# Effects of Outdoor Exposure on Properties of I-Joists





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# EFFECTS OF OUTDOOR EXPOSURE ON PROPERTIES OF I-JOISTS

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**Abstract.** Wood I-joists are often left uncovered and exposed to the weather during construction, allowing the oriented strandboard and laminated veneer lumber in these systems to be adversely affected by water absorption. Manufacturers typically specify that these materials be protected from wetting, but this can be difficult in wetter climates. There are few studies examining the potential effects of wetting on these building elements. In this study, flexural properties and ultimate tensile strength of I-joists exposed for extended periods of time during the rainy winter months in the Willamette Valley of western Oregon were evaluated. I-joists were removed from the field each month, dried, and then tested in static bending (flexure) using a six-point bending test. I-joist strength decreased as a function of exposure time and rainfall. Twenty-seven da of external exposure was associated with a significant increase in flexural variability. Further exposure was associated with significant decreases in I-joist strength (modulus of rupture). Although most I-joists never experience this degree of wetting, they can when construction is delayed. The results illustrate the detrimental effects of exposure to wetting during construction and support improved efforts to limit wetting.

***Keywords:*** Weathering, wetting, outdoor exposure, degradation, oriented strandboard, laminated veneer lumber, engineered wood.

## INTRODUCTION

Wood composite I-joists were first designed for and used in aircraft during the 1920s (Robins 1975). By the mid-1930s, composite I-joists with hardboard webs were used in various structures in Europe (McNatt 1980). I-joists became more widely used in the early 1970s, when technology and facilities were developed to allow mass production of prefabricated I-joists (Leichti et al 1990). I-joists were most commonly found in roof support beams but are now found in floor joists, garage door headers, and other framing applications (McNatt 1980). I-joists are designed for long-span loading and are used as an alternative to sawn lumber. In many cases, I-joists have superior properties and low variability compared with solid sawn lumber and, for this reason, have become a popular choice for builders. Advantages of these products include more uniform material properties, the ability to use smaller-diameter timber in manufacturing, and because they are dry when installed, a decreased tendency to shrink or deform during use. Similar to nearly all wood-based composites, I-joists are intended for dry-use applications because water absorption can lead to swelling, deformation, and losses in material properties. Manufacturers make efforts to protect I-joists from wetting and

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caution users to do the same, but there is little in the way of guidance concerning how much wetting can take place before adverse effects occur.

The most common materials used in I-joist assemblies are laminated veneer lumber (LVL) and oriented strandboard (OSB). The use of LVL in outdoor applications is limited by several durability issues, such as dimensional stability and biological degradation (Nzokou et al 2005). Long-term outdoor exposures of LVL in Japan showed that modulus of elasticity decreased 23% during a 6-yr period (Hayashi et al 2002). Durability of wood-based panels is one of the most important properties considered in housing construction (Norita et al 2008), thus many studies have been performed involving moisture effects on OSB (Lehmann 1978; River 1994; Okkonen and River 1996; Wu and Suchsland 1997; Norita et al 2008; Kojima and Suzuki 2011; Meza et al 2013). Kojima and Suzuki (2011) found that aspen OSB retained only 35% of its original modulus of rupture (MOR) after 1 yr of outdoor exposure in Shizuoka, Japan. Conversely, Meza et al (2013) observed a 30% decrease in MOR of OSB after 100 da of exposure in weather conditions similar to those encountered in this study. Very little has been studied about the effects of wetting on I-joists. Chen et al (1989) tested I-joists in a wetted state and found that moisture produced a nonlinear load deflection function. High moisture levels decreased the load deflection ratio for OSB and plywood webbed beams and decreased ultimate load capacity.

Although builders generally attempt to finish construction as quickly as possible, delays can be critical when I-joists are installed during rainy periods. In this study, we examined the effects of 138 da of exterior exposure of I-joists on moisture uptake, flexural properties, and ultimate tensile strength.

## MATERIALS AND METHODS

### Specimens

I-joists in this study were 406 mm deep × 2.6 m long and consisted of 59-mm-wide × 35-mm-deep Douglas-fir LVL flanges and a 10-mm-thick aspen OSB web. The commercially manufactured I-joists were stored outdoors under cover for 1 yr prior to exposure. Although changes in RH could have affected strength and stiffness properties compared with the fresh condition, the I-joists could still be used to assess the effects of external exposure on properties. Although ASTM Standard E105 (ASTM 2010b) and Section 3.3 of ASTM Standard D2915-10 (ASTM 2010a) call for 20-30 replicates per variable to delineate treatment differences, only eight to 10 units were tested during each interval because of limited quantities of I-joist stock (ASTM 2010a, 2010b).

