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INNOVATIVE-OPTIMISATION APPROACH TO DESIGN OF CONSTRUCTIVE COMPONENT IN BULK SOLID STORAGE BIN

Summary. There is presented in this paper a special problem concerning transport of bulk materials in the framework of complex logistic systems. There are typical problems occurring in silos, namely creation of funnels, arches and central tunnels. A quite simple, but efficient methods, which is suitable for elimination of the above-mentioned negative occurrences, is application of the so-called passive element installed inside in the silo. There is described in this paper a methodology applied for a design process, which enables to project the passive element in order to eliminate the above-mentioned negative phenomena in silos.

Keywords. Optimisation, passive element, high storage bin, simulating calculation.

PODEJŚCIE INNOWACYJNO-OPTYMALIZACYJNE DO PROJEKTU ELEMENTU KONSTRUKCYJNEGO W ZBIORNIKU MATERIAŁÓW SYPKICH

Streszczenie. Optymalizacja elementów maszyn znajduje zastosowanie również w dziedzinach, które są mniej typowe z punktu widzenia zastosowania. Takim ilustracyjnym przypadkiem jest metodyka projektu elementu pasywnego w wysokim zbiorniku materiałów sypkich. W artykule jest przedstawione innowacyjne podejście do rozwiązania projektu konstrukcji z zastosowaniem elementu pasywnego, przy wykorzystaniu nowoczesnych symulacyjnych procesów obliczeniowych. Element pasywny jest instalowany w wysokich zbiornikach w celu wyeliminowania występujących w nich negatywnych zjawisk.

Słowa kluczowe. Optymalizacja, element pasywny, wysoki zbiornik, obliczenia symulacyjne.

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. The typical application areas of the bulk material transport and handling

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are, for example: 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 important components situated in the framework of the bulk material transport chain is a storage bin. There are used two basic types of storage bins: the high storage bin, which is called silo and the low storage bin, i.e. bunker, both are pictured in the Fig. 1.

Fig. 1. Two basic types of storage bins: high – silo (left) and low – bunker (right)
Rys. 1. Dwa podstawowe typu zbiorników: wysoki – silos (po lewej) oraz niski – bunkier (po prawej)

2. PROBLEMATIC SITUATIONS 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 drawn schematically in the Fig. 2.

Fig. 2. Problematic phenomena in silos: funnel, arch, centric tunnel (from the left to the right)
Rys. 2. Niepożądane zjawiska w zbiornikach: lejek, sklepienie, tunel wewnętrzny (od lewej do prawej)

An illustrative 3-D view on the main storage problems in silo is visible in the Fig. 3. Here is presented a created arch inside, which is situated above the hopper and the second troubled situation is a central tunnel together with funnel above it. The arch is harmful and undesirable, because it is blocking discharging of material and the central tunnel causes unstable charging of material.

Such negative phenomena inside of 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 vibrating equipment fixed to the hopper externally, or pulsating air nozzles, [2], [3].

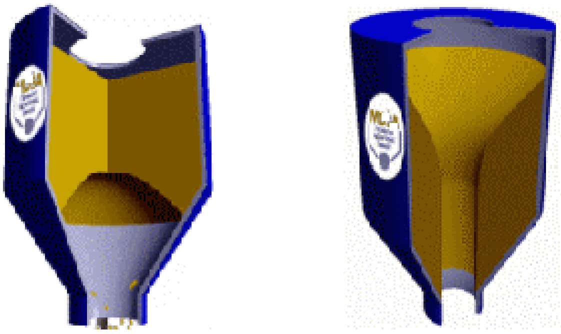

Fig. 3. Illustration of a created arch (left) and centric tunnel (right)
Rys. 3. Przykład powstałego sklepienia (po lewej) oraz tunelu wewnętrznego (po prawej)

One of effective and simple solution possibilities is installation of the so-called "passive element" into the silo, which is arranged and fixed at the horizontal level between the cylindrical shell and the conical hopper. There is presented in the Fig. 4 arrangement of the passive element in silo together with an extracted quarter part and also the cross-section of this quarter part, which was created for simulation purposes and calculations.

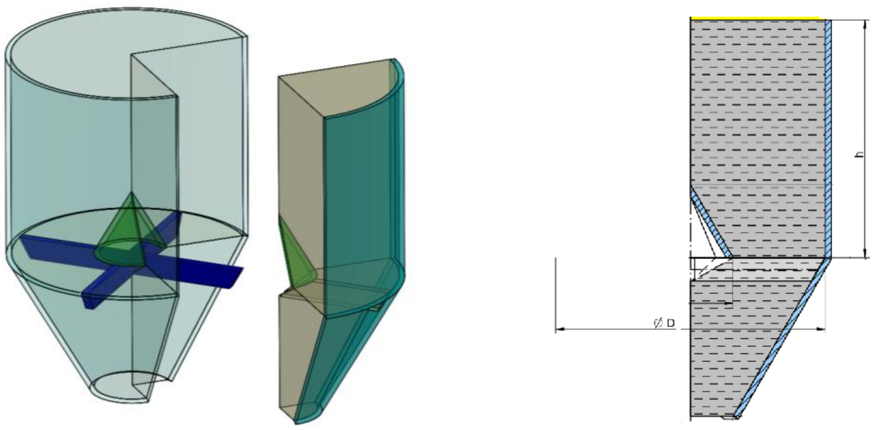

Fig. 4. Passive element in silo (left) and cross-section of its quarter part (right)
Rys. 4. Element pasywny w zbiorniku (po lewej) oraz ćwiartkowy przekrój poprzeczny (po prawej)

The passive element body has usually a conical or pyramidal shape 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. A vertical pressure caused by a whole column of bulk material, which is stored in silo, loads the passive element intensively. From this reason it is necessary to calculate the vertical loading of the passive element. In the next part there is described a methodology for calculation of the passive element vertical loading. This methodology is based on principles used for dimensioning of pressures in silos applying modern simulation methods that are creating an adequate simulation model of silo together with model of the installed passive element. The created model is investigated by means of simulation tools using suitable software equipment.

