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Wind and earthquake multi-hazard performances evaluation for steel frames

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SUMMARY: (10 pt)
A method for probabilistic multi-hazard performances evaluation of steel frames under wind and earthquakes is presented and applied to a case-study 60-storey building. The procedure is based on the so-called SAC-FEM approach, originally developed in earthquake engineering, and recently expanded by the authors to the wind engineering. The procedure leads to an optimal risk-based design configuration of the structures considering the two hazards.

Keywords: multi-hazard, wind, earthquake

1. INTRODUCTION

The need for approaches accounting for Multi - Hazard (MH) exposures in the structural design started to arise as a consequence of events related to a Multi - Hazard scenario occurred. However, when the structural design deals with MH scenarios, many different problems emerge, concerning both the lack of knowledge of how to cope with multiple hazards impacting on structures, the shortcomings of the traditional design philosophies about the complex interaction between different hazards or the correct evaluation of the combined effects of those hazards, or they could imply difficulties in identifying mitigation strategies. At today, a methodology for the design of structures under multiple hazard who considers the various performances evaluation in a coherent manner between the different threats is not available. In fact current design methods for natural hazard (e.g., wind, earthquake) tend to analyse ultimate limit states (ULSs) and serviceability limit states (SLSs) performances of a certain design solution under each hazard separately, and then aim to update the design if required by one of the hazards, something leading to a final design solution which is not a global optimum (i.e., eligible as the best one by considering both SLSs and ULSs for all the acting hazards), but it is rather a local one (mostly driven by one hazard and judged as acceptable for other hazards). However, approaches of this type that are not effectively multi-hazard have in some cases shown their ineffectiveness in situations that have occurred. Focusing on natural hazards as wind and earthquake, the goal is to understand if interference could occur in the design choices for steel buildings of a certain height, thus determining which driving design aspects is predominant, since not only the structural integrity must be assessed, but it also necessary to focus on the comfort of the occupants and the serviceability of the structure, in order to address also eventually conflictual design strategies. However, to have an effectively multi-hazard design, it is necessary to unify the language used in order to assess the structural performance for the different hazards to which reference is made (i.e., wind and earthquake in this case); only if the used frameworks are joined together, it is possible to obtain a common approach valid for both hazards, in order to compare structural responses both in linear (i.e., SLSs) and non-linear field (i.e., ULS). Thus, it is convenient to adopt a simplified analysis procedure that could be also implemented in Standards and in design practice (so-called SAC-FEMA method, originally introduced in the seismic field by Cornell in the early 2000s and more recently extended to the wind). It is important to underline that the focus here is on the correct design choices rather than on the simultaneous occurrence of the two hazards (which is known to be characterized by a very low probability).

2. METHODS

2.1 SAC-FEMA analysis method

With specific reference to wind and earthquake, the performances of steel high rise frame-building under multiple hazards are assessed in this work using the SAC-FEMA probabilistic analysis method. This performance-based-like approach provides the possibility to determine the Mean Annual Frequency (MAF) of a certain Limit State (LS) using a simplified algebric formulation, avoiding the complexity of the traditional integral expression; this simplification is made possible through appropriate assumptions which concerns both the demand and the capacity definition and also the hazard interpolation. From table 1 it is possible to note the main differences in terms of EDP, IM, hazard curve characterization and of the types of analysis that will be considered in this work. For specifics and further information on the SAC-FEMA probabilistic analysis method, it is considered appropriate to refer to the literature.

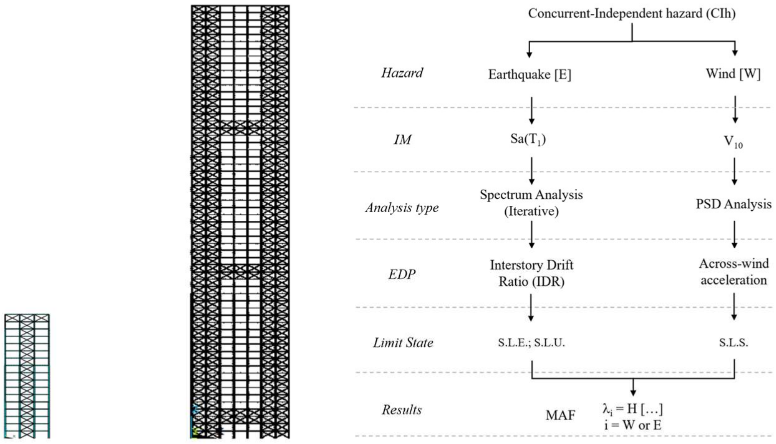
Table 1. Assumptions concerning the SAC-FEMA analysis method

SAC/FEMA Method	Earthquake	Wind
Intensity Measure	$Sa(T_1)$	V_{10}
Engineering Demand Parameter	Interstory Drift Ratio	Peak Acceleration
Hazard Distribution Function	Poisson	Weibull
Hazard Interpolation	H(s) = k0 exp[– k2ln2(s) – k1ln(s)]	
Demand	Lognormal Distribution	
Capacity	Lognormal Distribution	
Mean Annual Frequency	$\lambda_i^j = \sqrt{\phi} k_{0,i}{}^{1-\phi_i^j} \left[H_i\left(im^{\hat{C}^j}\right)\right]^{\phi_i^j} \cdot exp\left[\frac{1}{2} q_i k_{1,i}^2 \left({\beta_C^j}^2 + \phi_i^j \beta_{D,i}^2\right)\right]$	

Where:
i represents the Demand regime due to spatial main direction of Hazard;
j represents the Capacity regime due to the considered Limit State.

