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# Across-wind loads on tall buildings – Prescriptions of the upcoming Eurocode revision and wind tunnel test results

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**SUMMARY:**

The final draft of the Eurocode revision for wind actions on structures contains two models for predicting across-wind loads on tall buildings. The two models are presented and their behavior for variations of central parameters is investigated focusing on the parts of the parameter space where their applications border each other. It is found that the models provide very different predictions for the across-wind loads at these intersections. Across-wind loads are then investigated through wind tunnel tests carried out by Svend Ole Hansen ApS applying both the High-Frequency Base Balance (HFBB) and the High-Frequency Pressure Integration (HFPI) techniques. Finally, key results of the wind tunnel tests are compared with the Eurocode draft predictions and deviations are discussed.

*Keywords: Across-wind loads on tall buildings, Eurocode, Wind tunnel tests*

## 1. INTRODUCTION

Horizontal across-wind loads on tall buildings can be substantial, and their accurate prediction therefore essential for structural design. In the case of vortex shedding occurring at the natural frequency of the structure, across-wind inertial loads may become by far the dominating design parameter.

Several design codes have already incorporated models for across-wind loads, and in the final draft for the upcoming revision of the Eurocode for wind actions (Eurocode final draft, 2020), two such models are provided, whose scope of application depend primarily on the slenderness of the building.

It is of interest to investigate the predictions of the two models for key design parameters for tall buildings, such as peak top-floor acceleration. In the paper, the two models are introduced and applied on various parameter spaces for tall, rectangular-plan buildings within their stated scope of application. Both models cover the two cases of coinciding and separated vortex shedding frequency and natural frequency, and load predictions in both regimes will be investigated and compared. Since the scope of application of the two models is separated at a discrete value for the slenderness of the structure, it is also investigated if and how the predictions differ at this intersection.

Apart from codified procedures, wind loads on tall structures are often predicted through scale model wind tunnel tests. Across-wind loads on the CAARC benchmark building model have been determined from wind tunnel tests carried out by Svend Ole Hansen ApS applying both the High-Frequency Base Balance (HFBB) and the High-Frequency Pressure Integration (HFPI) methods, and the results are presented and compared with the predictions of the Annex G model.

## 2. THE UPCOMING EUROCODE REVISION

The upcoming revision of the Eurocode for wind actions on structures includes two models for predicting the across-wind loads on tall rectangular plan buildings. The applicability of the models depends on the slenderness of the structure expressed by the parameter $h/\sqrt{bd}$, where $h$ is the height and $b$ and $d$ are the horizontal dimensions of the building. For $3 \leq h/\sqrt{bd} < 6$, Annex G should be applied and for $6 \leq h/\sqrt{bd}$ Annex H should be applied.

A thorough description of the background for the new Eurocode draft prescriptions for across-wind loads in the Annexes G and H is beyond the scope of the paper, but a short introduction of the two annexes will be provided. The following sections contain shortened versions of these introductions.

### 2.1. Annex G, slenderness $3 \leq \mathbf{h}/\sqrt{\mathbf{bd}} < 6$

The procedures of Annex G are applicable to buildings only. The annex contains a few additional requirements for its application, one of which can be re-stated as a requirement for the ratio between the vortex shedding frequency $n_{\mathrm{v}}$ and the across-wind natural frequency of the structure $n_{\mathrm{e}}$:

$$\frac{n_{\mathrm{v}}}{n_{\mathrm{e}}} \leq 10 \cdot \mathrm{St}, \tag{1}$$

if the characteristic length $L$ in the Strouhal number St is taken as $\sqrt{b \cdot d}$, i.e. $\mathrm{St} = n_{\mathrm{v}} \cdot \sqrt{b \cdot d}/v_{\mathrm{m}}$, where $v_{\mathrm{m}}$ is the mean wind velocity.

Strouhal numbers for rectangular cross sections can be as low as $\mathrm{St} = 0.08$, in which case the requirement in Eq. (1) allows the natural frequency of the structure to be equal to the vortex shedding frequency, $n_{\mathrm{e}} = n_{\mathrm{v}}$.

### 2.2. Annex H, slenderness $\mathbf{h}/\sqrt{\mathbf{bd}} \geq 6$

The procedures of Annex H are formulated more generally, and are applicable to various kinds of slender structures, counting both buildings and bridges. The applied models resemble those applied for along-wind resonant response in the current Eurocode (Eurocode 1, 2005). The annex is applicable to both coinciding and separated vortex shedding- and natural frequencies.

### 2.3. Comparison of results

In the paper, key results from applying the procedures in Annex G and H are applied to tall, rectangular plan buildings for a parameter space within their scope of application in order to investigate their behavior to variations in central parameters as well as to illustrate their differences.

