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Load Analysis of Specific Design Component Situated in Bulk Solid Storage Bin

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Abstrakt This paper presents a specific problem, which occurs during transport of bulk materials within the framework of complex logistic systems. There are described in this article the most relevant problems that are arising in storage processes in silos as well as a possibility how to eliminate them. The typical problems in silos are: creation of funnels, arches and central tunnels. A simple, however efficient method, which is suitable for elimination of the above-mentioned negative occurrences, is application of the so-called passive element installed inside the silo. There is described in this paper an innovative methodology, which enables to project the passive element with the required characteristics in order to eliminate the above-mentioned negative phenomena in silos.

Key words bulk material, silo, funnel, arch, central tunnel, passive element

1. INTRODUCTION

Transport and handling of bulk materials creates a special category in the whole global area of material handling, taking into consideration also logistic aspects of the material flow systems. A new phenomenon, which is characteristic during the time interval of the last decades, is a rapidly increasing amount of transported volumes of bulk material in almost all industrial branches [6]. The typical application areas of the bulk material transport and handling are: mining industry, cement mills, heat power plants, ironworks and steel works, metallurgy and foundry industry, engineering and chemical industry, agricultural and food industry, waste management etc.

The transport chain of bulk materials is a complicated system, which consists of various transport and manipulation components. One of the most important components situated in the framework of the bulk material transport chain is a storage bin. There are used two basic types of the storage bins: the high storage bin, which is called silo and the low storage bins, called bunkers, Fig.1. According to the practical experiences it is possible to say that just the silos are often relevant sources of serious complications arising during transport of bulk materials and in this way they are causing failures or disturbances in the whole logistic chain, which is specified for transport of bulk materials.

High storage bin silo

Low storage bin bunkers

Fig.1 Two basic kinds of bulk solid storage bins

2. THE MOST FREQUENT PROBLEMS OCCURRING IN SILOS

There are some typical complications occurring during storage of bulk materials in silos. The most important of them are: funnel, arch and central tunnel, [1]. The principal schemes of these complications are illustrated in the Fig. 2.

Illustrative 3-D view on main storage problems in silo is visible in the Fig.3, where is presented a created internal arch situated above the hopper and the second problematic situation is a central tunnel, occurred together with funnel above it. The arch is a harmful and undesirable phenomenon, because it is blocking continuous discharging of material. On the other side the central tunnel causes an unstable charging of material.

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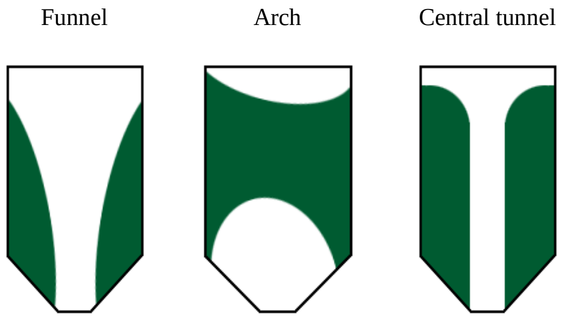

Fig.2 Illustration of the most frequent problem situations in silos

Such negative phenomena originating in the silo are able to disturb or to block the continual flowing-out of material from the silo and in this way it can be stopped the material flow in the whole transport process. Consequences of such negative occurrences can be defined even in ecological and safety categories. There are various technical and technological possibilities how to reduce or how to eliminate the above-mentioned negative appearances, for example application of vibrating equipment fixed to the hopper externally, or installation of pulsating air nozzles.

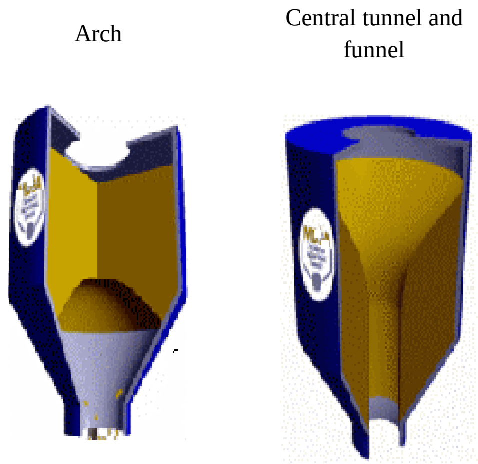

Fig.3 Visualisation of arch and central tunnel created in silo

One of effective and simple solution possibilities suitable for elimination of the problem situations in silos is installation of the so-called "passive element" into the silo. This passive element is arranged and fixed at the horizontal level between the cylindrical shell and the conical hopper, Fig. 4.

