. A total of 8 bearing walls were prepared, 4 of which were repaired, and 12 force tests were conducted indicated in ***Table 1***.

Table 1: *Specimens and test parameter*

Specimen	Wall length [mm]	Loading types	Type of joint in 1st test	Type of joint in 2nd test
A	910	Monotonic	Ordinally hard ware	Ordinally hardware + repair hardware
A-re				
B		Cyclic		
B-re				
C	1820	Monotonic		
C-re				
D		Cyclic		
D-re				
r-A	910	Monotonic	Only repair hardware	none
r-B		Cyclic		
r-C	1820	Monotonic		
r-D		Cyclic		

2.2 PAIRING HARDWARE

The repair hardware used in this study was a prototype developed in a previous study [4]. The shape of the repair hardware is shown in ***Fig. 3*** and ***4***, and it is larger than the joint hardware used in the study, with approximate dimensions of thickness t=1.6 mm, 200 x 120 x 55 mm. The screw holes are placed outside the edge of the joint hardware, allowing the repair hardware to be placed over the joint hardware and fastened with screws. The thickness of the steel plates of the joint hardware and the repair hardware are the same. The study used CPQ-45 screws to fasten four screws to the foundation and beams, six screws to the columns, and seven screws to the fascia side. Only one type of screw was used for the repair hardware to simplify the repair process.

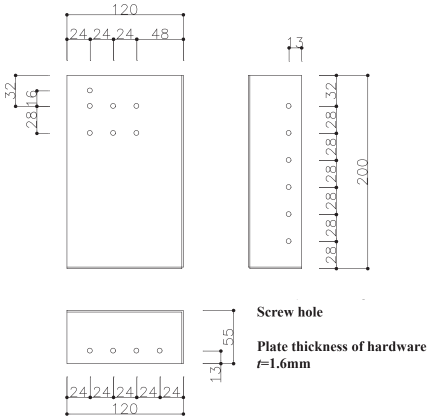

Figure 3: *Repair hardware*

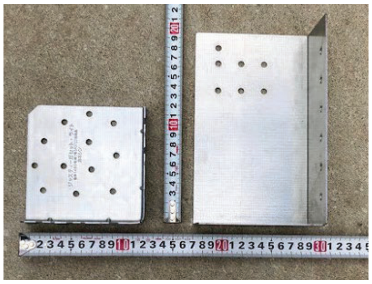

Figure 4: *Repair hardware*

2.3 REPAIR PROCESSING

This statement suggests that the study includes both a description of a test procedure and an installation procedure for reinforcement hardware in load-bearing walls. The test procedure likely describes the method used to evaluate the effectiveness of the reinforcement hardware in load-bearing walls, while the installation procedure describes the steps necessary to properly install the hardware in load-bearing walls. The procedure begins by applying a horizontal force to a specimen that has joint hardware attached. After the test is completed, the specimen is pushed back by the testing machine until the column is at right angles. The fastened hardware is not removed, and repair hardware is fastened over the fastened hardware. The repaired load-bearing wall is then subjected to another horizontal force. The flow of this procedure is illustrated in ***Fig. 5***.

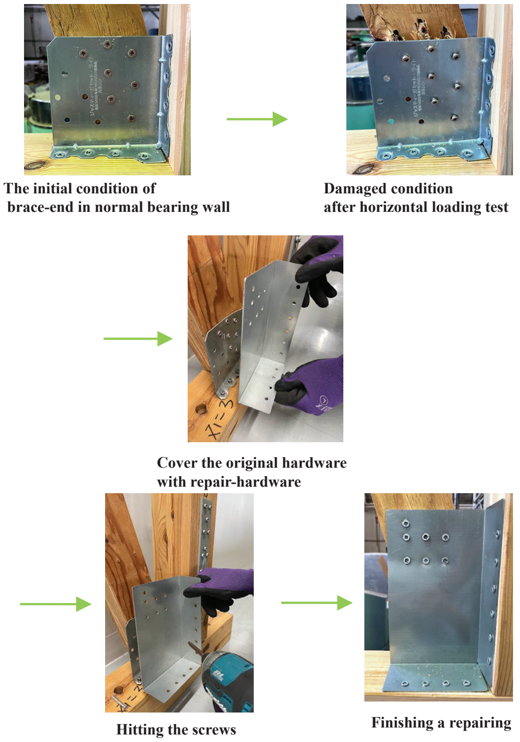

Figure 5: *Processing of tests and reinforcement of brace ends with hardware*

2.4 TEST METHODS

The test method in this study used a manual from the Japan Housing and Wood Technology Centre [5]. The

