# Numerical and Experimental Investigation of the Effect of Wind Load on Spherical Domes, Focusing on the Type of Roof Covering

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**ABSTRACT**

In today's architecture, the use of space structures is very common and has attracted the attention of designers. Various forms of these structures can be seen in architectural designs and structures, and one of these types of structures is spherical domes. To calculate the wind load on all structures, one of the most important coefficients required is the wind pressure coefficient (Cp), which actually considers the effect of the geometry of the structure in the calculation of the wind load on the structure. In the loading codes, the coefficient (Cp) is provided for some geometries. In this article, the effect of wind load on spherical domes with three height-to-span ratios of 0.25, 0.5 and 0.75 has been investigated. Also, the effect of surface roughness has been studied in this research.The maximum of negative pressure coefficients (suction) for domes with a height to span ratio of 0.25, 0.5, and 0.75 are obtained as -0.86, -1.07, and -1.22, respectively. In domes that have protrusions in the covering roofs, these protrusions cause a general change in the wind pressure coefficients compared to the wind pressure coefficients in the domes with a the covering becomes without protrusions; Therefore, the most effective position of the projection is when the projection of the dome is placed at an angle of 90 degrees to the direction of the wind ($\theta$=90°), in which case the pressure coefficients jump from negative values to positive values to Cp=+0.7 it arrives.

KEYWORDS: Keywords: Wind pressure coefficient; Computational fluid dynamics;Wind force;Wind tunnel; spherical dome.

## Introduction

In recent years, the construction industry has focused on the development of steel and composite structures due to the advantages of ease and speed of construction, effective use of materials, lightness and strength of structures [1]. Space structures (three-dimensional trusses) are one of these types of structures. In practice, space structures are usually used for roof coverings and, due to their inherent nature and various structural features, they either lack internal support or have minimal internal support. Given that most of these types of structures are lightweight structures, wind load is usually considered as the dominant lateral load. Structures must be designed so that, in addition to bearing gravity loads, they are also resistant to lateral loads such as wind. The requirement for a robust design under wind influence is to accurately obtain the wind pressure distribution coefficients on these types of structures. In fluid mechanics, there are two ways to calculate various parameters of the fluid flow field such as velocity and pressure. The first method is the numerical solution of the Navier-Stokes equations and continuity in computational fluid dynamics, which are numerically solved using various methods such as the finite difference method, the finite volume method, and the finite element method [2]. The second method is to conduct experimental tests in wind tunnels, which is considered one of the most efficient methods. Spherical domes are one of the common types of domes, in which the wind pressure coefficients change with the height-to-span ratio. Many studies have been conducted on the effect of wind load on structures [3-10]. In this study, the wind pressure coefficients on spherical domes with three height-to-span ratios of 0.25, 0.5, and 0.75 have been investigated, and the wind pressure coefficients have been obtained using wind tunnel tests and numerical modeling based on computational fluid dynamics using Ansys software. Figure 1 shows examples of spherical domes with different height-to-span ratios and coverings. The covering of this type of structure, such as that seen in Figure 1, can include concrete, wood, corrugated metal sheets, etc.

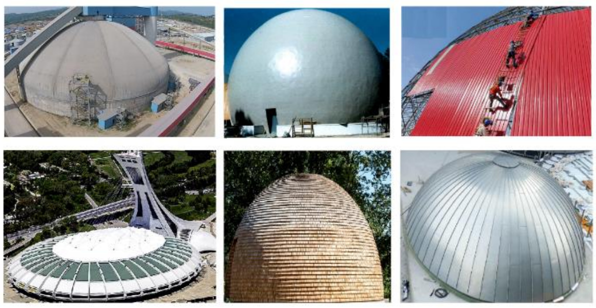

Figure 1. Some examples of spherical domes with different coatings

The pressure coefficient (Cp) depends on the geometry of the building, and the values of this coefficient are available in various codes. This coefficient is obtained by dynamic analysis of wind flow behavior. According to the codes, the pressure or suction caused by the wind on a component or the entire surface of a structure or building is obtained from equation (1).

$$p = I_w q c_e c_t c_g c_p c_d \qquad (١)$$

The dimensionless pressure coefficient Cp is defined as equation (2).

$$C_P = \frac{P - P_0}{\frac{1}{2}\rho U^2} \qquad (٢)$$

### 2- Wind tunnel test

One of the appropriate methods for investigating the effect of wind on structures is to use wind tunnel testing, and the use of this method is recommended in most codes. In Figure 2, the spherical dome models are shown along with images of the wind tunnel. As can be seen in this figure, to measure the wind pressure, a hole must be made at each point where the wind pressure is desired, and a hose is installed in each hole to measure the pressure, and the hose is connected to the pressure measurement sensor on the other side. Due to the limited number of sensors to measure the wind pressure coefficients, twenty holes are made on each model. The models are placed on a graduated plate in the wind tunnel and rotated 5 degrees to 90 degrees each time, and the wind pressure coefficients are measured at each angle. The wind inlet speed in numerical analyses and wind tunnel tests is considered to be 20 m/s.

