

TECHNICAL NOTE: EFFECTS OF LONG-TERM OUTDOOR EXPOSURE ON PROPERTIES OF I-JOISTS

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Abstract. I-joists manufactured using wood composites are intended for dry service condition. Situations arise where I-joists are exposed to excessive weather conditions. This exposure to moisture can degrade structural properties of I-joists. In a follow-up to a previous published study (King et al 2014) looking at the short-term exposure to moisture (138 d), this study extends the exposure days further to 1351 d (approx. 3.5 yr) to gain an insight into property changes and fine-tune the degradation model presented by King et al (2014). Long-term exterior exposure was associated with continued declines in maximum load and deflection at maximum load, but the rate of property loss decreased as the exposure period was extended. Bending failure modes shifted back from web buckling to shear type failures at the web–web and web–flange joints.

Keywords: Wood composites, durability, moisture, regression model.

INTRODUCTION

Wood composite I-joists are intended for use in dry service conditions. Rare situations may arise, however, where I-joists are exposed to excessive moisture for prolonged periods of time such as during flooding, prolonged construction delays, or due to poor construction practices (Johnson 2003; King et al 2014). Moisture uptake can lead

to swelling of the timber elements, producing permanent deformation and reducing properties of the composite.

King et al (2014) studied moisture effects on unprotected I-joists exposed outdoors during rainy season in western Oregon. I-joists were sampled four times at approximately 30-d intervals, conditioned to 12% MC, and destructively tested in a short-span bending test (King et al 2014). Although short-term exposure (27 d) resulted in no significant changes in average shear

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strength, increased variability was observed. Further exposure resulted in a shear strength reduction of approximately 18% after 138 d. Failure modes shifted from joist shear to web buckling as exposure time increased, illustrating the influence of irreversible thickness swelling in the oriented strand board (OSB) webs (King et al 2014).

While the original exposure period was prolonged in terms of typical residential construction, additional I-joists remained after this time and were left in place to assess the effects of much prolonged exposure on capacity. In addition, the goal was to determine how long-term exposure data affected the degradation model. It is recognized that I-joists would rarely be exposed under these conditions for this length of time, but there are few studies examining these effects which might prove useful if water intrusion in structures is discovered shortly after installation.

MATERIALS AND METHODS

Exposure

I-joist specimens (406 mm deep \times 2.6 m long containing 59-mm-wide \times 35-mm-deep Douglas-fir laminated veneer lumber (LVL) flanges and a 10-mm-thick aspen OSB web) were placed outdoors in an open field near Corvallis, OR (King et al 2014), in September 2012, and samples had been removed over 138 da and tested to failure. Nine to eleven of the 35 remaining specimens were randomly selected for removal from the field in June 2015, January 2016, and June 2016, resulting in 1008, 1224, and 1351 d of exposure, respectively. Specimens were conditioned to approximately 12% MC for 2–6 wk in an open area in which temperatures ranged from 20 to 23°C and RH from 30 to 70%. Rainfall data were collected from a weather station located approximately 5 km from the exposure site (CAS 2017). Further details regarding the exposure methods and site are detailed in King et al (2014).

Test Setup

A short-span six-point bending configuration was used to evaluate the I-joists. Web stiffeners were

attached at the ends of each joist. Every I-joist contained at least one web–web joint, which was positioned at least 100 mm from the reaction ends and within the outer 1/3 span. The test apparatus consisted of two reactions and four loading points spaced at $2L/10$, where L is the span length. A span-to-depth ratio of 6:1 was used, and deflection was measured at midspan. Lateral bracing was provided at the ends and at four locations along the span. Further details on the test configuration are provided elsewhere (Polocoser et al 2013; King et al 2014). Failure modes were classified based on those described in the ASTM Standard D5055 (ASTM 2013).

Statistical Analysis

The data were subjected to analysis of variance, and individual treatments were compared using unpaired t-tests ($\alpha = 0.05$). Data from the previous and current studies were used to develop linear regression models comparing the maximum load vs rainfall, rain days, and exposure time. The data were evaluated to determine if prolonged exterior exposure changed the model parameters determined in the previous work.