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specimen was anchored to a foundation steel beam with anchor bolts and horizontal forces were applied to the top of the specimen with an oil jack. Loads were applied using load cells and displacement transducers were used to measure the displacement of the test top and foundation. The loads were applied by monotonic tensile and repetitive positive and negative forces and the test results were processed using "pickpoint" [6] to calculate the structural performance.

3 TEST RESULTS

3.1 DAMAGED CONDITIONS

The main failure conditions of the specimens are shown in ***Fig. 6-9*** and listed in ***Table 2***.

The study found that in the 1P and 2P specimens using joint hardware, the main failure type was the pulling-out of screws. This occurred when the screws fastened to the brace penetrated into the brace and subsequently pulled out. The degree of screw pull-out was greater at the outermost end of the brace-edge than at the end of the brace attached to the central column. However, no screws were pulled out at the foundation, beams or columns, and no bending deformation or other damage was observed in the hardware.

In the repaired specimens, deformation was observed in many of the repair hardware in both the 1P and 2P specimens. Additionally, cracks were observed in the fiber direction at the foundation, beams and columns, starting at the screw holes. In the 2P specimens, the degree of screw pull-out was greater on the foundation side where the repair hardware was fastened, particularly on the lower right-hand side of the specimen, compared to the fascia joint in the center of the specimen. The repair hardware fastened to the foundation, beams and columns showed screw pull-out, while the screws fastened to the fascia side did not show any pull-out.

The specimens that used repair hardware only showed deformation of the hardware and cracking similar to the specimens that underwent repair. The 2P specimens showed screw pull-out at the foundation, beams and columns, while the 1P specimens did not show any screw pull-out. The 2P specimens showed no screw pull-out at the foundation, beams and columns. However, the screws on the fascia did not pull out in both specimens. The only exception was the r-C specimen, where the deformation of the repair hardware at the joint in the middle of the specimen was greater than at the joint in the lower right-hand corner of the specimen. At the repair hardware joints, the hardware was deformed first, followed by damage around the screws.

The screws were found to be in good condition and had not undergone any bending deformations during those tests.

The study found that using joint hardware alone resulted in screw pull-out as the main type of damage, while the use of repair hardware resulted in a combination of screw pull-out and other types of damage. This could be misleading as it may suggest that repair hardware is more prone to damage. However, the study also found that when repair hardware was used, the deformation of the bearing walls was greater, resulting in greater deformation at the joints, which also caused other damage. Despite this, the study found that the use of repair hardware did not result in a reduction in bearing capacity, which is considered to be a useful aspect of the repair hardware.

The study found that when only joint hardware was used, the damage was more pronounced in the fascia, but when repair hardware was used, the damage was more pronounced in the foundations, columns and beams. This suggests that the resistance mechanism changed when repair hardware was used. However, it is possible that the repair hardware was not the only factor in this change, and that internal damage to the foundations, columns and beams may have also contributed to the change in the resistance mechanism.

