Deflections of Nailed Shearwalls and Diaphragms

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Summary
In designing shearwalls and diaphragms, engineers need to distribute horizontal shear forces from diaphragms to shearwalls, and to wall segments within the shearwalls. In order to facilitate those calculations, stiffness or deflection for various types of shearwalls and diaphragms need to be determined. Currently, only deflections for blocked shearwalls and diaphragms are provided in various wood design codes. Deflection for unblocked shearwalls and diaphragms are, however, still not available. In this paper, deflection formulae for unblocked shearwalls, shearwalls without hold-downs and shearwalls sheathed on two sides are presented and compared to test results.

Keywords: deflections, diaphragms, unblocked shearwalls, shearwalls without hold-downs, shearwalls sheathed on two sides

1. Introduction
In designing shearwalls and diaphragms that make up the platform-frame structure, one of the remaining questions is how to distribute the horizontal shear forces between shearwalls and shearwall segments. This question can be answered when stiffness or deflection equations become available for all types of shear walls and diaphragms. Currently, only deflections for blocked shearwalls and diaphragms are provided in various wood design codes. Deflection for unblocked shearwalls and diaphragms are, however, still not available. In the Canadian wood design standard CSA O86-01, design values were provided for shearwalls without hold-downs and shearwalls sheathed on two sides. Stiffness or deflection formulae for these types of shearwalls are also needed.

In this paper, methodologies for deflections of blocked shearwalls and diaphragms are provided. Deflection formulae for unblocked shearwalls, shearwalls without hold-downs and shearwalls sheathed on two sides were developed. Good agreement between test results and prediction were obtained.

2. Diaphragm and Shearwall Deflections
Blocked diaphragms and shearwalls are normally designed in a similar fashion to a steel plate girder where the wood-based panels, similar to the webs of girders, are considered to resist shear stresses and boundary framing members, similar to flanges, are considered to provide resistance to flexural stresses. Intermediate framing members stiffen the panels against buckling and provide shear splices at panel edges [1].

Deflection formulae of blocked diaphragms and shearwalls were provided in the Commentary of...
CSA O86-01, Engineering Design in Wood [2]. For a blocked diaphragm, it is assumed that the total deflection is the summation of bending deflection from flanges (boundary framing members) carry the bending moment, shear deflection of the panels forming the webs, and nail slip deflection due to relative movement of panels to framing members along panel boundaries, see Equation 1.

\[ y = \frac{5vL^3}{96EA \, b} + \frac{vL}{4B_v} + 0.0006Le_n \]  

(1)

where:

- \( A \) = area of flange cross section, mm\(^2\)
- \( B_v \) = shear-through-thickness rigidity of sheathing, N/mm
- \( b \) = diaphragm width, mm
- \( E \) = elastic modulus of flange, N/mm\(^2\)
- \( e_n \) = nail deformation, mm
- \( L \) = diaphragm length, mm
- \( v \) = maximum shear due to factored design loads in the direction under consideration, N/mm
- \( y \) = lateral deflection at mid-span, mm

The deflection of a blocked shearwall can be estimated similarly using the same approach. For the shearwall, a fourth term is added to account for the rotation of the shearwall due to hold-down deflection, see Equation 2.

\[ d = \frac{2vH^3}{3EA \, b} + \frac{vH}{B_v} + 0.0025He_n + \frac{H}{b}d_a \]  

(2)

where:

- \( A \) = area of boundary element cross section, mm\(^2\)
- \( B_v \) = shear-through-thickness rigidity of sheathing, N/mm
- \( b \) = wall width, mm
- \( d \) = deflection at the top of the wall, mm
- \( e_n \) = nail deformation, mm
- \( H \) = wall height, mm
- \( v \) = maximum shear due to factored design loads at the top of the wall, N/mm

2.1 Unblocked Shearwalls

The behaviour of an unblocked shearwall is quite different from a blocked shearwall. Typical failures of the unblocked walls were observed along the unblocked horizontal joints [3]. Because of the weak unblocked lines formed by horizontal gaps between panels, unblocked shearwalls do not act as girders but more like a series of individual beams which interact because of their connection to framing members [1], as shown in Figure 1. Assuming that the wood-based panels and framing members are rigid and wood-based panel deflect relative to the framing, the deflection of an unblocked shearwall can be estimated as:

\[ d = \frac{2vH^3}{3EA \, b} + \sum_{i=1}^{n} \frac{v h_i}{B_{v,i}} + H \theta + \frac{H}{b}d_a \]  

(3)

where:

- \( n \) = number of continuous unblocked horizontal lines
- \( h_i \) = height of wall section i between unblocked lines, mm
- \( \theta \) = stud rotation, radian
Based on moment equilibrium and nail slip formula in A10.9.3.2 of the CSA O86-01 [2], stud rotation can be obtained as:

\[ \theta \approx 2.5dK_m \left( \frac{s_i}{s_i + b n_u} \right)^{1.7} \frac{H_{s_n}}{\sum_{i=1}^{n+1} \left[ d_{i_{2.6}} + (h_i - a_i)^{2.6} \right]} \]  \( (4) \)

where:
- \( d \) = nail diameter, mm
- \( K_m \) = service creep factor
- \( s_t \) = stud spacing, mm
- \( s_n \) = nail spacing at intermediate studs, mm
- \( a_i \) = neutral point of the rigid stud within the wall section (see Figure 2), mm, which is equal to 0.67\( h_i \) for panels with one unblocked side, and 0.5\( h_i \) for panels with two opposite unblocked sides.

