Study on Seismic Performance of Bearing Wall System Composed of Timber Lattice and Panel

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SUMMARY:
In this paper new wood shear wall system is proposed. The proposed wall system is constructed by nailing plywood to timber square lattice. In order to evaluate performance of the proposed wall, full scale static loading tests were carried out. Experimental results showed that the proposed bearing wall system has high bearing capacity and deformation performance. The experimental results were analyzed theoretically in this paper, an analytical model was proposed. It became clear by computer analysis that the experimental results can be simulated by the analytical model. An analytical method for the proposed shear wall system by finite element analysis is described in this paper.

Keywords: Timber structures, Seismic performance, Timber bearing wall

1. INTRODUCTION

In Japanese wood-frame dwelling construction in general, shear walls provide lateral resistance to earthquake and wind loads. The shear walls which consist of wood panels nailed to framing work are used frequently. There are many research on the shear wall performance (Murakami et al. 1999), it showed clearly that the shear walls with wood panels have high bearing capacity. Also in traditional wood structure of Japan, square lattice wall is used occasionally. Square lattice wall is constructed by half lap joint without glue and nail in Japanese traditional construction. An example of the lattice wall is shown in Figure 1. Advantage of the lattice wall is that it has high deformation capacity over 0.03 radian (Iwasaki et al. 2002; Ishigaki et al. 2008). But bearing capacity of the lattice wall is not so high because it has only bearing force based on partial compressive strain behavior of the lap joints. Japanese traditional dwellings have big roof truss and heavy Japanese tiles on the roof, so that the traditional dwelling must be designed to larger earthquake load than modern dwellings. In order to provide large lateral resistance, new type of shear wall which consist of wood panels nailed to the square lattice is proposed. In this paper, the investigation of the shear walls under static loading is presented, and computer simulation of the loading tests has been performed.

Figure 1. Square lattice wall

2. OUTLINE OF PROPOSED SHEAR WALL SYSTEM

Proposed shear wall specimen (PLW) for static loading test is shown in Figure 2. The dimensions of the specimen are 1.82m in width and 2.5m in height. The section of the components which construct lattice is 90mm x 90mm. Square timbers are Douglas fir. The joints of square lattice are half lap joint without nail and glue. Douglas fir plywood 12 mm thick was used for exterior and interior sheathing for test specimen and no finish materials were used. Nails (designated as N50) of 2.75mm diameter and 50mm length connected the lattice members and the sheathing boards. The ends of the lattice members were fastened to beams and columns around the members by lag bolts of 9mm diameter screw. The sections of the beams and columns are all 150mm x 150mm. In order to compare the performance of the specimen (PLW), square lattice wall without plywood (LW) was prepared for static loading tests. The specimen (LW) is shown in Figure 3.

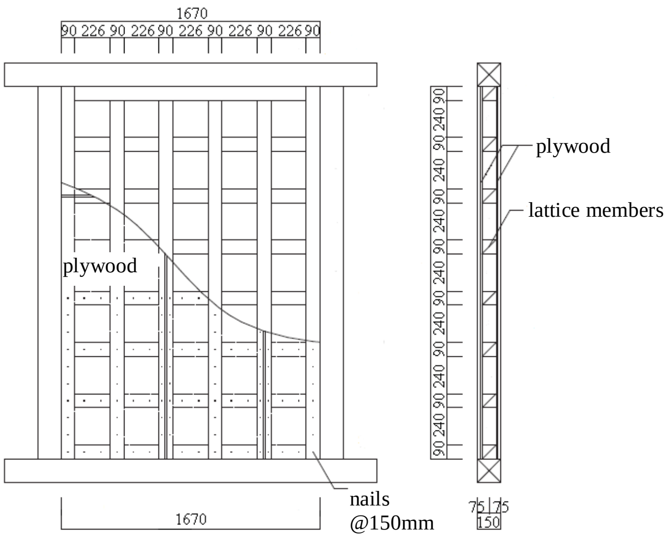

Figure 2. Test specimen of plywood-sheathed square lattice wall (PLW)

