Revisiting the Compression Parallel to Grain Design Values of Douglas-Fir

Byrne T. Miyamoto
Kevin Cheung
Milo Clauson
Arijit Sinha

Abstract

After the decrease in southern pine (*Pinus* spp.) design values, concerns were raised over the design values of Douglas-fir (*Pseudotsuga menziesii*), the most important structural species in the Pacific Northwest of the United States. Moreover, species need to be re-evaluated every 5 years for properties by the grading agencies. Variability within Douglas-fir lumber may have increased over time because of changes in the silvicultural practices and management techniques including the shift from government to private plantation. The compression parallel to the grain design values took the greatest hit for southern pine. To assess if there is any decrease in the compressional design values, No.2 grade Douglas-fir, of dimensions 38 by 89 by 2,438 mm, were attained from 36 different locations and were cut into 229-mm sections with 20 samples from each location. A total of 720 samples were tested to failure in compression parallel to grain according to ASTM International D4761. Additionally, 288 clear specimens were also tested. The compression strength was calculated and was compared among locations. The data were pooled to calculate the design values for compression parallel to the grain and compared with listed values in the National Design Specification. Variation of compressive strength within locations was observed, but even after accounting for the variation the calculated values are above the average reported value for clear wood specimens and higher than the code-recommended design value for nonclear specimens.

The Pacific Northwest region of the United States is considered to be one of the most productive softwood timberlands in the United States in terms of volume per acre (Western Wood Products Association 2005). A major species for this region is Douglas-fir (*Pseudotsuga menziesii*). Douglas-fir is the most important species for construction timber in the United States, with more than 70 percent of the harvested Douglas-fir being used for production of dimension lumber. For design purposes, Douglas-fir and larch (*Larix* spp.) are grouped together and called Douglas-fir larch (DFL). The design values for DFL as listed in the National Design Specification (NDS) for Timber Constructions are among the highest (American Forest and Paper Association [AFPA] 2015).

Design values have evolved over the years. One of the major changes was going from design values established from small clear specimens to one calculated after in-grade testing of dimension lumber with a representative sample across many regions in the Pacific Northwest (Jones 1989). The history of lumber testing and the code approval process is well documented in Kretschmann and Evans (2010), where the reader is directed for more background in this area. The in-grade testing as reported in Green and Evans (1988) was conducted in the late 1980s. Since the in-grade testing program, no diligent efforts were directed toward monitoring of design values over time (Kretschmann et al. 1999). This has become important in the wake of recent developments with another commercially important construction lumber species, southern pine (*Pinus* spp.).

In 2012 the Southern Pine Inspection Bureau (SPIB) recommended that the design values for southern pine be changed because of significant downgrades in strength. The American Lumber Standards Committee and the American Wood Council both reduced the design values for some

The authors are, respectively, Graduate Research Assistant, Dept. of Wood Sci. and Engineering, Oregon State Univ., Corvallis (Byrne.miyamoto@oregonstate.edu); Chief Engineer, Western Wood Products Assoc., Portland, Oregon (kcheung@wwpa.org); and Senior Faculty Research Assistant and Associate Professor, Dept. of Wood Sci. and Engineering, Oregon State Univ., Corvallis (Milo.Clauson@oregonstate.edu, Arijit.sinha@oregonstate.edu [corresponding author]). This paper was received for publication in December 2017. Article no. 17-00085.

Forest Prod. J. 68(2):132–137.
doi:10.13073/FPJ-D-17-00085

grades and dimensions of southern pine (AFPA 2015). This reduction in design values stemmed from a continuous monitoring of southern pine by SPIB. The monitoring entailed annual assessment of modulus of elasticity values from a mill determined by random sampling (Kretschmann et al. 1999).