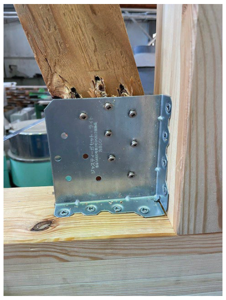


Figure 6: *Damaged condition1*

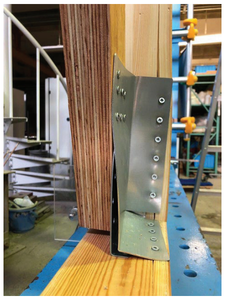


Figure 7: *Damaged condition2*


Figure 8: *Damaged Condition3*


Figure 9: *Damaged condition4*

Table 2: *Failure conditions*

Condition and specimen		Pulled out of screws			Failure of hardware	Failure of members
		Brace	Foudation	Beam		
Only normal hareware	A	✔				
	B	✔				
	C	✔				
	D	✔				
after repairing (damaged noral hardware and repair hardware)	A-re			✔	✔	✔
	B-re			✔	✔	✔
	C-re		✔	✔	✔	✔
	D-re		✔	✔	✔	✔
Only repairing hardware	r-A				✔	✔
	r-B				✔	✔
	r-C			✔	✔	✔
	r-D			✔	✔	✔

3.2 LOAD-DISPLACEMENT RELATIONSHIPS

The load-deformation angle relationships for specimens with joint hardware and those with repair hardware only are shown in ***Fig. 10-13***.

The study found that when comparing the load-deformation relationship of specimens with joint hardware to those with repair hardware only, the specimens with only repair hardware tend to have a smaller initial slope and behave differently in the initial phase of the applied force. After a period of stagnation, the load tends to rise again and the maximum load tends to reach the same level as the specimens with joint hardware. This behavior is likely due to plate buckling of the steel plate caused by the large unscrewed surface, and the transition to tensile deformation as the deformation progresses. This two-stage behavior is characteristic of the cases where this repair hardware is installed. The study found that the displacement at maximum load was clearly larger than that of the specimens with joint hardware, confirming that the hardware was designed to be a load-bearing wall with excellent deformation performance.

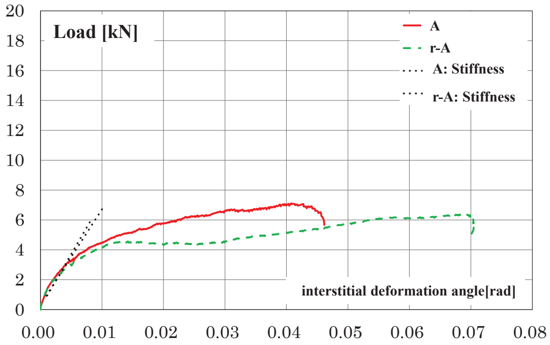


Figure 10: *Comparison with A and r-A(Load-angle)*

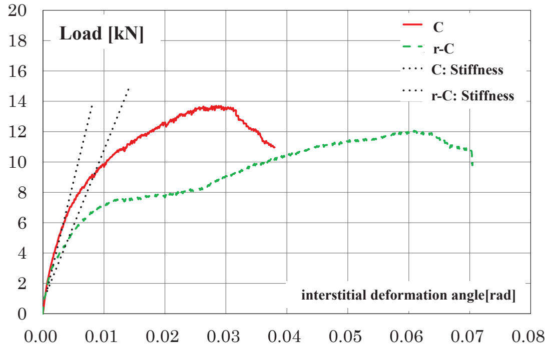


Figure 11: *Comparison with C and r-C(Load-angle)*

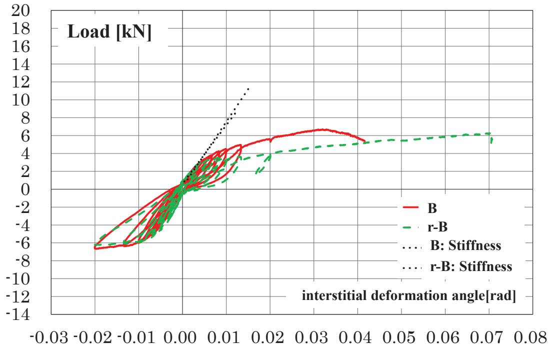
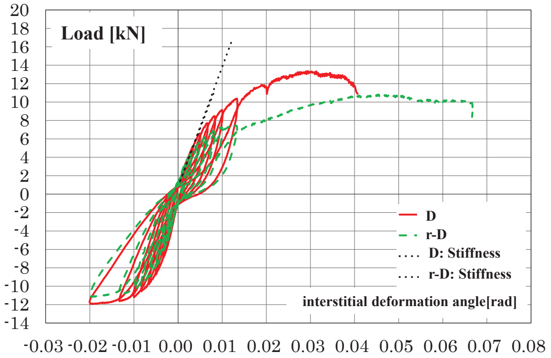


