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Resonance effects on façade behaviour under wind loading

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SUMMARY:
Façade structural verifications under wind loading are usually approached by equivalent static methods, but the designer should check whether a risk of vibrations exists. The threshold definition for the natural frequency, e.g. 5 Hz as proposed by the EN1991-1-4, appears rough and possible source of response underestimation. Indeed, literature shows scenarios for which the 5Hz limit is not accurate. Certain systems seem prone to vibration even if their natural frequency is higher than 10Hz. On the other side, for the most practical applications, the frequency limit seems exaggerated and several researchers propose the adoption of lower values. The aim of the authors is to identify the along wind loading and system characteristics for which the 5Hz limit is not reasonable and to propose robust criteria to identify the need of dynamic amplification assessment. Recently the authors have conducted a numerical study based on Single Degree of Freedom (SDOF) system analysis. According to their conclusions, particular attention should be given to the damping ratio and the size factor. Using Finite Element Analysis and experimental measurements, the two parameters will be investigated in detail into this work, permitting to define criteria to identify critical façade systems under the design wind loading.

Keywords: facade, wind, vibrations

1. INTRODUCTION

Often the codes and best practices aim at stating simple and comprehensive parameters to define the boundaries for the occurrence of a critical phenomenon. It is exactly the attempt of Eurocode (EN1991-1-4, 2005) and US building code (ASCE/SEI 7-10, 2010) when they establish a threshold for the possible vibration phenomena under along wind loading, which could determine a much larger response of the system than expected by quasi-static calculations. For instance, the Eurocode establishes that 5Hz is a reasonable limit to characterize façade elements, but historically this value has been considered overly conservative (Allen and Dalgliesh, 1974; Nagakami, 2003) mostly because of the expected wind power spectral density distribution. At the same time, several researches have been conducted to confirm this limit, especially in US where a specific facade limit does not exist and the only reference in the building code is 1Hz that relates to general building systems (Meyyappa et al., 1980; Moore, 2017; La Gasse, 2017). Some of them have identified systems, like appendages, fins, sub structures for solar energy collection, which have shown quite large vibrations even if their first natural frequency was larger than 10Hz (Geurts et al., 2000; Moravej et al., 2014).
Under this scenario, it would be desirable that a standard approaches this topic by considering a more accurate refinement of the conditions that can facilitate the resonance under wind loading. Natural frequency can’t be the only parameter that governs the phenomenon, but it should be

combined with others to identify critical combinations of structural and geometrical characteristics (Solari, 1982; Dyrbye and Hansen, 1999; CNR-DT 207/2008, 2010; Steenbergen et al., 2012). For this reason, the authors aim to exploit robust criteria to identify the combinations of wind loading parameters (surface height, wind mean value, turbulence) and system characteristics (damping, natural frequency) that results in risk of dynamic amplifications, on one side to avoid useless and time consuming dynamic assessment when the risk is very low and on the other side to make sure that a proper calculation is performed to apply dynamic factors, when the risk is not negligible.

Figure 1. An example of a façade with large glass panes and external glass fins

2. RESEARCH METHOD AND RESULTS

The authors have undertaken in the past a numerical study to try to narrow the major parameters affecting the occurrence of resonances under wind loading (Lori and Manara, 2022). They have used the SDOF representation of the façade element system (Biggs, 1964), by considering several possible wind loading scenarios. In particular, given a certain surface height with respect to the ground, a set of wind pressure Power Spectral Densities (PSD) have been generated by varying the mean wind velocity and by a constant turbulence factor. Depending in particular on the surface height on the ground, spectral areas exceeding the 1Hz threshold varies between 1 and 10% of the total spectral area. The PSD has been applied to the SDOF representation of the system, for different damping ratios and searching for the natural frequency of the system for which the dynamic response is within a certain percentage of the response given by the equivalent static method. The conclusions of the study were in line with the wide range of experiences reported in literature: a general statement only in terms of natural frequency limit is not recommended, as it can lead to underestimation of the vibration in some rare cases, being overly conservative for the most part of the applications tough.

