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Along-wind loads on boxy isolated tall buildings: Performance of international standards

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SUMMARY:
Typically, regional standards are used to determine along-wind loads on tall buildings at the preliminary design stage. When the buildings are boxy in geometry and located in typical terrain conditions, the standard derived loads are expected to be closer to those from a wind tunnel test unless there is an influence of peculiar structural dynamic effects. This paper compares the along-wind loads in detail for a selected building using Canadian, American, Australian, and European standards with the wind tunnel results. Overall, it is found that there are differences between the standards, out of which the European standard stands out to be very conservative, and the reasons for such differences are explained.

Keywords: Along-wind loads, standards, tall buildings.

1. INTRODUCTION

Regional standards have been widely used in predicting along-wind loads on tall buildings at the preliminary design stage. Wind tunnel tests are chosen when the building (i) possesses an unconventional geometry, (ii) is located in complex surroundings, (iii) is taller, (iv) has high slenderness, and (v) has intricate structural dynamic properties. Further, the influence of site-specific wind directionality on wind-induced response can be assessed in detail if one opts for wind tunnel tests. However, in the case of a boxy building in typical terrain conditions, there is a consensus that the along-wind prediction from standards is as good as the outcome of a wind tunnel test in the absence of any structural dynamic complications.

There are notable references (Zhu et al., 2002; Kwon and Kareem, 2013) that compared various standards in detail. This paper compares only the along-wind loads for a selected building using Canadian (NBC 2015), American (ASCE 7-22), Australian (AS/NZS 1170.2:2021), and European (EN 1991-1-4:2005) standards with the wind tunnel results. Based on the results, reasons for differences have been discussed.

2. COMPARISON OF LOADS

One sample wind tunnel-tested building has been chosen for comparison in this abstract. Loads have been estimated based on the chosen standards and compared against the wind tunnel results.

Note that the influence of wind directionality is not accounted for in these comparisons. A building located in typical code-specified terrain conditions without dense immediate surroundings has been selected to mimic the isolated condition scenario.

2.1. Study Building

The building selected is a boxy square building of height 113.5m located in suburban terrain condition (Category 3), and the details of the building including the photo and its axis system are provided in Fig. 1.

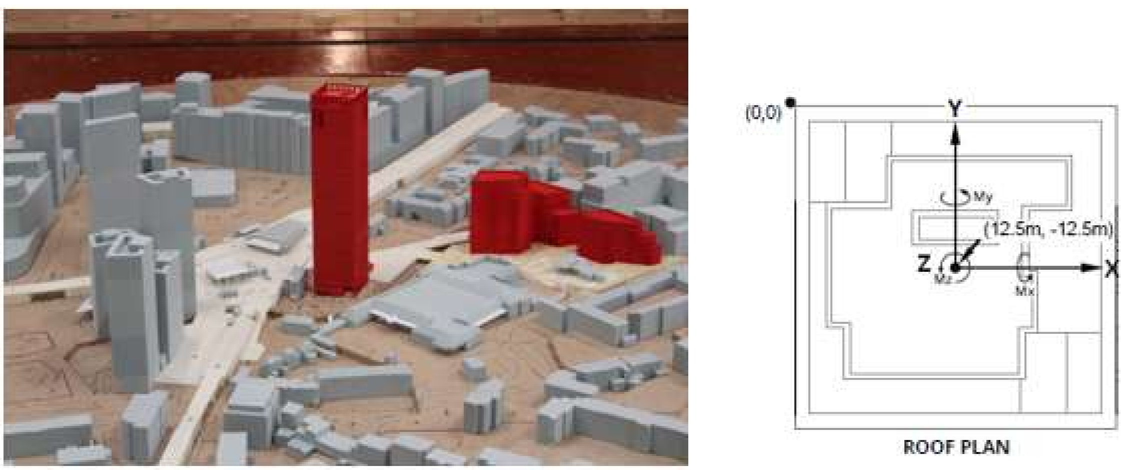

Figure. 1. Selected building.

Table 1. Comparison of non-directional peak along-wind loads on the selected building.

