TECHNICAL NOTE: LATERAL CONNECTIONS AND WITHDRAWAL CAPACITY OF WESTERN JUNIPER

Hayley Morris
Laboratory Technician
Willamette Valley Company
Eugene, OR 97402
E-mail: hayley.morris@wilvaco.com

*Arijit Sinha**†
Associate Professor
E-mail: arijit.sinha@oregonstate.edu

Byrne T. Miyamoto†
Graduate Research Assistant
Department of Wood Science & Engineering
Oregon State University
Corvallis, OR 97331
E-mail: byrne.miyamoto@oregonstate.edu

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Abstract. The goal of this project is to increase the amount of available information about western juniper wood to encourage its use in structural applications. This project evaluated the performance of connections involving western juniper wood and other common wood-based building materials. The tests for this project included edge lateral nail connection tests (ASTM 2007a), dowel bearing strength tests (ASTM 2007c), and withdrawal tests (ASTM 2007b). The performance of juniper and juniper-oriented strand board (OSB) connections were characterized. The results were also evaluated against predictive design equations found in the National Design Specification (NDS). The data obtained in this study suggest that NDS equations conservatively predict the load-carrying capacity of a juniper-OSB connection but consistently predict the failure mode.

Keywords: Oriented strand board, lateral connections, western juniper.

INTRODUCTION

Western juniper (*Juniperus occidentalis*) is a tree species native to central and eastern Oregon that is known for its ability to thrive in arid climates and its excellent resistance to decay from insects and fungi (Morrell 2012). It is one of the most abundant trees in central and eastern Oregon, and its pervasiveness is causing problems. Sage brush and grasses are hit especially hard by the overpopulation of juniper. This affects the endangered sage grouse, which uses the plants as shelter. Not only are juniper trees eliminating cover for the grouse, but they also provide a vantage point from which hawks can prey on the endangered birds. To help alleviate the stresses the trees put on the sage grouse and water supply in central and eastern Oregon, groups such as the Western Juniper Alliance and Oregon State University have been discussing harvesting juniper. However, lack of a market and low yields from juniper trees are impeding the harvesting efforts.

Juniper is a naturally durable species and hence can be used in a variety of applications where its durability attributes can be used. Decks are one of these areas in homes that are exposed to harsh conditions in which juniper would be a potential substitute for treated wood (Herbst 1978). There are many proposed commercial uses for western

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* Corresponding author
† SWST member

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juniper wood, including some structural applications, but a lack of design values make engineers and architects reluctant to choose juniper in their designs.

Wood species that are used in structural applications are listed in National Design Specifications (NDS) with design values associated with the strength of the wood under different loading conditions. Juniper is currently not listed in the NDS because of lack of test data on juniper. A project is currently underway at Oregon State University to establish design values for juniper that will be included in a future edition of NDS. For successful utilization of juniper in structures along with design values, a performance metric for its connections is also required. The two typical load types on connections in wood construction are lateral loading and withdrawal, and axial loading. The fasteners that are permitted by NDS to be used in these applications are dowel-type fasteners, such as nails and screws (AWC 2015).

The overarching goal of this study is to contribute to the available information about juniper wood to encourage its use in structural applications. This article will experimentally evaluate the performance of connection involving western juniper wood and other common wood-based building materials. Furthermore, the performance was evaluated agains existing NDS models.

MATERIALS AND METHODS

This study is part of a bigger study aimed at establishing the design values of western juniper. The samples for establishing design values were collected from five different locations in three states in proportion of the relative volume of timber present in the three states. Oregon contained the most standing western juniper with approximately 66%, followed by California (21%) and Idaho (13%). Hence, the sample size distribution between the states was based on the percentage of western juniper that the state contained. Within Oregon, the samples were collected from three different locations—Burns, Prineville, and Klamath. Once the materials were procured in the form of 101.6 × 101.6-mm cross section posts with 2.4-m length, they were cut to obtain samples for the design value study. While cutting the samples, sections of the posts were randomly drawn for this study. The sections were then cut to a cross section of 38 × 89 mm with a mix of heartwood and sapwood to be used for this study.

