Effect of environmental conditions on the flexural properties of wood composite I-beams and lumber

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Abstract

Flexural properties as affected by environmental conditions were evaluated for full-sized wood composite I-beams webbed with oriented strandboard (OSB), randomly oriented flakeboard (RF) and 3-ply Structural I plywood (PLY). Solid-sawn southern pine 2 by 10's, ordinarily used in light-frame building construction, were also tested for comparative purposes. Environmental conditions selected were 65 percent relative humidity (RH) (dry), 95 percent RH (humid) at 75°F, and 24-hour water-spraying (wet) at ambient temperature. In the dry condition, the OSB group carried the largest load among the four beam types, but the load capacities of the four beam types were not significantly different in the humid and wet conditions. Deflections at maximum load of the four beam types were significantly different in the three environmental conditions. The value for the lumber group was consistently higher than the I-beam types in each test condition. Loads at 1-inch deflection for the four beam types were also significantly different in the three environmental conditions. However, the value for the lumber group was consistently lower than those of the I-beam types. In the dry condition, most failures that occurred in the PLY group were in shear mode, while the majority of the OSB and RF members failed in bending, and the failures occurred in the flanges. In the humid condition, most of the I-beam and lumber specimens failed in shear and bending, respectively. In the wet environment, however, most of the I-beams failed in web buckling, while most of the lumber members failed in bending.

As the cost effectiveness of engineered products improves, wood composite I-beams are becoming more frequently used in medium- and light-frame wood structural systems (3,7,9). In general, wood composite I-beams are composed of solid wood or parallel-laminated veneer lumber as flanges, and wood-based panels as webs. A substantial amount of research has been reported concerning the engineering performance of wood composite I-beams in recent years. Results from the tests of composite wood/particleboard box- and I-beams indicated that the beams' load-deflection curves were linear to failure, exhibiting virtually no warning signals prior to failure. The beams were estimated to have 80 percent of the stiffness and 50 percent of the strength of a perfectly clear southern pine 2 by 10 (4).

The behavior of I-beams webbed with two different types of 1/4-inch-thick hardboards has also been investigated (10). These beams were 12 feet and 6 feet long, 11-7/8 inches deep, and fabricated with two pieces of 1-7/16- by 2-1/8-inch laminated veneer lumber on each side of the panels at top and bottom. The beams were conditioned to equilibrium moisture content (MC) at 50 percent relative humidity (RH) and 68°F, then tested destructively in bending. Analysis of the load-deflection curves showed hardboard webbed I-beams were linear to a load level equivalent to 60 percent of the rail shear strength of the web material determined from small specimen tests. Failure of the 12-foot hardboard webbed I-beams occurred in the tension flange with essentially no inelastic deformation prior to failure. Later, the behavior of I-beams with 1/4-inch plywood as a web material was included in the study. The results indicated that

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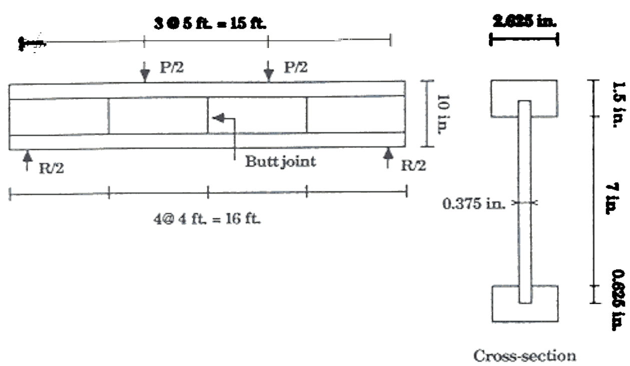