Figure 12: *Comparison with B and r-B(Load-angle)*



Fiure 13: *Comparison with D and r-D(Load-angle)*

The load-deformation angle relationships of the specimens with the joint hardware and after repair are then shown in ***Fig. 14-17***.

The study found that the initial stiffness of the specimens after repair tends to be smaller than before repair. This is likely due to the slightly smaller stiffness of the wall with only the repair hardware. However, the maximum load and displacement at maximum load of the specimens after repair were clearly larger than before repair. This suggests that the repair is effective in increasing the load-bearing capacity and deformation performance of the wall.

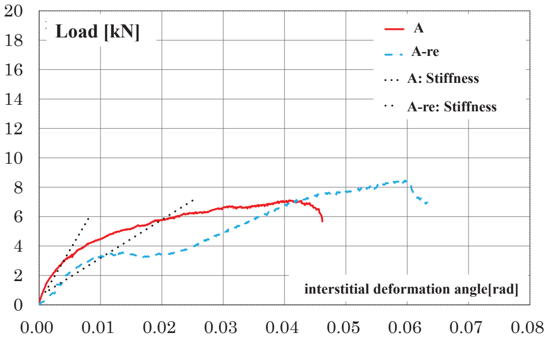


Figure 14: *Comparison with A and A-re(Load-angle)*

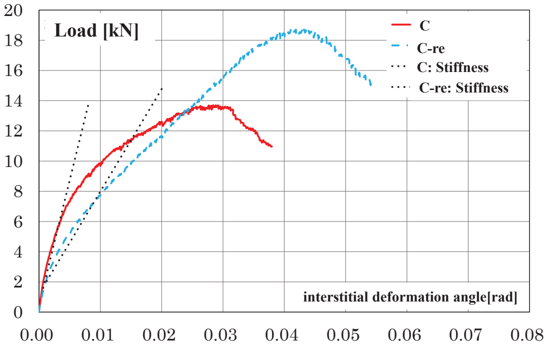


Figure 15: *Comparison with C and C-re(Load-angle)*

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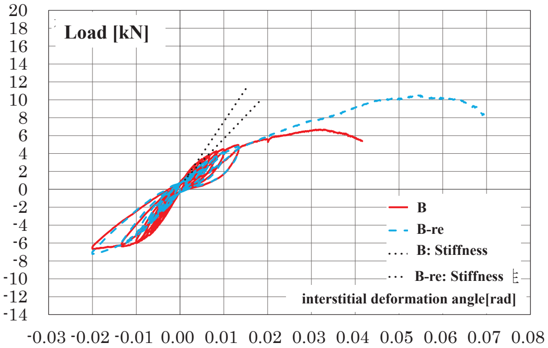

Figure 16: *Comparison with B and B-re(Load-angle)*

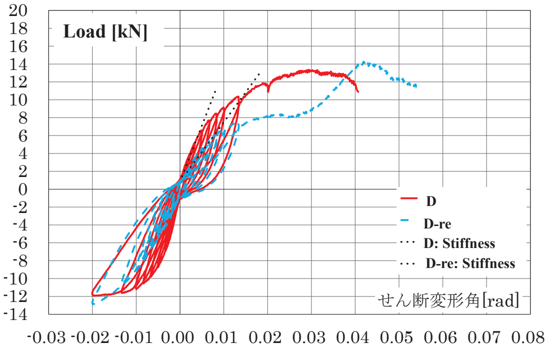

Figure 17: *Comparison with D and D-re(Load-angle)*

3.3 COMPARISON OF JOINTING HARDWARE AND REPAIR HARDWARE

The results using jointing and repair hardware are shown in ***Table 3*** and ***Fig. 18 -19***.