Test Matrix

The total specimen details, geometry, dimensions, and total number of tests are presented in Table 1. Withdrawal tests were conducted for two different fasteners each. A total of 54 lateral tests were conducted using three different thicknesses

Table 1. Test matrix detailing specimen dimensions and geometry, fastener specifications, number of specimens, and the test method for each test.

Test	Materials	Fastener type	Fastener specs	Sample size	Test method
Withdrawal	Juniper	Common smooth-shank nail	8 d ($L = 63.5$ mm, $D = 3.32$ mm)	32	ASTM (2007b)
		Wood screw	#6 ($L = 63.5$ mm, $D = 3.5$ mm)	32	
Lateral edge connection	Juniper – 9.5 mm OSB	Common smooth-shank nail	8 d ($L = 63.5$ mm, $D = 3.32$ mm)	18	ASTM (2007a)
	Juniper – 12.7 mm OSB			18	
	Juniper – 28.56 mm OSB			18	
Dowel bearing	Juniper	Common smooth-shank nail	8 d ($L = 63.5$ mm, $D = 3.32$ mm)	18	ASTM (2007c)
	9.5 mm OSB			9	
	12.7 mm OSB			9	
	28.56 mm OSB			9	

OSB = oriented strand board.

of oriented strand board (OSB). Because dowel bearing test was conducted on a subsample of the tested connections, only nine tests on OSB and Juniper were conducted for one connection assembly combination. Specific gravity (SG) for each of the specimen was calculated as per ASTM (2007d).

Withdrawal Test

For withdrawal tests, two fastener types were tested with juniper: an 8-d ($L = 63.5$ mm, OD = 3.32 mm) smooth-shank common nail and a 63.5-mm long #6 wood screw (OD = 3.5 mm). Juniper specimens with dimensions of 38 × 89 mm were cut to 406 mm in length. Nails and screws were driven in 100-mm increments along the radial face of the juniper board to a depth of 38 mm. The test was in accordance with ASTM (2007b). The specimens were stored in a conditioning room to maintain a consistent MC of approximately 13%.

The nail and screw withdrawal specimens were anchored to the test floor and loaded parallel to the axis of the fastener until the fastener came out of the sample. The tests were conducted using a universal testing machine (UTM) Instron model 5582 at a rate of loading of 2 mm/min. Testing was stopped when the peak load was reached and the load subsequently dropped. A total of 32 specimens were tested for both nails and screws. This test setup is shown in Fig 1(a). F1

Lateral Connection Test

The edge lateral connection test consisted of two types of materials: a juniper board and OSB procured from local vendors. Three different thicknesses of OSB were used—9.5, 12.7, and 28.56 mm. The OSB was of exterior grade manufactured with mixed hardwoods. The thickness of 9.5 and 12.7 mm represents typical sheathing OSB, whereas the thicker dimension represents a subfloor or a diaphragm application. The OSB was procured in 1219 × 2438-mm sheets and then cut into 76 × 203-mm sections. These sections were randomly drawn for assembly of the connections. The juniper board was a standard 2 × 4 board with dimensions of 38 × 89 mm cut to the length of 228.6 mm.

Once the materials were obtained, they were assembled into an edge connection. In an edge connection (Fig 2), the side member (OSB) is F2

