# A COMPARISON OF THE BUCKLING STRENGTH OF THIN-WALLED CYLINDRICAL AND BARREL-SHAPED PLYWOOD SHELLS

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# A COMPARISON OF THE BUCKLING STRENGTH OF THIN-WALLED CYLINDRICAL AND BARREL-SHAPED PLYWOOD SHELLS

By

EDWARD W. KUENZI, Junior Engineer

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In the testing of plywood cylinders in axial compression buckles always form inward. The suggestion was made concerning metal cylinders[1], that a barrel-shaped shell might develop a higher buckling load than a cylinder. Tests of plywood cylinders indicate that the buckling loads are independent of the diameters of the cylinders. It follows that the buckling loads of barrel-shaped shells should not be greater than those of cylinders unless the presence of the double curvature inhibits the formation of buckles. A few exploratory tests were made to obtain information on the effect of double curvature on buckling loads by comparing the buckling loads of thin-walled circular cylinders with those of matched barrel-shaped specimens.

## Description of Test Specimens

The specimens were made of rotary-cut yellow birch veneer of aircraft grade. The veneer was cut at the Forest Products Laboratory, and was all from the same log. The specimens were made by the bag-molding process in which layers of veneer were bonded with thermoplastic synthetic resin glue. Narrow strips of veneer were stapled to a wooden mandrel which had been turned to the proper shape and as subsequent layers of veneer were placed the staples in the preceding layer were removed. After the final layer of veneer had been stapled in place the outside of the specimen was wrapped with canvas, the entire assembly was placed in a rubber bag, and then in an autoclave where heat and pressure were applied. Removal of the specimen from the mandrel was accomplished by cutting the specimen in a lengthwise direction. The cut edges were then scarfed and glued together with a cold setting synthetic resin glue. All of the specimens were held in the testing Laboratory as a group for about a week to bring them all to the same moisture content. Prior to testing, the ends of the specimen were turned square and fitted with 1/2-inch plywood end blocks to maintain the circular shapes of the ends.

The following four plywood constructions were used:

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[1]H. L. Cox - Stress Analysis of Thin Metal Construction. Jour. Royal Aeronautical Society, Vol. 44, p. 231, 1940.

Construction 1.--Three equal ply thicknesses of 1/80-inch veneer, the grain direction of the face plies at an angle of 45° to the longitudinal axis of the specimen. ($\theta = 45°$)

Construction 2.--Two equal ply thicknesses of 1/100-inch veneer, the grain direction of the face plies at an angle of 45° to the longitudinal axis of the specimen. ($\theta = 45°$)

Construction 3.--Three ply, face and back of 1/100-inch veneer and core of 1/60-inch veneer, the grain direction of the face ply parallel to the longitudinal axis of the specimen. ($\theta = 0°$)

Construction 4.--Three-ply, face and back of 1/100-inch veneer and core of 1/60-inch veneer, the grain direction of the face ply perpendicular to the longitudinal axis of the speciman. ($\theta = 90°$)

The direction of the grain of adjacent plies was at right angles in all the specimens. A longitudinal axial section of each barrel-shaped specimen intersected the surface on an arc of a circle. In constructions 1 and 2 the diameter of the cylinder was 9 inches which corresponded to that of the ends of the barrel-shaped specimens. Center diameters of the barrel-shaped specimens in this series were 9-1/2, 10, and 11 inches. In constructions 3 and 4 the diameter of the cylinder was the same as that of the barrel-shaped specimens at the bulge which was 9 inches. The length of all specimens was 24 inches.

## Description of Tests

All specimens were tested in a hydraulic testing machine. Each specimen was tested with the upper end bearing against the machined surface of the testing machine head and the lower end resting on a flat machined plate mounted on a spherical bearing. The spherical bearing was adjusted to provide a uniform bearing on the top and bottom of the specimen. After this adjustment, screw jacks were placed under the corners of the bottom plate to prevent subsequent tilting of the plate. (Fig. 1) The load was applied at a slow uniform rate until failure occurred.

