THIN-WALLED PLYWOOD CYLINDERS IN BENDING

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THIN-WALLED PLYWOOD CYLINDERS IN BENDING[1]

By

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Summary

This report presents the results of tests of thin-walled plywood cylinders in bending. All specimens were simply supported at the ends and loaded at the third points. It was found that the results of bending tests, when plotted, developed a curve similar to that representing the results of compression tests reported in Forest Products Laboratory Mimeo. No. 1322, "Buckling of Long, Thin Plywood Cylinders in Axial Compression." The tests on cylinders in bending indicated buckling stresses about 10 percent higher than for the same cylinders in compression.

Description of Specimens

Specimens were made of aircraft grade yellow birch veneers, rotary cut at the Forest Products Laboratory. Three types of plywood were used: three-ply with faces of 0.010-inch and core of 0.025-inch veneer; five-ply with faces of 0.010-inch, cross bands of 0.025-inch, and core of 0.0125-inch veneer; and five-ply with faces of 0.010-inch and cross bands and core of 0.0167-inch veneers. Nine cylinders, each 10-1/2 inches in diameter and 46 inches long, and three flat panels for minor coupons were made of each type of plywood; three with the face grain in the axial direction, three with the face grain in the circumferential direction, and three with the face grain direction at 45° to the axis of the cylinder. In all instances the grain of adjacent plies was at right angles.

All plywood was manufactured flat with a film glue set in a hot press. The cylinders were formed by bending the flat plywood around a mandrel. Prior to forming, the plywood was scarfed, then moistened to facilitate bending, and finally bent around the mandrel upon which the scarf joint was glued with a thermosetting synthetic resin glue. Snugly fitting plywood diaphragms, 3/4 inch thick, were glued in the cylinders at the reaction and load points (fig. 1). The cylinders were proportioned so that under third-point loading

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[1] This mimeograph is one of a series of progress reports prepared by the Forest Products Laboratory to further the Nation's war effort. Results here reporte
are preliminary and may be revised as additional data become available.

the diaphragms at the load points were about 1-1/2 diameters apart.

No attempt was made to condition the specimens to a particular moisture content other than to keep them in the testing laboratory for about a week before testing.

Testing Methods

Each cylinder was tested in a hydraulic testing machine which was fitted to load the specimen by means of thin steel straps passed around it at the load diaphragms. The specimen was placed so that the scarf joint was on the tension side. The ends of cylinders that did not fail in the shear portion of the cylinder beam during the bending test were subsequently cut and tested in compression.

Several metalectric strain gages were placed at midlength of one specimen. The readings of these gages showed the strain distribution on a cross section of the cylinder to be approximately linear.

Minor specimens were tested in bending, compression, and tension to determine the mechanical properties of the material. The testing procedures followed for these coupons are described in Forest Products Laboratory Mimeo. No. 1322-B (supplement to No. 1322).

Test Results

Most of the specimens subjected to bending failed by buckling suddenly, with the plywood breaking immediately afterward. As soon as buckling occurred, the load dropped to less than one-half the buckling load. In size and shape, the buckles were approximately the same as those found in previous compression tests.

Many of the specimens buckled in the shear portion of the beam. About 90 percent of those with axial face-grain direction, and 50 percent of those with the face-grain direction at 45° to the axis, failed in that manner, but none of the specimens with circumferential face grain failed in any portion of the beam other than the middle third.

Computation of Results

The bending stresses (table 1) at maximum load were computed from the formula

$$f_b = \frac{M\left(r + \frac{t}{2}\right)}{\pi r^3 t}$$

where

f_b = stress in most remote fiber in pounds per square inch.

M = maximum bending moment in inch-pounds.

r = mean radius of the plywood cylinder in inches.

t = thickness of plywood in inches.

The buckling constant (k) was computed by means of the formula

$$k = \frac{f_b}{E_L} \frac{r}{t}$$

where E_L is the modulus of elasticity of the birch veneer. The values of E_L were obtained from tests on minor coupons and were computed in the manner discussed in Forest Products Laboratory Mimeo. No. 1322-B.

The buckling constant (k) for the compression tests was computed from the formula

$$k = \frac{pr}{E_L h}$$

where p is the average compressive buckling stress of the cylinder and h is the thickness of the plywood.