This downgrade in strength was caused by present-day silviculture practices. Silvicultural practices over the years have changed; as old-growth forests are slowly being depleted, forest managers turned to fast-growth, short-rotation plantations to achieve the timber demand. These plantations have decreased from 60-year-old stands to around 30- to 40-year-old stands, decreasing the stem diameter while increasing the amount of juvenile wood. As trees are grown at a fast rate and shorter rotation lengths, they tend to have more juvenile wood in them. Juvenile wood is the early-growth material produced by the tree, usually defined as the material 10 to 20 rings from the pith, depending on the species (Kretschmann 2008). Data shown by Kretschmann (2008) suggest that all properties in loblolly pine (*Pinus taeda*) were lowered by 15 to 30 percent with increased juvenile wood. Apart from juvenile wood, other practices such as density of plantation (Clark et al. 2008), intensive management practices, and growth conditions have an influence on mechanical properties of wood (Jordan et al. 2008). The reduction in design value of southern pine cannot be attributed solely to an increase in juvenile wood in the absence of supporting data regarding the percentage of juvenile wood found within the samples tested. To mitigate this, Dahlen (2013a, 2013b) studied the variability in bending properties due to an increase of juvenile wood in southern pine and Douglas-fir from six mills and reported a variability in properties of 33 to 51 percent and 50 to 78 percent for southern pine and Douglas-fir, respectively. Dahlen et al. (2013a, 2013b) also found that certain mills did not meet the grade requirement.

Wood species that produce more than 1,000 board feet per year, such as Douglas-fir and southern pine, are evaluated using destructive testing every 5 years (ASTM International 2016). This monitoring process ensures that there has not been any change in the product performance over this 5-year period. This study captured the effect on compressive strength from 36 locations across the Northwest United States rather than 6 locations spread across the Northwest and Canada as studied by Dahlen et al. (2013a, 2013b). Moreover, Douglas-fir of the Oregon and Washington region are grouped as one in the NDS. Canadian Douglas-fir is under a different species group in the NDS (AFPA 2015), and that is possibly the reason for a large variability in the property observed by Dahlen et al. (2013b).

Douglas-fir of Oregon and Washington is being tested every 5 years to see if there is any evidence of change in wood quality to justify an evaluation or reassessment of the species and subsequent change in design values. The objective of this study was to investigate whether there is any degradation in compressive strength of Douglas-fir parallel to the grain. Additionally, variation in compression properties due to location of the mill (or source of raw material) sampled was analyzed. Furthermore, design values were derived from the tested data set and compared with NDS listed values.

Methods and Materials

Test specimens

The specimens were sampled from 36 separate locations in the Pacific Northwest, all No. 2 dimensional lumber, at least 20 boards from each location. The lumber procured had dimensions of 38 by 89 by 2,438 mm. After procuring these materials, 10 boards were randomly selected from each mill. Two of these samples were cut to a length of 229 mm and marked A and B. Twenty samples from each location yielded a total of 720 specimens. The specimens were stamped with the description of location and the quality of wood. The specimens were boxed according to the mill number and brought to the testing location. The average moisture content (MC) of the lumber was 12 percent, with a range from 5 to 15 percent as received.

The second set of specimens was clear samples from No. 2 dimensional lumber specimens from the same 36 locations. The lumber had dimensions of 38 by 89 mm and was cut to the length of 229 mm. These specimens were clear of any defects such as knots and slope of grain. From each mill, 8 clear samples were obtained, for a total of 288 specimens. The samples were boxed and sent to the testing location. The average MC of the lumber was 12 percent as received. Before testing, both clear and nonclear samples were conditioned at 20°C and 65 percent relative humidity until an equilibrium moisture content (12%) was reached. After testing, ends of the sample were cut, their dimensions measured (for volume), and subsequently oven-dried for 24 hours to calculate specific gravity at 12 percent MC.