## Results of Tests

The results of tests are presented in table 1. All specimens failed by buckling. The buckles developed in the form of shallow indentations, usually appearing at midlength on the barrel-shaped specimens (fig. 2) but scattered over the entire length of the cylinders. The buckles appeared suddenly as the maximum load was attained, after which the load immediately decreased. On removal of the load the buckles disappeared but reappeared in their original positions when the load was applied a second time. It is assumed that the maximum loads were not influenced by the proportional limit of the material for they were well below the estimated loads at the proportional limit in compression in every case.

The results are best shown by the curves of figure 3 in which the ratio of the buckling load for the barrel-shaped specimen to that of the corresponding cylinder is plotted against the diameter variation in specimens. Each point on the curves represents the average results of two tests. The curves show that in most cases the buckling load of a barrel-shaped specimen was about 10 percent lower than the buckling load of the matched cylinder. In one instance, however, the barrel-shaped specimen buckled at a load about 5 percent higher than that of the matched cylinder.

## Conclusions

The results of the tests show that, in general, the thin-walled barrel-shaped specimens buckled at lower loads than the cylinders (table 1 and fig. 3). The test results hence indicate that moderate double curvature need not be considered in the design of thin-walled plywood shells to withstand axial compressive loads.

Table 1.--Results of compression tests on thin-walled cylindrical and barrel-shaped plywood shells[1].

| Specimen number | Plywood construction[2] | End diameter | Center diameter | Buckling load |
|---|---|---|---|---|
| | | Inches | Inches | Pounds |
| Construction No. 1.--3-ply (1/80", 1/80", 1/80") rotary cut yellow birch veneer | | | | |
| 1 | θ = 45° | 9 | 9 | 1,930 |
| 2 | " " | 9 | 9 | 1,925 |
| 3 | " " | 9 | 9-1/2 | 1,745 |
| 4 | " " | 9 | 9-1/2 | 1,500 |
| 5 | " " | 9 | 10 | 1,745 |
| 6 | " " | 9 | 10 | 1,525 |
| 7 | " " | 9 | 10 | 1,740 |
| 8 | " " | 9 | 11 | 1,675 |
| 9 | " " | 9 | 11 | 1,625 |
| Construction No. 2.--2-ply (1/100", 1/100") rotary cut yellow birch veneer | | | | |
| 10 | θ = 45° | 9 | 9 | 240 |
| 11 | " " | 9 | 9 | 305 |
| 12 | " " | 9 | 9-1/2 | 240 |
| 13 | " " | 9 | 9-1/2 | 275 |
| 14 | " " | 9 | 10 | 170 |
| 15 | " " | 9 | 10 | 265 |
| 16 | " " | 9 | 11 | 255 |
| 17 | " " | 9 | 11 | 230 |
| Construction No.3.--3-ply (1/100",1/60",1/100") rotary cut yellow birch veneer | | | | |
| 18 | θ = 0° | 9 | 9 | 1,125 |
| 19 | " " | 9 | 9 | 1,490 |
| 20 | " " | 8-1/2 | 9 | 1,235 |
| 21 | " " | 8-1/2 | 9 | 1,375 |
| 22 | " " | 8 | 9 | 1,435 |
| 23 | " " | 8 | 9 | 1,325 |
| Construction No. 4.--3-ply (1/100",1/60",1/100") rotary cut yellow birch veneer | | | | |
| 24 | θ = 90° | 9 | 9 | 1,590 |
| 25 | " " | 9 | 9 | 1,655 |
| 26 | " " | 8-1/2 | 9 | 1,395 |
| 27 | " " | 8-1/2 | 9 | 1,550 |
| 28 | " " | 8 | 9 | 1,440 |
| 29 | " " | 8 | 9 | 1,385 |

[1]The average moisture content of the plywood at test was about 5 percent.