	X	Y
Wind Speed (m/s)	21.5	
Terrain Category	III	
Height (m)	113.5	
Width (m)	23.3	23.7
Frequencies (Hz)	0.26	0.24
Damping (%)	2	

	Peak Along Wind Loads			
	My (Nm)	Mx (Nm)	Fx (N)	Fy (N)
NBC	1.27E+08	1.32E+08	2.04E+06	2.11E+06
ASCE 7-22	1.36E+08	1.41E+08	2.28E+06	2.34E+06
AS/NZS 1170.2	1.69E+08	1.75E+08	2.83E+06	2.92E+06
EN 1991-1-4	2.07E+08	2.14E+08	3.51E+06	3.64E+06
Wind Tunnel	1.31E+08	1.24E+08	2.03E+06	1.86E+06

Along-wind loads estimated based on various standards are compared against the wind tunnel results in Table 1. The NBC (Canadian) and ASCE (American) loading are the closest to the wind tunnel in this case. AS/NZS (Australian) standard-derived loads are somewhat higher than the wind tunnel results, but noticeably, the EN (European) standard predicted the highest of all.

While NBC considers the dynamic pressure at half the height for determining leeward pressure, all the remaining standards use the dynamic pressure at full height. Note that NBC uses mean hourly speed, ASCE uses 3-sec gust speed, AS/NZS uses 0.2-sec gust wind speed, and EN uses 10-min mean wind speed for the prediction. Appropriate conversion factors have been used to convert the 10-min mean speed provided in Table 1 to speed relative to other averaging times.

3. WIND VELOCITY PROFILE

Wind velocity profiles scaled to basic wind speed at 10m for the above project site have been found different between the standards as shown in Fig. 2 for Category 3 (Exposure B). This is one of the contributors to the difference between the standards. Though gust speeds are in reasonable agreement between EN and AS/NZS regardless of the unknown averaging time with EN, mean speed profile corresponding to EN stands out compared to the remaining standards.

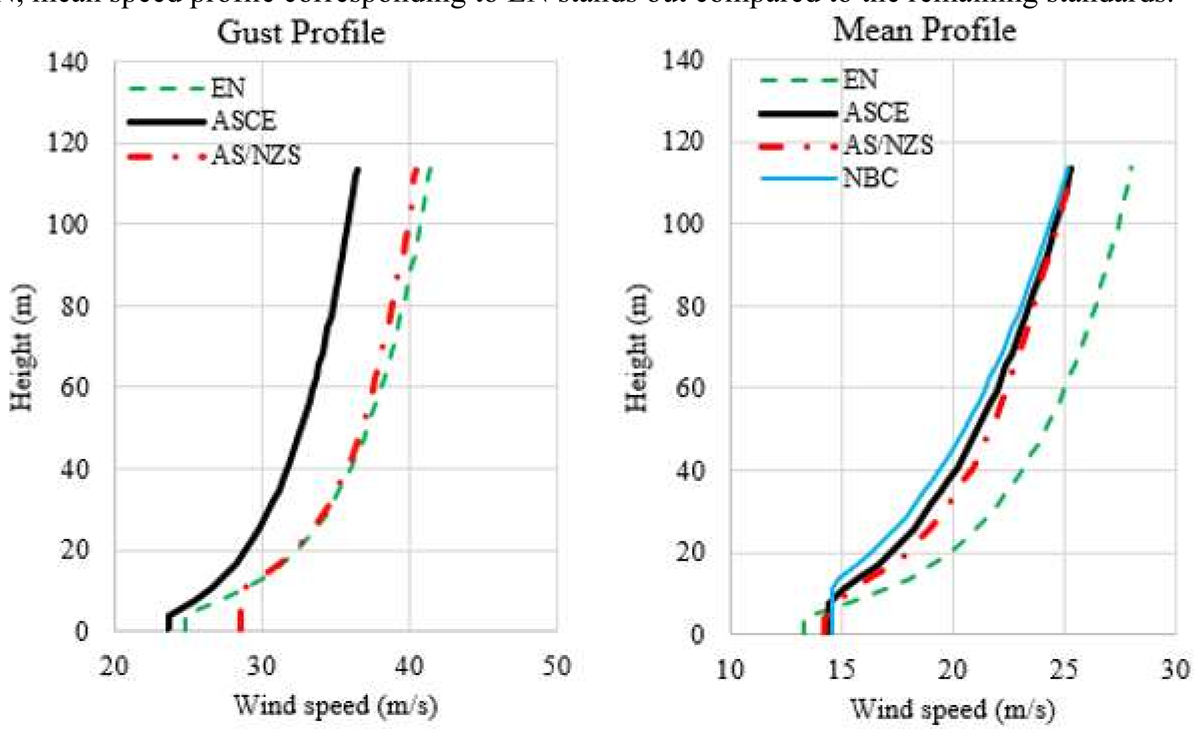

Figure 2. Comparison of wind speed profiles.

