ICWE 16
August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering

Practical experience using modified architectural form to mitigate across-wind response of a supertall building

John Kilpatrick [1], Will Yakymyk [2], Jason Garber [3]

[1] RWDI, Guelph, Ontario, Canada, john.kilpatrick@rwdi.com
[2] RWDI, Guelph, Ontario, Canada, will.yakymyk@rwdi.com
[3] RWDI, Guelph, Ontario, Canada, Jason.garber@rwdi.com

SUMMARY

The design of super-tall and mega-tall buildings is often controlled by serviceability limit states, e.g. building drift and occupant comfort. Across-wind response can be a significant factor in the performance under wind load and mitigating the response becomes important to ensure performance objectives are met. This paper presents recent wind tunnel investigations of modifications of the architectural form to mitigate the across-wind response of a tall building with an aspect ratio of approximately 19:1.

Keywords: Vented floors, porous crown, across-wind response, mitigation, supertall

1. BACKGROUND

Various approaches to reducing tall building motion under wind exist. Traditionally, one may choose to alter the buildings dynamic properties - mass, stiffness or damping - to achieve a reduction (Vickery, Isyumov & Davenport, 1981). An alternative approach uses building aerodynamics to mitigate the impact of wind. Aerodynamic means to mitigate vortex-induced across-wind oscillations of high-aspect ratio cylinders are well known (Zdravkovich, 1981) and include helical strakes, porous shroud structures, and splitter plates in the near wake. These approaches do not lend themselves well to the form of tall buildings.

Early studies of aerodynamic modifications to tall building forms indicated treatment to building corners, e.g. chamfering and/or venting slots (Kwok & Bailey, 1987) and introduction of openings or “gaps” in the building envelope (Dutton & Isyumov, 1990) were successful strategies. A good summary of RWDI’s previous experience with aerodynamic optimization approaches is provided in Xie (2014). Recently published work (Moorjani et al, 2021) presents detailed parametric model studies of the effectiveness of open floors on tall building models with aspect ratios varying from 7:1 to 10:1, with a view to optimizing this particular approach.

The authors of this paper recently undertook an investigation of the wind-induced responses of a H=550m super-tall building with a nearly square plan-form, having an extreme 19:1 aspect ratio. The study used the high frequency force balance (HFFB) technique. For reasons of confidentiality, the building will not be identified and data are presented in normalized format. Strategies to reduce the across-wind response are discussed in the following sections.

2. MITIGATION STRATEGIES

Wind tunnel studies of the baseline architectural configuration of the tower indicated a significant across-wind response affecting wind loads for strength design and vortex-induced oscillations impacting building accelerations for frequently occurring events. A number of migration strategies were developed in consultation with the project architect and consisted of two primary strategies: (a) introduction of porosity at the roof crown level, and (b) vented “blow-through” floors at single and multiple locations. The influence of multiple vented floor locations was assessed by maintaining the same total vented floor sail area in either the single or multi-level tests, although the relative location of the vented floors varied. Three levels of envelope porosity were considered (0%, 20% and 35%) for scenarios (a) and (b). Images of the test configurations are presented in Figure 1.