I-joists were cut to 2.59 m long, which allowed for short-span bending tests. The web and flanges of each I-joist had web-to-web and flange-to-flange finger joints at 1.22 m on center. The finger joints of the web and the flanges alternated at 610 mm on center. A set of smaller I-joists (356 mm deep) was also tested and produced similar results compared with the large I-joists (King 2014).

### Exposure

I-joists were exposed at an open field located near Corvallis, OR. The site receives approximately 1.2 m of rainfall per year, mostly between November and May. Each I-joist was weighed (nearest gram) before being exposed on an untreated lumber fence that suspended the units approximately 450 mm above ground. The samples were exposed to regular rainfall during a 138-da period in an orientation that approximates the situation of a partially constructed house. Rainfall data were collected from the Oregon State University Hyslop Farm, located approximately 5 km from the test site.

Eight to 10 I-joists were randomly selected and removed after 0, 27, 65, 95, or 138 da of exposure. The test was terminated at this point because the rainy season had ended and the samples had dried to the point at which further moisture changes were minimal. Eight units were initially tested, but sample size was increased after 95 da of exposure as individual unit variation began to increase.

Units removed from exposure were first weighed, and the differences between initial and final mass were used to calculate moisture content. The units were then conditioned to 12% MC for 2 to 3 wk in an open area in which temperatures ranged from 20 to 23°C and RH from 30 to 70% prior to further testing, allowing us to characterize permanent degradation that resulted from exposure and separate the reversible effects of moisture from the irreversible ones.

### Test Setup

I-joists were evaluated in a bending test similarly developed and described in more detail by Polocoser et al (2013) (Fig 1). Briefly, web stiffeners were attached at the ends of each unit before the I-joist was placed on an apparatus that applied loads at four equal points along the top flange spaced at a distance of 2L/10, where L is the span length. Web stiffeners were 50- × 100-mm-wide lumber pieces that spanned the distance between the flanges. Typically a three-point bending test is used in flexural analysis because it creates the largest moment. Section 6.2.6 of ASTM (2013) requires a three- or four-point bending test. The test setup in this experiment used a six-point bending test to approximate a distributed load because this is the most common loading in real-world I-joist applications. The advantages of a six-point bending test include constant values of shear between loading points and increased lateral restraint caused by shorter buckling lengths. The setup was designed for short-span testing that forced shear failures through the web as opposed to bending failures, which are more common in long-span testing. Lateral bracing was used to keep the I-joist from bending out of plane. As two hydraulic cylinders applied force, load cells under the bearing plates transmitted data to LabView 2010, a computer software package designed by National Instruments (Austin, TX). A linear variable differential transformer was positioned at midspan on the top flange to collect deflection data. Each I-joist was loaded at a rate of 5 mm/min. Load and deflection were continuously monitored, and these values were used to determine the maximum load and mode of failure.