4. WIND PRESSURE PROFILE

All the major international codes and standards consider pressure variations along the height of the structure on the windward façade following the wind velocity variations. However, the Eurocode simplified the vertical variations of wind pressure on the windward facade. Blocks of constant pressures have been used for the calculation of pressures on the windward façade towards the bottom and top. This is summarized in Fig. 3. This is having a significant impact on elevating the overall loads on the building.

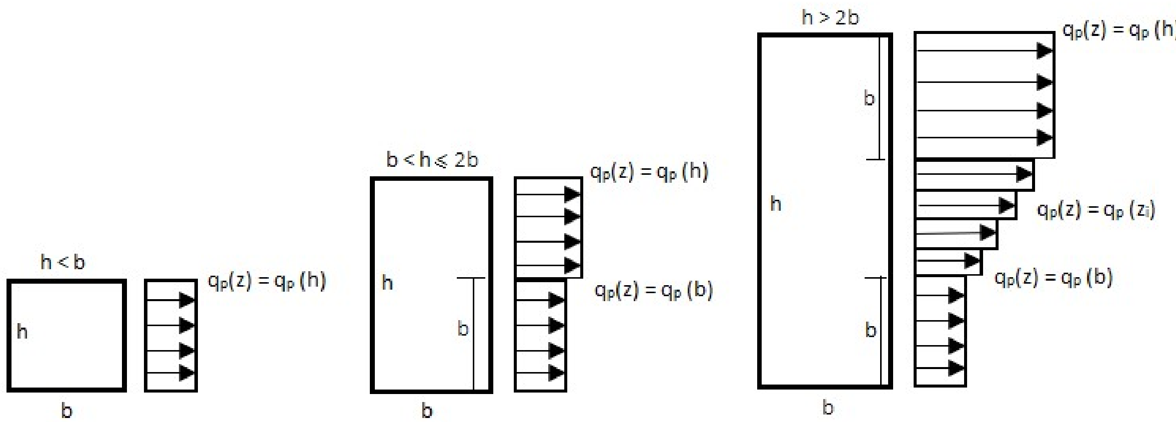

Figure 3. Wind pressure profile in European standard.

5. EXTERNAL PRESSURE COEFFICIENTS

For the prediction of along-wind loads, external pressure coefficients play an important role as well. For the specified building in this paper, the variation in combined windward (C_{pw}) and leeward (C_{pl}) external pressure coefficients is provided in Table 2. Once again, EN standard value is higher than the remaining standard.

Table 2. Combined external pressure coefficients.

	NBC	ASCE 7-22	AS/NZS 1170.2	EN 1991-1-4
C_{pw}-C_{pl}	1.3	1.3	1.17	1.5

Note that AS/NZS standard uses a combination factor of 0.9 while combining windward and leeward pressure coefficients. In the case of the EN standard, the lack of correlation between the windward and leeward sides is accounted for using a factor varying between 1 ($h/d \geq 5$) and 0.85 ($h/d \leq 0.85$). This section will be further explored in the full paper.

6. GUST FACTOR

A comparison of the gust factor between the standards is shown in Table 3. NBC's gust factor calculations are based on mean-hourly speed, while the remaining standards are based on gust speed.

Table 3. Comparison of gust factors.

	NBC	ASCE 7-22	AS/NZS 1170.2	EN 1991-1-4
Gx	2.17	0.91	0.99	0.93
Gy	2.21	0.92	1.00	0.94

5. CONCLUDING REMARKS

Boxy isolated tall buildings are still upcoming around the world, and many are initially designed based on the existing regional standards. Only a few of them are considered for wind tunnel tests, especially in developing nations. Considering the standard's prominent role in the design of such structures, the notable differences among them are alarming and shall be rectified. The full paper will elaborate on the subject matter.

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