Numerical simulation in the wind action analyses in silos with a windbreak

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Abstract. A windbreak, by definition, is the planting of single or multiple rows of trees to reduce the wind speed to leeward. In this work, was analyzed the efficiency of windbreaks in attenuating the external pressure coefficients of wind action in silos. The methodology was validated using the *Ansys Workbench* software, considering a height/diameter ratio equal to 0.5. In other applications was studied the influence of the neighborhood on the external pressure coefficients and streamlines between silos with different battery configurations. The significant reduction in external pressure coefficients was verified, highlighting windbreaks as an option to protect silos in open areas with high wind loads.

Keywords: silos, windbreak, numerical simulation, pressure coefficients, structural safety.

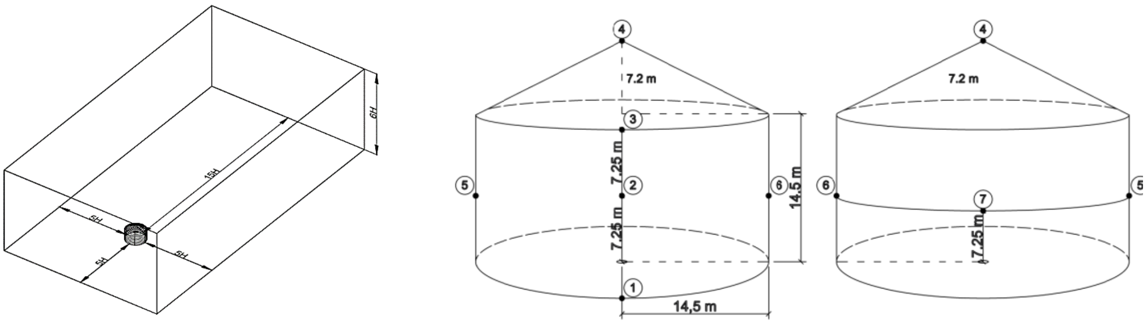
Introduction

The demand for storage of agricultural products leads to an increase in the number of cylindrical silos for the adequate conservation of products and distribution logistics. However, the structural integrity of these silos is subject to wind loads, inducing significant stresses and compromising their stability.

In the literature, recent studies have numerically addressed the effects of wind on silos. To clarify the observed ovalling vibrations in a group of 8 x 5 silos during a storm, 2D and 3D CFD simulations have been performed by Hillewaere *et al.* [1] to predict the aerodynamic pressure distributions on the silo walls numerically. The results in 2D indicated a forced, resonant structural response similar to the observed pattern of ovalling vibrations. In contrast, in the 3D model, the ovalling mode shapes might be excited by the transient pressures without preference for one or more ovalling modes. Mukherjee *et al.* [2] conducted wind-structure interaction studies on intermediate to tall (slenderness ratio range: 1.5 to 4.0) cylindrical silo shells. They concluded that the presence of a flat roof provides significant strengthening at the top of the silos against wind-induced radial deformation. Windbreaks appear as a potential solution to protect agricultural structures against the adverse effects of wind. Thus, our objective is to analyze, through computer simulations with the aid of *Ansys* software, the effects of windbreaks on the safety of silos.

Methodology

Numerical tests were performed using *Ansys Workbench* software and the fluid flow module (CFX). The geometries were modeled using AutoCAD software. For the control volume, the dimensions according to Franke *et al*. [3] were adopted, with limits of 5H on the face at 0° and both side walls, 6H for total height, and 15H behind the building (Fig. 1a) to allow the development of the flow. Here, H corresponds to the maximum height of the building, adding the height of the cylindrical body and the conical top and seven points around the silo were considered for the isolated measurement of the external pressure coefficient, denoted by *Cpe* (Fig. 1b).The boundary conditions are in Table 1.



(a) (b)

Figure 1. (a) Control volume and (b) front and back view of the structure of the points for taking the *Cpe*.

Table 1. Boundary conditions and non-dimensional parameters.

