

Evaluation of a reduced section modulus model for determining effects of incising on bending strength and stiffness of structural lumber

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Abstract

A quantitative model is presented for evaluating the effects of incising on the bending strength and stiffness of structural dimension lumber. This model is based on the premise that bending strength and stiffness are reduced when lumber is incised, and the extent of this reduction is related to the reduction in moment of inertia of the bending members. Measurements of voids and damage caused by incisor teeth showed that actual incision depth was not always equal to nominal depth. For lumber with 660 incisions/ft², the actual depth of the incisions was approximately equal to the targeted nominal depth. However, for lumber with 800 incisions/ft², the actual depth of the incisions was approximately 65 percent of the targeted nominal depth. The amount of damaged wood below the incision was found to extend 1.38 to 2.18 times the depth of the void left by the incising process. Using these data as input, the reduced moment of inertia model predicted lumber bending strength loss resulting from incising to within 7 percent accuracy, on average. To predict lumber bending stiffness loss resulting from incising, a complementary virtual work method was used, which resulted in predictions that were accurate to within 1 percent, on average. It was then showed that bending strength and stiffness losses can be calculated for lumber of various sizes. Currently, the National Design Specification (NDS) publishes a single reduction factor for bending strength, which is applied to all sizes of structural lumber and to all incising densities, up to the maximum allowed. This factor is overly conservative for large members and does not account for various types of incisor tooth dimensions and incision densities. The reduced section modulus model presented here would provide the much needed adjustment to current NDS incising factors.

Wood that will be used outdoors requires preservative treatment to prevent decay. Treatment involves impregnating the wood cells with chemical preservatives that retard the invasion of decay-causing fungi. In most cases, the preservative is infused into the wood members using a pressure process. However, difficult-to-treat species must be incised to receive the chemicals more readily. Incising is a pretreatment process in which small incisions, or slits, are punched into the wood surface. This increases the amount of exposed end- and side-grain surface area, which increases chemical preservative penetration and retention.

Although preservative treatment increases durability, the incising process is known to reduce stiffness and strength. The National Design Specification for Wood Construction (NDS) (ANSI/AF&PA 2001) publishes incising factors that reduce lumber design values by a ratio of 0.95 for modulus of elasticity (MOE) and 0.80 for bending, tensile, and compressive strength. These reductions are based on a maximum incision

depth and length of 10.2 and 9.5 mm (0.4 and 0.375 inch), respectively, and a maximum incising density of 1,100 incisions/ft² (1 ft² = 0.093 m²).

Luxford and Zimmerman (1923) tested two matched groups of incised specimens and a non-incised control group; one group was perforated green, air-dried, and left untreated and the other group was perforated green, air-dried, and treated. The bending strength and bending stiffness results for these groups are summarized in **Table 1**. Luxford and Zim-

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*Forest Products Society Member.

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Forest Prod. J. 55(9):77-83.

Table 1. – Average modulus of rupture (MOR) and MOE values from Luxford and Zimmerman (1923).

Group	Sample size	MOR (psi)	MOE (psi × 10 ⁶)
Perforated green, air-dried	10	8,820	1.98
Perforated green, air-dried, and treated	10	8,770	2.03
Control group	30	10,290	2.09
Ratio of incised/control (both incised groups combined)		0.85	0.96

merman (1923) stated that the observed reduction in strength of incised specimens to that of the control group was approximately equal to the reduction in section modulus. They made no statement with respect to MOE. The specimens were 100 mm (4 in) wide by 200 mm (8 in) deep by 2.4 m (8 ft) long and tested in third-point bending over a support span of 2.25 m (7.38 ft). The incisions were approximately 3.1 mm (0.125 inch) wide by 19 mm (0.75 inch) long by 19 mm (0.75 inch) deep; they were staggered such that the reduced cross sections were repeated every 51 mm (2 inches) along the longitudinal axis of the member. The incisions were spaced 6 mm (0.25 inch) apart across the width of the members. At a given cross section, the gross moment of inertia would be $7.1 \times 10^6 \text{ mm}^4$ (170.6 in⁴) and the reduced moment of inertia would be $6.4 \times 10^6 \text{ mm}^4$ (153.5 in⁴). This results in a reduced moment of inertia that is 90 percent of the gross moment of inertia. The calculations are shown in the Appendix.

Several other studies have also provided data that support strength and stiffness reductions in structural lumber (Lam and Morris 1991, Perrin 1978, Winandy et al. 1995). Strength losses were also observed in larger solid timbers (Harkom and Rochester 1930, Rawson 1927) and glued-laminated members (Schrader 1945). More recently, Winandy and Morrell (1998) evaluated the effects of pretreatment incising of dry lumber and subsequent waterborne-preservative treatment on the bending strength of 1,980 pieces of nominal 2 by 4 inch (standard 38 by 89 mm) lumber (hereafter called 2 by 4). In that study, three species groups (Douglas-fir, hem-fir, and spruce-pine-fir [South]) and two commercially produced machine-stress-rated (MSR) grades per species group were evaluated. Two incision densities (660 and 800 incisions/ft²), four incision depths (0, 5, 7, and 9 mm; 0, 0.2, 0.28, and 0.35 in), and three preservatives (CCA, ACZA, and ACQ-B) were evaluated (Table 2).