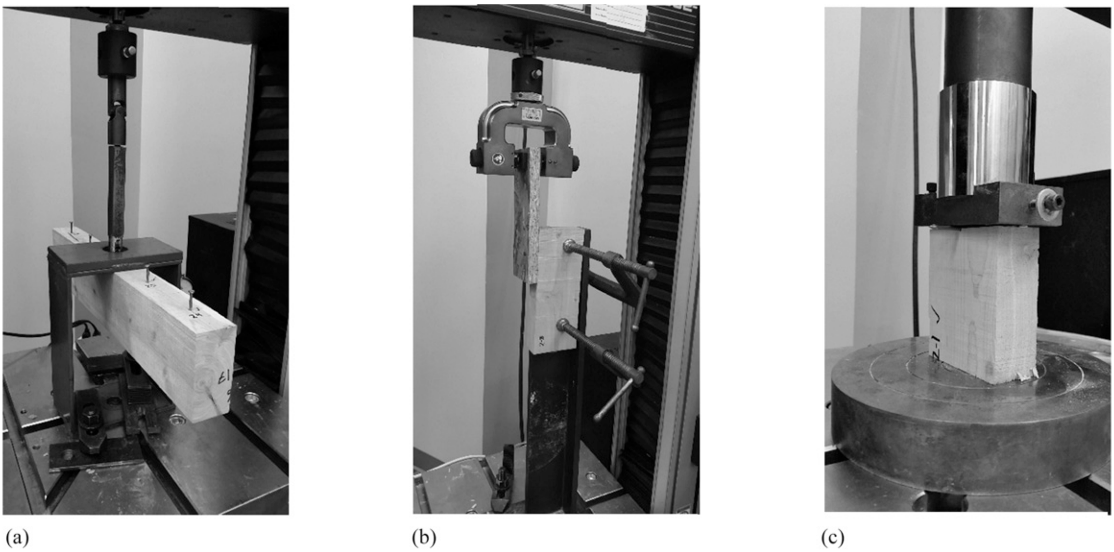
(a) (b) (c)

Figure 1. Test setup. (a) Withdrawal; (b) Lateral nail test; (c) Dowel bearing test.

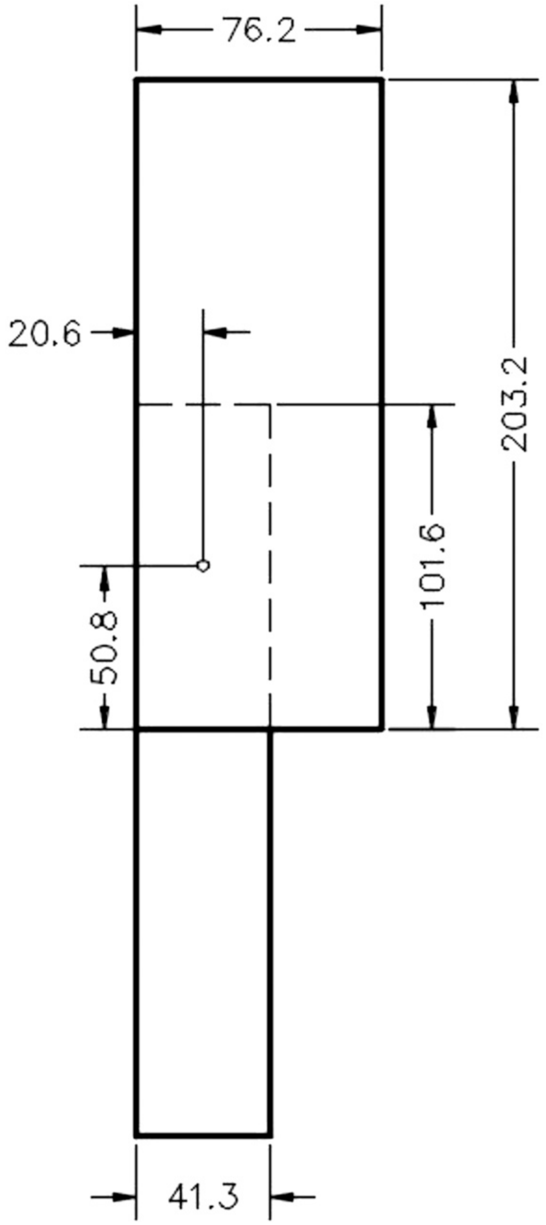

Figure 2. Schematic of connection (all dimensions in mm).

nailed to the main member (juniper board) 19 mm from the panel edge and loaded parallel to the fiber direction of the main member. The edge connection is a single shear nail connection constructed by predrilling both the main and side members with a drill diameter of 1.98 mm. The side member was lined up with the main member and connected with a smooth-shank nail measuring 79.4 mm in length with a diameter of 3.2 mm. The bending yield strength (F_{by}) for the nail was 620.5 MPa as stated by the manufacturer. The nail was driven into the predrilled members in the geometry shown in Fig 2. The assembled connections were stored in a conditioning room maintained at 20°C and 65% RH until the weight of the assembly stabilized.

