Strength of OSB Shear Walls with Over-Driven Sheathing Nails

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ABSTRACT

Eight shear wall specimens sheathed with 7/16 inch (11.11 mm) "Rated Sheathing" Oriented Strand Boards were assembled with over-driven sheathing nails and tested using the sequential phased displacement procedure. Studs were 2x4 Douglas Fir-Larch and sheathing nails were 8d cooler gun-driven nails. Nails were spaced at 3 inches (76 mm) on center along the edges and 12 inches (305 mm) on center at intermediate support. Edge nailing distance was 3/8 inch (76 mm). Specimens were constructed with four different over-driven nail depths: flush, 1/16 inch (1.59 mm), 1/8 inch (3.18 mm) and 3/16 inch (4.76 mm). Two specimens were built for each over-driven nail depth. To determine a lower bound on strength, all sheathing nails in a specimen were driven to the same depth.

Failure was concentrated in the vicinity of the sheathing nails. Nail failure observed during testing included pull through, tear out, withdrawal and fatigue. A combination of the pull through and tear out mechanisms was also observed. As the over-driven nail depth increased from flush to 3/16 inch (3.18 mm), the number of fatigued nails decreased almost linearly from approximately 20 percent to zero percent. Nail withdrawal decreased from approximately 10 percent for the specimens with flush driven nails to zero percent for the specimens with nails over-driven 1/16 inch (1.59 mm). Nail withdrawal did not occur in the other specimens. Nail pull through and tear out (or a combination thereof) increased from approximately 28 percent for the specimens with flush driven nails to about 58 percent for the specimens with sheathing nails over-driven 1/8 inch (3.18 mm) and 3/16 inch (4.76 mm). An average of 42 percent of the nails were undamaged or slightly damaged in all specimens.

Results from this study indicate that any level of over-driven sheathing nail depth will reduce the strength of a shear wall. The strength reduction was 5, 12, and 24 percent for the specimens with nails over-driven 1/16 inch (1.59 mm), 1/8 inch (3.18 mm), and 3/16 inch (4.76 mm), respectively. Although the reduction may not be significant for walls with sheathing nails over-driven only 1/16 inch (1.59 mm), reductions in the extent of 15 percent may be expected due to the random nature of over-driven depth that can be anticipated in the construction of wood shear walls. Parametric studies are necessary to examine the effect of combining different over-driven sheathing nail depths on the strength of shear walls. Additional tests and studies are necessary to expand the scope of this study to include other sheathing material thickness and type, nail type and size and stud spacing.

INTRODUCTION

Wood shear walls are used as the primary lateral force resisting system in most wood framed houses and wood frame low-rise commercial buildings. Historically, light wood construction has fared very well in seismic events. The ability of a shear wall to deform and dissipate energy in a ductile fashion as it is subjected to lateral loading results in very good seismic performance. Loss of life and collapse of a properly designed and constructed wood structure are uncommon and even rare (Hall, 1996). Recent earthquakes, however, have shown that wood structures having shear walls with over-driven sheathing nails are prone to significant seismic damage.

Pneumatically over-driven sheathing nails are one of the major structural deficiencies in wood shear wall design and construction. The top of the nail head should be flush with the surface of the sheathing material. If a nail is driven deeper than this ideal depth, the nail is considered to be over-driven. Following the January 17, 1994 Northridge Earthquake, a team of engineers (Los Angeles Task Force) sponsored by the Earthquake Engineering Research Institute (EERI), the National Science Foundation (NSF) and the Federal Emergency Management Agency (FEMA) scoured the shaken area

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and documented the structural failures that occurred during the event. The structural damage that occurred in the buildings surveyed was due primarily to code deficiencies and poor engineering, construction and inspection practices. Among the structural deficiencies found in shear wall design and construction were over-driven pneumatically installed sheathing nails. A large number of shear walls were found with over 50 percent of the sheathing nails over-driven (Hall, 1996). To evaluate existing wood construction and future construction that may be substandard with regards to the problem of over-driven sheathing nails, it is necessary for the engineer to know the strength of wood shear walls with over-driven nails.

PREVIOUS WORK

The issue of pneumatically over-driven nails in wood shear walls has been previously addressed (Ficcadenti, et al., 1996; Andreason and Tissel, 1994; Zacher and Gray, 1989) but not in enough detail to allow a comprehensive understanding of strength loss for a wall with severely over-driven nails. Based on testing conducted thus far, reasonable bounds have not been set on the strength reduction of a shear wall assembled with over-driven nails. In order to determine a lower bound on strength characteristics of a shear wall assembled with over-driven nails it is necessary to test variations of over-driven depth that will produce worst case conditions. Establishing a bound for walls assembled with 100 percent of the nails over-driven to a certain depth will produce the worst-case situation for analysis conditions. Furthermore, no research has been conducted on the effects of over-driven 8d cooler nails in 7/16 inch (11.11 mm) Oriented Strand Board (OSB) sheathing, which is one of the most common combinations of materials in many regions.

