Computational modeling of wind effects on a tall building by the finite element method

Bakdauren Narbayev, Yerlan Amanbek

Nazarbayev University

Abstract:

Pedestrian wind comfort plays important role in the urban environment. In our work, we consider a model obtained using the Computational Fluid Dynamics (CFD) around the tall building. Our focus is the Tower of Abu Dhabi Plaza in Nur-Sultan city (Kazakhstan), which will be the tallest building in Central Asia with a height of 382 m. We investigated the effect of the wind velocity for pedestrians solving the incompressible time-dependent Navier-Stokes equations in the deal.II library by the Finite Element Method (FEM) using the projection method. We present numerical simulation results for various scenarios. It has been found that the velocity profile can vary in the domain that creates different pedestrian comfort conditions including the extreme category [1] at places dedicated to pedestrian walking.

Figure 1: Abu Dhabi Plaza under construction
Source: Adapted from [2]

Methods:
To run the simulations of the flow, we used the step-35 case of the deal.II (open-source library), which helps to solve partial differential equations numerically by FEM. Particularly, we solved the incompressible time-dependent Navier-Stokes equations with the incoming flow that has a parabolic structure. It means that, first of all, no-slip boundary conditions on both the top and bottom boundaries of our model and the boundaries of the building are imposed. And secondly, the initial velocity values increase towards the middle of the vertical-left boundary. The equations themselves are as follows:

$$\begin{aligned} \mathbf{u}_t + \mathbf{u} \cdot \nabla \mathbf{u} - \nu \Delta \mathbf{u} + \nabla p = f, \\ \nabla \cdot \mathbf{u} = 0, \end{aligned}$$

where $\mathbf{u}$ is the velocity of the fluid and p is the pressure.

We generated the mesh for the provided setting and the code discretized it for the Navier-Stokes problem. The results are visualized by ParaView, which is open-source software.

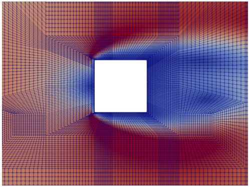

Figure 2: The part of the final mesh of the top view setting

Main Results:

We conducted numerical examples for various scenarios in 2D. The first case is the view from the side of the building and the second is from its top. We simulated numerically for different values of the incoming flow velocity in the x-direction. In addition, we studied the effect of different Reynolds numbers. Finally, we compared the velocity profile in the domain for different corner structures (round corners vs sharp corners) in the top view case. Particular parameters for the simulation results (figures on the right) are shown below.

Table 1: The parameters' values for the simulations in the figures

Reynolds number	200
Time step	5e-3
Duration	100
Maximum initial velocity	23 m/s
Boundary condition	No-slip

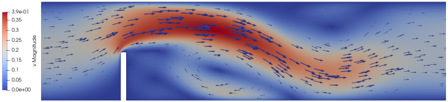

Figure 3: Side view

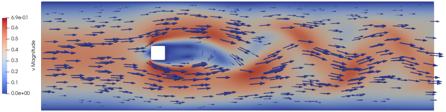

Figure 4: Top view with sharp corners

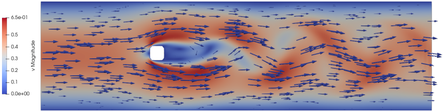

Figure 5: Top view with round corners

Conclusion:

The analysis and simulations indicate that the maximum initial velocity value of 23 m/s results in velocity values that belong to the exceeding category [1]. This means that the building's height and width increase the wind velocity to the level when pedestrians cannot reach their destinations.

Table 2: The maximum wind velocity values after simulations for different views

View	Maximum Velocity
Side	49.66 m/s
Top (sharp)	31.25 m/s
Top (round)	29.44 m/s

- Although the maximum velocity of the side view case is reached at height, which is greater than the building's roof, simulation suggests that the maximum velocity at pedestrian's height can reach a value of 25.47 m/s, which still belongs to the exceeding category [1].
- The maximum velocity of wind in the top view case with sharp corners is higher than that of the case with round corners by approximately 1.81 m/s. This implies that round corners best serve for purpose of holding the velocity of the wind from increasing its value.
- To prevent such an increase in wind velocity, it is evident to plant trees and add more obstacles in such places, where we can minimize the wind velocity so that pedestrians can walk.
- Finding such places and adding more parameters such as temperature is our focus for the next studies.

References:

[1] Adamek, Kimberley., Vasan, Neetha., Elshaer, Ahmed., English, Elizabeth., & Bitsuamlak, Girma., Pedestrian Level Wind Assessment through City Development: A Study of the Financial District in Toronto.Sustainable Cities and Society http://dx.doi.org/10.1016/j.scs.2017.06.004

[2] Sibom, Abu Dhabi Plaza. 16-Aug-2020. [Online]. Available: https://ru.wikipedia.org. [Accessed: 21-Oct-2020].