Discussion of "Review of Methods to Assess, Design for, and Mitigate Multiple Hazards" by Yue Li, Aakash Ahuja, and Jamie E. Padgett

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The authors have performed a useful service by providing a broad perspective on multihazard engineering. The discussers would like to complement that perspective by noting two results of practical significance in the context of design for multiple hazards.

Two Independent Hazards: Wind and Earthquakes

Current design practice with respect to these hazards is incorporated in, among others, ASCE 7-10 (ASCE 2010). This practice, while noted by the authors, deserves comment. Its basis is the observation that, in regions susceptible to experiencing strong winds and strong earthquakes, the probability of joint occurrence of these types of events is negligible. From this observation, it has been inferred that it is safe to design structures in such regions by ensuring that they conform to standard requirements under the assumptions that (1) only strong winds can occur and, separately, that (2) only strong earthquakes can occur.

This approach is inconsistent with the ASCE 7-10 (ASCE 2010) fundamental requirements, as is demonstrated in Duthinh and Simiu (2010) and Crosti et al. (2011a, b). Indeed, the Standard specifies the minimum load requirements in a probabilistic framework, meaning that the probability of exceedance of the load effect being considered may not exceed (or, in the language used by the Standard, "shall not be permitted to exceed") a specified mean recurrence interval, for example, 700 years for most typical structures. If the relevant load combination entailed the intersection of the events W and E (where W denotes the wind loading effect and E denotes the earthquake loading effect), then current practice would be acceptable. However, within the probabilistic framework mandated by the Standard, it is not the intersection, but rather the union of the events W and E, that is relevant.

This follows not only from simple equations, as well as simple, intuitive arguments, presented by Duthinh and Simiu (2010) and Crosti et al. (2011a, b), but also from Eq. (2) of the authors' paper, subsequently reproduced with a change of notation

$$P_f = \Sigma[P(F|W) + P(F|E)]$$

where P_f = probability of exceedance of a specified limit state, $P(F|W)$ = probability of exceedance of the limit state given the load effect W, and $P(F|E)$ = probability of exceedance of the limit state given the load effect E. Let the limit state being considered be defined as the limit state specified for design under wind loads. It is clear from Eq. (3) that $P_f > P(F|W)$, because, regardless of what criterion is used for seismic design, the probability of exceedance of the limit state specified for design under wind loads, given the load effect E, is larger than zero. Therefore, the design criterion for wind based on the assumption $P_f = P(F|W)$, implicit in the load combination specification of the Standard's Chapter 2, is not consistent with the minimum load requirement explicit in the very title of the Standard.

Whether Eq. (2) affects seismic design depends on the tail length of the probability distribution of wind effects. Hurricane wind speeds and earthquakes, each with a mean recurrence interval lower than 2,500 years, can combine to produce effects with mean recurrence intervals lower than 2,500 years comparable with the effects induced by the maximum considered earthquake. This issue is currently under study.

Two Dependent Hazards: Wind and Storm Surge

Storm surge is produced by hurricane winds and is strongly influenced by the topography and bathymetry local to the site being considered. Designing for the effects of the coupled hurricane wind and storm surge hazards requires a multihazard approach that can account for their combined effects and the influence of site specificity. Phan et al. (2007) have proposed approaches aimed at developing site-specific, risk-based design criteria for structures subjected to hurricane wind speed/storm surge effects. One of those approaches makes use of the time series of the sum of the simultaneous wind speed and storm surge effects, and involves the following steps:

1. Calculate the combined scalar effects σ_{ij} of the directional wind speeds v_{ij} and the corresponding storm surges S_{ij} for all i, j $(i = 1, 2, \ldots, n)$, where n is the number of simulated hurricanes used in the calculations, $j = 1, 2, \ldots, m$, and m is the number of wind speed directions being considered (e.g., $m = 16$). The combined effect could be, for example, the maximum stress in a member subjected to gravity loads and to loads induced by both wind and storm surge; or the left-hand side of the interaction equation for members subjected to combined axial load and bending moment [see Eqs. H1–1 of AISC (2011)]; or the aggregate loss of electrical power in a specified region because of damage to overhead power lines induced by wind and damage to underground cables caused by seepage of water following a storm surge and the consequent flooding.
2. Select, for each hurricane i, the largest of the effects σ_{ij}, denoted by σ_i.
3. Perform a probabilistic analysis of the univariate time series σ_i similar to the analysis applied to hurricane wind effects representing the maximum of the directional effects in each of a number n of simulated hurricanes (Simiu 2011). This analysis can yield effects σ_N corresponding to any specified mean recurrence intervals N.
4. For a design to be acceptable, σ_N must be less than the corresponding specified limit state associated with the mean recurrence interval N.

The determination of design wind effects consistently relies on a structural reliability approach in the load-effect space. Similar but less data-intensive and more conservative alternatives are also considered in Phan et al. (2007).

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