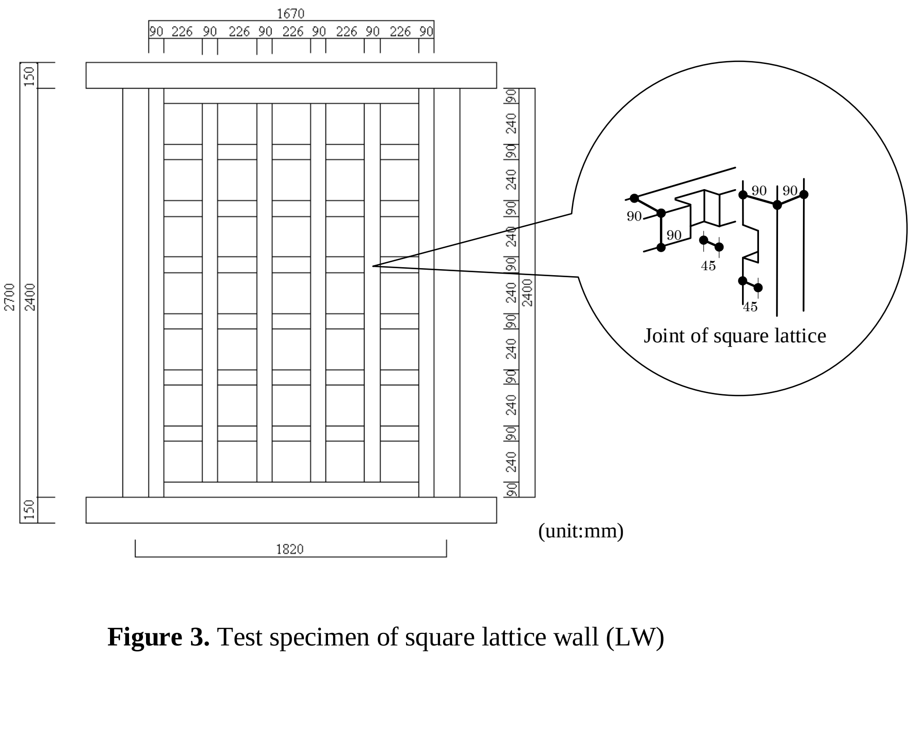

Figure 3. Test specimen of square lattice wall (LW)

3. STATIC LOADING TEST

3.1. Test Apparatus

The static loading test apparatus with a shear wall specimen in place is shown in Figure 4. Reversible horizontal loads were applied at the top of the frame by a hydraulic jack. The loading protocol is shown in Figure 5, and the loading to the specimen in the same amplitude is repeated 3 times.

Figure 4. Test apparatus

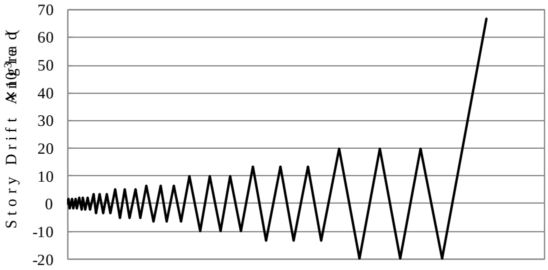

Figure 5. Loading protocol

3.2. Test results

The test results for static loading tests are presented in Figure 6 and Figure 7. The relations between story drift angle (relative displacement angle between the top and the base of the wall) and force of actuator are showed in the figure. Figure 6 and Figure 7 show that these specimens have stable hysteresis loop against the reversed cyclic loading. The enveloped curves of the experimental load are shown in Figure 8.