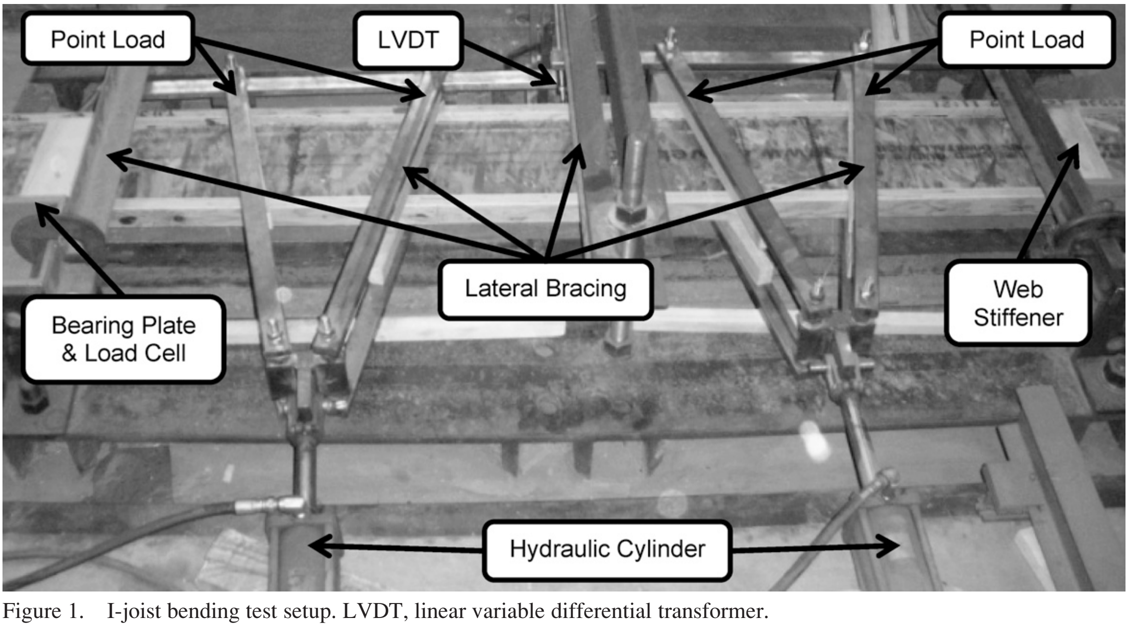


Figure 1. I-joist bending test setup. LVDT, linear variable differential transformer.

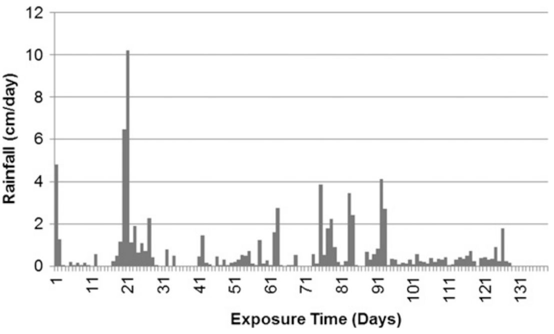


Figure 2. Daily rainfall amounts during the 138-da period when I-joists were exposed in western Oregon.

Failure mode was classified in accordance with failure codes listed in ASTM (2013). Additionally, a 150-mm-long sample was cut from a site away from the failure area to be tested in tension. Clamps were attached to each flange of this sample, and the top clamp was pulled at a rate of 5 mm/min until the I-joist failed. Load and deflection were continuously recorded to determine tensile strength. The failure zone was then examined to determine if the failure occurred in the wood or the resin.

## Statistics

The data were subjected to an analysis of variance, and individual treatments were then compared using unpaired t-tests ($\alpha = 0.05$). Assumptions of the regression, such as normality and homogeneity of variance, were evaluated using Shapio-Wilk and Levene's tests, respectively (Ramsey and Schafer 2002). Linear regression models were developed for the I-joist data comparing maximum load and deflection at maximum load vs exposure time, rainfall, and rain days. Best-fit models were determined using backward stepwise selection and evaluating extra sum of square F test at each level.

# RESULTS AND DISCUSSION

## Rainfall and Moisture Content

I-joists were exposed to 85 da of measureable rainfall during the 138-da test period. Most rainfall events were small (<10 mm); however, two events in the first 27 da delivered 40 and 101 mm of precipitation, respectively (Fig 2). Six rainfall events during the remainder of the exposure delivered 20-40 mm of rainfall. The samples were subjected to repeated wetting with limited opportunities for drying. Moisture contents of the I-joists increased steadily from 12% to approximately 50% within the first 27 da of exposure and then increased only slightly thereafter. Because we had a limited number of test pieces, it was not possible to destructively sample units to determine moisture distribution in the web and flange, but the data show that 1 mo of rainfall exposure resulted in dramatic increases in moisture content (Table 1). The I-joists showed evidence of weathering on the upper flange, but the web and lower flange appeared to be unaffected by sunlight exposure. This probably reflected the tendency for the closely spaced I-joists (approximately 150 mm between members) to shade one another on the test fence.

## Bending Test

Bending tests showed that maximum load did not differ significantly between nonwetted samples

Table 1. Effects of exterior exposure on moisture content (MC) and physical properties of I-joists.[a]

| Exposure period (days) | Replications | Total rainfall (mm) | Days with rain | MC at removal (%) | Bending tests: Maximum load (kN) | Bending tests: Deflection (mm) | Bending tests: Primary failure mode | Max tension load (kN) |
|---|---|---|---|---|---|---|---|---|
| 0 | 8 | 0 | 0 | 12.4 (0.5) | 54.63 (2.92) | 14.92 (1.48) | ZW | 2.98 (0.52) |
| 27 | 8 | 33.7 | 20 | 49.7 (1.3) | 53.29 (5.82) | 12.99 (1.39) | ZJ | —[b] |
| 65 | 8 | 47.1 | 48 | 50.1 (2.3) | 49.54 (5.87) | 12.91 (2.28) | ZJ | 3.14 (0.46) |
| 95 | 8 | 73.8 | 71 | 51.7 (2.5) | 45.03 (7.09) | 12.91 (2.17) | WB | 2.80 (0.32) |
| 138 | 10 | 85.2 | 104 | 52.3 (2.4) | 44.58 (5.75) | 12.99 (1.18) | WB | 3.04 (0.54) |