Figure 2 shows the results of the tests in bending and compression and, for comparison, the theoretical buckling curve for plywood cylinders in compression as taken from Mimeo. No. 1322.

The buckling coefficients for cylinders with 45° face grain were obtained from the coefficients of identical cylinders with 0° and 90° face grain and, therefore, were not readily plotted in figure 2. In figure 3 the buckling coefficients for all of the cylinders tested in bending were plotted against the coefficients for the matched cylinders tested in compression, including those with the grain at 45° to the axis.

The strain distribution in bending at a cross section of one cylinder is plotted in figure 4. The data given in this figure include values for effective modulus of elasticity (E_a) in compression or tension. These values were determined from the tests on the minor coupons.

Discussion of Results

The curves of figure 2 show agreement as to form between the theoretical curve for thin-walled plywood cylinders in compression and the actual curves obtained for both bending and compression. The curve representing the compression tests, however, seems low. The cylinders tested in compression were cut from the ends of the cylinders previously tested in bending and may have been slightly damaged in this previous test; moreover, the data of Mimeo. No. 1322 indicate that much scatter of the points can be expected.

The curve for the buckling constant for bending tests lies well above the theoretical curve for plywood cylinders in compression over the range in $\frac{E_1}{E_1 + E_2}$ commonly used in design. Considering only the curves that were obtained from the present tests, it is evident that the increase in bending stress over compression stress when buckling occurs is about 25 percent when $\frac{E_1}{E_1 + E_2}$ values are small, and about 10 percent when $\frac{E_1}{E_1 + E_2}$ values approach unity. The difference in percentage increase may be due to the fact that cylinders with axial face-grain direction are not as round and are likely to have greater initial imperfections than cylinders with cirumferential face-grain direction.

These tests were conducted on specimens that were free to buckle in a length equal to about 1-1/2 times the diameter of the cylinder. A length effect will no doubt be obtained if shorter lengths are tested; cylinders of shorter lengths will have higher buckling stresses. Due to differences in the aspect ratio of the buckle size, this effect will be greatest in the specimens having axial face grain and least in those having circumferential face grain.

The points plotted in figure 3 show that in most instances the buckling strengths in bending are higher than those in compression. There is a great deal of scatter, but from past experience this is to be expected for thin-walled cylinders of any material.

The strain-distribution curve of figure 4 shows that an approximately linear relation exists between the strain and the distance from the neutral axis, and that the neutral axis lies nearly at the center of the section. Deviations from these conditions may be attributed to variations of the effective modulus of elasticity of the material and to some shear stresses in the central portion of the cylinder. The ordinary flexure theory applies with reasonable accuracy to the buckling of thin-walled plywood cylinders, provided the compressive stress at the elastic limit of the material has not been exceeded.

Conclusions

The buckling stresses of thin-walled plywood cylinders in bending can be computed by the ordinary flexure theory provided the elastic limit of the material is not exceeded.

The buckling stress of a thin-walled plywood cylinder in bending can be assumed to be about 10 percent higher than the computed buckling stress of the cylinder in compression.

Table 1.--Results of tests on thin-walled plywood cylinders in bending. All yellow birch cylinders 10.5 inches in diameter