EXPERIMENTAL PROGRAM

Test Specimens

Eight shear wall specimens were assembled with different over-driven depths. The 8 ft x 8 ft (2.44 m x 2.44 m) specimens were constructed according to common field practice. Douglas Fir-Larch 2x4 (38 x 89 mm) studs at 16 inches (406 mm) on center were used as framing members. Studs were attached to the top and bottom plates using two 10d framing nails, 0.131 inch x 3 inches (3.33 mm x 76.2 mm). End studs were doubled to allow the required uplift force to be transferred through the studs into a bolted holdown. The dual end studs were fastened together along their length with 10d framing nails at 6 inches (152 mm) on center.

The specimens were sheathed with two 7/16 inch (11.11 mm) "Rated Sheathing" OSB panels. A 1/8 inch (3.18 mm) gap was left between the two sheathing panels. The sheathing was attached to the framing members with the 8 ft (2.44m) dimension parallel to the studs. Pneumatically 8d cooler nails at 3 and 6 inches (76 and 152 mm) on center along the edges of the panel and intermediate support, respectively, were used to attach the sheathing to the framing. A nailing edge distance of 3/8 inch (9.53 mm) was maintained for all specimens. Specimens were built with four different over-driven depths: flush, 1/16 inch (1.59 mm), 1/8 inch (3.18 mm) and 3/16 inch (4.76 mm). Two specimens were constructed and tested for each over-driven depth. To determine a lower bound in strength, all sheathing nails in a specimen were driven to the same depth. The nail gun was set using an adjustable nose piece to under-drive the nails approximately 1/16 inch (1.59 mm) of their final desired depth. The slightly under-driven nails were then driven to the proper depth using a hammer for the flush nails, and a hammer and special punch for the over-driven nails. Nails were usually within 1/64 inch (0.04 mm) of the desired depth (Jones and Fonseca, 2000).

Test Method

Specimens were tested using the SPD loading protocol (SEAOSC, 1997) with a First Major Event (FME) of 0.70 inches (18 mm). The cycling rate for the testing ranged from 0.30 Hertz for large amplitude displacements to 0.60 Hertz for the smaller displacements due to test equipment limitations. Displacements were measured at several locations and load and displacement data were sampled at a rate of 50 Hertz. No vertical load was applied to the specimens during testing.

OBSERVATIONS AND RESULTS

General Failure Mode

In general, a number of trends were observed during testing. At the beginning of the tests, the two sheathing panels rotated independently of each other in a rigid body motion. The load resistance originated primarily from the deformation of the sheathing nails as the panels rotated. Further into the tests, the 1/8 inch (3.18 mm) gap between the sheathing panels closed up at the top and the panels started resisting some motion by bearing and friction at that location. The gap at the bottom did not close during any test.

The OSB panels did not sustain any noticeable damage except in the vicinity of the nails. The first noticeable damage to the specimens was usually the tearing out of one of the four lower corners of a sheathing panel. Next, there was generally a progressive failure along any given edge of the panel, starting at one of the corners and progressing away from that corner. Eventually the failure progressed to the point that one or both OSB panels were totally detached from the framing along two edges. This trend was especially noticeable in the specimens assembled with nails over-driven 1/8 inch (3.18 mm) and 3/16 inch (4.76 mm).

Nail Failures

Four types of nail failure were observed during testing: pull through (nail pulled through the thickness of the sheathing), tear out (sheathing edge torn by nail), withdrawal (nail withdrew from the framing member) and fatigue (nail fatigued). The nail failure mode trend is shown in Figure 1. For specimens assembled with nails over-driven to any depth, pull through and tear out (or a combination thereof) were predominant. Occurrence of these failure modes increased from approximately 28 percent for the specimens with flush driven nails to about 58 percent for the specimens assembled with nails over-driven 1/8 (3.18) and 3/16 inch (4.76 mm). For the specimens with flush driven nails, approximately 20 percent of the nails experienced fatigue. As the over-driven nail depth increased from flush to 3/16 inch (3.18 mm), that percentage decreased almost linearly to zero percent. Nail withdrawal was uncommon and only seen in specimens with flush driven nails. A large percentage of nails were either undamaged or slightly damaged. The percentage of undamaged/slightly damaged nails increased from approximately 38 percent for those specimen with flush driven nails to about 46 percent for specimens assembled with nails over-driven 3/16 inch (4.76mm).

