Numerical models for wind fragility of industrial steel buildings

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SUMMARY
Issues related to the fragility analysis of steel industrial buildings under synoptic winds are discussed with specific reference to the roof of an industrial benchmark steel building. A multi-scale numerical modeling strategy is proposed, Limit States (LSs) are identified and associated to each structural analysis component before examining the following fundamental questions related to the fragility analysis: a) what is it the appropriate Intensity Measure (IM)?; b) is the "record-to record variability" concept (largely used in seismic engineering) valid/applicable to wind engineering problems?; c) is the "meta-fragility" concept useful to describe the fragility? Numerical structural analyses are conducted on a structural sub-structure, designated as micro-scale model, exploiting the availability of wind tunnel pressure time histories.

Keywords: fragility, performance-based wind engineering, probabilistic analysis

1. INTRODUCTION

Fragility analysis is widely used in structural engineering, especially for seismic design, to quantify performance and risks in a probabilistic setting

(Bakalis and Vamvatsikos 2018). The fragility is generally defined as the probability of occurrence for a certain limit state (LS), conditional to the hazard intensity (IM). Wind engineering studies on fragility began in late'80 (Clark 1984) and have continued through the years to produce useful design tools (Vickery et al. 2006), mainly derived as an extension of the more common seismic design procedure to other hazards. Nevertheless, a systematic analysis of some critical basic aspects, related to structural wind fragility, has never been conducted. Critical basic aspects are intended as those defining the basic sensitivity of the obtained fragility to different parameters/assumptions. Among these aspects, three items deserve particular attention because they are impacted by the uncertainties, considered in the fragility evaluation. This paper addresses them in a detailed manner.

The first point to address is related to the sufficient conditions and necessary conditions that define the IM adopted to express fragility. For example, many works proposed the mean wind velocity as IM (e.g., Sciaudone et al. 1997, Twisdale and Vickery 1995), but the necessity of considering a vectorial IM has often been highlighted (e.g., Barbato et al. 2013).

The second point should address, for wind engineering problems, the most appropriate definition of what is commonly called in earthquake engineering "record-to-record variability" (Bakalis and Vamvatsikos 2018): at the same IM value, a dispersion of the response is observed due to the intrinsic difference given by the effect of other input load parameters that are not included by the IM. Specifically, fluid-structure interaction (FSI) phenomena can play a prominent role, as well as structural dynamic characteristics (e.g., structural damping), whilst they are not fully associated with hazard intensity.

The third point regards the possibility of using the "meta-fragility" concept (Iervolino et al. 2007) to manage/represent the effect of some uncertain parameters on the structural fragility. Meta-fragilities are a sort of fragility for a given structural class which, whilst composed by the same structural typologies, are characterized by a certain variability in the mechanical or probability distribution shape characteristics; for example this effect may be represented by a set of fragility curves whose main parameters (e.g. log mean and log standard deviation) depend on these characteristics.

In this study, the three above-mentioned points are analyzed and discussed using a case-study structure a numerical multi-scale Finite Element analysis strategy. The case study is a steel industrial building composed of parallel steel portal frames and a gable roof structure.

2. CASE STUDY

The building is taken from Cantisani and Della Corte (2022). It consists of parallel portal frames with truss-type beams in the transverse X-direction and concentric braces in the longitudinal Y-direction. The geometry and the structural system are shown in Figure 1.