Test procedure

The test procedure followed ASTM D4761 (ASTM International 2013) for mechanical properties of lumber and wood-based structural materials. For each specimen, all dimensions were measured. Subsequently, each specimen was weighed and MC was measured using a Wagner MMC220 extended-range moisture meter. All measurements were appended onto a text file along with its label. The test setup is shown in Figures 1a and 1b. The tests were conducted on a Tinius Olsen 535-kN, 2.5-m stroke, screw-drive electric 61 by 61-cm working tabletop compression testing machine. The Tinius Olsen was equipped with an Advanced Calibration Technologies (ADTEK) load cell with a 445-kN maximum capacity, which was placed on the base to measure the applied load. A linear variable differential transformer (LVDT) was placed parallel to the load cell to measure the compressive deflection. Both the load cell and LVDT were inputs to an analog box, which was connected to a computer via Labview program, where it would register the readings and display outputs on-screen.

The specimen was placed on top of the load cell directly in the center (Fig. 1a). The Tinius Olsen was then lowered to apply a small load no larger than 1 kN to hold the specimen in place. The load was then applied at a rate of 15 mm/min. The specimen would then undergo a large load until failure. After failure, the failure points were marked for qualitative assessment. The data were then logged into a text file, the same as the measurements, with its maximum load and failure type.

Data and statistical analysis

Once all the specimens were tested the data were collected and analyzed. The data for clear and nonclear

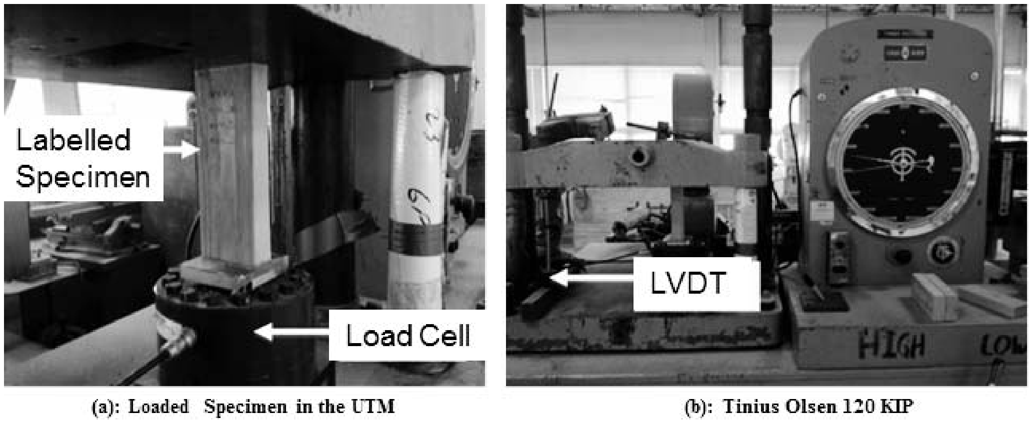

Figure 1.—Test setup: (a) specimen loaded in the Tinius Olsen testing machine; (b) the Tinius Olsen machine used for testing of specimen.

samples from each mill were entered into Excel spreadsheets. Data were averaged to obtain summary statistic in Excel. Additionally, an analysis of variance (ANOVA) was performed in the statistical program TIBCO Spotfire S+ to analyze the variation between mills after accounting for density of the specimen. Essentially, the density was treated as covariate and its regression coefficient was checked for statistical significance. Multiple comparisons were performed using Tukey's pair-wise test.

Results and Discussion

A typical load deflection plot for the compression test is presented in Figure 2. Although a compressive modulus can be derived from the load-deflection plot (Fig. 2), it is not a common property that is reported and hardly used in design. Because the objective of this study was to characterize the compressive strength, our discussion focuses only on the maximum load and corresponding calculated strength. The tests were stopped either when significant damage to the specimen was visually observed or when the load dropped to 15 percent of the postpeak load. Two predominant modes of failure were observed. These were buckling along a plane (80%) and crushing at the top (20% of the sample).

