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Stability Analysis of a Three-Layer Shell with Lightweight Filler Supported By Rigidity Ribs

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Keywords: sloping three-layer shell, circular three-layer shell, lightweight filler, longitudinal rib of rigidity, stability, shell rigidity, rib rigidity, shift parameter, rigidity parameter, curvature parameter.

Abstract: An analysis of the stability of sloping and circular three-layer shell structures with light transversal-isotropic filler, supported by rigidity ribs in the longitudinal and transverse directions is considered in paper. The quantitative dependences of the parameters of the stability loss on the physical and mechanical properties of the materials and the dimensions of these three-layer supported shells were obtained. The critical loads of freely supported three-layer shells with lightweight filler of four types which supported by one and three ribs in the longitudinal and transverse directions are given. The expediency of introducing rigidity ribs in three-layer shells is substantiated.

Introduction

Increasing the level of industrialization of construction requires the use of new efficient types of lightweight economic building structures. Three-layer construction based on high-flammable foam or oriented mineral wool and thin sheet materials is the best option strength and rigid construction. An analysis of the world experience of design and construction shows the prospect of using three-layer shells as enclosures and load-bearing elements of buildings and structures.

Three-layer shells have high weight characteristics, which allow at the same weight to withstand much higher loads than can withstand single-layer. However, thin carrier layers and lightweight filler are less resistant to local loading, so as a rule, three-layer shells are supported by longitudinal and transverse ribs.

Formulation of the Problem

Stability is one of the most important issues in the design and calculation of three-layer structures, since the inner layer has a small rigidity and the supporting outer layers have a relatively small thickness. Stability of three-layer structures is devoted to a lot of publications [1-3]. The influence of the geometric parameters of the shell and the elastic characteristics of the material on the value of the critical load is considered [4-6]; the solutions of problems for the cylindrical shell and the panel, for the conical shell at different loads and boundary conditions are given [7-9]; the applied methods for calculating the stability of reinforced and multilayered shells were propose [10-12].

However, at present, the issue of the stability of just the supported three-layer shells with lightweight filler has not been studied enough. There are no practical and theoretical bases for parametric studies of the stability of these shells.

Thus, obtaining of quantitative dependences of the stability loss parameters from the physic mechanical properties and sizes of a three-layer supported shell and stability analysis of this shell are high scientific relevance and practical value.

The aim of the work is stability analysis of three-layer shell building structures with a light transversal-isotropic filler, supported by rigidity ribs in the longitudinal and transverse directions, and justify the expedient of introducing rigidity ribs.

Materials and Methods

Calculation models have been constructed and algorithms for investigating the stability of three-layer shells of the following types have been developed: a sloping three-layer shell, supported by longitudinal (Fig.1) and transverse (Fig.2) rigidity ribs; circular three-layer shell, which is supported by longitudinal (Fig.3) and transverse (Fig.4) rigidity ribs [13-16].

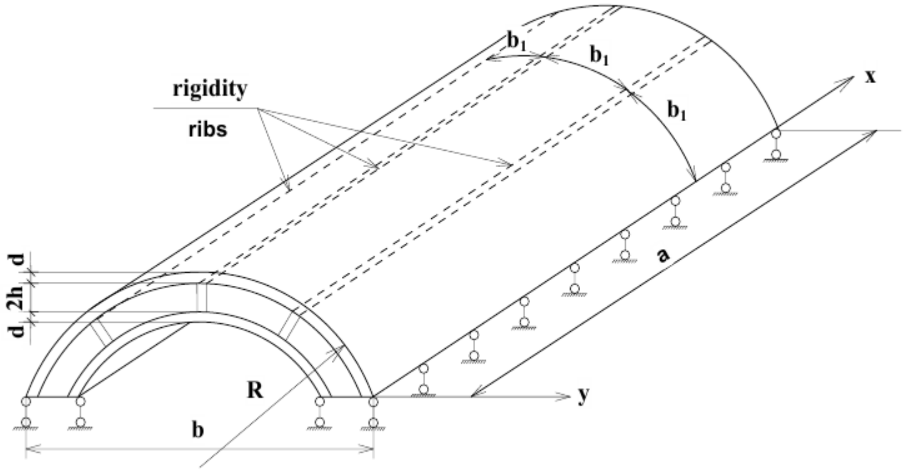

Fig. 1. Scheme of a sloping three-layer shell, supported by longitudinal rigidity ribs

