Numerical investigation of wind actions on elevated houses

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ABSTRACT:
During recent hurricane seasons, different levels of damage have been observed for elevated coastal houses due to wave and wind actions. Along the coastline, elevated residential houses are venerable to flooding and strong wind hazards. The structure unique aerodynamics are not well addressed in the current design guidelines. Although the structural design considers the velocity increase due to the increase in building height when elevated, recent post-hurricane surveys reveal severe damages on elevated building's walls and roof surfaces. The air flow through the building is affected by the presence of the air gap, the model dimensions, and height. This study uses the Computational Fluid Dynamics (CFD) numerical tool to perform a parametric study on elevated houses with different stilt heights and different aspect ratios. This study identifies the most critical configurations and geometrical ranges found to cause the maximum global forces on the structure.

Keywords: Elevated house, CFD, streamlines, wind tunnel, wind force, and stilt height.

1. INTRODUCTION

Coastal regions are considered the most attractive and strategical areas for population, business, and tourism. However, several tropical houses have experienced considerable wind-induced damages during recent hurricanes, including roof and wall cover loss (Amini and Memari, 2020). A recent example is Hurricane Sally, in 2020, which hit the southern coast of the United States with a wind speed of 165 km/h (105mph) (NOAA, 2020), caused total insured losses between one billion and three billion dollars (Behnken and (NASA), 2020). Hurricane Laura and Delta hit southwest Louisiana and caused a $5 billion total insurance loss. To reduce the risk of combined wind and wave actions on vulnerable coastal communities, FEMA and the construction industry have recommended elevating coastal houses to avoid flooding hazards. However, as the house is elevated on stilts, the wind speed increases (i.e. higher height), and the presence of the air gap beneath the building affects the overall wind actions on the building surfaces. Recent post-hurricanes surveys for elevated houses with different configurations have sustained severe damages (StEER, 2019). These houses were elevated using different stilt heights and a wide range of aspect ratios. Therefore, more investigation is needed to provide a comprehensive methodology to predict wind loads acting on elevated houses. The study presented here reports an extensive numerical analysis performed using Computational Fluid Dynamics (CFD) to investigate the aerodynamics of a single-story house. This study focused on identifying the geometrical controlling parameters which can assist in designing future experimental studies on elevated structures for codifying purposes.

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2. NUMERICAL MODEL DESCRIPTION

The numerical simulation was performed on a gable-roof typical residential building in full-scale. A typical low-rise gable roof model was adopted for this study. The model horizontal dimensions were 8.76 m long, 6.4 m wide, which is the same as the elevated house prototype tested in the Wall of Wind (WOW) Experimental Facility (EF) (Abdelfatah et al., 2020). The developed CFD model was first calibrated against the experimental results obtained from the WOW testing (Abdelfatah et al., 2020). After that, a parametric study was conducted using the Reynolds-Averaged Navier–Stokes (RANS) model to visualize the wind flow around the building and assess wind actions on elevated structures and their variations with the building stilt height and aspect ratio. The CFD study covers a wide range of building plan aspect ratios, by changing the model length, varying from 1 to 2.5 with a 0.25 increment. A wide range of stilt heights has been considered varying between 0 (i.e. on ground) to 4.8m with a 0.6m increment. For each case, the model was tested under three wind directions: 0º (i.e. acting along the ridge line), 45º, and 90º.

The turbulent model named RNG k-ε was used to perform the simulation as recommended by (Jeong et al., 2002; Tominaga et al., 2015). Where, k is the turbulent kinetic energy, and ε is the turbulent dissipation rate. This model can moderately predict and enhance the turbulent kinetic energy. As recommended by (Franke and Baklanov, 2007), the domain dimensions were chosen to avoid any external effect by means of the domain walls. The domain region was divided into three million cells to precisely monitor the flow streamlines, as shown in Fig. 1. All the necessary boundary conditions were calculated precisely to define the exact wind profile to match this simulated at the WOW (Abdelfatah et al., 2020).

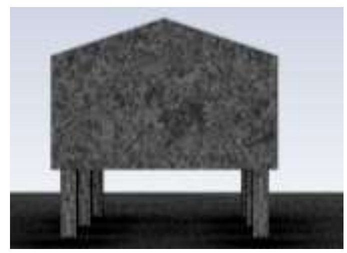
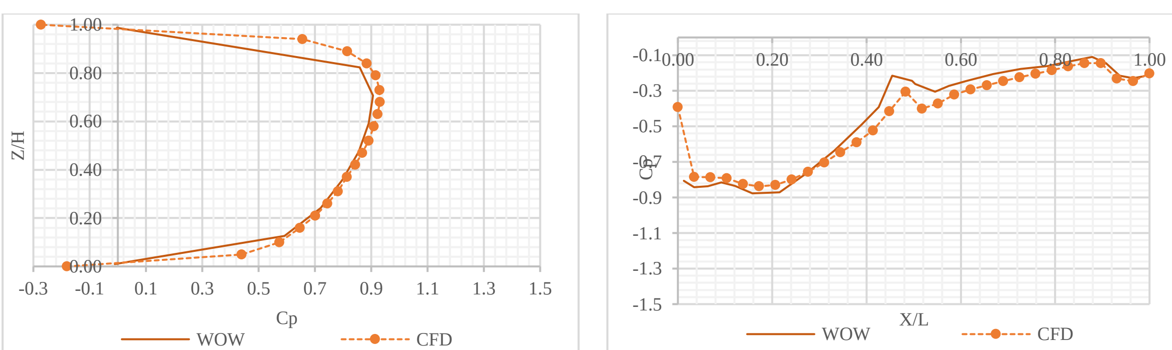


