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HARDBOARD-WEBBED I-BEAMS: EFFECTS OF LONG-TERM LOADING AND LOAD--ETC(U)

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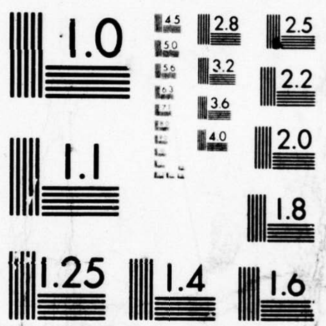

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EFFECTS OF LONG-TERM LOADING AND LOADING ENVIRONMENT.

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ABSTRACT

Twelve-foot and 6-foot I-beams with webs of two different hardboard materials and plywood were subjected to constant loads in three different humidity environments. After 17,000 hours of test, the performance of the hardboard-webbed I-beams appears to be at least comparable to that of I-beams with plywood webs.

Results of this study will be useful to researchers, designers, and building code officials for judging the acceptability of wood-base materials in structural components such as I-beams.

HARDBOARD-WEBBED I-BEAMS: EFFECTS OF LONG-TERM LOADING AND LOADING ENVIRONMENT[1/]

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INTRODUCTION

A recent study conducted at the U.S. Forest Products Laboratory (11)[3/] demonstrated that the short-term behavior of hardboard-webbed I-beams could be reasonably predicted using fundamental engineering theory and basic material properties. However, effects of long-term loading and of loading environment on the behavior of such beams are more difficult to determine. A possible approach to this problem would be to develop a method to extend data obtained from small specimen tests to predict the behavior of full-size structural components. However, no methods are known for predicting long-term behavior of full-size components using only small specimen data.

The approach used in this study was to subject the full-size structural components to long-term loading under different loading environments. Data obtained will supplement the short-term test results obtained from another study (11), and the combined results will provide a basis for judging the suitability of hardboard material for utilization in larger structural components.

SCOPE AND OBJECTIVES

The testing reported in this paper represents the completion of approximately two-thirds of the entire test series planned for the long-term loading study of hardboard webbed I-beams (table 1). Testing has thus far yielded considerable data on the performance of such beams; information reported here is expected to be supplemented by the data from tests presently in process and by tests yet to be conducted. At the completion of the entire long-term loading study, a complete, factorial experiment will have been conducted on 12-foot and 6-foot I-beams, having webs of two different hardboard materials and plywood, and subjected to constant loads in three different humidity environments. However, completion of the study lies years in the future. The present results are reported after 17,000 hours of testing.

1/ A version of this paper was presented at the 30th Annual Meeting of the Forest Products Research Association, Toronto, Canada, July 12-15, 1976.

2/ Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

3/ Underlined numbers in parentheses refer to literature cited at the end of this report.

Table 1.—Description of long-term load tests [1]

I-beam web material and span length	Number of specimens tested		
	Controlled cyclic humidity [2]	Uncontrolled exterior exposure [3]	Uncontrolled interior exposure [4]
Hardboard A, 6-foot span	[5] 4	[6] (4)	[6] (4)
Hardboard B, 6-foot span	[5] 4	[6] (4)	[6] (4)
Plywood, 6-foot span	[6] 2	—	—
Hardboard A, 12-foot span	(2)	[6] 3	[6] 3
Hardboard B, 12-foot span	(2)	[6] 3	[6] 3
Plywood, 12-foot span	(4)	[6] 2	[6] 2

1/Materials as described in Table 1; parentheses indicate tests proposed but not completed.

2/Constant temperature 85° F; one complete RH cycle consisted of the following: 20 pct RH for 48 h, 80 pct RH for 48 h.

3/Roofed pole buildings with all sides open to the weather.

4/Single story timber-arch mill building heated during the winter.

5/Two beams loaded to induce web shear stress equal to 15 pct of the rail shear strength. Two beams loaded to induce web shear stress equal to 25 pct of the rail shear strength.

6/Beams loaded to induce web shear stress of 250 lb/in.

RESEARCH MATERIALS

Two commercial, high-density, tempered hardboards were selected as web material for test beams: Material A, a 1/4-inch-thick, dry-felted, dry-pressed hardboard; and material B, a 1/4-inch thick, wet-felted, wet-pressed hardboard. These materials were selected because they have shear properties comparable to other materials currently acceptable for light-frame construction by building codes and industry standards. Also, mechanical properties of similar materials are available.

In addition, I-beams with a web of 1/4-inch thick, exterior, Group 1, Douglas-fir plywood were included in this study to provide a basis for judging the performance of the hardboard-webbed I-beams. Plywood is the accepted standard for use in structural components such as box beams, I-beams, and "stressed-skin" panels, and complete designs which describe its use in detail are available (1,2,12).

