THE 3DIMENSIONAL (TRIAXIAL) INDICATOR FOR A BULK SOLID PRESSURE OBSERVATION IN A SILO

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TŘÍDIMENZIONÁLNÍ (TŘÍOSOVÝ) SNÍMAČ PRO SLEDOVÁNÍ NAPĚTÍ SYPKÝCH HMOT V ZÁSOBNÍKU

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Abstrakt

V současné době neexistují prostředky schopné zaznamenávat skutečné tlaky (napětí) ve skladovacích systémech. Dostupné prostředky-snímače pracují pouze v systému 2D a jsou situovány na vnější plášť skladovací jednotky. To je příčinou proč často stěnové tlaky jsou měřeny místo skutečných tlaků (napětí) v sypké hmotě nasypané ve skladovací jednotce. Problém se ještě více stupňuje z pohledu skladování prášků a adhezních materiálů (často kovové konstituce) tokově závislých na skladovacích podmínkách a okolního prostředí (doba skladování, teplota, vlhkost, apod).

Tento příspěvek se zabývá sledováním tlaků (napětí) sypkých hmot a hmot práškového a granulačního charakteru ve skladovacích systémech za pomocí nově vyvinutého 3Dimenzionálního (tříosového) snímače. Nová konstrukce zařízení a metodika samotného měření byla intenzivně vyvíjena za účelem zjišťování skutečných tlaků (napětí) ve skladovacích a dopravních systémech. Reálné poznatky a výstupy z tohoto R & D jsou zveřejněny v tomto příspěvku.

Abstract

Yet, there are not investigated means able to register real stresses/pressures inside storage systems properly. Current indicators work in 2D generally and moreover, usually are situated to inner circumference of a silo body. That is the reason, why often a wall stress/pressure has been measured instead of a real stress/pressure inside bulk solids pored in a silo. The problem is more acute in regard to transport of tough flow powder, which often changes flow properties depending upon storage and environmental conditions, such as storage time, temperature, moisture, etc. Detection of the real pressure inside the storage mass using the stress/pressure indicator may be a possible solution of the problem, which is encouraged by modelling of the particulate solid flow.

The paper deals with a bulk solid pressure observation inside a silo using new developed 3Dimensional (Triaxial) Indicator. New design and conception of the 3D indicator have been developed exclusively for detecting of real stresses/pressures inside vessels, bunkers and silos. Real results and outputs of the investigation will be presented and discovered in the paper.

Key words: 3Dimensional (Triaxial) Indicator, Bulk Solid, Pressure, Silo

Introduction

In present, there are a lot of storage systems not working properly in Czech industry. The problem is more acute in regard to transport of a tough flow powder, which often changes flow properties depending upon storage and environmental conditions, such as storage time, temperature, moisture, etc. The reason is the complexity of powders and the ease with which their bulk properties may change [4]. The nature of powders therefore is such that an adverse combination of environmental factors can cause an otherwise free flowing powder to block or flow with difficulty [4,5]. Conversely, a very cohesive powder may be processed satisfactorily if the handling conditions are optimized.

Traditional property measurement techniques like angle of repose, timed flow through an aperture and even modern instrumentation provide answers for some materials, but generally suffer high variability. The reasons for this are numerous, but the lack of a normalized packing condition is the most important.

The well-known shear cell technique invented by Jenike is able to provide shear strength data that has long been used for the design of bins and hoppers so that the contained material can be reliably discharged by gravity flow. Indeed, the focus of most powder characterization instruments has been to assist in the design of powder handling machinery rather than to characterize and classify material flow properties [4].

The apparatus used for measuring the bulk solid properties of a powder is, for the most part, rather simple [4,5]. The difficulty is to interpret the results obtained. The first "swallow" that may be a possible to help to the problem solution is an identification of a pressure inside storage mass using pressure (stress) detectors furnished the 3D Indicator. The 3D Indicator is able to assure a clear image to pressure/stress identifications in a particulate solid. Moreover, the third dimension is unique and enriches the area of the pressure knowledge.

Theoretical Calculation of Pressure State on a Bulk Solid Element (see Fig. 1)

Taking account the normal and shear stress acting on a bulk solids cube taken out of a silo, there are one principal normal stress and two shear stresses loading each cube surface (Fig. 1). Because of associate shear stresses have been occurred on the bulk solid cube surface, there is necessary to detect "only" 3 normal stresses, i.e. σ_1, σ_2, σ_3, and 6 shear stresses, i.e. τ_{xz}, τ_{xy}, τ_{yx}, τ_{yz}, τ_{zx}, τ_{zy}. Considering the fully development model just the nine stresses may assure detecting necessary shear and normal stresses completely. Unfortunately, there is almost impossible to design a model able to depict just these shear stresses needed to fully description.