Specimen number	Number of plies	Angle of grain of face plies to axis	Ply thicknesses			Theoretical $\frac{E_1}{E_1 + E_2}$	Modulus of elasticity E_L	Buckling stress		Buckling constant		Portion of beam in which failure occurred
			Face plies	Cross bands	Core ply			Bending	Compression	Bending[1]	Compression[2]	
		Degrees	Inch	Inch	Inch		1,000 p.s.i.	p.s.i.	p.s.i.			
1-1	3	0	0.010		0.025	0.800	2,366	1,860	1,720	0.093	0.090	Shear
1-2	3	0	.010		.025	.800	2,366	1,900	1,810	.100	.088	Shear
2-1	3	90	.010		.025	.200	2,433	2,380	1,940	.121	.094	Bending
2-2	3	90	.010		.025	.200	2,433	2,340	1,900	.114	.090	Bending
2-3	3	90	.010		.025	.200	2,433	2,380	1,880	.121	.090	Bending
3-1	3	45	.010		.025		2,345	1,830	1,490	.085	.075	Shear
3-2	3	45	.010		.025		2,345	1,690	1,890	.085	.093	Bending and shear
3-3	3	45	.010		.025		2,345	2,160	1,940	.109	.096	Shear
4-1	5	0	.010	0.0125	.0125	.713	2,513	3,220	2,940	.118	.109	Shear
4-2	5	0	.010	.0125	.0125	.713	2,513	3,310	2,580	.123	.096	Shear
4-3	5	0	.010	.0125	.0125	.713	2,513	3,060	2,850	.112	.106	Bending and shear
5-1	5	90	.010	.0125	.0125	.287	2,499	3,660	2,600	.137	.098	Bending
5-2	5	90	.010	.0125	.0125	.287	2,499	3,650	2,910	.134	.109	Bending
5-3	5	90	.010	.0125	.0125	.287	2,499	2,840	3,020	.104	.114	Bending
6-1	5	45	.010	.0125	.0125		2,418	3,690	2,800	.140	.105	Bending
6-2	5	45	.010	.0125	.0125		2,418	3,790	2,940	.143	.112	Bending
6-3	5	45	.010	.0125	.0125		2,418	3,570	2,790	.131	.102	Shear
7-1	5	0	.010	.0167	.0167	.635	2,380	3,686	3,340	.121	.112	Bending
7-2	5	0	.010	.0167	.0167	.635	2,380	3,510	3,390	.112	.117	Shear
7-3	5	0	.010	.0167	.0167	.635	2,380	3,950	2,990	.134	.104	Shear
8-1	5	90	.010	.0167	.0167	.365	2,408	3,740	2,950	.125	.097	Bending
8-2	5	90	.010	.0167	.0167	.365	2,408	4,250	3,180	.142	.104	Bending
8-3	5	90	.010	.0167	.0167	.365	2,408	4,220	3,110	.137	.104	Bending
9-1	5	45	.010	.0167	.0167		2,460	4,220	3,000	.134	.098	Bending
9-2	5	45	.010	.0167	.0167		2,460	3,910	3,250	.121	.106	Bending
9-3	5	45	.010	.0167	.0167		2,460	3,960	3,090	.126	.098	Bending

[1] The buckling constant for bending is denoted by $k = \frac{f_b r}{E_L t}$.

[2] The buckling constant for compression is denoted by $k = \frac{pr}{E_L h}$.