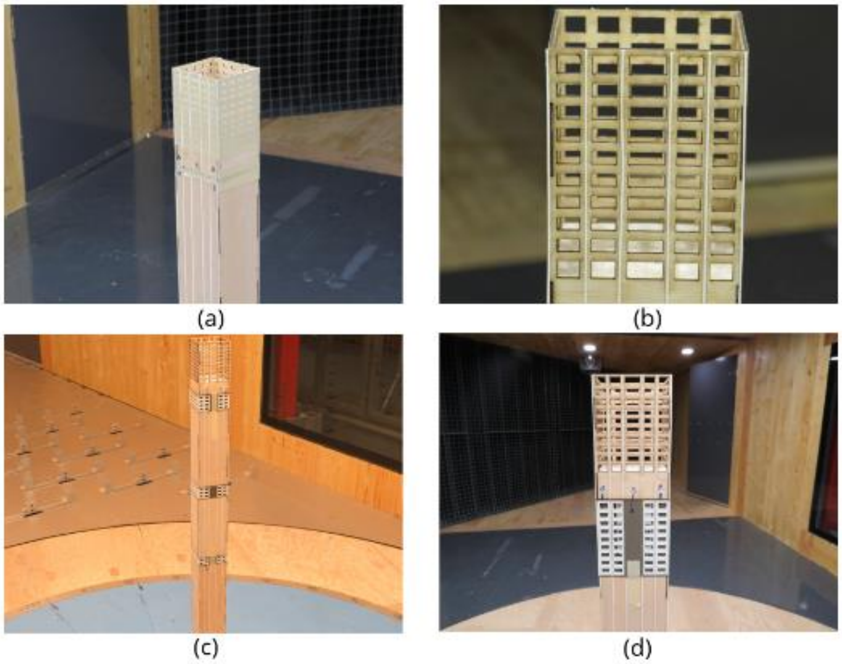

Figure 1 - select aerodynamic mitigation measures

3. WIND TUNNEL RESULTS

The baseline configuration of the tower with solid roof crown (Figure 1a) had a significant vortex induced response at MRI less than 1-year, and across-wind buffeting response at the 50-year MRI (Figure 2).

Introduction of 35% envelope porosity (Figure 1b) at the roof crown of the building (H_{crown}=1.25W_{max}) impacted along-wind base overturning moments only marginally (-5%) while reducing across-wind base moments by -26% at the 50-year MRI. Porosity of 20% at the roof crown level was also effective at reducing across-wind moments, but to a lesser degree (-22%). The addition of distributed vented floors (Figure 1c) where the floor heights equalled H_{vent} =

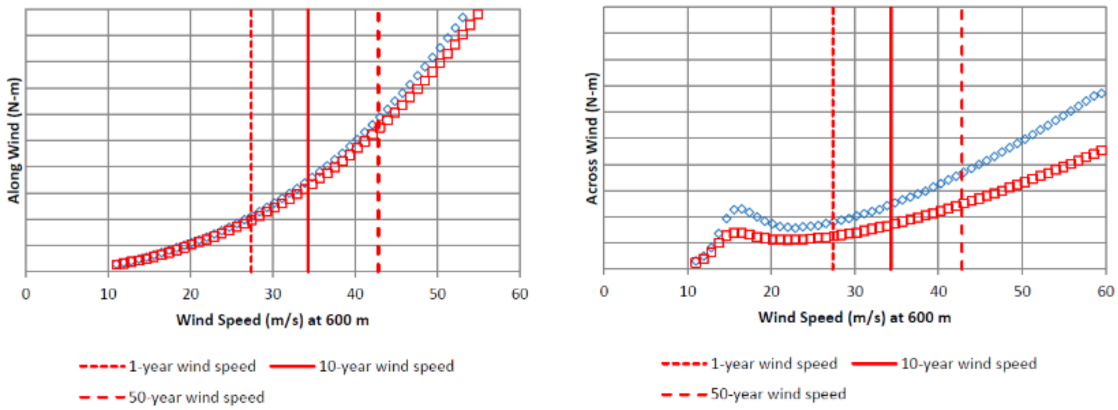

Figure 2 - impact of mitigation [option (a) vs option (c)]

0.25Wmax, 0.35Wmax, and 0.5Wmax at elevations 0.6H, 0.75H and 0.9H respectively, further reduced the across-wind base moment (-38%) at the 50-year MRI (Figure 2). An alternative vented floor level arrangement, having height equivalent to the sum of the distributed vented floors, i.e. $H_{vent} = 1.1W_{max}$ at elevation 0.85H (Figure 1d), was not quite as effective as the distributed vented floor, reducing the across-wind base moment by -33% at the 50-year MRI.

4. CFD SIMULATIONS

To understand the capability of computational fluid dynamics (CFD) to model the aerodynamic response of the supertall building employing mitigation measures, simulations were performed for (i) the baseline building, and (ii) the building with porous crown and multiple vented floor locations. Atmospheric flow physics was modelled using large eddy simulation (LES) carried out in OpenFOAM, using inlet flow boundary conditions modelled after the wind tunnel experiments employing a synthetic inflow generation method (Aboshosha, 2015). Computational domain and grid sizes were based on best practice guidelines (Franke et al, 2007). Select results from the simulations were compared with wind tunnel predictions and are shared in the following figures. The agreement between the across-wind spectra at the vortex shedding onset speed is quite good (Figure 3), while the CFD estimated accelerations were generally conservative (Figure 4).