Condition	*Parameters*
Method of mesh	Tetrahedron
Reference pressure	101325 [Pa]
Air temperature	25 [°C]
Flow regime	Subsonic
Relative pressure of outlet	0 [Pa]
Roughness	0.08 [m]
Inlet	$U/U_{ref} = (Z/Z_{ref})^{\alpha}$
α	0.105
Z_{ref}	10 [m]
U_{ref}	30 [m/s]
Minimum number of iterations	100
Maximum number of iterations	500
Turbulence model	*RNG K-Epsilon*

Numerical applications

1.1 Application 1: Insulated Silo (Validation)

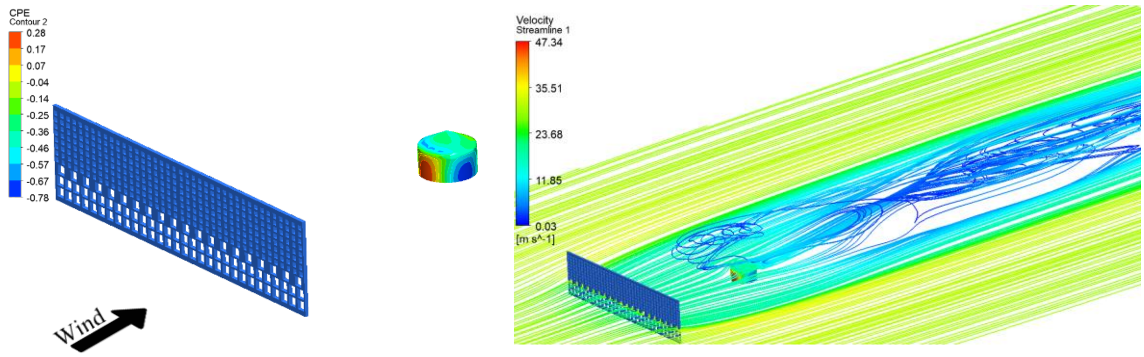
Case 1 (insulated silo without windbreak): Here, the *Cpe* was calculated with the wind incidence at 0º on the windward side and compared with Andrade Jr [4] for validation. The dimensions proposed by [4] were adopted: D=690 mm, H=345 mm, and b=173 mm for the height of the conical cover, with a scale of 1/42 for H/D=0.5. Table 2 presents the values obtained for the external pressure coefficients. Then, the *T-test* was used to determine significant differences between the present work results and [4], considering a null hypothesis that the means are not different. Thus, for wind at 0° and a one-tailed distribution, p-value=0.49 was obtained for a critical t=2.03. As 0.49<2.03, it to conclude that the difference between the mean values of *Cpe* is insignificant.

Table 2. *Cpe* for the insulated silo without windbreak with H/D=0.5.

Boundary	*1st*	*2nd*	*3rd*	*4th*	*5th*	*6th*	*7th*	*8th*	*9th*	*10th*
Andrade Jr [4]	0.93	0.69	0.46	0.22	-0.01	-0.25	-0.49	-0.72	-0.96	-1.20
Present work	0.9	0.67	0.44	0.20	-0.03	-0.27	-0.5	-0.73	-0.97	-1.20

Boundary	*11th*	*12th*	*13th*	*14th*	*15th*	*16th*	*17th*
Andrade Jr [4]	-1.44	-1.67	-1.9	-2.14	-2.37	-2.61	-2.84
Present work	-1.43	-1.67	-1.9	-2.14	-2.38	-2.61	-2.85

Case 2 (insulated silo with windbreak): With the addition of a windbreak, there was a significant reduction in the external pressure coefficients throughout the silo. At *Points 1* and *2* (Fig.1b), the reduction in overpressure was around 65%, and there was also a decrease in suction around the entire silo, with the top being the point with the highest difference, with a reduction of almost five times in the pressure coefficient. At *Point 7* (Fig.1b), without a windbreak, the overpressure reached 0.47 while, in this case, a suction of -0.14. The contour lines in Fig. 2a show a not-very-pronounced suction at the top of the silo. In contrast, were observed the highest suction values on the sides of the cylindrical body and the edge of the silo roof cone in the windward direction. This phenomenon, observed in Fig. 2b, was possibly caused by the base vortices generated by the windbreak, which altered the flow behavior, causing the recirculation of air masses.