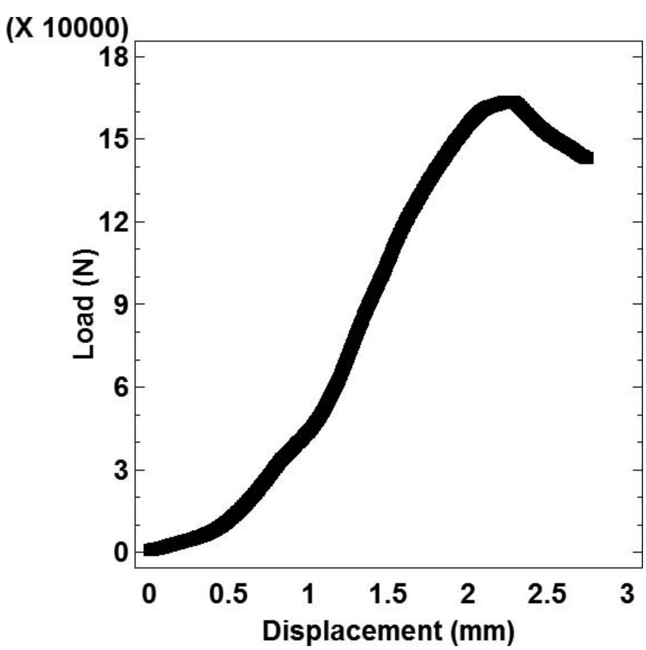

Figure 2.—A typical load-deflection plot.

Compressive strength

The mean and coefficient of variation (CV) for compressive strength of the clear samples are presented in Table 1. The mean values for the clear samples ranged from 45 to 73 MPa, with a combined mean of 59 MPa. The *Wood Handbook* (Kretschmann 2010) lists average values for clear specimens of four different kinds of Douglas-fir classified according to geographic locations. The value we are using for comparison in this article is an average of coastal Douglas-fir and interior Douglas-fir values as reported in the *Wood Handbook,* which averaged 49 MPa. This was done as the locations varied across the states of Oregon and Washington. Locations 3 and 4 were the only locations with an average compressive strength below the standard 49 MPa as reported in the *Wood Handbook*. A probable reason might be the presence of juvenile wood in those mill samples. All other locations met or exceeded the average values. The CVs were relatively low, ranging from 3 to 28 percent, with 29 of the locations below 15 percent. When the boards are being scanned in the mill, the scanner scans the log to allow for the optimal amount of boards along with the least amount of waste. These scanners cannot distinguish between juvenile wood and mature wood, causing pieces of lumber to have different percentages of both mature and juvenile wood.

Table 2 shows the mean along with the CV for the nonclear wood samples. The combined mean compressive strength was 36 MPa, with a CV of 22 percent. All of these samples did not meet the standard of 49 MPa as listed in Kretschmann (2010), because the sample means ranged from 47 MPa to as low as 26 MPa. This was expected, as the *Wood Handbook* reports strength value of clear specimens. The CV for the nonclear samples when pooled together (22%) was considerably higher than the clear samples (15%). The increase in the CV and the decrease in the means were expected in the nonclear samples because of the different variables, such as knots or cracks in the sample. Figure 3 represents the difference in the two sample groups broken down as per each location from which the sample was obtained, showing the increased strength in the clear

Table 1.—Summary statistics for compressive strength of clear Douglas-fir lumber.[a]

Location	Specific gravity	Compressive strength (MPa)			
		Mean	Median	SD	CV (%)
1	0.57	63	62	3	5
2	0.51	53	52	2	3
3	0.41	45	45	3	7
4	0.52	49	46	9	18
5	0.51	56	57	12	22
6	0.59	62	62	14	22
7	0.50	52	52	3	6
8	0.46	55	55	2	4
9	0.61	60	61	5	9
10	0.58	58	58	4	7
11	0.59	59	59	7	12
12	0.50	56	56	5	8
13	0.64	64	63	10	15
14	0.63	62	62	9	14
15	0.62	61	60	5	8
16	0.52	55	55	4	8
17	0.49	54	54	4	7
18	0.47	68	68	4	6
19	0.52	65	66	7	10
20	0.56	66	65	6	8
21	0.52	65	64	8	13
22	0.56	60	60	6	10
23	0.59	64	60	7	11
24	0.53	62	62	18	28
25	0.56	65	62	11	16
26	0.56	63	63	9	14
27	0.66	73	73	6	9
28	0.61	51	49	4	9
29	0.58	58	57	9	16
30	0.53	59	59	6	10
31	0.54	69	67	6	9
32	0.56	57	57	7	12
33	0.49	54	53	10	19
34	0.51	59	59	1	2
35	0.50	58	58	6	10
36	0.46	54	54	3	6

[a] Sample size for each mill was 8. CV = coefficient of variation.

