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Experimental investigations on the stability of stiffened cylindrical shells of steel silos

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ABSTRACT

Owing to technological reasons the silos are frequently supported in a discrete way, usually by column heads. This kind of support causes a significant accumulation of compression meridional stresses in a cylindrical shell in support regions, which may lead to local buckling. The problem of determining shell resistance over the support region for different shapes of ribs constitutes a current research issue. One of highly preferred methods of strengthening this zone is the use of short ribs interconnected with a circumferential ring. Both the results of tests on the resistance of such shells and numerical analysis allowing to determine the course of this research are presented in this study. It has been demonstrated that the global resistance of the stiffened shells supported discretely is always much smaller from that in similar shells supported uniformly around the perimeter.

1. Introduction

Cylindrical walls of steel silos are often supported on columns' heads (Figs. 1, 2) or on the ceiling beams in production buildings. In such cases the silo walls are longitudinally compressed as cylindrical shells discretely supported on columns along the width of s_0 (Figs. 2, 3).

The vertical reaction of the single discrete support N_1 (Fig. 3a) with an arbitrary width s_0 causes meridional compression stress σ_{x01} determined by formula (1) at $x = 0$, which is much higher than the stress σ_{x0} obtained for a shell uniformly supported around the perimeter (Eq. (2)):

$$\sigma_{x01} = \frac{N_1}{s_0 \cdot t} \tag{1}$$

$$\sigma_{x0} = \frac{n \cdot N_1}{2\pi \cdot r \cdot t}. \tag{2}$$

The meridional compression stresses σ_{x01} for shell's column supports with number $n \geq 3$ are several times larger than stresses σ_{x0} along the bearing edge ($x = 0$) for a uniformly supported shell. The local instability of the unstiffened cylindrical shell in the discrete support regions (Fig. 2a) is studied in interalia [1–4]. The strengthening of the supporting zone due to buckling is often executed by short ribs with the length L_1 (Fig. 2b). The resistance of such shells has been tested by Komman and Pasternak [5–7].

It is often assumed that the use of transition ring over the ribs with length $L_1 > r$ (Fig. 2c) provides a uniform distribution of meridional stresses σ_x around the entire perimeter just above the ring. One might think that the ribbed, bottom portion of the shell wall could act as a rigid apron referred to in EN 1993-4-1:2007 + AC:2008 (p. 5.4.2(1b)) [8], and that is supposed to be able to provide a state of meridional stress, such as in the case of the shell uniformly supported on the circumference of the silo, although the actual support is realized by means of columns. This provision in the standard for the role of a circumferential apron in the dispersion of stress gradient from the support reaction N_1 (Fig. 3a) is not correct, which can be shown by any simple numerical analysis of the state of stress in this zone.

The authors have done a series of experimental tests on ribbed cylindrical shell walls supported discretely showing clearly that short ribs connected by a transition ring (Figs. 1, 2) are not able to provide the uniform distribution of meridional stresses σ_x in the cylindrical silo shell, supported discretely by columns, and that compression silo shell can buckle in the zone placed over the short ribs.

2. Methods of the analysis of stability of cylindrical steel shell walls in the region of discrete supports

Samuelson and Eggwertz [9] have proved clearly, that the main stream of meridional compression stress σ_{x01} (Fig. 3a) in the cylindrical shell supported discretely on bearings with the width s_1 is not dispersed at an angle $\alpha = 45°$, as it is taken in planar members according to Saint–Venant principle. Hence, some authors [1,4] have considered that safe value of stresses in analyzed resistance of shells is equal to the maximum of meridional stresses $\sigma_x = \sigma_{x01}$ (Fig. 3a) occurring at the bottom

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Fig. 1. Examples of stiffened, column supported steel silos with the use of transition ring over short ribs.

edge of the shell. The design value of meridional stresses $\sigma_{x,Ed}$ at the level $x = 0$, determined on the basis of the modified formula (Eq. (1)) should be less than the value of design critical stresses $\sigma_{x,Rd}$, determined in accordance with current standards.

Knödel and Ummenhoffer [3] have proposed a less conservative way of determining the value of stresses $\sigma_{x,Ed}$ at the level x corresponding to the half of height of the buckling wave, assuming that the angle of dispersion of the stress stream up to the half height of the wave is $\alpha = 75°$ (Fig. 3a). Another approach in the analysis of the resistance of shell walls, column supported has been applied by Hotała [2], who proposed the determination of the critical reaction $N_{1,Rd}$ from the discrete support, as compared with the design value of reaction $N_{1,Ed}$. He has also calibrated the buckling curve needed to determine the value $N_{1,Rd}$. Similarly, the analysis of the resistance of cylindrical, column supported shells has been proposed by Komman [5], who determined the critical reaction $N_{1,Rd}$ in the case of short ribs used over the column supports (Fig. 2b). Komman and Pasternak [5–7] have clearly shown that the use of short ribs has a beneficial influence on the resistance of discretely supported cylindrical shell, and that the basic shape of buckling for this system occurs as displacement of the upper edges of ribs

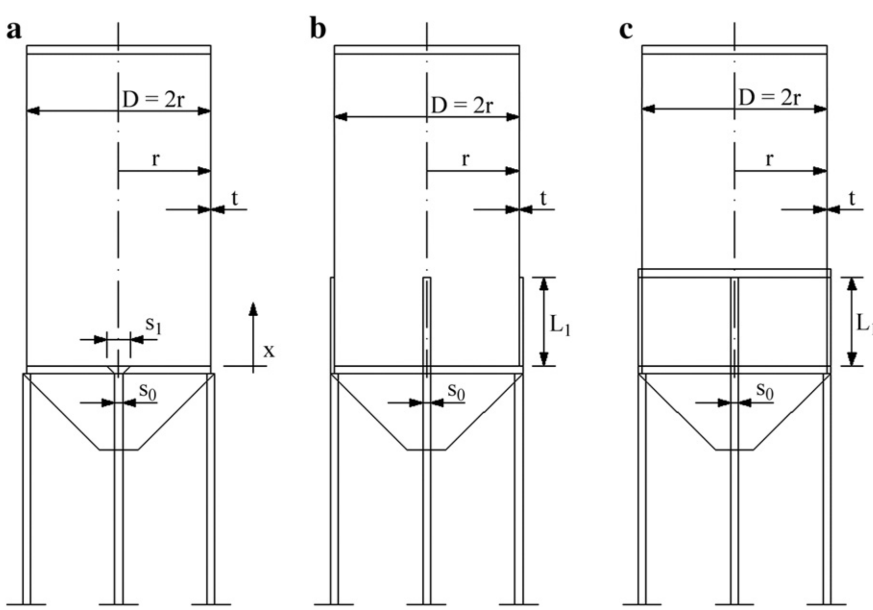

Fig. 2. Cylindrical shells of steel silos supported by columns: a) without ribs, b) with short ribs, c) with short ribs and transition ring.