The 3Dimensional Indicator for a Silo Stress/Pressure Measurement

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ABSTRACT: *The paper deals with a silo stress/pressure measurement of a real bulk solid using the 3D indicator. New design and conception development of the 3D indicator were provided for detecting of real stresses/pressures inside vessels, bunkers and silos.*

Yet, there are not investigated means able to register real stresses/pressures inside storage systems deeply. Current indicators work in 2D generally and moreover, usually are situated to inner circumference of a body silo. 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 for the problem, which is encouraged by modelling of the particulate solid flow.

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1 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. Conversely, a very cohesive powder may be processed satisfactorily if the handling conditions are optimized. Powders are often considered as a mass of solid particles or granules. In fact, these particles are usually surrounded by air (or other fluid) and it is the solids plus fluid combination that significantly affects the bulk properties of the powder. It is perhaps the most complicating characteristic because the amount of fluid can be so variable [3].

A particulate solid is an assembly consisting of particles of various shape, size, number, but the same bulk density. Particulate solids incl. powders are probably the least predictable of all materials in relation to flowability because of the large number of factors that can change their theological properties. Therefore, its properties depend on a lot of factors, such as mechanical-physical properties (size distribution, shape, porosity and so on) [1,2], environmental conditions mentioned above and actual conditions among particulates considered for fine particles/powders, in particular (electrostatic and chemical changes, Van der Walls forces, mechanism of growth created agglomerates from individual particulates, etc.).

Identification of pressure (pressure) inside the storage mass using stress (pressure) detector may be a possible solution for the problem, which is provided by modeling of the particulate solid flow.

The detector with a silo model is able to assure a clear image to pressure/stress identifications in particulate solid. Moreover, the third dimension is unique and enriches the area of the pressure knowledge (see Fig. 9).

Taking account the normal and shear stress acting on a bulk solids cube takes out of a silo, there are one principal normal stress and two shear stresses loading each cube surface (Figure 1).

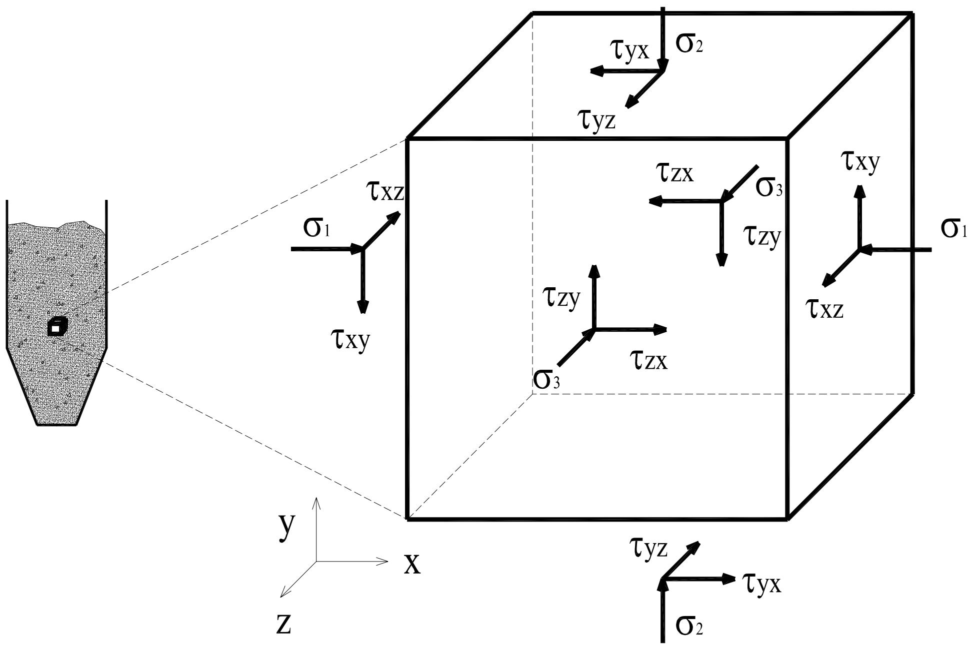

Figure 1 – A small cube (right) takes out of the silo (left) and its rearrangement to principal stress directions for explanation of normal and shear stresses acting on individual cube surfaces

2 DESIGNING OF THE 3D INDICATOR MODEL

Fist idea to a model designing for detecting real stresses (pressures) in a silo was to determine stresses (pressures) acting in every possible available direction. So, a model that just describes principal normal stresses (σ) and shear stresses (τ) has been developed (Figure 2), and on the base of the model was decided to detect 18 stresses that deform bulk solid cube surfaces. 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 the model able to depict just the shear stresses needed to fully description.