[2]The angle given is that of the direction of the grain of the face ply with respect to the axis of the shell.

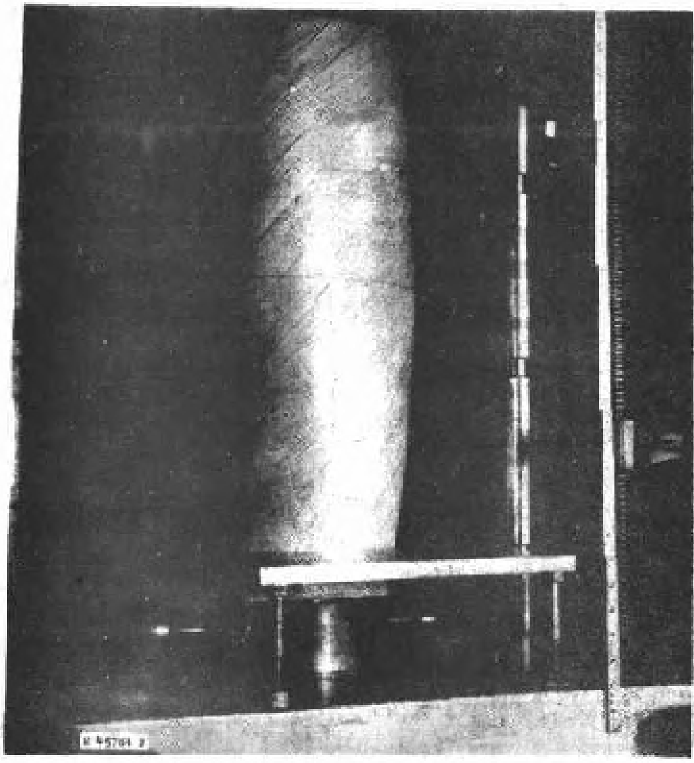

Figure 1.--Method of determining the buckling strength of a thin-walled barrel-shaped plywood specimen.

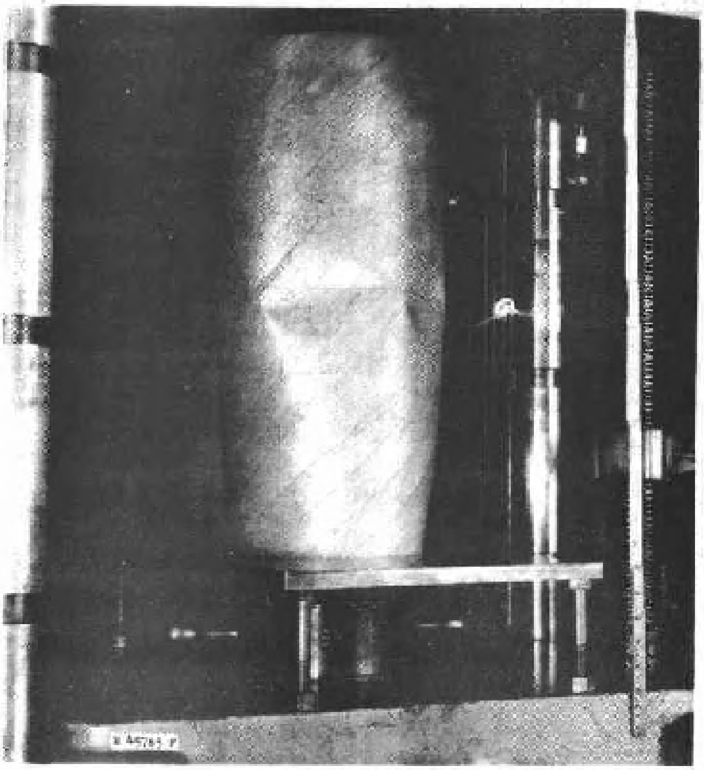

Figure 2. -Typical failure of a thin-walled barrel-shaped plywood specimen showing buckles at mid-length.

