LABORATORY TESTING TO INVESTIGATE PNEUMATICALLY DRIVEN BOX NAILS FOR THE EDGE NAILING OF 3/8" THICK PLYWOOD SHEAR WALLS

Seb J. Ficcadenti, S.E.!, Thomas A. Castle, C.E.!!
Deborah A. Sandercock iii and Robert K. Kazanjy, P.E.iv

ABSTRACT

Laboratory tests were conducted to investigate the performance of pneumatically driven box nails used in 3/8" thick plywood sheathed shear wall panels. Panels built with 8d pneumatically driven box nails were compared to panels built with 8d common wire nails. Panels built with different percentages of over-driven box nails (where the nail head pierces the face of the plywood sheathing by at least 1/16 of an inch) were also tested to determine the effect of overdriving on panel strength.

INTRODUCTION

A total of nine (9) plywood wall panels were tested. Four (4) panels were built with common wire nails and five (5) panels were built with pneumatic box nails. All the panels were 8 feet tall and 8 feet long and similar in framing configuration, sheathing type, nail size and nail spacing. The only variation between the panels was the type of nail used (common or box) and the method of nail installation (by nail gun or hand).

!Principal, Ficcadenti & Waggoner Consulting Structural Engineers, Inc., Newport Beach, CA 92660
!!Principal, Ficcadenti & Waggoner Consulting Structural Engineers, Inc., Newport Beach, CA 92660
!!Graduate Student, Department of Civil and Environmental Engineering, University of California, Irvine, CA 92717 and Design Engineer, Ficcadenti & Waggoner Consulting Structural Engineers, Inc., Newport Beach, CA 92660
ivSenior Development Engineer, Department of Civil and Environmental Engineering, University of California, Irvine, CA 92717
Two of the four panels built with common nails had nails with a yield strength typical of common nails produced today (approximately 132 ksi [1]). The other two panels had common nails with a slightly lower yield strength (tested at 95 ksi) to create control samples with capacities similar to the capacity given in the Uniform Building Code [2]. Of the five panels built with box nails, the first two panels were general samples. The remaining three panels had specific percentages of over-driven nails, built intentionally to study the effects of over-driving.

All the panels were subjected to the same displacement based cyclic loading sequence. Strength, stiffness and energy dissipating qualities of the different panels were noted. Other interesting results were the failure mode and the post testing residual integrity of each sample. The testing was documented through data, graphs, photos and notes (some of which are included in this report).

BACKGROUND

It is and has been a common practice of designers to specify the use of common nails for the edge nailing of 3/8" thick plywood shear walls. The nails specified in the Uniform Building Code (U.B.C.) plywood shear wall tables are either common wire or galvanized box and designers use these nails because tested allowable design values are readily available. In the field, however, it is a common practice for 3/8" thick plywood shear walls to be built using pneumatically driven box nails. The U.B.C. [2] does not specifically define whether the pneumatically driven box nails fit the criteria to allow the use of given tabulated values found in Table 23 - I - K - 1 (Table 25 - K - 1 in previous editions of the U.B.C.). Since the use of the pneumatically driven box nail has been common for a number of decades and is still the preferred method in constructing 3/8" thick plywood shear walls, a need to investigate the strength of such panels was identified.

The U.B.C. design values for plywood shear walls are based on the application of a reasonable load factor to ultimate load capacities determined through testing of actual shear walls. The American Plywood Association (A.P.A.) has done a number of tests both to verify U.B.C. values as well as to investigate different configurations. The A.P.A. tests have relied on load factors of 3.0 and higher to be acceptable[4]. It must be noted that the A.P.A. tests and those used to determine the U.B.C. values were unidirectional tests that subjected the panels to monotonic loading.

The tests in this study, however, subjected the panels to cyclic loading. The cyclic loading facilitated the investigation of the energy dissipating qualities of the panels, along with their strength and stiffness.

The panels with over-driven nails were tested because it is a common occurrence when using pneumatic nail guns to install a certain number of over-driven nails. This is due to two factors: (1) the nail gun provides a single strike installation wherein the nail is fully embedded with one strike from the gun and (2) although the force with which the gun hits the nail is constant at any one setting, the density of the receiving member (studs, plates, posts, etc.) varies from location to location. As a result, a pneumatically nailed panel typically contains a number of nails that pierce the sheathing in locations where the receiving member is softer than the locations at which the setting on the nail gun was made.