Figure 2: Details of the tested models with wind tunnel components

In Figure 3, spherical dome models are shown along with images of the wind tunnel. As can be seen in this figure, to measure wind pressure, a hole must be made at each point where the wind pressure is of interest, and a hose is installed in each hole to measure the pressure, and the hose is connected to the pressure measurement sensor on the other side.

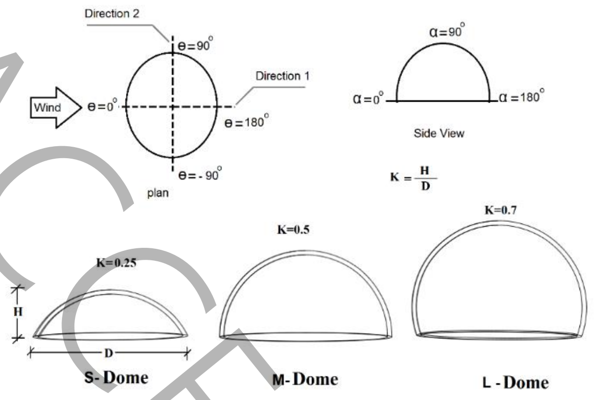


Figure 3: Details of the spherical dome models studied

**4- Numerical modeling**

Simulations were performed using CFD method in ANSYS Fluent . The k-epsilon model was used in this study due to its good agreement with the experimental results. In Figure 4, the contour of the pressure coefficients on the domes S, M, and L resulting from numerical modeling is observed. The pressure coefficients are also plotted in Cartesian and polar coordinates. It is observed that with increasing the height to diameter ratio of the dome (k), the maximum positive pressure coefficients and also the maximum negative pressure coefficients (suction) increase.

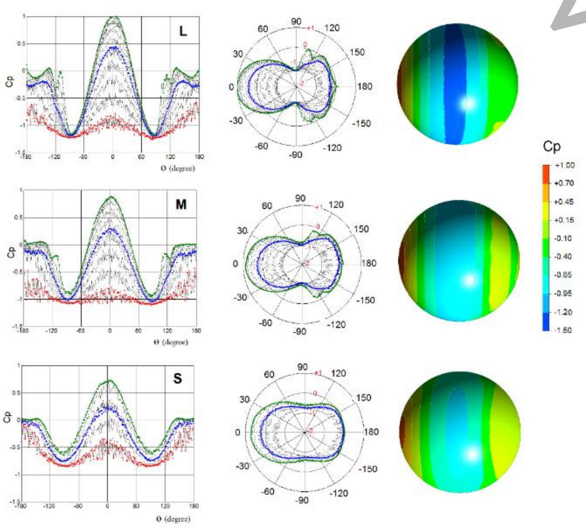


Figure 4: Contour of wind pressure coefficients along with a graph of these coefficients in spherical domes resulting from numerical modeling

**4- Numerical modeling of domes with protrusions in the cover**

In this section, with the aim of investigating the effect of creating protrusions in the roof covering similar to what is presented in Figure 1, the effect of these protrusions has been investigated. In Figure 5, the creation of protrusions on the surface has been investigated. Figure L-1 has four protrusions that divide the roof into four areas. The number of protrusions gradually increases until in sample L-8, the number of protrusions in the roof reaches 18. These domes have been modeled in the software and the results are presented. In Figure 6, the contour of the pressure coefficients on these domes has been drawn. With the increase in the number of these protrusions on the surface of the structure, the change in the pressure coefficients is clearly evident.

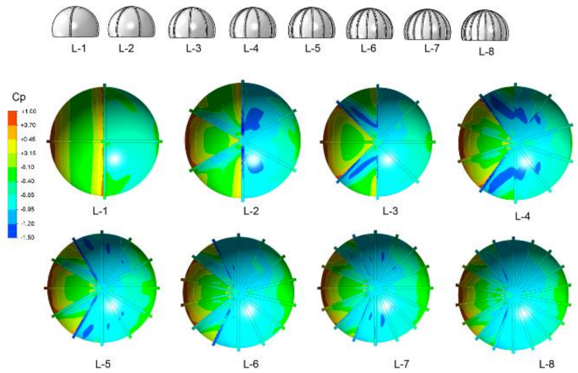


Figure 6: Contour of pressure coefficients on L-shaped spherical domes with protrusions created on the structure

**5. Conclusions**

In this paper, the effect of wind load on spherical domes was investigated and the wind pressure coefficients on this type of domes were presented using wind tunnel testing and numerical modeling based on computational fluid dynamics (CFD). The following results were obtained from the research**.**

a) As the height to opening ratio of the dome increases, the maximum negative pressure (suction) values increase. In domes with a low height to opening ratio, a larger area of the dome is subjected to suction, so that in the wind tunnel test, it is observed that domes with low heights are pulled upwards from the bottom of the tunnel under the influence of wind load.

b) The maximum positive pressure coefficients obtained from numerical modeling in domes S, M and L are equal to 0.66, 0.78 and 1.02, also the maximum negative pressure coefficients (suction) for the mentioned domes are equal to -0.86, -1.07 and -1.22 respectively. By observing the pressure coefficient contours, it is observed that the pressure coefficient is almost constant at θ=150° to θ=180° for all domes.

C). The most effective position of the protrusion is when the dome protrusion is at θ=90°, in which case the pressure coefficients jump towards positive values to Cp=+0.7.

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