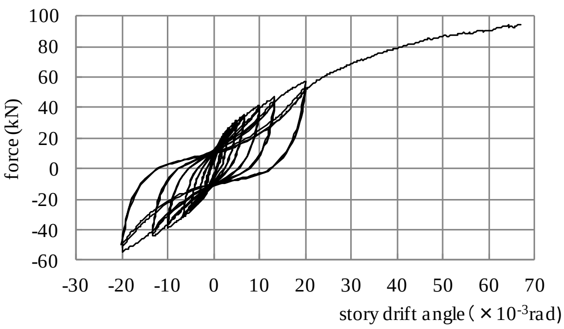

Figure 6. Load-drift angle curve for PLW

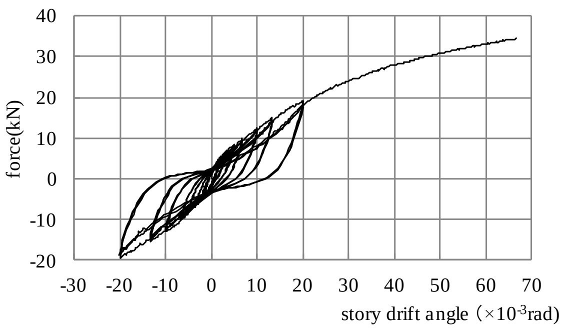

Figure 7. Load-drift angle curve for LW

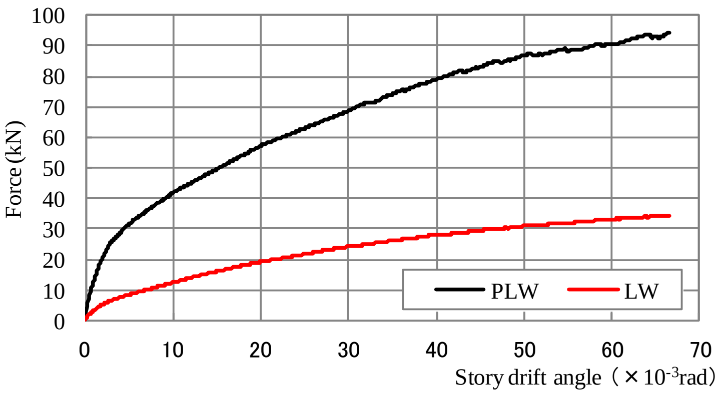

Figure 8. Enveloped curves of experimental results

It showed that bearing capacity of the plywood-sheathed lattice wall (PLW) is much larger than that of lattice wall (LW). And it is shown that bearing force of these specimen have not reduced in story drift angle more than 0.03radian. Equivalent stiffness and equivalent damping factor of this result (PLW) are shown in Table 1.

Table 1. Equivalent stiffness and viscous damping factor for PLW

Story Drift Angle ($\times10^{-3}$rad)	Equivalent Stiffness (kN/rad x 10^{-3})			Viscous Damping Factor		
	1st Loop	2nd Loop	3rd Loop	1st Loop	2nd Loop	3rd Loop
1.00	10.5	10.8	10.6	0.149	0.149	0.145
2.22	9.2	9.2	9.2	0.161	0.153	0.152
3.33	7.5	7.4	7.3	0.174	0.179	0.176
5.00	6.0	5.8	5.7	0.191	0.185	0.182
6.67	5.0	4.9	4.8	0.187	0.182	0.179
10.00	4.0	3.9	3.8	0.188	0.174	0.171
13.33	3.4	3.3	3.2	0.175	0.163	0.160
20.00	2.8	2.6	2.5	0.169	0.146	0.142

The equivalent damping factor is calculated by dividing energy dissipation by elastic deformation energy. The energy dissipation is calculated by summing the areas enclosed by the hysteretic loops. As the story drift angle becomes larger, the equivalent stiffness shows a tendency to decrease. On the other hand the equivalent damping factor has a near constant value of about 0.15 to 0.19. Although equivalent stiffness has a constant value by repetitive load, equivalent damping factor shows a tendency to decrease.

4. ANALYTICAL STUDY

This section describes analytical study on the proposed wall system. The analysis model was made by taking the experiment results into account. Incremental loading simulation was performed by the analysis model.

4.1. Analysis Model

Analysis model is shown in Figure 9, which modeled the experimental spacemen, as is shown in Figure 4. The analysis model is two-dimensional model for finite element analysis, which is composed of elastic beam elements and elastic shear plate elements. Square lattice is modeled by elastic beam elements, and non-linear spring showed in Figure 11, which is used for modeling behavior of the lap joint.

