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STRESS BULK MATERIAL MEASUREMENT IN STORAGE SYSTEMS USING 3DIMENSIONAL DETECTOR

The measurement process of a bulk material stress using new 3D developed indicator, including the procedure for processing values within the interactive software environment that was created, and has been thoroughly explained in the paper and researched in an actual silo loaded with a poured bulk solid. Real results and outputs of the investigation have been presented and discovered in the paper.

POMIAR NAPRĘŻEŃ POCHODZĄCYCH OD MATERIAŁÓW SYPKICH W ZBIORNIKACH PRZY UŻYCIU CZUJNIKA TRÓJWYMIAROWEGO

Proces pomiaru naprężeń materiałów sypkich za pomocą nowo opracowanego wskaźnika 3D, wraz z procedurami do przetwarzania wartości w ramach interaktywnego środowiska programowego, które zostało stworzone i dokładnie wyjaśnione w referacie, oraz zbadane na rzeczywistym zbiorniku, załadowanym sypkim materiałem stałym. W artykule zostały podane rzeczywiste wyniki i dane wyjściowe z badań.

1. INTRODUCTION

In the past fatal injuries would often happen when the system operator, who was trying to ensure the flow of material from the storage system by use of mechanical means, would be buried during the fill. It is much better today with newly designed storage systems, and ensuring the continuous flow of material has become more efficient, making the problems a rare occurrence. Still, there is a whole line of obsolete systems in use today with operating problems and it is very difficult to identify the location and nature of the malfunction in order to propose measures for ensuring the trouble-free operation of the system.

We normally encounter problems during the process of transporting, handling and storing bulk solids in silos and containers [3]. The problem increases for long-term storage due to the occurrence of undesirable incidents when filling and emptying stored solids. These incidents cause flow disruptions (funneling, arching, creating an arch, vault, etc.) in storage systems as a result of the storage conditions, the effects of the surrounding environment [4]

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and the generally natural and entirely unpredictable characteristics of bulk solids, the structure of the storage equipment, etc. For this reason, bulk solids, especially those with a powdery structure, are among the least predictable materials in relation to the above-mentioned incidents, to which factors involving their mechanical-physical properties (unconfined yield pressure, the angle of internal friction, initial sheer stress, flow factor, etc. [6]), geometric properties (size distribution, shape, porosity, etc.) and interparticle character, where it generally applies that the less particles there are, the more influence they have (electrostatic and capillary forces, Van der Wallsovy forces, etc.), can be added [2].

In-depth research of the causes behind these failures, based on the precise identification of the stress in the bulk solid being stored, can result in the precise and long-lasting elimination of the character of the material that leads it to create the above-mentioned failures.

Even there are no adequate means for us to precisely detect the place and time of a possible failure [1]. Today's commercially produced pressure (stress) indicators work in 2D and are situated on the perimeter of the cover for the storage equipment. This is the reason why the stress or pressure of the wall is often measured instead of the actual pressure of the bulk solid stored in the container.

For this purpose a 3Dimensional indicator for bulk solids (Fig.2, [8-11]) has been designed and constructed for allowing the actual stress in critical areas where the failures tend to occur to be detected. The change in stress (pressure), rather an increase in it, is the indication that a failure has occurred. Earlier indicators were based on the presumption that pressure and its fluctuations were transmitted to the wall of the container and for this reason they were located directly on the container (silo) wall itself. Unfortunately, this measurement often didn't reflect the real situation or the actual status due to the poor transmission of the signal from the source of the problematic material. The 3D indicator, including a methodology for identifying pressures using the SW developed for it (Fig.7), is able to completely solve these problems and, moreover, register all sudden occurrences that take place directly within the bulk solid.

2. THE APPLICATION FOR CONNECTING THE MODEL OF THE 3 DIMENSIONAL INDICATOR TO A 16-BIT CARD NI

A model of the functional connection of the 3D indicator with all four detectors and its location in the storage silo is shown in Fig.6 (schematic of the connection Fig.1). The stress of the bulk solid [Pa] in its actual location is transmitted from the surface of the bulk solid (Fig.5-h) to the deformation faces with the detectors (tensometric sensors, Fig.8) connected to the full bridge. The deformation is registered by a change in the stress [V] on the terminal outputs of the bridge connected to an AD 524C measuring amplifier (Fig.3). These measuring amplifiers are moreover powered by the base voltage Vs emitted from the power source (Fig.4) and the given change in stress [V] is registered by transmitting the signal from the terminal block to the measuring card located in the computer. The signals (a total of 4, see Fig.8) can then be properly saved and processed with the appropriate measuring software for multi-channel observation.

