WORLD CONFERENCE ON TIMBER ENGINEERING 2025
BRISBANE, AUSTRALIA
Advancing Timber for the Future Built Environment

DEVELOPMENT OF SIMPLE SEISMIC REINFORCEMENT METHOD OF TRADITIONAL WOODEN – APPLICATION OF LATTICE BEARING WALL –

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ABSTRACT: In Japan, there is a system of Important Preservation Districts for Groups of Traditional Buildings to preserve towns with traditional buildings. In Important Preservation Districts for Groups of Traditional Buildings, many buildings from before the 1981 revision of the earthquake-proofing standards have been preserved, so seismic reinforcement of these buildings is an urgent task. As cost is one of the factors preventing the progress of seismic reinforcement, this study aims to devise a simple, cost-saving seismic reinforcement method. In this study, assuming reinforcement in the sliding doors section, the lattice bearing wall, which has high toughness, transparency and breathability and is easy to construct, and which has been developed in the laboratory, will be applied. A reinforcement plan to reinforce the floor and ceiling without stripping them was devised, tested and evaluated.

KEYWORDS: wooden structure, lattice wall, Japanese traditional wooden building, reinforcement at sliding doors

1 – INTRODUCTION

In Japan, since the stricter seismic resistance standards were introduced in 1981, buildings that do not meet the new seismic resistance standards are now being made more resistant to earthquakes[1)]. In Important Preservation Districts for Groups of Traditional Buildings, where traditional wooden buildings are preserved, there are many private houses that do not meet the seismic resistance standards. In many cases, seismic reinforcement in private houses is at the occupants' own expense, although subsidies are available, so the cost of seismic reinforcement is a factor in the lack of progress in seismic reinforcement. The aim of this study is to promote seismic reinforcement of traditional wooden buildings by devising a simple, cost-saving seismic reinforcement method.

2 – REINFORCEMENT METHOD

2.1 REINFORCEMENT POLICY

To keep costs down, the aim is to devise the reinforcement method that not to rip out the floors and ceilings. Part of the mud walls was to be taken out and reinforced with structural plywood. As shown Fig. 1, a characteristic feature of traditional wooden buildings is the continuous arrangement of mud walls in the depth direction. On the other hand, in order to ensure continuity in the depth direction, sliding doors are often provided in the frontage direction. As a result, it is difficult to ensure the bearing capacity in the frontage direction, and the frontage direction often determines the building's bearing capacity. Based on the above, we considered the application of lattice bearing walls, which we have been developing in our laboratory, to the sliding doors part of buildings with traditional wooden building. The lattice bearing wall is a bearing wall with high toughness, transparency and breathability and is easy to construct. An image of the proposed reinforcement is shown in Fig. 2. As the thin lintel lacks bending performance, they were to be replaced by lintel with a cross-sectional performance of about 105 square degrees. A part of the lintel was chipped off to reduce the surface

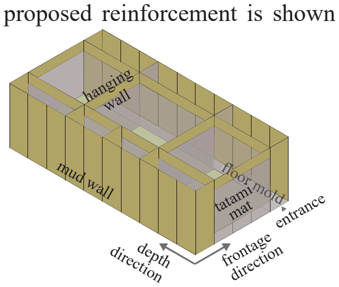

Figure 1: Example of room configuration in traditional building

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https://doi.org/10.52202/080513-0388

to be found from the perspective of design (Fig. 3).

