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Optimizing openings through tall buildings to mitigate their crosswind response

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SUMMARY:
High-rise structures are becoming taller and more slender due to developers attempting to maximize their project value. However, with increasing slenderness comes increased crosswind response due the phenomenon of vortex shedding. The development of passive systems such as vents can mitigate the crosswind response. The primary vortex shedding mitigation techniques are reducing the coherence of vortex shedding along a building's height, modifying separated shear layer structure, and stabilizing the near-wake region of a building. This study builds upon previous work by focusing on the importance of stabilizing the near wake region versus altering the separated shear layer. These methods are explored via differing vent configurations that passively direct the flow to the areas of interest. In total, twenty-nine targeted vent configurations were tested at Skidmore, Owings & Merrill's boundary layer wind tunnel facility. Stabilizing the near shear layer closest to the separation point was the most influential in reducing the crosswind response of a structure by reducing the peak power spectral density, crosswind moment coefficient, and peak base overturning moment. The effectiveness of vent configurations were studied with the intent of applying this knowledge to future vented structures.

Keywords: Crosswind, Vented Structures, Vortex Shedding

1. INTRODUCTION

As structures become taller with smaller cross-sectional areas the crosswind response begins to dominate the structural design (Kwok, K.C.S. 1982). An engineer can manage this excitation by stiffening the structure using excess material, adding active systems such as a tuned mass damper, or utilizing passive systems such as vents through the structure (Kareem et al., 1999). Passive systems entail altering the architectural form of the structure to mitigate the excitation caused by the approaching flow. Previous research has shown that reducing the coherence of vortices along the structure's height, altering the shear layer flow, and stabilizing the wake region are the objectives of any passive system intending to reduce crosswind response (Zdravkovich, 1981; Moorjani et al.,2021). This study aimed to determine the importance of stabilizing the near wake versus altering the separated shear layer, which is broken up into a near and far portion of the separated shear layer along either side of the body (Figure 1).

2. EXPERIMENTAL SETUP

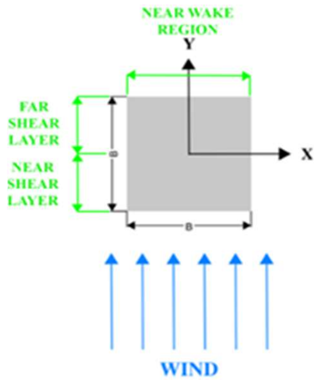

Figure 1. Base model with vent located at 70% of the model's height

Figure 2. Typical model orientation and definition of targeted flow areas

Wind tunnel testing on a rigid model was conducted at Skidmore, Owings & Merrill's (SOM) boundary layer wind tunnel facility in Chicago, IL. The high frequency force balance (HFFB) was calibrated using the international benchmark established at the 12th International Conference on Wind Engineering in Cairns, Australia (Holmes & Tse, 2014). A lightweight base model using low-weight and high-stiffness industrial-grade ROHACELL® 71 foam was fabricated. The model was fabricated at a 1:700 geometric scale. Model height, H, was 585 mm (23.03 in), corresponding to a full-scale height of 410 m (1344 ft). Model width, B, was 83.4 mm (3.29 in), corresponding to a full-scale width of 58.5 m (192 ft), giving a slenderness ratio of 7:1. Vent configurations were made of a durable lightweight balsa wood. The balsa wood was cut into removable wedges that were placed in or taken out of the model vent to develop the varying vent configurations tested. This model was placed on a HFFB for the analysis of base forces and moments (Figure 2). A single vent at 70% of the building height was placed in the base model corresponding to the optimum height of a single vent from previous testing (Moorjani et al., 2021). Twenty-nine targeted vent configurations were tested in open terrain (Exposure C) profile developed previously (Moorjani et al., 2021). These configurations consisted of angled, curved, and straight vents with leeward vents closed and leeward vents opened (Table 2.1).

