**Effect of arch height on wind load in shape dome structure**

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**ABSTRACT**

In an optimal design of a dome building, the outer shell with curved shape, plays an important role in the architectural approach, bearing capacity, and structural strength in vertical and lateral loads. In this research, effect of arch in domes against wind is studied, numerically. For this purpose, domes with fixed height–diameter proportion in Type C ground and with the speed and turbulence intensity matching ASCE7 regulations are numerically simulated and the amounts of pressure coefficients (\(C_p\)) are represented on central line corresponding to the wind direction and the rings around the dome with different heights including 0, 0.25h, 0.5h, 0.75h and h. Results indicated the great effect of arch height on \(C_p\) and the percent of under pressure surfaces.

**KEYWORDS:** Dome, CFD, Wind Load, Spatial Structure, Arch.

1. Introduction

In the geometry design of domes, a number of factors along with the lateral loads exerted are usually taken into account. A number of research studies have shown that, specifically, domes to be resistant to symmetrical loads while they are susceptible to asymmetrical loadings like those created by wind or snow [1]. In addition, the load created by wind is a function of the structure geometry. The present study is an attempt to investigate the effect of height in arch of domes on the experienced wind load. For this purpose, five different arch of domes with different heights and similar height – diameter proportion are studied against wind (Figure 1a).

2. Materials and Methods

Present research investigates the effect of the form of domes on \(C_p\), which is a non-dimensional parameter and can be obtained by \(C_p = \frac{\Delta P}{\frac{1}{2}\rho U^2}\), where, \(\rho\) and \(U\) are the density of air and its velocity, respectively. \(\Delta P\) is the pressure difference between the dome surface pressure \(P\) and free-stream pressure \(P_1\). The prototype dome dimensions, which are selected for this study, have an approximate sphere diameter of 168m. The sphere diameter were truncated to a base diameter of 144m and a height of 45m. Letchford and Sarkar [2] studied models of parabolic domes of nearly spherical shape, with a base diameter of 480mm and an apex height of 150mm (Figure 1b). The wind tunnel created a simulation of Exposure C, ASCE7-98 wind code conditions at a scale of 1:300 by using 4 upwind spires, a 240mm fence and 18mm chain floor roughness at 200mm spacing up to the model domes. The mean velocity and turbulence intensity at model apex height are 18m/s and 15\%, respectively. \(Re\)ynolds is approximately, 4.6×10\(^5\). Boundary layer characteristics are also the target values for inlet condition to the test domain for the numerical calculations.

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3. Numerical procedure

This paper evaluates the $C_p$ on the surface of the dome based on 3D steady RANS-RNG implementing Ansys-Fluent software. Figure 2 presents the numerical inlet velocity and turbulent intensity profiles compared to the wind-tunnel measurements and target ASCE7-98 Exposure C code profiles. The profile of Figure 2(a) and 2(b) are used to apply the average imposed velocity to the software and the intensity of turbulence concordant to the ground, respectively. It is not possible to directly apply the profile of turbulence intensity to the Ansys-Fluent software; therefore, values are applied through turbulent kinetic energy ($k$) and turbulent dissipation rate ($\varepsilon$). As it is shown in Figure 2, applied profiles are in accordance with the experimental models.

$$\begin{align*}
K &= \frac{3}{2}(U_{avg})^2 \\
\varepsilon &= \frac{k^2}{l} \\
l &= \frac{0.07L}{\mu^3}
\end{align*}$$

where, $U_{avg}$ is the average ratio of speed to velocity, $I$ is the intensity of turbulence, $l$ is the hydraulic diameter, and $C_\mu$ is the coefficient of the ground type.

Figure 2: Different numerical inlet profile compared to the wind-tunnel measurements and target ASCE7-98 Exposure C code profiles

Results of numerical analysis are shown for $\beta$ angle in the range of 0 to 180 degrees, calculated along the meridian in the wind direction. Figure 3(a) and (b) evaluates the effect of size and number of the mesh over the accuracy of the CFD results. As it is clear from Figure 3(b) the number of $2.49\times10^6$ mesh has the most accordance. Figure 3(c) also shows the verification of the optimized numerical results with Letchford and Sarkar [2].

4. Results and Discussions

Related results to the $C_p$ observed at the central line parallel to the wind direction for the single-arched domes with a height–diameter proportion of 0.5 are presented in Figure 4.

Figure 4: The polygon for $C_p$ at the central line parallel to the wind direction for different domes
Moreover, $C_p$ values obtained for the circles round the domes at different heights for the domes with height–diameter proportion of 0, 0.25b, 0.5b, 0.75b, and b are summarized in Table 1. For all figures and counters, the direction of wind is from left to right.

Table 1: Min and max values of $C_p$ on the central line parallel to the wind direction

<table>
<thead>
<tr>
<th>The name of the dome</th>
<th>Height = 0.25h - 0</th>
<th>Height = 0.5h</th>
<th>Height = 0.75h</th>
<th>h = 0.75h</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_p$ in the windward region of the dome</td>
<td>Minimum pressure coefficient</td>
<td>Maximum pressure coefficient</td>
<td>$C_p$ relative to the central line</td>
<td></td>
</tr>
<tr>
<td>Arch 0</td>
<td>0.61</td>
<td>0.93</td>
<td>1.52</td>
<td>3.91</td>
</tr>
<tr>
<td>Arch 0.25b</td>
<td>0.62</td>
<td>0.85</td>
<td>1.21</td>
<td>2.89</td>
</tr>
<tr>
<td>Arch 0.5b</td>
<td>0.69</td>
<td>0.82</td>
<td>1.08</td>
<td>2.60</td>
</tr>
<tr>
<td>Arch 0.75b</td>
<td>0.70</td>
<td>0.80</td>
<td>0.94</td>
<td>1.79</td>
</tr>
<tr>
<td>Arch b</td>
<td>0.63</td>
<td>0.63</td>
<td>0.74</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Results of the analyses showed that the max and min values in the windward region of the dome at different heights, shown in the graph, are usually used for designing purposes.

5. Conclusions

In the present study, Effect of arch height on wind load of shape dome structure was investigated. Verification showed that RANS-RNG turbulence model is an appropriate model for numerical simulation of domes. Results of this study showed that arch height play an important role in the amount of lateral wind load on the domes. The max and min $C_p$ occur on the central line parallel to the wind direction and at the front and top of the dome. By increasing the arch height, min and max $C_p$ is decreased and increased, respectively. Also, under pressure surface is reduced with increasing arch height. Results of this study showed that the lowest amount of wind force is applied to the domes with arch height of b, 0.25b, 0.75b and 0.5b, respectively.

References