The lateral connection testing was also performed on a UTM Instron 5582. The test used a 100-kN load cell with a displacement rate of 5 mm/min (Fig 1b). The main member of the specimen was clamped to a right-angled metal bracket, which was clamped to the base of the UTM. The metal bracket allowed the specimen to remain upright, whereas the side member was clamped to the crosshead of the UTM with a compression clamp. Measures were taken to reduce eccentricity in loading caused by geometry. Once the specimen was securely clamped, the UTM would apply a tensile force until failure, at which point the test would be stopped and the specimen removed before returning the crosshead to its original position. This was performed so as not to bend the nail back to its original position. Load–deflection (crosshead) data were recorded and failure mode was observed. After taking the samples out of the UTM, the samples were cut to salvage the fastener so that a yield mode could be observed with greater clarity.

Dowel Bearing Test

For the dowel bearing test, a sample was cut from the side and main members of the connection test specimens. The main member (juniper) had an 89 × 101.6-mm section cut from it, whereas the side member (OSB) had a 76.2 × 76.2-mm section cut from it. A 3.00-mm hole was drilled near the edge of the two samples to allow for a table saw to cut at half the diameter of the hole, creating a half hole for the nail to rest in. The specimens were stored in the ASTM conditioning maintained at 20°C and 65% RH until the weight of the assembly stabilized.

The dowel bearing specimen was placed into the UTM with a nail placed in the half hole as shown in Fig 1(c). Once the specimen was loaded, the crosshead of the UTM applied a compressive force at a rate of 1 mm/min. The test stopped when the crosshead came into contact with the specimen.

After testing (withdrawal, lateral, and dowel bearing), subsections were cut from the samples for density measurement using oven-drying method. Subsection of both juniper and OSB were analyzed for density measurements.

Calculating Lateral Connections and Dowel Bearing

After testing, the data were analyzed and load–deflection curves were created for the lateral connections and dowel bearing tests. To calculate yield load as well as the dowel bearing yield load for both the main and side members (F_{es} and F_{em}), F3 the 5% offset method was used as shown in Fig 3. To perform this method, first a linear portion of the curve was determined by running regressions on the parched dataset until the correlation close to unity was observed. Then, a tangent to the linear portion of the curve was offset by 5% of the dowel diameter in the positive direction. The intersection of the offset line and the load–deflection curve is the yield point (P_{yield}) of the connection. This definition of P_{yield} is also applied to determine the P_{yield} in a dowel bearing strength test (AFPA 1999). Thus, the dowel bearing strength is also defined by the yield strength.

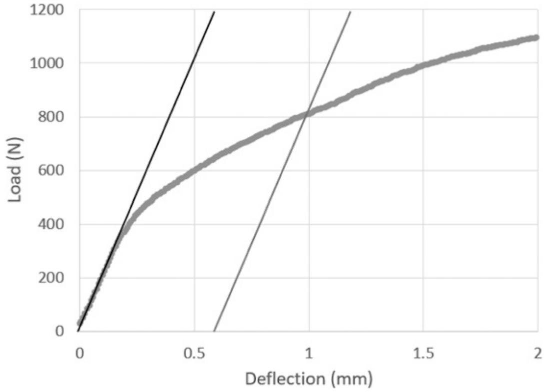

Figure 3. A typical load–deflection curve for a connection test. P_{yield} is calculated using a 5% offset method.