Figure 1. Numerical model of the 1.8m elevated house

3. RESULTS

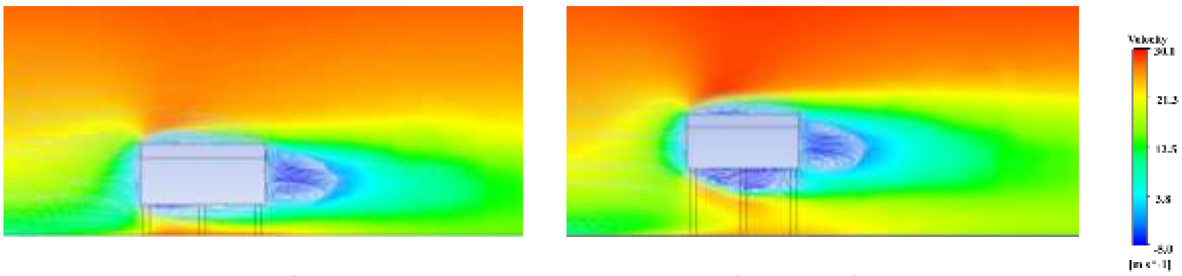
The developed CFD model was first validated using the experimental results obtained from the WOW testing (Abdelfatah et al., 2020). Fig. 2 shows the plots of the mean pressure coefficient variation with model length (L) and model height (H) in both methods. The slices have been taken at the mid span of the 1.8m stilt case in case of zero wind direction. The figures reveal a good agreement between the experimental and numerical results. The differences between the results do not exceed 10%.



(a) 1.8m stilt case

(b) 4.8m stilt case

As mentioned in the introduction, the parametric study covers two variables: the stilt height and the building plan aspect ratio. For all the studied cases, the mean pressure coefficient was calculated using the 3-sec velocity at the mean roof height as a reference velocity. By increasing the stilt height, the difference in the mean pressure coefficient was not significant for the 0º and 90º wind directions. However, for the 45º wind direction, there was a high suction around the stilt which increases as the stilt height increases. The resulting local mean pressure coefficients were similar for the elevated house's different aspect ratios in case of wind acting parallel to the roof ridge. However, for 45º and 90º wind directions, the suction occurring on the roof surface and the floor surface was significantly higher for larger aspect ratio.



(a) 1.8m stilt case (b) 4.8m stilt case

Figure 3. Flow streamlines for wind acting @ 0º direction

The flow streamlines showed differences in the vortices size and location, which clarify the variation in the resulting wind pressures for each case, as shown in Fig. 3. The size of the flow separation region increased as the stilt height increased. However, the flow separation region decreased by increasing the model aspect ratio. The air movement speeds up as it passed through the air-gap, and the velocity is higher in the small stilt cases, as shown in Fig. 3.

This paper also investigates the effect of changing the stilt height and aspect ratio on the total uplift, shear force, and overturning moments. By changing the model stilt height or the aspect ratio, the normalized forces were calculated by dividing the total force of the stilt case by the on-ground case's total force. The total shear force acting on the foundation showed a considerable increase as the stilt height increases, as shown in Fig. 4. On the contrary, the total uplift force was reduced by elevating the house due to the new suction force acting on the floor surface. A significant increase of the overturning moment was observed and varied between 450% and 800% increase compared to its on-ground counterpart.

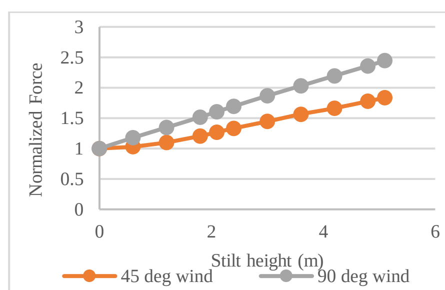


Figure 4. Normalized shear force relation with the stilt height

4. CONCLUSION

The current numerical study showed that the aspect ratio and elevation from the ground level of an elevated structure affect the air flow characteristics, including the size of vortices, the wind speed, and the wind shear stresses acting on the model surfaces. Consequently, the resulting wind pressure, uplift force, shear force, and overturning moment are affected as well. More details about the flow characteristics, mean pressures, and wind forces will be provided in future work.

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