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DETERMINATON OF VELOCITY DISTRIBUTION AT SILO OUTLET

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Abstract

Silo is widespread solution for storing granular materials. Similarity between behaviour of granular materials and fluids allow of storing in silos. These behaviours are flowing during filling and discharging. Predicting of arching and discharge rate is required for silo designing. There are two methods to predict of discharge rate Johanson's method and Beverloo's one. In these models velocity is constant along outlet. Our new model prediction of velocity is not constant. There is good agreement between results of our model and experimental analysis. Our model gives good describing velocity of flowing along outlet. And the model explain for independence of velocity from filling height of silo.

Keywords: silo, granular material, discharge rate

1. INTRODUCTION

There are two methods to predict of discharge rate Beverloo's [1961.] method and Johanson's [1965.] one. In these models velocity distribution is constant. In this work we show results of measuring velocity distributions along radius of outlet and these result are compared with results of a new flowing model. First the new model (published in [3]) is shown shortly.

2. NEW FLOWING MODEL

Model for predicting of discharge rate is based on a hypothesis of formation and brake of instable arches at outlet. According to hypothesis particles move arbitrarily in silo but for an instant these stop above outlet at instable arches. Then arch brake and material moves as free fall [3]. So velocity of material flowed out through orifice can be computed like free fall.

Velocity distribution at outlet is determined by height and shape of arch. Therefore function of shape of instable arch *f(r)* have to be determined in polar coordinate system. Using variational calculus and experimental methods [3] surface of arch is describing as an axis symmetric parabola (Fig. 1.).

$$f(r,\varphi) = h\left(1-\left(\frac{2r}{d}\right)^2\right) \qquad (1)$$

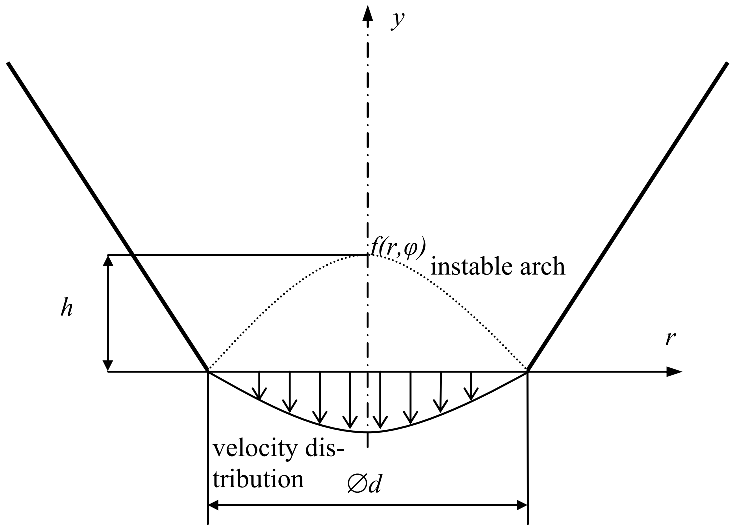

Fig. 1. Outlet and instable arch

Velocity at outlet in case of free fall:

$$v = \sqrt{2gh}\,. \qquad (2)$$

We can not measure directly height of arch. Instead of direct measuring we define a coefficient. δ is a coefficient of shape of arch that is function of material properties of granular material. This is rate of height and width of arch $\delta = h/d$. Substituting this and function of surface and ordering:

$$v(r,\varphi) = \sqrt{2g\delta d}\sqrt{\left(1-\left(\frac{2r}{d}\right)^2\right)} \qquad (3)$$

Equation (3) that describes velocity distribution is verified by experimentals. Aim of this work is showing results of them.

3. METHOD OF MESURING OUTFLOW VELOCITY

Diameter of our silo model (Fig. 2.) is 100 mm, height is 1500 mm. Hopper is changeable and easy to make it because of small size. Three load cell are built in experimental equipment. Loads to silo (1), hopper (2) and lock (3) can be measured. Measuring system is joined to computer by amplifier.

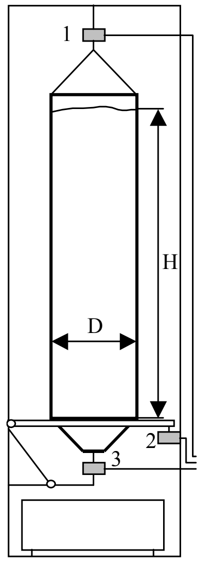

Fig. 2. Silo model

Method of measuring distribution of velocity is dividing the flow of granular material into two parts. Baffle is used with predetermined *b* size of slot (Fig. 3.). And two discharge rates are measured. Average velocity flow out certain areas is computed fom these datas. Diameter of outlet is 31 mm, size of slot is increased from 2 mm to half of diameter with 1 mm steps. Examined material is poppy seeds. Experiments are repeated three times with every settings.