The study found that the maximum load on the specimens with repair hardware only was slightly lower than on the specimens with joint hardware, but the energy absorbed was higher. The ratio of the maximum load value of the repair hardware only divided by the value of the joint hardware was 89% for the r-A specimen, 94% for r-B, 88% for r-C and 80% for r-D. The ratio of energy absorbed was 136% for r-A, 153% for r-B, 158% for r-C and 138% for r-D.

The study found that the ratios of the load-bearing walls with repair hardware to those with joint hardware were more than 80% (88% on average) for maximum load, more than 60% (85% on average) for stiffness and more than 136% (146%) for energy. As shown in Figure 12, all were greater than the joining hardware with regard to energy, confirming that the effect was more akin to reinforcement than repair. Although the maximum load and stiffness values were not 100%, it was confirmed that the structural performance was at a level similar to that of a load-bearing wall with jointed metalwork. Based on these results, the study concludes that the repair hardware is considered to be effective in terms of repair for the joint hardware covered in this study.

Table 3*: Comparison of specimens with joint and repair hardware*

Specimen	Maximum load [kN]	Reparid/ Original	Stiffness [kN/mm]	Reparid/ Original	Energy [kN・mm]	Reparid/ Original
A	7.11	89.9%	0.26	88.5%	692.95	136.1%
r-A	6.39		0.23		943.09	
B	6.69	94.5%	0.27	88.9%	586.57	153.8%
r-B	6.32		0.24		902.28	
C	13.70	88.0%	0.60	61.7%	1121.44	158.5%
r-C	12.06		0.37		1777.71	
D	13.37	80.9%	0.46	104.3%	1172.23	138.4%
r-D	10.82		0.48		1622.71	
Ave.		88.3%		85.8%		146.7%

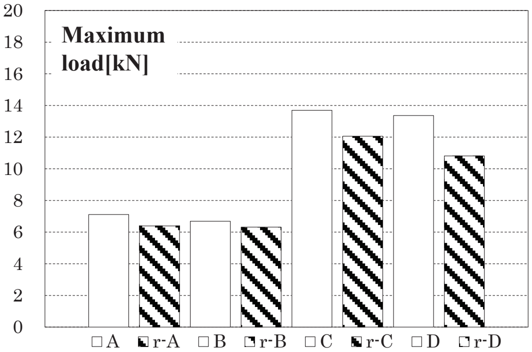

Figure 18: *Comparison of maximum loads on specimens with jointing hardware and reinforcing hardware*

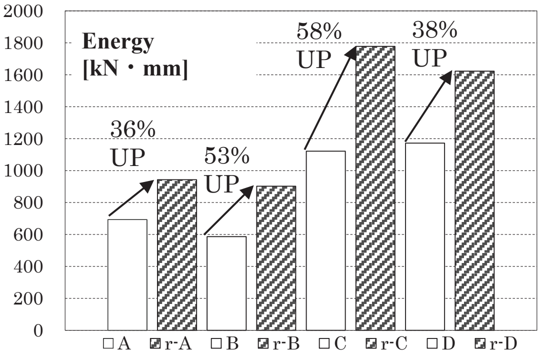

Figure 19: *Comparison of energy on specimens with jointing hardware and reinforcing hardware*

3.4 COMPARISON BEFORE AND AFTER REPAIR

Comparisons before and after repair are shown in ***Table 4***, maximum load comparisons in ***Fig. 20*** and energy comparisons in ***Fig. 21***.

The study found that compared to the specimens before repair, the specimens after repair had lower initial stiffness, but increased maximum load and energy. The ratio of the post-repaired value divided by the pre-repaired value for maximum load was 120% for the A-re specimens, 156% for the B-re, 136% for the C-re and 106% for the D-re. The energy ratios were 131% for the A-re specimens, 240% for the B-re, 173% for the C-re and 123% for the D-re. No trend was found within the scope of this study with respect to these repair effects for different wall lengths.

