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Aerodynamic Evaluation and Modification of Tehran International Tower Section Exposed to Annual Winds

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ABSTRACT: In the current research, the numerical simulation of the wind flow around the geometry of the 56-story Tehran International Tower exposed to different wind velocities in different directions has been performed and the aerodynamic forces, amplitudes, and frequencies of their fluctuations have been calculated. Then, according to the unfavorableness of any aerodynamic force acting on the tower from a structural point of view, from the combination of the average values and the range of fluctuations of the aerodynamic coefficients at each wind velocity and angle in the city of Tehran, a criterion for the aerodynamic evaluation of the Tehran International Tower exposed to annual winds has been presented. Numerical calculations have been done in an unsteady incompressible manner using the k-ω SST turbulence model. The most critical wind speeds and positions on the tower are detected at the directions of 0 and 20 degrees at wind speeds of 15 and 10 m/s, respectively. In order to improve the aerodynamic properties changes are made in the geometry of the tower and a new geometry is introduced and its aerodynamic coefficients are compared with the current geometry of the tower. According to the obtained results, the modified geometry has lower total aerodynamic coefficients than the original geometry in all critical wind situations and causes an average reduction of 21% in the total aerodynamic coefficients compared to the original geometry.

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1- Introduction

The forces acting on towers through wind, called aerodynamic forces, play an important role in the design and structural considerations of the tower. The forces acting on towers fluctuate over time due to the phenomenon of vortex shedding. The presence of these oscillations in aerodynamic forces induces vibrations in the structure and causes the phenomenon of Vortex Induced Vibrations (VIV). In addition to causing the phenomenon of fatigue in the tower structure, these vibrations can also lead to the occurrence of the phenomenon of resonance, if the frequency of the vortex shedding is close to the natural frequency of the tower. Research has been done on the interactions of fluid flows against blunt bodies. These studies are performed either experimentally in the wind tunnel, or via numerical simulations of the fluid flow called Computational Fluid Dynamics (CFD). Tehran International Tower is a 56-story residential tower with a height of 162 meters. The geometry of the Tower cross section can be simplified as a prism with twelve faces. One of the objectives of the present study is to evaluate the aerodynamic efficiency of the tower cross section and then reform it in such a way that either the forces acting on it or the amplitude of the fluctuations get reduced. In the research of Mukherjee et al. [1] the pressure distribution on different surfaces of a tower with a Y-shaped cross-section at angles of attack from 0 to 60 degrees experimentally in the wind tunnel and numerically using the Ansys CFX solver and with K-Epsilon and SST turbulence models were obtained. According to the results, the accuracy of the K-Epsilon turbulence model is better than SST. model, but the SST model has the ability to more accurately predict the pressure in the region with high turbulence. Sanyal et al. [2] compared the pressure and load caused by the aerodynamic force resulting from the wind blow on buildings with Y-shaped cross-section with corner modifications including chamfering and rounding by Ansys CFX solver and two turbulence models namely K-Epsilon and SST was done. The results were compared with the experimental data in the same flow condition and it was concluded that the modification by rounding the corners is more effective in reducing the load caused by the wind than chamfering. The cross section of the Tehran International Tower has three axes of symmetry. As a result, it is enough for one-sixth of the tower geometry to be examined in terms of aerodynamic performance and the obtained results can be generalized to the rest of the geometry.

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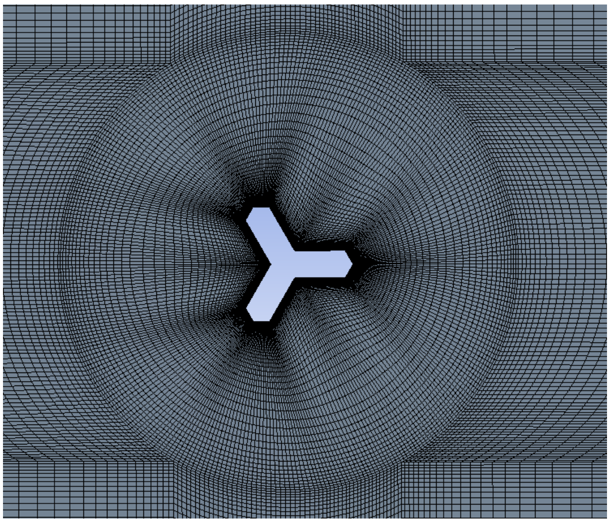

