Experimental analyses for estimating strength and stiffness of shear walls in wood-framed construction

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ABSTRACT

One of the prominently important performance required for shear wall of wood-framed construction system should be to resist against the lateral forces subjected to wind or seismic load, and the shear strength and stiffness of wall are assessed on the basis of experimental results or results of calculation in accordance with the design guide[1] to wood-framed construction in Japan.

As to the specified calculation method in the guide for estimating shear strength and stiffness of wall, the properties of nailed joints and sheathing materials are dominant factor to correlate the also specified experimental results objected to a full-sized wall components. However, very limited experimental qualitative information pertaining to relationship between the result of calculation and experiment is available.

In this situation, this paper firstly shows the results on the properties of nailed joint and sheathing material and then shows the results of test determining the strength and stiffness of the shear wall according to the specified method for assessment in guide.

Data obtained from two experimental approaches the followings could be concluded; Calculated yield strength is approximately agreed with the experimental yield strength, and calculated stiffness is 65% of experimental stiffness.

1. INTRODUCTION

The wood-framed construction system has been introduced around the middle of 1970’s in Japan and this system has increasingly been applied into mainly timber housing area. From the view point of structural safety requirement, the strength and stiffness of shear wall should play important role in the system, and a couple of analyses have been already reported [2],[3],[4].

In the guide, yield strength (Py), stiffness (K) and ultimate strength (Pu) are determined based on the experimental results as shown Figure 1.

And the calculation method of yield strength Py (equation (1)) and stiffness K (equation (2)) are specified as follows and shown Figure 2.

Figure 1 Yield strength Py, stiffness and ultimate strength [1].

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\[ P_{\text{cal}} = P_{\text{nail}} \times s \quad (1) \]

where:
- \( P_{\text{cal}} \): calculated yield strength of shear wall
- \( P_{\text{nail}} \): experimental yield strength of nailed joints
- \( S \): number of nails = minimum \( \{ m-1, (n-1) \cdot \frac{w}{h} \} \)
- \( m \): number of nails for the horizontal direction of one side
- \( n \): number of nails for the vertical direction of one side

\[
\frac{1}{K_{\text{cal}}} = \frac{2}{K_{\text{nail}}} \times \left\{ \frac{1}{h(m-1)} + \frac{h}{w^2(n-1)} \right\} + \frac{h}{Gw} \quad (2) \]

where:
- \( K_{\text{cal}} \): calculated stiffness of shear wall
- \( K_{\text{nail}} \): experimental stiffness of nailed joints
- \( m \): number of nails for the horizontal direction of one side
- \( n \): number of nails for the vertical direction of one side
- \( G \): Shear modulus
- \( t \): Thickness of sheathing

The key factor in the specified calculation method in the guide are apparently properties of nailed joint and sheathing materials, however, only limited information on the quantitative relationship between calculated results according to the specified method and actual properties of nailed joint and sheathing materials is reported.

The main purpose of this paper is to provide the experimental data of shear walls, nailed joint and shear modulus of sheathings, and is to clear the relationship between the calculated and experimental strength and stiffness.

The scope and some details of experimental approach are shown in Figure 3.
2. EXPERIMENT OF SHEAR WALLS

2.1. Specimens
Shape and dimension of specimens are shown in Figure 4. Species of studs are Spruce-pin-fir (SPF) and side of walls consisted of the double studs. Hold-down metal fasteners are used at the bottom of corner to resist against uplift force due to lateral loads. Bottom and top plate of each wall assembly was firmly attached to an 89mm × 89mm timber and bottom timber secured steel basement of test apparatus.

Four kinds of sheathings (Canadian Softwood Plywood (CSP), Oriented Strand Board (OSB), Gypsum board and VW board) were tested. Nails were used CN50 and GN40 (GN40 was used only for gypsum board) which were provided Japanese Industrial Standards (JIS). Specimens of shear walls prepared two types of nails spacing which were 100mm and 50mm around the sheathings except the center (center nail spacing was 200mm). Table 1 shows the specification of sheathings and nails.

