Sheathing Nail Bending-Yield Strength – Role in Shearwall Performance

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Abstract

Average nail bending-yield strength is used in the yield mode equations to establish reference single-nail lateral connection capacities that are the basis of shearwall design. By modifying the bending-yield strength of the sheathing fastener, connection lateral design capacity can be increased. This investigation sought to determine if bending-yield strength of the sheathing fasteners has a significant effect on shearwall performance as measured by maximum capacity, initial stiffness, displacement at maximum capacity, energy dissipated, ductility, and fastener failure modes. The study included cyclic single-nail lateral connection tests, numerical models of cyclic shearwall performance, and cyclic tests of shearwalls where sheathing nail bending-yield strength was the controlled source of variation. Sheathing nail bending-yield strengths were 600 MPa, 790 MPa, 1000 MPa, and 1660 MPa. Governing single-nail yield mode was Mode III, for all nails and reference design capacities were numerically bounded by 267 N and 387 N, which were the reference capacities for the 600 MPa and 1660 MPa nails, respectively. Shearwall tests following the CUREE test protocol showed significant differences in shearwall ultimate capacities between walls made with 600 and 790-MPa nails and the walls made with the 1000 or 1660-MPa nails. Initial stiffness, displacement at ultimate capacity, energy dissipated, and ductility were not affected by sheathing nail bending-yield strength. Overall, the sheathing nail bending-yield strength does not appear to be a strong factor in the cyclic performance of shearwalls when bending-yield stress is greater than 1000 MPa.
1. Introduction

The yield mode equations are used to establish the reference design capacities for nails and spikes. The numerical value of the governing yield mode is employed in design to establish allowable capacities for shearwalls and diaphragms and nailed connections. The parameters used in the yield mode equations include embedment capacities of the materials, geometry of the connection, fastener geometry, and bending-yield strength ($f_{yb}$) of the fastener. In the derivation of shearwall and diaphragm allowable shear properties, the capacity is a linear function of the lateral single-nail connection capacity (APA 138). This design method assumes that the single-nail connection properties translate directly to the assembly performance.

Bending-yield strength of nails can be manipulated by wire chemistry and the amount of cold working that is imposed on the wire. The specified minimum $f_{yb}$ of sheathing nails that is typically used in wood-to-wood connections with diameter in the range of 2.5 mm to 3.7 mm is 690 MPa (ASTM F1667, AF&PA 2001). Typical structural nails in this size class have mean $f_{yb}$-values in the range of 690 MPa to 896 MPa.

The objective of this research was to examine the hypothesis that the shearwall performance is a function of sheathing nail $f_{yb}$ as suggested by current design practice where performance is evaluated based on maximum capacity ($P_{max}$), initial stiffness ($K_0$), displacement at maximum capacity ($\delta_u$), energy dissipated (Energy), and ductility.

2. Methods and Materials

Stanley BOSTITCH® manufactured nails with four characteristic $f_{yb}$ values: 600 MPa, 790 MPa, 1000 MPa, and 1660 MPa. The nails were 2.87-mm diameter and 60-mm long with a round head and smooth shank. The nail $f_{yb}$ was determined by test following ASTM F1575. The other building materials were Stud grade Douglas Fir-Larch and 11-mm oriented strand board (OSB) sheathing (Exposure 1). The average moisture contents were 8.7% and 7.1%, respectively.

The yield mode equations of NDS, Part 11 (AF&PA 2001) were used to determine the expected yield mode and reference design capacity of the single-nail connections (Table 1).

2.1 Lateral Single-Nail Connection Tests

The CUREE loading protocol as described in ASTM E2126 was used to evaluate the single-nail connection properties. The test specimens were made using materials that were extracted from shearwall specimens after the walls had been tested. The configuration of the connection test specimens was that of a sheathing nail connection that would be used for a static lateral nail resistance test. Twenty-four connection specimens were tested with each type of nail. The test specimen, fixture, and instrumentation are described by Anderson (2005).
The data were evaluated with a program, SASHFIT (Elkins and Kim 2003), to extract the hysteretic parameters necessary to characterize the nonlinear cyclic connection behavior. These were summarized as mean values and used in the CASHEW shearwall models as described in Section 2.3.

