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Column-supported silos: Elasto-plastic failure

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ABSTRACT

This paper presents a study of the failure behaviour of column-supported silos with flexible engaged steel columns, based on finite element analyses. For a wide range of silo and column geometries, the influence of all geometrical parameters to the failure behaviour will be demonstrated. An important finding is that the height over which the column is attached to the silo initially has a positive influence to the failure behaviour and the failure load, but proves to be disadvantageous from a certain critical height.

1. Introduction

For practical reasons, thin-walled steel silos are frequently supported by engaged columns or local supports (e.g. brackets), whether or not in combination with longitudinal and/or ring stiffeners [1–5].

Easy access beneath the hopper is required to conveniently discharge the contents of the silo by gravity flow into trains, trucks or other conveying systems. However, these discrete supports introduce high forces into the silo wall above the terminations of the engaged column. These forces result in axial compressive stress concentrations in the shell wall, which are detrimental for the bearing strength of such a locally supported silo. In comparison with a ground supported silo, the failure load is reduced due to premature failure, either by elastic buckling, plastic yielding, or a combination of both phenomena.

The engaged columns are used for smaller silo structures, whether or not in combination with ring stiffeners [4]. These engaged steel columns have a rectangular or a square cross-section and are attached to cylindrical silo wall by welding. This welded connection gradually transfers the ground reaction force of the column into the shell wall by shear forces. Such an engaged column must fulfil at least two essential conditions. Firstly, the column must withstand higher loads than the shell wall itself. Indeed, the column must be able to fully absorb the supporting reaction and transfer this reaction force into the shell wall. In other words, the column must have a sufficiently large cross-section so that the column does not yield. Secondly, the clamped column must have a minimum moment of inertia to resist the inward oriented displacement at the top of the column, which is in the vicinity of the location where failure occurs. As a result of these two conditions, failure will occur at the silo wall above the terminations of the engaged column and not at the column itself.

The purpose of this study is to examine the above mentioned criteria based on the results of numerical simulations with the finite element package ABAQUS [6].

2. Geometry

The column-supported silo and the corresponding symbols of the geometrical parameters are presented in Fig. 1.

2.1. Silo geometry

The cylinder radius R has a constant value, while all other geometrical parameters are relative to the cylinder radius R. In this way, the results can be converted to silos with a radius different from 1.0 m. The radius-to-thickness ratio R/t is varied between 200 (i.e. relative thick silo wall) and 1000 (i.e. relative thin silo wall). In this study, the ratio of the cylinder height to the cylinder radius h/R corresponds with a constant value of 8.0. Based on another

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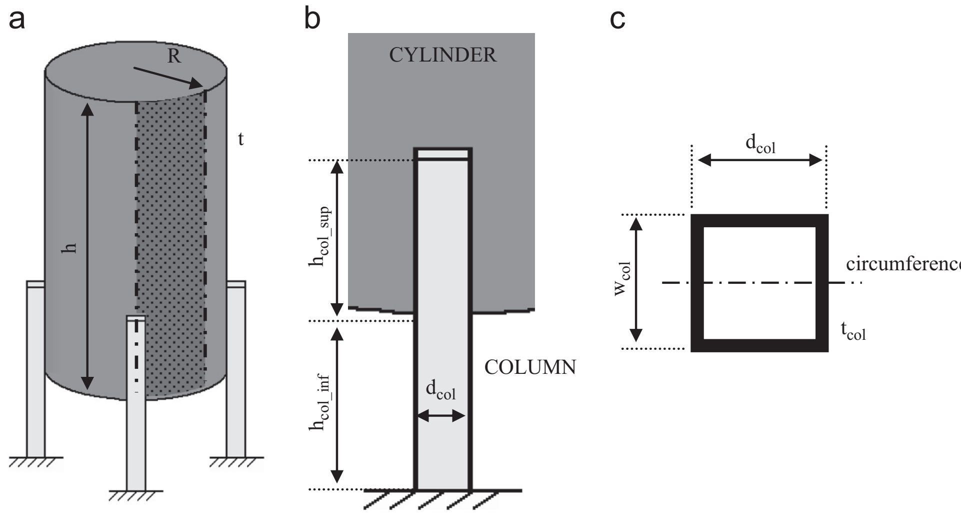

Fig. 1. Geometrical parameters of a column-supported cylinder. (a) Cylinder, (b) column — front view and (c) column — cross-section.