<table>
<thead>
<tr>
<th>Sheathings</th>
<th>thickness (mm)</th>
<th>Nails *1</th>
<th>Space of nails (mm)</th>
<th>Number of test specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSP Plywood</td>
<td>9.5</td>
<td>CN50</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OSB</td>
<td>9.5</td>
<td>CN50</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gypsumboard</td>
<td>12.5</td>
<td>GN40</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VW board *2</td>
<td>9.0</td>
<td>CN50</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*1 : Japan Industrials Standards A 5508
*2 : volcanic ash and wood fiber compound board

2.2 Procedure of experiment
The racking tests of wood-framed shear walls were carried out according to JIS A 1414 without tie-rods method. Test
specimens of shear walls were subjected by monotonic and cyclic loading. At first monotonic loading test was determined by yield displacement (Dy) for the Structural Design Guide described above and then cyclic loading tests were carried out based on the protocol which was shown Figure 5. Same loading protocol was used with nailed joint tests. Number of cyclic test on shear walls was three on the same sheathings and nail space. Loading rate of shear walls was approximately 1mm/sec, or less.

Shear displacement was calculated by the equation (3) and shown in Figure 4 and it subtracted displacement due to rotation of panel from the apparent horizontal displacement.

$$\delta = \delta_1 - \delta_2 \times \frac{h}{w}$$

where

- $\delta$: True deformation (mm)
- $\delta_1$: Horizontal displacement (mm)
- $\delta_2$: Rotation of panel due to vertical displacement (mm)
- $h$: height of panel
- $w$: length of panel

2.3 Results

Typical load-displacement curve for CSP plywood shear wall nailed by CN50 with spacing 100mm was shown in Figure 6. In this figure yield strength (Py), stiffness (K) and ultimate strength (Pu) were shown as a bold line. In this report all lateral loads of shear walls are corresponding to the wall length 0.91 meter.

Relationship between the yield strength Py and ultimate strength Pu for all test results was shown in Figure 7. The high correlation was admitted and ultimate strength Pu is about 1.5 times higher then Yield strength Py.

Relationship between the load for 1/120 radian deformation and yield strength Py are shown in Figure 8. The yield strength Py of the evaluation method in this paper is almost similar to the strength at 1/120 radian deformation.
Summary of the lateral load test on shear walls is shown in Table 2. Cyclic data is shown as the average of three tests.

From observation of test panels that were subjected to the lateral load, punching out of nails from the sheathings and pulling out of nails from the studs were confirmed as main failure modes. Under cyclic loading, fatigue fractures of nails caused at the part of walls.

4. EXPERIMENT OF NAILED JOINTS

4.1 Specimen and Test Procedure

Single shear tests of nailed joints were carried out in which materials were picked up from shear walls tested. Test specimens were consisted of the timber and sheathings as shown in Figure 9. Cyclic loading tests based on the protocol that was shown in Figure 5. Same loading protocol was used with shear wall tests. Number of monotonic and cyclic test on nailed joints was six on the same sheathings and nail length. Loading rate of nailed joints was approximately 1mm/sec or less.

4.2 Results of single shear test of nailed joints

Typical load-displacement curve of nailed joint for CSP plywood that is nailed CN50 was shown in Figure 10. In this figure yield strength (Py), stiffness (K) and ultimate strength (Pu) were shown as a bold line.

Relationship between the yield strength Py and ultimate strength Pu for all test results was shown in Figure 11. The high correlation was admitted and ultimate strength Pu is about 1.6 times higher then Yield strength Py.

