CASE STUDIES ON THE IMPACT OF SURROUNDING BUILDINGS ON WIND-INDUCED RESPONSE

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ABSTRACT

In multi-tower and/or multi-phase developments, the impact of prominent nearby surroundings can play a large role in the aerodynamic conditions of proposed developments. This paper focuses on two case studies: i) two 160 m tall residential towers atop a prominent transportation terminal and ii) a tall (220 m) residential tower in complex terrain with significant future development. Comparisons will be made of the structural wind loads on the towers under various sheltering conditions. Both cases quantifies the amplification of wind loads due to vortex shedding off an existing upwind building 4 to 6 building widths upstream, as well as the role that a future development might play in modifying these amplifications. Comparisons will also be made to various empirical methods. This study also examines the aerodynamic impact of the two respective proposed towers in case i) as a result of their relative proximity within 2 building widths.

Keywords: Wind loads, aerodynamic interference factors, dynamics, code

1. INTRODUCTION

In multi-tower and/or multi-phase developments, the impact of prominent nearby surroundings can play a large role in the aerodynamic conditions of proposed developments. However, for the practicing designer, there is little design guidance which falls readily to hand which advises on how one might assess the adverse impact of surroundings.

The 2010 NBCC [1] recommends the Experimental Procedure for buildings that may be subjected to buffeting or channeling effects caused by upwind obstructions, but is unclear regarding what situations might cause adverse buffeting or funneling response.

The 2010 ASCE 7 Standard provides similar guidance, recommending the Wind Tunnel procedure if the building has response characteristics making it subject to across-wind loading, vortex shedding, instability due to galloping or flutter; or it has a site location for which channeling effects or buffeting in the wake of upwind obstructions warrant special consideration. Very little additional guidance is given to the practitioner. While this is perhaps beneficial to the Wind Engineering practitioner, there are practical design decisions which are impacted by significant departures from the initial concept design of a development.

Other codes of practice give similar recommendations. While this guidance is well placed, it would be useful to have some provisions embedded in code to permit evaluation of potential wind impacts due to surrounding buildings at early design stages, for the purposes of concept design and preliminary costing exercises. A literature review suggests that there are a number of good guidelines in existence, and the author will use selected advice to illustrate its value in identifying potential wake interference problems.

2. SELECT RESEARCH ON INTERFERENCE

The adverse aerodynamic interference effects on the responses of tall buildings caused by proximity to adjacent structures has been systematically studied since the 1970’s. Many point to the collapse of 3 of 8 of the cooling towers at the Ferrybridge Power Station in West Yorkshire, England, in 1965 as one of the seminal moments in the
formation of the field of Wind Engineering – aerodynamic interference is cited as one of the causes of the failure of these cooling towers, though there were several other factors which contributed. The degree of interference effect has been shown by numerous researchers to be influenced by the geometric massing of the upstream building, with buildings of similar height or higher upstream having larger adverse impacts on mean and fluctuating along-wind and across-wind loading.

Khanduri et al (1998) reviewed the state-of-the-art of wind-induced interference effects, and also undertook parametric studies on prismatic building models to evaluate and identify or map locations wake interference effects as a function of the spacing between buildings, where the spacing was a function of the breadth of the upwind building. Khanduri introduced Interference Factors (IF’s) to describe the change in mean and fluctuating along- and across-wind loading due to aerodynamic interference between simple square cylinders. An important part of Khanduri (1997) was identifying influence areas for dynamic interference effects (Figure 1). Clearly, when the upstream building was nearly adjacent to the study building, or quite distant (say 8 building diameters upstream), adverse effects were negligible. The most significant impacts occurred with buildings spaced between 3 and 6 diameters apart.

Significant work has been carried out on this topic since the late 1990’s, and recent efforts by Mara et al (2012, 2014) take these concepts further. Mara identifies aerodynamic interference effects (AIF’s) which are related to the change in mean and fluctuating external wind forces, and Total Interference Effects (RIF’s) which identifies the total interference effect on peak building response, including inertial forces. Figure 2 illustrates the RIF for the peak across-wind response of a tall building in open country wind exposure, at a non-dimensional wind velocity of V/fD=10 and 2% critical structural damping. For this particular plot, it is clear that the maximum amplification of the total across-wind response of a tower at a critical non-dimensional wind speed of V/fD=10 occurs when the spacing to the interfering building is 4-6 times the breadth of the upwind building, and the buildings are not aligned in the lateral direction.

Perhaps the only criticism of these studies which prevents the work from being adopted by code is that these (and other) studies take a simplistic approach to the issue of interference. Prismatic (square) buildings are used in boundary layer flows which are based on uniform upwind terrain, while in reality the wind profiles and surroundings of a tall building in many developed cities is far more complicated.

The value of the empirical wind tunnel studies noted above is perhaps in the indicative rather than absolute values of the wake interference phenomenon. Regardless, this is still of value and worthy of merit for inclusion in a code-based assessment method. To date, the author is not convinced that computational fluid dynamics (CFD) simulations are appropriate for global assessment of interference effects, though it has been adopted to evaluate changes in local surface pressures.

3. CASE STUDIES OF WIND-INDUCED INTERFERENCE IN ACTUAL BUILT ENVIRONMENT

Based on the factors identified in the preceding sections, two case studies have been selected by the author to evaluate the relevance of the aforementioned interference factors in real urban building environments.