Table 2.—Summary statistics for compressive strength of No. 2 grade 2 by 4 nonclear (in-grade) Douglas-fir lumber.[a]

Location	Specific gravity	Compression strength (MPa)			
		Mean	Medium	SD	CV (%)
1	0.57	40	39	8	20
2	0.57	34	35	5	15
3	0.52	34	32	7	21
4	0.54	38	38	7	19
5	0.54	33	33	4	14
6	0.53	38	36	9	24
7	0.56	32	32	5	16
8	0.55	35	35	5	15
9	0.55	38	37	7	19
10	0.54	37	38	6	15
11	0.58	37	37	10	28
12	0.53	34	34	5	15
13	0.56	37	38	5	13
14	0.52	39	37	7	19
15	0.54	35	34	8	23
16	0.54	33	35	5	14
17	0.57	36	36	6	16
18	0.59	39	38	9	22
19	0.58	41	40	8	19
20	0.57	43	43	9	22
21	0.57	39	38	8	21
22	0.55	38	37	9	23
23	0.57	40	39	9	23
24	0.56	36	34	10	27
25	0.51	38	37	9	24
26	0.58	39	40	9	23
27	0.6	46	47	9	20
28	0.54	28	26	4	15
29	0.56	33	31	7	22
30	0.55	31	30	6	20
31	0.6	38	39	7	17
32	0.56	35	34	5	16
33	0.55	34	34	6	17
34	0.55	32	30	6	20
35	0.57	35	35	6	17
36	0.58	31	31	5	17

[a] Sample size for each mill was 20. CV = coefficient of variation.

specimens. The horizontal line represents the reported average value of clear samples (49 MPa) as per the *Wood Handbook*. ASTM D198-09 (ASTM International 2009) calls for all clear specimens, which allow for less variability. This sample batch was used to look at the differences in the two sample batches.

To assess the location differences, an ANOVA was performed on the data. Assumptions of ANOVA such as normality and homogeneity of variance were evaluated using Shapiro-Wilk test and Levene's test, respectively. The level of significance in this study was set to $\alpha = 0.05$. The distribution of clear wood and nonclear wood is presented in Figure 3. The populations tested for clear wood and nonclear wood appeared to be normal, which was verified by a Shapiro-Wilk test. The population tested for clear wood appears more normally distributed than that of nonclear wood (Fig. 4), which is expected.

There was a significant difference between the locations from where clear samples were obtained ($P < 0.001$). These differences mainly occurred in locations 3 and 4, which both had lower compressive strength values. A group-wise comparison revealed that all locations between locations 13 and 27 were significantly different from the mean compressive strength of location 3. Similarly, locations 18 to 23 showed significant differences compared with location 4. Both locations 3 and 4 had the lowest mean values and were expected to show differences when compared with the rest of the locations. The mean values of locations 3 and 4 were driving the ANOVA results. However, if we omit locations 3 and 4 from the ANOVA, the difference in mean compressive strength of locations was still significant ($P < 0.05$). The CV of location 3 was 7 percent, whereas location 4 was 18 percent. The CV of location 3 had an expected value for clear specimens, whereas the CV obtained from data of location 4 is higher than average. Wood obtained from location 3 also had the lowest specific gravity (0.41) of the entire population sampled, which might be the reason for lower compressive strength. The specific gravity correlated well with the observed strength (correlation of coefficient of 0.51) for the clear sample. Moreover, a lack-of-fit test suggested that a linear assumption between specific gravity and compressive strength is valid.

