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Experimental and design loads of pressure of bulk materials against silo wall

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Abstract

These investigations were carried out on silo models, free-standing silos and silo batteries. The researches include the evaluation of value of pressure and temperature field on the silo wall as well as temperature gradient, registration of simultaneity of these loads.

There were used sensors placed in the silo wall and bottom and sensors placed into material as sounder. The researches include either the evaluation of influences of the strength parameters of wall. Each of these investigated parameters is a random variable. Collection of such data as pressure, temperature, strengthen coefficients is of great significance, so the authors measured these loads many times. There is the need of calculation such quantities of statistics as characteristic, design value of measured loads and strength parameters, material and loads coefficient partial coefficient of safety, reliability indexes etc. These data were subjected to statistical accounts. The data obtained from calculations can be used in designing similar silos and in silo codes [1].

Keywords: silo, pressure, measurement, experiment, temperature, reliability

1. Introduction

In general, two methods to determine bulk material pressures can be used, namely, the indirect and direct method. The indirect method consists of determining the strains in the silo structure, for example on the concrete surface or on the hoop reinforcing. But obtained in this way the tensile strains are very difficult to interpret in view of thermal, dynamic influence. Therefore, the above mentioned inadequacies of the indirect method have led to direct pressure investigations. The direct method was based on pneumatic, dynamometer, bonded wire strain gauge (used in ’70 and ’80), magneto elasticity sensors. The short history of development of this sensor constructions is described in [5,7]. One of the most applied pressure sensor, works on principle magneto elastic, was invented by research team [2] in ’80 and ’90 is shown in Fig. 1. The sensors are placed in the silo wall and bottom or during silo realization or they are exchanged during duration of experiment (Fig. 2, 4). This sensors has diameter about 17 cm when they are placed in walls and diameter about 25 cm when they are placed in bottom. Fig. 3 shows the results of pressure against wall.

They were used for measuring pressure and temperature. The same magneto-elastic principle was used in construction of another sensor, which works as sounder. The gauge which looks like a disk, 30 cm in diameter and 1,5 cm thick (Fig.5) [3,4,5]. The pressure exerted by bulk solid on the gauge dipped in it. The gauge was suspended on a steel line fixed to the silo ceiling. They were used for measuring pressure and temperature against silo wall on fly ash (Fig. 6, 10) , flour, coal (Fig. 11, 12), gypsum (Fig. 11, 13), copper concentrate (Fig. 11, 13), cement (Fig. 2, 3), wheat (Fig. 9), rape silo (Fig, 7,8,10). Another, smaller sensors and sounders (5 cm in diameter, Fig. 15,16) were used on silo models. (Fig 15,17). This sensors were used in investigations of pressure in full scale silo and model silo on rape silos with pipe elements for reduction of pressure (Fig.7,17). Some results of horizontal pressure p_h for silos with diameter D are shown on Fig 3,10,12,13,14. They are described by using non dimensional coefficient α, $p_h = \alpha * \gamma_s * D$, γ_s is specific weight. Comparisons of coefficient α for this measured materials due European Code are presented on Fig. 21

2. Acting loads on silo construction.

The following equation must be fulfilled with regard to the reliability requirement:

$$S_G \leq R_G \text{ or } Z = R_G - S_G \geq 0 \tag{1}$$

There are loads $\boldsymbol{S_G}$ acting against silo construction (characterized by $\boldsymbol{R_G}$), such as material pressure p_h, pressure of aeration and homogenisation, temperature gradient across the silo wall ΔT, temperature field on the silo wall caused by storage grain T, insolation and daily temperature variation, displacement caused by, for example, shrinkage, loads caused by post tensions, and other as concentrated loads, such as patch loadings, loads caused by eccentricity of discharching material ets. From these loads only pressure of material p_h, temperature T and ΔT , wind loads are measurable, and only some aspects of this loads. Strength R_G of silo construction, is charakterized by such parameters as: stell and concrete, strength, cover, diameter of bars, quantity of reinforced horizontal and vertical bars, adhesion of bars to concrete, quality of lap splices, type and quality of wall strengthening, openings in the silo wall, imperfections, cracks, condition of bars taking into account corrosion, technical condition of concrete, i.e. carbonisation, etc.