The I-beam flanges were cut to the required size from parallel laminated wood veneer panels 15 feet long, 25 inches wide, and 1-1/2 inches thick. Web stiffeners were cut from nominal 2-inch thick construction grade lumber. A phenol-resorcinol adhesive was used to bond the materials. No nails or other mechanical fasteners were used.

RESEARCH METHODS

Evaluation of the Web and Flange Materials

Flange material was conditioned to equilibrium moisture content at 68° F and 50 percent relative humidity (RH). Compression, tension, and rail shear specimens of hardboard and plywood were cut to size, randomly selected, and tested in accordance with ASTM Standards D 805-72 (4), D 1037-72 (5), and D

3044-72 (6). All small specimens were conditioned at 68° F and 50 percent RH. The results of these evaluations are listed in table 2.

A nondestructive test method was used for determining the modulus of elasticity of each piece of the flange material. Each nominal 1-1/2 by 2-1/8 inch by 12-foot piece with laminations (2-1/8 in. dimension) vertical was simply supported at the ends and vibrated transversly at its natural frequency. The elastic modulus was estimated using the measured vibration frequency, weight, and specimen dimensions. To minimize variation, pieces of flange material with the closest values of elastic moduli were then matched in groups of four for use in the same beam. Average elastic modulus for each group was used to calculate the deflection of the beam in which that group was used.

To indicate the reliability of the data obtained by nondestructive tests, the modulus of elasticity of 11 pieces of flange material was determined using the nondestructive transverse vibration method, and then each piece was tested destructively as described by ASTM Standard D 198-67 (3). The average elastic modulus determined using the nondestructive test method was only 3 percent greater, which showed that the reliability of the nondestructive tests was very good.

An average value of 92,000 pounds per square inch (lb/in.^{2}) for the modulus of rigidity of the flange material—i.e., its plate shear modulus—was determined in accordance with ASTM Standard D 3044-72 (6). Five 24 by 24-inch specimens were sawn from one nominal 1-1/2 by 25-inch by 15-foot panel. The specimens were planed to 3/4-inch thickness

Table 2.—Basic strength and elastic properties of web material used in this study

Type of test 1/	Number of specimens	Strength				Elastic modulus	
		Average	Estimated standard deviation	Lowest observed value 2/	Adjusted value 3/	Average	Estimated standard deviation
		Lb/in.^{2}	Lb/in.^{2}	Lb/in.^{2}	Lb/in ^{2}	Lb/in ^{2}	Lb/in ^{2}
				HARDBOARD A 4/			
Compression parallel	10	4,640	600	3,550	1,140	762,000	54,000
Tension parallel	24	4,740	380	4,040	1,290	764,000	40,500
Rail shear	24	3,040	240	2,730	870	—	—
Plate shear	24	—	—	—	—	321,000	19,200
				HARDBOARD B 4/			
Compression parallel	10	5,700	540	4,720	1,510	864,000	59,000
Tension parallel	24	6,050	540	5,070	1,620	850,000	72,500
Rail shear	24	4,200	400	3,180	1,020	—	—
Plate shear	24	—	—	—	—	334,000	18,300
				PLYWOOD P 4/			
Compression parallel 5/	9	4,800	920	4,260	1,360	1,441,000	433,000
Tension parallel 5/	20	5,800	1,100	3,800	1,210	1,386,000	221,700
Rail shear 5/	20	960	70	850	270	—	—
Plate shear	20	—	—	—	—	83,000	11,500

1/ Tests made in accordance with ASTM D 1037-72 except plate shear modulus (modulus of rigidity) was determined by the procedure used for plywood, ASTM D 3044-72.

2/ Estimate of "near minimum" values used a nonparametric or distribution-free technique (7).

3/ Lowest observed value multiplied by 0.48 for duration of load and divided by 1.5 for unforeseen conditions.

4/ Hardboard A—a 1/4-in. thick, dry-felted, dry-pressed, high-density, tempered hardboard.
Hardboard B—a 1/4-in. thick, wet-felted, wet-pressed, high-density, tempered hardboard.
Plywood P—a 1/4-in. thick, exterior Group 1, Douglas-fir plywood.

5/ Load applied parallel to grain of face ply.

and conditioned at 50 percent RH and 68° F prior to testing.

Design and Construction of I-Beams

Figure 1 shows dimensions and a typical cross section of the I-beams used in this study. Beams for a 12-foot span were designed to carry 100 pounds per linear foot (lb/ft), without exceeding an allowable web shear stress of 250 lb/in.^{2}, the maximum allowable value for plywood for shear perpendicular to the plane of the plies. The 100 lb/ft load is based on a 50-pounds-per-square-foot (lb/ft^2) load. Forty lb/ft^2 is the design live load for residential floor construction. The additional 10 lb/ft^2 consists of sheathing, flooring, and future dead loads. The purpose of testing the shorter, 6-foot beams was to include specimens in which web shear failure is more probable.