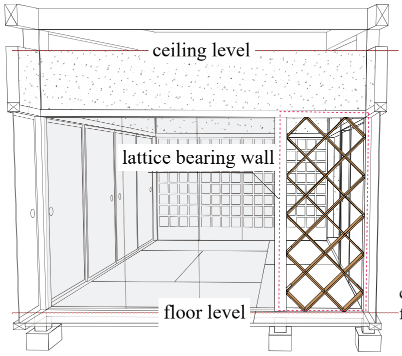


Figure 2: Image of the proposed reinforcement

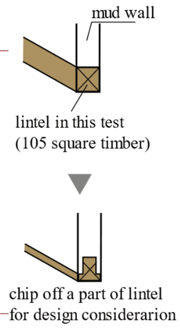


Figure 3: Lintel chipped partition

2.2 LATTICE BEARING WALL

Our laboratory has been developing lattice bearing wall for the seismic reinforcement of tenement buildings, many of which remain in Osaka[2,3)]. In contrast to conventional lattice walls assembled vertically and horizontally, which are resisted by the embedding, this bearing wall forms a truss-like shape and is resisted by compressive forces. As a result, thicker timber is not required. The composition of thin timber increases the efficiency of ventilation and lighting. In addition, in many cases, the bond between foundation and sill is not strong in tenements. The foundation and sill need to be reinforced in order to apply load-bearing walls that possess a high strength. Therefore, in order to ensure the high toughness without increasing the bearing capacity of this load-bearing wall too much, slits are made in the timber at the joint so that tensile timber does not work and only compression timber resists. In addition, as no moment resistance is expected from the phase-notched parts, the difference in bearing capacity due to the accuracy of the phase-notched parts is small, and amateur construction is also possible[4)]. Based on the above, this bearing wall is suitable for traditional wooden buildings with flexible structural performance and is expected to be widely used from the viewpoint of easy construction. Details of the joint and lattice are shown in Fig. 4 and 5.

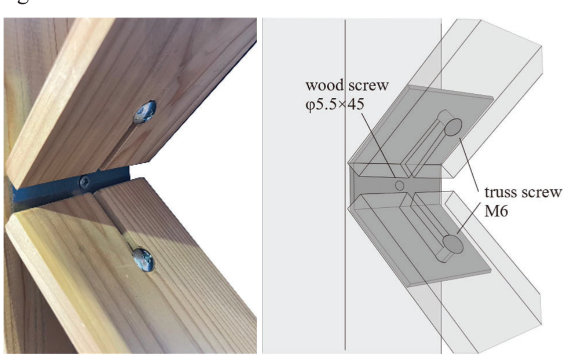


Figure 4: Image of lattice bearing wall's joint

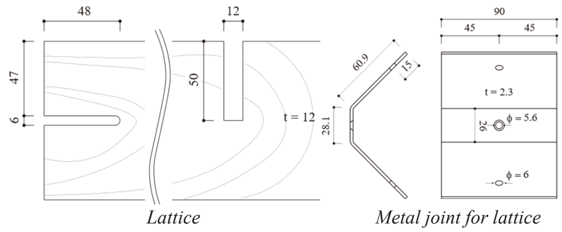
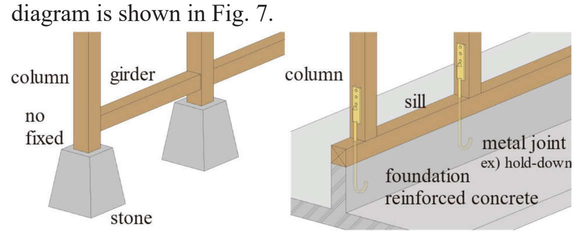


Figure 5: Particulars of Lattice bearing wall

3 – IN- PLANE SHEAR TEST

3.1 TEST METHOD

Traditional wooden buildings are often not strongly bonded to the foundations and often the column bottoms are not fixed and the columns are on top of the foundation stones (Fig. 6). Therefore, taking into account that the column bottoms move separately, the conventional test method of fixing the column bottom is considered to result in a larger experimental value. Therefore, the column bottoms were not fixed, and an axial force of 1 tonf per column was initially applied from the top of the beam by a tie rod, assuming the actual building load, to prevent lifting and movement of the column bottom. The specimen diagram is shown in Fig. 7.



Traditional wooden building Modern wooden building

Figure 6: Difference of fix between leg of column and foundatioon

The beam was controlled by the horizontal displacement of the beam and the forces were applied three times, positive and negative, every 6.1, 9.1, 13.7, 18.2, 27.3, 36.4 and 54.6 mm (equivalent to 1/450, 1/300, 1/200, 1/150, 1/100, 1/75 and 1/50 rad in terms of apparent shear deformation angle) respectively, followed by at a unilateral force was applied up to 273 mm (equivalent to 1/10 rad). The apparent shear deformation angle was calculated by using the following equation (1). The mounting position of the displacement transducer is shown in Fig. 7.