The study found that the use of repair hardware tends to increase the maximum load by more than 100% and the energy by more than 120%. Based on these results, it can be considered that repair hardware has a repair effect. However, it has been shown that the maximum load of those using only repair hardware is 85% of those using only joint hardware. It is believed that the joint hardware after damage also contributes to some extent, working in a combined manner and resulting in a higher maximum load. With regard to energy, the contribution of the repair hardware is considered to have been significant. In terms of stiffness, on the other hand, the results showed that there was no significant repair effect.

***Table 4**: Comparison of before and after repairing with hardware*

Specimen	Maximum load [kN]	Reparid/ Original	Stiffness [kN/mm]	Reparid/ Original	Energy [kN・mm]	Reparid/ Original
A	7.11	120.1%	0.26	38.5%	692.95	131.4%
A-re	8.54		0.10		910.37	
B	6.69	156.8%	0.27	44.4%	586.57	240.6%
B-re	10.49		0.12		1411.07	
C	13.70	136.6%	0.60	41.7%	1121.44	173.1%
C-re	18.72		0.25		1940.72	
D	13.37	106.8%	0.46	52.2%	1172.23	123.0%
D-re	14.28		0.24		1442.2	
Ave.		130.1%		44.2%		167.0%

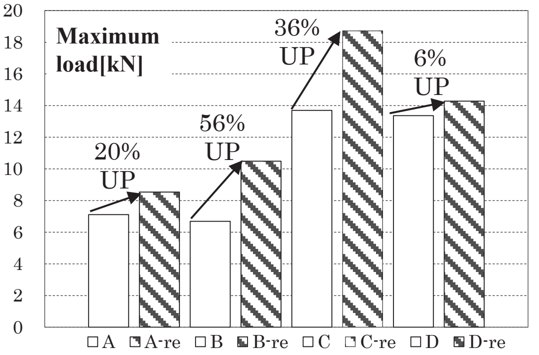

***Figure 20:** Comparison of maximum loads on specimens before and after reinforcement*

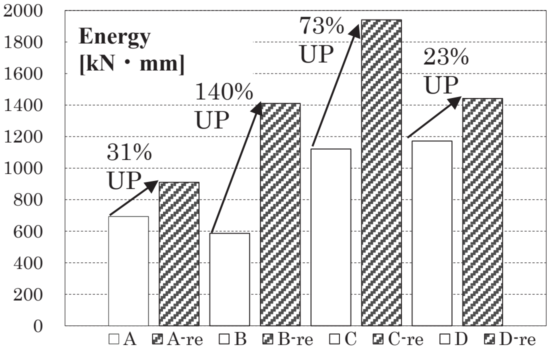

***Figure 21:** Comparison of energy on specimens before and after reinforcement*

4 CONCLUSION

The study investigated the effectiveness of repair hardware in reinforcing load-bearing walls that have undergone damage. The findings of the study are as follows:

1. The ratio of the structural performance of the repaired hardware alone to that of the joined hardware, the repaired hardware had values of around 88% for maximum load, 85% for stiffness and 146% for energy, confirming that the hardware is expected to be effective in repairing the damage.
2. The values obtained by dividing the post-repair by the pre-repair were more than 106% for maximum load and 123% for energy. It was confirmed that the repair was effective with regard to load capacity and deformation performance. However, with regard to stiffness, the repair effect was small. No influence of different wall lengths and application methods was found within the scope of this study with regard to these values.
3. The maximum load was considered to have been restored by the combined action of the damaged joint hardware and the repair hardware. The contribution of the repair hardware was considered to be the main contribution with regard to energy.
4. For stiffness, the effect was small. With regard to screw damage, the damage in the fascia was more pronounced in the case of the joint hardware only, whereas it was more pronounced in the foundation, columns and beams after the repair, suggesting that this difference in resistance mechanisms may have influenced the lack of increased stiffness.

In the current study, cyclic force tests were conducted incrementally. However, in recent years, research using more complex cyclic force tests such as fatigue tests has progressed [7],[8]. It is suggested that future research should examine this specimen using such force tests.

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