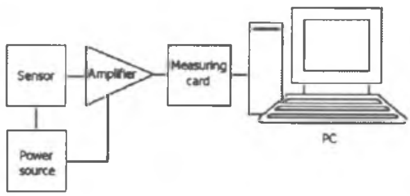

Fig.1. A description of the measuring system consisting of the power source, tensometric sensor, measuring amplifier, measuring card NI and PC. Source: [9]

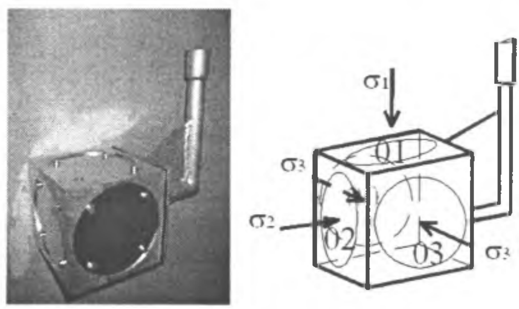

Fig.2. The structure of the 3D stress indicator (left) with 4 tensometric sensors shown, e.g. 4 measuring channels. Source: [9]

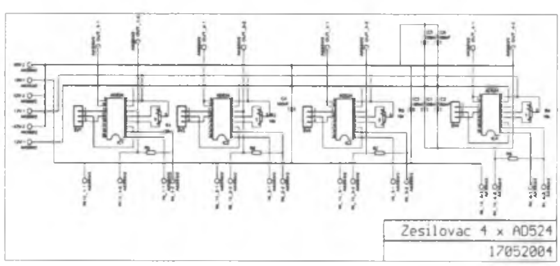

Fig.3. Design of the circuit connection 4x AD 524C measuring amplifiers. Source: [9]

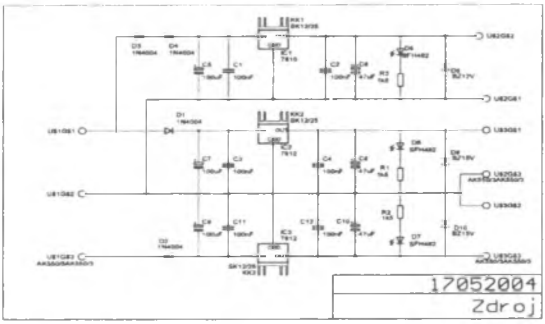

Fig.4. Design of the circuit for the input power source. Source: [9]

2.1. IMAGE OF THE STATE OF STRESS IN A BULK SOLID USING A 3D INDICATOR

The state of stress in the bulk solid, i.e. the size and character of the stress acting on the element of the bulk solid in the storage system, can be detected and precisely identified using a 3Dimensional indicator. The size of the stress (pressure) on the face of the deformation detector is the stress of the bulk solid in the given location. It is possible to set up a calibration curve when calibrating these deformation detectors, i.e. showing various stresses and observing their deformation, and thereafter assign an exact size for the normal stresses of the amplified deformation (V) of the individual faces detected (Fig.2).

For locating the indicator (Fig.2) in the body of the storage equipment (Fig.6), it is necessary to position it along the principal directions of axes x, y and z so that the condition for precisely identifying the main normal stresses σ_1, σ_2, σ_3 in the principal directions of the axis of the Cartesian coordinate system (Fig.5) is fulfilled.