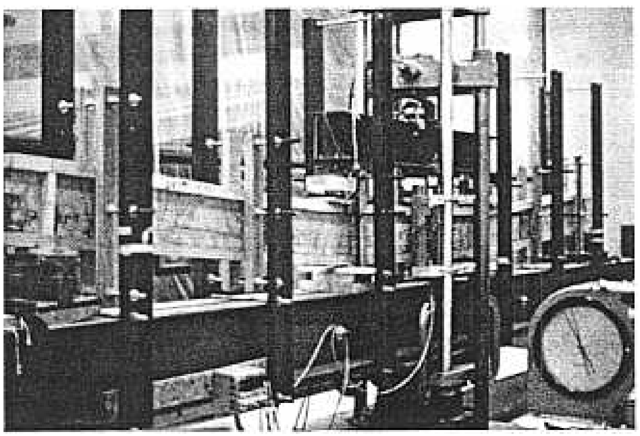

Figure 1 I-beam configurations (top) and testing set-up (bottom).

under a short-term destructive test, the 12-foot hardboard webbed I-beams were twice as strong and 50 percent stiffer than the equivalent plywood webbed specimens (8).

The bending strength of fabricated beams with flanges of minimally machined whole or half stems of lodgepole pine and webs made of lodgepole pine flakeboards has also been evaluated (5). The results indicated that the beams conditioned and equilibrated at 7 to 10 percent MC carried more load at failure than those of Douglas-fir and larch 2 by 10's, 2 by 12's, and 9.5-inch-deep beams fabricated with parallel-laminated Douglas-fir veneer flanges. Moreover, the pine beams had significantly less deflection than 2 by 10's or beams fabricated with laminated-veneer flanges, and were equal in stiffness to 2 by 12's.

More recently, the flexural properties of four types of I-beams webbed with plywood, waferboard, and OSB made of aspen, were evaluated at 55 percent RH and 75°F, and compared with southern pine lumber data (6). The I-beams were 16 feet long, 10 inches deep, and were fabricated with solid southern pine lumber flanges with cross-sectional dimensions of 2-5/8 by 1-1/2 inches. It was found that OSB I-beams carried more load and higher stress at failure than the other I-beam types. Failures of members webbed with OSB, waferboard, and plywood were not frequently associated with the failure of the flange-web joint in tension. Comparisons between I-beams and 2 by 10 southern pine lumber indicated that the load capacities and maximum stresses for the two groups were not significantly different. However, I-beams and 2 by 10 southern pine lumber were statistically different with respect to beam stiffness. The I-beams carried higher loads at 1-inch deflection than did the lumber members.

It is recognized that composite I-beams in medium- and light-frame structural systems may often encounter humid and/or wet environments during their service life or during on-site construction. However, most investigations related to the performance of composite beams have been conducted in ambient or dry environments, as previously mentioned. For a better understanding of the engineering performance of composite beams in service environments, information with regard to their flexural properties as affected by the MC level is needed. Therefore, the objective of this study was to evaluate the effect of various environmental conditions on the flexural properties of wood composite I-beams and compare the resulting properties with those of southern pine lumber.

Materials and methods

The I-beams were built up from solid wood flanges and wood composite panels as webs. The flange stock was southern pine lumber of grades No.1 Dense and Select Structural with a minimum machine stress rating (MSR) MOE of 2.2×10^6 psi. The flange elements, 2.625 inches wide and 1.5 inches deep, were finger-jointed at random intervals along the beam's length to accomplish the production of long beams, but the intervals between the finger joints were never less than 72 inches. The web materials were 3/8-inch wood composite panels, i.e., Structural I C-C grade southern pine plywood (PLY), 3-layer oriented strandboard (OSB), and randomly oriented flakeboard (RF) fabricated with a 50/50 mixture of sweetgum and red oak flakes and bonded with liquid phenol-formaldehyde. Plywood was commercial board, but the OSB and RF were noncommercial boards. Panels were sawn and used in beam fabrication such that the major panel axis (8-ft. direction) was perpendicular to the length of the beam. All webs were butt-jointed at 4-foot intervals. Flange-web joints and butt joints in webs were bonded with phenol-resorcinol adhesive. The solid lumber specimens tested in this study, No. 2 southern pine 2 by 10's, ordinarily used as standard supporting members in light-frame building structures, were purchased at a local retail lumberyard in 16-foot lengths. The I-beams were fabricated with a depth of 10 inches and a total length of 40 feet by Trus Joist Corp. at Valdosta, Ga., and each beam was later trimmed to two 16-foot testing members at Auburn University's Forest Products Laboratory. The I-beam configuration, as well as the location of butt joints, is pictured in Figure 1.

