Numerical study of the wind effect on scallop domes

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Abstract. The effects of the action of wind on scallop domes were numerically investigated using the software *Ansys*, as well the interference of the neighborhood on the external pressure coefficient and the streamlines between geometrically identical domes. The influence of the proportion on the neighborhood interference in scallop domes and the variations in the dimensions of the structures on the pressure coefficients and streamlines were also investigated. Five simulations were analyzed involving six-grooved domes and geometry height variations for validation. The numerically obtained coefficients were compared with values in the literature. Other applications investigated the influence of grooves on the external pressure coefficient and the effect of wind on the grooved domes. Another application analyzed the interference of the neighborhood on the external pressure coefficients and streamlines between three geometrically identical domes and, finally, the influence of the proportion in the study of the interference of the neighborhood. Here, the variations in the dimensions of the structure affected the pressure coefficients and the streamlines were analyzed. It was possible to verify the versatility and efficiency of the computational method used in the analysis of the action of wind.

Keywords: wind action, pressure coefficients, scallop domes, neighborhood effect.

1 Introduction

A dome is a curved roof structure that spans an area on a circular base, producing an equal thrust in all directions. They have a convex surface with double curvature, making them suitable for roofing, and can be built directly on the ground or on cylindrical walls. In this work, the effects of the action of wind on scallop domes were numerically investigated using the software *Ansys* to verify the influence of the number of grooves on the external pressure coefficient and the effect of the wind on scallop domes. The interference of the neighborhood on the external pressure coefficient and the streamlines between geometrically identical domes was also analyzed.

2 Methodology

Numerical tests were performed using *Ansys Workbench software*, fluid flow module (CFX). The geometries were modeled with AutoCAD software, being composed by the structure to be analyzed, surrounded by the control volume, whose dimensions was adopted according to Sadeghi, Heristchian, Aziminejad and Nooshin [1]: length of 4,0m, a width of 24m and a height of 2,6m, with the dome centered inside it. The wind direction considered was 0° concerning the domes and the basic wind speed adopted was 38 m/s.

3 Numerical applications

Case 1: Here, to validate the methodology, it was adopted the scallop domes as with 6 grooves with variations in the height of the geometry, adopting the aspect ratio given by $k=h/D$ the relationship between height (h) and diameter (D) fixed at 50cm. Considering the two decimal place precision, for k=0,1, the greatest difference (24%) occurred between the first boundary, starting from the outer edge to the inner line of the dome. The same occurred for the domes with k=0,2. In the scallops domes with six grooves and k=0,3;...; 0,5, the values for the

Cpe contours were similar (Tab. 1) when compared to those presented by Sadeghi, Heristchian, Aziminejad and Nooshin [1]. However, for *k*=0,4 and *k*=0,5, at the top of the geometry crest, an area of the larger contour can be observed, which has a high aspect ratio and, consequently, presents the highest *Cpe* values. Comparing with Sadeghi, Heristchian, Aziminejad and Nooshin [1], a difference of 17% and 13% were obtained for the maximum and minimum pressure coefficients, respectively. According to Sadeghi, Heristchian, Aziminejad and Nooshin [1] with the increase in the aspect ratio of the dome, the lengths of its grooved parts decrease, especially in the grooves at 90º concerning the wind direction, due to the type of cutout of this dome. In this way, with the increase in the aspect ratio, the suction effect of the critical groove was increased; for example, Cpe_{min}=- 0.88 for *k*=0,3 and Cpe_{min}=-1.31 for *k*=0,5 was obtained.