The passive element body has a conical or pyramidal shape usually and its main function is to hinder creation of the above-described problems due to its "passive being" inside of the stored material, i.e. it is surrounded by the bulk material directly, [2].

A vertical pressure generated by a whole column of the bulk material, which is stored in silo, is loading the passive element intensively. From this reason it is necessary to calculate this vertical loading of the passive element. There is described in the next part an innovative methodology developed for calculation of the passive element vertical loading.

This methodology is based on principles used for dimensioning of pressures in silos, together with application of modern simulation methods, which enable to create an adequate simulation model of silo as well as model of the installed passive element. The created model is investigated by means of simulation tools using suitable software and hardware equipment.

3. LOAD ANALYSIS OF THE PASSIVE ELEMENT

The dominant loading of the passive element is a vertical pressure. The vertical pressure in silo can be calculated by means of the Pascal's law, equation (1) or using the Rankine's theory, equation (2), however the most frequently is application of the Janssen's equations (3):

$$\sigma_1 = \sigma_2 = \rho g h \,, \qquad (1)$$

$$\sigma_1 = \rho_s g h \,, \quad \sigma_2 = k\,\sigma_1 \,, \qquad (2)$$

$$\sigma_1 = \frac{\rho_s . g . R}{f . k} . \left(1 - e^{-\frac{f.k}{R}.h}\right),$$

$$\sigma_2 = \frac{\rho_s . g . R}{f} . \left(1 - e^{-\frac{f.k}{R}.h}\right), \qquad (3)$$

where is

σ_1 - vertical pressure,

σ_2 - horizontal pressure,

ρ_s - powder density,

g - acceleration of gravity,
h - height of material column,
R - hydraulic radius of silo,
f - friction coefficient,
k - Rankine's coefficient of lateral pressure.

If we are comparing these above-mentioned equations, so we can see that according to the Pascal's theory the both pressures in silo would be the same, i.e. the vertical pressure σ_1 and the horizontal pressure σ_2 are equal. However, such assumption is correct only for fluids and not for bulk material.

This fact was evident already for Rankine, who corrected or modified the relation for horizontal pressure by means of the coefficient of lateral pressure *k*, which is called the Rankine's coefficient:

$$k = \frac{1 - \sin\varphi}{1 + \sin\varphi}, \qquad (4)$$

where φ is the angle of internal friction of given bulk solid.

Considering that $k \langle 1$, there is also $\sigma_2 \langle \sigma_1$, i.e. the dominant pressure in silo is the vertical pressure, of course. The same fact is resulting from the Janssen's equations, too. So, if we want to dimension the passive element, the dominant loading is vertical pressure.

Thus, one the one hand there is at disposal the theory of Pascal, which is a simple linear theory with regard to the course of vertical pressure inside of silo and on the other hand there is used the theory of Janssen usually, which is a typical non-linear theory, [3]. Comparison of these vertical pressure courses according to the both theories is presented on the Fig. 5, where the line course corresponds to Pascal and the three curves are obtained from the Janssen's equations (3). The height "*h*" of bulk material in silo is situated on the vertical axis and the vertical pressure values are on the horizontal axis.

The passive element has to be dimensioned with regard to the vertical pressure, which is caused by column of bulk material in silo. There is now a question, which of the both theories has to be applied for dimensioning of the passive element, which of the both method is the best for practical purposes. In order to answer this question there was performed a theoretical experiment based on simulative calculations at our Department in the framework of the research task solution.

