second edition

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a guide for ASCE 7-10 Standard users and designers of special structures

EMIL SIMIU, PE, PhD

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PREFACE

For most common types of structure, standard provisions on wind loads are in principle adequate for design purposes. The ASCE 7-10 Standard, among other standards, has incorporated a great deal of wind engineering knowledge accumulated within the last half-century. However, because the Standard has been developed by successive accretions, not always smoothly, its previous versions have been perceived by some practitioners as complicated and unwieldy. In an effort to respond to the demand for a clearer document, the ASCE 7-10 version of the Standard has been substantially expanded and revised. However, difficulties remain.

One of the main objectives of this book is to help the reader better understand the ASCE 7-10 Standard provisions for wind loads and apply them with confidence and ease. To this end, the book presents a guide to the Standard that explains the rationale of the provisions and illustrates their use through a large number of detailed numerical examples. Particular attention is given to the numerous changes made in the 2010 version of the ASCE Standard. Comparisons are presented between—or among—results of alternative provisions specified by the Standard for the same type of building. The comparisons show, for example, that for low-rise buildings, the so-called envelope procedure does not necessarily yield the lowest wind loads, as the Standard asserts. They also show that wind loads yielded by alternative regular methods, by regular and simplified methods, or by alternative simplified methods, can exhibit significant differences.

Wind loads and effects on special structures cannot in general be estimated by using standard provisions based on tables and plots. Rather, they need to be based on aerodynamic testing in the wind tunnel or larger facilities, and on information on the extreme wind speeds at the site. The Standard's provisions on the wind tunnel method are still vague and incomplete. In particular, they contain little or no material on dynamic analyses, the dependence of the response on wind directionality, and the calibration of the design mean recurrence intervals to account for larger-than-typical errors and uncertainties in the parameters that govern the wind-induced demand.

Some design offices have a policy of requiring wind effects estimates from more than one consultant. This is prudent, and justified by the fact that, owing to the lack of adequate standard provisions on the wind tunnel procedure, estimates by various laboratories can differ significantly. For example, recent estimates of the New York World Trade Center towers response to wind, performed by two well-known consultants, were found to differ by over 40%.

Consultant reports need, therefore, to be carefully scrutinized, and the need for transparency in their presentation cannot be overemphasized. The book includes as an appendix a report by Skidmore Owings & Merrill LLP, which presents a practitioner's perspective on the current state of the art in wind engineering and is a testimony to the need for transparent, traceable, and auditable procedures. Material presented in the book enables structural engineers to "ask the right questions," scrutinize effectively wind engineers' contributions to the determination of wind effects, and determine wind effects efficiently and accurately on their own, just as structural engineers do for seismic effects. This requires the use by the structural engineer of aerodynamic or aeroelastic data supplied by the wind engineer in standard, electronic form, and of directional extreme wind speed data obtained from wind climatological consultants. The wind effects of interest include internal forces, demand-to-capacity indexes for individual member design, as well as deflections and accelerations needed to check serviceability requirements. The book describes in detail modern, effective, and transparent methods for estimating such wind effects for any specified mean recurrence interval.

Wind effects on individual members are functions of influence coefficients that differ from member to member. In the past, the lack of sufficiently powerful computer resources did not allow this dependence to be taken into account accurately. The capability to do so is now routinely available. It has created a bridge between the wind engineer and the structural engineer that makes it possible to integrate the wind and structural phases of structural design more clearly and accurately than was heretofore possible. Public domain database-assisted design software referenced in the book allows the effective implementation of this capability.

Until about two decades ago, the time domain solution of large systems of differential equations posed insurmountable computational problems, and dynamics calculations were performed by using the spectral (frequency domain) approach, which transforms the differential equations of motion into algebraic equations. This approach is not always transparent and intuitive, and in practice suppresses phase information needed to correctly add wind effects from various sources (e.g., from two perpendicular lateral motions).

Computational capabilities and measurement technology developed in last two decades have made it possible to replace the frequency domain approach by the typically more effective time domain approach. The time domain approach, used in publicly available software referenced in the book, is not limited to the estimation of loads through the summation of pressures measured at large numbers of ports. Rather, in the integrated format known as database-assisted design, it can be directly and effectively applied to the design or checking of individual member strength, and can thus substantially improve structural design accuracy. In particular, the time domain approach eliminates the need for large numbers of cumbersome load combinations, based on guesswork—the method currently being used—and performs the requisite combinations through simple algebraic addition of time series of load effects. The improvements inherent in the use of time domain rather than frequency domain methods can be compared to those inherent in the calculation of structural response by finite element rather than by slide-rule based techniques.

The book contains material on structural reliability under wind loads that provides, among other matters, a perspective on the limitations of the Load and Resistance Factor Design (LRFD) approach, and a procedure for the calibration of design mean recurrence intervals. The calibration is required to ensure adequate safety levels if uncertainties in the determination of wind effects exceed typical uncertainties assumed in the ASCE 7 Standard. To date, the role of errors and uncertainties in the specification of design mean recurrence intervals has not been addressed by the ASCE 7 Standard provisions for the wind tunnel procedure, with the result that some designers and wind engineers resort to "magic numbers" that may be inadequate. For example, the same design mean recurrence interval is implied in the Standard for ordinary buildings and for tall buildings, whose response depends on dynamic parameters, including damping, which may exhibit large uncertainties. A reliability-based approach that takes into account such uncertainties can yield, for some tall buildings, longer mean recurrence intervals and hence larger wind effects than those specified in the ASCE Standard.

Structural reliability is also useful because it helps engineers design structures that do not consume more material and do not contain more embodied energy than necessary to ensure adequate safety levels. Inadequate safety levels can result in wind-induced losses, which are visible and costly. On the other hand, the cost of unnecessary materials—of "fat," as opposed to "muscle"—is much less visible to the public eye, but is nonetheless real, in monetary, energy consumption, and carbon footprint terms.

The book addresses incipient efforts to estimate ultimate capacities under fluctuating wind loads, aimed to achieve designs that are safer, more economical, and less demanding of embodied energy than those based on linear methods of analysis. The book also addresses wind-induced loss estimation, a topic fraught with difficulties, owing to the nonlinearities typically associated with the analysis of failures. Finally, in response to requests by students and