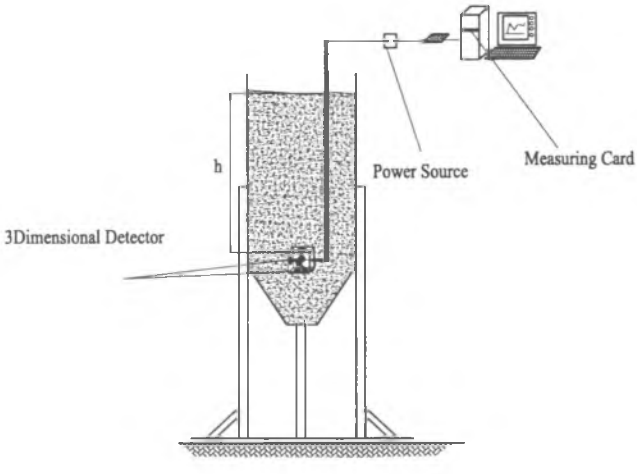

Fig.5. The setup of the 3Dimension indicator – the power source-terminal box-measuring card and the indicator for measuring pressure in the storage equipment. Source: [9]

2.2. MEASURING THE STATE OF STRESS OF A GRANULAR BULK SOLID-BRALEN IN A GLASS MODEL OF THE SILO

In order to compare the actual pressures in a real glassed-in model of a silo (Fig.6) able to track individual phases of the filling, the effects of stress on the 3D indicator (Fig.2) were measured by gradually pelting it with the granular substance.

Bralen is a high-molecular polythene with a unique chain of molecules. It is distinguished by its bulk density ρ_s=450 kg.m^{-3} (particle density is ρ_p=919 kg.m^{-3}). It is an artificial substance made from petroleum derivatives (produced by SLOVNAFT, SR) and is supplied semi-finished in granular form for further processing. The granules are similar in shape to a cylinder and for this reason the particle distribution of the substance is found in a relatively narrow band.

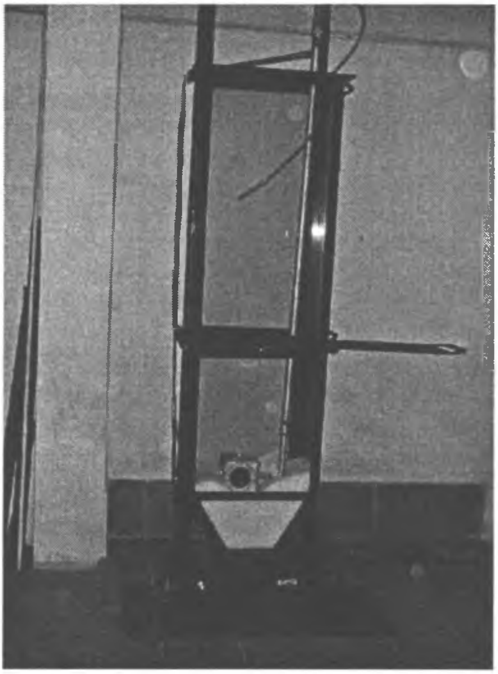

Fig.6. An actual model of a silo with details of the indicator and filling in progress. Source: Laboratory for Bulk Solids, Assoc. Prof. Jiri Zegzulka, Ph.D.

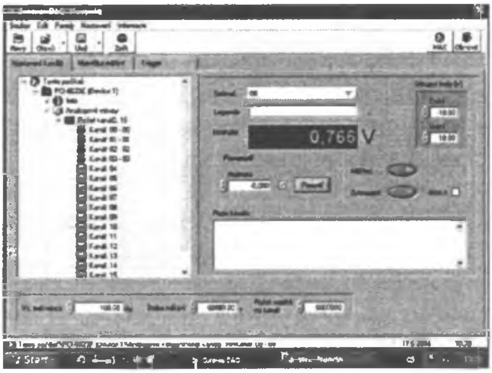

Fig.7. The development environment of the COMNES DAQ for detecting 4 signals from the 3D indicator Development of the SW-Consymea, spol. s r.o.

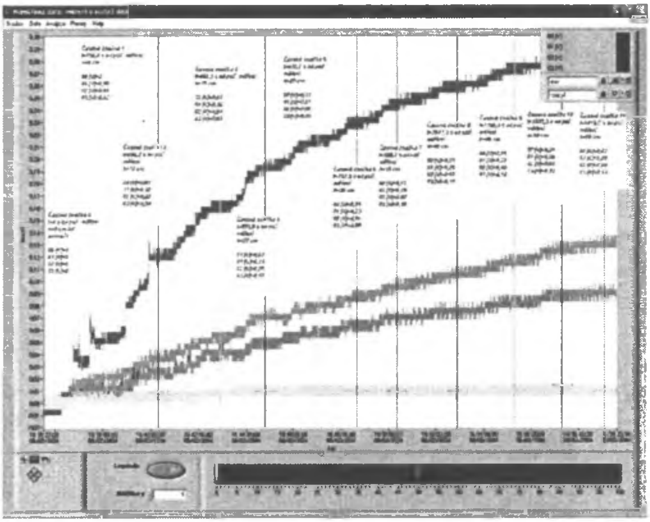

Fig.8. A chronological display of the stress on tensometric sensors 00, 01, 02, 03 when filling with a layer of BRALEN. Source: [9].