Balance of bulk material element cube (see Fig. 1) is expressed in the following Eq. (1-3):

$$\frac{\partial \sigma_2}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} = 0 \tag{1}$$

$$\frac{\partial \sigma_1}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yz}}{\partial z} + \rho_s . g = 0 \tag{2}$$

$$\frac{\partial \sigma_3}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} = 0 \tag{3}$$

The final equation of the cube balance is derived (4):

$$\frac{\partial^2 \sigma_2}{\partial x^2} - \frac{\partial^2 \sigma_1}{\partial y^2} - \frac{\partial^2 \sigma_3}{\partial z^2} - 2\frac{\partial^2 \tau_{xz}}{\partial x \partial z} = \gamma_s . \frac{\partial}{\partial y} \tag{4}$$

where

γ_S is bulk weigh defined:

$$\gamma_s = \rho_s \,.\, g \qquad [N.m^{-3}] \qquad (5)$$

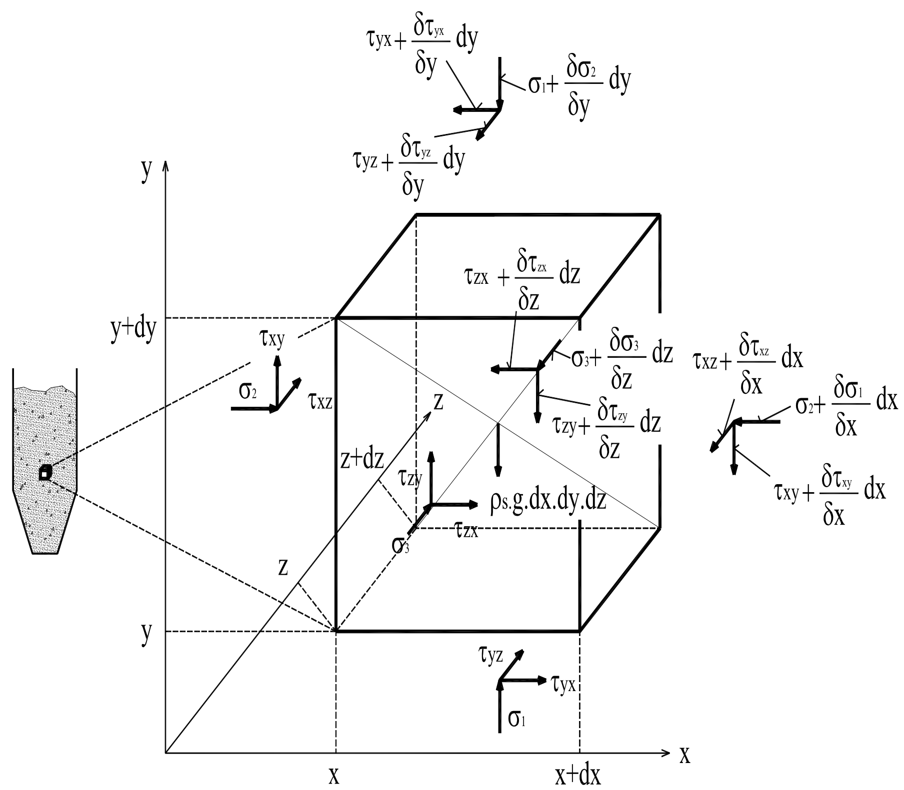

Fig.1 A small bulk material cube (right) taken out of the silo (left) and its rearrangement to principal stress directions for explanation

Model developed at VŠB-Technical University of Ostrava, Lab. of Bulk Materials with financial support the grant N$_o$. 101/03/D039

The first assumption to propose the 3D Indicator (Fig. 2) was to design a rigid cube base made of a water resistant material: Aluminum with Manganese additive (co. mark: DURAL), which is pliant for cutting process but sufficient to avoid its deformation by a bulk solid loading. Moreover, a small bulk material cube on the Fig. 1 inspires by designing the rigid cube base (Fig. 2). The dimension of the rigid cube is fixed up for needed electronics (Fig. 2 right) to its body and for sufficient deformation of detectors on the inner surface of the flexible faces to be able to detect principal normal stresses σ_1, σ_2, σ_3 in the x, y, z directions.

The real stress/pressure of detectors placed on circle steel faces of 3D Indicator model (see Fig. 2) has been measured on individual steel faces (Fig. 2, detail) of the model and registered in the form of the timed graph. Necessary to say, that the considered stresses σ_1, σ_2, and double σ_3 are principal stresses investigated in the main x, y and z direction (axis).