$$\theta = (\delta_1 - \min(|\delta_2|, |\delta_3|)) \,/\, h \qquad (1)$$

θ : apparent shear deformation angle

δ : horizontal displacement

(Subscript denotes displacement transducer's number)

h : difference in height direction between

(From the bottom of the column to the axial-center of the beam)

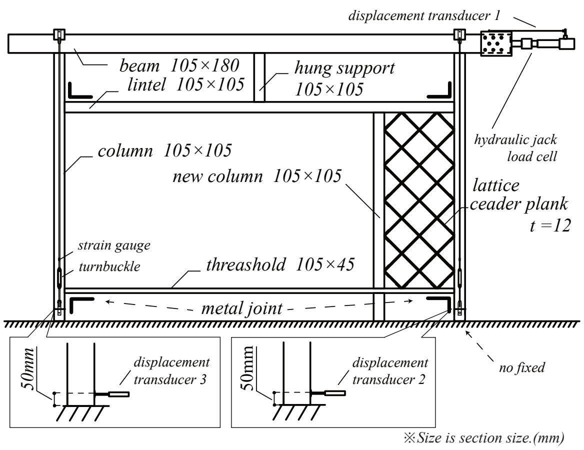


Figure 7: Test sppecimen

3.2 TEST SPECIMEN

The test specimens reproduced 3940mm (2-ken) and 2955mm (1.5-ken) frame of sliding doors part and were all made of Japanese cedar. In previous experiments[3)], plywood was used for lattice, but from a design point of view, Japanese cedar was used in this experiment. As shown in Table 1, the joints were made with tenon, but the joints between the lintel/ threshold and the columns were reinforced with metal joints. The dimensions of the lattice are shown in Fig. 8 and the metal joint is shown in Fig. 9. An overview of the reinforcement methods in the underfloor section is given in Table 2. Four reinforcement patterns were prepared so that the specification could be selected according to the underfloor conditions and required bearing capacity.

Table 1: Each joining method and dimensions

joint	column-beam	column-lintel	column-threshold
joining method (dimensions)	tenon 60×30×90	tenon metal plate 30×30×60	tenon metal plate 5×70×15

joint	hung support - column・beam	support - threshold・girder
joining method (dimensions)	tenon 90×30×45	thrusting diagonal screw

joint	new column - threshold	new column - lintel
joining method (dimensions)	tenon 90×30×15	tenon 90×30×45

joint	new threshold - column・new column	column - girder
joining method (dimensions)	tenon, metal plate 30×30×60	tenon, metal plate 30×30×90

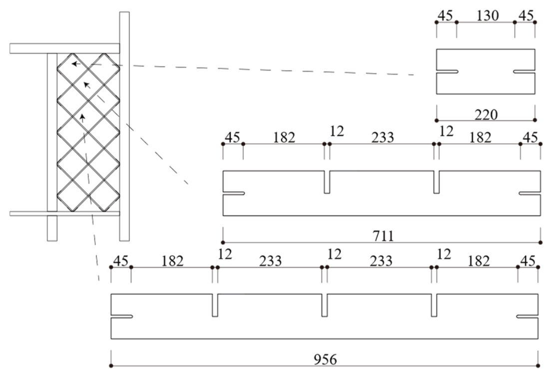


Figure 8: Dimensions of lattice

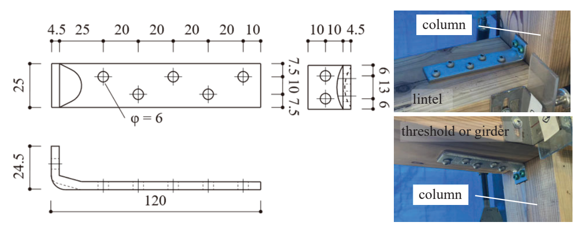
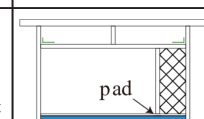
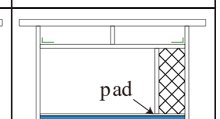
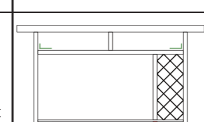
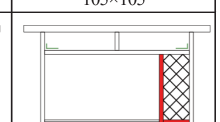