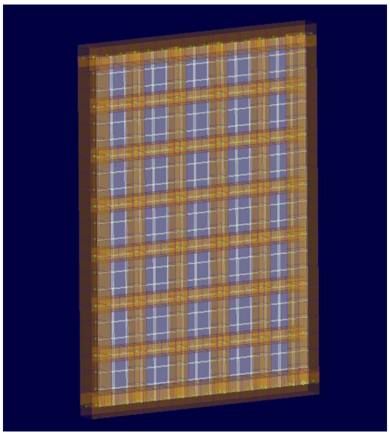

Figure 9. Analysis model by finite element method

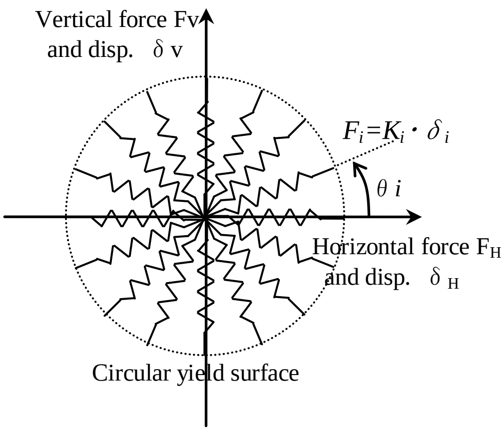

Figure 10. A multiple shear spring element

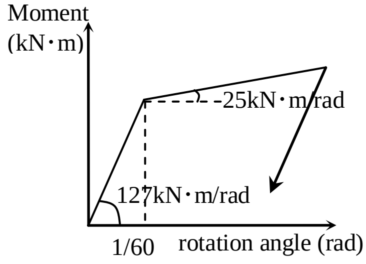

Figure 11. Analysis model for lap joint

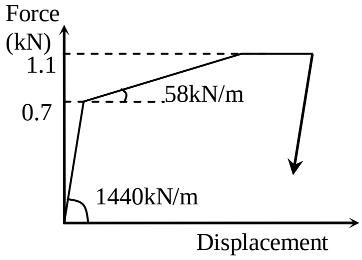

Figure 12. Analysis model for a nail

$$\begin{Bmatrix} F_H \\ F_V \end{Bmatrix} = \sum_{i=1}^{8} K_i \begin{bmatrix} \cos^2\theta_i & \cos\theta_i \cdot \sin\theta_i \\ \cos\theta_i \cdot \sin\theta_i & \sin^2\theta_i \end{bmatrix} \begin{Bmatrix} \delta_H \\ \delta_V \end{Bmatrix} \tag{4.1}$$

Plywood is modeled by elastic shear plate elements, and non-linear spring showed in Figure 12 is used for modeling the nails connecting plywood to lattice. To model the characteristics of two dimensional behavior of a nail, non linear multiple shear spring model (Wada et al. 1985) which have the property of circular yield surface was used. In this analysis a multiple shear spring element is composed of eight spring elements. Modeling concept of the shear spring is showed in Figure 10. Horizontal force F_H and vertical force F_V are described in Eq. 4.1 by using each directional displacement δ_H and δ_V.

4.2. Analysis Results

Analysis results of the simulation for the static loading tests are shown in Figure 13.