A similar analysis for nonclear samples suggests significant differences between the mean compressive

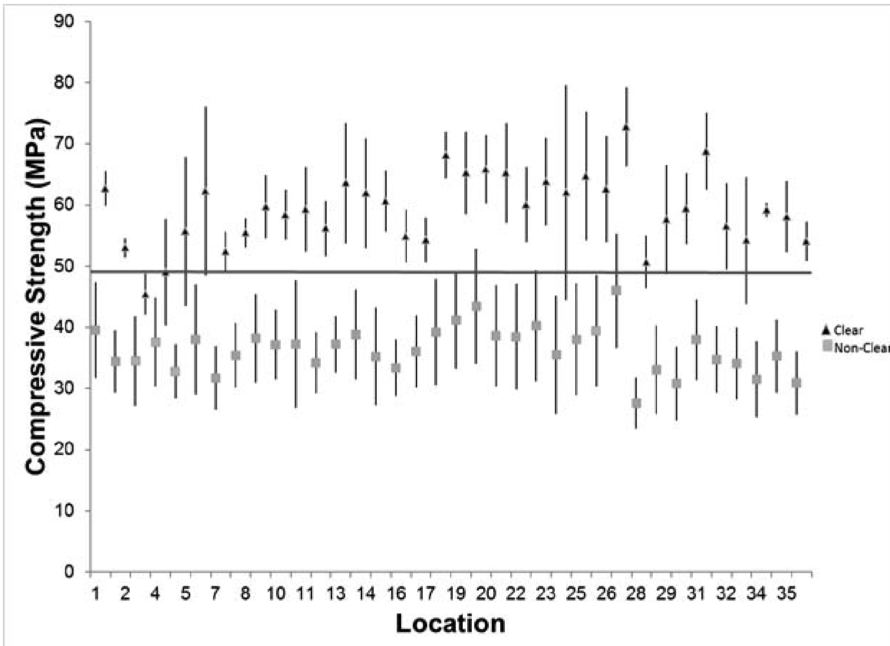

Figure 3.—Location-wise average along with standard deviation of compressive strength of clear and nonclear Douglas-fir specimen. Horizontal line depicts the average reported value in Kretschmann (2010).

strength between the locations ($P << 0.0001$, ANOVA). As there were more samples, the confidence in any statistical test increases and was reflected in the P value for the ANOVA. Nonclear samples expectedly exhibited much more scatter than the clear samples and hence there were marked significant differences between the mean compressive strength values of a few locations. Similar to clear specimens, nonclear specimen compressive strength properties were highly correlated with specific gravity.

Design values

Design values as listed in the NDS for timber construction are based on in-grade testing values. Hence, we used nonclear wood sample data for calculating the design values. The guidelines specified in ASTM D245 (ASTM International 2011) were followed to calculate design values. To summarize the steps involved: the samples with the lower value from A and B from each board were taken and recorded, reducing the samples size from 720 to 360. The data were then adjusted for an MC of 15 percent, following the procedure stated in the ASTM D1990 Equation A1.2. The adjusted values were then plotted in histograms and fitted through a normal distribution curve as shown in Figure 4. Then a fifth percentile tolerance limit was determined as per procedures in ASTM D2915 (ASTM International 2017a), using order statistics, with a sample size of 360 and an order statistic of 12. The fifth percentile value thus obtained was multiplied by a factor listed in ASTM D245 and ASTM D2555 (ASTM International 2011, 2017b) to account for a safety factor and 10-year cumulative duration of load effect. The calculated design value from the data set at hand was 10.3 MPa. The corresponding NDS value for No. 2 Douglas-fir larch is 9.3 MPa. The calculated value after accounting for all safety factors and duration of load effect was 10 percent higher than the design values in