The normalized results in Table 2 show average ratios of incised to non-incised bending strength and bending stiffness for each lumber group. In this paper, the ratio of incised to non-incised bending values will be referred to as the residual bending value. Overall, the average residual bending strength was observed to be approximately 0.80; however, the average residual bending strength of individual groups ranged from 0.55 to 0.92. The residual bending stiffness averaged approximately 0.91, and results for individual groups ranged from 0.74 to 1.03. Groups showing the greatest reduction in bending strength and stiffness had a maximum incision depth of 7.1 mm (0.28 inch) and density of 660 incisions/ft². The reduction in strength and stiffness was most heavily influenced by incision depth and density. In addition, the observed residual strength and stiffness value exceeded the NDS factors of 0.80 for strength and 0.95 for stiffness. Moreover, these

results correspond to incision densities (660 and 800 incisions/ft²) that are much lower than the maximum allowed density of 1,100 incisions/ft² in the standard. Therefore, there is evidence that the NDS published values might be nonconservative for small sizes of structural dimension lumber at the stated maximum incision dimensions and density.

An analytical procedure is needed for accurate calculation of reductions in strength and stiffness resulting from incising. The NDS states that if incision patterns exceed the maximum allowable incising dimensions and density, then the reduction factors must be determined by test or by a reduced cross-sectional analysis. The analysis procedure recommended in this paper is based on work originally published by Luxford and Zimmerman (1923).

Although the work of Luxford and Zimmerman (1923) shows that a reduced section modulus methodology is technically feasible for calculating the residual bending strength of large incised structural lumber and timbers, this has not been proven with small structural lumber or for bending stiffness. Accurate incision dimensions are required for accurate evaluation of the reduced section modulus procedure.

Objective

The objective of this study was to evaluate the technical feasibility of the reduced section modulus method for predicting the effect of incising on strength and stiffness of dimension lumber. Data reported by Winandy and Morrell (1998) were used as the basis for establishing the incising reduction factors for varying dimensions and densities of incisions (Table 2).

Procedures

To evaluate the reduced section modulus method, accurate and complete data were gathered on the dimensions of the actual incision openings and the spacing between incisions for each different incision density. These data were used to analyze each lumber group using the reduced section modulus method.

Incision dimensions

The first step was to characterize the actual dimensions of the incision patterns using the same specimens studied by Winandy and Morrell (1998). For characterizing the density pattern, specimens had 660 or 800 incisions/ft² incised with 5- and 7-mm- (0.2- and 0.28-in-) long teeth, for a total of four categories (Fig. 1). Approximately the same amount of area is shown in Figure 1a and 1b, which allows visual comparison of the relative density between the two incising patterns. The center-to-center distance between incisions across the width and length of the specimens was measured, as well as the width and length of individual incision openings. This information was used to determine the shape of the reduced cross sections and the frequency that these sections occurred along the length of the lumber.

Unpublished data also gathered during the Winandy and Morrell (1998) study included depth of incision for each lumber group listed in Table 2. Measurements were taken from several samples of cross sections similar to those shown in Figure 2. These specimens were cut at the center of an incision at its deepest penetration, and the depth of the incision was measured.

Table 2. – Normalized MOR and MOE values for incised lumber (Winandy and Morrell 1998).^a

Species group ^b	Grade	Treatment ^c	SG	660 incisions/ft ²		800 incisions/ft ²	
				0.2-in	0.28-in	0.2-in	0.29-in
HF	1650f/1.5E	CCA	0.43	0.90 (0.91)	0.69 (0.88)	0.87 (0.92)	0.86 (0.94)
	2400f/2.0E	CCA	0.48	0.84 (0.90)	0.65 (0.79)	0.92 (0.92)	0.87 (0.91)
	1650f/1.5E	ACZA	0.44	0.89 (1.03)	0.68 (0.91)	0.89 (1.00)	0.92 (1.02)
	2400f/2.0E	ACZA	0.48	0.89 (0.96)	0.68 (0.93)	0.90 (0.99)	0.83 (1.01)
DF	1800f/1.8E	ACZA	0.46	0.79 (0.87)	0.55 (0.74)	0.82 (0.92)	0.77 (0.84)
	2400f/2.2E	ACZA	0.52	0.86 (0.88)	0.62 (0.78)	0.84 (0.97)	0.78 (0.86)
SPF-S	1650f/1.5E	CCA	0.43	--	0.82 (0.96)	0.87 (0.95)	--
	2250f/1.9E	CCA	0.47	--	0.74 (0.91)	0.90 (0.92)	--
	1650f/1.5E	ACQ-B	0.43	--	0.68 (0.81)	0.82 (0.98)	--
	2250f/1.9E	ACQ-B	0.47	--	0.69 (0.82)	0.77 (0.87)	--
Avg. of normalized data				0.86 (0.93)	0.68 (0.85)	0.86 (0.94)	0.84 (0.93)

^aNormalized values were obtained by dividing averages of incised groups by averages of non-incised groups. Values are normalized MOR, values in parentheses are normalized MOE. 1 inch = 25.4 mm.