3. Determination of safety for the silo structure

Limit state equation (1) includes parameters of design values:

$$S_G = \Sigma_i (t_{mi} S_{xi,k}) \tag{2}$$

$$R_G = \Sigma_i (\gamma_{mi} R_{xi,k}) \tag{3}$$

where t_{mi} and γ_{mi} are load and resistance factors, respectively and $S_{xi,k}$ $R_{xi,k}$ are components of loads and strength of silo construction, S_G – denotes multi componential action effects, that is, for example, force in horizontal reinforced bars in case of wall strength, is a function of many parameters as: pressure, temperature gradient across the silo wall ΔT ect, R_G – is the resistance, i.e. concrete and bar strength in the case of wall strength, index "k" significa characteristic values. In order to estimate global safety factor ϖ - it is suitable to use characteristic parameter values S_{xik} and R_{xik}:

$$\varpi S_G{}^k \leq R_G{}^k \tag{5}$$

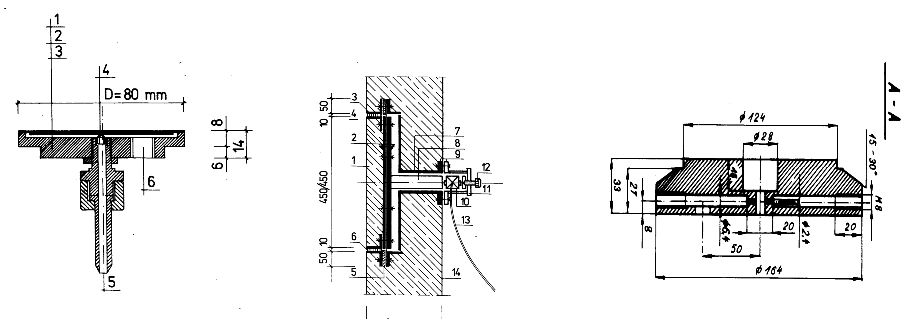


Fig. 1 Sensors construction based on pneumatic, dynamometer, magneto elastic phenomena used during pressure and temperature measurements