Figure 9: Particulars of metal joint

Table 2: Outline of test specimen and reinforcement method

Test specimen	1 - 2	1 - 1.5	2 - 2
Outline of the reinforcement method	girder pad※1)		girder, pad support in the center
Size of above component(mm)	90×90 t = 15		90×90, t=15 105×105
Simple diagram Blue : existiong Red : new Green : metal joint	 pad		 pad
Column span	3940mm (2-ken※2))	2955mm (1.5-ken)	3940mm (2-ken)

Test specimen	3 - 2	3 - 1.5	4 - 2	4 - 1.5
Outline of the reinforcement method	support under the new column		Penetration of new column New thick threshold	
Size of above component(mm)	105×105		105×105 105×105	
Simple diagram Blue : existiong Red : new Green : metal joint				
Column span	3940mm (2-ken)	2955mm (1.5-ken)	3940mm (2-ken)	2955mm (1.5-ken)

※1) A wood that adjust the gap between two members. In this case, it fills the space between the threshold and girder, and transmits vertical force (Fig. 10).

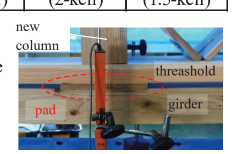


Figure 10: Pad

※2) One of the units of the ancient Japanese measurement law. 1-ken = 1970mm

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4 – TEST RESULT

The load-deformation angle relationship for each specimen is shown in Fig. 11. The bearing capacity per fixture for each 0.2 Pu/Ds and the simplicity of installation are shown in Table 3. A correlation was observed between simplicity of construction and bearing capacity. Deformation of each test specimen at 1/10 rad is shown in Fig. 12.

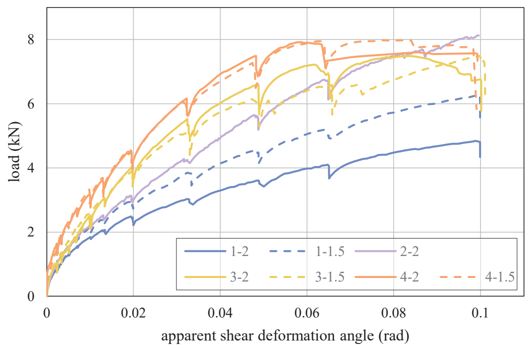

Figure 11: Relationship of load – apparent deformation angle

Table 3: Evalution of bearing capacity

Test specimen	1-2	1-1.5	2-2	3-2	3-1.5	4-2	4-1.5
Bearing capacity (kN)	1.47	1.77	1.84	2.24	2.29	2.75	2.78
Bearing capacity	small → large						
Simplicity of construction	easy → difficult						

5 – CONSIDERATION

5 .1 CONSIDERATION OF TEST SPECIMEN

As different behaviour was observed depending on the reinforcement method, the characteristics are summarised below.

Specimen 1 and 2: Vertical forces on the new columns were borne by the girder and threshold. As shown in Fig. 13, the vertical displacement caused the new column to fall out of the lintel, but the short lattice was considered to be effective in transferring the load while suppressing large deformations. Since the energy was absorbed by the deformation of the threshold and girder, the joints were displaced following the deformation, so that the failure of the lattice almost did not occur. The deformation of the lattice is shown in Fig. 14. In test specimen 2, the deflection of the girder and threshold was reduced by the central support and the load continued to extend because the threshold was supported by the support through the girder.

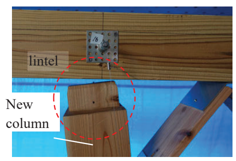

Figure 13: Falling of new column from lintel

1-2 *1-1.5* *2-2*

Figure 14: The deformation of the lattice at 1/10rad

Specimen 3: The new support bear the vertical forces, which relieves the burden on the threshold and reduces the deflection of the threshold. The deformation of the lattice is shown in Fig. 15. At 2955mm (1.5-ken), the lattice was removed due to a crack between the slit and the phase notch in front of 1/10 rad. One reason for this may be that the overburden in the surrounding lattice increased due to the forgetting to screw in the joint metal plate, as shown in Fig. 15.

