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EXPERIMENTAL ANALYSIS OF THE NATURAL VIBRATIONS AND STABILITY OF CYLINDRICAL SHELLS REINFORCED WITH RECTANGULAR PLATES

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The paper presents experimental results on the effect of reinforcing cylindrical shells with rectangular plates on the axial compressive critical loads and the natural frequencies and modes of two sets of shells

Keywords: cylindrical shell, reinforcement with rectangular plates, critical loads, natural frequencies, vibration modes, axial compression

Introduction. Experimental data of the natural vibrations and stability of rib-reinforced cylindrical shells are reported in many publications [2–6, 8]. However, there are very view experimental studies on other types of reinforcement. For example, the effect of reinforcement of shells with rectangular plates has not been examined at all. In this connection, the present paper discusses the results from an analysis of the influence of such reinforcement plates on the natural frequencies and modes of cylindrical shells and their critical loads under axial compression. The efficiency of this type of reinforcement will be demonstrated. Similar results were obtained in [7] by calculation.

1. Characteristics of Test Shells. Two sets of cylindrical shells were tested. Their geometry is summarized in Table 1.

Three shells of the first set (Nos. 1–3) were made from a lavsan film. The nonreinforced shell No. 1 was made by bonding a film with BF-2 adhesive on a precision cylindrical mandrel. Shells Nos. 2 and 3 were made by reinforcing shell No. 1 with plates $k = 6$ and $k = 9$ in number and $b = 10.3$ and $b = 7.3$ cm in width, respectively. The lengths and thicknesses of all plates were equal: $L = 23.8$ cm and $h = 0.0175$ cm. All plates had both long edges flanged, flanges being 1 cm wide. The plates were bonded to the inside surface of the shells with BF-2 adhesive. After testing shell No. 2, the plates were removed and the shell was wiped clean with acetone. After that, the plates with $b = 7.3$ cm were bonded to shell No. 2 to make it No. 3. The cross section of one of the plate-reinforced shells ($k = 6$) is shown in Fig. 1. Three shells of the second set (Nos. 4–6) were made from a OT4-1 titanium alloy rolled sheet. Shell No. 4 was not reinforced. Shells Nos. 5 and 6 were reinforced with plates attached along meridians. The plates of shell No. 5 had length $L = 37.5$ cm, width $b = 27.3$ cm, and thickness $h = 0.03$ cm, while the plates of shell No. 6 had length $L = 37.5$ cm, width $b = 16$ cm, and thickness $h = 0.03$ cm. All the plates had two 1 cm flanges on both long edges. It is by these flanges that the plates were fixed to the inside surface of the shell with five screws spaced at 8.7 cm. Shells Nos. 5 and 6 were reinforced with three and six plates, respectively.

2. Determination of Critical Loads. The shells of the first set were tested on a set-up described in [1]. The shells of the second set were tested on a 30-ton Baldwin testing machine (USA, 1950). The loading method and the set-up were detailed in [3, 4]. The local buckling of all the shells was accompanied by snaps and occurrence of dents, which deepened with increasing load. Local buckling occurred under loads of approximately $0.8P$ (P is the global buckling load) in the shells of the first set and $0.75P$ in the shells of the second set. The test was stopped once the load taken up by the shell abruptly decreased. The number of circumferential waves observed after global buckling was $n = 5-6$ approximately. The test results for the shells of the first and second sets are summarized in Tables 2 and 3, respectively.

Table 2 indicates that retesting shells weakly changes the critical loads, which warranted making shells Nos. 2 and 3 from shell No. 1. The plate-reinforcement increased the critical loads substantially for the shells of the two sets, did not change the critical stresses in the lavsan shells, and considerably decreased the critical stresses in the metal shells.

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TABLE 1

Set No.	L, cm	R, cm	h, cm
1	23.8	9.25	0.0175
2	40	15	0.03

TABLE 2

Shell No.	P, kg	P^{avr}, kg	$\sigma / 10^5$, Pa	$\sigma^{avr} / 10^5$, Pa
1	16.6	16.43	16.33	16.16
	16.3		16.03	
	16.4		16.13	
2	37.7	33.70	18.06	16.14
	30.9		14.80	
	32.5		15.57	
3	38.7	35.03	17.86	16.17
	33.9		15.65	
	32.5		15.00	

TABLE 3

Shell No.	k	P, kg	$\sigma / 10^5$, Pa
4	0	1350	477.7
5	3	1455	275.4
6	6	1790	313.7

3. Determination of the Natural Frequencies and Vibration Modes. The natural frequencies and vibration modes were determined for the shells of the second set. The resonant method was used. An electrodynamic vibrator was used to excite vibrations of the shells. Its moving coil, $5.42 \cdot 10^{-3}$ kg in mass, was rigidly fixed to the wall of the shell in its midsection. The shells were inserted vertically into the circular slots of steel disks filled to a depth of 0.5 cm with Wood metal melt, which, when hardened, rigidly fixed the lower ends of the shells. The disks were rigidly attached to a massive bedplate. The excitation and measurement techniques are detailed in [5].