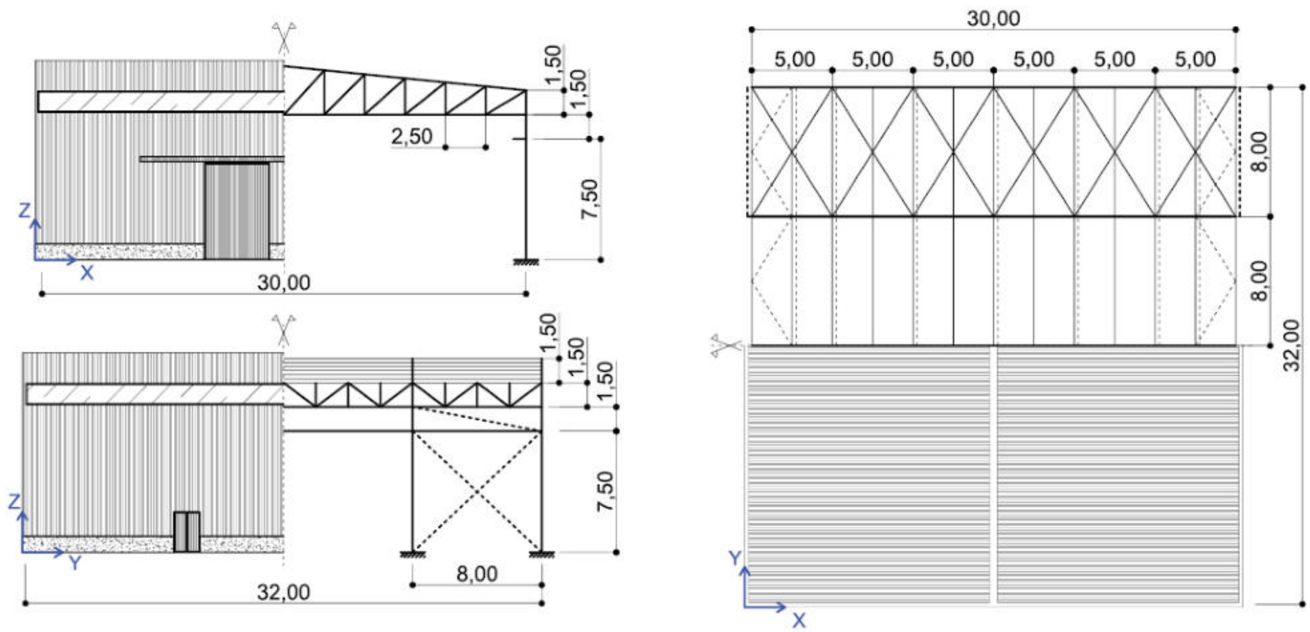

Figure 1. Geometry of the industrial building case study. Dimensions are in meters; bold lines represent steel members. Adapted from Cantisani and Della Corte (2022).

The cross sections of the main structural members are reported in Figure 2; the design tables below are extracted from Cantisani and Della Corte (2022); the orange-highlighted configuration is used. The roof is made of cold formed shaped sheets (steel deck type), fixed to the bottom beams by screws; the surface of each steel deck panel is 2.5m by 8m.

3. FEM MODEL: PRELIMINARY RESULTS

A Multi-Level modeling strategy is adopted by considering the whole structural system at the "macro-scale"; the whole roof is modeled by an equivalent planar shell at the "meso-scale"; a single steel roof sheet (panel) with the supporting beams and elasto-plastic screws is modeled at the "micro-scale". The models are developed in the Ansys® software and are represented in Figure 3. Focus is made here on the micro-scale analysis.

Table 5. Design output for the archetype buildings: Lateral load resisting structural system.

Case study	Column	Truss chords (top and bottom)	X-Braces	Single brace	Longitudinal chord (at 7.5 m,
PCB-SHS-AQ	HE 500 M	2 UPN 180 2 UPN 140	SHS 80x5	SHS 110x5	2 UPN 280
PCB-SHS-MI	HE 500 M	2 UPN 140 2 UPN 120	SHS 80x5	SHS 110x5	2 UPN 280
PCB-SHS-NA	HE 700 M	2 UPN 140 2 UPN 120	SHS 80x5	SHS 110x5	2 UPN 280
PCB-2 L-AQ	HE 500 M	2 UPN 180 2 UPN 140	2 L 90x9	2 L 130x12	2 UPN 280
SCB-SHS-AQ	HE 450 M	2 UPN 220 2 UPN 140	SHS 80x5	SHS 110x5	2 UPN 280
SCB-2 L-AQ	HE 450 M	2 UPN 220 2 UPN 140	2 L 90x9	2 L 130x12	2 UPN 280
SCB-2 L-MI	HE 400 M	2 UPN 160 2 UPN 120	2 L 90x9	2 L 130x12	2 UPN 280
SCB-2 L-NA	HE 500 M	2 UPN 140 2 UPN 120	2 L 90x9	2 L 130x12	2 UPN 280

Table 6. Design output for the archetype buildings: Roof structural system.

Case study	Purlins	Roof braces
PCB-SHS-AQ	HE 220 A	2 L 80x8
PCB-SHS-MI	HE 160 B	2 L 80x8
PCB-SHS-NA	HE 160 B	2 L 80x8
PCB-2 L-AQ	HE 220 A	2 L 80x8
SCB-SHS-AQ	HE 220 A	2 L 80x8
SCB-2 L-AQ	HE 220 A	2 L 80x8
SCB-2 L-MI	HE 160 B	2 L 80x8
SCB-2 L-NA	HE 160 B	2 L 80x8

Figure 2. Cross sections of main steel members. Adapted from Cantisani and Della Corte (2022).