1-2 *2-2* *3-2* *4-2*

1-1.5 *2-2 (two lattice bearing walls)* *3-1.5* *4-1.5*

Figure 12: Deformation of each test specimen at 1/10 rad

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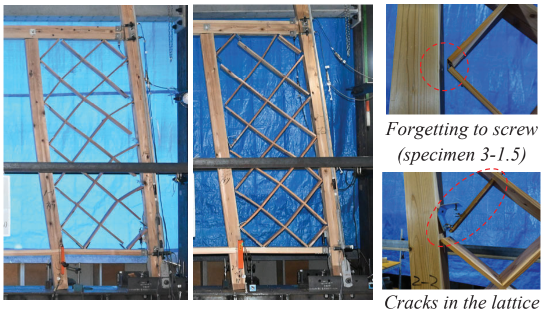


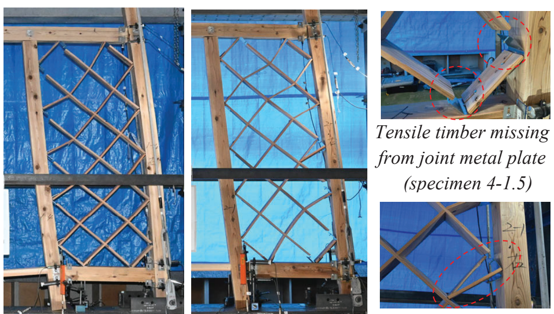
Forgetting to screw (specimen 3-1.5)

Cracks in the lattice (specimen 3-1.5)

3-2 *3-1.5*

Figure 15: The deformation at 1/10rad

Specimen 4: The stiffness of the frame was increased by making the new column directing to the ground and by installing a new thicker threshold. At 2955mm (1.5-ken) in front of 1/10 rad, the lattice was fallen due to a crack between the slit and rabbet joint. The deformation is shown in Fig. 16.



Tensile timber missing from joint metal plate (specimen 4-1.5)

Cracks in the lattice (specimen 4-1.5)

4-2 *4-1.5*

Figure 16: The deformation at 1/10rad

The bearing capacity of specimens 1 and 2 was determined by the bending stiffness of the girder and threshold, so the bearing capacity increased in the order of 1-2＜1-1.5＜ 2-2 and in the order of the shorter span of the girder. The effect of the distance between columns on specimens 3 and 4 was small due to the low load-bearing capacity of the existing threshold.

5 .2 TWO LATTICE BEARING WALLS

Two lattice bearing walls can also be installed in 3940mm(2-ken), which can be expected to have greater bearing capacity than in 2955mm (1.5-ken). In addition tests, the bearing capacity of lattice bearing walls placed on both sleeves was checked in the specification of specimen 2-2. The respective load-deformation angle relationships are shown in Fig. 17 and a comparison between a single lattice bearing wall and two lattice bearing walls is shown in Table 4. The deformation of the lattice is shown in Fig. 18. In the lattice on the left side, which was not seen in the one-piece arrangement, there was embedded caused by the head of the new column and missing the new column leg (Fig. 18). In traditional wooden buildings, the opportunities of using as one room have decreased due to changing lifestyles, and sliding doors may be closed at all times. The bearing capacity of such frame of sliding doors part, such as when four lattice bearing walls are placed on the entire surface of the sliding doors part, should be checked in the future.

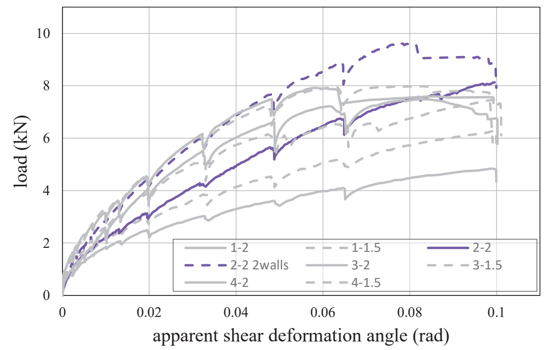
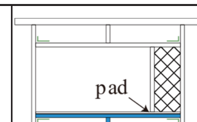
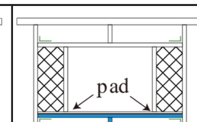