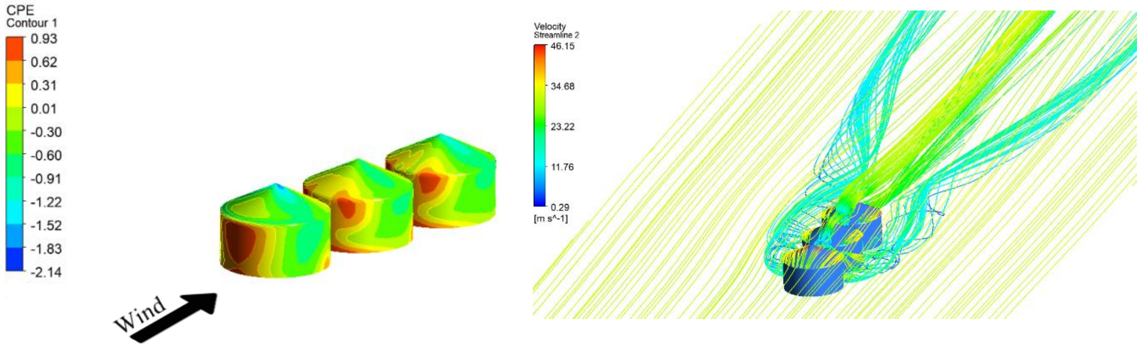


(a) (b)

Figure 2. (a) Pressure coefficients distributions and (b) streamlines in the silo with windbreak.

1.2 Application 2: Three Aligned Silos

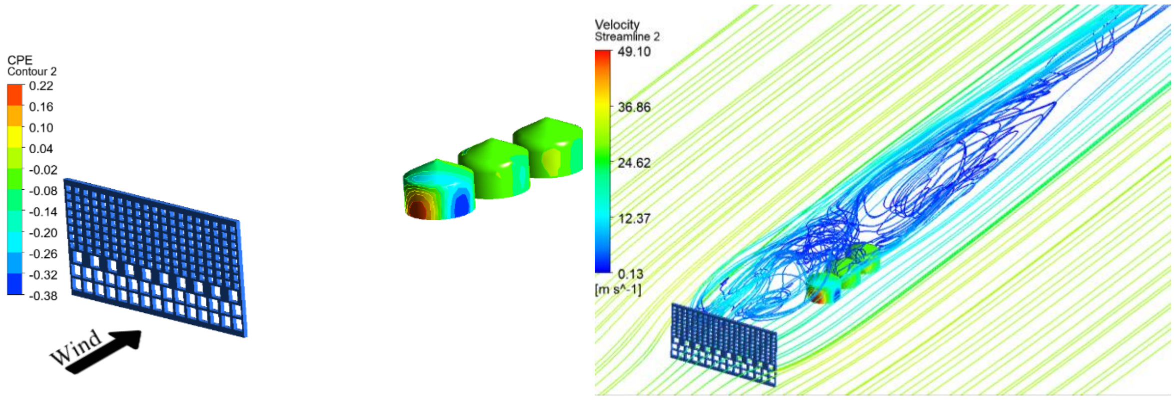
Case 1 (*Three aligned silos without windbreak*): Here, the windward silo presented high overpressure zones on the windward side (Fig. 3a). In the other silos located behind the first, was noted a decrease in the pressure contours which indicates smaller overpressure zones due to the shielding effect. However, large suction zones appeared due to the base vortices generated on the leeward side of the first structure that interfered with the flow regime and the wake. This turbulence between the structures was due to the flow trying to reestablish the atmospheric boundary layer, which was made impossible by the proximity of the silos (Fig. 3b).



(a) (b)

Figure 3 (a) Pressure coefficients distributions and (b) streamlines in the three aligned silos without windbreak.

Case 2 (*three silos aligned with the windbreak*): Here, there was a reduction in the values of the silo pressure coefficients. These remained between 0.20 and 0.25 for the overpressures (Fig. 4a), while the maximum suction reached -0.33. For *Silos 2 and 3*, the contours were smaller, varying between -0.12 and -0.04. This significant reduction from one silo to the other can be explained by their geometric arrangement, causing the shielding effect (Fig. 4b).



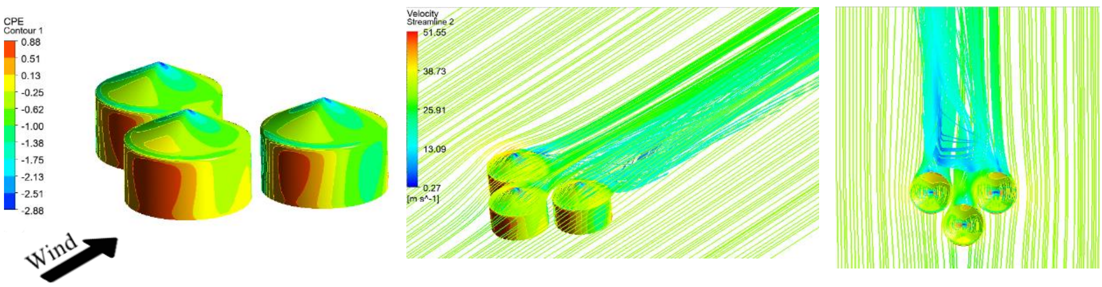
(a) (b)

Figure 4. (a) Pressure coefficients distributions and (b) streamlines in the three aligned silos with the windbreak.