Yield Strength Predictions

To calculate the predicted yield strength of the lateral connection, the equations from the NDS and APA technical report 12 Table 1-1 were used (AWC 2015). They are called the European yield models (EYM). A single shear connection (as studied in the article) can yield in six possible ways. The equations to calculate all possible yield modes and the corresponding yield strengths are provided in the NDS. The lowest yield strength is then taken and adjusted using adjustment factors listed in the NDS to give the lateral design value. This is the predicted yield strength and the corresponding mode of yielding is the predicted yield mode. The inputs for these calculations include the main and side member thicknesses, diameter and length of the fastener, dowel bearing strength of the main and the side member, and certain geometrical details. To ascertain the dowel bearing strength, there are two ways. Dowel bearing strength can be determined experimentally. Otherwise, the species of the main member and the sheathing must be known to be able to calculate SG. The dowel bearing strength for the main member (F_{em}) can be found in the NDS Table 12.3.3 and the dowel bearing strength of the side member (F_{es}) can be found in Table 12.3.3B (AWC 2015). F_{by} was provided by the manufacturer. Although manufacturers often state the benchmark values rather than the actual values, the minimum benchmark value is used for design of connections. Therefore, the analysis was conducted using manufacturer-provided values.

RESULTS AND DISCUSSION

Withdrawal

A comparison of withdrawal capacities of juniper determined experimentally and as per NDS equations is presented in Fig 4. The average F4 withdrawal capacity of juniper wood for nails and screws tested were 26.78 N/mm (coefficient of variation [COV] 13%) and 106.24 N/mm (COV

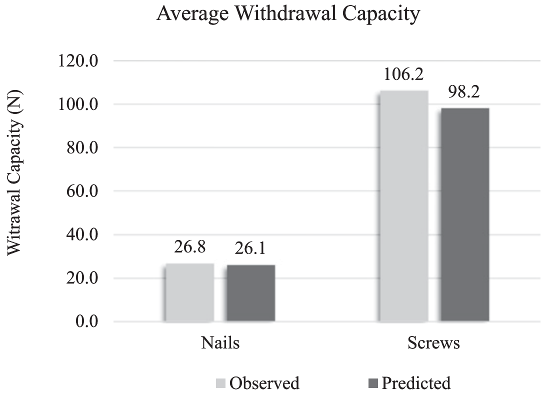

Figure 4. Withdrawal values of juniper with nails ($L = 63.5$ mm, $D = 3.32$ mm) and screws ($L = 63.5$ mm, $D = 3.5$ mm). (a) Mode III (b) Mode IV.

16%), respectively. The NDS equation generated a predicted withdrawal capacity of 26.1 N/mm for nails and 98.2 N/mm for screws. As seen in Fig 4, the predicted values closely matched observed values. For smooth-shank 3.38-mm diameter nails, Douglas-fir has a withdrawal resistance of 28.75 N/mm (Wang et al 2011). Juniper had a comparable withdrawal value. As a comparison, spruce with an SG of 0.42 has a withdrawal capacity of 70 N/mm for a 3.5-mm diameter wood screw (Kariz et al 2013).

The average SG of juniper as tested for the withdrawal samples was 0.44. This value is also consistent with the previous findings of Leavengood (2012).

Dowel Bearing Test

A summary of results from the dowel bearing tests are presented in Table 2 along with their associated COVs and their average SG. The juniper had an average dowel bearing strength of 40.93 MPa. This experimentally obtained value is substantially higher than the NDS reported 25.1 MPa, which is based on the SG of the material. The NDS-predicted value was determined from NDS Table 12.3.3 (AWC 2015) using western juniper's calculated SG of 0.44. The COV associated with the dowel bearing strength (30%) is comparable to previously published data on dowel bearing of similar materials (27%, Sinha et al 2011).

Table 2. Summary of dowel bearing strength results.

		OSB		
	Juniper	9.5 mm	12.7 mm	28.6 mm
No. of samples (n)	27	9	9	9
Dowel bearing strength (MPa)	40.93	65.93	51.17	26.61
Coefficient of variation (%)	30	29	24	17
Specific gravity	0.44	0.58	0.53	0.52

OSB = oriented strand board.

The NDS assumes a constant density for the structural sheathing panels for all thickness and consequently gives one dowel bearing value. For OSB, it is 32 MPa (SG of 0.5) as listed in Table 12.3.3B of the NDS. The average dowel bearing strength of 9.5-mm OSB, 65.93 MPa, was much higher than the NDS-listed value of 32 MPa (NDS Table 12.3.3B). The average dowel bearing strength of 12.7-mm OSB was 51.17 MPa and for 28.6-mm OSB was 26.61 MPa. Dowel bearing strength decreases with increase in thickness, a trend similar to that observed by Sinha et al (2011). This could be a function of decrease in SG as the thickness increases (as observed from Table 2) and increase in void space between the strands. More studies are needed, however, to validate this attribution.