In all, 50 beams were prepared for testing in the long-term loading study. Twenty-four 12-foot I-beams were prepared; eight with web material A, eight with web material B, and eight with plywood. Twenty-six 6-foot I-beams were fabricated; 12 with web material A, 12 with web material B, and 2 with plywood. Test results for 26 of these 50 beams are reported here; the remainder are presently subject to test or are set aside for tests yet to be undertaken. For a specific breakdown of specimen beams reported on here, see table 1.

Beams similar to those tested in the long-term loading study—prepared at the same time—were subjected to short term loading as reported in (11). Results of those tests are given in an appendix to this paper.

Experimental Procedure and Loading Method

The effect of long-term load and loading environment was studied by loading hardboard and plywood-webbed I-beams and subjecting them to the following environments:

(1) Controlled cyclic.—85° F temperature and cyclic relative humidity. One complete relative humidity cycle consisted of the following: 20 percent RH for 48 hours; 80 percent RH for 48 hours.

(2) Uncontrolled interior.—The shelter for this environment consisted of a single story timber arch mill building which was heated during winter months.

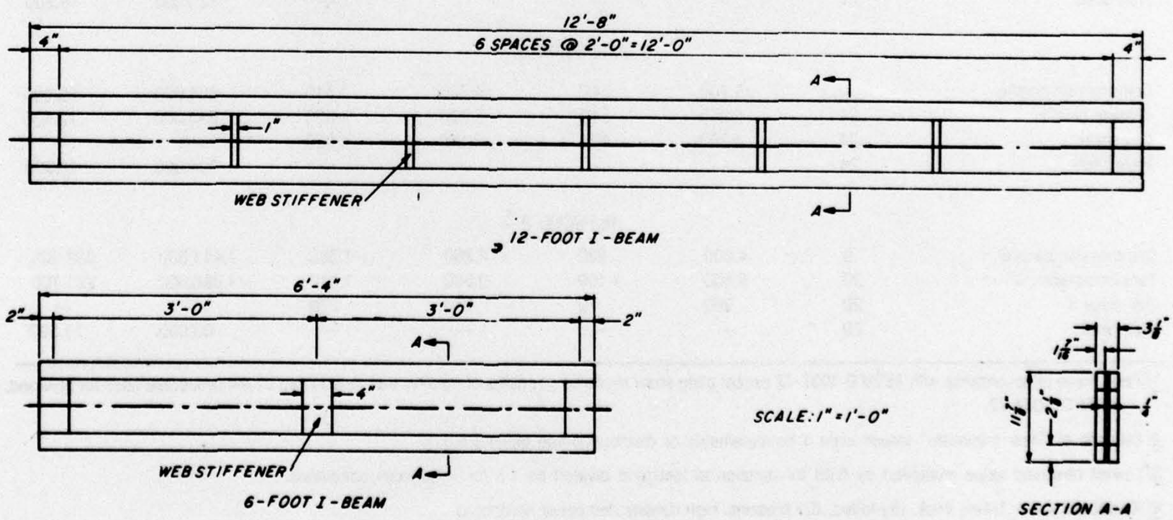

Figure 1. — Details of the 6-foot and 12-foot I-beams used in this study.
(M 143 780)

(3) Uncontrolled exterior.—Shelter consisted of a roofed pole building with all sides open to the weather.

Environment 1 was selected because of reports in (9) and (10) that cyclic moisture conditions and increased moisture content accelerated the creep rate of small, hardboard bending specimens. Environments 2 and 3 were selected to simulate the type of exposure that the I-beams might encounter in actual use.

The 12-foot I-beams in the uncontrolled exterior and interior environments were loaded at five equally spaced points to simulate a uniform load of 100 lb/ft (figs. 2 and 3). This would be the total load distributed to a floor joist spaced 2 feet on center for a nominal design load of 50 lb/ft^2. This load results in a web shear stress of 250 lb/in.^{2}, the maximum value for the plywood for shear perpendicular to the plane of the plies (2).

The 6-foot I-beams in the cyclic humidity environment were loaded at mid-span using the loading frame shown in figure 4. A lever system provided a four to one mechanical ad-

Figure 2.—Twelve-foot I-beams in uncontrolled interior environment.
(M 142 281)