[a] Values represent means of eight replicates per exposure period, whereas figures in parentheses represent one standard deviation.
[b] Not tested.

and those exposed for 27 da. However, standard deviations (SDs) increased sharply after exposure (Table 1). One of the attributes of I-joists is material uniformity, and these results show that even relatively short exposures increased variability. Continued exposure led to steadily lower maximum loads that were significantly lower than the controls after 65 da (t-test, $p$ value $= 0.027$). I-joists lost 9.3% of their original strength after 65 da of exposure and 18.4% strength after 138 da of exposure. Centerline deflection decreased significantly for the I-joists but only showed small changes in SD compared with the control (t-test, $p$ value $<0.05$). Deflection decreased but not significantly after 27, 65, 95, or 138 da of exposure. This suggests that the I-joists were becoming less stiff with prolonged moisture exposure. Similar results were obtained with smaller I-joists (356 mm deep) exposed under the same condition for 566 da (data not shown).

## Regression

Two linear regression models were developed using maximum load or deflection at maximum load (dependent variables) and exposure time, total rainfall, and number of rain days (explanatory variables). The best-fit models are presented here:

$$\text{Load} = 52.93 - 0.0870\ \text{Rainfall} \qquad (1)$$

$$\text{Deflection} = 11.23 - 0.016\ \text{Rainfall} \qquad (2)$$

There was significant evidence that I-joist maximum load was dependent on amount of rainfall received during the exposure period ($p$ value $<0.001$). Deflection at maximum load compared with rainfall performed the best as per extra sum of squares F-test and is presented as Eq 2. There was significant evidence that I-joist deflection at maximum load was correlated with rainfall ($p$ value $= 0.0018$). Although maximum load and deflection at maximum load were regressed against rainfall, exposure days, and rain days, the final model that explained most data variability did not use exposure and rain day terms. Rainfall was highly correlated with exposure days and similarly, rain days were highly correlated with rainfall. Hence, only one of these variables was sufficient to capture the essence of variability in maximum load (or deflection) contained within the experimental data through a regression.

## Bending Test Failure Modes

In addition to declining maximum load, exterior exposure also affected the mode of failure. All units not exposed to wetting failed in shear, whereas failures were caused by a mix of shear, web buckling, and bond failure in samples exposed for 27 or 65 da. Web buckling became more frequent in samples exposed for 95 or 138 da. Wetting should induce swelling and permanent deformation, and these effects are more likely to occur in the OSB web. The shift in failure mode supports the premise for a weakened web.

The failure codes used to define failures of I-joists are outlined in ASTM (2013). Shear failures can be classified as ZJ-, ZW-, and IJ-type failures. FTJ-type failures are considered bond failures and can be classified as good bond, poor bond, or bad bond, indicating how well the adhesive performed. Z-type failures appeared in each group of I-joist tests but became progressively less frequent as exposure increased.

Shear-type failures occurred for the control I-joists. The most common failure mode for the control test was a ZW-type failure in which the bottom flange at the end of the beam developed a crack that propagated horizontally and then ran through the web at an approximately 45° angle and then horizontally through the top flange (Fig 3a). The other, less frequent shear failure observed was a ZJ-type failure (Fig 3b). A ZJ failure is similar to the ZW failure except that the failure through the web follows the web–web finger joint vertically as opposed to the 45° angle. Polocoser et al (2013) also found that the most frequent failure in short-span bending tests was of the Z-type classification.