Three environmental conditions were chosen for this study: 1) dry condition (65% RH at 75°F); 2) humid condition (95% RH at 75°F); and 3) wet condition (24-hr. water-spraying). The dry condition was used to simulate a normal use condition, the humid condition was used to simulate protected exterior use during rain or very humid weather, and the wet condition was intended to simulate on-site construction immediately after heavy rain.

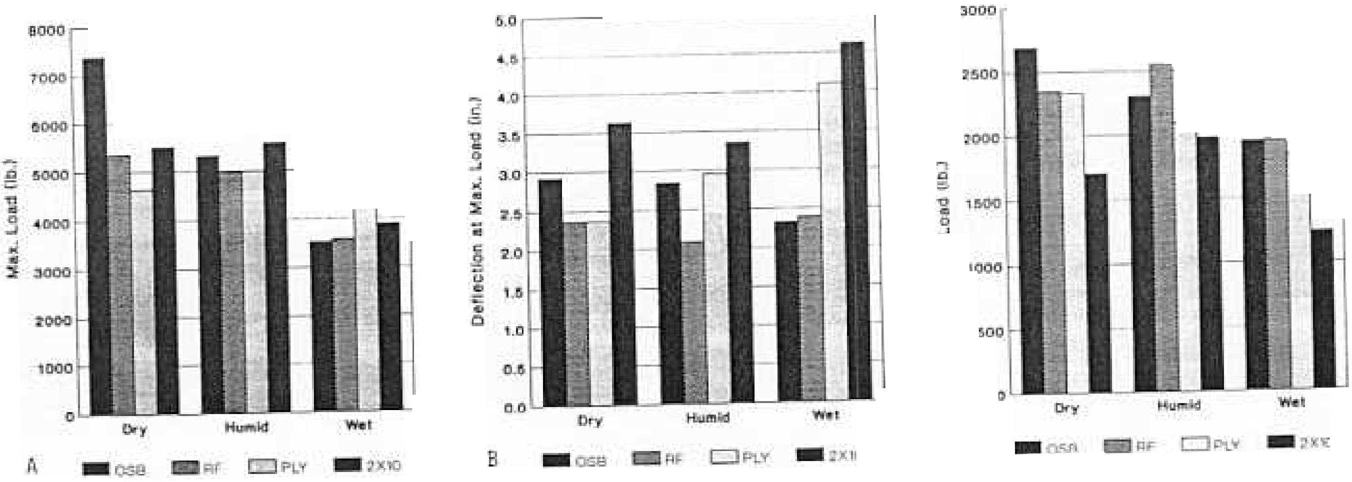

Figure 2. — Flexural properties for four beams types evaluated under three envorinmental conditions. A. Load capacities; B. Deflections at maximum load; and C. Loads at 1-inch deflection.

TABLE 1. — *Simple statistics for lumber and I-beams in three environmental conditions.*

Condition	Beam type	Statistics (n=4)	Maximum	At 1-in. deflection	Deflection[a]	MC
			------- (lb.) -------		(in.)	(%)
Dry	PLY	Mean	4,646	2,334	2.37	11.4
		SD[b]	606	289	0.60	0.1
	RF	Mean	5,363	2,354	2.37	12.8
		SD	2,156	289	0.93	0.1
	OSB	Mean	7,380	2,696	2.93	11.5
		SD	1,209	146	0.39	0.2
	2 by 10	Mean	5,509	1,706	3.63	10.0
		SD	797	271	0.83	1.0
Humid	PLY	Mean	4,998	2,091	2.96	18.1
		SD	582	111	0.19	0.5
	RF	Mean	4,969	2,566	2.09	17.9
		SD	962	175	0.36	0.3
	OSB	Mean	5,315	2,306	2.85	17.7
		SD	1,418	196	0.57	0.7
	2 by 10	Mean	5,528	1,977	3.36	13.8
		SD	1,497	554	0.66	0.5
Wet	PLY	Mean	4,392	1,841	4.10	29.8
		SD	657	272	0.87	0.9
	RF	Mean	3,586	1,968	2.39	44.3
		SD	666	303	0.26	6.1
	OSB	Mean	3,534	1,952	2.33	42.4
		SD	369	125	0.30	1.2
	2 by 10	Mean	3,890	1,242	4.62	38.0
		SD	1,407	321	0.69	9.1

[a] Deflection at maximum load.
[b] SD = standard deviation.