### 2.2 Shearwalls without Hold-Downs

For shearwalls without hold-downs, the uplift force is resisted by nail joints attaching the edge of the panel to the bottom plate. In this case, deflection formula for blocked shearwalls can be used where the deflection, \( d_a \), is determined by the nail joints along the bottom plate, as shown in Figure 3.

Based on force equilibrium, the nail deflection at the tension end is

\[ d_a \approx 2.5dK_m \left( \frac{(vH - P)s_n / b}{n_u} \right)^{1.7} \]  \( (5) \)

where \( s_n \) is the nail spacing around panel edge.

### 2.3 Shearwalls with Sheathings on Two Sides

Test results showed that the lateral load capacities are cumulative in the elastic range when same or different sheathing are applied on both sides [4,5]. As a result, shearwalls with sheathings on two sides can be treated as two separate walls, and the deflection of the shearwalls can be determined based on shearwalls sheathed with wood-based panels once the load distribution between the two sides can be determined.

\[ d = \frac{2v_p H^3}{3EA_b} + \frac{v_p H}{B_v} + 0.0025HE_{e_n} + \frac{H}{b} d_a \]  \( (6) \)

where \( v_p \) is the factored design load resisted by the side of wood-based panels at the top of the wall.
Assuming that $k_n$ and $k_g$ are the respective stiffness of the joints with wood-based panel and gypsum wallboard, and $s_n$ and $s_g$ are the respective nail spacing of the joints with wood-based panel and gypsum wallboard, the factored design load resisted by the side of wood-based panels is then:

$$v_p = \frac{v}{1 + \left(\frac{k_g}{k_n}\right)\left(\frac{s_n}{s_g}\right)} \quad (7)$$

### 3. Comparison with Test Results

Deflections obtained from tests as well as from predictions are summarized in Table 1. For blocked shearwalls and other configurations, predicted deflections are in good agreement with test results for loads up to one-third of factored lateral resistances. However, the formulae underestimate deflections at the factored lateral resistance. This is probably because the nail-slip formula in the CSA O86-01 underestimates joint slips at the factored lateral load resistance.

#### Table 1. Comparison of tested and predicted deflections for shearwalls with various configurations

<table>
<thead>
<tr>
<th>Type</th>
<th>Panel thickness mm</th>
<th>Nail diameter mm</th>
<th>No. of tests</th>
<th>Displ. at 1/3 factored lateral resistance, mm</th>
<th>Displ. at factored lateral resistance, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Test</td>
<td>Model</td>
</tr>
<tr>
<td>Blocked</td>
<td>9.5</td>
<td>3.0</td>
<td>8</td>
<td>1.83</td>
<td>1.86</td>
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<tr>
<td></td>
<td>12.5</td>
<td>3.0</td>
<td>4</td>
<td>1.76</td>
<td>2.29</td>
</tr>
<tr>
<td>Unblocked</td>
<td>9.5</td>
<td>3.3</td>
<td>2</td>
<td>1.92</td>
<td>1.71</td>
</tr>
<tr>
<td></td>
<td>9.5*</td>
<td>3.0</td>
<td>2</td>
<td>1.57</td>
<td>1.93</td>
</tr>
<tr>
<td>No hold-</td>
<td>9.5</td>
<td>3.0</td>
<td>1</td>
<td>2.17</td>
<td>1.95</td>
</tr>
<tr>
<td>downs</td>
<td>9.5</td>
<td>3.3</td>
<td>2</td>
<td>0.97</td>
<td>0.95</td>
</tr>
<tr>
<td>Two sides</td>
<td>9.5 b</td>
<td>3.0</td>
<td>3</td>
<td>0.79</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>9.5 c</td>
<td>3.0</td>
<td>1</td>
<td>0.58</td>
<td>0.52</td>
</tr>
</tbody>
</table>

Note: All shearwalls are 2.44 m in height. Nail spacing are 150 mm around panel edges (except panel edges along unblocked lines) and 300 mm at intermediate studs.

- a. Nail spacing is 150 mm everywhere.
- b. 12.7 mm gypsum wallboard nailed with screws ($d = 2.7$ mm) at nail spacing 200 mm around panel edges.
- c. 12.7 mm gypsum wallboard nailed with screws ($d = 2.7$ mm) at nail spacing 100 mm around panel edges.

### 4. Conclusion

Deflection formulae for unblocked shearwalls, shearwalls without hold-downs and shearwalls sheathed on two sides were developed and compared to test results. Further work is needed to improve the accuracy of the formulae and applicability to tall walls. Work is also needed to extend the nail slip formula to joint slip at its capacity so that deflections can be accurately estimated under earthquakes or strong winds.

### 5. Reference