Table 2 Results of strength and stiffness of shear walls

<table>
<thead>
<tr>
<th>Sheathings</th>
<th>Nail</th>
<th>Space of nails (mm)</th>
<th>Py (kN) mono.</th>
<th>Py (kN) cyclic</th>
<th>Pu (kN) mono.</th>
<th>Pu (kN) cyclic</th>
<th>K (kN/cm) mono.</th>
<th>K (kN/cm) cyclic</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSP Plywood</td>
<td>CN50</td>
<td>100</td>
<td>4.42</td>
<td>4.18</td>
<td>7.95</td>
<td>6.72</td>
<td>3.84</td>
<td>3.89</td>
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<td></td>
<td></td>
<td>50</td>
<td>10.79</td>
<td>9.28</td>
<td>17.03</td>
<td>13.22</td>
<td>7.01</td>
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<td>OSB</td>
<td>CN50</td>
<td>100</td>
<td>7.43</td>
<td>6.65</td>
<td>12.69</td>
<td>9.09</td>
<td>10.54</td>
<td>9.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>11.07</td>
<td>11.66</td>
<td>15.75</td>
<td>16.61</td>
<td>8.67</td>
<td>12.31</td>
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<tr>
<td>Gypsumboard</td>
<td>GN40</td>
<td>100</td>
<td>2.66</td>
<td>2.35</td>
<td>4.38</td>
<td>3.38</td>
<td>4.80</td>
<td>3.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>4.81</td>
<td>4.33</td>
<td>7.89</td>
<td>6.24</td>
<td>4.12</td>
<td>3.69</td>
</tr>
<tr>
<td>VW board *1</td>
<td>CN50</td>
<td>100</td>
<td>5.00</td>
<td>4.10</td>
<td>8.31</td>
<td>6.13</td>
<td>9.23</td>
<td>7.64</td>
</tr>
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<td></td>
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<td>50</td>
<td>7.23</td>
<td>7.42</td>
<td>10.50</td>
<td>10.51</td>
<td>8.64</td>
<td>7.22</td>
</tr>
</tbody>
</table>

*1: volcanic ash and wood fiber compound board
Cyclic data was shown as the average of three tests.
5. EXPERIMENT OF PANEL SHEAR TEST

5.1 Specimen and Test Procedure

Panel shear tests were conducted based on prEN 789:1995. Test specimens were same types of sheathings as those used in shear walls. (CSP plywood, OSB, Gypsum board, VW board) Sheathings consisted of 400mm width and 600mm height, and steel plate rails or timber rails were bonded to both sides of test specimen. On the end of both pair of rails consisted of a bevel of 14° where the major compression load is to be applied. Specimen and test apparatus was shown in figure 12.

5.2 Results of panel shear for sheathings

Stress-strain curves of panel shear test for CSP plywood sheathing are shown in Figure 13. And results of shear modulus and strength are shown in Table 4. OSB shows high shear modulus however, the value of standard deviation is very high. Gypsum board shows high shear modulus although the strength is low. In the calculation of shear walls, the average values of sheathing materials were used.
6. DISCUSSION

From the aspect of comparison of calculated and experimental values of shear walls, relationship between calculated and experimental values of yield strength $P_y$ and stiffness $K$ were shown in Figure 14. High correlation between calculated and experimental yield strength was shown as in Figure 14. Experimental yield strength is approximately 80% of the calculation yield strength. Experimental stiffness is approximately 65% of the calculation stiffness. The possible reason of difference is the influence of loading rate. Loading rate of shear wall and nailed joint was approximately 1mm/sec, however loading rate of nailed joints in the shear wall should be slow.

![Figure 12 Test specimen and test apparatus.](image)

![Figure 13 Stress-strain curve of CSP plywood](image)

<table>
<thead>
<tr>
<th>Sheathing</th>
<th>Shear Modulus $G$ (kN/cm²)</th>
<th>Shear Strength $T$ (N/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSP Plywood</td>
<td>49.8</td>
<td>429.2</td>
</tr>
<tr>
<td>OSB</td>
<td>122.1</td>
<td>658.8</td>
</tr>
<tr>
<td>Gypsum board</td>
<td>72.3</td>
<td>114.7</td>
</tr>
<tr>
<td>VW board</td>
<td>65.0</td>
<td>280.3</td>
</tr>
</tbody>
</table>

Table 4 Results of shear modulus and strength of sheathings
7. CONCLUSION

On the basis of the results obtained from both experiment analysis and calculated strength and stiffness of shear walls, the followings could be concluded.

1. Shear walls in wood framed construction are available to obtain Yield strength, stiffness and ultimate strength which were specified in the design guide to wood-framed construction in Japan.

2. The values of yield strength and stiffness of the shear walls were calculated using test results on nailed joints and shear modulus of sheathing materials, and were compared with the results of lateral load tests. As the results of comparison, yield strength obtained by tests showed about 80% of the calculated values, while stiffness of test results showed about 65% of the calculated values.

8. REFERENCE


