11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

BUCKLING STRENGTH OF CYLINDRICAL METAL SILOS CONTAINING BULK SOLIDS

Michał Wójcik[1] and Jacek Tejchman[2]

[1] Gdańsk University of Technology, Narutowicza 11/12, 80-233 Poland,
mwojcik@pg.gda.pl
[2] Gdańsk University of Technology, Narutowicza 11/12, 80-233 Poland,
tejchmk@pg.gda.pl

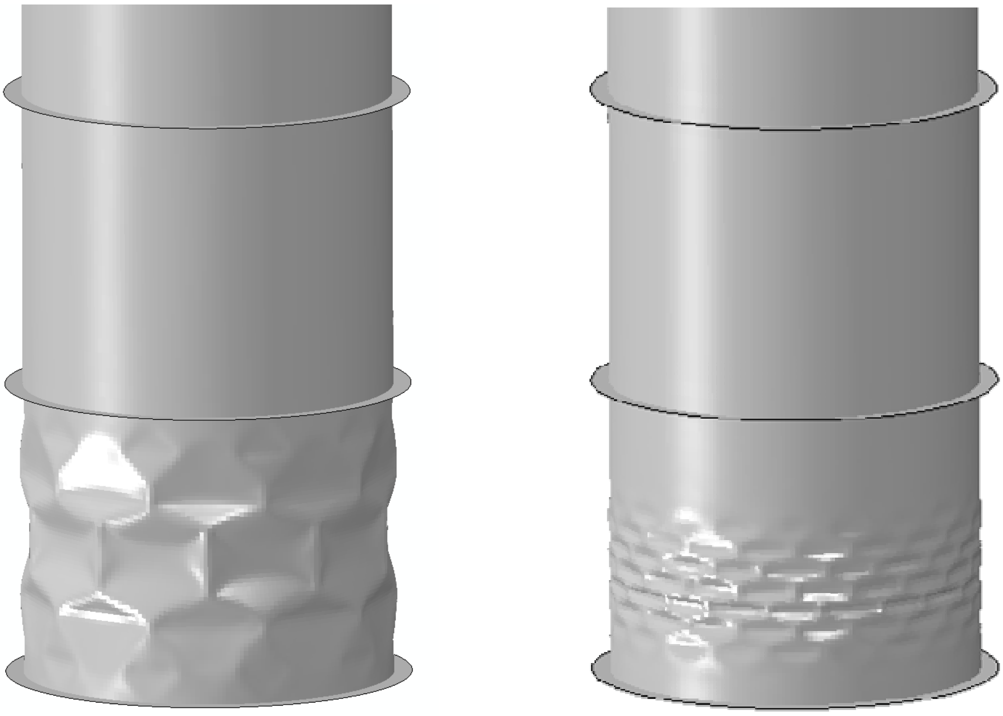
Key Words: *FE analyses, Silo Buckling, Sand, Hypoplasticity,Imperfections.*

Cylindrical silos are frequently used to store different bulk solids. In contrast to liquids and gases, solids exert both normal and shear forces on silo walls. The shear ones result from the friction between silo walls and silo fill and are mainly responsible for a buckling failure. The normal forces, however, have a positive effect on the buckling behaviour of silos since normal pressure produced by the stored material decreases amplitudes of initial wall imperfections. Moreover, solids give a lateral support for cylindrical silo walls when they move inwards during a buckling process. The positive strengthening effect in cylindrical silos is mainly dependent upon the solid stiffness [1]-[4].

The resistance of bulk solids against shell deformation is usually simulated by a Winkler foundation model which describes the bulk solid as a set of horizontal linear [1] or non-linear springs without tensile forces [2]. However, horizontal springs are not able to realistically capture the solid shear stiffness [4].

The aim of the present research works is to perform 3D buckling numerical analyses of thin-walled cylindrical metal silos containing cohesionless sand and to determine in numbers the influence of the solid on the buckling strength. Finite elements analyses of a silo filling process were carried out with the commercial program ABAQUS. A hypoplastic constitutive model 5], [6] has been implemented which is capable of describing a number of significant properties of bulk solids such as: non-linear stress-strain relationship, dilatant and contractant behaviour, pressure dependence, density dependence, deformation direction dependence and material softening. The hallmark of this model is its simple formulation and procedure for determining material parameters with standard laboratory experiments. The material parameters are related to granulometric properties, viz. size distribution, shape, angularity and hardness of grains. Comprehensive static and dynamic non-linear analyses with both the geometric and material non-linearity were carried out with a perfect and an imperfect silo shell. Different initial geometric imperfections were assumed. FE results were compared with corresponding experiments performed at University of Karlsruhe [2].

The obtained FE results show that initial geometric imperfections in the form of the 1st eigen-mode of the perfect empty shell were the most detrimental. There appeared many buckles around the cylinder perimeter similarly as in experiments [2], [3]. Buckles were smaller in silos containing bulk solids (Fig.1). The numerical buckling studies of a silo containing sand clearly showed a strengthening effect of about 10%-30% of the stored bulk solid on the buckling strength of the empty silo (as in experiments).



a) b)

Figure 1. Deformed bottom thin ring of cylindrical metal silo model: a) empty silo and b) silo containing sand (initial imperfection in the form of 1st eigenmode of perfect shell with maximum amplitude of 0.53 mm)

REFERENCES

[1] J.M. Rotter and Q. Zhang, Elastic buckling of imperfect cylinders containing granular solid". *J Struct. Eng.*, 116:2253-71, 1990.

[2] P. Knoedel, *Stabilitatsuntersuchungen an kreiszylindrischen stahlernen Siloschussen.* Dissertation, University of Karlsruhe, 1995.

[3] T. Ummenhofer, *Stabilitatsverhalten imperfekter zylindrischer Stahlsiloschalen - experimentelle und numerische Untersuchungen*. Dissertation, University of Karlsruhe, 1996.

[4] J. Tejchman and T. Ummenhofer, Bedding effect in bulk solids in silos: experiments and a polar hypoplastic approach. *Thin-Walled Structures* 37, 333-361, 2000.

[5] J. Tejchman, *FE modeling of shear localization in granular bodies with micro-polar hypoplasticity.* Springer Series in Geomechanics and Geoengineering (eds. Wu and Borja), Springer Verlag, Berlin-Heidelberg, 2008.

[6] J. Tejchman and J. Górski, Computations of size effects in granular bodies within micro-polar hypoplasticity during plane strain compression. *Int. Journal for Solids and Structures* 45, 6, 1546-1569, 2008.