As an example, the peak top-floor acceleration as a function of the building's slenderness is shown in Figure 1 applying the parameters provided in Table 1. It is seen that at the intersection $h/\sqrt{b \cdot d} = 6$, the two models deviate substantially in their prediction of this key parameter.

**Table 1.** Parameters applied for the determination of peak top-floor accelerations.

| Property | Symbol | Value |
|---|---|---|
| Basic wind velocity | $v_{\mathrm{b}}$ | 24 m/s |
| Roughness length | $z_0$ | 0.05 m (Category II) |
| Building width (across-wind) | b | 30 m |
| Building depth (along-wind) | d | 50 m |
| Natural frequency | $n_e$ | $46/h$ [Hz] ($h$ is building height in meters) |
| Building density (constant) | $\rho_{\mathrm{B}}$ | 160 kg/m$^3$ |

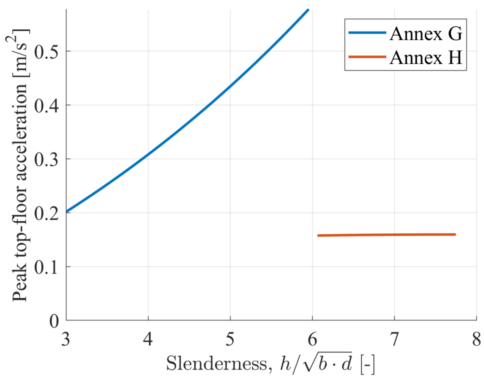


**Figure 1.** The predicted peak top-floor acceleration as a function of the building slenderness $h/\sqrt{b \cdot d}$ as determined using the applicable annex. Relevant parameters are given in Table 1.

## 3. WIND TUNNEL TESTS

Scale model wind tunnel tests with the benchmark CAARC building (see e.g. [CITE]) have been carried out by Svend Ole Hansen ApS in their boundary layer wind tunnel in Copenhagen, Denmark. Wind loads were measured with both the High-Frequency Base Balance (HFBB) and the High-Frequency Pressure Integration (HFPI) methods using, respectively, a base-balance and a pressure tap model with the same outer geometry. The pressure model is shown in Figure 2.

**Figure 2.** Photo of the applied scale pressure model of the CAARC building.

The advantage of the HFBB method is that the integrated wind loads are measured without discretizations, and that for a linear bending mode shape, the base bending moments are direct measurements of the modal wind load. The advantage of the HFPI method is that the distribution of the wind pressures is measured, enabling more insight into the underlying aerodynamic mechanisms. A drawback of both methods is that the model is static during testing, whereby aeroelastic effects are ignored.

### 3.1. Experimental setup

The 1:383 scale model of the CAARC building, either the HFBB or the HFPI, are placed on a turntable in the boundary layer wind tunnel without neighboring structures and wind loads are measured for wind directions perpendicular to both the wide and the narrow facades.

Profiles of the mean velocity $v_{\mathrm{m}}$ and the along-wind and horizontal across-wind turbulence intensities $I_u$ and $I_v$ of the simulated flow field will be illustrated in the paper.

The wind loads were for both testing types measured for 90 seconds for each wind direction at a scanning rate of 500 Hz. The measured signals were subsequently processed spectrally to remove contributions from the natural frequency of the HFBB model and to correct the frequency response of the tubes used for the HFPI tests.

### 3.2. Results

Results of the wind tunnel tests presented in the paper will focus on full-scale across-wind loads determined from the measurements on both the base-balance the the pressure models. Key results will include:

- The magnitude of resulting equivalent static crosswind bending moment at the base of the building, including both resonance and background load contributions, and the magnitude of the peak top floor acceleration for serviceability conditions.
- Illustrations of the spectral distribution of the resulting crosswind loads, and illustrations of the vertical distribution of the crosswind loads focusing on the frequency and magnitude of vortex shedding loads and load correlations along the height.

## 4. COMPARISON OF CODE PREDICTIONS AND WIND TUNNEL RESULTS

The paper will present a direct comparison of full-scale values for key design parameters such as the peak equivalent static base bending moment and peak top-floor acceleration level between the results of the wind tunnel tests and a code calculation following Annex G of the new Eurocode draft, since the slenderness of the CAARC building falls within the scope of Annex G. Deviations will be discussed in the context of comparing the approaches in the two annexes.

**REFERENCES**

Eurocode final draft, 2020. Eurocode 1 - Actions on Structures - Part 1-4: General Actions - Wind Actions. Final draft: April 2020 version. 0th ed. CEN/TC 250, 2020-04.

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