The results of the research into the state of stress of Bralen were processed on diagrams (Fig.8 and 9) charting the stress on individual detectors loaded with a granulated bulk solid, Bralen, while pouring it into the model (Fig.6).

The relation between individual main normal stresses σ_1, σ_2 and σ_3 are pictured in Fig.9 and compared with the earlier published theories of Rankine [7] and Janssen [6].

A relatively good unity approaching the theories of Rankine [7] can be seen by comparing the theoretical values analyzed in Fig.9 according to Rankine (1867, [7]) and

Janssen (1895, [6]) with the actual values of stress measured on individual detectors 00, 01, 02 and 03 (fig. 2).

Even if this theory [6] doesn't provide a more accurate description of the influence of the geometry of the storage equipment, especially for cases where the height of the silo H is 8 to 10 times smaller than the hydraulic radius of the outlet, i.e. h≤ (8 to 10).R and of the influence of the mechanical-physical properties of the stored substance in the form of the yield coefficient *k* and the angle of internal friction of the stored bulk solid φ the same as Janssen's theory does [6], Rankine's theory better applies to granulated artificially produced bulk solids. Using Rankine's theory is good above all for light and easily flowing bulk solids and granulated solids, where the bulk solid has the tendency to flow by itself, in essence like a liquid, and the diffusion of pressure (stress) in the bulk solid is assumed to occur evenly without consideration for the effects of friction created by the particles.

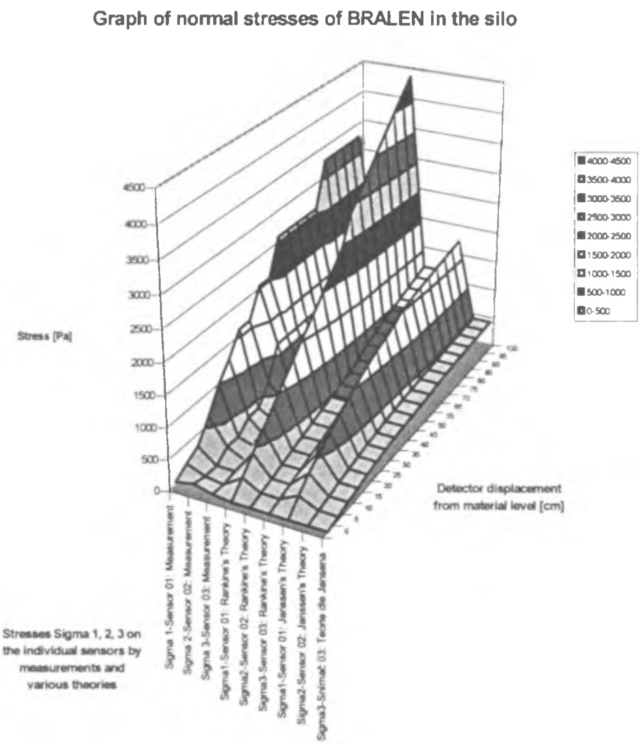

Fig.9. A 3D graph of the mutually dependent normal stresses of Bralen recorded on a 3D indicator in the silo (Fig.6) and how they stand up to the theories. Source: [9]

3. CONCLUSIONS

The functionality of the device has been verified with measuring done on selected material-granules of BRALEN with specific mechanical-physical and geometric parameters. The actual possibility for carrying out industrial measurements of changes in the triaxial stress in bulk solids in actual silos is the result of the figures given in Fig.8 along with the subsequent comparison done by conducting measurements in a model of a glassed-in silo (Fig.6). This device can determine and describe the complete state of stress of the bulk solid in a 3D picture at its present location in the silo and provide assistance for uncovering failures that become more relevant for dynamic manufacturing changes (funneling, arching, creating arches, etc.).

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