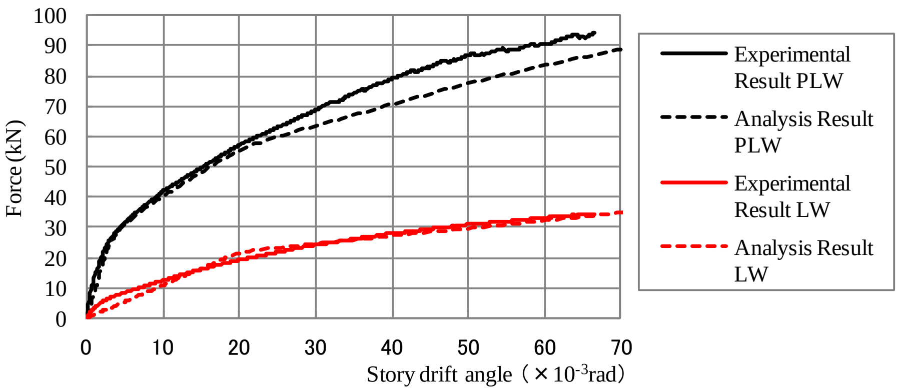

Figure 13. Enveloped curves of experimental results and analysis results

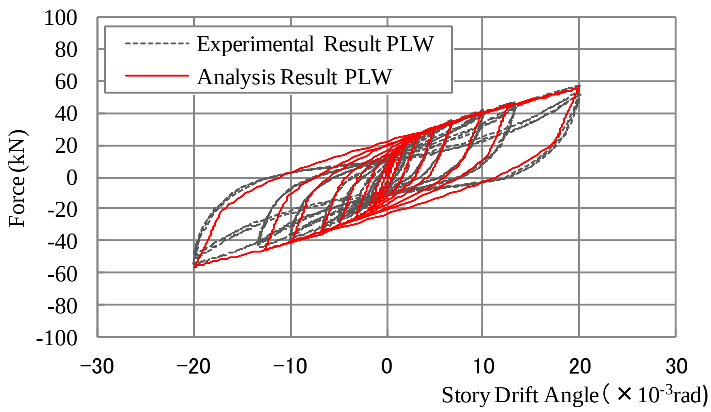

Figure 14. Hysteresis loops of experimental result and analysis result

Table 2. Equivalent stiffness and viscous damping factor of analysis result for PLW

Story Drift Angle ($x10^{-3}$rad)	Equivalent Stiffness (kN/rad x 10^{-3})				Viscous Damping Factor			
	1st Loop	2nd Loop	3rd Loop	Analysis Results	1st Loop	2nd Loop	3rd Loop	Analysis Results
1.00	10.5	10.8	10.6	13.5	0.149	0.149	0.145	0.070
2.22	9.2	9.2	9.2	10.9	0.161	0.153	0.152	0.144
3.33	7.5	7.4	7.3	8.0	0.174	0.179	0.176	0.197
5.00	6.0	5.8	5.7	6.2	0.191	0.185	0.182	0.219
6.67	5.0	4.9	4.8	5.1	0.187	0.182	0.179	0.239
10.00	4.0	3.9	3.8	4.1	0.188	0.174	0.171	0.239
13.33	3.4	3.3	3.2	3.5	0.175	0.163	0.160	0.228
20.00	2.8	2.6	2.5	2.8	0.169	0.146	0.142	0.219

The figure compares the enveloped curves obtained from the reversed cyclic loadings. It shows that the simulated load-deformation relationships agreed quite well with the experimental results, and the non-linear finite element method is an appropriate tool to analyze sheathed shear walls. On the other hand, hysteresis loops obtained from the reversed cyclic loadings are shown in Figure 14. In the figure, although a fair approximation can be realized by the finite element analysis, the hysteresis loop of analysis result has higher energy dissipation capacity than the experimental result. Thus equivalent stiffness and equivalent damping factor of the analysis results are shown in Table 2 as compared with experimental results. In the table, although the equivalent stiffness values of analytical results are in good agreement with the experimental results, the analytical equivalent damping values are much larger than experimental results. In order to analyze more accurately, it is necessary to take degradation of hysteresis loop into consideration.

5. CONCLUSIONS

Results obtained from this study are summarized as follows:
1) It is clearly showed that this bearing wall system has high bearing capacity and deformation performance, and it does not decrease in story drift angle greater than 0.03radian.
2) The way to make analysis model of this wall system from experiment results was proposed. And results of having analyzed by finite element method were in good agreement with the experiment results.
3) It becomes clear from analysis results that in order to analyze more accurately, it is necessary to take degradation of hysteresis loop into consideration.

AKCNOWLEDGEMENT
Experimental results of bearing wall systems were provided by Uotsu syaji corporation. The authors wish to express their appreciation to all the members of this research.

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