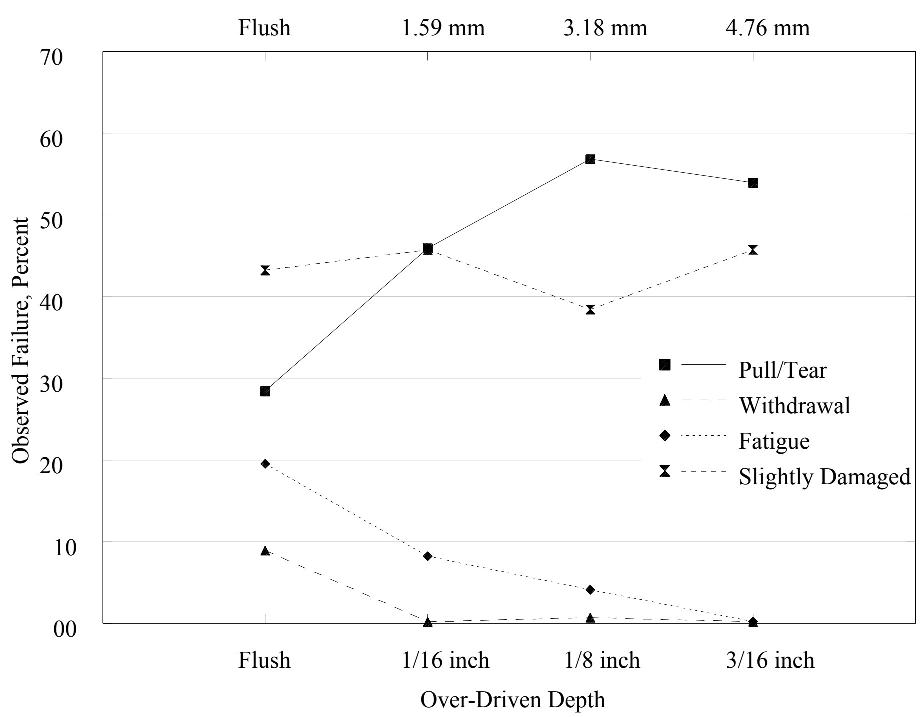

Fig. 1 Nail Failure Trend

As the over-driven depth increased from flush to 3/16 inch (3.18 mm), the tendency was for the nails to pull through or tear out (or a combination of these two failure mechanisms). Nail withdrawal was eliminated since more energy was required to withdraw a deeper driven nail, and nail fatigue was significantly reduced and even eliminated because the effective panel thickness (actual thickness minus the over-driven depth) was too thin to cold work a nail to its fatigue strength. As a nail is driven deeper into the sheathing, the effective panel thickness is too thin to fully develop the strength of the nail and the sheathing becomes the limiting factor on the strength of the wall.

Measured Results

The observed trend is helpful in determining any reduction in strength for walls with over-driven sheathing nails. The summary of the measured results is listed in Table 1. The ultimate strength for each specimen is listed in column 3. The ultimate loads for each series of tests (FLUSH-1 and FLUSH-2, etc.) were within a 10 percent range, indicating that the tests were consistent and a third test was not required (SEAOSC, 1997). The average for each series of tests is shown in column 4. As compared to the strength of the specimens with flush driven nails, the reduction in average strength was 5, 12 and 24 percent for the specimens assembled with nails over-driven 1/16 inch (1.59 mm), 1/8 inch (3.18 mm) and 3/16 inch (4.76 mm), respectively. These values represent a lower bound in strength since all nails in a specimen were driven to the same depth.

Load factors, which have been computed by dividing the average ultimate loads by the target design loads, are listed in Table 1, column 6. The target design loads shown in column 5 were calculated using a shear of 390 plf (1.74 kN/m) as specified in the National Evaluation Report No. 272 (NER-272, 1997). Although there is no guideline specifying load factor adequacy, recent literature suggests that a load factor of approximately 2.7 is adequate for wood shear walls (Tissel, 1993; Dinehart and Shenton, 1998). Therefore, all load factors listed in Table 1, even that corresponding to specimens with flush driven nails, are lower than the suggested value.