Four specimens were randomly selected from the population of each beam type and exposed to each environmental condition. For the dry and humid conditions, beams were stored in a controlled environment at a constant temperature of 75°F for at least 6 weeks. For the wet condition, beams were supported at a height 5 feet above the unshaded ground and continuously water-sprayed for 24 hours. The average MC for each beam type was approximately equal or exceeded the fiber saturation point (FSP) (Table 1).

After these exposures, each beam was tested to failure in flexure with third-point loading according to the ASTM standard D 198-76 (2) by using a modified 60-ton Tinius-Olsen testing machine (Fig. 1). All beams were tested on a 15-foot span with the best flange or edge (visually less defects) in tension. Loads and corresponding deflection measurements were obtained by using a computer-controlled data acquisition system. A 25-kip universal load cell was used to sense the loads, while a linear potentiometer was used to measure the midspan deflection. All tests were conducted with a constant load rate of 0.20 inch per minute, and the data acquisition system made load and deflection readings at 3-second intervals. After a beam failed, the test data were printed, and a load-deflection curve was plotted. A 5-inch segment was cut from the end of each beam to determine the beam's MC. Failure patterns of beams were recorded and photographed for use in failure mode analysis.

Results and discussion

Beam performance

The testing results and their statistics are summarized in Table 1, and the flexural properties for the four beam types, evaluated under the three environmental conditions, are plotted in Figure 2.

Analyses of variance (ANOVA) for the flexural properties of lumber and I-beams in different environments were performed at the 90 percent probability level, and the results of Duncan's multiple-range tests are summarized in Table 2. Load capacities for lumber and I-beam types were significantly different only in the dry condition. In this environment, OSB specimens carried significantly greater loads than the other three beam types, while lumber members, RF, and PLY types did not show significant differences in load capacities.

ANOVA for deflections at maximum load showed significant differences between beam types in all three environmental conditions. Results of Duncan's multiple-range test indicated that, in the dry condition, lumber specimens deflected significantly more than PLY and RF types, but the OSB deflections were not significantly different from the other three beam types. In the humid condition, the RF type deflected significantly less than the other three beam types and the deflections for lumber and the other two I-beam types were not significantly different from each other. In the wet environment, deflections at maximum load were not significantly different between lumber and PLY types; or between RF and OSB types. However, values for the former two types were significantly different from the latter two types.

Load at a common deflection, 1 inch, was used to compare the relative stiffness of the tested beams. A 1-inch deflection, or L/180, represents the maximum allowable deflection for roof beams or joists in commercial and institutional applications (1). In this study there were significant differences in loads at 1-inch deflection in all three environmental conditions. Further analyses indicated that in the dry environment, OSB members carried the greatest load at 1-inch deflection and the lumber specimens carried the least load at this deflection point; and RF and PLY types carried greater loads than lumber and smaller loads than the OSB specimens. In the humid environment, RF members carried greater loads at 1-inch deflection than PLY and lumber groups, while no significant differences were found between RF and OSB types or among OSB, PLY and lumber members. In the wet environment, lumber specimens carried significantly smaller loads at 1-inch deflection among all four beam types, while no significant differences in loads at 1-inch deflection were found among the other three I-beam types.

Environmental effects

The variations of the flexural properties of each beam as affected by the environmental conditions can be seen in Figure 2. As shown in Figure 2A, the load capacity of OSB beams decreased with the increase in humidity level. ANOVA indicated that the load capacity in the OSB group was significantly different among the environmental conditions at the 90 percent probability level. Duncan's multiple-range tests, as shown in Table 3, showed that environmental conditions had significant effect on the strength of OSB members. There is a 28 percent and 52 percent loss in load capacity from dry to humid and from dry to wet, respectively, for the OSB members. However, significant differences in load capacities among the environmental conditions were not observed for the RF and PLY groups. For the lumber group, members in the wet environment carried significantly less load as expected, while no significant difference was observed between the specimens in the humid and dry environments.