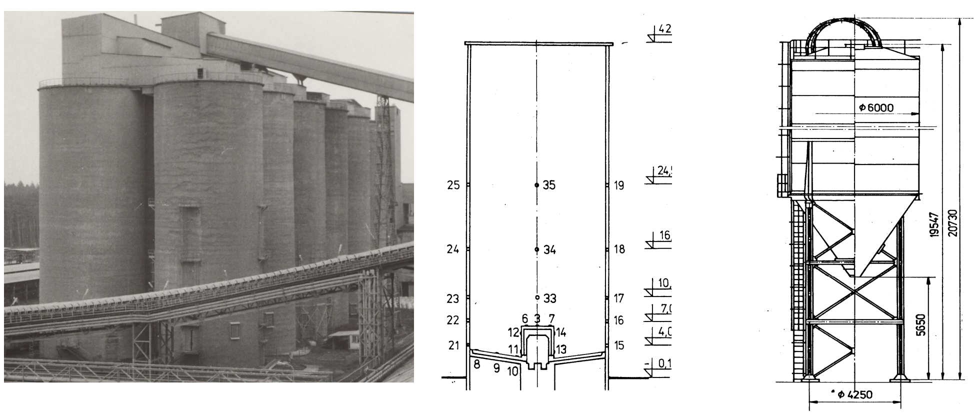


Fig. 2 Research of silos for cement

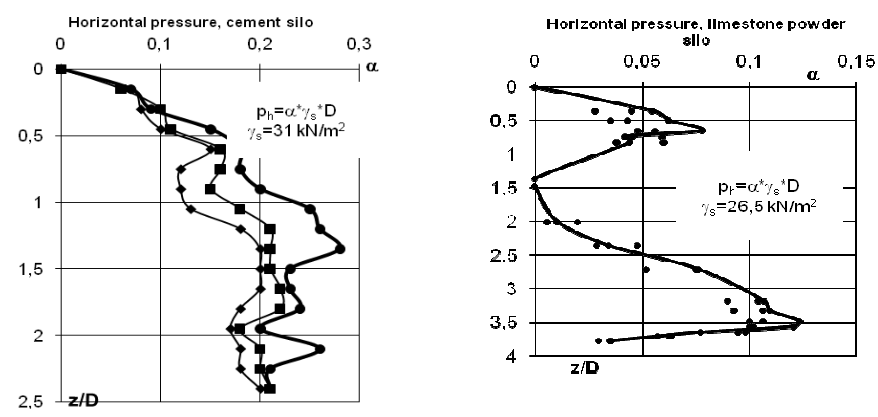


Fig. 3 Horizontal pressure against silo walls

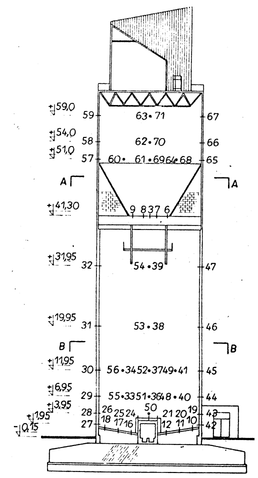


Fig. 4 Research of silo for limestone powder

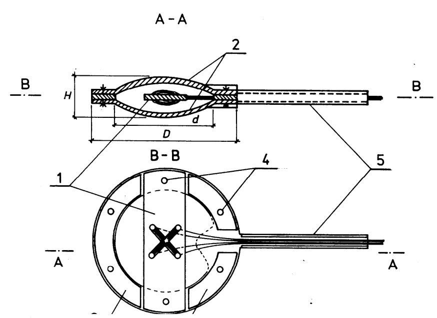
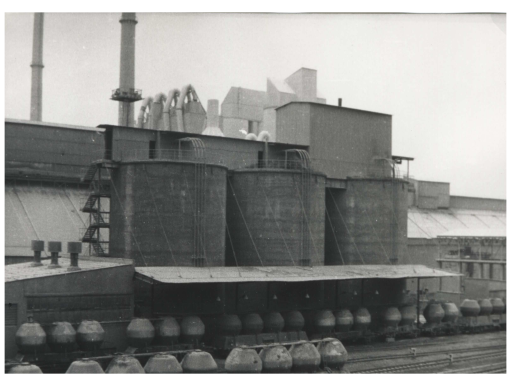


Fig. 5 Sounder sensor design by Borcz A.