MATERIALS

All the panels are similar except for the change in the nail type, method of installation and the percentage of over-driven nails. The panels are framed with Douglas Fir - Larch 2x4 stud grade members for the sill plates, top plates and intermediate vertical studs. The 4x4 posts at the ends of the panel are also Douglas Fir - Larch. The panel sheathing is 3/8" type CDX plywood.
The sheathing is applied in two vertical 4 foot x 8 foot sheets with a 2x4 stud at the adjoining panel edge.

All framing members are connected using vinyl coated 16d sinkers. Sheathing nails are either 8d common nails or 8d pneumatically driven box nails and spaced at 2 1/2" on center. All nails used are American made and nails of each nail type came from the same box. Figure 1 shows the sample panel.

Figure 2 shows the heads of the different nails tested. Dimensions given for head and shank diameters are from Federal Specification FF-N-105B (Type II, style 10-common nail per paragraph 3.6.11.2 & Type II, style 4-box nail per paragraph 3.6.5), [3]. All other dimensions are from caliper measurements of actual nails used in testing.
TEST METHODS

The testing apparatus used is shown below in Figure 3. It consisted of a raised metal base where the sill of the test panel was attached to resist sliding, and a steel I-beam at the top that was placed on the test panel to uniformly induce the lateral load to the top plate of the wall. The test setup also included threaded rods at each end of the panel connecting the I-beam to the metal base that provided resistance to overturning. Loading of the test panel was accomplished by a hydraulic jack that moved the I-beam which in turn loaded the test panel. A load cell was placed between the jack and the I-beam to measure the resistance of the panel. Computers were used both to set the loading sequence that drove the jack and to record the data from each test. This data included elapsed time, displacement and resisting force and was recorded 50 times per second. In this set up, displacements due to sliding and overturning were reduced to a minimum so the recorded displacements at the top plates were due to pure racking of the test panel. Therefore, strength, stiffness and energy dissipating properties could be derived directly from the recorded values for displacement and resistance.

![Diagram of Testing Assembly](image)

FIGURE 3. Testing Assembly

The loading sequence used in the testing is a modification of the cyclic loading sequence now being considered by the Structural Engineers Association of Southern California Ad Hoc Committee on Testing Standards. The modified loading sequence reduced the number of cycles at a given displacement increment. The proposed sequence from the Testing Committee has a four cycle ring down series plus three additional cycles at each increment of displacement, whereas the modified sequence has only the four cycle ring down series at each increment of displacement. Each four cycle ring down series consists of an initial maximum induced displacement for that increment followed by a ring-down to 75%, to 50% and to 25% of the initial displacement. The modified sequence reduced the total number of cycles from 72 to 39 cycles. The larger number of cycles in the sequence under consideration by the Testing Committee can cause fractured nails due to fatigue. Fractured or fatigued nails have not been reported in timber structures damaged by seismic events.
Below are the labels and descriptions for each of the test panels:

- **PANELS 1A & 1B**: hand-driven common nails (95 ksi)
- **PANELS 2A & 2B**: pneumatically driven box nails
- **PANELS 3A & 3B**: hand-driven common nails (132 ksi)
- **PANEL 4A**: pneumatically driven box nails (50% of the nails are overdriven at least \( \frac{1}{16} \) inch)
- **PANEL 4B**: pneumatically driven box nails (20% of the nails are overdriven at least \( \frac{1}{16} \) inch)
- **PANEL 4C**: pneumatically driven box nails (80% of the nails are overdriven at least \( \frac{1}{16} \) inch)

**RESULTS AND DISCUSSION**

The ultimate strength and the displacement at the top of the panel at the U.B.C. specified design load were recorded for each test panel. Factors of safety for the panels were generated by comparing the ultimate strength to the value derived from the U.B.C. for this type of shear wall. From the displacement values, a drift percentage was calculated at design load for each test panel.

Hysteresis loops were generated by plotting load values versus displacement values on a graph. These loops describe the energy dissipating capacity of each panel. The energy absorbing or dissipating ability of a panel is defined as the area within the hysteresis loops. This area is influenced by the amount of deflection the panel can withstand beyond its elastic range before it sustains a substantial loss in lateral resistance capacity. This inelastic deflection without a substantial loss of capacity and the resultant damage to the panel are the mechanisms by which the panels dissipate energy.

Table 1 below shows the maximum load value for each of the test panels and the displacement at the top of the wall at the U.B.C. specified design load. The capacity for this type
of wall was interpolated from U.B.C. Table 23- I - K-1 for a 3/8" CDX plywood wall with 8d nails at 2 1/2" on center with studs at 16" on center and was found to be 565 plf (4520 lbs. for an 8 foot panel). The factor of safety was calculated by dividing the ultimate load by the design load. In plywood shear wall construction, it has been determined through other testing that a factor of safety of 3.0 or higher is acceptable. All the test panels met this criteria. The percentage drift value is the amount of displacement at design loads divided by the height of the wall in inches. From the graphs of the load vs. the displacement, the overall ductility for each of the different panels can be compared. The areas from each of the graphs can be used to make a comparison of the energy dissipating capabilities of the different test panels.