All tests were conducted at constant levels of excitation. Figure 2 shows the dependence of the experimental natural frequencies on the number of circumferential waves (n) for shells with $k = 0$ (circles), $k = 3$ (triangles), and $k = 6$ (squares). The dashed lines are drawn as a guide for an eye. The plate-reinforcement substantially increases the natural frequencies of the shells. Figure 3*a*–*c* show the natural circumferential modes at the minimum natural frequencies for the shells of the second set with k = 0, 3, 6, respectively. The arrows indicate the points of application of dynamic loads; the dashed lines show ranges of vibrations about the circle that represents the midcross-section of the shells. The ranges of vibrations were measured with a noncontact vibration transducer. Figure 3 demonstrates that the plate-reinforcement of the shells changes their natural modes substantially.

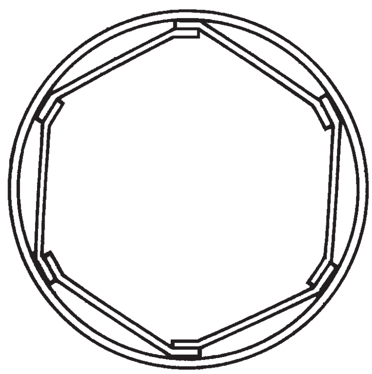


Fig. 1

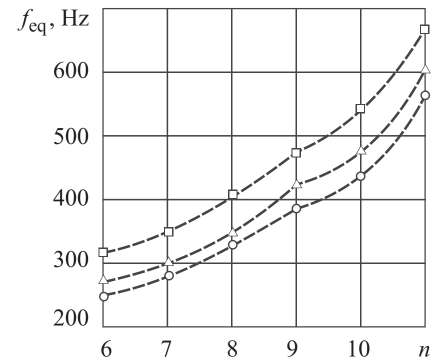
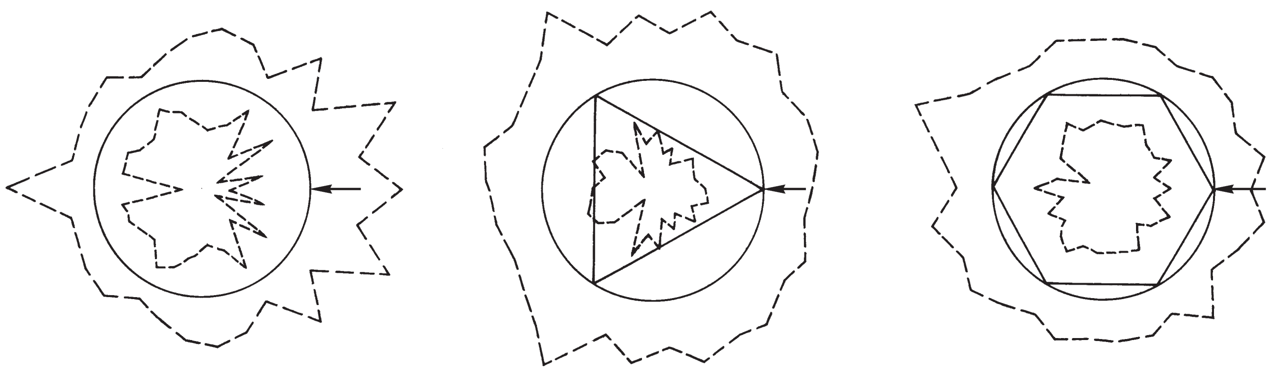


Fig. 2



a *b* *c*

Fig. 3

Conclusions. The experimental data obtained indicate that the plate-reinforcement has a weak effect on the critical stresses of the lavsan shells and considerably decreases the critical stresses of the metal shells. Also, the experimental results demonstrate that it is possible to substantially increase the critical loads and natural frequencies by increasing the number of reinforcement plates. Note that the dependence of the critical stresses on the number of reinforcement plates was theoretically studied in [7] alone; therefore, such studies should be continued.

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