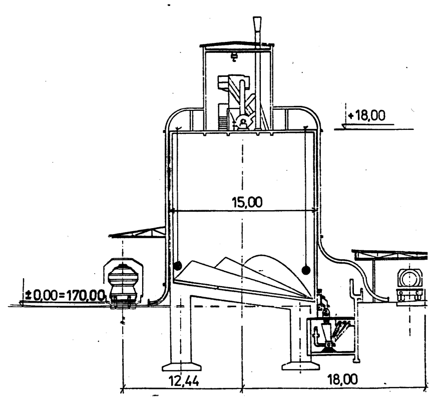


Fig. 6 Measuring of pressure on fly ash silo

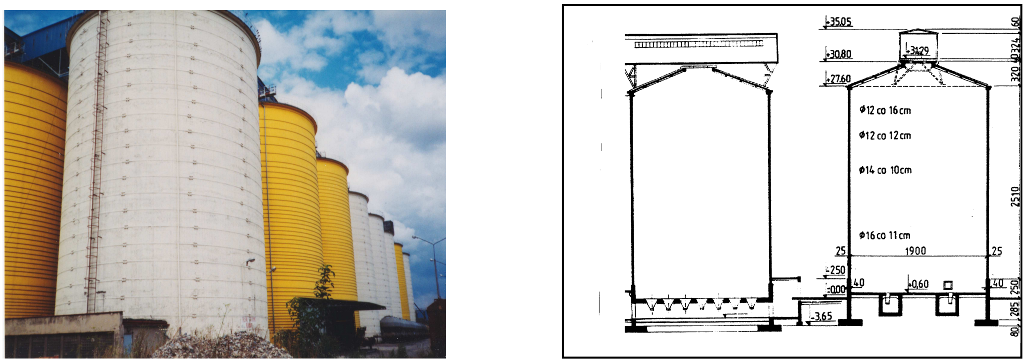


Fig. 7 Measuring of pressure on rape concrete silo

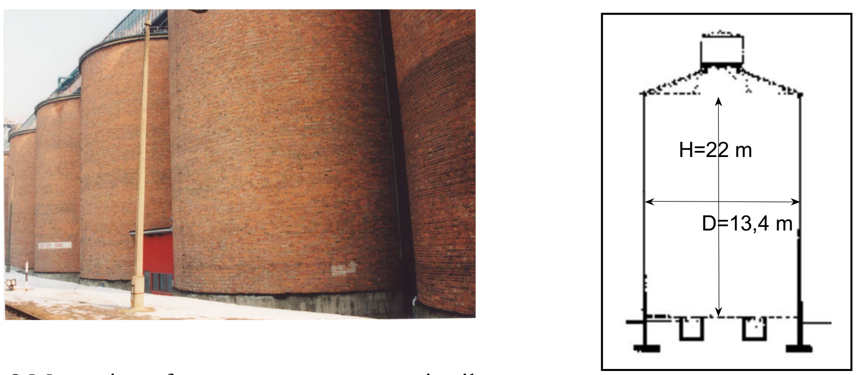


Fig. 8 Measuring of pressure on rape ceramic silo

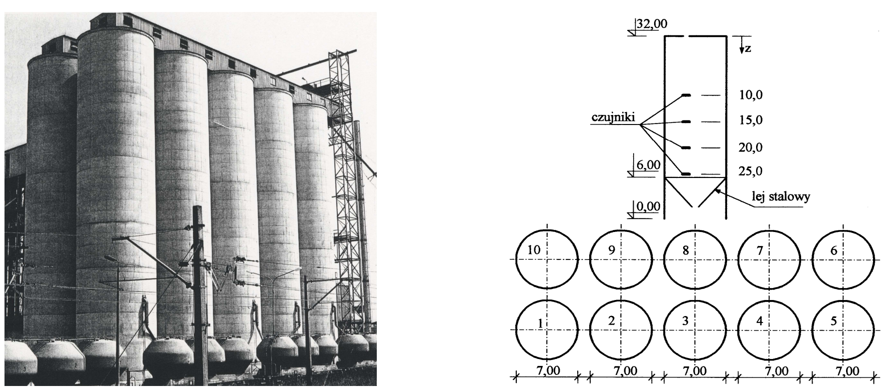


Fig. 9 Measuring of pressure on wheat silo

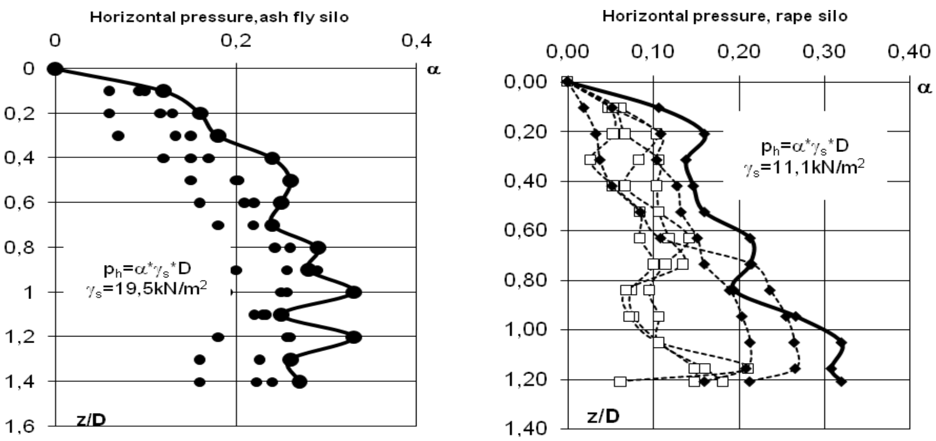
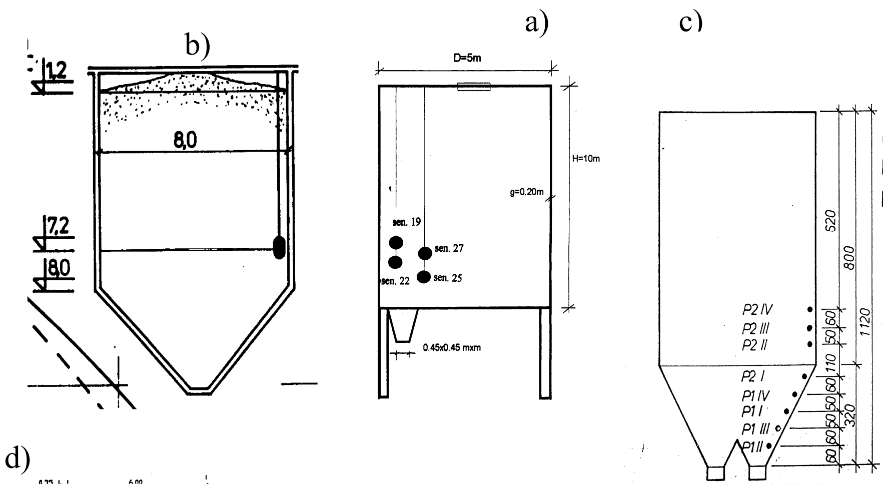