2.2 Shearwall Tests

Eight shearwalls 2400 by 2400 mm were constructed using 38 by 89-mm framing spaced 406 mm on center, 11-mm OSB sheathing, and complete anchorage with hold-downs (Fig. 1). The nails with different $f_{yb}$ values were used only for the sheathing nails, the framing nails were typical construction nails. The sheathing nails were spaced 102 mm on the perimeter and 305 mm in the field. The framing nails followed the IBC (2003). Two walls with each $f_{yb}$ sheathing nail were tested.

The shearwalls were tested in accordance with ASTM E2126 following the same cyclic (CUREE) loading protocol that was used for the single-nail connections. The reference displacement of 75 mm was established from experience and to maximize the potential to cause post-yield behavior. Initial stiffness ($K_0$) was determined from the ascending branch of the first primary cycle between 10% and 40% of the maximum load. Energy was the total area enclosed by all loops of the hysteretic load-displacement diagram, and ductility was calculated as the displacement at maximum load divided by the yield load displacement.

2.3 Numerically Modeled Shearwalls

The average cyclic single-nail connection hysteretic parameters were used in CASHEW (Folz and Filiatrault 2000), which combines the geometry of the shearwall with the hysteretic connection parameters to predict the cyclic load-displacement response and energy dissipation of the shearwall under user-defined loading. The shearwall hysteretic
parameters and user-defined properties were then used in a program that performs dynamic
time-history analysis where the shearwall is assumed to be adequately represented by a
single-degree-of-freedom model. The single-degree-of-freedom hysteretic model was used
to predict shearwall responses to the CUREE loading protocol. This was described by Sutt
et al. (2004) and Anderson (2005) for these and other analyses.

3. Results and Discussion

The mean nail $f_{yb}$ and computed reference connection capacities are shown in Table 1. The
computed yield modes for the single-nail connections were found to be Mode III,
regardless of nail $f_{yb}$. The 600 MPa nail is not in compliance with ASTM F1667 for this
diameter class -- the $f_{yb}$ is less than the required minimum of 690 MPa. The low $f_{yb}$ value
of this treatment was deliberate; the experimental design represented nails that ranged from
-15% to approximately 240% of the minimum specification.

The single-nail connection hysteretic parameters are completely detailed in Anderson
(2005) for each single-nail test. The summarized results (Table 2) show an increase in
initial stiffness (p-value = 0.002) and connection capacity (p-value < 0.001) with
increasing $f_{yb}$ relative to the properties of the 790 MPa nail. The lower two nails (600 MPa
and 790 MPa) performed equivalently with respect to maximum capacity ($P_{max}$). The
capacity of the connections with 1000 MPa nails was 9% greater than the capacity of the
connexions with 790 MPa nails, and the 1660 MPa nail connections had maximum
capacities 26% greater than that of the 790 MPa nails. The computed reference design
capacities (Table 1) were enhanced by a greater percentage with increased $f_{yb}$ than the
tested connection ultimate capacities; the reference design capacity was increased 33% for
the 1660-MPa nail connection as compared to the connection with the 790-MPa nail.

The single-nail connection performance properties were not directly reflected in the
CASHEW model results (Table 3). The CASHEW shearwalls showed an increase in
capacity with each increment in sheathing nail $f_{yb}$. The $K_0$, $\theta$, and energy dissipated were
not affected by the sheathing nail $f_{yb}$ treatment. The shape of the backbone curves from the
CASHEW tests generally followed the shearwall tests (Fig. 2).

<table>
<thead>
<tr>
<th>Nail $f_{yb}$</th>
<th>$f_{yb}$ (MPa)</th>
<th>Reference Design Capacity (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>600</td>
<td>599.8</td>
<td>43.7</td>
</tr>
<tr>
<td>790</td>
<td>792.9</td>
<td>25.0</td>
</tr>
<tr>
<td>1000</td>
<td>999.8</td>
<td>39.6</td>
</tr>
<tr>
<td>1660</td>
<td>1661.7</td>
<td>30.8</td>
</tr>
</tbody>
</table>

Table 1. Nail $f_{yb}$ properties (n=24) and controlling computed single-nail reference
design connection capacities.
Table 2. Test results for cyclic single-nail lateral connection tests by nail $f_{yb}$ ($n=24$).