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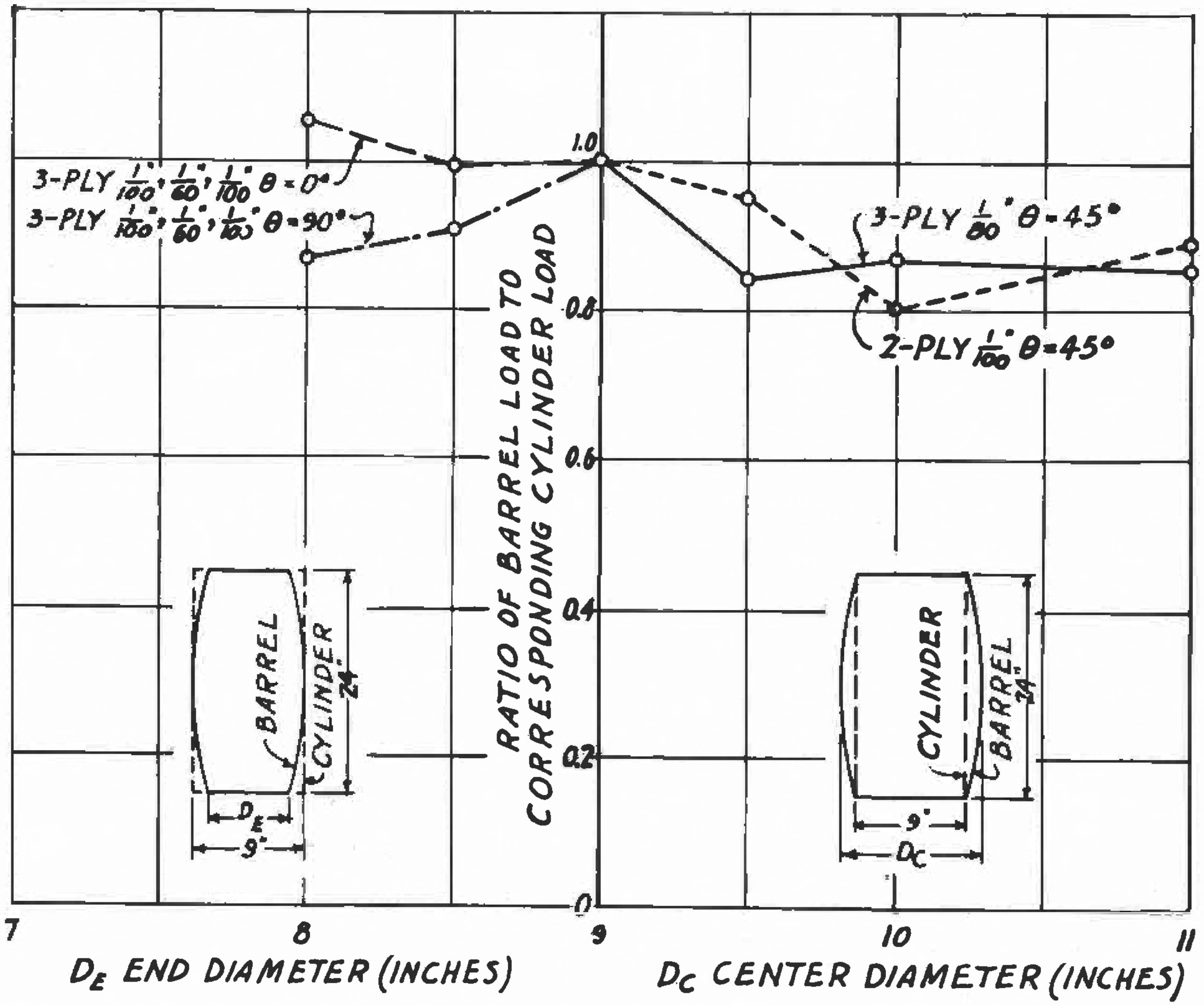


Figure 3.--Effect of double curvature on the buckling strength of thin walled shells.

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