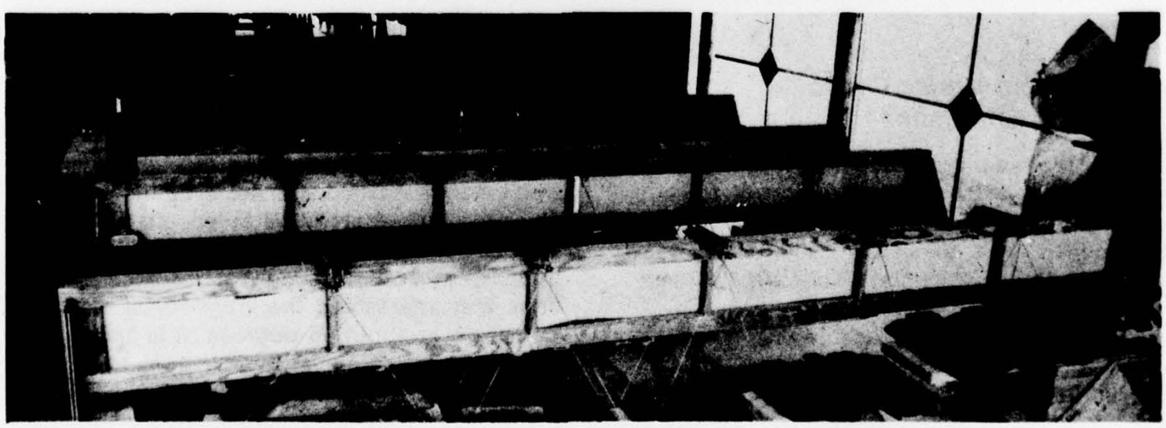

Figure 3. — Twelve-foot I-beams in protected exterior environment.
(M 142 283)

vantage, and the same load could be applied to two beams at the same time. The end reactions of each beam were initially measured using electrical load cells to insure that the total applied load was properly transmitted to each beam. The loads applied to the hardboard-webbed I-beams induced web shear stresses of either 15 or 25 percent of the rail shear strength of the web material (table 3). The 15-percent stress level was selected based on a publication by Lundgren (7) in which he suggested 15 percent of ultimate as a maximum shear stress for beams exposed to the elements for extended periods. A stress level of 25 percent of ultimate was assumed to be an upper limit for design. The loads applied to the plywood-webbed I-beams induced a web shear stress of 250 lb/in.^{2}

Deflections of both the 6 and 12-foot beams were measured every 48 hours with a wire deflectometer. Table 1 summarizes the various specimens and test conditions.

Table 3 — Average deflection of 6-foot I-beams subjected to cyclic relative-humidity exposure

Number of beams tested	Web material	Percent of rail shear strength	Stress	Deflection: Initial	Deflection: After 1 year
			Lb/in.^{2}	In.	In.
2	Plywood	27	250	0.11	0.51
2	Hardboard A	15	460	.10	1/ .52
2	...do...	25	760	.14	1/ .95
2	Hardboard B	15	630	.09	.46
2	...do...	25	1,050	.15	1.09

1/Last reading before failure; these beams failed at a duration of 6 to 9 months.

Figure 4. — Six-foot I-beams in cyclic humidity environment. (M 142 284)

ANALYSIS OF RESULTS

6-Foot Beams Under Cyclic Humidity Conditions

Figure 5 is a plot of deflection versus time for the 6-foot I-beams subjected to a temperature of 85° F and a cyclic RH. One complete RH cycle consisted of the following: 20 percent RH for 48 hours; 80 percent RH for 48 hours. The change in RH did not occur instantaneously, and there were slight variations. Each curve is the average time-deflection data for two companion beams that were subjected to the same load (fig. 4). The value listed for each curve is the web shear stress level.

When loaded to induce a web shear stress of 25 percent of the rail shear strength of the web material, the pair of I-beams with web material A failed after 4,500 hours and the pair with web material B failed after 11,400 hours. For both cases, failure was preceded by wavelike web deformation that occurred along lines that intersected the longitudinal axis of the beam at about 45 degrees. It is apparent that the constant load and cyclic humidity conditions did accelerate failure of the webs because the specimens were loaded to induce only a web shear stress of 25 percent of the rail shear strength. Both pairs of hardboard-webbed I-beams loaded to induce a web shear stress equal to 15 percent of the rail shear strength of the web material did not fail after 17,000 hours; however, wavelike deformations were present in the webs of the I-beams made with web material A.

When the I-beams with web material A failed after 4,500 hours, they were removed and replaced with two companion plywood-webbed I-beams. The plywood-webbed I-beams were loaded to induce a web shear stress of 250 lb/in.^{2} which is the maximum allowed for plywood for shear perpendicular to the plane of the plies. After 11,500 hours, the plywood-webbed I-beams have not failed, and no web deformations are visible.

Time-deflection curves for the plywood-webbed and hardboard-webbed I-beams that have not failed are similar, and it appears that the rate of creep is decreasing with time for both groups (fig. 5). However, the I-beams with webs of hardboard A and hardboard B are loaded to a considerably higher web shear stress level than the plywood-webbed beams. This suggests that I-beams with these particular hardboard web materials will perform at least comparably to the plywood-webbed I-beams.