Fig. 10 Horizontal pressure against silo walls



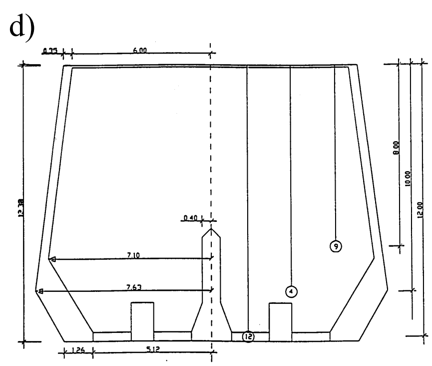


Fig. 11 Silos for a) sand, b)gypsum, c) coal, d) copper concentrate

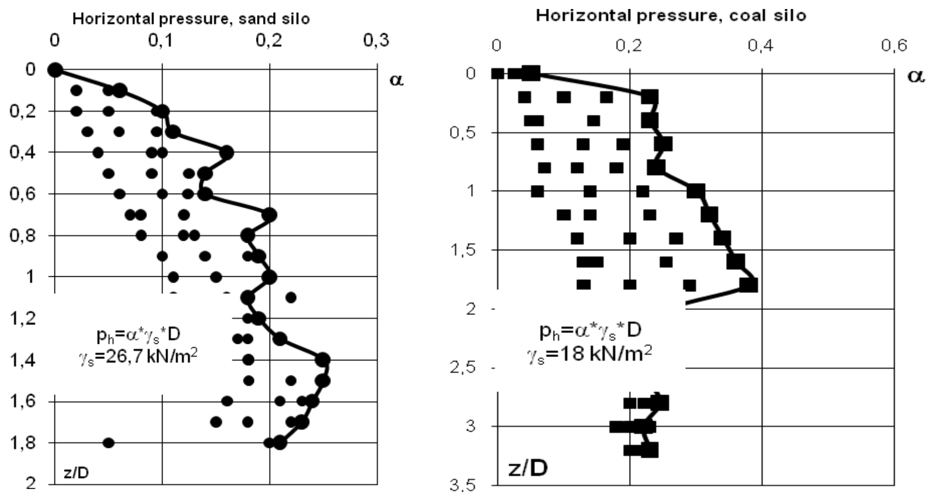


Fig. 12 Horizontal pressure against silo walls

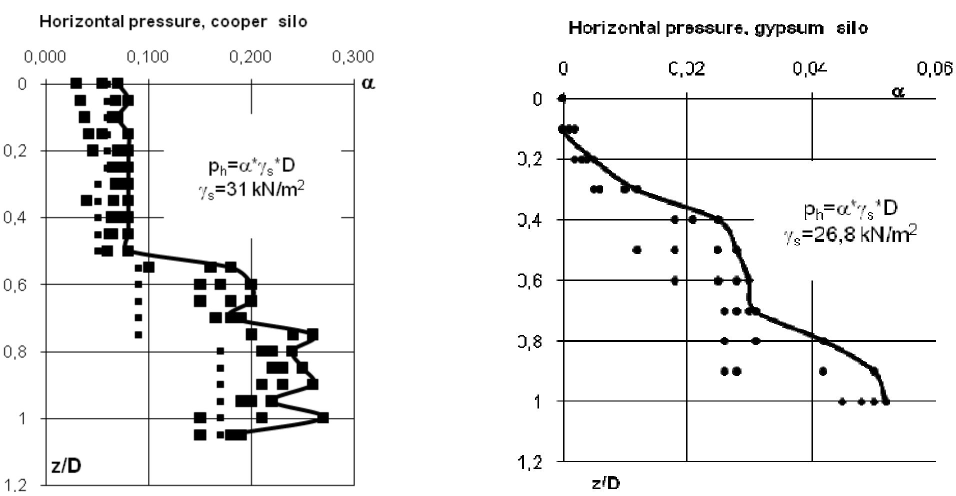
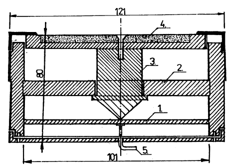
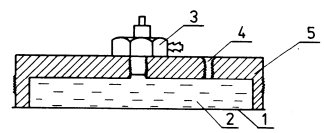


