MODELLING OF GRANULAR FLOW IN SILO WITHIN NON-LOCAL HYPOPLASTICITY USING MATERIAL POINT METHOD

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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. In spite of extensive experimental and theoretical studies of silo problems, silos fail with a frequency much higher than the rate of structural failure of other industrial structures. The failures are connected with large economic loss and accompanying people accidents due to design, construction and user errors. Silo failure can be devastating as it can result in loss of the container, contamination of the material it contains, loss of material, cleanup, replacement costs, environmental damage and possible injury or loss of life. Most of silo failures take place at the onset of discharge and they usually lead to catastrophic collapse of the entire silo. They are mainly caused by a lack of knowledge concerning complex characteristic phenomena occurring in bulk solids in silos in the interaction with the silo structure. Except of non-symmetric wall pressures, seismic and wind loads, stresses created by temperature difference between the silo wall and stored bulk solids, potential internal explosion of the stored material and differential settlement of the foundation or support columns should also be considered during the design process. The characteristic phenomena which may be created during confined flow of granular bulk solids in silos are [1] e.g.:

- sudden and significant increase of wall stresses,
- different flow patterns,
- formation and propagation of both wall and interior shear zones,
- fluctuation of pressures and
- strong autogeneous dynamic-acoustic effects.

2. Calculations by MPM

The main intention of the theoretical research presented in the paper is to explain the above mentioned phenomena in granular bulk solids and to describe them with numerical FE models verified by experimental results. In order to describe the behaviour of solids during silo flow, a hypoplastic constitutive model was used [2]. The model can reproduce the essential features of bulk solids. It takes into account such properties as: incremental non-linearity, dependence on pressure level, density and direction of stretching rate which are characteristic of granular bulk solids. The material parameters can be obtained with standard laboratory experiments. They can be related to the granulometric properties of materials, such as grain size distribution curve, shape, angularity and hardness of grains. To model shear zones with a certain thickness and spacing and a related deterministic size effect, and to preserve the well-posedness of boundary and initial value problems, the model was enhanced by a characteristic length of micro-structure by means of a non-local theory [3], [4].

A non-local approach is based on a spatial averaging of tensor or scalar state variables in a certain neighborhood of a given point (i.e. material response at a point depends both on the state of its neighborhood and the state of the point itself). Thus, a characteristic length l_c can be incorporated and softening can spread over material points. It is in contrast to classical continuum mechanics, wherein the principle of local action holds (i.e. the dependent variables in each material point depend only upon the values of the independent variables at the same point). The hypoplastic FE-calculations were carried out with a non-local modulus of the deformation rate.

A non-local hypoplastic constitutive model was applied to describe the behaviour of granular bulk solids during advanced silo flow using the Material Point Method (MPM) [5]-[6], which is a numerical method that combines the best aspects of Lagrangian and Eulerian discretizations. In this method the material is not connected with the finite element mesh. MPM deals instead of finite elements with material points which carry the information needed for the analysis (mass, momentum, stresses, constitutive parameters). The material points pass the required information to the mesh in each time step. The time step data are resolved on the mesh level and given back to the material points. The material point positions, stresses and constitutive parameters are next updated. In the calculations, the open-source program Uintah has been used with GIMP (Generalized Implementation of Material Point Method) [7].

Quasi-static and dynamic simulations were performed for small and large silos. Flow with controlled and free outlet velocity was considered under plane strain conditions. The behaviour of cohesionless dry granular bulk solids was studied. Attention was paid to the formation of shear zones along walls and in the interior of solids. The numerical results were compared with corresponding own tests. Satisfactory agreement was achieved between experimental and numerical outcomes. In addition, different numerical aspects of MPM were analyzed.

4. References

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