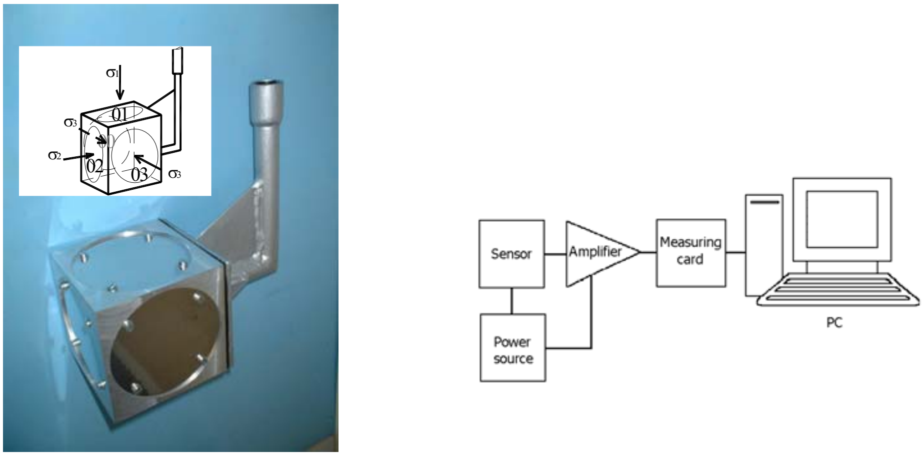

Fig.2 Real apparatus for a silo pressure observation furnished with deformation detectors placed on inner faces (left) and its measuring system (right)

The investigated stresses can be reported in the graphs (Fig. 3) followed the final graph (Fig. 4) which is "keystone" of the research. The final 3D graph (Fig. 4) is depicted by mutual composing the 2D graphs (Fig. 3).

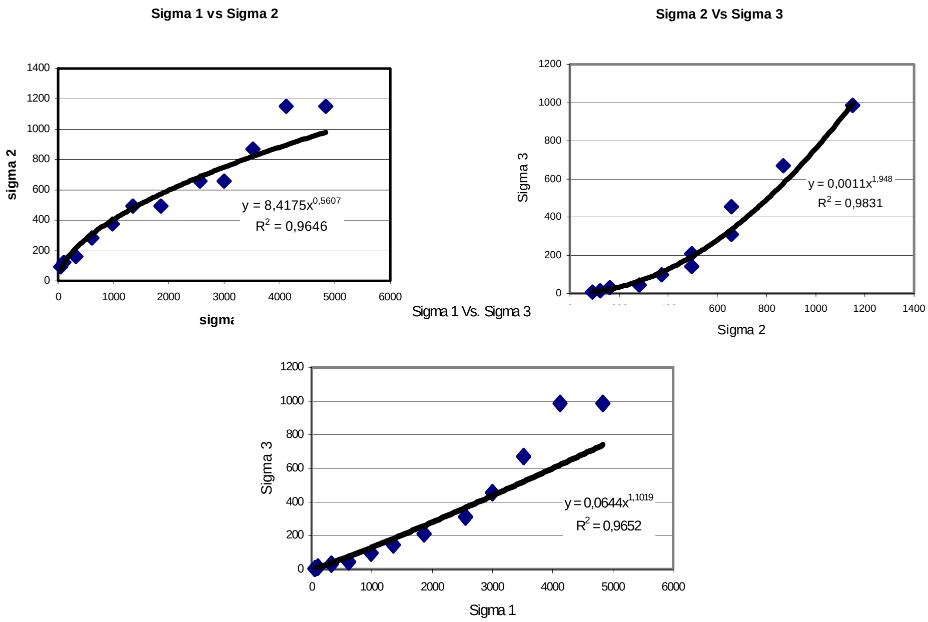

Fig. 3 – Graphs of the dependence of mutual normal stresses

Conclusion

A possibility of the triaxial principal stress description of a bulk solid on the 3D indicator projected model has been developed. The model is very useful to fully description of a

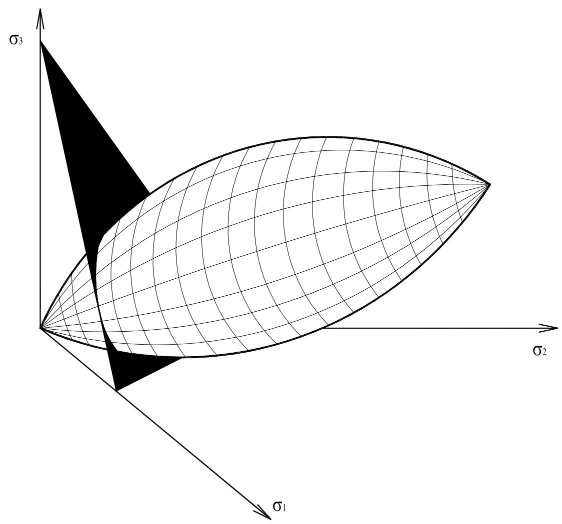

Fig.4 A surface in a principal stress space

bulk solid state by a material silo loading. By using the model procedure depicted here, Jenike Shear Machine needed to 2D bulk solid stress description [4] can be avoided. A bulk solid stress measurement on the 3D indicator model can be become a standard to 3D fully bulk solid stress behavior description. Contribution to the area of the bulk solid triaxes stress observation is to find the method that can indicate a bulk solid stress direct to an inner bulk solid body.

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