The ratios of beam deflection at differing durations of loading to the deflection measured immediately after applying load (initial deflection) are listed in table 4 for the cyclic humidity environment. Note that the ratios for the plywood-webbed beams at the shear stress level of 250 lb/in.^{2} are initially not as great as ratios for beams with webs of hardboard A at 460 lb/in.^{2} and hardboard B at 630 lb/in.^{2} These loadings represent 27 percent rail shear strength of the plywood and 15 percent rail shear strength for both hardboards

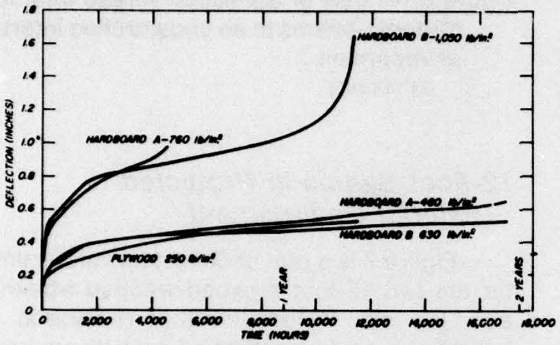

Figure 5. — Plot of deflection versus time for 6-foot I-beams in cyclic humidity environment.

(M 145 681)

Table 4. — Summary of results for 6-foot I-beams under load in cyclic humidity environment 1/

Beam number and shear stress level 2/	Deflection expressed as a percent of initial deflection											
	Time in months											
	0	1	2	3	4	5	6	9	12	15	18	21
						HARDBOARD A						
A22A-760	100	381	496	535	558	592	627	Failed				
A22B-760	100	393	527	570	600	650	697	Failed				
A39A-460	100	300	410	440	450	475	495	535	570	640	685	695
A39B-460	100	280	365	385	390	405	420	450	460	505	530	525
						HARDBOARD B						
B14A-630	100	311	379	395	405	421	432	453	463	495	510	510
B14B-630	100	356	456	478	483	500	517	539	550	594	611	611
B48A-1050	100	433	530	557	570	593	613	660	757	953	Failed	
B48B-1050	100	375	459	481	488	506	522	556	597	688	Failed	
						PLYWOOD						
P60A-250	100	259	305	332	377	395	417	459	500	—	—	—
P60B-250	100	245	280	305	350	375	390	430	470	—	—	—

1/ Loads applied at center-span to induce theoretical shear stress level indicated in first column.

2/ For stress values, both absolute and as percent of rail shear strength, see table 3.

(table 3). However, after 12 months of exposure the ratios are comparable.

Also of interest is the actual magnitude of the deflections (table 3). Note that the initial deflection for each I-beam at the various stress levels was less than 1/360 of the span (here, 0.2 in.), the maximum recommended for floor beams (2). After exposure to the cyclic humidity environment for 1 year, the deflection of each beam exceeded 1/360 of the span. However, this particular environment is considerably more severe than would normally be encountered. Companion 6-foot I-beams have been fabricated and it is planned to subject these I-beams to identical loads in an uncontrolled indoor and outdoor environment. This will permit comparison of I-beam behavior in the more severe environment with that in an average or normal environment. The results of these comparisons will be reported in the future.

12-Foot Beams in an Uncontrolled Interior Environment

Figure 6 is a plot of deflection versus time for the two 12-foot plywood-webbed I-beams and the six 12-foot hardboard-webbed I-beams which were subjected to an uncontrolled indoor environment. All beams were loaded at five equally spaced points along the 12-foot span to induce a maximum web shear stress of 250 lb/in.^{2} This shear stress level is the maximum allowed for plywood and is 8 percent and 6 percent of the rail shear strength of hardboard A and B, respectively.

For the range of deflections of the six hardboard-webbed I-beams shown in figure 6, initial and long-term deflections of the hardboard-webbed I-beams are approximately 60 percent of the deflection for the plywood webbed I-beam, but long term deflections expressed as a percent of the initial deflections (table 5) are comparable. The smaller initial deflections are due in part to the higher shear stiffness of the hardboard (table 2). After 17,000 hours of testing, none of the eight I-beams have failed, nor do they exhibit any visible signs of distress. Deflections have not exceeded 1/360 of the span, and it appears that the deflection of each beam is approaching a limiting value. It is planned to monitor these beams several more years or until failure occurs.

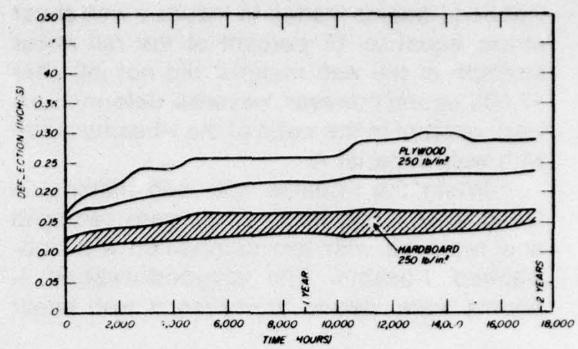

Figure 6. — Plot of deflection versus time for 12-foot I-beams in an uncontrolled interior environment.
(M 145 680)

12-Foot Beams in Protected Exterior Environment

Figure 7 is a plot of deflection versus time for the two 12-foot plywood-webbed I-beams and the six 12-foot hardboard-webbed I-beams subject to a protected exterior environment. These beams were loaded in a similar manner to those in the uncontrolled interior environment and to an identical shear stress level. As a result, the static or initial deflection of these beams was essentially the same as that for the beams in an interior environment. Comparisons of values in tables 5 and 6 and of curves in figures 6 and 7 show that the creep of the beams was greater in the exterior than in the interior environment. This is probably due to the more severe exterior humidity conditions.

