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Bio-inspired geometries in mitigating the fire-enhanced wind load of a low-rise building

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1. INTRODUCTION

Bushfires result in widespread damage to the environment, infrastructure, and communities. Apart from the destruction of the structures caused by burning, wind loading of the structure also increases due to the complex interaction of the thermal plume with the wind, resulting in an enhanced airflow. In athermal conditions, wind loads on low-rise buildings have been studied extensively in engineering research due to the wind-induced damage to these structures in strong wind episodes like hurricanes. However, the interaction of such a complex flow field with a structure has been largely overlooked and is infrequently explored in previous studies. In addition, the application and effectiveness of bio-inspired geometry modifications to a building have not been reported in the literature.

2. PHYSICAL MODEL AND NUMERICAL METHODS

As the Mach number is low ($Ma \ll 0.3$), and the building height is at the scale of 10 meters, the aerodynamics is governed by the incompressible Navier-Stokes equations and solved by using the hybrid recursive regularized lattice Boltzmann method (HRR-LBM). The boundary condition at the fluid-structure interface is handled by the feedback immersed boundary method (IBM). The energy equation is solved by the finite difference method (FDM) and fire is modelled as a simple volumetric heating source model. The Vreman model is used for the SGS stress in LES. The vortex method is adopted to synthesize the turbulent boundary layer at the inlet of the computational domain. Two gabled-roof buildings with a roof pitch of $3:5$ and an eave height of H are studied here: the sharp edge and the scalloped edge. A sinusoidal pattern with a peak radius of $r_p/H = 0.025$ and trough radius of $r_t/H = 0.15$ and wavelength of $\lambda/H = 0.1$ is applied to the edges of the scalloped building, and the corners are rounded with r_p. The Reynolds number based on the wind velocity [1, 2] is set to $Re_H = UH/\nu = 2.54 \times 10^5$. The heat release rate of fire is kept constant as $191.6kw$ [1] and is liberated in a cubical domain with dimensions $0.05H \times 0.05H \times 0.5H$. The Rayleigh number is $Ra_H = 8.77 \times 10^{18}$ and the Prandtl number is $Pr = 0.71$.

3. RESULTS AND DISCUSSIONS

Figure 1 compares the flow field around the sharp-edge structure in wind-only ($ShE - Wo$) and fire-enhanced wind ($ShE - FeW$) cases. As shown, the fire source has a substantial impact on the flow field. Specifically, the vortical structures of time-averaged flow fields are quite different. The horse-shoe vortex, which is a characteristic vortical structure of a wall-mounted bluff body, is much smaller and closer to the building in the mean flow field as in Fig. 1.

Figure 2 compares the mean pressure coefficient for two different lines extending over the ridge ($x = 0$) and normal to the ridge ($z = 1.375H$) for the sharp edge (ShE) structure as well as the scalloped edge building (ScE) in wind-only (Wo) and fire-enhanced wind (FeW) cases. In wind-only conditions, the roof edge ($x = 0$) is exposed to the highest wind load. For the fire-enhanced wind case, however, the flank areas are exposed to a considerably higher pressure load (40%) due to the interaction of the counter-rotating vortex pair with the roof, as can be seen in Fig. 1. The strong suction on the side walls is related to the formation of the wake vortices in this area. The pressure coefficient on the

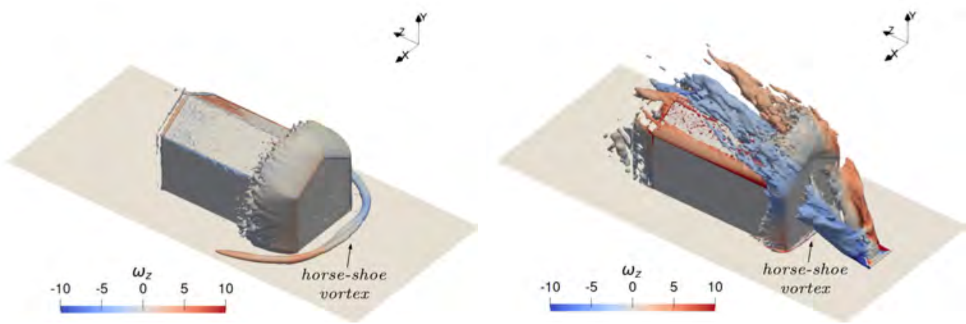

Figure 1. Vortical structures identified by Q-criterion ($Q = 2$) applied to the mean flow and colored by mean streamwise vorticity: (left) sharp edge building in wind-only condition ($ShE - Wo$) and (right) sharp edge building in fire-enhanced wind condition ($ShE - FeW$).

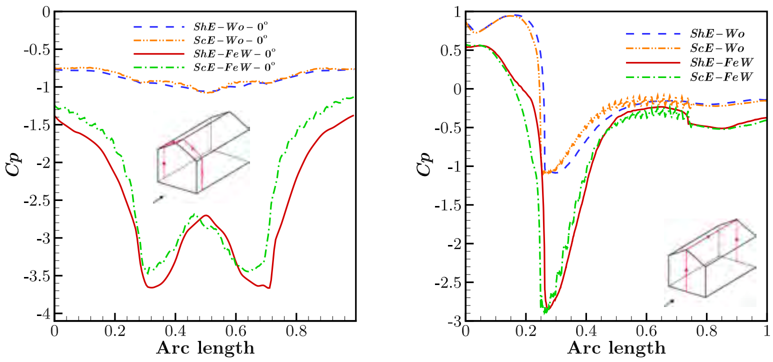

Figure 2. Comparison of the mean pressure coefficient for sharp edge building in wind-only condition ($ShE - Wo$) and in fire-enhanced wind condition ($ShE - FeW$) as well as the scalloped edge building in wind-only condition ($ScE - Wo$) and in fire-enhanced wind condition ($ScE - FeW$) along: (left) the critical section line ($z = 1.375H$), and (right) over the midplane ($x = 0$).

windward face of $ShE - FeW$, as shown in Fig. 2-(a), is lower compared to the other case due to the blocking effect of the fire plume. On the building ridge, the pressure coefficient substantially drops due to the higher velocity magnitude and formation of a larger separation bubble. The pressure field recovers further downstream of the ridge but remains slightly lower than the wind-only case. On the leeward face, a lower-pressure field is formed. In addition, scalloping the edges of the building can notably decrease the roof load by increasing the momentum exchange in the boundary layer via the streamwise vorticity generated between the tubercle peaks [3].

4. CONCLUSIONS

A three-dimensional numerical study is conducted to explore the role of fire-enhanced wind on the wind load of a gable roof building. Two major conclusions have been drawn. First, in fire episodes, the building roof experiences a much higher wind load compared to wind-only conditions. Second, the proposed bio-inspired geometry can effectively reduce the wind load on the roof in both fire-enhanced wind and wind-only conditions.

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