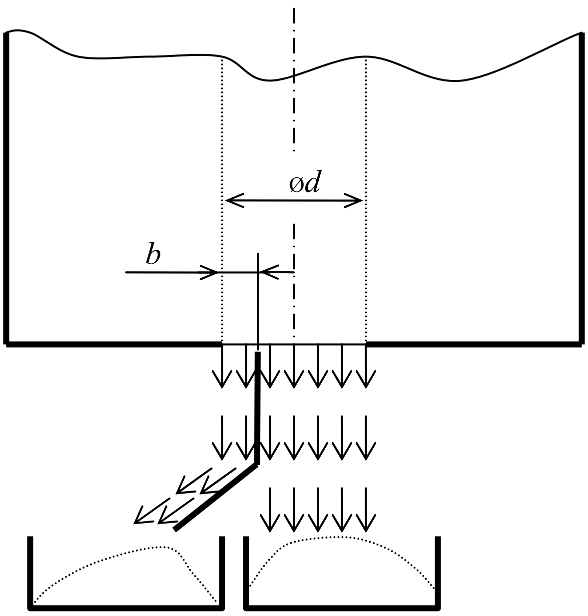

Fig. 3. Measuring of velocity distribution

Results of measuing are mass of material and flowing time in function of *b* szie of slot.

4. COMPARISON OF RESULTS FROM CALCULATION AND MEASURING

Computational model contains a δ coefficient that can be measured as material property [3]. In 1. table these coefficients are shown. These are calculated from measured discharge rates at funnel flow [3].

1. table. δ coeficient to different materials

Material	Wheat	Maise	Poppy seeds	Oat	PE-LD
δ	0.4	0.3	0.46	0.3	0.3

Average velocity of material flow through the slot can be calculated from discharge rates. In order to comparison these are calculated from equation (3). Discharge rate with *b* slot size and A_b area:

$$W = \rho \int_{-\varphi}^{\varphi} \int_{\frac{R\cos(\varphi)}{\cos(\alpha)}}^{R} \sqrt{2g\delta d} \sqrt{\left(1-\left(\frac{2r}{d}\right)^2\right)} r dr d\alpha \ , \qquad (4)$$

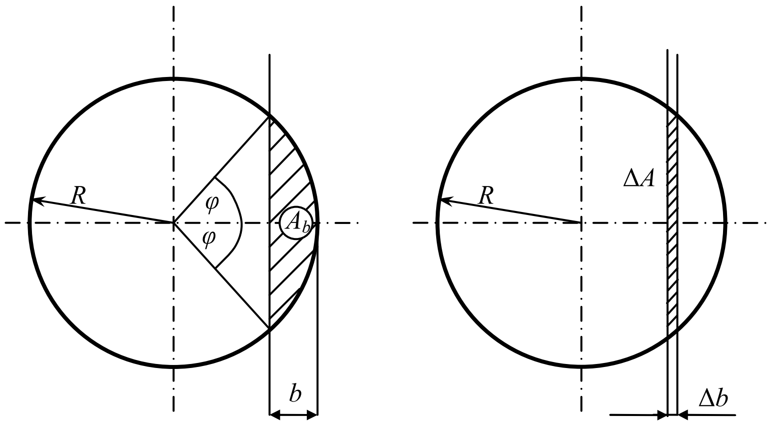

Fig. 4. Sizes of outlet

where φ is half of angle to *b* slot size:

$$\varphi = \arccos\left(1-\frac{b}{R}\right) . \qquad (5)$$

Average velocity of material flow though ΔA area:

$$v = \frac{\int_{-(\varphi+\Delta\varphi)}^{\varphi+\Delta\varphi} \int_{\frac{R\cos(\varphi+\Delta\varphi)}{\cos(\alpha)}}^{R} \sqrt{2g\delta d} \sqrt{\left(1-\left(\frac{2r}{d}\right)^2\right)} r dr d\alpha - \int_{-\varphi}^{\varphi} \int_{\frac{R\cos(\varphi)}{\cos(\alpha)}}^{R} \sqrt{2g\delta d} \sqrt{\left(1-\left(\frac{2r}{d}\right)^2\right)} r dr d\alpha}{\Delta A}$$

Measured and calculated discharge rates at slot sizes are shown in Fig. 5. Using constant velocity as Johanson [2] and Beverloo [1] discharge rates can be calculated from A_b area of slot.