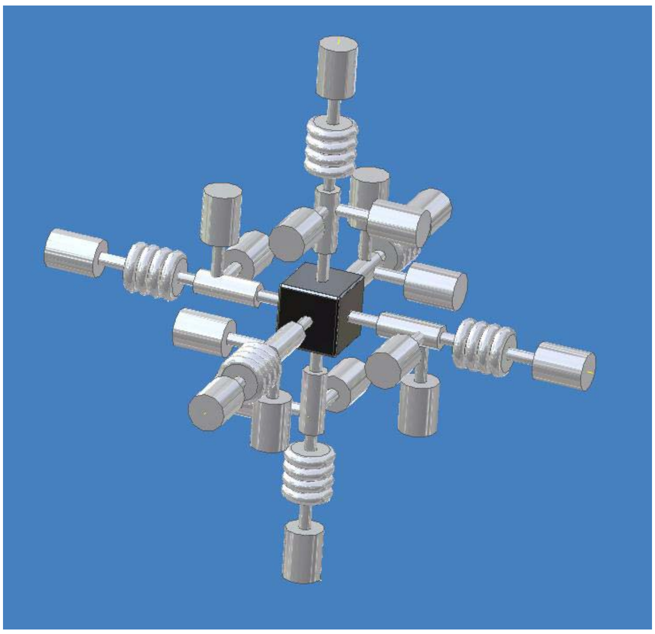

Figure 2 – Fully described model developed with detectors determining normal and shear stresses incl. depicting associated shear stresses

3 MODEL DEVELOPED AT VŠB-TECHNICAL UNIVERSITY OF OSTRAVA, LAB. OF BULK MATERIALS WITH FINANCIAL SUPPORT THE GRANT N_O. 101/03/D039

On the base of the previous proposed and developed model (Fig. 2), an idea to create a similar and much low-costly model was brought about designing and modeling the model (Fig. 4) much modest, simple, and able to detect 3 principal normal stresses (σ_1, σ_2, σ_3). Taking account accurate and good-quality setting the main x, y and z directions, the principal normal stresses are able to describe and depict Mohr's circle describing the stress state in bulk solid fully without shear stress knowledge (Fig. 8).

Assembling the new 3D indicator model is depicted in the Fig. 3 and Fig. 4. The model (Fig. 4) is consisted of the rigid massive cube furnished with flexible steel lids and deformation detectors. The bulk solid stress acting on the lid is transmitted to deformation detectors via AD transmitter to a computer.