Figure 2B shows the trends of deflections at maximum load for beams as affected by environmental conditions. ANOVA showed that the deflections at maximum load for OSB, PLY, and lumber groups were significantly different among the environmental conditions at the 90 percent probability level (Table 3). Results of Duncan's multiple-range test indicated that, for the OSB group, beams tested in the dry condition deflected significantly more than those tested in the wet environment, while the specimens tested in the humid condition deflected neither significantly more than those tested in the wet condition nor significantly less than those tested in the dry condition. For the PLY and lumber groups, the greatest deflection of members occurred in the wet condition, while the deflections of specimens in the dry and humid conditions were not significantly different (Table 3).

Figure 2C shows the trends of loads at 1-inch deflection for beams, as affected by environmental conditions. As indicated in Table 3, load values were significantly

TABLE 2. — *Results of Duncan's multiple-range test for all beam types in three environmental conditions (α = .1; n = 4).*

	Dry		Humid		Wet	
	Beam type	Mean[a]	Beam type	Mean	Beam type	Mean
Maximum load (lb.)	OSB	7,380 A	2 by 10	5,578 A	PLY	4,392 A
	2 by 10	5,509 B	OSB	5,315 A	2 by 10	3,890 A
	RF	5,363 B	PLY	4,998 A	RF	3,585 A
	PLY	4,646 B	RF	4,989 A	OSB	3,534 A
Deflection[a] at maximum load (in.)	2 by 10	3.63 A	2 by 10	3.36 A	2 by 10	4.62 A
	OSB	2.93 AB	PLY	2.95 A	PLY	4.10 A
	PLY	2.37 B	OSB	2.85 A	RF	2.39 B
	RF	2.37 B	RF	2.09 B	OSB	2.33 B
Load at 1-in. deflection (lb.)	OSB	2,696 A	RF	2,566 A	RF	1,958 A
	RF	2,354 B	OSB	2,305 AB	OSB	1,952 A
	PLY	2,334 B	PLY	2,091 B	PLY	1,841 A
	2 by 10	1,705 C	2 by 10	1,977 B	2 by 10	1,242 B

[a]Means followed by the same capital letter are not significantly different.

TABLE 3. — *Results of Duncan's multiple-range test for all beam types as affected by the environmental conditions (α = .1; n = 4).*

	OSB		RF		PLY		2 by 10	
	Condition[a]	Mean[b]	Condition	Mean	Condition	Mean	Condition	Mean
Maximum load (lb.)	D	7,380 A	D	5,363 A	H	4,392 A	H	5,528 A
	H	5,315 B	H	4,989 A	D	3,585 A	D	5,509 A
	W	3,534 C	W	3,585 A	W	3,534 A	W	3,890 B
Deflection at maximum load (in.)	D	2.93 A	W	2.39 A	W	4.10 A	W	4.62 A
	H	2.85 AB	D	2.37 A	H	2.95 B	D	3.63 B
	W	2.33 B	H	2.09 A	D	2.37 B	H	3.36 B
Load at 1-in. deflection (lb.)	D	2,696 A	H	2,566 A	D	2,334 A	H	1,977 A
	H	2,304 B	D	2,354 A	H	2,091 AB	D	1,706 AB
	W	1,952 C	W	1,958 B	W	1,841 B	W	1,242 B

[a] D = dry condition; H = humid condition; W = wet condition.
[b] Means followed by the same capital letter are not significantly different.