Table 1. External pressure coefficients of the scallop dome with six grooves considering *k* = 0.1; ...; 0.5

k = 0,1									
Sadeghi *et al.* [1]	+0,25	+0,00	-0,25						
Present work	+0,19	-0,02	-0,24						
Difference	0,06	0,02	0,01						
k = 0,2									
Sadeghi *et al.* [1]	+0,50	+0,25	+0,00	-0,25	-0,50	-0,75			
Present work	+0,40	+0,19	-0,02	-0,24	-0,45	-0,67			
Difference	0,10	0,06	0,02	0,01	0,05	0,08			
k = 0,3									
Sadeghi *et al.* [1]	+0,75	+0,50	+0,25	+0,00	-0,25	-0,50	-0,75	-1,00	
Present work	+0,62	+0,40	+0,19	-0,02	-0,24	-0,45	-0,67	-0,88	
Difference	0,13	0,10	0,06	0,02	0,01	0,05	0,08	0,12	
k = 0,4									
Sadeghi *et al.* [1]	+0,75	+0,50	+0,25	+0,00	-0,25	-0,50	-0,75	-1,00	-1,24
Present work	+0,62	+0,40	+0,19	-0,02	-0,24	-0,45	-0,67	-0,88	-1,09
Difference	0,13	0,10	0,06	0,02	0,01	0,05	0,08	0,12	0,15
k = 0,5									
Sadeghi *et al.* [1]	+0,75	+0,50	+0,25	+0,00	-0,25	-0,50	-0,75	-1,00	-1,24
Present work	+0,62	+0,40	+0,19	-0,02	-0,24	-0,45	-0,67	-0,88	-1,09
Difference	0,13	0,10	0,06	0,02	0,01	0,05	0,08	0,12	0,15

Case 2: In this case, wind pressure coefficients in three distinct dome scenarios with various aspect ratios are studied. All domes have the same diameter, varying their elevation, denoted by h, from 0,1*D* to 0,5*D*, with *D* being its diameter. The three situations analyzed, different by the number of grooves in each geometry (10, 14, and 25), aim to investigate the influence of the grooves on the wind behavior and, consequently, on the pressure coefficients. Initially, the wind action was simulated in domes with 10 grooves, with a 0º wind direction. The pressure coefficients obtained, as well as the pressure contour lines, can be seen in Fig. 1(a). It was found that, as the aspect ratio was increased, there was an increase in the external pressure coefficient. It was also noted a significant suction area to leeward, especially in the domes with *k* = 0,3;...;0,5, and, for these, it was noted that the module higher values of the pressure coefficient, they are directed to the grooved sections between 36º and 108º concerning the wind direction and, similarly, in the grooves between 252º and 324º, thus evidencing the increase in the indentations represented by the contour lines. Also, that Cpe_{min} for *k*=0,4 and *k* = 0,5 occurred in the groove at 72º and 288º for the wind, this suction being relieved at the top and lee side of the geometries. To the windward side, it was observed that the Cpe_{max} occurred in the frontal part of the domes configured with an aspect ratio greater than 0,3. For the domes with 14 grooves, the same geometric parameters previously adopted were maintained. Figure 1(b) shows the pressure coefficients and isobaric lines, as well as the pressure distribution on the external surface of the domes. It was noted that the isobaric lines behaved similarly to the previous case, in which the domes had 10 grooves; however, with the increase in grooves and, consequently, in the number of geometry sections, there was an increase in indentations, and these, in turn, were predominantly located at 51º and 77º

Comparing with the 10-groove geometries, a decrease in the external pressure coefficients was noted. For cases with 14 grooves, the increase in the number of grooved sections influenced the result of the coefficients. Finally, five situations were simulated with the same aspect ratio variations for the domes with 25 grooves (Fig. 1(c)), and a significant difference was observed in the results obtained for the external pressure coefficients when compared to the cases with 10 and 14 grooves. A 23% reduction in Cpe_{min} was noted with to the 14-slotted geometry and 26% concerning the 10-slotted domes. An increase in indentations was noted for the case with 25 grooves (Fig. 1(c)), demonstrating the tendency of the module highest coefficients, to be directed towards the sections delimited by the grooves. For *k*=0,5, Cpe_{min} was concentrated on sections between 58° and 86° for to the wind direction and, similarly, on grooves between 302° and 331°, in addition to converging to the crest of this geometry. When comparing the cases with 10, 14, 25 grooves, it was noted that the wind behaved similarly and the maximum and minimum coefficients were concentrated in the same regions, with the maximum in the windward sections and the minimum at the top and sides of geometries. As the number of grooves was increased, a decrease in pressure coefficients was noticed, showing the influence of the grooves. Therefore, the dome with 25 grooves presented a better performance regarding the minimum external pressure coefficient and was chosen for Case 3.