1.3 Application 3: Three Silos arranged in a Triangular Way

Case 1 (*three silos arranged in a triangular way without a windbreak*): In this case, the pressure coefficient values remained like *Case 1* of *Application 1* (Fig. 5a). However, at the top of the structures, the flow behavior was more uniform (Fig. 5b). The most notable turbulence generated in this situation occurred at the beginning of the conveyor belt, in the space between the silos (Fig. 5c). Possibly, the flow on the surface of the first silo, when accelerating, broke away at the transition between the silos, which, due to its configuration, caused the appearance of two narrow passages subject to the Venturi effect and responsible for creating negative pressures.

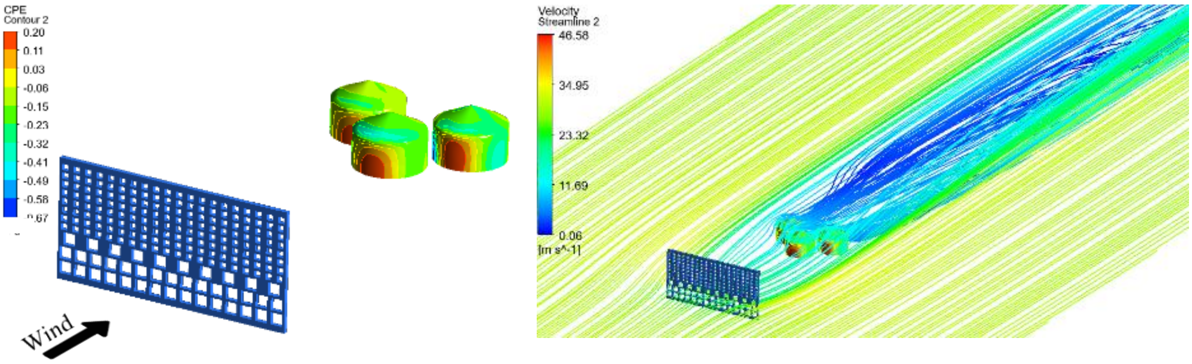
This phenomenon would justify the high suction values recorded on the right side of the rear silo, which reached -1.12, and on the left side of the third silo, they reached -1.6, values that, when compared to the previous silo, are four times higher.



(a) (b) (c)

Figure 5. (a) Pressure coefficients distributions, (b) streamlines and (c) top of three silos arranged in a triangular way without a windbreak.

Case 2 (*three triangularly arranged silos with windbreak*): With the presence of the windbreak, was observed a decrease in the pressure coefficient values in all silos. The largest overpressure zones presented Cpe_{max}=0.20 and the suction zones Cpe_{min}=-0.67 (Fig. 6a). It was possible to observe the action of the Venturi effect in the narrowings between the silos, which was probably responsible for generating the highest suction value in this case, since in this zone the pressure coefficient reached its minimum value. The resistance caused by the silos was attenuated by the vortex wake (Fig. 6b), with few risk zones for the top of the buildings. Therefore, this is a recommended configuration for the arrangement of these large silos.



(a) (b)

Figure 6. (a) Pressure coefficients distributions, (b) streamlines of three silos arranged in a triangular way with windbreak.

4. Conclusions

This study presented the distribution of wind pressure in isolated silos and silo batteries through numerical simulations using *Ansys Workbench* software, considering different configurations for the silos, such as quantity, size, and location on the site, together with the addition of a windbreak, to assess the relevance of their use to protect buildings.

For validation was used a cylinder silo with a height and diameter ratio of 0.5. The results obtained by the simulation showed significant similarity with the literature data, presenting very similar zones and coefficients throughout the building. In the configuration of *Application 2*, with three silos aligned in a row, the shielding effect reduced the pressure contours in the silos after the first. However, for the cases aligned in more than one row, the proximity between the buildings caused an acceleration in the wind speed due to the successive narrowing zones between them. Among the cases presented, the configuration that proved to be the most efficient was the triangular arrangement (*Application 3*). In this case, the overpressure coefficients were lower even without a windbreak, and, in addition, the turbulence caused by the structure did not affect the vortex wake over a long distance. For this configuration, with the addition of the windbreak, was noted a significant reduction in all pressure coefficients.

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