**TABLE 1.**

<table>
<thead>
<tr>
<th>PANEL</th>
<th>MAXIMUM LOAD</th>
<th>ULTIMATE CAPACITY</th>
<th>DISPL. @ DESIGN LOAD (565 plf)</th>
<th>SAFETY FACTOR</th>
<th>% DRIFT @ DESIGN LOAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>13860#</td>
<td>1733 plf</td>
<td>0.24 in.</td>
<td>3.072</td>
<td>0.25 %</td>
</tr>
<tr>
<td>1B</td>
<td>14189#</td>
<td>1774 plf</td>
<td>0.37 in.</td>
<td>3.145</td>
<td>0.39 %</td>
</tr>
<tr>
<td>2A</td>
<td>14056#</td>
<td>1757 plf</td>
<td>0.27 in.</td>
<td>3.115</td>
<td>0.28 %</td>
</tr>
<tr>
<td>2B</td>
<td>14534#</td>
<td>1817 plf</td>
<td>0.23 in.</td>
<td>3.221</td>
<td>0.24 %</td>
</tr>
<tr>
<td>3A</td>
<td>14956#</td>
<td>1870 plf</td>
<td>0.25 in.</td>
<td>3.315</td>
<td>0.26 %</td>
</tr>
<tr>
<td>3B</td>
<td>14308#</td>
<td>1789 plf</td>
<td>0.36 in.</td>
<td>3.171</td>
<td>0.38 %</td>
</tr>
<tr>
<td>4A</td>
<td>15292#</td>
<td>1912 plf</td>
<td>0.33 in.</td>
<td>3.389</td>
<td>0.34 %</td>
</tr>
<tr>
<td>4B</td>
<td>16287#</td>
<td>2036 plf</td>
<td>0.19 in.</td>
<td>3.610</td>
<td>0.20 %</td>
</tr>
<tr>
<td>4C</td>
<td>14863#</td>
<td>1858 plf</td>
<td>0.25 in.</td>
<td>3.294</td>
<td>0.26 %</td>
</tr>
</tbody>
</table>

All the test panels have very similar stiffness at design values. The first two common nail panels, 1A and 1B, were built using nails with a yield strength of 95 ksi to get a control sample with capacities close to U.B.C. specified values. The other two common nail panels, 3A and 3B, were built with the common nails having a yield strength of 132 ksi which is typical of present day common nails [1]. The second pair of common nail panels were slightly stronger than the first panels tested. The weaker nails bent easier and dug into the sheathing. This led to the nail pulling through the sheathing at a lower force level than the nails with a higher yield strength. The box nail panels, 2A and 2B, were general box nail panels and had strengths comparable to the stronger common nail panels. The test panels built with a specific percentage of over-driven box nails, 4A, 4B and 4C, were found to be as strong as or stronger than the common nail panels.

The load vs. displacement graphs are shown below in Figures 5A through 5F (repeated tests are not included - graph of 1A shown, 1B is similar). Energy dissipation is measured by the area within the loops on the graph. Through numerical integration it was determined that the panels built with the box nails have areas from 18% to 38% greater than the areas for the common nail panels.
FIGURE 5A.: Panel 1A

FIGURE 5B.: Panel 2A

Figure 5C.: Panel 3A
FIGURE 5D: Panel 4A

FIGURE 5E: Panel 4B

FIGURE 5F: Panel 4C
It is important to note the sudden drop in capacity on the graphs of the common nail test panels (see 1A and 3A). The box nail panel with 80% of its nails over-driven also has a drop in capacity, although it is not as drastic as it is with the common nail panels. These drops in capacity are the result of the edge nails at the center vertical joint pulling through the plywood sheathing. Figure 6 depicts the pulled through plywood nails at this center vertical joint. The common nail panels "unzipped" at the center. Almost all the nails pulled through at this vertical joint. The failure of the common nail panels was abrupt. The thick smaller head of the common nails penetrates most of the first plywood layer and its arrowhead shape makes it easier for the head to wedge its way through the remaining sheathing.