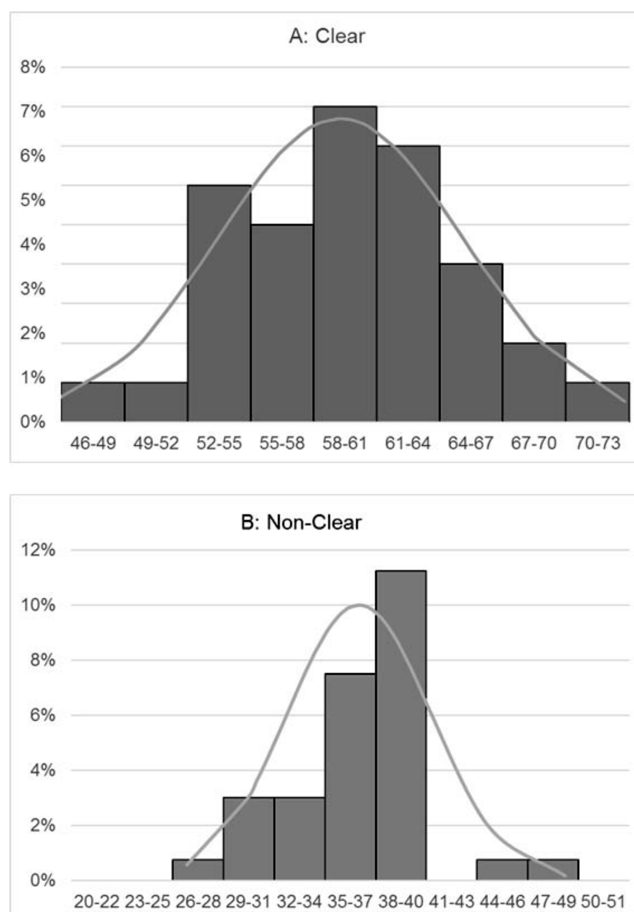

Figure 4.—Distributions for clear and nonclear wood samples tested for compressive strength.

the NDS. This suggests that there was negligible deterioration in properties.

This scenario of the sampled data set yielding a design value higher than that listed in the code is desirable. This difference, however, could be a result of interaction of many factors. First, the design values listed in the NDS are grouped for Douglas-fir and larch (another important western species) after testing has been performed on the group. The values obtained in this study are for Douglas-fir only; hence some differences are inevitable. Compressive strength of clear specimens of western larch is higher than that of Douglas-fir (Kretschmann 2010). If western larch were tested along with Douglas-fir, it would have yielded a higher design value. Second, the samples collected represent one cross section in time, which makes the data predisposed to influences by certain volumes of lumber with low strength (e.g., location 3) or high strength. Third, the NDS presents design values for the entire Douglas-fir larch group found in Oregon and Washington. In our sampling plan, we did not sample from all the regions throughout the two states. Locations were predominantly in western slopes of the Cascades mountain range in both states, coastal Oregon, and a few in the southern Washington area. Conditions are ideal for growth of Douglas-fir in this region (Drow 1965) and Douglas-fir from here are generally stronger than other Douglas-fir (Drow 1965).

From the results it is clear that there is a difference in properties between the locations for both clear and nonclear wood samples. This might be a direct consequence of the quality of incoming raw material feedstock. Variation of compressive strength within locations exists, but even after accounting for the variation, the calculated values are above the average reported value for clear wood specimens and higher than the code-recommended design value for nonclear specimens.

Conclusions

The data obtained from testing 720 nonclear wood samples and 288 clear wood samples from 36 different locations of the Pacific Northwest region of the United States suggest that compressive strength of Douglas-fir has not changed over time. Within the constraints of data collected, statistically significant variation of compressive strength between locations was observed, with data from a couple of locations yielding an average compressive strength less than the reported value for clear specimens. Strictly talking about the Pacific Northwest region, there was no evidence to suggest that variability within Douglas-fir lumber may have increased over time. Moreover, calculated design value for Douglas-fir using the nonclear data was 10 percent higher than the reported design value in the NDS. These results suggest that Douglas-fir retained its compressive strength over time. The reliance of this study on Douglas-fir harvested primarily from the western slope of the Cascades in southern Washington and Oregon indicates that additional testing of a more diverse sample set including Douglas-fir and larch from a broader geographic area will be required before definitive conclusions can be drawn regarding compressive design strength. However, because western larch has a higher average compressive strength than any Douglas-fir, it is unlikely that a substantial deviation from the current results will be observed. Additional testing is recommended to investigate other important design properties such as flexural and shear strengths.