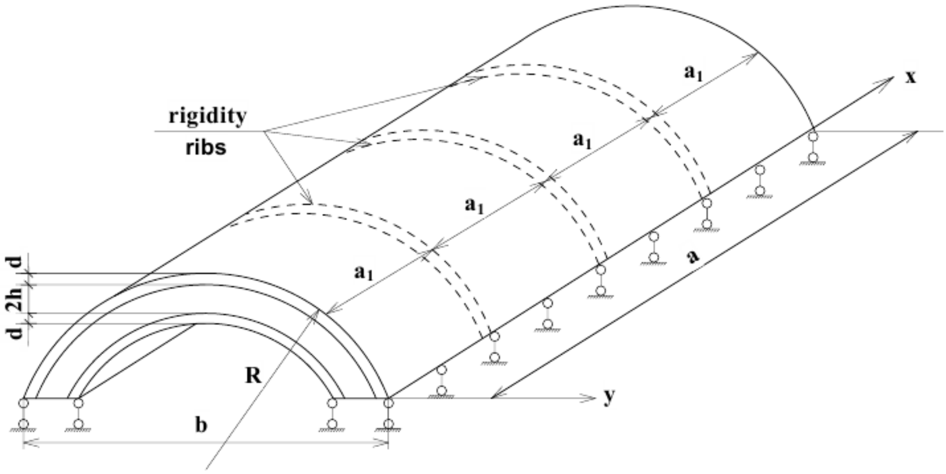

Fig. 2. Scheme of a sloping three-layer shell, supported by transverse rigidity ribs

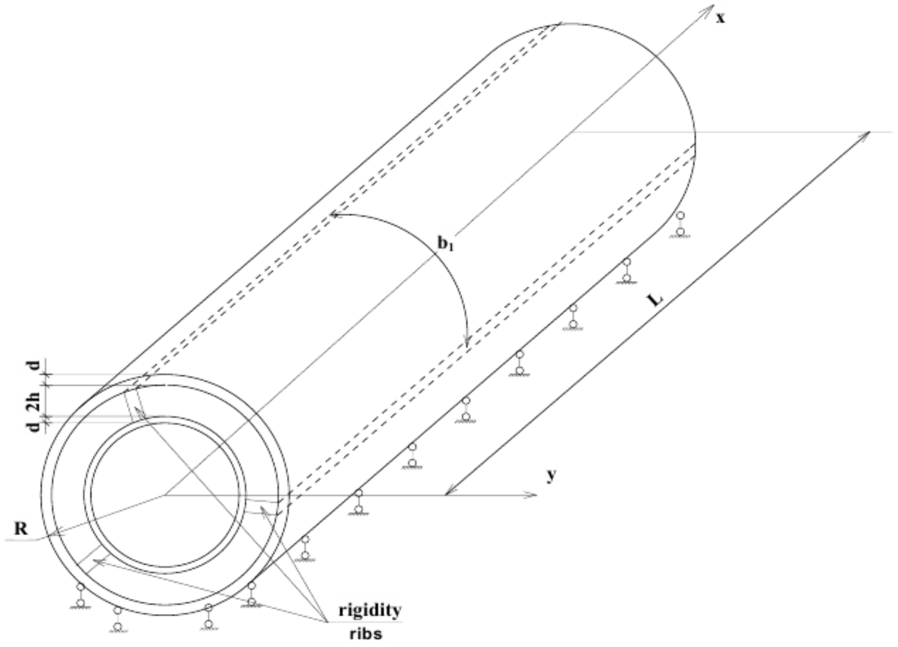

Fig. 3. Scheme of a circular three-layer shell, supported by longitudinal rigidity ribs