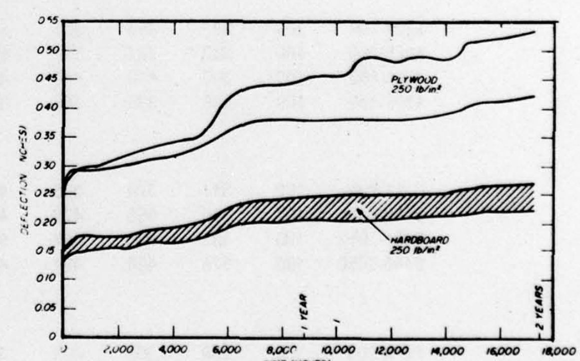

Figure 7. — Plot of deflection versus time for 12-foot I-beams in a protected exterior environment.
(M 145 682)

Table 5. — Summary of results for 12-foot I-beams under load in interior environment 1/

Beam number	Deflection expressed as a percent of initial deflection — Time in months: 0	1	2	3	4	5	6	9	12	15	18	21
						HARDBOARD A						
A10	100	115	115	125	125	130	130	[illegible]	145	145	160	160
A13	100	117	128	133	139	144	144	156	161	161	172	178
A16	100	117	128	128	128	133	133	139	147	150	150	162
						HARDBOARD B						
B11	100	110	120	120	125	130	135	140	135	145	155	155
B17	100	115	120	125	125	135	135	140	135	145	150	155
B46	100	117	123	128	137	137	145	150	150	155	155	155
						PLYWOOD						
P12	100	121	129	132	138	139	143	150	157	161	161	168
P15	100	119	128	138	150	150	156	159	163	178	188	181

1/ Loads applied at five locations spaced 2 ft on center to induce a theoretical web shear stress of 250 lb/in.^{2}

Table 6. — Summary of results for 12-foot I-beams under load in exterior environment 1/

Beam number	Deflection expressed as a percent of initial deflection — Time in months: 0	1	2	3	4	5	6	9	12	15	18	21
						HARDBOARD A						
A1	100	145	150	155	159	164	168	205	214	214	223	236
A4	100	132	141	141	150	150	155	182	195	200	205	214
A7	100	142	142	146	154	154	158	192	200	208	208	221
						HARDBOARD B						
B2	100	141	150	150	155	155	159	182	195	195	195	205
B5	100	136	159	159	168	173	177	205	214	214	218	232
B8	100	136	141	141	150	150	155	177	186	186	191	200
						PLYWOOD						
P3	100	174	176	185	191	197	203	250	262	291	288	306
P6	100	148	148	150	153	155	160	183	190	190	193	205

1/ Loads applied at five locations spaced 2 ft on center to induce a theoretical web shear stress of 250 lb/in.^{2}

After 17,000 hours of testing, none of the eight I-beams have failed but the deflection of both beams with plywood webs has exceeded 1/360 of the span. The rate of creep of the hardboard-webbed I-beams is decreasing with time and it appears that the deflections are approaching a limiting value. It is planned to monitor these I-beams several more years or until failure occurs. In addition, 12-foot companion I-beams will be subjected to similar loadings in the cyclic humidity environment. (See "Scope and Objectives.")

Effect of Cyclic Humidity on Beam Properties

The four hardboard-webbed and two plywood-webbed 6-foot I-beams which did not fail while under load in the cyclic humidity environment were removed and tested using procedures described in (11). When removed for static testing, the hardboard-webbed beams had been exposed to load and cyclic humidity environment for 17,000 hours, and the plywood-webbed beams for 11,500 hours. All beams were removed near the end of the 48-hour dry cycle (20 pct RH) and then conditioned for 20 days at 68° F and 50 percent RH prior to testing.

Averages of results of these tests, as well as averages of tests of similar specimens not subjected to long-term loading or cyclic humidity, are given in table 7. Note that in each case the average ultimate load and load-deflection ratio are less for the I-beams subjected to loading in a cyclic humidity environment. This suggests that subjecting the beams to load in a cyclic humidity environment does affect their ultimate strength and load-deflection ratio. However, this environment is considerably more severe than would normally be encountered.