3. RESULTS

Full-scale overturning moments were found with an assumed natural period of ten seconds and damping ratio of 2% shown in Figure 3. Every model decreased the crosswind moment compared to the base model (i.e., vents closed). It was found that increasing vent size consistently reduced the overall structural response. Vent configurations that had leeward and windward vents opened consistently improved overall structural response compared to those with leeward vents closed. Comparing the angled vent locations, it appears there are minor reductions in the crosswind moment when venting air closer to the separation point as opposed to further in the separated shear layer. As for the curved vents the effectiveness of venting closer to the near shear layer is more pronounced with a noticeable difference between the long and short curve vent full-scale moment. Results suggest that disrupting flow closer to the separation point is crucial to minimizing the crosswind response of the structure. This result can also be seen in the reduction of power spectral density peaks and crosswind dynamic moment coefficients.

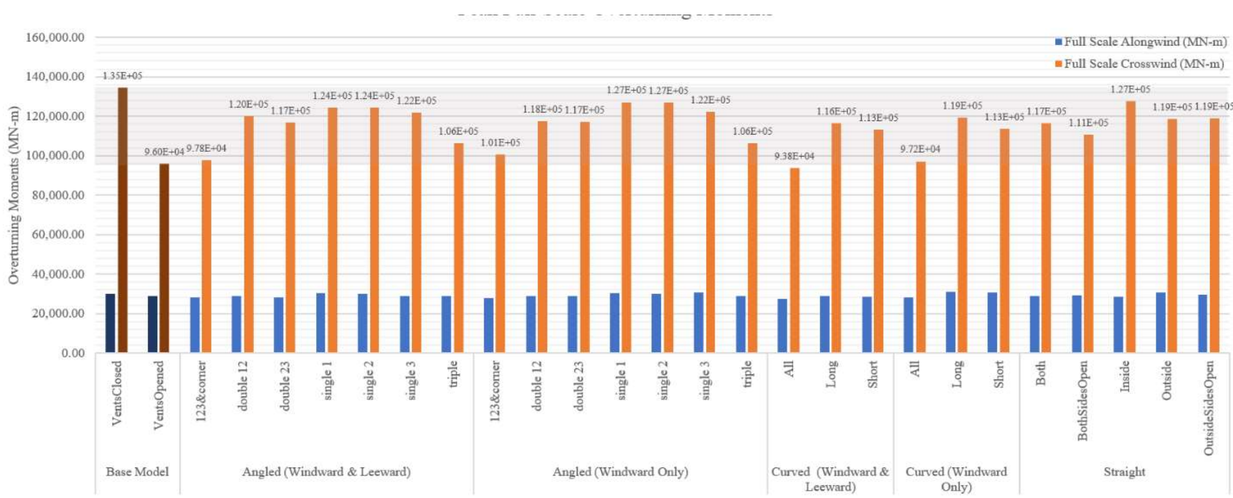

Figure 3 Full-scale overturning moments for each vent configuration

4. CONCLUSION

An open terrain wind profile was used at SOM's boundary layer wind tunnel facility was used to test various vent configurations on a rigid prismatic square building. This study focused on the importance of altering the separated shear layer versus stabilizing the near-wake region to mitigate the crosswind response of a high-rise structure. In total, twenty-nine targeted vent configurations were tested. It was also found that two configurations performed similarly or better than the base open model in terms of full-scale overturning moments. Vent configurations that target air closer to the windward edge of the model had greater reductions in overturning moment than those that vented further away. The wake focused vent configurations did not reduce the overall structural response as efficiently as those that altered the near separated shear layer. Given the results of this testing it is apparent that there are targeted methods to direct the air acting on the structure through a vent to mitigate vortex shedding.