RESULTS AND DISCUSSION

Exposure

Measurable rainfall (>0.01 cm) occurred on 450, 539, and 605 da for the 1008, 1224, and 1351 d exposures, respectively. I-joists were exposed to cyclic wetting and drying as Corvallis, OR, typically encounters cool, wet winters and dry, hot summers. Three wet/dry cycles were observed from daily rainfall data for those sampled at 1008 da and four wet/dry cycles for the other groups (Fig 1). Mass measurements of I-joists sampled in January 2016 (1224 d) showed an average weight gain of 45%, while those sampled in June 2015 and 2016 were within 5% of their initial weight, supporting the premise that the samples were exposed to complete wetting and drying that occurred between the wet and dry seasons. This process would result in repeated swelling and shrinkage of the I-joist elements,

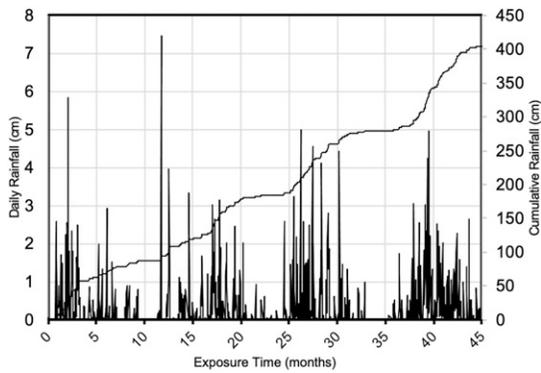


Figure 1. Daily and cumulative rainfall at the exposure site during the exposure period (CAS 2017). Samples at 1008, 1224, and 1351 d correspond to 34, 40, and 45 mo, respectively.

creating stress on any connections between components. The top and sides of the upper flange surfaces as well as the upper exposed surfaces of the lower flange were bleached and heavily checked. Weathering of the webs was apparent, but most strands on the surface remained intact. Visual signs of decay were absent, and all specimens appeared to be sound. The absence of visible fungal attack is not surprising, especially in the flange. Douglas-fir heartwood is moderately resistant to decay, and the risk of decay at the site is moderate according to the Scheffer climate index (Scheffer 1971; Scheffer and Morrell 1998). It was surprising to observe no visible evidence of decay in the web because OSBs are very susceptible to fungal attack. However, the exposure conditions tend to minimize the risk of decay above ground because rainfall periods are characterized by cooler temperatures less conducive to fungal growth, while the warmer summer conditions are quite dry and would result in limited moisture for fungal growth above the ground.

Bending Test

Maximum load dropped significantly between the initial (<138 d) and long-term exposures (Table 1). Maximum load decreased significantly between 138 and 1008 da of exposure (p -value < 0.0001) and 1008 and 1224 (p -value = 0.026) or 1351 (p -value = 0.043) days of exposure. No

statistically significant difference was observed between 1224 and 1351 d of exposure (p -value = 0.296). The largest decrease in maximum load was observed after 1224 d with I-joists retaining only 56% of their initial value. Variability, as judged by the coefficient of variation, in load for the long-term exposed I-joists tended to be lower than that found for the short-term exposure (Table 1).

A large drop in deflection at maximum load and an increase in variability were observed after the long-term exposure. Statistically significant differences were found between all long-term exposed joists and the last short-term exposure sample (p -values 0.032, <<0.0001, and <<0.0001 for 1008, 1224, and 1351 d, respectively). The largest decrease in deflection at maximum load was found after 1351 exposure days, where 64% of the initial value was retained (Table 1). The short-term exposure showed increasing variability in deflection until the exposure midpoint and then a decrease to the last collection point. Variability in deflection during the long-term exposure was highest at 1008 d and decreased steadily to 1351 d, suggesting that all of the I-joists had experienced declines in properties.

Failure modes were studied as per the classification provided in ASTM D5055. The ASTM classifies several failure modes. However, for brevity, only the ones observed are described. ZJ failure involves a failure line running horizontally along the bottom flange–web joint at the end of the beam, then proceeds vertically along the web–web joint, and then proceeds horizontally along the top flange web joint toward the center span. Failure lines primarily follow glue joints. ZW failure type involves a failure line which runs horizontally through bottom flange, then proceeds predominately at a diagonal through the web, then runs horizontally within the top flange. Damage may occur at the web–flange joint but is mostly limited to the flanges themselves. Combination of ZJ and ZW occurs frequently.