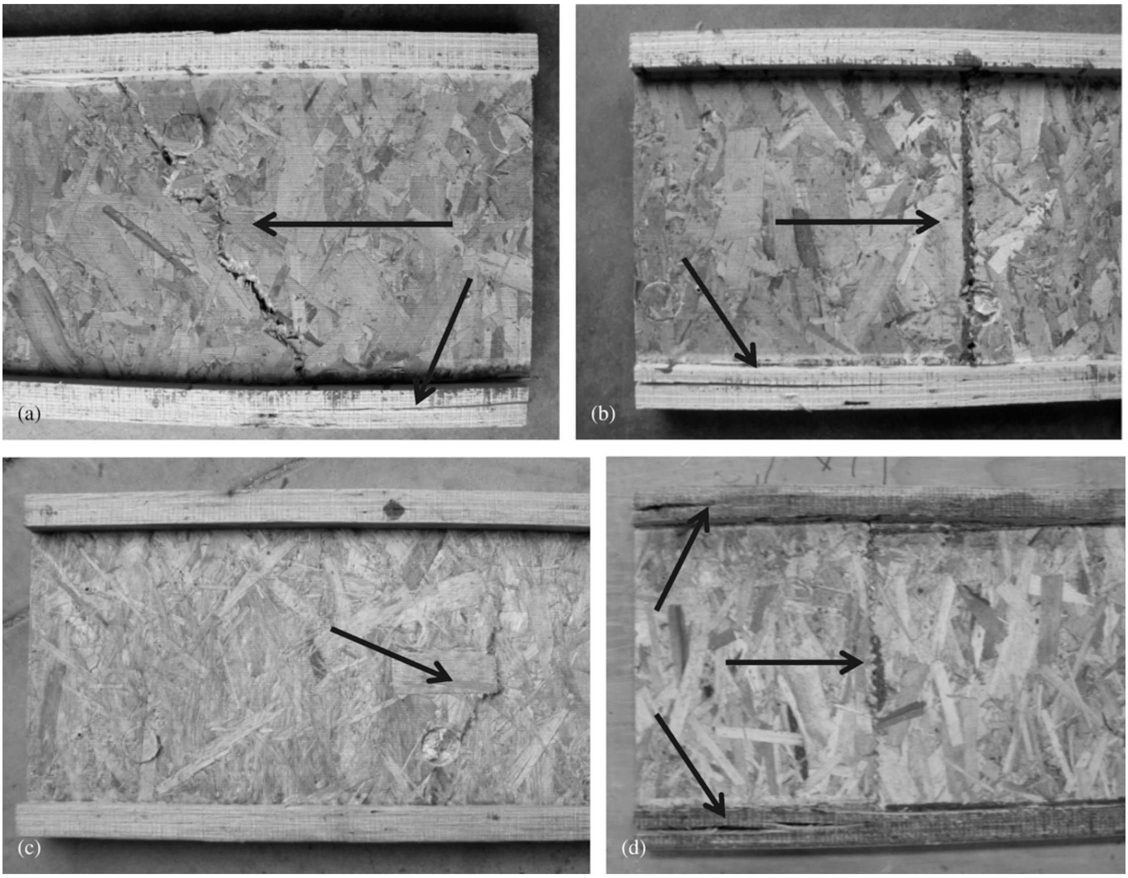


Figure 3. Various failure modes of I-joist: (a) ZW, (b) ZJ, (c) WB, and (d) IJ.

I-joist failure modes began to diversify after 27 da of exposure. The most frequent failure mode was again the Z-type failure, but FTJ- and WB-type failures were also observed. Z-type failures accounted for 50% of the failures observed. The FTJ failures occurred in the middle section of the I-joists with 70-100% wood failure along the glue joint. Another, less frequent failure mode for the 27-da exposure samples was web buckling classified as WB (Fig 3c). Web buckling was caused by a weakened web, which was caused by moisture swelling of the OSB. Web buckling after exposure to moisture was consistent with findings by Chen et al (1989) although those I-joists were tested at much higher moisture contents.

The failure modes for the 65-da exposure period were again composed of ZJ, FTJ, and WB failure types with the dominant failure mode being Z-type failures (63% of failures). FTJ-type failures were the second most frequent mode, whereas WB-type failures were least frequent. The FTJ-type failures had 70-100% wood failure along the glue joint.

I-joists exposed for 95 and 138 da primarily experienced WB-type failures and some Z-type failures. The increase in WB-type failures further supports the notion of a weakened web caused by OSB swelling. An IJ-type failure occurred in the 95-da exposure test (Fig 3d). IJ failures were in the Z-type failure class but had a horizontal flange–web joint failure that extended both ways from the web–web failure line. Both the 95- and 138-da exposure tests had WB-type failures that accounted for 63% of the failures.

