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Model Uncertainties and Structural Reliability of Tall Buildings Subjected to Wind Loads

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ABSTRACT

Methods for estimating wind-induced effects and safety margins for tall building design are not definitively established. This explains why independent estimates of wind-induced base moments for the World Trade Center towers differed from each other by more than 40 % [1]. In particular, current treatments of uncertainties result in lower nominal reliability levels for tall than for rigid buildings. First, uncertainties in natural frequencies and damping ratios are disregarded or seriously underestimated. Second, the direction-dependent aerodynamic pressures and wind climate are jointly modelled with no regard for errors inherent in the generally incorrect assumptions that (a) parent populations of the extreme wind speeds can be identified, and (b) short samples drawn from such putative populations can be used for long-term predictions of extremes. Third, safety margins for wind loading (wind load factors) are based on first-order second-moment techniques that are adequate for some rigid structures, but do not reflect the complex reliability picture typical of tall buildings, for which, unlike for rigid buildings, wind effects are proportional to wind speeds raised to powers larger than two.

The wind load factor is defined as $WLF=P_{STD}/P_{ASD}$, where P_{LRFD} and P_{ASD} are the wind effects for Strength Design (STD) and Allowable Strength Design (ASD), respectively. P_{ASD} corresponds to the mean recurrence interval (MRI) of the basic wind speed (e.g., 50 years) and a 50th percentile of the uncertainty distribution of the response. P_{STD} corresponds to an MRI greater than 50 years, and a larger than 50th percentile (to fix the ideas, assume, say, 250 years and 90 %). The STD and ASD combinations are then [2]:

$$1.2D + L + W_{250-yr,90\%} \qquad (1a)$$

$$D + W_{50-yr,50\%} \qquad (1b)$$

In Eqs. 1a and 1b, D, L, and W are the dead, live, and wind *effect*. The choices of MRIs and percentiles can be modified as deemed appropriate via calibration by professional consensus. The random wind effects reflecting knowledge uncertainties are obtained via multiplication of the wind effects calculated without accounting for those uncertainties by the random uncertainty factors *a, b, c*; *a* reflects errors in wind tunnel pressure

measurements, and wind speeds are affected by the product *bc*, where *b* reflects modeling and sampling errors in the estimation of extremes, and *c* reflects uncertainties in wind speed conversion from 10 m above open terrain to the top of the building. The distribution of the uncertainty in the wind effect must also account for uncertainties in natural frequencies and damping ratios, via random uncertainty factors *T* and *D*. To estimate that distribution, Monte Carlo simulations are used to obtain realizations of the design parameters, and wind effects are calculated on the basis of those realizations.

We considered a 60-story building in Miami, rectangular in plan, with height H=185 m, B=45.72 m and D=30.48 m, linear modal shapes, and fundamental periods of vibration with means 5.84 s and 5.66 s [3]. Four cases were considered. *Case I*: The building is *rigid* and, as is assumed in the ASCE 7-05 derivation of the wind load factor, there are *no knowledge uncertainties. Case II*: The building is *flexible* and there are *no knowledge uncertainties. Case III*: The building is *flexible*, *a*, *b*, and *c* have truncated normal distributions with unit mean and 5 %, 7.5 %, and 5 % coefficient of variation (c.o.v.), respectively, and the fundamental periods $\{T\}$ and damping ratios $\{D\}$ are deterministic. *Case IV*: The building is *flexible*, with the uncertainties of Case III, except that $\{T\}$ has a truncated normal distribution with 5 % c.o.v., and $\{D\}$ is lognormal with mean 1.64 %, median 1.5 %, and c.o.v. 0.44 [4]. The results, shown for two building columns, are member-dependent [3]. For Case I the calculated load factor is as low as 1.74, i.e., somewhat lower than the typical ASCE 7 value aplicable to hurricane regions [2], a result that may be expected given the assumed 250-yr MRI.

Column	Case I	Case II	Case III	Case IV
47th floor	2.01	2.03	2.25	2.66
3rd floor	1.74	2.07	2.44	2.68

Our example suggests that, absent special unaccounted-for strength reserves, current tall building design procedures can lead to designs with reliability lower than that of typical rigid buildings covered by the ASCE 7 Standard, confirming results obtained in [5].

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