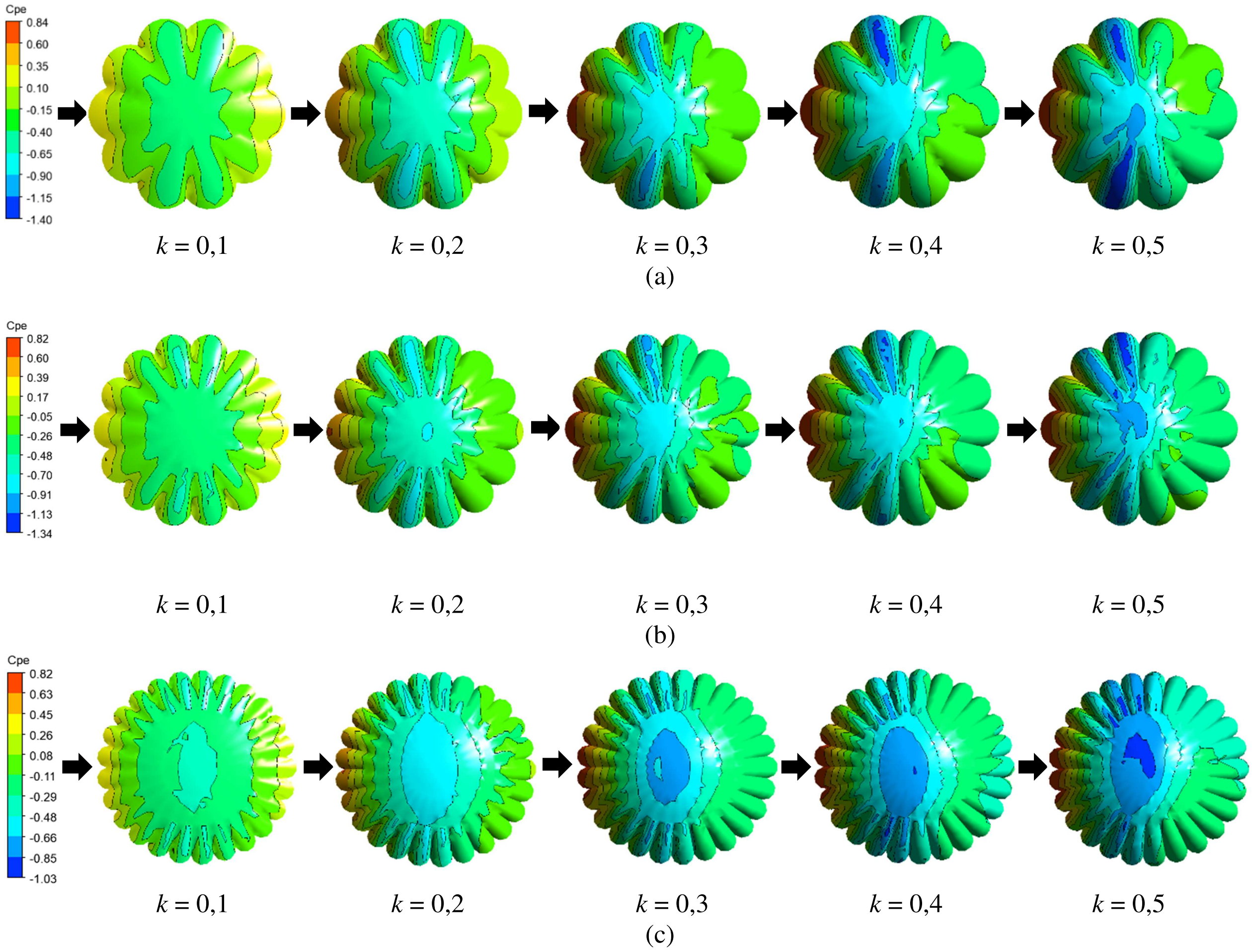
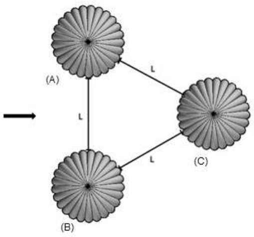
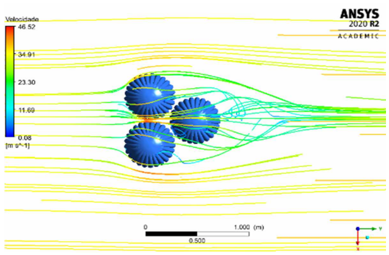