![Common nail panel](image1)

**FIGURE 6.** Common nail panel

![Box nail panel](image2)

**FIGURE 7.** Box nail panel

Some of the box nail panels also had nails pull through the sheathing. This pull through was not as pervasive or as sudden as with the common nail test panels and resulted in a more gradual degradation of the panel. Very few nails pulled through the sheathing on the box nail panels that had low percentages of over-driven nails. Most of the box nails simply withdrew slightly out of the stud. This withdrawal measured approximately 1/4 of an inch or less, and is depicted in Figure 7. The test panels with relatively few over-driven box nails showed no sudden drop in capacity. The test panel with 80% of the box nails over-driven has a relatively gradual drop in capacity due to incremental pull through of the nails. The resultant damage to the test panels is summarized below:

- **Panel 1A:** Almost all the nails on both sides of the adjoining panel edge pulled through the sheathing.

- **Panel 1B:** All the nails on the right side of the adjoining panel edge pulled through the sheathing.

- **Panel 2A:** Most of the nails pulled out of the stud slightly at the adjoining panel edge with only 6 or 8 nails pulling through the sheathing.

- **Panel 2B:** Similar to Panel 2A.
Panel 3A: All the nails on left side of the adjoining panel edge pulled through the sheathing.

Panel 3B: All the nails on right side of the adjoining panel edge pulled through the sheathing.

Panel 4A: Almost all the nails on left side of the adjoining panel edge pulled through the sheathing.

Panel 4B: Most of the nails pulled out of stud slightly at the adjoining panel edge with only a very few nails pulling through the sheathing.

Panel 4C: All the nails on right side and about half of the nails on the left side of the adjoining panel edge pulled through the sheathing.

CONCLUSIONS

The following conclusions were reached from the testing: (1) the $3/8"$ thick plywood panels built with 8d box nails are as strong as or stronger than those built with 8d common nails, (2) the box nail and the common nail panels have a similar stiffness at design level loads, (3) the box nail panels have a more gradual degradation than the common nail panels, (4) the box nail panels have a higher energy dissipating ability than the common nail panels, (5) a high percentage of over-driven box nails adversely affects the strength of the panel, but does not bring its strength below a comparable common nail panel without over-driven nails and (6) the box nail panels have a greater residual integrity after the test than do the common nail panels.

The shape of the nail head has a large effect on the panel performance when installed with $3/8"$ plywood. The head of the common nail causes it pull through the thinner plywood more easily for three reasons: (1) when driven flush the thick head penetrates most of the first plywood layer, (2) its tapered head aids it in working through the remaining sheathing, and (3) the area on the underside of the head that is used to bear against the plywood is smaller on the common nails than on the box nails (0.04851 square inches versus 0.05927 square inches). The 22% larger head area on the underside of the box nail results in a larger capacity to resist pull through as compared to the common nail head.

These cyclic tests confirm that $3/8$ inch thick plywood shear walls installed with pneumatically driven box nails are as strong as or stronger than similar shear walls installed with hand driven common nails. A similar result was reported in monotonic tests conducted by the American Plywood Association in 1976 by Noel R. Adams [5] where he concluded:

"Equality of box and common nails for this application is probably associated with the type of failure encountered. Box nails have approximately the same diameter heads as common nails, although thickness of both head and shank is less than for common nails. Since specimens in these tests typically failed by pulling nail heads through the plywood, it is understandable that the two types of nails with equal head size should provide equal strengths."

Adams' tests showed that $3/8$ inch thick plywood shear walls installed with common nails and with box nails have equal strength when subjected to monotonic loading. In addition Adams
found that both common nailed and box nailed \( \frac{3}{8}'' \) plywood shear walls failed by pulling nail heads through the plywood.

The cyclic tests in this study show that common nailed \( \frac{3}{8}'' \) inch thick plywood shear walls fail by pulling nail heads through the plywood. However, pneumatically driven box nailed \( \frac{3}{8}'' \) inch thick plywood shear walls are less likely to fail in this way. Instead, they are more likely to fail through nail withdrawal that characteristically dissipates more energy than the nail pull through mode of failure. As previously stated, the differences in failure mode can be attributed to the different net areas on the underside of the respective nail heads. The box nail's 22\% larger net area on the underside of its head affords it greater resistance against premature failure due to its nail head pulling through the plywood.

The most significant difference between the panels built with box nails to those built with common nails was in their abilities to dissipate energy. The box nail panels went through more cycles without failure than the common nail panels. The greater ductility of the panels with box nails makes the use of box nails preferable from a seismic engineering stand point. It is also important to note the even those panels with high numbers of over-driven box nails were still found to be as strong as the common nail panels and have higher ductility characteristics.

REFERENCES