^bHF = hem-fir; DF = Douglas-fir; and SPF-S = spruce-pine-fir (South).

^cCCA = chromated copper arsenate; ACZA = ammoniacal copper zinc arsenate; and ACQ-B = ammoniacal copper quat type B. ACQ-B includes copper as CuO and the quat as didecylidimethylammonium chloride; this mixture is then dissolved in a solution of ammonia and water.

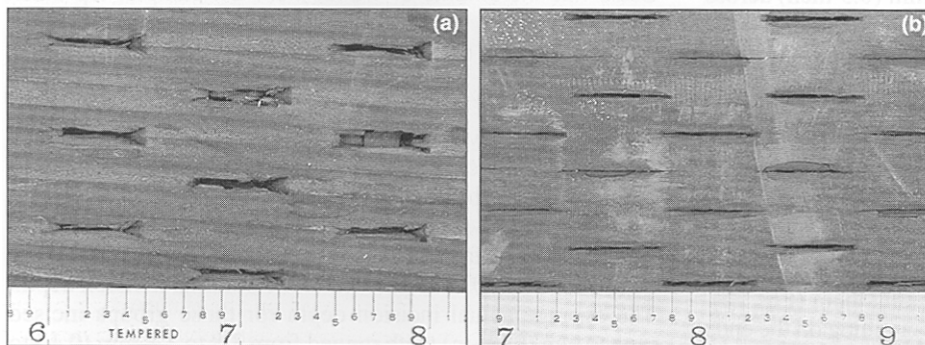


Figure 1. –Top surface view of incision patterns for lumber incised with 7-mm- (0.28-in-) long teeth: (a) 660 incisions/ft²; (b) 800 incisions/ft² (1 ft² = 0.093 m²).

Wood damage below incisions

Additional information was gathered to determine whether penetration of the incisors caused any wood damage. To observe the incision profile, samples from each lumber group (**Table 2**) were cut along the longitudinal axes of the incisions, such as the sample shown in **Figure 3**. From these longitudinal cross sections, the same depth of the incision void was measured (see **Fig. 2**) as well as the depth of the damage zone that occurred below the penetration of the incisor. Wood damage was defined as visible perpendicular-to-grain crushing of wood fibers. The depth of wood damage was estimated based on a visual assessment of where wood fibers were undisturbed longitudinally.

Reduced section modulus analysis

The reduced section modulus analysis was conducted using two different approaches for bending strength and stiffness. For bending strength, Luxford and Zimmerman (1923) indicated that reduced moment of inertia could be a simple predictor of strength loss caused by incising. Using this approach assumes that the reduced cross section governs the strength of the entire member. Because strength is a local property, this assumption seems reasonable. The research reported here

evaluated the validity of this assumption. The actual dimensions of incision width and the depth of wood damage were used to determine a reduced cross section for each lumber group. The procedure used to determine the reduced cross section for each group is illustrated in the Appendix.

In the Luxford and Zimmerman (1923) results (**Table 1**), bending stiffness was not reduced as much as bending strength. Because stiffness is a global property, we hypothesized that the reduced section modulus approach would not be appropriate at only one cross section. For this reason, a complementary virtual work analysis was employed to determine lumber deflection, which could be modified to incorporate the reduced section modulus concept. Complementary virtual work was used by analyzing the incised lumber specimens as having alternating cross sections along the length of the lumber. Hernandez et al. (1992) used this method to analyze glued-laminated timber with varying material properties along the length of the beam. In the study reported here, the cross sections of the incised lumber alternated between full cross sections, and the same reduced cross section was used for the bending strength analysis. The distance between the full and reduced cross sections was the center-to-center spacing measured for the two different incising patterns. The

loading configuration and support span assumed in this analysis were the same as those used in the actual lumber tests by Winandy and Morrell(1998).

The predicted bending strength reduction was determined for each group by dividing the calculated moment of inertia of the reduced cross section by the gross moment of inertia of the full cross section. For predicted bending stiffness, the calculated deflections of the non-incised specimens were divided by the deflection of the incised specimens. These calculated reduction factors were then compared to the normalized values in **Table 2**. Comparisons were made by dividing the predicted reduction factor by the actual normalized ratios.

Results and discussion

Incision dimensions

When conducting measurements on specimen surfaces like those shown in **Figure 1**, the center-to-center spacing was found to be fairly constant. However, the dimensions of the incisions varied with incisor tooth length and incision pattern density.