Figure 1. Variation of external pressure coefficients on scallop domes with (a) 10 grooves, (b) 14 grooves, (c) 25 grooves and different aspect ratios

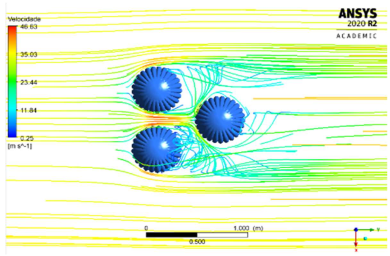
Case 3: The distribution of wind pressure distribution on an object is not only a function of its shape, but also is a function of the effect of the nearby objects, according to Sadeghi, Heristchian, Aziminejad and Nooshin [2]. Thus, this effect was studied, as well as the Venturi effect and the blowing effect on the external pressure coefficient between the cups. The domes were named *A, B,* and *C*, with *A* and *B* being the source of interference, and dome *C*, referred to as the reference dome (Fig. 2(a)). All have 25 grooves and ratio k=0,5 and were positioned at a distance L, which varies in the range [0;2*D*], measured from their outer edge, where *D* is the diameter of the dome. To calculate the wind speed along the control volume, 38m/s was adopted for the basic speed. The neighborhood effect tends to decrease with increasing distance between them. Thus, for L=0,25D and L=0,5D, a smaller influence of the interference domes *A* and *B* on the reference dome *C* was noticed. In addition, there was an increase in the flow velocity caused by the bottleneck in flow between the *A* and *B* geometries, making the external pressure coefficients higher on the surfaces where the taper has occurred (Fig. 2(b-c)). Vortex shedding became more evident from the setting of L=0,25D and, consequently, the blowing effect caused by the interference domes became more active. This dynamic effect generated by wind turbulence from structures *A* and *B* caused changes in pressure, causing the *Cpe* of reference dome *C* to increase. For the last two simulations, L=D and L=2D were adopted, there was a small interference from the neighborhood, and the values of the external pressure coefficients were similar to those found in the previous case. In the L=D configuration, domes *A* and *B* had no interference from the neighborhood, while dome *C* had a small decrease in the Cpe_{max} region. Furthermore, there was no change in the values of the pressure coefficients and the wind taper started to decrease and, consequently, the interference of the effects on the structures (Fig. 2(e)). As the value of *L* increases, the areas of overpressure in the reference domes also increase. Furthermore, the critical suction range tends to increase in these domes and, for *L*=2*D*, the wider area is reached with the highest suction, different from those with low values of *L*, which suffered from the shielding effect of the domes of interference *A* and *B* (Fig. 2(f)). It was noted that, for the distance *L*=2*D*, the external pressure coefficients remained the same as in the previous case considering 25 grooves and the ratio *k*=0,5; unlike the domes spaced at *L* < *D*, which suffered directly from the effects caused by the presence of the neighborhood. Concerning the wind speed in the simulations, a percentage increase of approximately 21% was observed about the basic speed, especially in areas where the bottleneck in the wind caused by the proximity of the structures occurred, reaching approximately 46m/s making the external pressure coefficients larger on these surfaces.