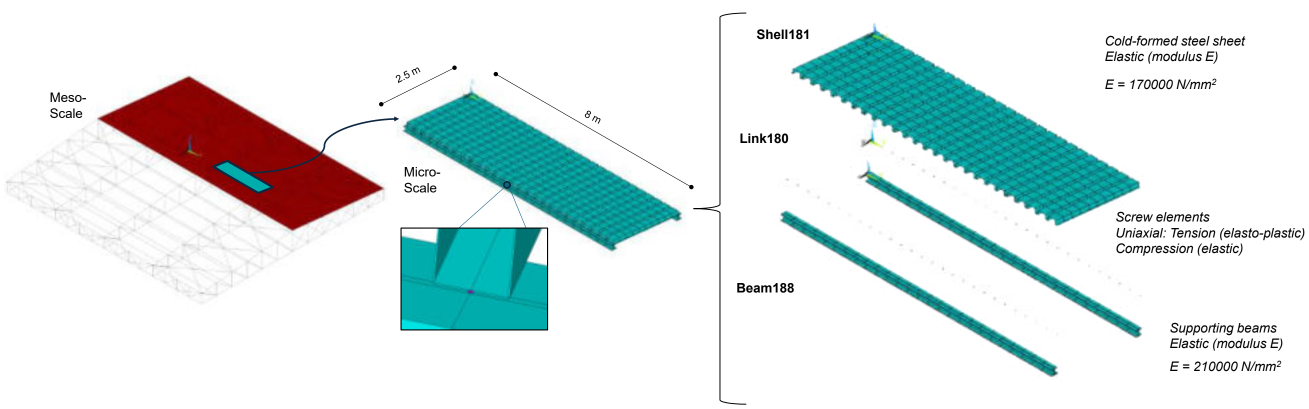

Figure 3. Details of the "micro-scale" FEM model of the single roof panel.

Wind loads are determined by considering wind pressures, obtained from wind tunnel tests conducted at the CRIACIV wind tunnel. The total number of pressure taps is sufficient to have more than one pressure tap in each individual steel panel. Figure 4 illustrates a typical individual roof panel on the roof and the distribution of the taps. Time histories are extracted from the wind tunnel database, i.e., a "database-assisted-design approach" (e.g., Sadek and Simiu, 2002) to conduct non-linear time history analyses for fragility evaluation purposes.

The model allows for the evaluation of the forces inside the screw and the steel cold formed sheet (see Figure 5). The group failure of the screws is considered as Limit State (LS).

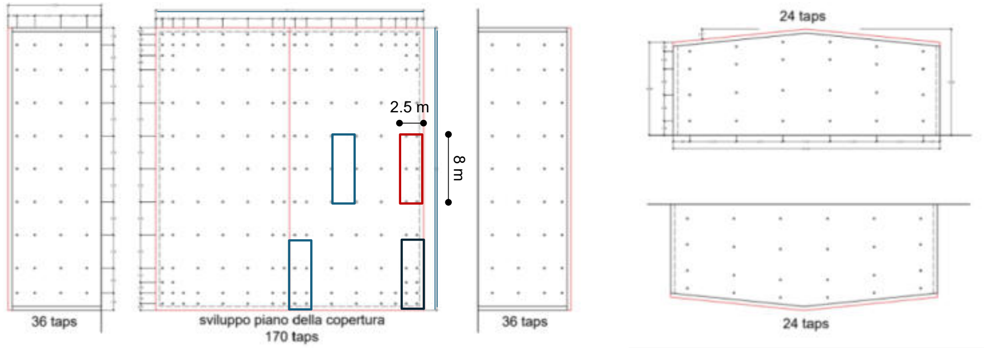

Figure 4. Details of the pressure taps and positioning of the single panel on the roof.

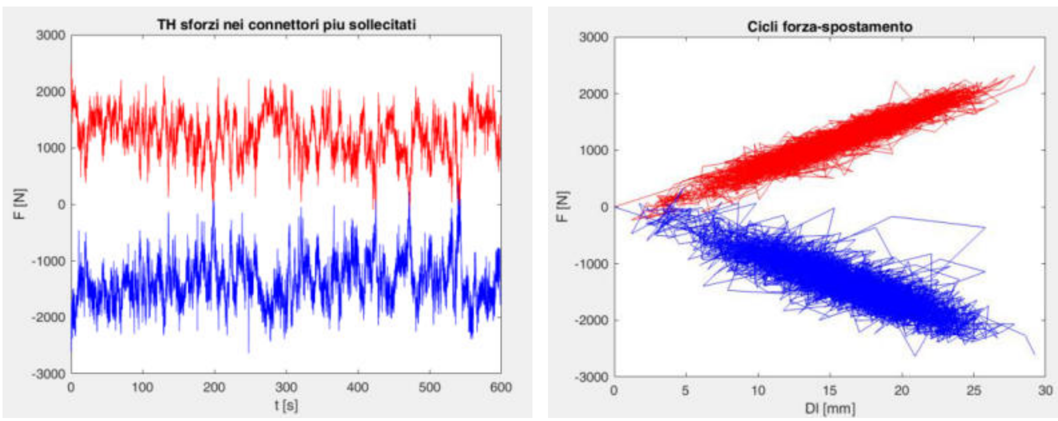

Figure 5. Case of mean wind velocity V10=20 m/s. Time histories of axial forces (left) and force-deformation cycles (right) for the most stressed screw during simulated, single wind event.

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