Table 1. Summary of the Measured Results

Over-Driven Depth	**Specimen Reference**	**Ultimate Load, lbs (kN)**	**Average Ultimate Load, lbs (kN)**	**Target Design Load[1], lbs (kN)**	**Load Factor[2]**	**1997 UBC Design Load[3], lbs (kN)**	**UBC Load Factor[4]**
Flush	FLUSH-1	8,268 (36.8)	8,238 (36.7)	3,120 (13.9)	2.64	3,920 (17.4)	2.10
	FLUSH-2	8,207 (36.5)					
1/16 inch (1.59 mm)	OD116-1	7,731 (34.4)	7,807 (34.7)		2.50		1.99
	OD116-2	7,882 (35.1)					
1/8 inch (3.18 mm)	OD118-1	7,190 (32.0)	7,256 (32.3)		2.33		1.85
	OD118-2	7,321 (32.6)					
3/16 inch (4.76 mm)	OD316-1	6,124 (27.2)	6,285 (28.0)		2.01		1.60
	OD316-2	6,446 (28.7)					

[1] Calculated based on NER-272 Table 19 for 7/16 inch (11.11 mm) APA Rated Sheathing, DFL, and 0.133 inch (2.78 mm) diameter by 2-3/8 inch (60.33 mm) long nails and Footnote 11.

[2] Calculated by dividing the Average Ultimate Load by the Target Design Shear.

[3] Calculated based on the 1997 Uniform Building Code (UBC) Table 23-II-I-1 for 7/16 inch (11.11 mm) meeting the UBC Standard 23-2 or 23-3 with 8d common or galvanized nails at 3 inch (76.20 mm) on center at edges and footnote No. 4.

[4] Calculated by dividing the Average Ultimate Load by the 1997 UBC Design Shear.

The design load calculated from shear values given in the Uniform Building Code (ICBO, 1997) is shown in Table 1, column 7. The "UBC" load factors, listed in Table 1, column 8, were computed by dividing the average ultimate loads by the 1997 UBC design load. The value from the UBC doesn't apply to the sheathing nails used in this testing program, however, that value is often used incorrectly by engineers in the design of shear walls (Jones and Fonseca, 2000). As listed in column 8, such an oversight would result in seriously low load factors.

Ultimate Strength

The average strength for each series of tests is shown is Figure 2. The reduction in strength decreases almost linearly as the nail over-driven depth increased from flush to 3/16 inch (3.18 mm). For the specimens with nails over-driven 3/16 inch (3.18 mm), however, the linear relationship slightly over estimates the strength of the specimen. The effective panel thickness was only 1/4 inch (6.36 mm) when the nails were over-driven 3/16 inch (3.18 mm), and a 1/4 inch (6.36 mm) panel may be too thin to develop the strength of nails.

CONCLUSIONS

The following conclusions are drawn from this study:

1. Any level of over-driven sheathing nail depth will reduce the strength of a shear wall. Walls with nails flush-driven and over-driven 1/16 inch (1.59 mm), however, will exhibit similar strength. The strength reduction for the specimens assembled with 1/16 inch (1.59 mm) over-driven nails was only 5 percent, which corresponding to a lower bound on strength since all nails were over-driven to the same depth. Thus, shear walls assembled with nails over-driven less than 1/16 inch (1.59 mm), will sustain adequate load factor.

2. Additional tests are necessary to determine an acceptable percentage of nails in a shear wall that are over-driven 1/8 inch (3.18 mm) and 3/16 inch (4.76 mm). Furthermore, it is necessary to investigate the effects of over-driven nail depth combinations on the strength of shear walls since over-driven nail depth is stochastic.