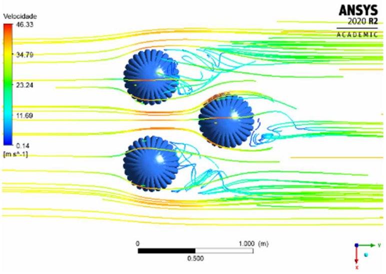
(a) Geometric configuration



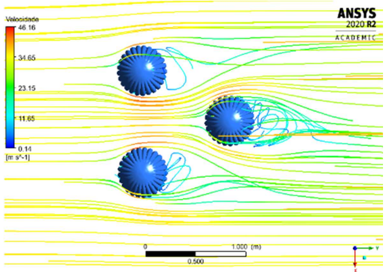
(b) *L*=0,01*D*



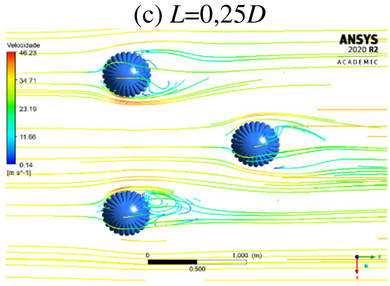
(c) *L*=0,25*D*



(d) *L*=0,5*D*



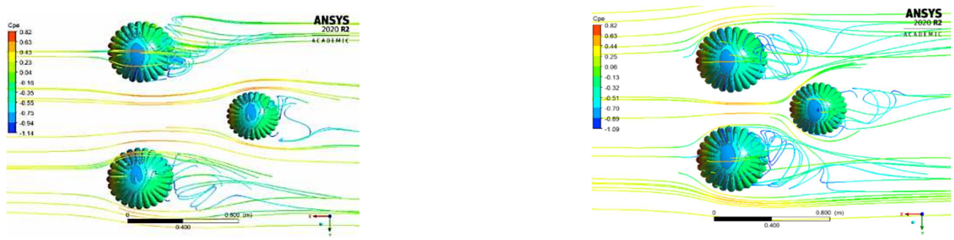
(e) *L*=*D*



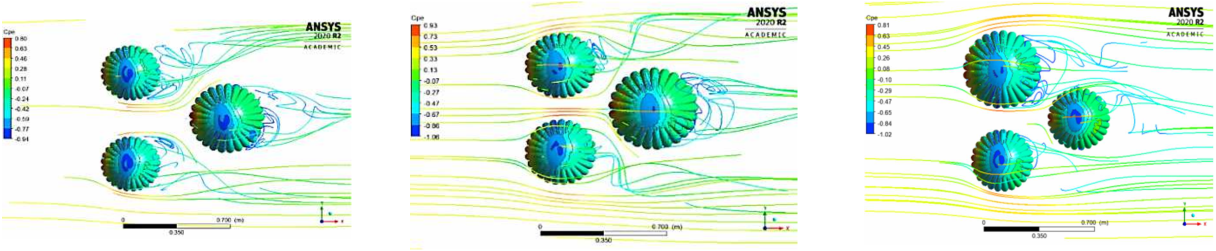
(f) *L*=2*D*

Figure 2. Geometric configuration and variation of external pressure coefficients and the streamlines with respect to the arrangement of three scallop domes with 25 grooves and *k*=0,5