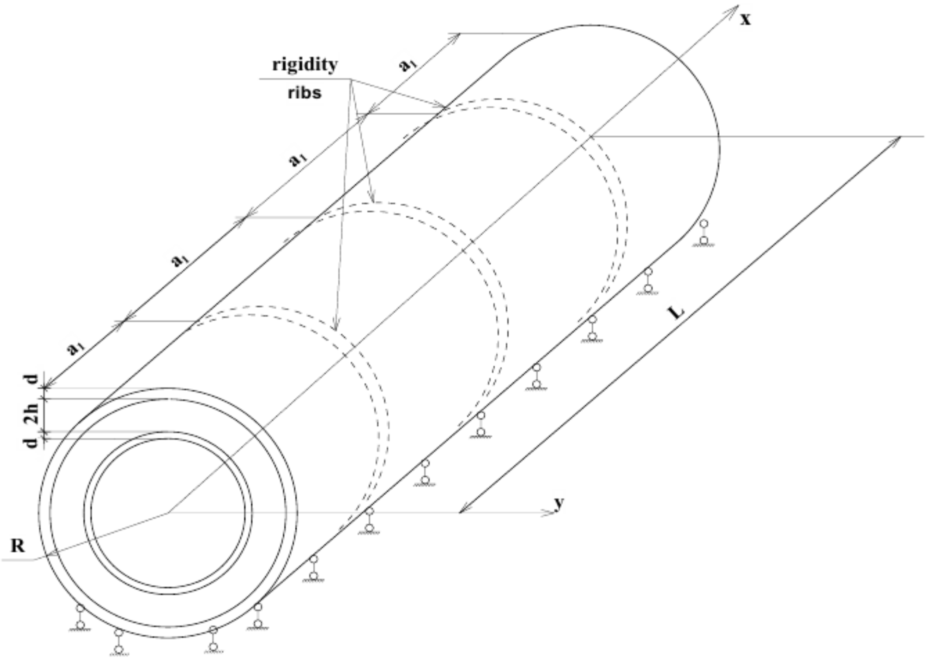

Fig. 4. Scheme of a circular three-layer shell, supported by transverse rigidity ribs

Research Results

When designing supported three-layer shells with lightweight filler, rigidity ribs should be positioned so as to obtain increased values of the elastic parameters of the aggregate. This will ensure local stability of the outer layers.

In order to determine the feasibility of introducing rigidity ribs, a numerical analysis of the stability of supported three-layer shells with a foam aggregate of FC type (μ= 0.4) of three types performed in the work. The material of the supporting layers of the shell is Duralumin D-16T, with a thickness of δ=0.1 cm (E=6.9 105 kg/cm^2, B=158.103 kg/cm, μ=0.33).

Table 1 presents the critical load values of a freely supported sloping three-layer shell with lightweight filler supported by one and three longitudinal ribs of rigidity (Fig.1). Shell dimensions: a=60 cm, b=40 cm, R=100 cm.

Table 1. Values of the critical load of the three-layer sloping shell with lightweight filler, supported by longitudinal ribs of rigidity

№	2h, mm	G, kN/m^2	k_0	α^2	P_{cr} sloping shell with freely supported longitudinal edges		P_{cal}, when supported by 1 longitudinal rib (γ=0,1)		P_{cal}, when supported by 3 longitudinal rib (γ=0,3)	
					m_t	P_{cal}, kN	m_t	P_{cal}, kN	m_t	P_{cal}, kN
1	15,0	8130	4,500	2,751	0,354	86,57	0,437	107,00	0,609	149,00
2	15,0	12400	2,950	2,751	0,499	122,00	0,547	134,00	0,764	186,60
3	9,5	15000	1,540	6,388	1,323	139,00	1,876	198,00	2,175	229,60
4	4,0	12700	0,768	28,173	2,795	66,70	2,789	67,00	2,884	68,00
5	4,0	56630	0,172	28,173	6,756	161,40	6,879	164,00	7,164	171,00
6	10,0	7950	3,070	5,821	0,525	61,00	0,788	91,00	0,884	102,50
7	10,0	3260	7,480	5,821	0,322	37,30	0,341	39,00	0,659	76,00
8	14,5	8900	3,970	2,932	0,510	118,00	0,939	172,00	0,989	227,00
9	13,0	12400	2,560	3,594	0,612	114,60	0,881	164,00	0,971	181,70
10	20,0	7260	6,720	1,597	0,179	75,41	0,278	117,00	0,399	168,10