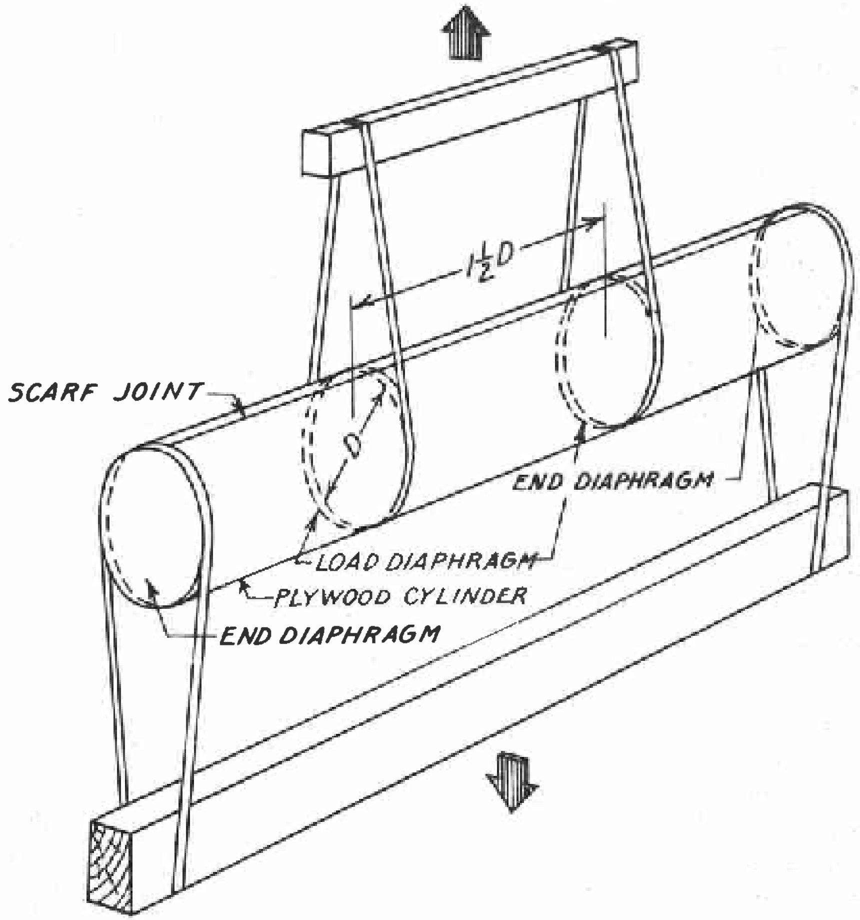

Figure 1.--Apparatus for testing thin-walled plywood cylinders in bending.

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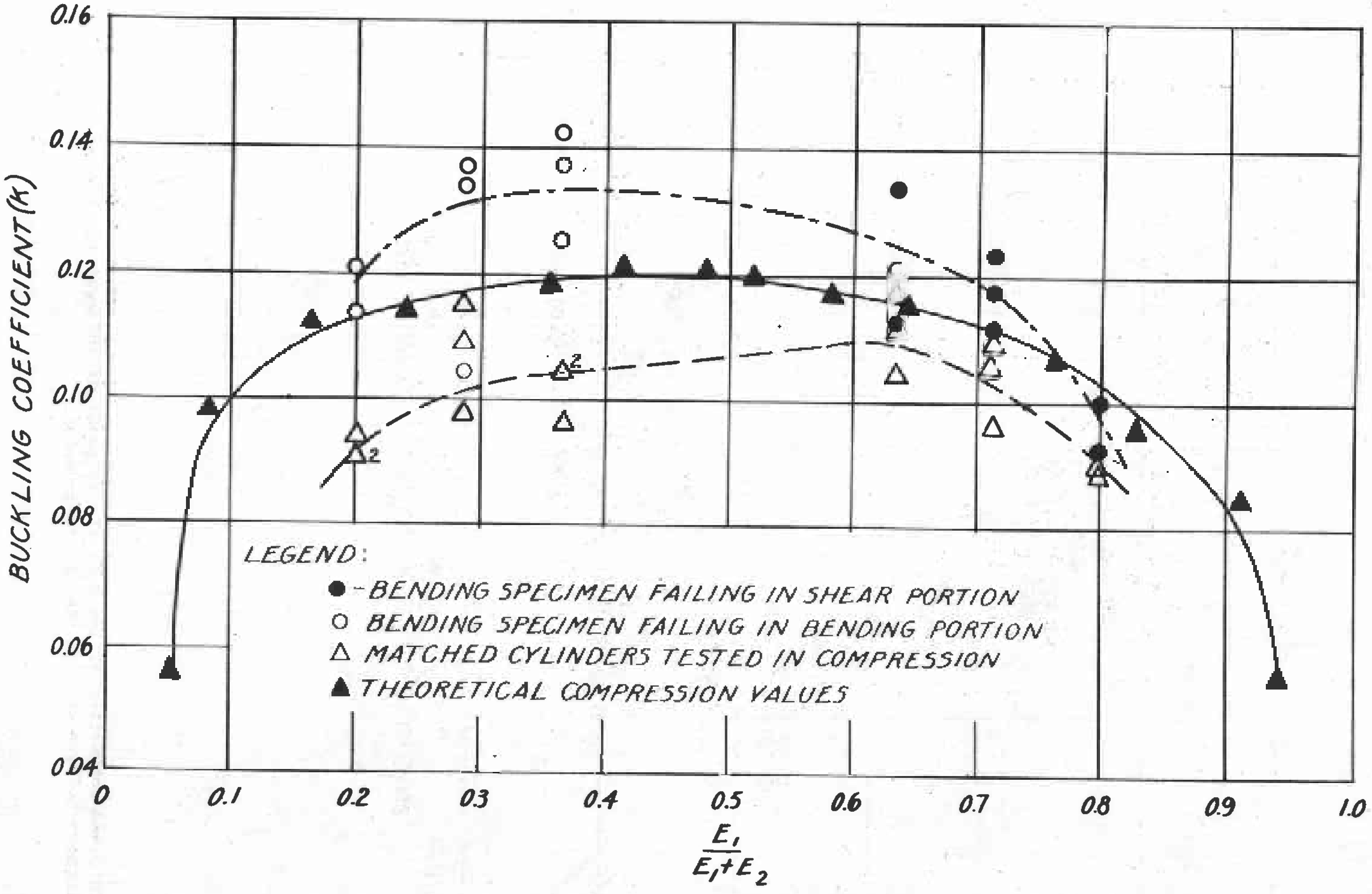

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Figure 2.—Results of tests on thin-walled plywood cylinders in bending. Grain direction of face plies 0° or 90°.