Case 4: In this case, two 25-grooved scallop domes were studied to verify the influence of proportion in the study of neighborhood interference. The same aspect ratio as in the previous case was adopted, varying the diameter, height, and distance of the domes. According to the previous case, there was a greater influence of the neighborhood when *L*≤*D* and, consequently, in the first two simulations, the distance was adopted as *L* = *D* and *L* = 0,5*D*, respectively. The diameter of the interference domes was fixed at *D* = 0,5m and, for the reference dome, the value of D'=4/5*D* was assumed in both applications. The external pressure coefficients and current lines for these profiles are shown in Fig. 3(a-b). Adopting these same distances, there was no discrepancy in the results when compared to the values obtained in the previous case, and also the isobaric lines and the current lines were distributed similarly, with a change of 9% in the first simulation and 3% in the second simulation for the minimum external pressure coefficient. In the third and fourth simulations (Fig. 3(c-d)), the diameter of 4/5*D* was adopted for the interference domes and the value of *D* was fixed for the reference dome. The distance used was *L*=0,5*D* and *L*=0,25*D*, respectively. The results for the third simulation showed a reduction, in module, of 11% of the Cpe_{min}, when compared to the case with the same distance between the domes, demonstrating the tendency of attenuation of the suction values according to the reduction in the proportion of the domes of interference. It was also verified that this same pressure coefficient, in module, increased as the distance between the structures decreases, as observed in the fourth simulation (Fig. 3(d)), contrary to what occurred in the first two simulations, in which the Cpe_{min} declined with the proximity of the domes. The Cpe_{min}, in turn, had its value increased as the structures approached, due to the "funneling" of the wind caused by the interference domes. For the last simulation, *L*=0,25*D* was adopted. One of the interference domes was designed with a diameter equal to *D*, while the other interference geometry and the reference dome were configured with D'=4/5*D* (Fig. 3(e)). As in other simulations involving neighborhoods, it was found that the minimum pressure coefficient of the interference domes to leeward, in module, was greater than that of the reference domes, due to the mat formed between the geometries. In general, in the simulations of this case, there were no significant changes in the pressure coefficients or the distribution of the streamlines, compared to the previous case. However, in the domes with 4/5*D*, as the distance from the other buildings was made, the pressure coefficient, in module, was reduced as a result of the decrease in the proportions of the geometry. Still, the reduction pressure coefficient was not significant. In turn, the diameter domes D showed results similar to the previous case.



(a) *L=D; D'*=4/5*D* (b) *L*=0,5*D; D'*=4/5*D*



(c) *L*=0,5*D; D*=4/5*D'* (d) *L*=0,25*D; D*=4/5*D'* (e) *L*=0,25*D; D*=4/5*D'*

Figure 3. Variation of external pressure coefficients and the streamlines with respect to the arrangement of three scallop domes with 25 grooves and *k*=0,5

4 Conclusions

In the first case, five applications involving scallop domes with six grooves and with variations in the height of the geometry, the coefficients obtained numerically were compared with the literature for validation. The pressure coefficients presented differences concerning the literature, in the order of 13% and 17%, for the minimum and maximum pressure coefficients, respectively. In the second case, the influence of the grooves on the external pressure coefficient and the wind distribution in the structure was investigated considering domes with 10, 14, 25 grooves. It was noticed a decrease in the pressure coefficients as the number of grooves was increased, proving the influence of the grooves on the result of the coefficients. In the third case, the interference of the neighborhood on the external pressure coefficient and the current lines between three domes with identical geometric characteristics, with 25 grooves and the ratio *k*=0,5 was analyzed. The results showed that the wind action caused changes in pressures and current lines in the vicinity of the structures, especially when $L<D$, and they became almost null from $L=2D$. As for the wind speed, there was a percentage increase of approximately 21% concerning the adopted basic speed, seen, above all, in the areas of "tapering" of the wind caused by the proximity between the structures, causing an increase in the external pressure coefficients in these areas. In the last case, the influence of proportion in the study of neighborhood interference for domes with 25 slots and ratio k = 0.5 was investigated, and also the effect of variations in structure dimensions on pressure coefficients and streamlines. It can be noted that, for this configuration, compared to the previous case, the pressure coefficients and the distribution of the current lines did not show significant changes less than the 4/5 D domes which, as the distance of the buildings, the pressure coefficient, in module, was reduced.

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