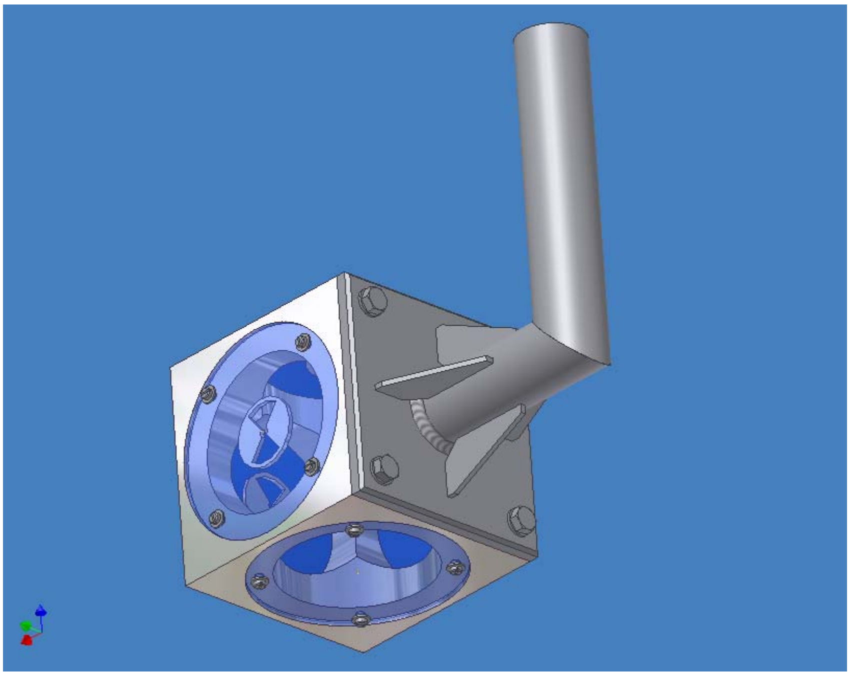

Figure 3– Assembling the 3D indicator model inside a silo

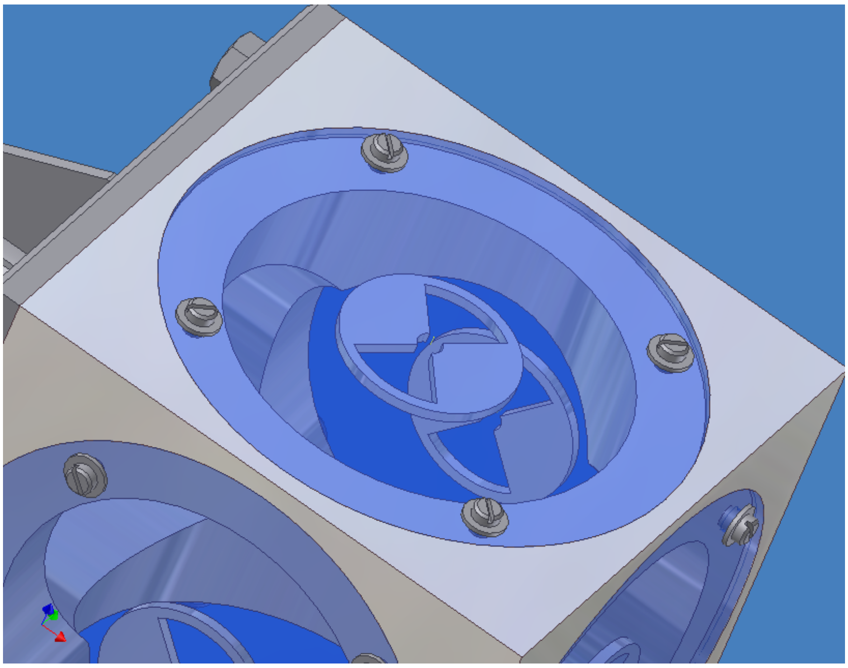

Figure 4 –The detail showing the deformation detector furnished the steel inner face

4 MODELING STRESSES (PRESSURES) ON INNER FACE OF 3D MODEL INDICATOR

For good agreement a real and theoretical application of the 3D Indicator model (Fig. 3), a silo model for detecting inner bulk solid stress has been designed and installed in the Laboratory of Bulk Materials on behalf of Prof. Jiří Zegzulka, director of the laboratory.

The deformation detectors (Fig. 4) placed on inner faces of deformation elements were designed and pasted after modeling stresses on the face by a silo loading with dry sand to 3 meter level from a model discharge outlet (Fig. 5 and Fig. 6). The mentioned detectors have been calibrated by a constant pressure of a liquid. In the case, the stresses reach same value in each direction. The stress and deformation distribution on deformation detector furnished with the circle steel inner face by the stress modeling are depicted in the Fig. 5 and Fig. 6.

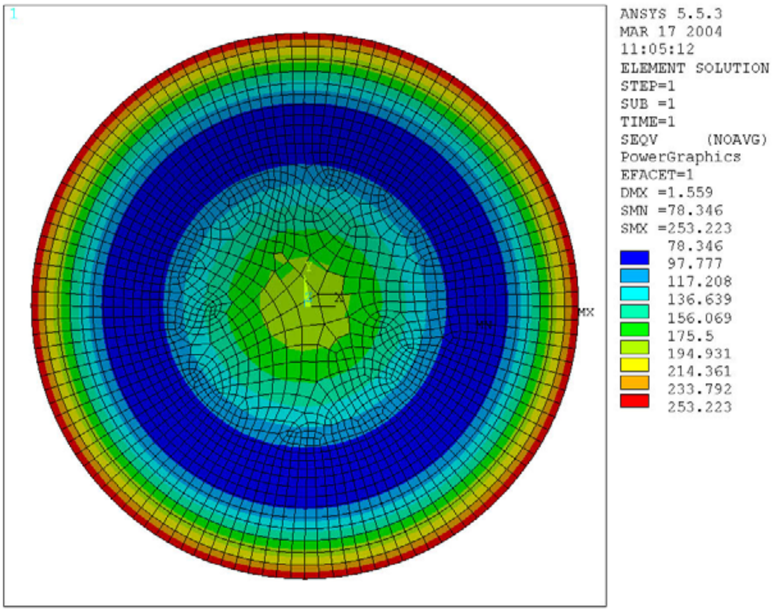

Figure 5 – Stress distribution modelling (in Pascals) on the circle steel face of the 3D indicator model which a detector in the centre is placed on