The spacing dimensions for each incising pattern are provided in **Table 3**. Variability in the measurements and the fact

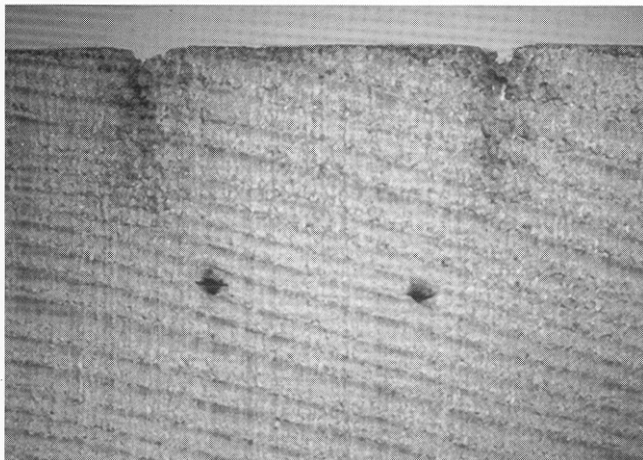


Figure 2. – End-grain cross-sectional view of incisions in dry Douglas-fir with 5-mm- (0.2-in-) deep incisions at 800/ft² density. Center-to-center distance between pin holes was 6 mm (0.25 in).

that incisor heads have a fixed pattern led us to assume nominal spacing. The 660-incisions/ft² pattern was assumed to have a center-to-center spacing of 12.7 mm (0.5 inch) across the width and 19 mm (0.75 inch) along the length of the specimens. The 800-incisions/ft² pattern had a center-to-center spacing of 10 mm (0.4 inch) across the width and 12.7 mm (0.5 inch) along the specimen length.

As for dimensions of the actual incisions, two dramatically different types of openings were observed. One type of opening appears to have formed by wedging the incisor into the wood surface and separating the wood fibers (**Fig. 1b**). The other type of opening appears to have crushed the wood fibers below the wood surface instead of separating them (**Fig. 1a**). Winandy and Morrell (1998) refer to this crushing on the ends of the incisions as “Crow’s feet.” In the majority of cases, groups with 800 incisions/ft² had the less severe type of incision damage, and the group with 660 incisions/ft² had the more severe “Crow’s feet” damage. This difference in incision damage is clearly visible in **Figure 1**.

The dimensions of the incisions were found to be related to the length of the incisor teeth (**Table 4**). The length of the incision produced by each type of tooth was rather constant, regardless of incision density. For both incision patterns, the 5-mm- (0.2-inch-) long teeth produced 10-mm- (0.41-inch-) long incisions and the 7-mm- (0.28-inch-) teeth produced 12.9-mm- (0.51-inch-) long incisions. (Note: incisor tooth shape, incisor pressure, and wood density dictate the depth of the incision.) However, for incisor teeth of the same length, the width of the incisions was approximately 25 to 40 percent greater for the 660-incisions/ft² pattern than for the 800-incisions/ft² pattern (**Table 4**).

In addition to measurements of incision dimensions on the lumber surface, unpublished data from Winandy and Morrell (1998) were used for measurements of incision depth. These measurements were taken on cross-sectional specimens, like that shown in **Figure 2**, for samples taken from each group. The results of these measurements are summarized in **Table 5**.

For the groups with 660 incisions/ft², the average actual incision depths were nearly equal to the nominal incision depths

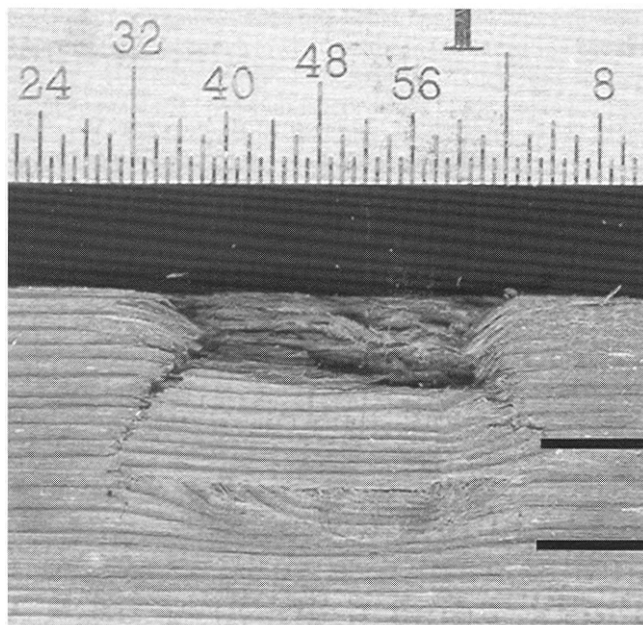


Figure 3. – Longitudinal cross-sectional view of damage in dry hem-fir caused by 5-mm (0.2-in) teeth at 800/ft² density. Scale has increments of 1/64th inch. On sample, top black line indicates approximate nominal depth of incision and lower line approximate depth of damage.