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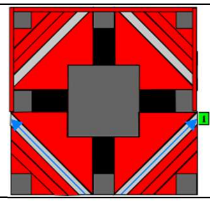
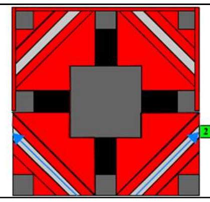
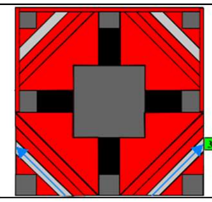
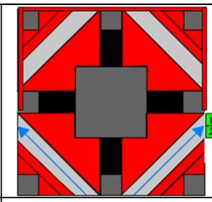
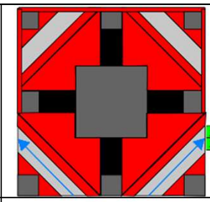
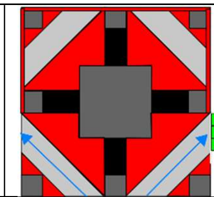
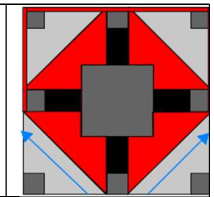
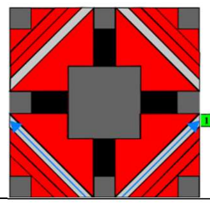
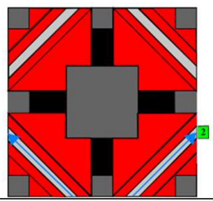
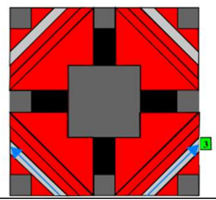
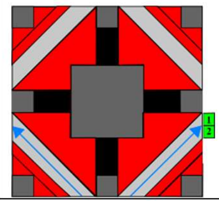
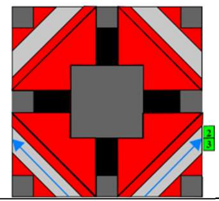
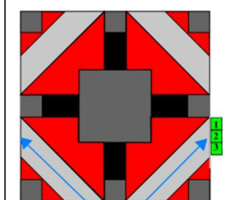
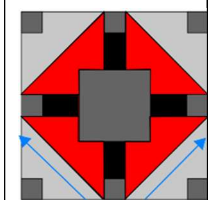
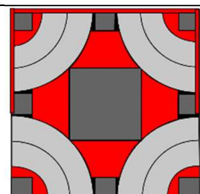
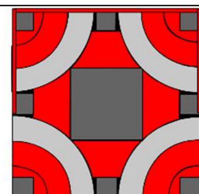
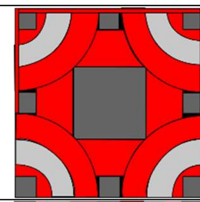
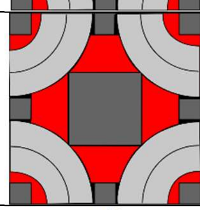
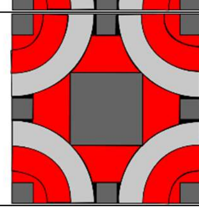
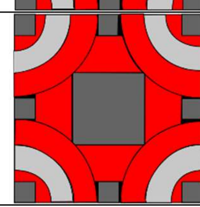
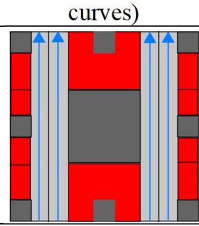
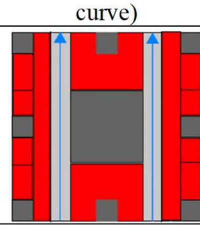
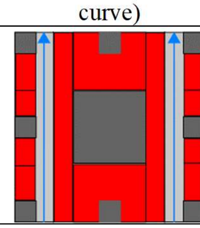
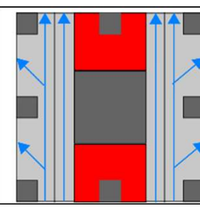
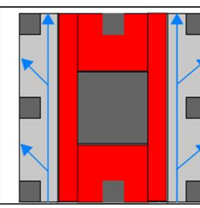
Table 2.1 Experiment 2 developed vent configurations

Angled Vents Targeting Near Shear Layer	Windward Vents Opened							
	Windward & Leeward Vents Opened							
		Single 1 (Vent to location 1)	Single 2 (Vent to location 2)	Single 3 (Vent to location 3)	Double 12 (Vent to location 1 & 2)	Double 23 (Vent to location 2 & 3)	Triple (Vent to location 1, 2, & 3)	123&Corner (Vent to location 1, 2, 3, & Corner)
Curved Vents Targeting Near Shear Layer	Windward Vents Opened							
	Windward & Leeward Vents Opened							
		All (Vent through both curves)	Large (Vent through large curve)	Short (Vent through short curve)				
Straight Vents Targeting Near wake and Shear Layer								
		Both (Inside & outside vents open)	Inside (Inside vent open)	Outside (Outside vent open)	BothSidesOpen (Inside, outside, & shear layer open)	Outside&SideOpen (Outside & shear layer open)		