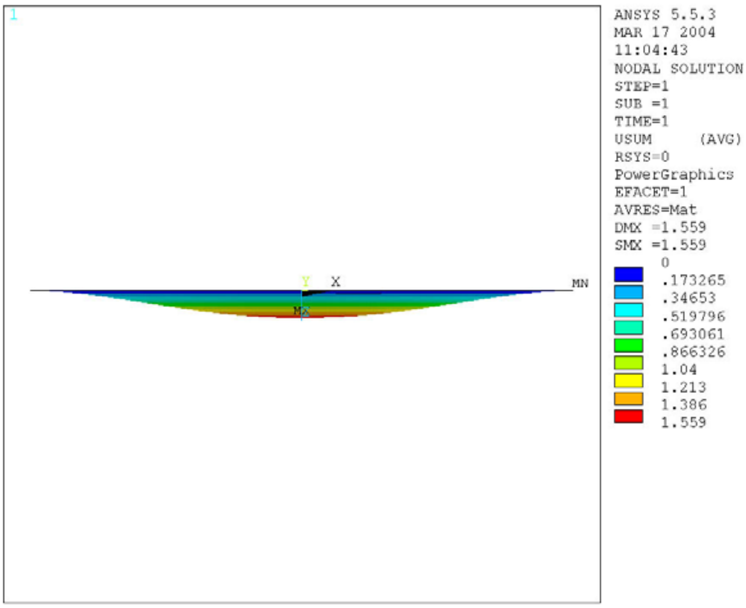

Figure 6 – Deformation distribution modelling (in millimetres) on the circle steel face of the 3D Indicator model which a detector in the centre is placed on

5 AN EXAMPLE OF THE REAL STRESS (PRESSURE) ACTING ON THE MODEL FACE BY STEP BY STEP A SILO LOADING

The real stress/pressure of detectors placed on circle steel faces of 3D Indicator model has been measured on individual steel faces of the model and registered in the form of the timed graph (Fig. 7). By knowing the stresses by reading the stress fixed value (Fig. 7) for x, y and z direction, the well-known Mohr's circle describing the real bulk stress state may be depicted (Fig. 8). Considering the different stress value by step by step a silo loading, i.e. σ_1, σ_2, σ_3 for same loading state, the yield locus that totally reports bulk solid state, which is an envelope of Mohr's Circles, can be plotted easily (Fig. 8). Necessary to say, that the considered stresses σ_1, σ_2, σ_3 are principal stresses investigated in the main x, y and z direction (axis). The investigated stresses can be reported in the 3D graph (Fig. 9), which is "keystone" the research.

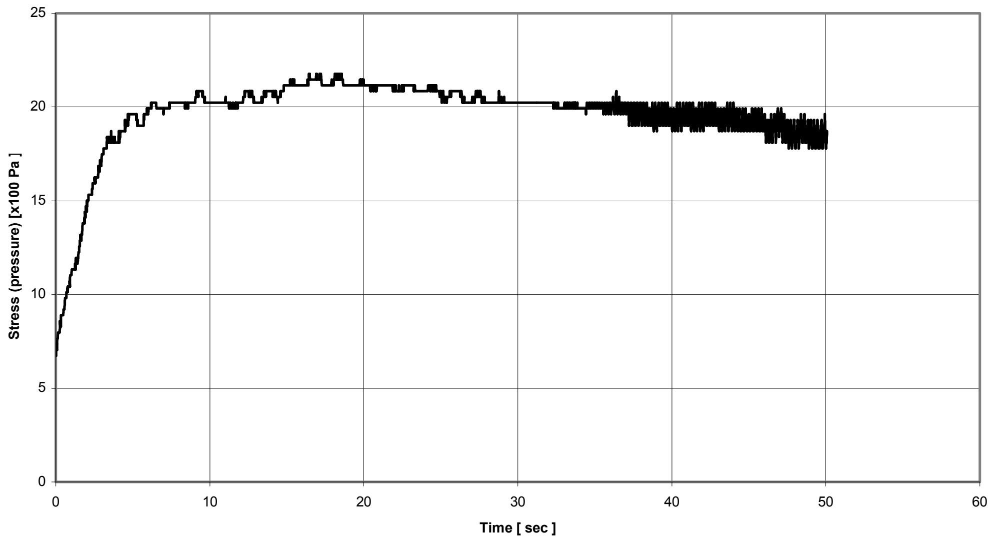

Figure 7 – Stress (in Pascals) Vs. proceeding time (in sec.) on the steel face of the 3D Indicator model