Lateral Connection Test

A summary of lateral connection test results is presented in Table 3, including the average experimental yield strength, failure modes, and coefficient of variation. The yield strength of the connection was calculated using the 5% offset method as explained previously. The COV for these tests seems to be large, in the range of 22-34%. Several previous studies have reported COVs in the range of 16-21% (Sinha et al 2011; Sinha and Avila 2013). A possible reason for this could be the inherent defects in juniper, such as slope of grain, knots, etc., that causes ample variation in the property tested. Generally, the thicker sheathing material yielded at a higher load.

For comparison of the experimental values, yield load of the connections were predicted using NDS equations. The predictions were done in two

Table 3. Summary of lateral nail test results.

OSB thickness (mm)	Observed			Predicted (using experimental dowel bearing)			Predicted (using NDS dowel bearing values)		
	Z' (*N*)	COV (%)	Mode	Z' (*N*)	Mode	Design index	Z' (*N*)	Mode	Design index
9.5	491	26	IIIs	618	IIIs	0.79	425	IIIs	1.15
12.7	537	34	IIIs	610	IIIs	0.88	462	IIIs	1.16
28.6	599	22	IV	642	IV	0.93	570	IV	1.05

COV = coefficient of variation; NDS = national design specification; OSB = oriented strand board.

ways. First set of predictions were by using experimentally calculated dowel bearing strength of both, the juniper and OSB, using the average of nine subsample tests as input. The second set of predictions was done by using NDS tables for dowel bearing strength—Table 12.3.3 and Table 12.3.3B were used for juniper and OSB, respectively. Both predicted values were then multiplied with load duration factor of 1.6 to bring it to the same pedestal for comparison. The predictions are also presented in Table 3.

Using experimental dowel bearing strength of the main and the side member, the EYM equations overpredict the yield strength of the connection. On the other hand, using NDS-tabulated SG-based dowel bearing strength for juniper and OSB, the equations underpredict the yield strength of the connections. To gauge the degree of over- and underprediction, a design index was created, which is the ratio of the observed yield load to the predicted yield load. A design index greater than 1.0 suggests underprediction of the yield strength, which is desirable as it would provide certain extra provision for safety when designing. Kent et al (2004) and Sinha et al (2011) had previously evaluated the NDS models and concluded that they reasonably predict the yield strength of connections. Contrary to their findings, Theilen et al (1998) concluded that NDS yield models overestimate the observed yield strength of connections. The result of this study suggests that the NDS yield model approach is an adequate indicator of the yield strength of connections between juniper and OSB if the NDS-listed dowel bearing strength of the framing and sheathing member are used. Hence, it is advisable to use NDS-tabulated values for dowel bearing strength to calculate EYM-based yield strengths of connections.

The NDS equation also predicts the mode in which the connection will yield. There was a high level of consistency in the predicted yield mode and the observed yield mode for all the connection type and geometries. The predominant yield mode observed for juniper and the 9.5- and 12.7-mm OSB was mode IIIs (Table 3), which implies yielding by bending of the nail in the main member (Fig 5a). The NDS predictions for yield mode were consistent across both these thicknesses. Only one sample for the 9.5-mm thickness and four samples for the 12.7-mm thickness showed an exception and failed in mode IV. For thicker side members, generally a mode IV yielding is observed. In mode IV yielding, bending of the fastener occurs inside both, the framing and the sheathing member, followed by the development of plastic hinges at the bending points (Fig 5b). It was the

(a) Mode III (b) Mode IV

Figure 5. Yield modes observed.

predominantly observed mode of yielding for 28.6-mm thick OSB sheathing (all specimen yielded in mode IV), and there was high level of consistency in the prediction and observed modes of yielding. This suggests that NDS yield models are good predictors of the yielding mode for a connection and also a reasonable predictor for the load at which the connection will yield. For connections to yield by mode IV, they must have adequate member thicknesses to allow bending of the fastener and to facilitate formation of the plastic hinge in both members (Blass et al 1999; Sinha and Avila 2013). This was possible with thicker OSB sheathing.