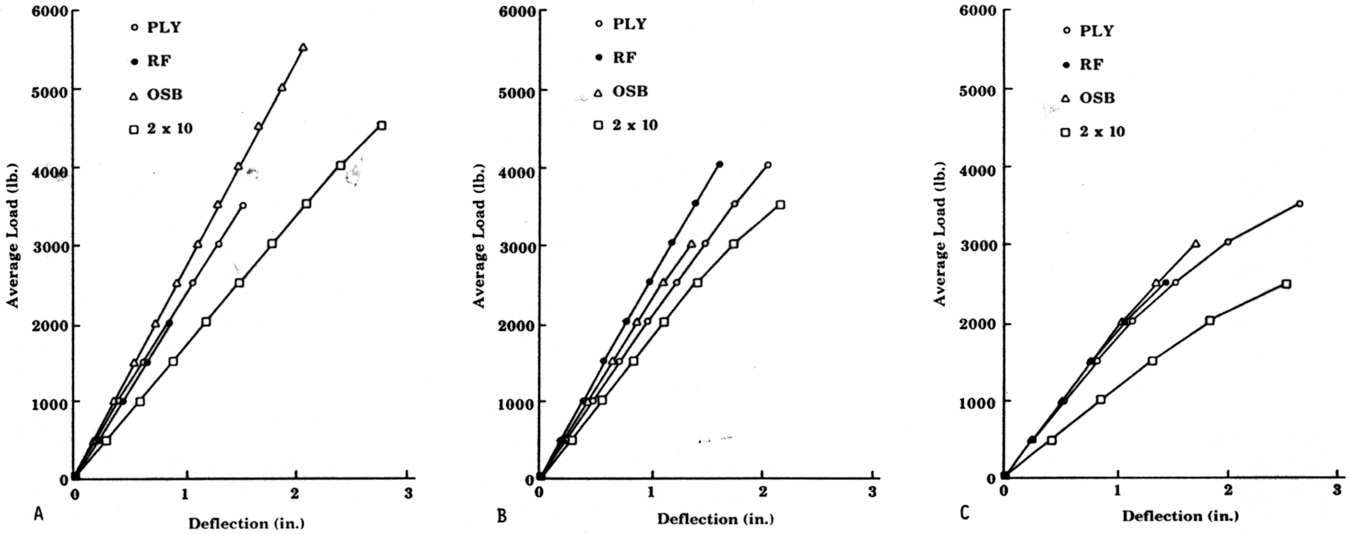

Figure 3. — Load-deflection curves for beams tested in the A. dry condition; B. humid condition; and C. wet condition.

TABLE 4. — *Beam failure modes in three environmental conditions.*[a]

Beam type	Beam no.	Dry	Humid	Wet
PLY	1	Bending (F)	Bending (F)	Buckling (W)
	2	Shear (W)	Shear (W)	Buckling (W)
	3	Shear (W)	Bending (F)	Buckling (W)
	4	Shear (W)	Shear (W)	Buckling (W)
RF	1	Bending (F)	Buckling (W)	Shear (W)
	2	Bending (F)	Bending (F)	Shear (W)
	3	Shear (W)	Shear (W)	Bending (F)
	4	Bending (F)	Shear (W)	Buckling (W)
OSB	1	Bending (F)	Buckling (W)	Buckling (W)
	2	Bending (F)	Shear (W)	Buckling (W)
	3	Bending (F)	Buckling (W)	Buckling (W)
	4	Bending (F)	Shear (W)	Buckling (W)
2 by 10	1	Bending	Bending	Bending
	2	Bending	Bending	Bending
	3	Bending	Bending	Bending
	4	Bending	Bending	Bending

[a] F = flange; W = web.

different among environmental conditions for all four beam types at the 90 percent probability level. At this common deflection point, OSB specimens carried significantly more load in the dry condition than in humid and wet conditions, and members in the wet condition carried significantly less load than members in the humid and dry conditions. For the RF group, beams carried significantly less loads in the wet environment while the members tested in dry and humid conditions did not differ significantly. The PLY group carried significantly more load in the dry condition than in the wet environment, while no significant differences were found between specimens tested in the humid condition and the other two conditions. Lumber carried significantly more load in the humid environment than in the wet condition, while no significant differences were found between members tested in the dry condition and the other two environments.

Load-deflection characteristics

Load-deflection curves for the four beam types tested are plotted in Figure 3. These curves are drawn through average load-deflection points (n=4) at 500-pound intervals, and each end point represents the load at first beam failure. The most noticeable features of these curves include 1) the decrease of linearity with an increase of moisture level of the beam; and 2) more of a decrease of stiffness with increasing load in lumber, as compared to I-beams.