Reinforcement of the shell by one longitudinal rib increases the critical load by 22% generally, and reinforcement by three longitudinal ribs - by 29%, compared to the shell without ribs of rigidity.

Table 2 presents the critical load values of a freely supported sloping three-layer shell with lightweight filler supported by one and three transverse ribs of rigidity (Fig.2). Shell dimensions: a= 60 cm, b= 40 cm, R= 100 cm.

Reinforcement of the shell by one transverse rib increases the critical load by 3,7% generally, and reinforcement by three transverse ribs - by 7,4%, compared to the shell without ribs of rigidity.

Table 3 presents the critical load values of a freely supported circular three-layer shell with lightweight filler supported by one and three longitudinal ribs of rigidity (Fig.3). Shell dimensions: L= 60 cm, R= 20 cm.

Reinforcement of the shell by one longitudinal rib increases the critical load by 43% generally, and reinforcement by three longitudinal ribs - by 54%, compared to the shell without ribs of rigidity.

Table 4 presents the critical load values of a freely supported circular three-layer shell with lightweight filler supported by one and three transverse ribs of rigidity (Fig.4). Shell dimensions: L= 60 cm, R= 20 cm.

Reinforcement of the shell by one transverse rib increases the critical load by 5,1% generally, and reinforcement by three transverse ribs - by 9,4%, compared to the shell without ribs of rigidity.

Table 2. The value of the critical load of the three-layer sloping shell with lightweight filler, supported by transverse ribs of rigidity

№	2h, mm	G, kN/m^2	k_0	α^2	P_{cr} sloping shell with freely supported longitudinal edges		P_{cal}, when supported by 1 transverse rib (γ=0,1)		P_{cal}, when supported by 3 transverse rib (γ=0,3)	
					m_t	P_{cal}, kN	m_t	P_{cal}, kN	m_t	P_{cal}, kN
1	15,0	8130	4,500	2,751	0,354	86,57	0,369	90,30	0,372	91,00
2	15,0	12400	2,950	2,751	0,499	122,00	0,529	129,60	0,562	137,00
3	9,5	15000	1,540	6,388	1,323	139,00	1,351	142,00	1,380	145,00
4	4,0	12700	0,768	28,173	2,795	66,70	2,884	68,90	2,975	71,00
5	4,0	56630	0,172	28,173	6,756	161,40	6,845	163,50	6,885	164,60
6	10,0	7950	3,070	5,821	0,525	61,00	0,534	61,80	0,544	63,00
7	10,0	3260	7,480	5,821	0,322	37,30	0,346	39,70	0,351	40,60
8	14,5	8900	3,970	2,932	0,510	118,00	0,543	124,10	0,591	135,00
9	13,0	12400	2,560	3,594	0,612	114,60	0,642	120,20	0,659	123,00
10	20,0	7260	6,720	1,597	0,179	75,41	0,186	77,10	0,201	84,00

Table 3. The value of the critical load of the three-layer circular shell with lightweight filler, supported by longitudinal ribs of rigidity

№	2h, mm	G, kN/m^2	k_0	α^2	P_{cr} circular shell with freely supported longitudinal edges		P_{cal}, when supported by 1 longitudinal rib (γ=0,1)		P_{cal}, when supported by 3 longitudinal rib (γ=0,3)	
					m_t	P_{cal}, kN	m_t	P_{cal}, kN	m_t	P_{cal}, kN
1	15,0	8130	1,769	557	0,166	16,70	0,292	28,20	0,296	29,80
2	15,0	12400	1,195	557	0,246	24,00	0,423	42,50	0,810	81,00