(**Table 5**). However, for the groups with 800 incisions/ft², the average actual incision depths were much less than the nominal incision depths. For example, the average actual incision depth for the 800-incisions/ft² groups incised with 5-mm (0.2-in) teeth ranged from 3 to 3.8 mm (0.11 to 0.15 in), which is approximately 60 to 75 percent of the nominal incision depth. The average actual incision depth for those groups incised with 7-mm (0.28-in) teeth ranged from 3.8 to 4.8 mm (0.15 to 0.19 inch), which is approximately 50 to 62 percent of the nominal incision depth.

The authors believe that no changes in hydraulic line pressure occurred between the runs of the two incising patterns. If so, the force at which the incisor head was pressed into the lumber surface would have been constant. The results in **Table 5** suggest that the incising equipment was set to a constant pressure. Thus, less force per tooth was applied in the 800-incisions/ft² pattern than in the 660-incisions/ft² pattern. Constant force on the higher incision density resulted in less force per tooth.

Wood damage below incisions

All specimens from all groups exhibited some amount of wood damage below the incisions. The ratio of damaged wood depth to actual incision depth was determined for each specimen. Measurements were taken using digital image analysis software. As shown in **Figure 3**, the first line indicates the measured incision depth and the second line the estimated depth of wood damage. The calculated ratios for each group are summarized in **Table 6**.

The depth of the damage zone ranged from 1.38 to 2.18 times the actual incision depth. The most important result from this evaluation was that all groups exhibited significant wood damage below the incisions. The ratio of average dam-

Table 3. – Measured and assumed dimensions for center-to-center distance between incisions.^a

Incisions/ft²	Incisor tooth length	Avg. distance		Assumed distance	
		Transverse	Longitudinal	Transverse	Longitudinal
			(in)		
660	0.20	0.493	0.757	0.50	0.75
	0.28	0.477	0.753	0.50	0.75
800	0.20	0.402	0.531	0.40	0.50
	0.28	0.398	0.506	0.40	0.50

^aAverage distance values are based on at least 10 measurements from actual specimens.

Table 4. – Measured and assumed dimensions for incision width and length.^a

Incisions/ft²	Incisor tooth length	Avg. incision dimension		Assumed incision dimension	
		Width	Length	Width	Length
(in)					
660	0.20	0.067	0.407	0.070	0.410
	0.28	0.099	0.517	0.100	0.520
800	0.20	0.053	0.413	0.055	0.410
	0.28	0.070	0.519	0.070	0.520

^aAverage dimension values are based on at least 20 measurements from actual specimens.

Table 5. – Actual incision depths measured from lumber cross sections.^a

Species group	Grade	Treatment	SG	660 incisions/ft ²		800 incisions/ft ²	
				0.2-in	0.28-in	0.2-in	0.28-in
HF	1650f/1.5E	CCA	0.43	0.20(29.5)	0.30(19.1)	0.14(31.5)	--
	2400f/2.0E	CCA	0.48	0.19(23.8)	0.26(25.0)	0.13 (35.2)	--
	1650f/1.5E	ACZA	0.44	0.21 (23.7)	0.34 (17.8)	0.14(25.6)	0.19 (17.0)
	2400f/2.0E	ACZA	0.48	0.20 (21.7)	0.33 (18.8)	0.13 (21.7)	0.16 (23.5)
DF	1800f/1.8E	ACZA	0.46	0.20 (27.6)	0.31 (27.5)	0.13(23.7)	0.15(23.2)
	2400f/2.2E	ACZA	0.52	0.20 (26.5)	0.27 (33.8)	0.11 (36.6)	0.17 (62.1)
SPF-S	1650f/1.5E	CCA	0.43	--	0.28 (32.6)	0.15 (28.3)	--
	2250f/1.9E	CCA	0.47	--	0.28 (27.1)	0.12 (27.8)	--
	1650f/1.5E	ACQB	0.43	--	0.31 (26.6)	0.12 (30.4)	--
	2250f/1.9E	ACQB	0.47	--	0.34 (106.3)	0.13 (26.2)	--

^aValues are average incision depths (in); values in parentheses are coefficients of variation.

aged wood depth to actual incision depth was never less than 1.38, and the average ratio of all groups combined was 1.75.

Reduced section modulus analysis

Using the incision measurements and damage zone results of **Tables 3** through **6**, the reduced moment of inertia and stiffness loss were calculated for each lumber group. The predicted reductions in moment of inertia and stiffness were divided by the actual reduction ratios (**Table 2**), resulting in ratios that indicated the accuracy of the predictions (**Table 7**). Values near 1.0 indicate good accuracy. The average ratio for bending strength of all groups was 1.07, which means that the average strength prediction was within 10 percent accuracy. The ratios for predicted strength loss were slightly higher for the 660-incisions/ft² groups with nominal 7-mm (0.28-inch) incisions than for all the other groups. For lumber stiffness, the ratio of predicted to actual loss ranged from 0.90 to 1.19, with an overall average of 1.01. This means that the average

stiffness loss was predicted with very good accuracy with the complementary virtual work method.