Failure modes

The observed modes of beam failure were classified as either bending, shear, or web buckling. Table 4 summarizes the failure modes of the beams tested in the three environmental conditions. For the beams tested in the dry condition, failures were nearly always abrupt. The three I-beam types emitted an audible tearing sound an instant prior to catastrophic failure, while cracking noises were clearly heard in solid lumber members at the higher levels of load. Most failures in the PLY group were in shear mode, and occurred in the vicinity of the butt-joint in the web. However, the majority of the OSB and RF members failed in bending, and the failures occurred in the flanges. All the lumber specimens failed in bending, and failures were most frequently initiated in the vicinity of natural defects, i.e., knots and sloped grains. For the beams tested in the humid condition, one-half of the I-beam groups failed in shear, and all of the lumber specimens failed in bending. However, in the wet condition, most of the I-beams failed in web buckling. These failures were probably caused by the softening effects of water in the wood fibers, and the decrease of strength in the web materials as the beam moisture level increased.

Conclusions

1. In the dry condition, load capacities of OSB webbed I-beams were significantly greater than the other three beam types, while RF, PLY, and lumber members were not significantly different. In the humid and wet conditions, load capacities of the four beam types were not significantly different.

2. Significant differences in deflections at maximum load were found for the four beam types tested in each

environmental condition, with the value for the lumber members consistently higher than those of the I-beam types.

3. Significant differences in loads at 1-inch deflection were found for the four beam types in each environmental condition. Southern pine lumber consistently had the smallest value among the four beam types.

4. As the MC of the beams increased, the OSB group lost a greater percentage of load capacity than the other groups. For the PLY and lumber groups, beams deflected the most in the wet environment.

5. Overall performance of all beam types in the three different environmental conditions indicated that wood composite I-beams carried similar or slightly higher loads at 1-inch deflection than No. 2 grade southern pine 2 by 10 lumber. Also, lumber members were not as stiff as I-beams.

6. Flexural behavior of the beams was reflected by their failure modes. Fibers in the wood were softened and the strengths of the web materials were decreased as the beam moisture increased. As a result, more I-beams failed in web buckling, whereas most of the 2 by 10 lumber failed in excessive deflection.

7. Additional studies on the long-term performance of composite I-beams and solid lumber members as affected by the environmental conditions are in progress and they will be reported in separate articles.

Literature cited

1. American Institute of Timber Construction. 1985. Timber Construction Manual. 3rd ed. John Wiley & Sons, N.Y.
2. American Society for Testing and Materials. 1983. Static tests of timbers in structural sizes. ASTM D 198-76. ASTM, Philadelphia, Pa.
3. Booth, L.G. 1974. The effect of flange-web joint displacement on the design of plywood web I-beams. J. of the Institute of Wood Science. 6(6):13-24.
4. Johnson, J.A. et al. 1976. The performance of composite wood/particleboard beam under two-point loading. Wood and Fiber 8(2):85-97.
5. Koch, P. and E.J. Burke. 1985. Strength of fabricated joists with flanges of minimally machined whole or half stems of lodgepole pine. Forest Prod. J. 35(1):39-47.
6. Leichti, R.J. 1986. Assessing the reliability of wood composite I-beams. Ph.D. diss. Auburn Univ., Auburn, Ala.
7. McNatt, J.D. 1980. Hardboard-webbed beams: research and application. Forest Prod. J. 30(10):57-64.
8. ________ and M.J. Superfesky. 1983. Long-term load performance of hardboard I-beams. Res. Pap. FPL-441. USDA Forest Serv., Forest Prod. Lab., Madison, Wis.
9. Sliker, A. and O. Suchsland. 1982. Examination of a sinusoidal joint for assembling wood I-beam components. Forest Prod. J. 32(7):16-20.
10. Superfesky, M.J. and T.J. Ramaker. 1976. Hardboard-webbed I-beams subjected to short-term loading. Res. Pap. FPL-264. USDA Forest Serv., Forest Prod. Lab., Madison, Wis.