The largest difference in strength and load-deflection ratio was observed for 6-foot I-beams with web material A. Two companion beams of this type, A39A and A39B, were subjected to a 2,000-pound load under cyclic humidity conditions for 17,000 hours. A39A sustained 6,900 pounds when tested statically, and A39B, 11,400 pounds. Average ultimate load for this pair of beams was 9,200 pounds. By comparison, average ultimate load for six similar beams not subject to these conditions was 11,800 pounds.

Moreover, while under load in the cyclic humidity environment, deflection of beam A39A was 35 percent greater than for A39B (table 4), and residual deflection in A39A after removal of load was 50 percent greater.

It was also observed that the webs of beams A39A and A39B deformed (wavelike deformations in the plane of the web) while under constant load in the cyclic humidity conditions. The web deformations, resembling those in beams loaded at a higher shear stress

Table 7. — Effect of cyclic humidity environment on beam properties

I-beam web material	Values for I-beams conditioned at 68° F and 50 percent relative humidity (from (11))				Values for I-beams subjected to long-term loading and cyclic humidity condition 1/				
	Number of beams	Average ultimate load 2/	Average load-deflection ratio 3/	Average moisture content 4/	Number of beams	Average ultimate load 2/	Average load-deflection ratio 3/	Average moisture content 4/	Average residual deflection 5/
		Lb.	Lb/in.	Pct		Lb	Lb/in.	Pct	In.
Hardboard A	6	11,800	37,900	5.0	2	9,200	31,400	7.3	0.53
Hardboard B	2	15,400	36,900	5.2	2	15,200	31,300	6.9	.43
Plywood	4	6,400	19,800	7.2	2	5,800	17,500	9.1	.36

1/ Duration of loading and exposure for hardboard-webbed I-beams — 17,000 hours.
Duration of loading and exposure for plywood-webbed I-beams — 11,500 hours.

2/ Average short-term load the beams sustained.

3/ Initial or linear portion of the load-deflection curve.

4/ Moisture content of web material at time of test based on ovendry weight.

5/ Average residual deflection measured immediately after removal of long-term load.

level, remained after the load was removed. I-beams with webs of plywood and hardboard B loaded to induce a web shear stress of 15 percent of the rail shear strength contained no visible web deformations.

The presence of the web deformation in I-beams with web material A is related to several other performance characteristics. For example, when tested statically, I-beams with webs of hardboard A failed via web shear, whereas I-beams with webs of hardboard B failed via tension in the flange. The average residual deflection for the I-beams with web material A was greater than that for the I-beams with webs of either plywood or material B (table 7). In addition, the load-deflection curves for I-beams with web material A (fig. 8) were nonlinear and did not have a distinct proportional limit.

These observations show that the development of visible web distortions does indicate an alteration in the behavior and performance characteristics of the I-beams. It is probable that failure was initiated while under constant load even though the beams continued to sustain the applied load.

Also of interest are the average moisture contents of the web materials (table 7). As expected, the moisture contents of the plywood and hardboard web material exposed to cyclic humidity and then conditioned at 68° F and 50-percent RH were higher than the moisture contents of the web materials under the same conditioning but without cyclic exposure. The increase in the long-term and short-term deflections of the 6-foot I-beam is probably due in part to this moisture absorption.

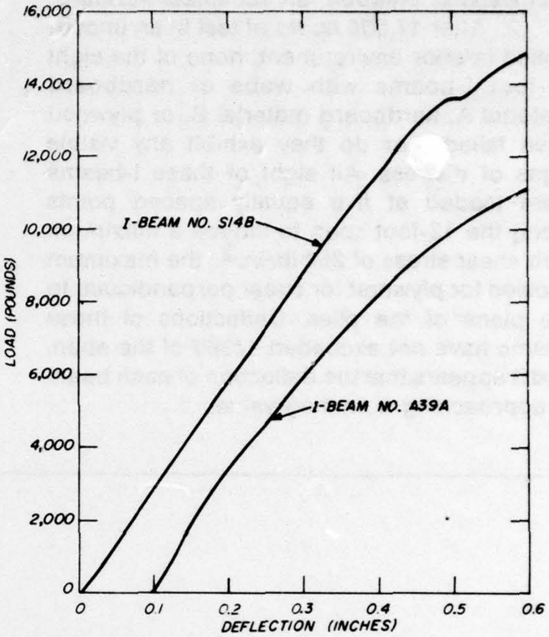

Figure 8. — Load-deflection curves for 6-foot hardboard-webbed I-beams tested after 17,000 hour exposure to cyclic humidity environment. (M 145 683)

SUMMARY

1. When loaded in a cyclic humidity environment to induce a web shear stress of 25 percent of the rail shear strength of the web material, the pair of 6-foot I-beams with web material A—a 1/4-inch, dry-felted, dry-pressed, high-density tempered hardboard—failed after 4,500 hours of test. Under the same conditions the pair of I-beams with web material B—a 1/4-inch, wet-felted, wet-pressed, high-density tempered hardboard—failed after 11,400 hours of test. For both cases, failure was preceded by wavelike web deformations that occurred along lines that intersected the longitudinal axis of the beam at about 45 degrees.