### Tension Test Failure Modes

Tension tests on sections removed from the I-joists showed that rainfall exposure had no negative effect on ultimate load nor did it alter the location of the failure (Table 1). These results appear to be at odds with the bending test results. The moisture-induced changes primarily occurred in the web and away from the joint. The bottom flange should be most affected by this effect because water can collect at this location, resulting in greater moisture uptake in the OSB. This should have led to increased swelling and greater effects on the OSB–flange bond. The data do not support this process and suggest that the web–flange bond was less affected by wetting than the OSB. Results suggest that I-joists could be made more weather-resistant by using more moisture-resistant OSB, such as the materials offered for subflooring; however, the best practice would still be to protect these materials from wetting during storage and to cover them as soon as possible when they are installed in a structure.

## CONCLUSIONS

I-joists exposed outdoors during the winter in western Oregon experienced increased moisture contents coupled with losses in flexural properties during the test period. Variance in flexural strength nearly doubled after 27 da of exposure. One of the main advantages of I-joists is uniformity in properties, but data show the drastic effect wetting can have on this attribute in a very short time. The effects of exterior exposure on flexural properties were significant after 65 da of exposure. Progressive changes in failure mode supported the view that swelling of the OSB web caused by wetting was the primary cause of strength loss. Exterior exposure had no negative effect on tension properties. The results illustrate the negative effects associated with wetting of I-joists and why these materials need to be protected from moisture.

## REFERENCES

ASTM (2010a) D2915. Standard practice for sampling and data-analysis for structural wood and wood-based products. American Society for Testing and Materials, West Conshohocken, PA.

ASTM (2010b) E105. Standard practice for probability sampling of material. American Society for Testing and Materials, West Conshohocken, PA.

ASTM (2013) D5055. Standard specification for establishing and monitoring structural capacities of prefabricated wood I-joists. American Society for Testing and Materials, West Conshohocken, PA.

Chen GH, Tang RC, Price EW (1989) Effect of environmental conditions on the flexural properties of wood composite I-beams and lumber. Forest Prod J 39(2):17-22.

Hayashi T, Miyatake A, Harada M (2002) Outdoor exposure tests of structural laminated veneer lumber I: Evaluation of the physical properties after six years. J Wood Sci 48(1):69-74.

King DT (2014) Biological degradation of wood composite assemblies. MS thesis, Oregon State University, Corvallis, OR.

Kojima Y, Suzuki S (2011) Evaluation of wood-based panel durability using bending properties after accelerated aging treatments. J Wood Sci 57(2):126-133.

Lehmann WF (1978) Cyclic moisture conditions and their effect on strength and stability of structural flakeboards [wood-base composite panels]. Forest Prod J 28(6):23-31.

Leichti RJ, Falk RH, Laufenberg TL (1990) Prefabricated wood composite I-beams: A literature review. Wood Fiber Sci 22(1):62-79.

McNatt JD (1980) Hardboard-webbed beams: Research and application. Forest Prod J 30(10):57-64.

Meza L, Sinha A, Morrell JJ (2013) Effect of wetting during construction on properties of Douglas-fir plywood and oriented strandboard flooring. Forest Prod J 63(5/6):199-201.

Norita H, Kojima Y, Suzuki S (2008) The aging effects of water immersion treatments in wet-bending for standardized testing of wood panels. J Wood Sci 54(2):121-127.

Nzokou P, Zyskowski J, Boury S, Kamdem DP (2005) Natural decay resistance of LVL made of veneers from durable and non-durable wood species. Holz Roh Werkst 63(3):173-178.

Okkonen EA, River BH (1996) Outdoor aging of wood-based panels and correlation with laboratory aging: Part 2. Forest Prod J 46(3):68-74.

Polocoser T, Miller T, Gupta R (2013) Evaluation of remediation techniques for circular holes in the webs of wood I-joists. J Mater Civ Eng 25(12):1898-1909.

Ramsey FL, Schafer DW (2002) The statistical sleuth: A course in methods of data analysis. Cengage Learning, Independence, KY. 768 pp.

River BH (1994) Outdoor aging of wood-based panels and correlation with laboratory aging. Forest Prod J 44(11/12):55-65.

Robins JG (1975) The wooden wonder: A short history of the wooden aeroplane. J. Bartholomew and Sons Ltd., Edinburgh, UK. 55 pp.

Wu Q, Suchsland O (1997) Effect of moisture on the flexural properties of commercial oriented strandboards. Wood Fiber Sci 29(1):47-57.