Figure 17: Relationship of load – apparent deformation angle

Tabel 4: Comparison of bearing capacity

Test specimen	 pad	 pad
Bearing capacity (kN)	1.84	2.52

Embedded by new column (left)

New column missing from threshold (left)

Left *Right*

Figure 18: The deformation at 1/10rad (Two lattice bearing walls)

5 .3 NEGATIVE SIDE EVALUATION

In this test, specimens 1 and 2, which utilize the existing, are considered to be weaker on the positive side, as this is determined by the bending of the threshold and large pulls. In addition, as the aim was to check the difference in bearing capacity due to the reinforcement method in the area under the new columns, the force was applied by pushing through. However, because of the lack of positive-negative symmetry, the positive side is stronger, especially in specimens 3 and 4, which were reinforced at the foot of the new columns, and the negative side has to be taken into

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account for evaluation. The load-displacement relationship for the negative side up to 1/50 rad is shown in Fig. 19. Table 5 shows the maximum bearing capacity at 1/50 rad. As can be seen from Fig. 19, the negative side shows approximately the same behaviour, regardless of the reinforcement method. Reinforced specimens 3 and 4 have a slightly higher bearing capacity, but the difference does not appear as large as on the positive side. This is predicted to be due to the fact that the bearing capacity of the negative side is determined by the bending performance of the lintel. As can be seen from Table 5, the difference between the positive and negative sides is small for specimens 1 and 2, while the positive side is clearly stronger for specimens 3 and 4. The reason for this is that in this test, 105-square timber was used to ensure minimum bending performance of the lintel, but there are thicker lintels in preserved traditional wood buildings, such as those shown in Fig. 20, where the lintel are 200 in diameter. In the case of lintel with such cross-sectional performance, it is expected that the bearing capacity will be sufficient on the negative side, and it is possible that the bearing capacity will be determined by the positive side.

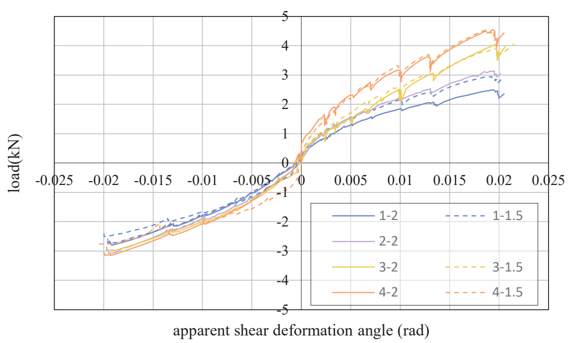
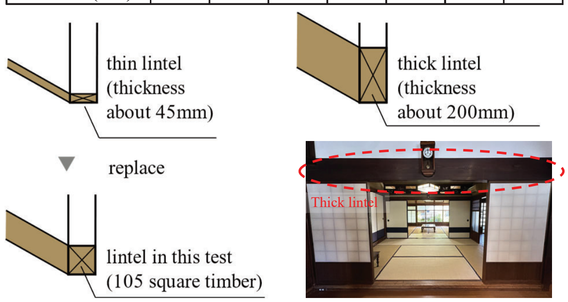


Figure 19: Relationship of load – apparent deformation angle

Table 5: Comparison of positive and negative

Test specimen	1-2	1-1.5	2-2	3-2	3-1.5	4-2	4-1.5
Positive side (kN)	2.49	2.94	3.13	4.04	3.89	4.55	4.55
Negative side (kN)	2.81	2.74	3.08	3.02	2.51	3.16	2.78



Lintel assumed in this experiments *Possible lintel*

Figure 20: Cross-sectional performance of lintel

Based on these points, additional experiments will be conducted to evaluate the negative side by pulling off and the change in bearing capacity due to changes in the members will be investigated by analysis in the future.

6 – CONCLUSION

In simple seismic strengthening of the sliding doors part frame in traditional wooden building, a certain level of bearing capacity could be obtained by applying lattice bearing walls. In the future, we would like to carry out analytical studies and consider the application to different cases.

7 – ACKNOWLEDGMENT

This study was conducted in cooperation with The Cultural Properties Division of the Uda City Board of Education Secretariat and Saya Architect's office.

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