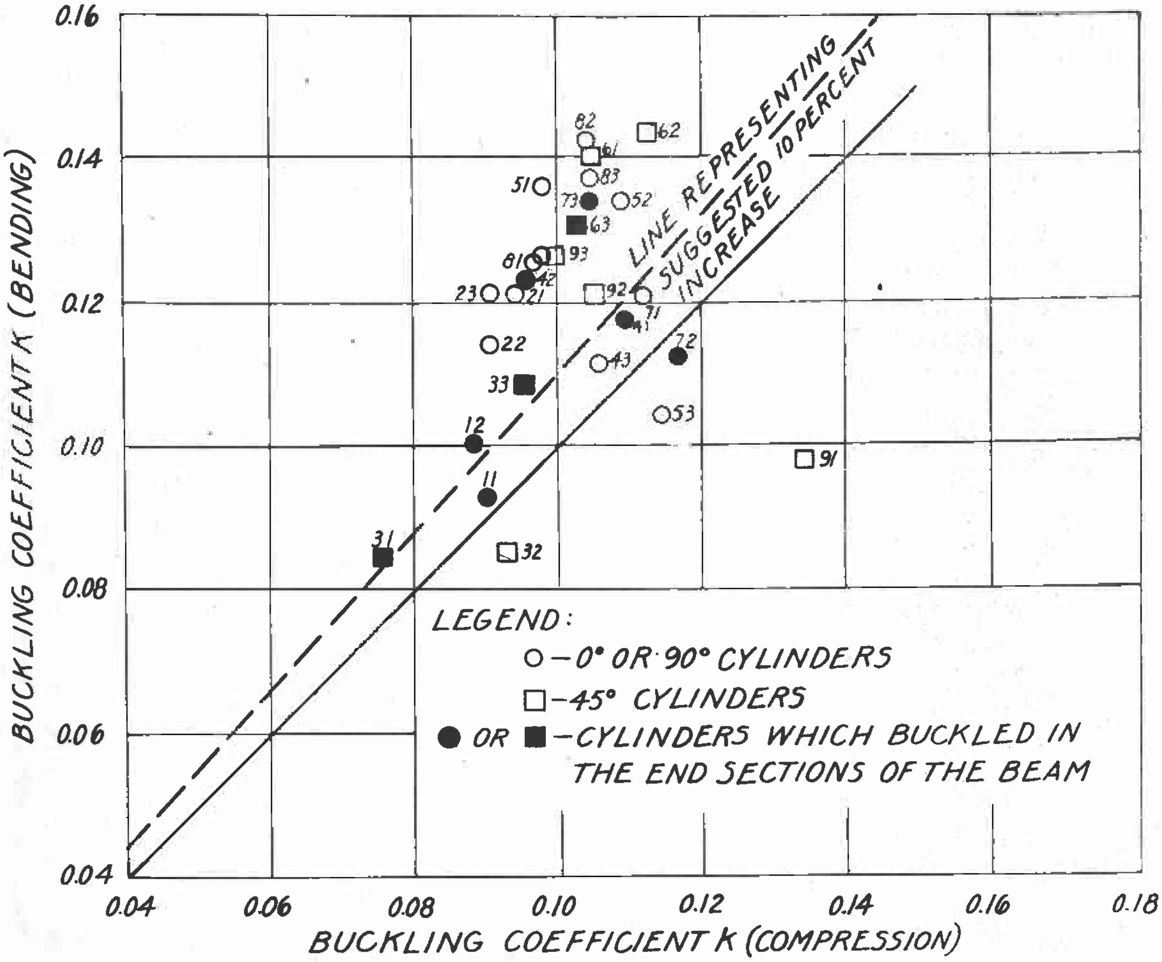

Figure 3.--A comparison of the buckling constant of thin-walled plywood cylinders in bending with that in compression.