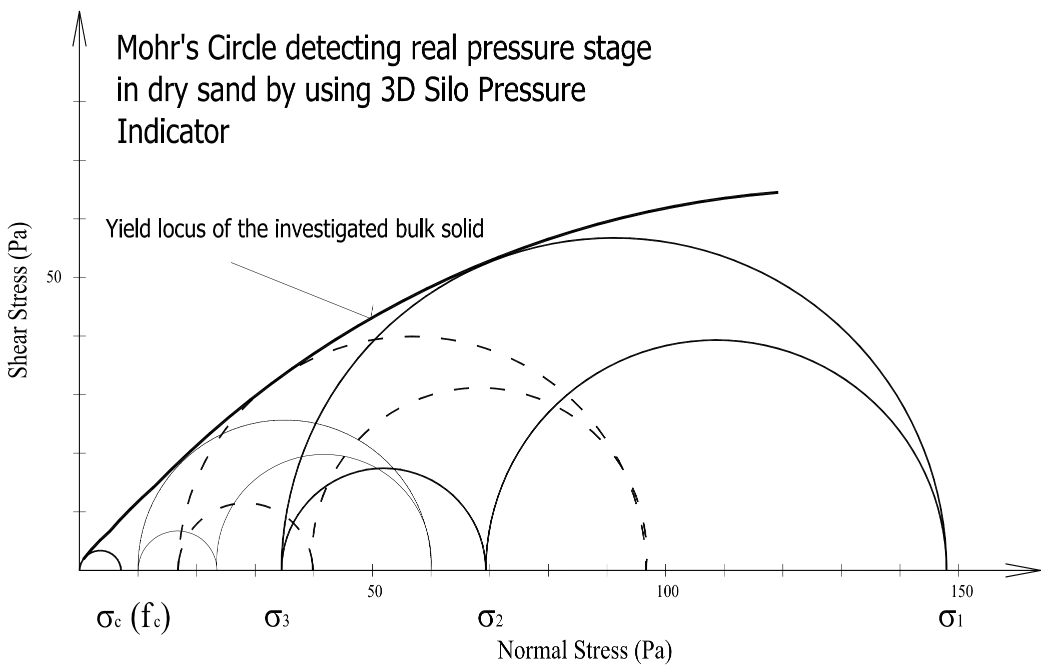

Figure 8 – Shear stresses (in Pascals) Vs. detected normal stresses (in Pascals) on the steel face of the 3D indicator model

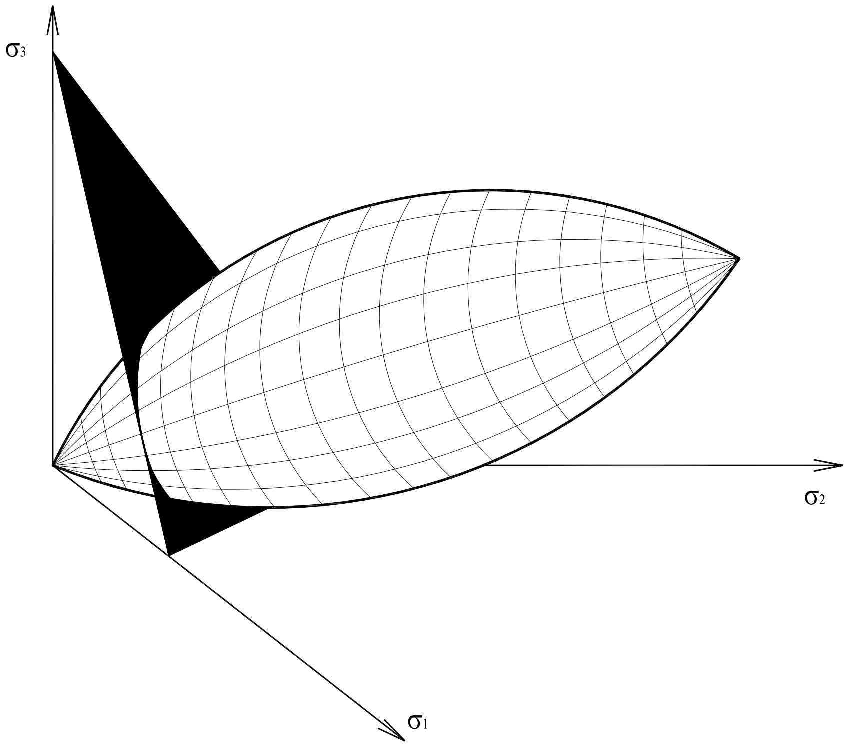

Figure 9 – A surface in a principal stress space

6 CONCLUSIONS

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

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