To further simplify the reduced section modulus method, we calculated strength and stiffness loss for an equivalent rectangular cross section with a reduced moment of inertia equivalent to the values reported in **Table 2**. As an example, we used the average group values in **Table 2**. For three groups, the average residual bending strength was approximately 0.85 and the average residual bending stiffness approximately 0.93. For the fourth group, the average residual bending strength was more severe (0.68); the corresponding loss in bending stiffness was 0.85. For these 2 by 4 data, the equivalent rectangular cross section that produced a 0.85 moment of inertia reduction had a uniform reduction of 2.54 mm (0.10 inch) in width and depth. In other words, a 36- by 86-mm (1.4- by 3.4-inch) reduced cross-sectional member has a moment of inertia that is 0.85 times that of a 38- by 89-mm (1.5-inch by 3.5-inch) full-size member.

For bending stiffness, the uniform reduction in width and depth required to achieve a 0.93 reduction in moment of inertia was only 1.3 mm (0.05 inch). For the severe case (660 incisions/ft², 0.28-inch incisor), the uniform reductions in cross section were 6 mm (0.24 inch) for bending strength and 2.54 mm (0.10 inch) for bending stiffness. Applying these uniform reductions in width and depth to other sizes of lumber re-

sulted in the estimated incising reduction factors reported in **Table 8**.

For the example given in **Table 8**, we used average reductions reported in **Table 1**. In three groups, average bending strength loss was due to incising of approximately 0.85 and average bending stiffness loss to incising of approximately 0.93. The fourth group had a more severe average bending strength reduction of 0.68 and a corresponding bending stiffness reduction of 0.85. Based on these reductions of bending strength and bending stiffness, we calculated the simple reductions in rectangular cross section for nominal 2- by 4-in. lumber. This uniform reduction in cross section (width and depth) was then applied to other lumber sizes. The uniform reduction in width and depth of bending members assumes that surface damage caused by incising is the same for all sizes of lumber.

This presents a proposed method for developing incising factors for various sizes of lumber, based on test results on a single size. It should be emphasized, however, that this sim-

Table 6. – Ratio of wood damage zone depth to actual incision depth. ^a

Species group	Grade	Treatment	SD	600 incisions/ft ²		800 incisions/ft ²	
				0.2-in	0.28-in	0.2-in	0.28-in
HF	1650f/1.5E	CCA	0.43	1.87(8)	2.03(7)	2.18(8)	--
	2400f/2.0E	CCA	0.48	1.95(9)	1.93(8)	2.05(9)	--
	1650f/1.5E	ACZA	0.44	2.16(9)	1.52(7)	2.09(7)	1.71(8)
	2400f/2.0E	ACZA	0.48	1.93(6)	1.76(6)	1.68(9)	1.90(9)
DF	1800f/1.8E	ACZA	0.46	1.81(9)	1.38(8)	1.44(8)	2.00(9)
	2400f/2.2E	ACZA	0.52	1.76(7)	1.77(11)	1.57(7)	1.60(9)
SPF-S	1650f/1.5E	CCA	0.43	--	1.55(6)	1.54(9)	--
	2250f/1.9E	CCA	0.47	--	1.63(9)	1.54(7)	--
	1650f/1.5E	ACQB	0.43	--	1.49(8)	1.63(7)	--
	2250f/1.9E	ACQB	0.47	--	1.41(7)	1.58(8)	--

^aValues in parentheses are sample size for each group.

Table 7. – Prediction results of reduced section modulus model. ^a

Species group	Grade	Treatment	SG	660 incisions/ft ²		800 incisions/ft ²	
				0.2-in	0.28-in	0.2-in	0.28-in
HF	1650f/1.5E	CCA	0.43	0.97(1.02)	1.03(0.94)	1.01(1.02)	--
	2400f/2.0E	CCA	0.48	1.04(1.03)	1.17(1.09)	0.98(0.91)	--
	1650f/1.5E	ACZA	0.44	0.94(0.88)	1.10(0.95)	1.00(0.94)	0.91(0.91)
	2400f/2.0E	ACZA	0.48	0.97(0.97)	1.06(0.90)	1.01(0.98)	1.02(0.93)
DF	1800f/1.8E	ACZA	0.46	1.10(1.07)	1.44(1.19)	1.13(1.04)	1.10(1.12)
	2400f/2.2E	ACZA	0.52	1.02(1.06)	1.24(1.12)	1.11(1.00)	1.12(1.09)
SPF-S	1650f/1.5E	CCA	0.43	--	0.96(0.92)	1.05(1.00)	--
	2250f/1.9E	CCA	0.47	--	1.05(0.97)	1.03(1.04)	--
	1650f/1.5E	ACQB	0.43	--	1.15(1.07)	1.12(0.98)	--
	2250f/1.9E	ACQB	0.47	--	1.12(1.06)	1.19(0.10)	--
Average ratio for strength = 1.07				Average ratio for stiffness = 1.01			

^aValues are ratios of predicted strength to actual strength; values in parentheses are ratios of predicted stiffness to actual stiffness.

