Applicability of DAD methodology for low-rise buildings to European and Italian wind load standards

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ABSTRACT:
In the last decade the DAD (Database-Assisted Design) method has been developed as a reliable calculation procedure to estimate structural wind loads and the design of low-rise, industrial buildings. This approach has been introduced as an alternative to prescriptive design standards. As ASCE7-16 already contemplates the use of DAD (Sec. C31.4.2), application of this method could also be extended to European and Italian standards, resulting in an effective tool for structural design against high wind loads. In this work, maximum bending moments are compared at selected cross sections of steel portal frames of five industrial buildings, calculated using both DAD, European (Eurocode 1, "EC1"), Italian (NTC18 & CNR-DT 207/2008 or "CNR") and American (ASCE 7-16) provisions. The comparisons indicate that the moment magnitudes, estimated through the standards, are similar and conservative compared to DAD results when the building is located into an "open country" exposure scenario. However, the DAD method better reproduces turbulence effects on the variation of the pressure coefficients when a suburban terrain is considered.

Keywords: Database-Assisted Design, aerodynamics, industrial buildings, structural wind forces, bending moments.

1. INTRODUCTION

This work examines the wind-resistant design of low-rise buildings. These structures are either residential or industrial with a roof height less than 20 m and a fundamental natural frequency larger than 1 Hz. Dynamic amplification effects induced by wind loads are usually negligible, and the fluctuating wind forces can be applied quasi-statically. Consequently, an equivalent, static structural analysis under slowly varying fluctuating loads can be used. Wind loads are usually determined as a combination of time-dependent distributed pressures acting on the envelope of the building. The pressure loads are usually expressed in terms of dimensionless aerodynamic pressure coefficients (C_p); the C_p values are employed to estimate the structural loads together with their tributary areas.

In order to improve the structural design against wind loads, the NIST (National Institute of Standard and Technology, USA) has developed the DAD method (e.g., Simiu et al., 2003). Using a large collection of wind tunnel tests, this method employs pressure time histories measured on a reduced-scale model to design the full-scale structure and its main wind force resisting system. The main advantage of this method relies on the possibility of directly applying a representative pressure load field, which simulates the partial temporal pressure load correlation (non-simultaneity of the load peaks or "gust" pressures) without introducing any simplifications or assumptions during the design process.

This work aims at comparing the pressure loads and their effects, i.e. bending moments (Seo and Caracoglia, 2010) extracted through the DAD computer software, against the instructions of the European, Italian and American wind load standards. In particular, the comparison is carried out by examining the maximum internal forces (e.g. peak bending moments) acting in selected cross

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sections of different steel portal frames. Furthermore, the probabilistic method by Sadek and Simiu (2002) has been considered to evaluate the peak effect accounting for the inherent load randomness. Because estimates obtained using Sadek and Simiu (2002) are based on the whole information contained in the experimental time series, they are more stable than estimates directly based on observed peaks from wind tunnel data. Five prototype industrial buildings have been analyzed with variable geometry (e.g. horizontal-plane dimensions, eave height, roof inclination, structural frame external constraints) and wind exposure: open country with roughness length z_0 = 0.03 m = 0.01 ft, or suburban with z_0 = 0.3 m = 0.1 ft. The aerodynamic databases, from which the C_p time histories have been extracted, are the Western University database (UWO/NIST) and the Tokyo Polytechnic University database (TPU).

2. MODELS AND METHODS

Using the DAD software (*Wind*DESIGN) it is possible to combine the building geometric parameters with the aerodynamic information to obtain the time series of the internal forces at the cross section of interest, produced by turbulent wind pressures referenced to a unit mean-wind speed (1 ft/s) at the eave height. Based on the wind tunnel model buildings, finite-element models of the five structures have been created and, according to the various standard recommendations, wind pressure loads have been applied as equivalent, concentrated loads on the principal structural frames [Fig. 1(a)]. For a "rigid" structure with no dynamic resonance effects, the wind-induced internal forces are proportional to the square value of the mean wind speed. Therefore, the structural analysis results are normalized by the square of the wind speeds to enable the comparisons with the DAD software data.

3. RESULTS AND DISCUSSION

The analysis of the results in Fig. 1(b) suggests that the design standard results are usually consistent, predicting peak internal bending moments very close to each other; estimated moments are usually conservative in comparison with DAD predictions. The DAD method allows to reduce wind loads and their effects, i.e. lead to smaller-size structural elements when the building is located in open country scenario. Furthermore, the DAD method better analyses turbulence effects when a suburban terrain exposure is considered, because the DAD relies on a realistic wind speed profile without any simplifications or initial assumptions.

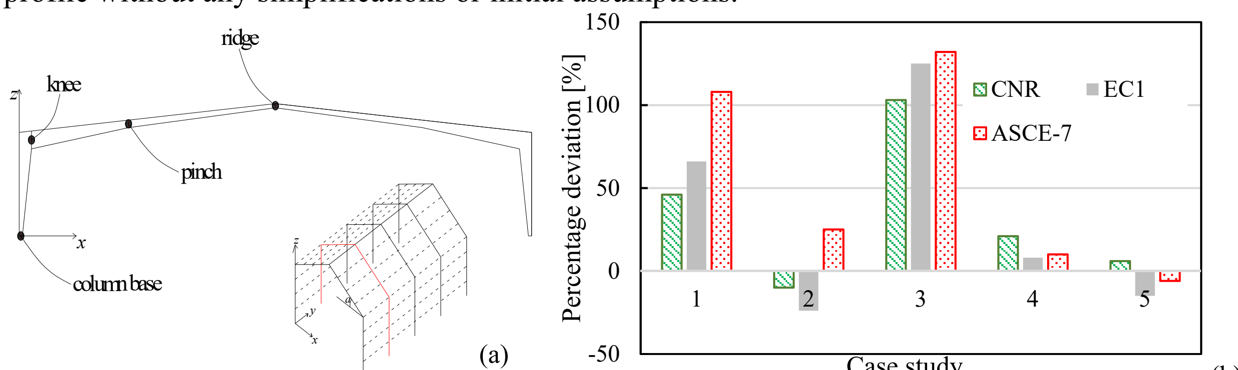

Figure 1. (a) Typical steel portal frame showing cross sections, selected for structural analysis; (b) Comparison among Italian (CNR), EC1 and ASCE-7 standards – bending moment in the knee cross section.

In Fig. 1(b) a positive percentage deviation means that the bending moment predicted using the standards are larger (i.e. conservative) relative to DAD predictions; on the contrary, a negative deviation underlines that the DAD forecasts a larger-magnitude effect, i.e. more realistically represents the wind pressure field acting on the structure. In all the cases, the peak bending moments estimated by the probabilistic method (Sadek and Simiu, 2002) are more stable and conservative than observed extreme values, extracted from the wind tunnel data records.

4. CONCLUSIONS

The DAD method is a reliable alternative for the structural design against high wind loads and should possibly be considered for implementation into the European and Italian wind load standards. Future research might consider non-linear structural analysis and inelastic response.

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