Fig.13 Horizontal pressure against silo walls

a) 


b)

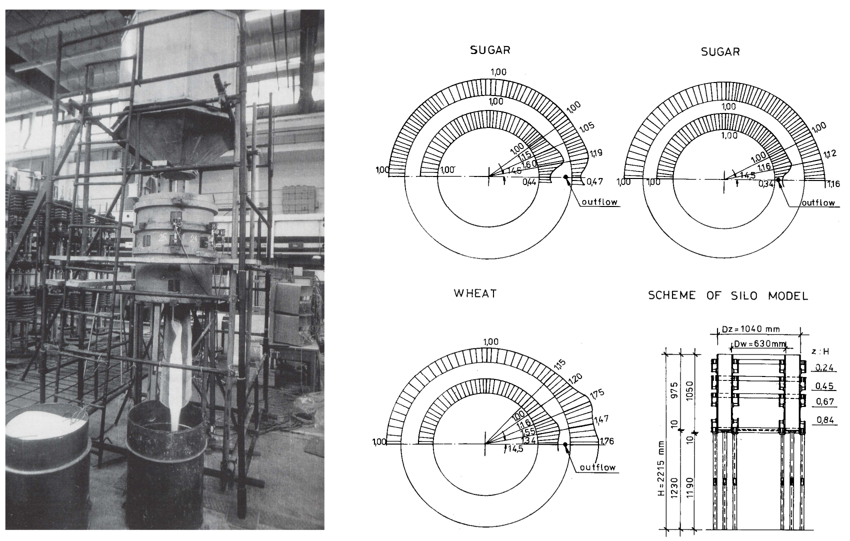
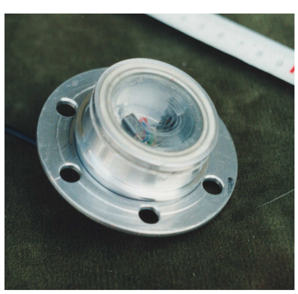
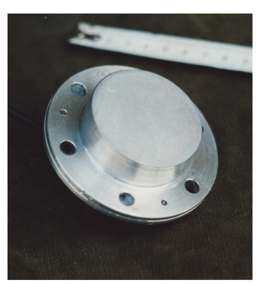


Fig. 14 Model of silo for sugar, sensors of Kaminski and Zubrzycki [7] functioning on the base a) electric resistance tensometer b) oil layer - pressure converter and some results of pressure


a)


b)

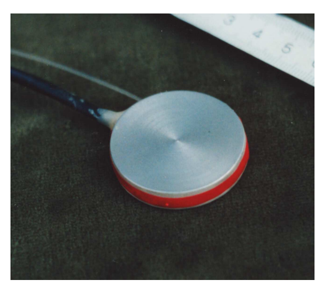
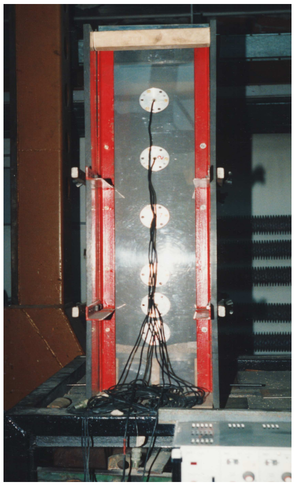

c)

Fig. 15 View of sensors used in models a) for friction forces b)for horizontal and vertical pressure c) sounder