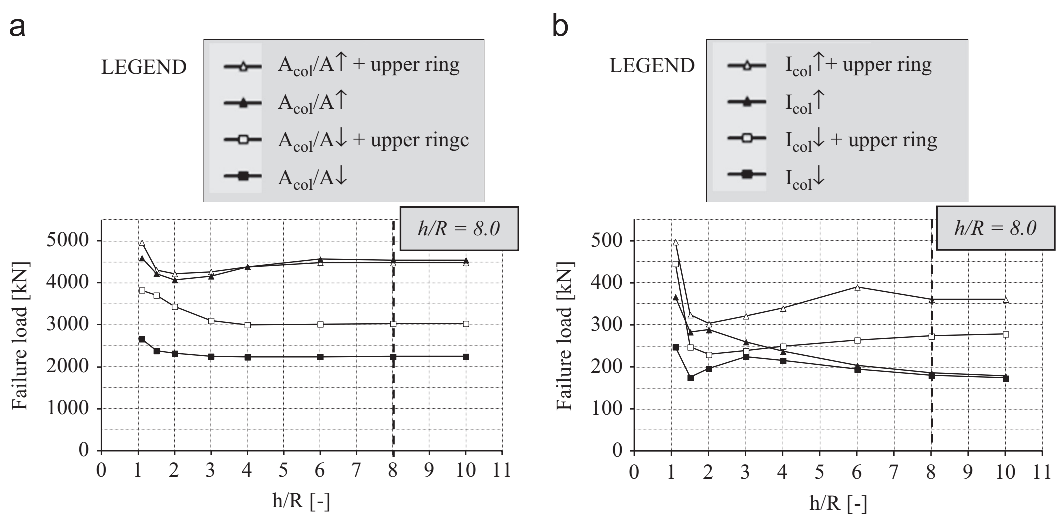

Fig. 2. Influence of the cylinder height h on the failure load F_u.[1]. (a) R/t=200 and (b) R/t=1000.

Table 1
Geometrical parameters of the cylinder.

Parameter	Dimension	Value(s)
R	m	1.0
R/t	–	200; 400; 600; 800; 1000
h/R ($=h_{ref}/R$)	–	8.0

parametric study,[1] which is not yet published, the choice of this geometrical parameter (and thus also the location of the top edge of the cylindrical barrel) has been made. On the one hand, a uniformly distributed axial load is applied at this edge, and on the other hand boundary conditions are imposed which restrain the out-of-roundness displacements. The general trends are illustrated in Fig. 2. Both for thick-walled (i.e. R/t=200) and thin-walled (i.e. R/t=1000) silos, h/R=8.0 corresponds with a height at which the boundary conditions imposed at the upper edge of the cylinder are sufficiently far removed from the zone where respectively yielding and/or elastic buckling occurs. An additional height ($h/R>8.0$) no longer effects the failure behaviour and the failure load F_u.

The set of geometrical parameters of the silo as considered in this paper is given in Table 1, using the symbols of Fig. 1.

2.2. Column geometry

The engaged columns are uniformly distributed along the circumference. In this study, the number of columns n_{col} is always equal to 4. The total height of the column is divided into two parts. The height over which the column is attached to the shell wall is represented by h_{col_sup}. The ratio of the "attached" column height to the cylinder radius h_{col_sup}/R is varied between 0.50 and 2.00. The height h_{col_inf} represents the height between the clamped lower edge of the column and the lower edge of the cylindrical silo. In the design of the silo, this height will be chosen in function of the height of the hopper, and the free space required for the emptying of the silo. Both very short columns (little clearance under the silo) and very high columns (more clearance under the silo) are considered; the ratio of the "unattached" column height to the cylinder radius h_{col_inf}/R is varied between 0.05 and 4.00.

The width of the column, both in circumferential d_{col} and radial direction w_{col}, is divided by the radius R and these dimensionless

[1] Dimensions of the engaged columns: $0.05 \leq d_{col}/R = w_{col}/R \leq 0.20$; $1.0 \leq t_{col}/t \leq 5.0$; $0.5 \leq h_{col\_sup}/R \leq 2.0$; $h_{col\_inf}/R = 0.5$).