STABILITY ANALYSES OF CYLINDRICAL STEEL SILOS WITH CORRUGATED SHEETS AND COLUMNS CONTAINING BULK SOLIDS

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1. Introduction

Silos are engineering structures widely used in industries and farms to store, feed and process bulk solids that is essential to agricultural, mining, mineral processing, chemical, shipping and other industries. They are mainly built from concrete or metal (steel and aluminium). Metal silos can be built of thin-walled isotropic plain rolled sheets (which can be welded, riveted or screwed around the silo perimeter) or of thin-walled corrugated curved sheets strengthened by vertical stiffeners (columns) distributed uniformly around the silo circumference and connected with screws. Those latter are frequently used in the engineering practice due to an economical steel consumption and a small silo weight. In these silos, it is assumed that horizontally corrugated wall sheets carry circumferential tensile forces caused by horizontal wall pressure and columns carry vertical compressive forces due to the vertical wall friction traction exerted from bulk solids. A common mechanical failure form in all metal silos is a stability loss caused by the compressive wall friction force due to the interaction between the silo fill and silo wall. particularly during eccentric filling and discharge and dynamic mass flow. In contrast to many buckling analyses performed for silo shells with isotropic plain rolled thin-walled walls, the comprehensive buckling analyses of silos consisted of horizontally corrugated sheets and vertical stiffeners are still in minority [1]-[5].

2. DEM calculations

The aim of our research works was to determine in numbers the influence of the solid stiffness on the strength of the silo structure by performing 3D numerical FE analyses for thin-walled cylindrical metal silos with plain and corrugated walls containing different solids [6]. The numerical analyses were carried out for filling and emptying of silos. Comprehensive static and dynamic FE analyses were carried out with the commercial program ABAQUS. The behaviour of the bulk solid (sand and wheat) has been described by a hypoplastic constitutive model which captures the salient properties of granular bodies [7].

Despite the discrete nature of granular bulk solids, the mechanical behaviour of confined configurations in the quasi-static regime can be reasonably described by the principles of continuum mechanics. Hypoplastic constitutive models have been developed at Karlsruhe University. In these models the stress rate tensor is assumed to depend on stress, strain rate and void ratio via isotropic non-linear tensorial functions based on the representation theorem. The constitutive models were formulated by a heuristic process considering the essential mechanical properties of granular materials undergoing homogeneous deformation. A striking feature of hypoplasticity is that the constitutive equation is incrementally nonlinear in deformation rate. The hypoplastic models are capable of describing some salient properties of granular materials, e.g. non-linear stress-strain relationship, dilatant and contractant volumetric change, stress level dependence, density dependence and strain softening. A further feature of hypoplastic models is the inclusion of the critical states, i.e. states in which a grain aggregate can deform continuously at constant stress and volume (void ratio). Moreover, both the coaxiality (coincidence of the direction of the principal stresses and principal plastic strain increments) and stress-dilatancy rule are not assumed a priori. In contrast to some conventional elasto-plastic models, a decomposition of deformation into elastic and plastic parts, the formulation of a yield surface, plastic potential, flow rule and hardening rule are not needed. In spite of the fact that the failure surface and flow rule are not prescribed in hypoplasticity, they emerge as by-products The hallmarks of these models are their simple formulation and procedure for determining material parameters with standard laboratory experiments. The material parameters can be related to the granulometric properties of granular materials, such as grain size distribution curve, shape, angularity and hardness of grains. A further advantage lies in the fact that one single set of material parameters is valid for a wide range of pressures and densities. Hypoplastic models perform well for monotonous deformation paths due to rearrangements of the grain skeleton. However, they show evident shortcomings for deformation with small amplitudes. In this case, the first and subsequent unloading-reloading cycles are identical to the virgin loading-unloading. A disadvantage of the excessive accumulation of deformation is called ratcheting and is due to the fact that the stress is the only memory parameter. A modified relationship was used to avoid it and to improve the small strain behaviour (the so-called intergranular concept) [8]. A hypoplastic model was also enriched by non-locality in order to describe shear localization during silo flow [7], [9].

The non-linear analyses were carried out with both the geometric and material non-linearity for perfect and imperfect silo shells. Initial geometric imperfections in the form of the first eigen-mode were assumed (with a different amplitude). A distinction was made between a global, local and distortional stability loss. The numerocal results were comapred with the outcomes by Eurocode. The innovative point of this study is that the stiffness of the bulk solid was taken into account in stability analyses of silo shells during filling and emptying in which its behaviour was described with a realistic constitutive model. The numerical outcomes are import for the safety and optimization of silos.

3. References

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