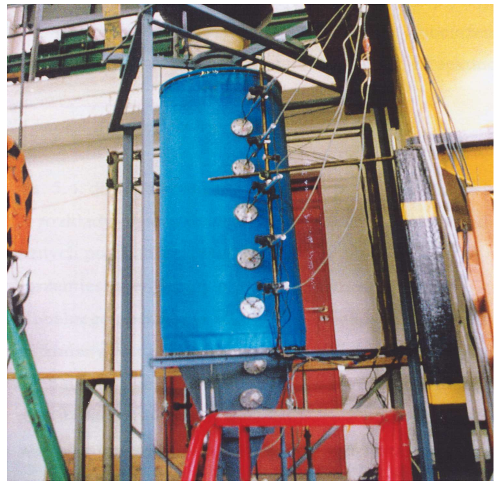


Fig. 16 Measurement pressure of bulk materials on silo models

Results of calculation of this coefficient for rape silo are presented on Fig. 18.
Another coefficient of construction safety [13,14,15] is described by β, the reliability indices interval: $\beta=z_m/\sigma_z$, and reliability index of risk failure $p_f=\Phi(-\beta)$, where z_m i the mean value of function Z, σ_z is standard deviation of Z, $\Phi(-\beta)$ is Laplace function $Z= R_G - S_G$ for $z_m \geq \beta * \sigma_z$ construction work in safe area. Coefficient β is equal according to European standards 3,7 ÷ 6,7, $p_f=10^{-3} \div 3 \cdot 10^{-8}$. Coefficient β can be separated to two β_R and β_S connected with strength and loads. According to [17] there are three classes of safety coefficients RC1, RC2, RC3 but in [15,16] we can use either RC0 class. In the last proposal, in case typical for silo loads, where live loads are grater than dead, and when $R \leq R_d$; $S \geq S_d$)=max, R and S are independent (index d is design level). β=3,7 (p_f=10-4), β_S=2,59 (p_f=0,005), β_R=2,96 (p_f=0,0015). Some results were receivrd from investigation on full scale silo, as rape silo [7-12]. According to [13,14,18] loads coefficients γ_f is equal between 1,1 (for temperature) 1,2 ÷ 1,5 (for pressure) but under control of material properties range of γ_f is 1,2 ÷ 1,35. Coefficient of loads coincidence is 0,9. According to [16] γ_f can be lower than 1,2 for RCO class. In the case of silo loads, when loads of pressure are bigger than temperature loads and big variation of dead loads γ_f can be equal 1,3 for RCO class. According to [11] coefficient of loads coincidence can change from 0,8 to 0,9 for silos under acting high temperatures.

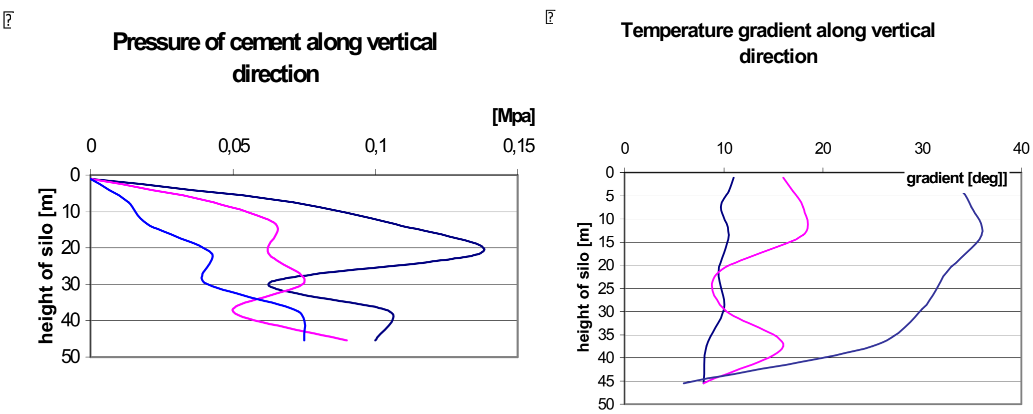


Fig. 17 Results of pressure and temperature gradient measured on full scale silo [3]