3	9,5	15000	0,625	1295	0,476	20,70	0,801	33,80	0,826	36,70
4	4,0	12700	0,311	5703	0,976	9,60	1,668	15,80	1,679	16,90
5	4,0	56630	0,072	5703	0,867	8,60	1,193	11,70	1,226	12,10
6	10,0	7950	1,242	1178	0,243	11,60	0,410	19,10	0,419	20,00
7	10,0	3260	3,029	1178	0,264	12,60	0,330	15,80	0,340	16,70
8	14,5	8900	1,609	593	0,187	17,70	0,302	28,60	0,317	30,00
9	13,0	12400	1,035	727	0,287	22,00	0,488	37,40	0,498	38,50
10	20,0	7260	2,72	323	0,223	38,80	0,365	63,50	0,404	70,40

Table 4. The value of the critical load of the three-layer circular shell with lightweight filler, supported by transverse ribs of rigidity

№	2h, mm	G, kN/m^2	k$_0$	α^2	P$_{cr}$ circular shell with freely supported longitudinal edges		P$_{cal}$, when supported by 1 transverse rib (γ=0,1)		P$_{cal}$, when supported by 3 transverse rib (γ=0,3)	
					m$_t$	P$_{cal}$, kN	m$_t$	P$_{cal}$, kN	m$_t$	P$_{cal}$, kN
1	15,0	8130	1,769	557	0,166	16,70	0,175	17,50	0,179	18,10
2	15,0	12400	1,195	557	0,246	24,00	0,254	25,70	0,258	26,00
3	9,5	15000	0,625	1295	0,476	20,70	0,480	20,90	0,483	21,00
4	4,0	12700	0,311	5703	0,976	9,60	1,101	10,50	1,106	11,00
5	4,0	56630	0,072	5703	0,867	8,60	0,904	8,90	1,002	9,60
6	10,0	7950	1,242	1178	0,243	11,60	0,260	12,40	0,271	12,90
7	10,0	3260	3,029	1178	0,264	12,60	0,287	13,40	0,294	13,90
8	14,5	8900	1,609	593	0,187	17,70	0,193	18,30	0,198	18,80
9	13,0	12400	1,035	727	0,287	22,00	0,303	23,50	0,312	24,70
10	20,0	7260	2,72	323	0,223	38,80	0,230	40,00	0,244	42,50

In work is denoted:

B – cylindrical rigidity of the outer layers by tensile; E – the modulus of elasticity of the outer layers; μ– Poisson's coefficient; G$_3$ – filler shift modulus; $k_0 = \frac{Bh}{G_3 b^2}$ – shift parameter of the sloping shell; $k_0 = \frac{Bh}{G_3 R^2}$ – shift parameter of the circular shell; $\alpha^2 = \frac{(1-\mu^2)b^4}{R^2\pi^4(h+0.5\delta)^2}$ – curvature parameter of the sloping shell; $\alpha^2 = \frac{(1-\mu^2)R^2}{(h+0.5\delta)^2}$ – curvature parameter of the circular shell

Conclusions

Quantitative dependences of the parameters of the stability loss on the physical and mechanical properties of the materials and the dimensions of the three-layer reinforced shell were obtained. It is found that critical load and critical rigidity ribs increase with increasing number of ribs; the critical rigidity of the ribs increases, and the maximum load decreases with increasing aspect ratio of the shell; with increasing rigidity of the ribs, the critical load increases to a certain limit, after which it remains constant and equal to the critical load of the shell, closed between the ribs.

It should be noted that these three-layer shells operating in the conditions of longitudinal compression, it is most advisable to support by ribs of rigidity, normal to the outer layers and located in the bending plane of the shell along the compressive load. In this case, the critical compression load increases significantly, because it depends on the modulus of normal elasticity of the filler in the direction normal to the outer layers.

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