2.2 Description of case studies

The use of analysis methodologies that have the same level of approximation at the base in the evaluation of structural performances for different hazards (SAC-FEMA method), allows to use a single language. From a multi-hazard perspective, then, it makes sense to exploit this advantage offered to evaluate how the design solutions to be adopted change as the structural flexibility changes and how the dominant hazard varies considering different structural height. These assessments were made on two 2D steel buildings of different heights (17 floors – 59.5 m and 60 floors – 210 m). It was decided not to consider a pre-dimensioning for a specific hazard in order to evaluate the effects of any design configurations considered on the monitored response parameters. These are steel shear-resisting frames, for which the initial configuration was identified following a pre-sizing for vertical loads only, considering a precautionary use coefficient for the structural elements (for U.L.S. combination: bracing system and outriggers 30%, columns 60%, beams 30%). Out-of-plane deformations are disabled and that beam-column joints and beam-column-outrigger trusses (or bracing system trusses) are modelled as "hinges". This application has better efficacy when considering a site characterized by both particularly intense wind phenomena and by equally important seismic events. Thus, the case studies are designed to be inserted in a site with high seismicity and high wind (it was assumed an ideal site whose seismic hazard is that of the L'Aquila site, Italy, and whose windy hazard is that of the Orlando site in Florida, U.S.A.). The following figure (Figure 1 c) shows a summary of the analysis process carried out for both hazards considered, starting from the parameter used to define the intensity of the hazard (V_{10} for wind, $Sa(T_1)$ for earthquake), the type of analysis performed (PSD Analysis for wind and Iterative Spectrum analysis for earthquake), the monitored response parameter commonly called Engineering Demand Parameter - EDP (Interstory Drift Ratio for earthquake and Across-wind peak acceleration for wind) and finally the limit states considered (S.L.E. and U.L.S. for seismic analysis and S.L.S. for wind analysis).



a) b) c)

Figure 1. 2D steel buildings of different heights considered in the application: (a) 17 floors; (b) 60 floors and (c) summary of the analysis process carried out for both wind analysis and earthquake analysis.

3. RESULTS

An equal design strategy has different consequences in the two cases considered (17-storey and 60-storey building): if the mere variation of the sections of the structural elements is not effective in obtaining configurations close to the optimal one, the insertion of a global stiffening element (such as the outrigger) instead has a certain weight in achieving the satisfactory design solution (Figure 2). However, even this choice is only partially effective, because its best application is related to the case of buildings particularly sensitive to both hazards considered (the 60-storey building). For the 17-storey building, this strategy is effective only in the case of the U.L.S., since this Limit State is connected to the entry into the plastic field of the structural elements, having strengthened the structure through an increase in the inertial properties of the sections has resulted in a reduction of plasticization. This choice did not have a significant effect on S.L.E. (earthquake), as this Limit State is connected not to the entry into the plastic field of the structural elements, but to the value of the displacements; having reduced the structural period has in fact resulted in an increase in the seismic action to which the structure is subjected without having a significant reduction in displacements. Thus, from the analysis of frames of different heights it is possible to observe how, considering a truly multi-hazard design, such an approach is essential when the structure does not have a marked sensitivity towards one of the hazards considered (i.e., 60-story plane frame examined). In this way, the key issue connected to the need for uniformity of analysis methods and language for the PBE under different hazards (i.e., unified framework problem) can be addressed, using a unique metric for the assessment of structural performances under wind and earthquake loads.

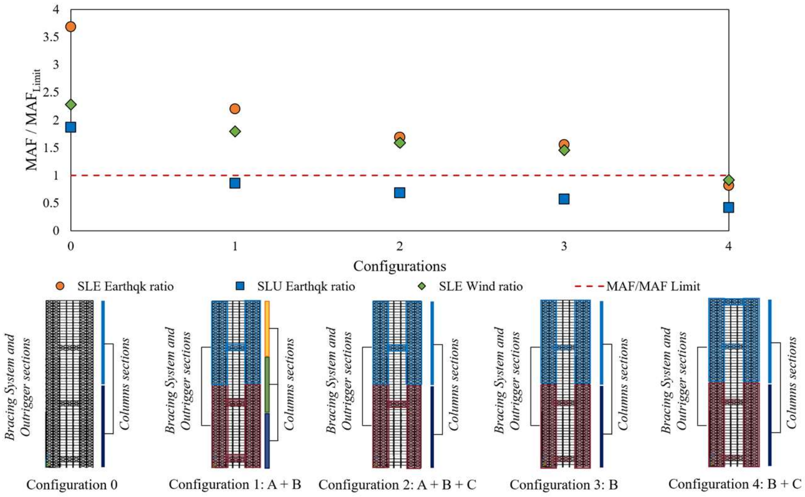


Figure 2. Evaluation of MAF/MAFLimit for different design configurations of the 60-Floors steel plane frame

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