The short-term exposure revealed a shift in the failure mode from shear type (ZW and ZJ

Table 1. Outdoor exposure information and short-span bending test results.^{a,b}

Exposure (d)	Rainfall (cm)	Days with rain	N	Load (kN)		Deflection (mm)		Predominant failure(s) ^d
				Mean	COV (%) ^c	Mean	COV (%) ^c	
0	S	0	7	54.6	5.3	14.9	9.9	ZW
27	34	20	8	53.3	10.9	13.0	10.7	ZJ
65	47	48	8	49.5	11.8	12.9	17.7	ZJ
95	74	71	8	45.0	15.8	12.9	16.8	WB
138	85	104	9	44.6	12.9	13.0	9.1	WB
1008	280	450	10	34.2	10.2	11.2	21.3	ZJ/WB
1224	359	539	9	30.5	13.9	9.7	18.8	ZJ
1351	405	605	11	31.5	11.1	9.6	14.8	ZJ

^a Data from exposure periods 0-138 d from King et al (2014).

^b Load and deflection from the bending test at the point of maximum load.

^c Coefficient of variation.

^d Failure modes classified from Section X5 in (ASTM 2013).

classification, ASTM (2013)) in the control and first two exposure periods to web buckling during the last two exposure periods (King et al 2014). Both shear type failure modes consist of the failure line running horizontally along the top and bottom flange–web joints and either diagonal shear through the thickness of the web or along the web–web joint for ZW and ZJ failures, respectively (ASTM 2013). Web buckling typically occurred near the unstiffened loading points. Sixty percent of specimens exposed for 1008 d failed in shear at the web–web joint (ZJ), and 40% failed with web buckling. ZJ type failures were the most common failure modes for the last two long-term exposure samples. In addition to shearing at the web–web joint, ZJ failures also showed increased adhesive failure at the web–flange joint. The shift from shear failures to web buckling during the short-term exposure supported the premise that the OSBs experienced more substantial degradation than the LVL flange or glued joints. Failures at the web–web joint suggest that the web/flange adhesive bonds are affected to a greater extent than the OSB web after long exposure to prolonged wet/dry cycles.

Degradation Models

The linear regression model previously developed for the short-term exposure data in which maximum load was regressed against rainfall (King et al 2014) was further explored to determine the effects of prolonged exposure. The

I-joint specimens for short- and long-term exposure were from the same source and were placed outdoors at the same time. Including the long-term data for maximum load resulted in an increase in the coefficient of determination (R^2) from 30% for the short-term data to 74% for all data combined. The improved fit likely results predominately from the large rainfall difference between short- and long-term exposure specimens and to a lesser extent from the increased sample size and decreased variability in values as the exposure period was extended. A slope reduction from that of the short-term data Eq 1 was observed when short- and long-term data were combined Eq 2.

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

$$\text{Load} = 52.01 - 0.0569 \text{ Rainfall} \quad (2)$$

The change in slope is consistent with the premise that mechanical property loss rates decrease with increasing exposure time (Bodig and Fyie 1986; River 1994). Fitting the combined data to an exponential model Eq 3 produced only marginal improvements in R^2 and RMSE compared with the linear model. Relationships between I-joint properties and number of days with measurable rain and exposure time were also investigated but failed to improve the model. It is entirely possible that key changes in properties occurred between the last short-term and first long-term exposure measurement periods, but there is no way to determine if additional changes occurred without

repeating the tests. Moisture exposure to OSBs results in nonrecoverable thickness swelling, which is greatest in magnitude during the first exposure and continues to increase with each swell/shrink cycle (Moya et al 2009). The importance of nonrecoverable thickness swelling to mechanical performance of OSBs, along with differential expansion coefficients creating additional stresses at LVL–OSB and OSB–OSB bond lines over multiple swell/shrink cycles, is not properly captured by simple factors such as rainfall or exposure time. Future work in modeling I-joist mechanical property loss during cyclic moisture exposure conditions would benefit from directly measuring the change in bonding strength at the LVL–OSB and OSB–OSB bond lines in I-joists.

$$\text{Load} = 52.22e^{(-0.00141 \text{ Rainfall})} \quad (3)$$

CONCLUSIONS

Long-term exterior exposure of I-joists for up to 1351 days was associated with continued declines in maximum load and deflection at maximum load, but the rate of property loss decreased as the exposure period was extended. Bending failure modes shifted back from web buckling to shear type failures at the web–web and web–flange joints. The exposure periods evaluated were unreasonably long compared with those an I-joist could experience in practice but would be useful for determining the potential effects of poor construction practices that permitted periodic moisture intrusion on properties.

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