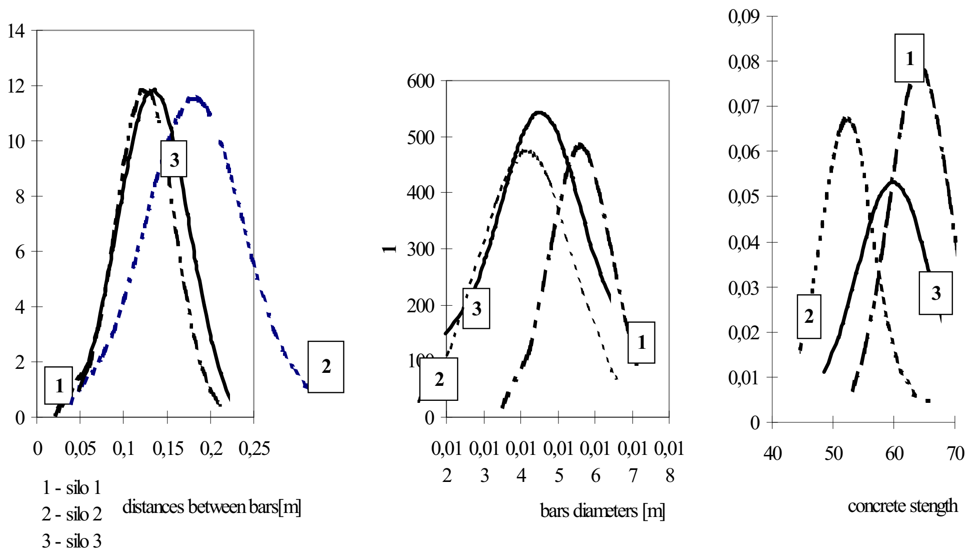


Fig. 18 Some results of measurements of parameters of strength of silo wall

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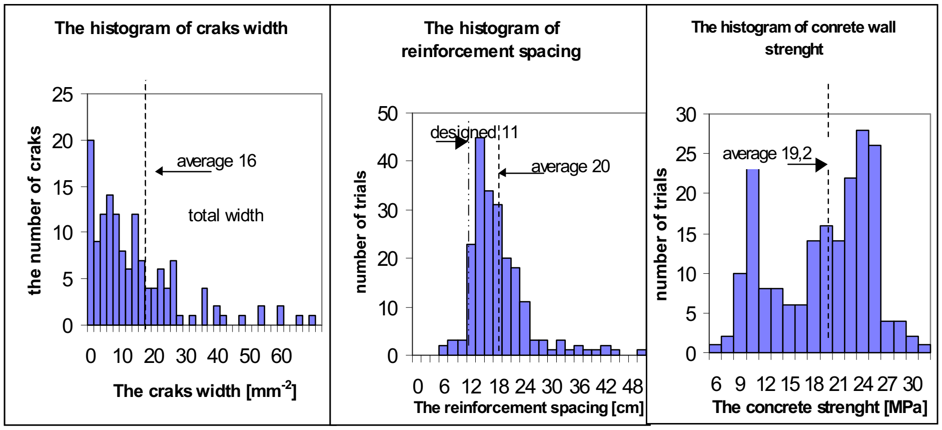

Fig. 19 Some results of measurements of parameters of strength of silo wall

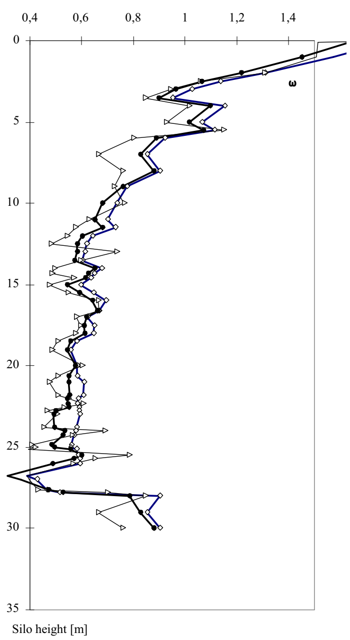

Fig. 20 Distribution of safety index ϖ a ccording to height of silo [11]

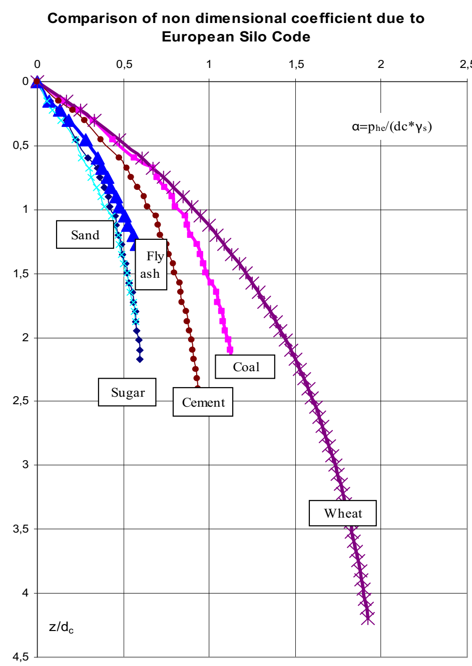

Fig. 21 Comparison of pressure due to European Code

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