CONCLUSION

This study examined the withdrawal capacity of both nails and screws in western juniper wood and the lateral edge connection of juniper with standard sheathing material. This study generated baseline data for withdrawal for common nails and screws in juniper. The equations based on NDS for withdrawal adequately predicted the withdrawal capacity of nails and screws in juniper. The results also quantified the performance of juniper as a main member in laterally loaded connections with three thicknesses of OSB. These results were also evaluated against the NDS yield models, which are based on dowel bearing capacity of the species forming the connections. NDS tables and equations conservatively predicted the performance of juniper-OSB connections because of an underestimation of dowel bearing strength using the NDS-based empirical equations. Moreover, NDS yield models consistently predicted the mode of yielding of the connections. The results indicate that NDS equations are conservative and, hence, are adequate to calculate its withdrawal and lateral design values.

REFERENCES

American Forest and Paper Association (AFPA) (1999) General dowel equations for calculating lateral connection values. AFPA 12, Washington, DC.

ASTM (2007a) F 1575. Standard test method for determining bending yield moment of nails. American Society for Testing and Materials, West Conshohocken, PA.

ASTM (2007b) D 1761. Standard test method for mechanical fasteners in wood. American Society for Testing and Materials, West Conshohocken, PA.

ASTM (2007c) D 5764. Standard test method for evaluating dowel-bearing strength of wood and wood-base products. American Society for Testing and Materials, West Conshohocken, PA.

ASTM (2007d) D 2395. Standard test methods for density and specific gravity (relative density) of wood and wood-based materials. American Society for Testing and Materials, West Conshohocken, PA.

AWC (American Wood Council) (2015) National design specification® for wood construction. AWC, Washington, DC.

Blass HJ, Ehlbeck J, Rouger F (1999) Simplified design of joints with dowel-type fasteners. Vol. 3, Pages 275-279 *in* Proc., Pacific Timber Engineering Conference. Forest Research Institute Limited, Rotorua, New Zealand.

Herbst JR (1978) Physical properties and commercial uses of western juniper. Pages 169-177 *in* RE Matin, JE Dealy, and DL Caraher, eds. Proc. Western Juniper Ecology and Management Workshop, January 1977, Bend, OR. Gen. Tech. Rep. PNW-74, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station.

Kariz M, Kuzman MK, Sernek M (2013) The effect of heat treatment on the withdrawal capacity of screws in spruce wood. BioResources 8(3):4340-4348.

Kent SM, Leichti RJ, Rosowsky DV, Morrell JJ (2004) Effect of wood decay by *Postia placenta* on the lateral capacity of nailed oriented strandboard sheathing and douglas-fir framing members. Wood Fiber Sci 36(4): 560-572.

Leavengood S (2012) Juniper factsheet. Oregon Wood Innovation Center, Oregon State University. http://juniper.oregonstate.edu/factsheet.php (January 2017).

Morrell JJ (2012) Resistance of selected wood-based materials to fungal and termite attack in non-soil contact exposure. For Prod J 61(8):685-687.

Sinha A, Avila DG (2013) Lateral load-carrying connection properties and withdrawal capacity of hybrid poplar. Wood Fiber Sci 46:97-108.

Sinha A, Gupta R, Nairn JA (2011) Thermal degradation of lateral yield strength of nailed wood connections. J Mater Civ Eng 23(6):812-822.

Theilen RD, Bender DAN, Pollock DG, Winistorfer SG (1998) Lateral resistance of ring-shank nail connections in southern pine lumber. Trans ASAE 41(2):465-472.

Wang Y, Wen-ching S, Kasemsiri P, Hiziroglu S (2011) A comparison of the withdrawal resistance load of nails using experimental and interference approaches. Wood Mater Sci Eng 6(4):213-218.