Fig. 1. structured grid around the tower's cross section

2- Methodology

Considering the effect of aerodynamic forces on the tower at a maximum wind velocity of 15 meters per second, it can be said that the Mach number of the flow is 0.04, which is much smaller than the threshold of compressibility of the fluid flow. Therefore, to simulate the atmospheric conditions in the present study by Ansys Fluent software, the pressure-based method has been used. Also, due to the oscillating nature of lift and drag aerodynamic forces in the flow regime of the present study, the solution should be done transiently. To numerically simulate turbulence in the present study K-Omega SST. model. is Used. In order to couple the equations of velocity and pressure, the Semi-Implicit Method for Pressure-Linked Equations (SIMPLE) method has been used. Boundary conditions applied in the boundaries of the numerical domain are velocity inlet and pressure outlet, and for the upper and lower boundaries of the solution field, a wall with zero shear or zero-shear wall is considered. The walls of the examined object utilized no-slip condition and are without surface roughness. The mesh type used in the present study is an O-Type grid around the object which is placed in a rectangular field. The usage of this type of domain is very common in similar research. The dimensions of the solution domain are 8 times the characteristic length in the upstream and left and right of the object and 32 times the characteristic length in the downstream. Also, for the diameter of the O-type part of the solution domain, the diameter 4 times the characteristic length is used. The mesh types used in the current simulations, are structured grids (Fig. 1).

3- Results and Discussion

Fluid flow numerical simulation around the cross section of the tower in seven wind directions Fig. 2 at four velocities of 1, 5, 10, and 15 meters per second has been performed. In

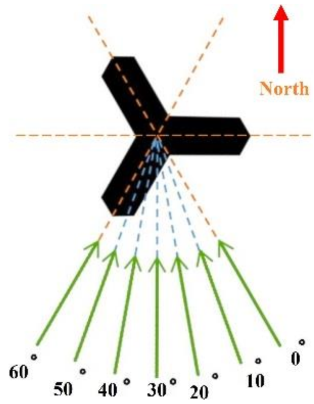

Fig. 2. Phase velocity dispersion curves for a steel pipe with outer diameter of 220 mm and wall thickness of 4.8 mm

Table 1. most critical wind directions in each velocity

wind velocity (m/s)	most critical wind direction (degrees)	scale of critical wind directions
15	0	7.839
10	20	4.26
5	20	1.1
1	0	0.036

order to compare the criticality of aerodynamic conditions, the mean values and the amplitude and frequency of oscillations of the lift and drag coefficients are obtained. The amplitude of the fluctuations was calculated by Fourier analysis. In order to compare the flow condition in different directions and wind velocities (in terms of aerodynamic criticality), the quantities of average values and amplitudes of fluctuations of lift and drag coefficients can be added together

and multiplied by the weight function $\frac{V_\infty^2}{V_{\max}^2}$ in each of the seven angles which wind blows from zero to sixty degrees and at constant wind velocities to yield the scale of critical wind directions Table 1. (V_{max} is the maximum wind velocity examined in simulations that is 15 m/s and V_∞ is the wind velocity in the investigation). The reason for using a weight function at this point is to illustrate and highlight the importance of higher velocity magnitudes in aerodynamic criticality.

Now the rotational position around the height axis of the tower in the geographical zone which the tower is placed should be investigated. It should be checked that the geographical directions that have the windiest days at the velocities that are more critical for the tower do not face the positions of the tower that will create more critical conditions if the wind

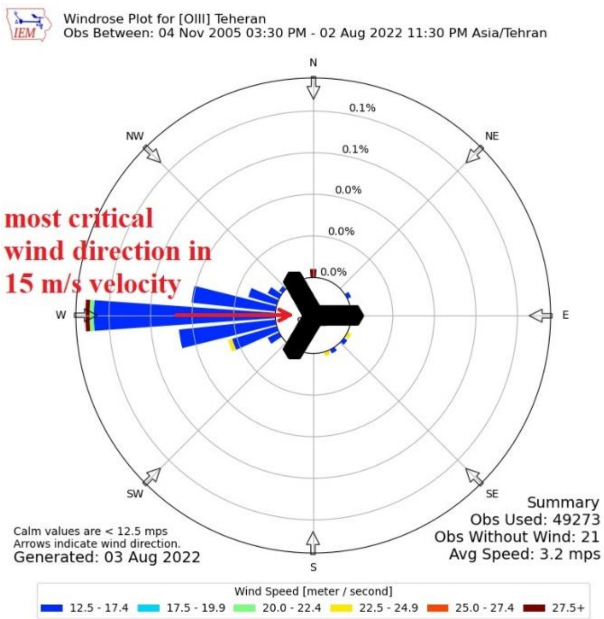

Fig. 3. wind rose of Tehran with the 15 m/s velocity highlighted

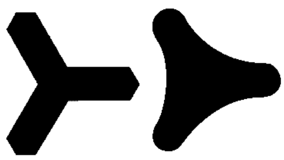

Fig. 4. modified geometry (right) and the original geometry (left)