Literature Cited

American Forest and Paper Association (AFPA). 2015. National design specification® for wood construction. AFPA, Washington, D.C.

ASTM International. 2009. Standard test methods of static tests of lumber in structural sizes. D198-09. *In:* Annual Book of ASTM Standards. ASTM International, West Conshohocken, Pennsylvania.

ASTM International. 2011. Standard practice for establishing structural grades and related allowable properties for visually graded lumber. D245-06. *In:* Annual Book of ASTM Standards. ASTM International, West Conshohocken, Pennsylvania.

ASTM International. 2013. Standard test methods for mechanical properties of lumber and wood-based structural materials. ASTM D4761-13. *In:* Annual Book of ASTM Standards. ASTM International, West Conshohocken, Pennsylvania.

ASTM International. 2016. Standard practice for establishing allowable properties for visually-graded dimension lumber from in-grade test of full-size specimens. ASTM D1990-16. *In:* Annual Book of ASTM Standards. ASTM International, West Conshohocken, Pennylvania.

ASTM International. 2017. Standard practice for sampling and data-analysis for structural wood and wood-based products. D2915-17. *In:* Annual Book of ASTM Standards. ASTM International, West Conshohocken, Pennsylvania.

ASTM International. 2017. Standard practice for establishing clear wood strength values. D2555-17. *In:* Annual Book of ASTM Standards. ASTM International, West Conshohocken, Pennsylvania.

Clark, A., III, L. Jordan, L.Schimleck, and R. F. Daniels. 2008. Effect of initial planting spacing on wood properties of unthinned loblolly pine at age 21. *Forest Prod. J.* 58(10):78–83.

Dahlen, J., P. D. Jones, R. D. Seale, and R. Shmulsky. 2013a. Mill variation in bending strength and stiffness of in-grade southern pine No. 2 2 × 4 lumber. *Wood Sci. Technol*. 47:1153–1165.

Dahlen, J., P. D. Jones, R. D. Seale, and R. Shmulsky. 2013b. Mill variation in bending strength and stiffness of in-grade Douglas-fir No. 2 2 × 4 lumber. *Wood Sci. Technol*. 47:1167–1176.

Drow, J. T. 1965. Relationship of locality and rate of growth to density and strength of Douglas-fir. Research Paper FPL-RP-2018. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin.

Green, D. W. and J. W. Evans 1988. Mechanical properties of visually graded lumber: Volume 1, A summary. PB-88-159-389. National Technical Information Service, Alexandria, Virginia.

Jones, E. 1989. Sampling procedures used in the in-grade lumber testing program. *In:* Proceedings of the Workshop Sponsored by the In-Grade Testing Committee and Forest Products Society. Proceedings 47363. Forest Products Society, Madison, Wisconsin.

Jordan, L., A. Clark III, L. R. Schimleck, D. B. Hall, and R. F. Daniels. 2008. Regional variation in wood specific gravity of planted loblolly pine in the United States. *Can. J. Forest Res*. 38:698–710.

Kretschmann, D. E. 2008. Influence of juvenile wood content on shear parallel, compression, and tension transverse to grain strength and mode I fracture toughness for loblolly pine. Research Paper FPL-RP-647. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. 27 pp.

Kretschmann, D. E. 2010. Mechanical properties of wood, chap. 5. *In:* Wood Handbook: Wood as an Engineering Material. General Technical Report FPL-GTR-190. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin.

Kretschmann, D. E. and J. W. Evans. 2010. History of lumber submission under ASTM D 1990 since the North American in-grade testing program. General Technical Report FPL-GTR-189. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin.

Kretschmann, D. E., J. W. Evans, and L. Brown. 1999. Monitoring of visually graded structural lumber. Research Paper FPL-RP-576. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin.

Western Wood Products Association (WWPA). 2005. In-grade lumber testing and design values for dimension lumber. WWPA, Portland, Oregon.