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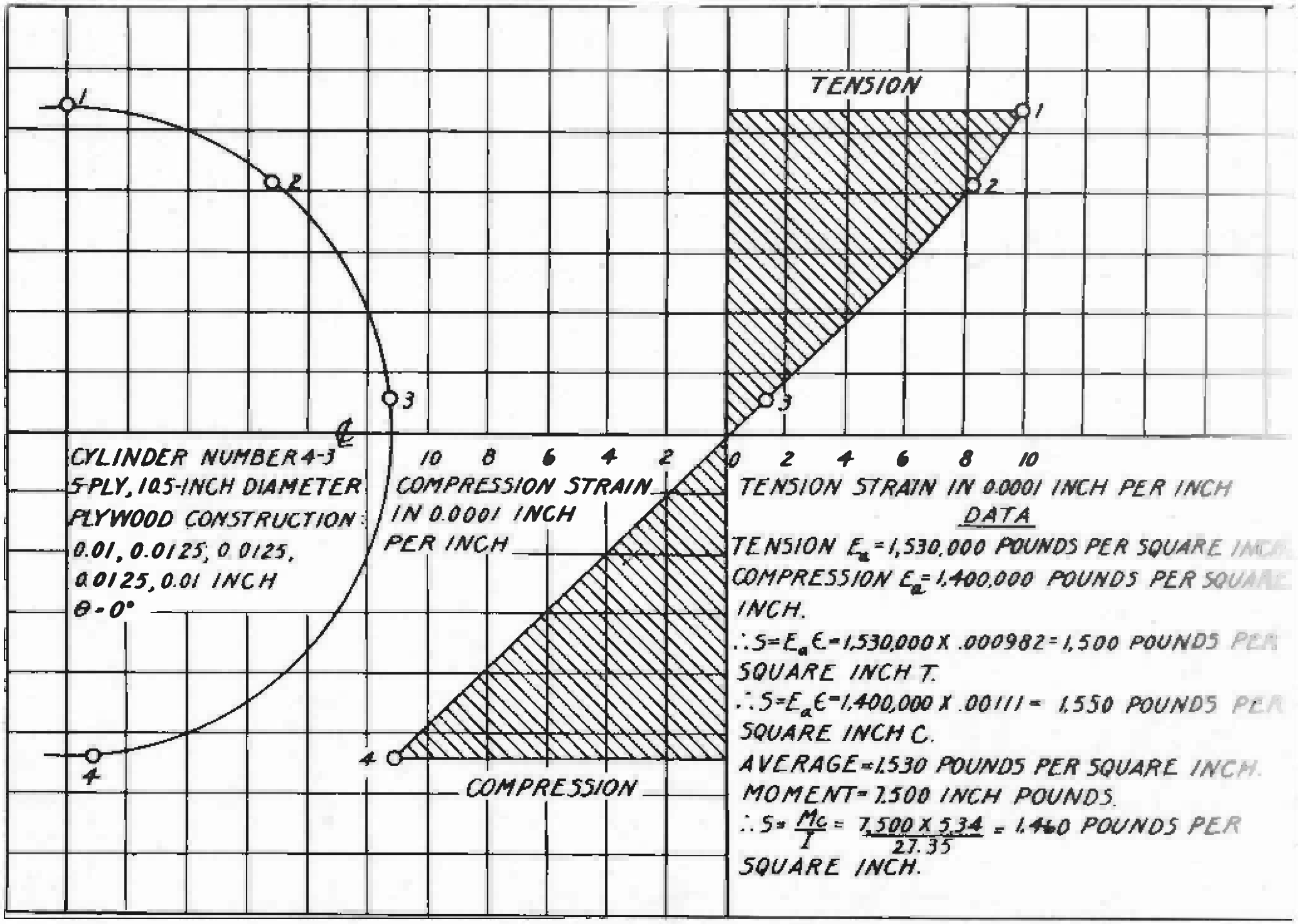

Figure 4.--Strain distribution at the center of a thin-walled plywood cylinder in bending. Strains measured with metalectric strain gages at about one-half the buckling load.

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