Table 8. – Calculated bending strength and stiffness reduction factors for various sizes of structural lumber. ^a

Nominal size (in)	Average case ^b		Severe case ^c	
	Bending strength reduction	Bending stiffness reduction	Bending strength reduction	Bending stiffness reduction
2 by 4	0.856	0.926	0.679	0.856
2 by 6	0.883	0.941	0.735	0.883
2 by 8	0.895	0.947	0.759	0.895
2 by 10	0.903	0.951	0.776	0.903
2 by 12	0.909	0.954	0.787	0.909
4 by 4	0.891	0.944	0.753	0.891
4 by 8	0.932	0.965	0.842	0.932

^aFor this example, we used average reductions reported in Table 1. See text for explanations of results.

^bBased on uniform reduction in cross section of 0.10 inch for bending strength and 0.05 inch for bending stiffness.

^cBased on uniform reduction in cross section of 0.24 inch for bending strength and 0.10 inch for bending stiffness.

plified reduction method requires either test data like those presented in **Table 2** or an initial prediction of strength and stiffness loss based on actual incision dimensions and the reduced section modulus model presented here. This analysis method offers the flexibility to account for changes in the in-

cisor shape that cause a measurable change to the reduced cross section of the lumber.

Conclusions

Our analysis of bending and stiffness data for incised lumber specimens showed that incision dimensions vary on the basis of incision density, incisor tooth length, and wood density (specific gravity [SG]). In addition, areas of damaged wood that occur below the incisions should be considered when defining a reduced cross section for incised lumber. The reduced moment-of-inertia approach predicted loss in bending strength to within 7 percent of the observed results, and a complementary virtual work method predicted reductions in bending stiffness to within 1 percent. Specifically, we found the following:

- For lumber with 660 incisions/ft², the actual depth of the incisions was approximately equal to the targeted nominal depth.
- For lumber with 800 incisions/ft², the actual depth of the incisions was approximately 65 percent of the targeted nominal depth.
- The amount of damaged wood caused by penetration of the incisor teeth can be 1.38 to 2.18 times the depth of the void left by the incising process.
- Surface damage of lumber resulting from incising increases as the amount of pressure per tooth increases.
- Using a reduced moment of inertia approach, lumber bending strength loss resulting from incising was predicted to within 7 percent accuracy, on average.
- Using a reduced moment of inertia approach with a complementary virtual work method, lumber bending stiffness loss resulting from incising was predicted to within 1 percent accuracy, on average.
- With the reduced moment of inertia approach, we calculated that bending strength and stiffness reductions decrease as the cross section of the lumber increases (assuming the incision dimensions remain constant).

In summary, the reduced moment of inertia method for calculating bending strength and stiffness loss resulting from incising appears to be technically feasible. The NDS currently publishes a 0.80 incising factor for bending strength and a 0.95 factor for bending stiffness. These fac-

tors are applied to all sizes of structural lumber, and they can be applied to incision densities and incisor tooth lengths that are much more severe than those evaluated in this study. We found that the bending strength and stiffness adjustments are dependent on the incision dimensions (i.e., reduced cross section) and lumber size. Therefore, application of a single incising factor to all lumber sizes and all incision densities (up to a maximum allowed) is not accurate.

Literature cited

American National Standard/American Forest and Paper Association (ANSI/AF&PA). 2001. NDS: National design specification for wood construction. ANSI/AF&PA, Washington, DC. 174 pp.

Harkom, J.F. and G.H. Rochester. 1930. Strength tests of creosoted Douglas-fir railway beams. Circ. No. 28. Dept. Interior, Canadian Forest Serv., Ottawa, ON, Canada.

Hernandez, R., D.A. Bender, B.A. Richburg, and K.S. Kline. 1992. Probabilistic modeling of glued-laminated timber beams. Wood and Fiber Sci. 24(3):294-306.

Lam, F. and P.L. Morris. 1991. Effect of double-density incising on bending strength. Forest Prod. J. 41(9):43-47.

Luxford, R.F. and C.W. Zimmerman. 1923. Effect of perforations on the strength and treatment of Douglas-fir (air-dried). Unpublished report L-119-10. USDA Forest Serv., Forest Products Lab., Madison, WI.

Perrin, P. 1978. Review of incising and its effect on strength and preservative treatment of wood. Forest Prod. J. 28(9):27-33.

Rawson, R.H. 1927. A study of the creosote treatment of 6-inch by 12-inch Douglas-fir beams, covering boiling-under-vacuum-pressure process and influence of incising. In: Proc. Am. Wood Preservers' Assoc. 23:203-213.