3. COMPUTING PROPOSAL OF THE PASSIVE ELEMENT

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

$$\boldsymbol{\sigma_1} = \boldsymbol{\sigma_2} = \rho \, . \, g \, . \, h \, , \tag{1}$$

$$\boldsymbol{\sigma_1} = \rho_s \, . \, g \, . \, h, \quad \boldsymbol{\sigma_2} = k \, . \, \sigma_1, \tag{2}$$

$$\sigma_1 = \frac{\rho_s . g . R}{f . k} . \left(1 - e^{-\frac{f.k}{R}.h}\right), \; \sigma_2 = \frac{\rho_s . g . R}{f} . \left(1 - e^{-\frac{f.k}{R}.h}\right), \tag{3}$$

where:

- σ_1 – vertical pressure [Pa];
- σ_2 – horizontal pressure [Pa];
- ρ_s – powder density [kg/m^3];
- g – acceleration of gravity [m/s^2];
- h – height of material [m];
- R – hydraulic radius of silo [m];
- 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 Pascal's theory the both pressures in silo would be the same, i.e. the vertical pressure $\boldsymbol{\sigma_1}$ and the horizontal pressure $\boldsymbol{\sigma_2}$ 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:

$$\mathbf{k} = \frac{1 - \sin\varphi}{1 + \sin\varphi}, \tag{4}$$

where $\boldsymbol{\varphi}$ is the angle of internal friction of given bulk solid.

Considering that **k** < 1, there is also $\boldsymbol{\sigma_2} < \boldsymbol{\sigma_1}$, 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. Comparison of these vertical pressure courses according to the both theories is presented on the Fig. 5, where the line course corresponds to the Pascal's theory and the three curves are obtained from the Janssen's equations (3) for three various values coefficients of friction between material and silo. 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.

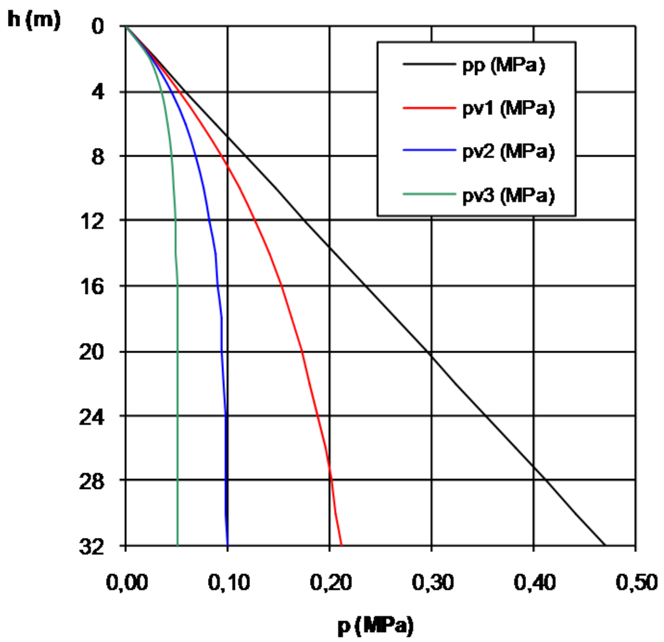

Fig. 5. Behaviour of the vertical pressures in silo
Rys. 5. Przebieg ciśnień pionowych w zbiorniku

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 1st computational method consists in application of the linear Pascal's theory, which is "user-friendly" and the 2nd 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. In this figure is visible the simulating model covered with the finite element net, (left) and also result of compression stress calculation using the FEM methods (right).

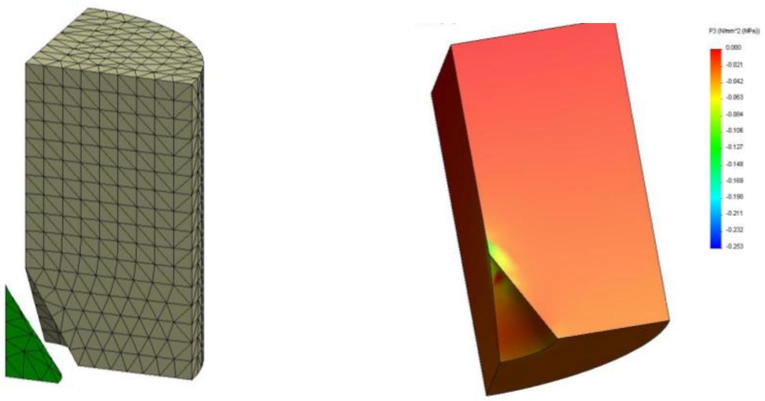

Fig. 6. Model of silo with covering net (left) and presentation of compression stresses in silo (right)
Rys. 6. Zdyskretyzowany model zbiornika (po lewej) oraz przedstawienie naprężeń ciśnienia w zbiorniku (po prawej)

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. CONCLUSIONS

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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