Both pairs of hardboard-webbed I-beams loaded in the cyclic humidity environment to induce a web shear stress equal to 15 percent of the rail shear strength have not failed after 17,000 hours; however, wavelike deformations have developed in the webs of I-beams with web material A.

The pair of plywood-webbed I-beams loaded in the cyclic environment to induce a web shear stress of 250 lb/in.^{2} have not failed after 11,500 hours. But the long-term deflection of the hardboard-webbed I-beams is about equal to the deflection of the hardboard-webbed I-beams that were loaded to induce a web shear stress of 15 percent of the rail strength. Fifteen percent of the rail shear strength of web material A is 460 lb/in.^{2} and for material B 630 lb/in.^{2}. Therefore, for these particular conditions it appears that the performance of the hardboard-webbed I-beams is comparable to the performance of I-beams with webs of plywood, an accepted standard.

2. After 17,000 hours of test in an uncontrolled interior environment, none of the eight 12-foot I-beams with webs of hardboard material A, hardboard material B, or plywood have failed, nor do they exhibit any visible signs of distress. All eight of these I-beams were loaded at five equally spaced points along the 12-foot span to induce a maximum web shear stress of 250 lb/in.^{2}, the maximum allowed for plywood for shear perpendicular to the plane of the plies. Deflections of these beams have not exceeded 1/360 of the span, and it appears that the deflection of each beam is approaching a limiting value.

3. None of the eight 12-foot I-beams exposed to a protected exterior environment have failed after 17,000 hours of test. These beams are loaded to induce a web shear stress of 250 lb/in.^{2} and are similar to the 12-foot beams exposed to the uncontrolled interior environment. After 17,000 hours of test, the beams exhibit no visible signs of distress, but the deflection of both I-beams with plywood webs has exceeded 1/360 of the span.

4. Static test results for 6-foot I-beams exposed to cyclic humidity conditions (table 7) show that the strength and load-deflection ratio of these beams were reduced by exposure and loading in the cyclic environment. Also, the web material of these I-beams did absorb additional moisture in the cyclic humidity environment. The reduction in strength and load-deflection ratio is probably due in part to the absorption of moisture by the web material.

CONTINUATION OF LONG-TERM LOADING

Continued monitoring is planned for the 12-foot I-beams currently under load—for several more years or until failure occurs. In addition, it is planned to load eight similar 12-foot I-beams in the cyclic humidity condition to a shear stress level of 250 lb/in.^{2} Also, eight of the 6-foot I-beams will be placed under load in the protected exterior environment and eight will be loaded in the uncontrolled interior environment (table 1). This will provide comparative long-term loading data for I-beams with three different web materials and two different span lengths subjected to three different loading environments. These comparisons will be reported in the future.

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Appendix

Table 1A. — Summary of I-beam short-term load tests

6-foot I-beams			12-foot I-beams		
Beam number	Ultimate Load	Load-deflection ratio 1/	Beam number	Ultimate load	Load-deflection ratio 1/
	Lb	Lb/in.		Lb	Lb/in.
WEB MATERIAL A					
A23A	12,800	38,500	A31	12,400	10,000
A23B	14,300	47,600	A37	10,500	11,500
A49A	9,800	40,000	A41	11,700	10,500
A49B	10,400	33,300	A43	13,900	10,800
A50A	12,200	35,700	—	—	—
A50B	11,000	32,500	—	—	—
Average	11,800	37,900	Average	12,100	10,700
Standard deviation	1,670	5,500	Standard deviation	1,420	630
WEB MATERIAL B					
B53A	15,300	42,100	B29	16,900	12,100
B53B	15,500	31,700	B32	13,200	10,800
—	—	—	B35	16,600	10,700
—	—	—	B44	16,400	11,600
Average	15,400	36,900	Average	15,800	11,300
Standard deviation	140	7,350	Standard deviation	1,730	670
PLYWOOD WEB MATERIAL					
P33A	6,500	21,200	P27	6,200	7,800
P33B	6,000	18,100	P30	5,600	7,700
P36A	6,700	20,100	P51	5,800	7,100
P36B	6,300	—	P54	6,500	8,000
Average	6,400	19,800	Average	6,000	7,700
Standard deviation	300	1,570	Standard deviation	400	390

1/ Slope of the initial or linear portion of the load-deflection curve.

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Hardboard-webbed I-beams: Effects of long-term loading and loading environment, by Michael J. Superfesky and Terry J. Ramaker, Madison, Wis., FPL, 1978.
17 p. (Research Paper FPL 306)

I-beams with webs of three materials--two hardboards and plywood--are compared for performance after 17,000 hours of loading.

KEYWORDS: Composite members, hardboard, I-beams, plywood, web material.

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