Figure 2 shows for instance a comparison between the frequency limits, calculated by the frequency of the system that gives a dynamic factor of 1.1 according to the proposed approach (left) and by means of the method proposed in Annex B of the EN1991-1-4, in function of damping factor (Lenk et al., 2010) and mean wind velocity. It is evident that the proposed method highlights more critical combinations of wind velocity and damping than the method of the Eurocode does. The reason of the differences has been mostly identified into the peak factor, which results lower in the Eurocode method than in the assumption used by the authors. However, inconsistencies with the code seem confirmed by the experimental data collected by the authors and adopted for the method calibration. For this reason, further investigations have been conducted and they will be shown into this paper. In addition to the investigations about the peak factor, also correlation between size factor and dynamic factor have been studied for different damping conditions, still making use of a combination of experimental data and numerical simulation by Finite Element Analysis. The results, quite surprising from a certain perspective, show that the current structural factor is probably overestimating the occurrence of vibrations under the most part of the conditions. However, when isolating the dynamic factor, it can be seen like this part of the definition seems frequently underestimating the actual resonance effect by uniform load distribution, especially when small damping factors are considered. It is the combination with the size factor, more on the safe side, to determine the safe side character of the complete structural factor parameter.

3. CONCLUSIONS AND FUTURE WORK

The authors are investigating the topic of the definition of a frequency limit that would allow to ignore vibration effects due to wind loading, as suggested in EN1991-1-4 by means of the 5Hz current limit. The topic is controversial, as several researchers consider that such a current limit is quite conservative, but other literature studies have shown occurrence of vibrations despite a first natural frequency of more than 10Hz. By means of the investigations of this paper, joined with the previous conclusions obtained by the same authors (Lori and Manara, 2022), it is concluded that the dynamic factor part of the structural coefficient could be improved and that the frequency limit definition should be given in terms of combination of other parameters of the system, like geometry and damping factor, in order to avoid the frequent application of an excessive value of the structural factor or, less frequent but possible, underestimation of vibrations. A criterion for the definition of the frequency limit in function of the wind loading characteristic is proposed, supported by some numerical investigation by Finite Element Analysis and making use of available experimental measurements. Future work will involve refinement of the criterion and further validations by experimental data.

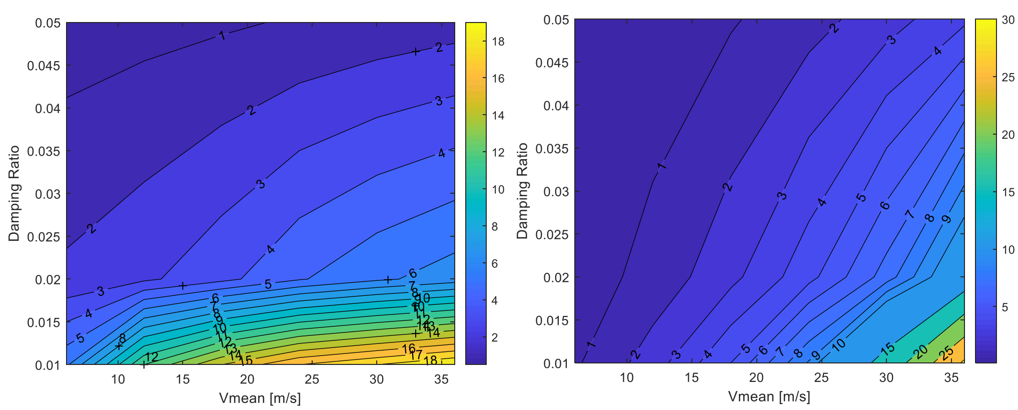

Figure 2. Minimum frequency without dynamic effects for different conditions of damping and mean wind velocity calculated by the proposed approach by L=188m (left) and by EN1991-1-4 Annex B (right)

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