3.1 Case Study #1

Case study #1, presented in Figure 3a and 3b, is a multi-tower development in the southern United States, comprised of office, hotel and residential towers situated above a train station. The two main towers of the development are of similar height (160m), with spacing between the towers of approximately 2.5 building diameters. RWDI was involved in wind tunnel testing of these towers for existing (Figure 3a) and future (Figure 3b) surrounding scenarios. Structural sign convention for the tower is provided in Figure 4.

Figure 5 indicates a severe peak across-wind response in the Mx base moment for winds approaching from 200°. For the existing surroundings, the wind-induced response of the southern-most tower, Tower 3, is influenced by wake buffeting from a 6-sided tower upwind to the SSW. The upwind tower is of similar breadth, and moderately taller. The spacing between the upwind building and Tower 3 is on the order of 4.5 times the breadth of the upwind tower.
For the future scenario, a super-tall building is located immediately to the south of Tower 3, a distance of 3-4 building diameters upstream. The super-tall building to the South was anticipated to have a much more significant wake impact on Tower 3 than the 6-sided building to the SSW, but wind tunnel tests proved this belief to be deceptive (Figure 6). In fact, the presence of the super tall building to the south has a mitigating effect on the peak across-wind Mx base moments for winds approaching from 200˚, though another across-wind peak is now present for winds approaching from 180˚, where the supertall building is directly upwind.

Unfortunately, the wind-induced response of the case study tower was not measured without the interfering building, since the interfering tower is an existing building, topped out in 1985. However, based on the fluctuating across-wind response from adjacent wind directions, one could infer that the peak across-wind response from 200˚ wind direction may be in the order of 1.5 - 2 times the across-wind response in the absence of the interfering building. The non-dimensional wind speed V/fD associated with the response curve in Figure 5 is between 6 and 7, and damping was taken to be 2.5%.

The fluctuating lift response IF’s from Khanduri suggest that an IF of about 1.1 may have been anticipated for the Case Study #1 tower, while data from Mara et al suggest an appropriate RIF may have been 1.1 < RIF < 1.2. These values are significantly different from the amplification of response inferred from the wind tunnel data for 200˚ wind direction. This may be related to a complex flow pattern in the multi-tower development. However in Figure 6 it is evident that the across-wind response for winds approaching from 180˚ has increased on the order of 10%, which is consistent with the Khanduri and Mara research, and flow patterns within the multi-tower development are expected to be more symmetric for this wind direction.

The interference factors extracted from literature are not predicting the absolute magnitude of the increase in peak response well, but they are correctly identifying that response is likely to increase.

### 3.2 Case Study #2

Case study #2, presented in Figure 7a and 7b, is a 220 m single-tower development in the United Kingdom with residential occupancy. RWDI was involved in wind tunnel testing of these towers for existing (Figure 7a) and future (Figure 7b) surrounding scenarios. Sign convention for the tower is provided in Figure 8.

For the existing surroundings, the My base overturning moment of the tower is governed by a large across-wind response to winds from the south (Figure 9, blue curves). The addition of future surroundings to the south, the wind-induced response of the study building is strongly influenced by interference from a tower upwind, directly to the south (Figure 9, red curves). The upwind tower is of similar breadth, and moderately taller. The spacing between the upwind building and Tower 3 is on the order of 6-7 times the breadth of the upwind tower.

Based on the fluctuating across-wind My base moment response illustrated in Figure 9, one can infer that the peak across-wind response has increased by about 30% as a result of the interfering building. Note maximum across-wind response does not occur when the buildings are in perfect alignment, i.e. wind approaching from 190˚, but for winds about 10˚-20˚ either side. The non-dimensional wind speed V/fD associated with the response curve in Figure 9 is about 8, and damping was taken to be 2%.

The fluctuating lift response IF’s from Khanduri suggest that an IF of about 1.0 - 1.1 may have been anticipated for the Case Study #2 tower, and data from Mara et al suggest a similar RIF. These values are slightly lower that the amplification of response indicated in the wind tunnel data in Figure 9. This may be related to a complex shear layer in the wake of the interfering tower, which has a rectangular footprint with a plan aspect ratio of 1:2.

### 4. CONCLUSIONS

Interference factors, while developed on generic prismatic cylinders in uniform terrain, do have value in providing an order of magnitude estimate of the adverse wind impacts related to aerodynamic interference from surrounding buildings. Limited results of two Case Studies indicate higher than anticipated interference factors. Contributing factors for the discrepancy may include the influence of additional surrounding buildings, and geometries of interfering building which vary from a square planform.
Admittedly wind tunnel testing is preferred for the purpose of assessing demand on the main lateral wind load resisting system. However, in early design stages interference factors may be helpful in identifying “problems” before design progresses to latter stages when the costs of mitigating a wind-issue increase.

REFERENCES


ASCE (2010), Minimum Design Loads for Buildings and Other Structures, ASCE 7-10, Reston, VA.


Figure 1: Influence Areas for Dynamic Interference Effects (Khanduri 1997)

Figure 2: Peak (Total) Across-wind Response Interference Factor, V/fD=10 (Mara et al 2013)
Figure 3: Wind tunnel test of Case 1: a) existing; and b) future surroundings

Figure 4: Case Study #1 - Sign Convention

Figure 5: Wind-induced overturning moment, Case 1 – existing surrounds
Figure 6: Case 1 - impact of future surrounds on overturning moment

Figure 7: Wind tunnel test of Case 2: a) existing; and b) future surroundings

Figure 8: Sign convention
Figure 9: Wind-induced overturning moment, Case 2 – existing (blue) and future (red) surrounds