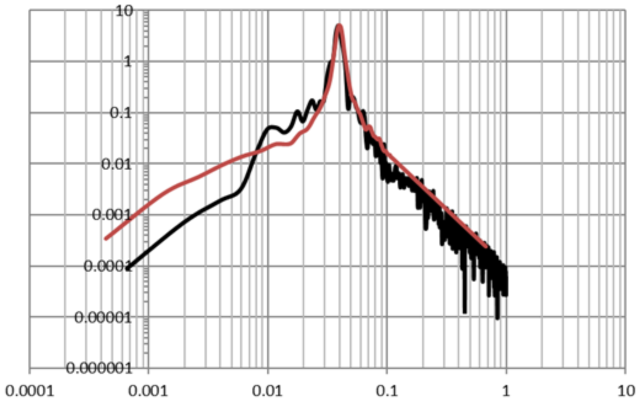

Figure 3 - Generalized force spectra (black - CFD, red - WT)

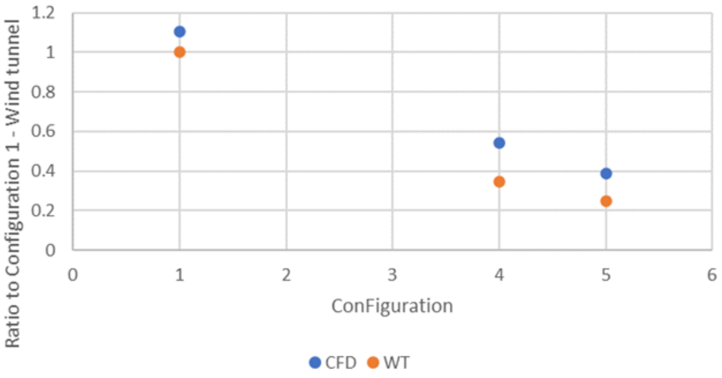

Figure 4 - Predicted peak vortex-induced acceleration

5. CONCLUSIONS

For this 19:1 aspect ratio tower and building geometry, the most practical solution to mitigate the across-wind response involved the introduction of roof crown porosity and distributed vented floor levels in the building. Distributing the vented floor over the building height was more efficient than having equivalent vented floor area concentrated at one location. Increased envelope porosity ratio (35% vs 20%) was more successful at reducing the across wind response. Similar conclusions were drawn for the impact of these mitigations based on CFD simulations; good agreement of the fluctuating responses with the wind tunnel was found.

REFERENCES

Aboshosha, H., Elshaer, A., Bitsuamlak, G.T., El Damatty, A., 2015. Consistent inflow turbulence generator for LES evaluation of wind-induced responses for tall buildings. Journal of Wind Engineering and Industrial Aerodynamics 142, 198–216.

Dutton, R., Isyumov, N. 1990. Reduction of tall building motion by aerodynamic treatments. Journal of Wind Engineering and Industrial Aerodynamics 36, 739-747.

Franke, J., Baklanov, A., 2007. Best Practice Guideline for the CFD Simulation of Flows in the Urban Environment: COST Action 732 Quality Assurance and Improvement of Microscale Meteorological Models.

Kwok, K.C.S, Bailey, P.A. 1987. Aerodynamic Devices for Tall Buildings and Structures, Journal of Engineering Mechanics, 113, 349-365.

Moorjani, R.R, Lombardo, F.T, Devin, A.F., Young, B.S., Baker, W.F., Ray, S.D. 2021. Influence of vented floors on the across-wind response of tall buildings, Journal of Wind Engineering and Industrial Aerodynamics, 209, 104480.

Vickery, B.J., Isyumov, N., Davenport, A.G. 1983. The role of damping, mass and stiffness in the reduction of wind effects on structures, Journal of Wind Engineering and Industrial Aerodynamics, 11, 285-294.

Xie, J. 2014. Aerodynamic optimization of super-tall buildings and its effectiveness assessment, Journal of Wind Engineering and Industrial Aerodynamics, 130, 88-98.

Zdravkovich, M.M. 1981. Review and classification of various aerodynamic and hydrodynamic means for suppressing vortex shedding, Journal of Wind Engineering and Industrial Aerodynamics, 7, 145-189.