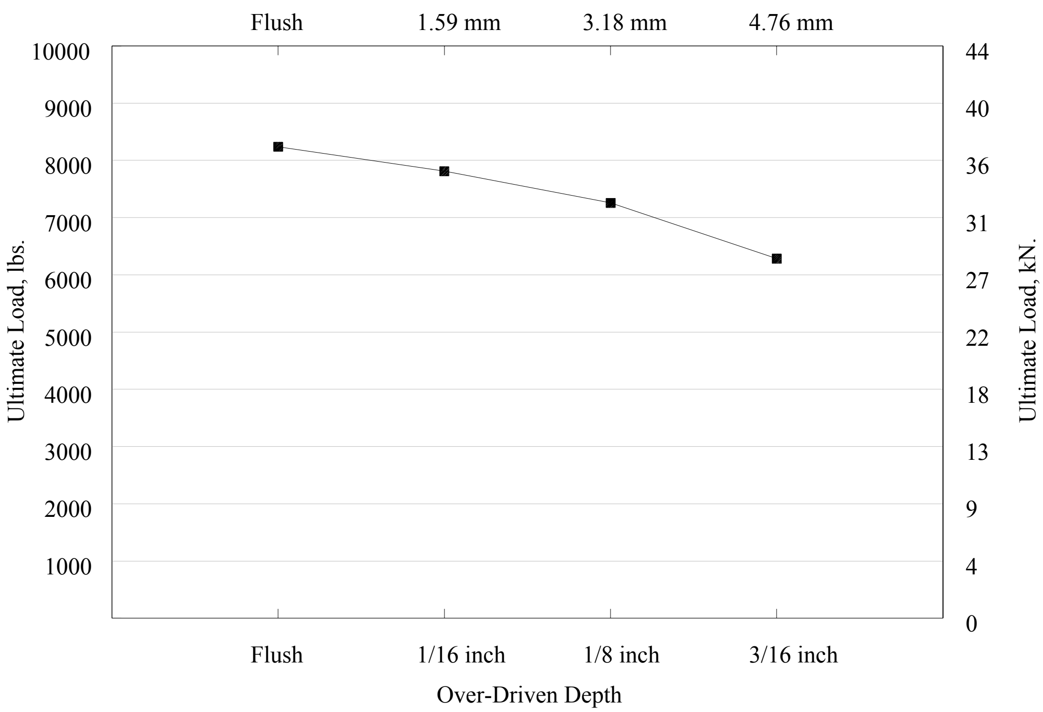

Fig. 2 Specimen Strength

3. Strength reductions in the extent of 15 percent may be expected due to the random nature of over-driven depth that can be anticipated in the construction of wood shear walls.

4. The reduction in strength is approximately linear as the nail over-driven depth increases, such a relationship may be used to determine the strength of a shear wall with over-driven sheathing nails. Additional tests are necessary to determine and validate this linear relationship.

5. The strength reduction may be calculated using interpolation functions between target design loads corresponding to the actual and effective panel thicknesses. Parametric studies are necessary to determine reasonable functions to span different over-driven depths.

6. The strength of shear walls may be seriously compromised if constructed with any significant percentage of nails over-driven to any depth and incorrect values are used to calculated design target shear. Design target shear must be computed using data corresponding to actual construction materials that have been approved by national evaluation services. The engineer must ensure that the materials used in construction are those specified or, alternately, use the values for design corresponding to materials that will actually be used.

REFERENCES

Andreason, K.A. and Tissell, J.R. 1994. "APA Report T94–9 - Effects of Overdriven Nails in Shear Walls." American Plywood Association, Technical Services Division. April.

Dinehart, D.W. and Shenton, H.W. 1998. "Comparison of Static and Dynamic Response of Timber Shear Walls." Journal of Structural Engineering, ASCE, Vol. 124, No. 6. pp.686-95.

Ficcadenti, S.J., Castle, T.A., Sandercock, D.A., and Kazanjy, R.K. 1996. "Laboratory Testing to Investigate Pneumatically Driven Box Nails for the Edge Nailing Distance of 3/8" Thick Plywood Shear Walls." Proceedings. SEAOC 64th Annual Convention, Structural Engineers Association of California, SEAOC. Indian Wells, CA. pp. 389-399.

Hall, J.F. 1996. "Northridge Earthquake of January 17, 1994: Reconnaissance Report, Volume 2 - Wood Buildings." Earthquake Spectra: Vol. 11, Suppl. C, Jan. pp. 25-176.

International Conference of Building Officials. 1997. Uniform Building Code. Whittier, CA.

Jones, S.N. and Fonseca, F.S. 2000. "Cyclic Testing of Oriented Strand Board Shear Walls with Over-Driven Nails." Brigham Young University, Department of Civil and Environmental Engineering Technical Report No. CES-00-03.

NER-272. 1997. "Power-Driven Staples and Nails for Use in All Types of Building Construction." National Evaluation Services, Inc.

Structural Engineers Association of Southern California. 1997. Standard Method of Cyclic (Reversed) Load Tests for Shear Resistance of Framed Walls for Buildings. SEAOSC, Whittier, CA.

Tissell, J.R. 1993. "APA Report 154 - Wood Structural Panel Shear Walls." American Plywood Association, Technical Services Division. Revised May.

Zacher, E.G. and Gray, R.G. 1998. "Lessons Learned From Dynamic Tests of Shear Panels." Structural Design, Analysis and Testing. Proceeding of the Sessions Related to Design, Analysis and Testing at Structural Congress '89. A. H–S. Ang, ed. ASCE. New York, NY. May. pp. 134-142.