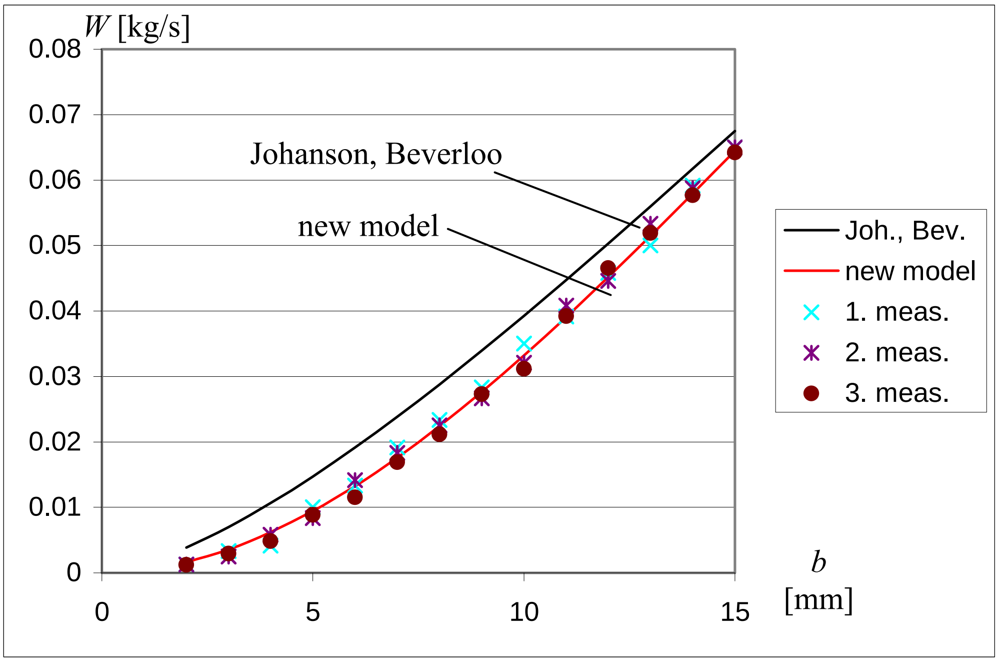

Fig. 5. Discharge rate in funtion of slot size

In Fig. 5. can be seen that measured discharge rates show good agreement with results of new model. We can make conclusion that new model gives better prediction of velocity distribution than the other models. Average velocity at 1 mm slots was calculating from discharge rates in order to examine velocity distribution. Comparison can be seen in Fig. 6.

Function of measured points is not known, so a cubic Taylor polynom was fit to them. But fitted curve is quadratic because of symmetry. Deviation of measured velocity is derived from deviation of slot adjustment.

After examination of results we find out new model shows very good agreement with results of measuring.

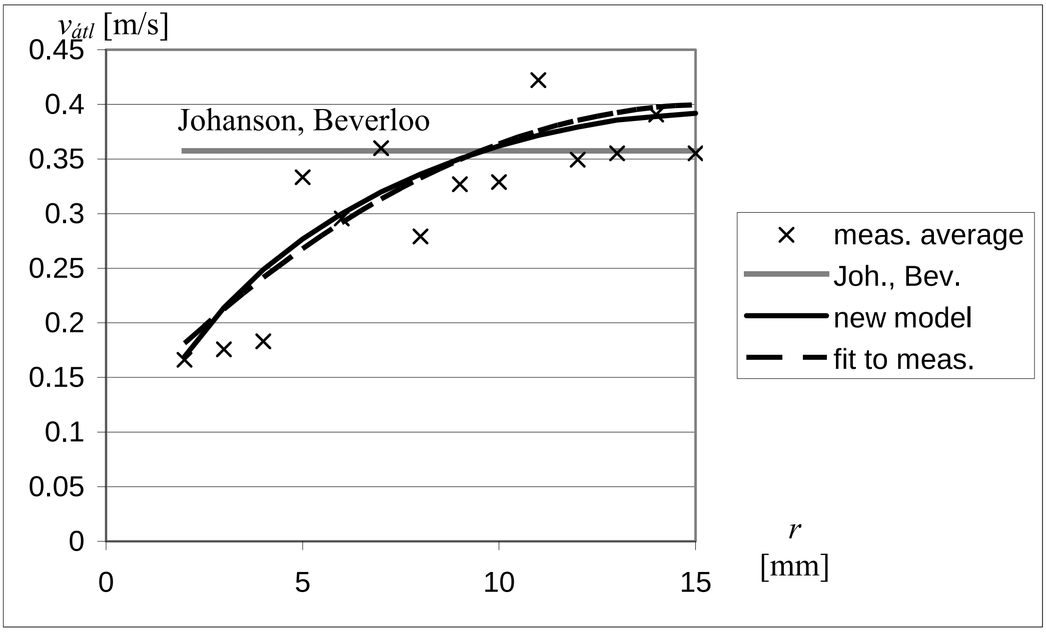

Fig. 6. Velocity distribution along outlet radius

5. SUMMARY

In contrast to assumption of other models [1], [2] outflow velocity is not constant along diameter of outlet. It was verified by experiments in case of funnel flow. Principle of new theoretical outflow model was shown. Fully in reference [3]. Hypothesis of continually formation and brake of instable arches at outlet and discharge rate from this hypothesis was verified previously [3]. This gives explanation for independence of discharge rate from filling height that is practical results without verification. In this work measuring and results of outflow velocity distribution along outlet diameter are shown. Prediction of new outflow model shows good agreement with experiments. Correctness of model shown in [3] is confirmed by results.

6. REFERENCES

1. Beverloo, R.: The flow of granular solids through orifices, Chem. Eng. Sci. 15, 1961., 262
2. Johanson, J. R.: Method of calculating rate of discharge from hoppers and bins, Society of Mining Engineers, 1965.
3. Oldal István: Method of determining rate of discharge from silo, TC15-YOUTH IMEKO SYMPOSIUM, Castrocaro Terme, 4-7. may. 2005.