blows on them. The wind rose of Tehran city is extracted from the Iowa state university environmental mesonet website [3] and from data exported from Mehrabad airport. Now, it can be said that for the wind velocities of 15 and 10 meters per second, which generate larger forces, the critical wind direction is aligned with the wind rose directions that have the highest number of windy days Fig. 3. this deficit can be improved by rotating the tower around the axis of height by thirty to fifty degrees. There are several methods to modify the geometry of the tower in the present study, such as chamfering, rounding, and cutting square pieces from the corners. In the present study, as a correction of the geometry, the pointy corners of the cross-sectional geometry got curved Fig. 4. In order to compare the original and modified geometries, quantities of averaged and the amplitudes of fluctuations of lift and drag coefficients are added together and multiplied by the weight function of $\frac{V_\infty^2}{V_{max}^2}$ in each wind direction from zero to sixty degrees (V_{max} is the maximum

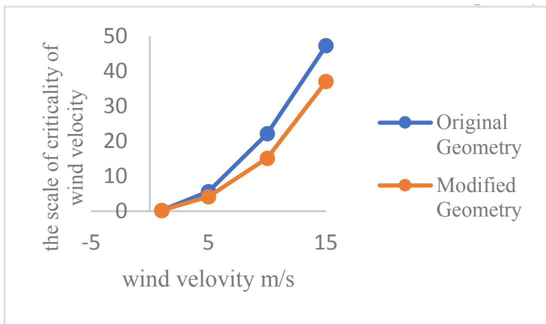

Fig. 5. the scale of criticality of wind velocity

wind velocity examined in simulations that is 15 m/s and V_∞ is the wind velocity in investigation) to show the effect of greater importance of larger velocities in aerodynamic forces. And make a summation from 0 to 60 degrees in each velocity to yield the scale of criticality of wind velocity Fig. 5. It can be acknowledged that in terms of total aerodynamic coefficients, the modified geometry has a better performance than the original geometry of the tower. Now, in order to evaluate the frequency of fluctuations of the aerodynamic coefficients of lift and drag, the natural frequency of the structure must first be determined. The closer the oscillation frequency of the aerodynamic coefficients to the natural frequency of the structure, the more critical the conditions will be. The natural frequency of the structure is yielded by the approximate relationship presented in Ref. [4] is with respect to tower's height about 0.278. Now, since the maximum frequencies of drag and lift oscillations in the original geometry are 0.07 and 0.037, respectively, and in the modified geometry are equal to 0.0884 and 0.0458, an increase of 20.8% in the frequency of drag oscillation and 19.2% in the frequency of lift oscillations can be seen. However, given that the frequency of oscillations of the aerodynamic coefficients of lift and drag are still a long way from the natural frequency of the structure, it can be said that the modified geometry has not made the situation that more critical.

4- Conclusions

In this research, the wind flowing at four different velocities of 1, 5, 10, and 15 meters per second and from seven different directions around the Tehran International Tower section was numerically simulated and the most critical conditions in terms of the sum of the average values were determined. The most critical condition for the wind velocity of 15 meters per second is the blowing direction of 0 degrees for the original geometry and the blowing direction of 10 degrees for the modified geometry. According to the results and the wind rose of Tehran, if the tower rotates around the height axis by 30 to 50 degrees clockwise or counter-clockwise, the tower will face the geographical directions having lesser windy days with the critical velocity. Also, a modified geometry has been proposed to improve the aerodynamic conditions of the tower, which in all cases has a better performance than the original geometry in terms of the comparative aerodynamic parameters. Therefore, the modified geometry has generally improved the aerodynamic properties of the tower section.

References

[1] S. Mukherjee, S. Chakraborty, S. Dalui, A. K. Ahuja, Wind induced pressure on 'Y' plan shape tall building, Wind and Structures an International Journal, 19(5) (2014) 523-540.

[2] P. Sanyal, S. K. Dalui, Effect of Corner Modification on 'Y' Plan Shaped Tall Building Under Wind Load, Wind and Structures, 30(3) (2020) 245-260.

[3] https://mesonet.agron.iastate.edu/sites/dyn_windrose.phtml?station=OIII&network=IR__ASO

[4] B. R. Ellis, an assessment of the accuracy of predicting the fundamental natural frequencies of buildings and the implications concerning the dynamic analysis of structures, Proceedings of the Institution of Civil Engineers, 69 (1980) 763-776.

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