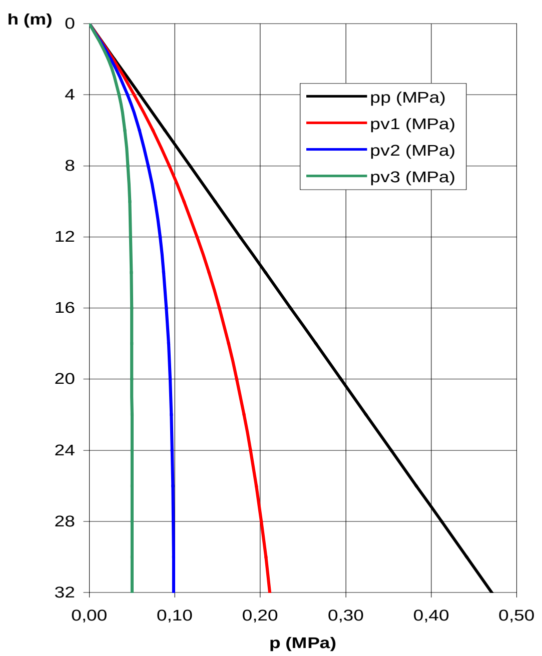

Fig.5. Comparison of vertical pressure behaviours according to the theory of Pascal and Janssen

The basic principle of this simulation process is calculation of the pressure state in a virtual model of silo with the installed passive element, using two principally different calculation approaches:

- the first computational method consists in application of the linear Pascal's theory, which is "user-friendly" and simple,
- the second computational method is more sophisticated, because it integrates the Finite Element Method (FEM) together with application of the Drucker-Prager's model.

The Drucker-Prager's model is an isotropic elastic-plastic material model applicable especially for solutions of simulation tasks concerning bulk materials, which can be used in combination with the FEM favourably for volumetric simulation of cohesive as well as in-cohesive materials. However it is complicated and demanding with regard to the software and hardware equipment, as well as it is time demanding.

In order to simplify the complicated calculation process, it was used a quarter-model of silo, which is presented in the Fig. 6 (for cylindrical and angular silo) together with the finite element net, in order to apply the FEM method.

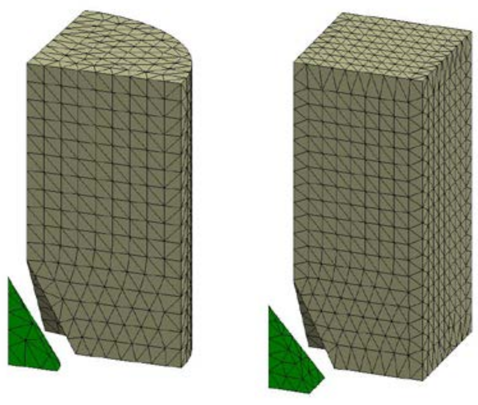

Fig.6 Quarter-model of silo (cylindrical and angular shape) and the installed passive element, together with the finite element net

There were calculated vertical loadings of the passive element in silo that are caused by the pressure of bulk material column, using the above-mentioned two computational methods at various loading levels, i.e. for various heights of the bulk material column. Results obtained by means of the Pascal's linear theory are corresponding very closely with the results from the Drucker-Prager's model, which is integrated with the FEM.

According to comparison of the obtained results it is possible to define a methodology for determination of vertical loading of the passive element:

- in the case of a fast and informative calculation or dimensioning it can be used the linear theory according to Pascal and the obtained results are conforming sufficiently, with the suitable accuracy,
- if there is required a more precise dimensioning, it is necessary to apply the FEM with the Drucker-Prager's model on condition that there is at disposal the required software and hardware equipment, taking into consideration seriousness of time.

4. CONCLUSION

The passive elements, which are installed in silos, are simple designed components indeed, but they are important components arranged in the whole bulk material transport chain. The results obtained from the simulation calculations that are described in this article, are useful from the practical point of view, because they enable to perform a strength-dimensioning of the passive element by means of two described methods: the first method is a simple and practical application of the linear Pascal's law and the second method is a sophisticated simulation process, which integrates the FEM with the Drucker-Prager's model.

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