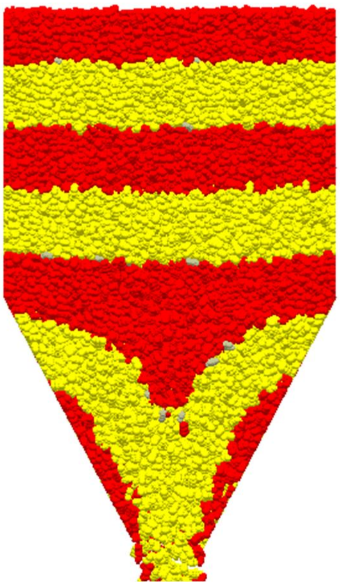
DEPARTAMENTO DE CONSTRUCCIÓN Y VÍAS RURALES
ESCUELA TÉCNICA SUPERIOR DE INGENIEROS AGRÓNOMOS
UNIVERSIDAD POLITÉCNICA DE MADRID

"APPLICATIONS OF THE DISCRETE ELEMENT METHOD TO THE STUDY OF GRANULAR MATERIALS STORED IN SILOS AND HOPPERS"



AUTHOR

CARLOS GONZÁLEZ MONTELLANO. AGRICULTURAL ENGINEER.

SUPERVISED BY:

FRANCISCO AYUGA TÉLLEZ. PROFESSOR.

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SUMMARY

Silos are containment structures widely used for storing and handling granular materials in numerous industrial processes, such us agricultural, food, mining, chemical or pharmaceutical industries. The correct design of these structures requires ensuring their structural safety (mainly based on a good prediction of the pressures exerted by the stored material) and the proper functioning of the silo in the process where they are included (usually related to flow pattern, segregation, arching or discharge rate issues)

Pressure prediction is not always an easy task since their value is variable depending on the silo state (filling or discharge). In addition, pressure values may increase randomly at certain local points on the silo wall due to accidental asymmetries during the filling and discharge situations or to the presence of imperfections in the silo walls. The values of the pressure distributions are usually assessed in practice using analytical procedures based on Jansen's or Reimbert's equations, considering special provisions to account for the filling or discharge situations. On the other hand, the flow pattern occurring during discharge (usually classified in two types: mass flow and funnel flow) is taken as a function of the variables characterising the hopper geometry (inclination, shape, outlet size…) and those related to the friction within the particles and between particles and walls. Based on some of these variables and using continuum models, several authors, such us Jenike (1964), developed design charts to estimate the expected flow pattern.

However, pressure distributions and flow pattern are not always very well predicted for all possible cases using these analytical techniques. For that reason, several numerical techniques have been used for a better and more real understanding of the silo phenomena. The finite element method (FEM) is one of them and has been used for correctly predicting some loading conditions. However, the continuous nature of FEM invalidates this technique for simulating dynamic situations, such us silo discharge. For this reason, other numerical techniques, such us the discrete element method (DEM) (Cundal and Strack (1979)), are becoming more and more popular nowadays. The main drawback of this technique is that the simulation of a real handling simulation is not always feasible, mainly due to the high compute time consumed in a DEM simulation. However it is still a promising methodology because it is capable of describing the mechanical behaviour of granular assemblies at a particle interaction level. It makes this technique effective for simulating the numerous phenomena within the silo field, both for professional and investigation purposes.

DEM has broadly been used for investigating different silo phenomena, such us pressure distributions, flow pattern or segregation processes. However, many of these DEM simulations were based on 2D models, which are not always representative enough of the reality. In other cases, the numerical models were not validated against experimental results or were not based on properly measured values of the material properties. Because of that, there is still a big necessity of establishing adequate procedures for generating really representative DEM models. In addition, many simulation procedures, commonly used in DEM models, need further investigation for assessing their validity.

The present work aims at shedding some more light on some of these silo phenomena. Different DEM models have been generated to simulate the filling and discharge processes in a small silo with a hopper at its base and considering two different materials: glass beads and corn grains. In order to produce realistic DEM models, most of the microscopic material and interaction properties required for the model definition have been determined experimentally. The

apparatuses used for these experimental determinations were designed and built specifically for this case and results obtained were largely discussed. Additionally, the preliminary models developed using these measured values where experimentally validated and corrected when necessary in order to check the representability of the numerical model.

All numerical results obtained from the DEM models developed in the present work were analysed in order to assess whether DEM is capable of reproducing the expected behaviour and to understand some important phenomena occurring during silo filling and discharge. The influence of some microscopic parameters (such us friction parameters) on the character of the numerical results has been investigated and the different behaviour of both materials considered has been analysed. Finally, the implications of some procedural issues regarding the simulation definition (such us the particle size generation, filling procedure or optimal time averaging) have been analysed and some practical recommendations are presented.