<table>
<thead>
<tr>
<th>Nail $f_{yb}$</th>
<th>Cyclic Performance Parameter</th>
<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td>$K_0$</td>
<td>$P_{max}$</td>
</tr>
<tr>
<td></td>
<td>(N/mm)</td>
<td>(N)</td>
</tr>
<tr>
<td>600</td>
<td>450 (83.4)</td>
<td>1273 (245.0)</td>
</tr>
<tr>
<td>790</td>
<td>420 (61.5)</td>
<td>1279 (142.2)</td>
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<tr>
<td>1000</td>
<td>520 (55.4)</td>
<td>1395 (177.8)</td>
</tr>
<tr>
<td>1660$^{c}$</td>
<td>548 (66.0)</td>
<td>1606 (190.6)</td>
</tr>
</tbody>
</table>

$^a$Parenthetical values are standard deviations.
$^b$11-mm OSB with DF-L framing.
$^c$n=21

The cyclic (CUREE) shearwall tests were summarized with average backbone curves (Fig. 2). The test walls did not follow the same trend with respect to ultimate capacity as the CASHEW models predicted (Table 3). Analysis of variance (significance level = 0.05) of the performance parameters for tested walls in Table 3 indicated that $K_0$, $\delta_u$, Energy, and ductility were not affected by sheathing nail $f_{yb}$. However, a significant difference was identified for $P_{max}$. A subsequent comparison test using Tukey’s least significant difference procedure (significance level = 0.05) showed that shearwall capacities for the 600 and 790-MPa sheathing nails were equivalent and the shearwall capacities for the 1000 and 1660-MPa sheathing nails were equivalent.

Fig 2 Average backbone curves by sheathing nail $f_{yb}$ for cyclic (CUREE) shearwall tests from Anderson et al. (in review).
The failure mode of every nail in each test shearwall was observed (Anderson 2005). Withdrawal was the typical failure mode for the 600, 790, and 1000-MPa sheathing nails. Some fatigue was observed in each of these test walls. Nail fatigue failure was increased as a failure mode when the nail $f_{yb}$ was 1660 MPa while withdrawal failure was decreased.

<table>
<thead>
<tr>
<th>Nail $f_{yb}$</th>
<th>Wall</th>
<th>$K_0$ (N/mm)</th>
<th>$P_{max}$ (kN)</th>
<th>$u$ (mm)</th>
<th>Energy (kN•mm)</th>
<th>Ductility</th>
</tr>
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<tr>
<td>Test walls</td>
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<tr>
<td>600</td>
<td>1</td>
<td>1,964</td>
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<td>14,846</td>
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<td></td>
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<td>31.8</td>
<td>53.6</td>
<td>14,055</td>
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<td>Mean</td>
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<td>68.8</td>
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<td>77.5</td>
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<td>74.7</td>
<td>15,251</td>
<td>9.08</td>
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<tr>
<td></td>
<td>Mean</td>
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<td>38.30B</td>
<td>76.1</td>
<td>15,717</td>
<td>9.42</td>
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<td>Numerically modeled (CASHEW) walls</td>
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<td></td>
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<tr>
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<td>1,985</td>
<td>37.0</td>
<td>51.4</td>
<td>15,587</td>
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<td>2,201</td>
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<td>40.4</td>
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<td>15,844</td>
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</table>

$^a$Tukey’s least significant difference comparison ($a=0.05$).

4. Conclusions

The single-nail connection tests and calculated reference design capacities showed that shearwall capacity should increase with increased sheathing nail $f_{yb}$. Cyclic tests of shearwalls showed peak capacity of the shearwalls having 1000-MPa sheathing nails was 12% greater than the peak capacity of shearwalls with 790-MPa sheathing nails; no further increase in ultimate shearwall capacity was observed by using 1660-MPa sheathing nails. Similarly, sheathing nails with $f_{yb}$ 15% below the specified minimum value of 690 MPa do not diminish shearwall performance when compared to shearwalls with sheathing nails that meet current $f_{yb}$ specification. The implication of this result is that the yield mode equations are more conservative at lower $f_{yb}$ levels than at elevated levels of $f_{yb}$ in wood sheathing-framing connections. The single-nail connection tests also suggested that the initial stiffness of shearwalls should increase with increasing sheathing nail $f_{yb}$ above 790.
MPa, but the CASHEW shearwalls and shearwall tests contradicted this expectation. The initial stiffness, displacement at peak capacity, energy dissipated, and ductility of shearwalls were not affected by sheathing nail $f_{y_b}$. The dominant failure mode for the sheathing nails was withdrawal; the 1660-MPa sheathing nail exhibited more fatigue than the other nails. We concluded that $f_{y_b}$ of the sheathing nail $f_{y_b}$ is not a major factor in shearwall performance when $f_{y_b}$ exceeds 1000 MPa.

5. Acknowledgements

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6. References