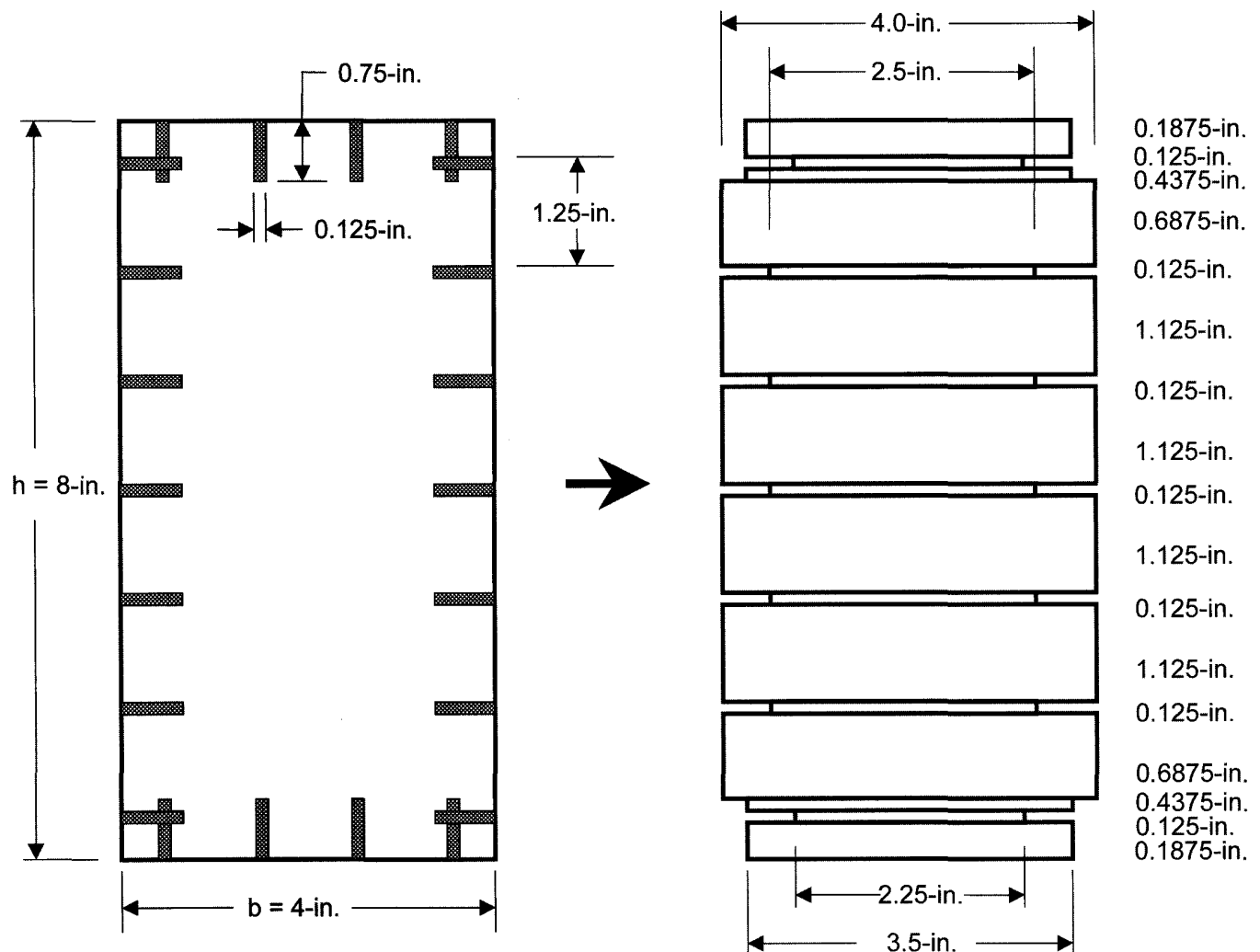
Schrader, O.H., Jr. 1945. Tests of creosoted laminated stringers. Engineering News Record 135:650-653.

Winandy, J.E. and J.J. Morrell. 1998. Effects of incising on lumber strength and stiffness: Relationships between incision density and depth, species and MSR grade. Wood and Fiber Sci. 30(2):185-197.

_____, _____, and S.T. Lebow. 1995. Review of effects of incising on treatability and strength. In: Proc. Wood Preservation in the 90s and Beyond. Forest Prod. Soc., Madison, WI. p. 65-69.

Appendix. Calculations of gross and reduced moment of inertia

Calculations for Luxford and Zimmerman (1923) specimens. (1 in = 25.4 mm)



Gross moment of inertia: $I_{gross} = bh^3/12 = (4)(8)^3/12$

$I_{gross} = 170.7\text{ in}^4$

Reduced moment of inertia: $I_{reduced} = 153.5\text{ in}^4$

Reduced moment of inertia was determined by "collapsing" the width based on the incision widths and depths. This resulted in a cross section with 17 layers. Parallel axis theorem was then used to determine the reduced moment of inertia.