Searching for Simplicity

The Evolution of Wind Provisions in Standards and Codes in the United States

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This article will provide an historical overview of the evolution of wind provisions in standards and codes in the United States. From the 1972 edition of the American National Standards Institute's *Minimum Design Loads for Buildings and Other Structures* (ANSI A58.1) — which later became the American Society of Civil Engineers' *Minimum Design Loads for Buildings and Other Structures* (ASCE 7) — to the current ASCE 7-05 and the International Code Council's 2006 International Building Code (IBC), one trend is consistent. Through their evolution, the complexity of wind design has been steadily increasing.

This article discusses the history of the wind provisions standards in the United States, specifically ANSI A58.1 and ASCE 7. The latter half focuses on the evolution of wind provisions in the model building codes in the U.S., such as the IBC and its three legacy model building codes. In conclusion, the author makes a plea for action leading to a way out of this complexity.

[Editor's Note: This article was originally published in two parts; it has herein been incorporated into one article.]

WIND PROVISIONS IN STANDARDS

This section traces the evolution of wind provisions in ASCE 7 and its predecessor standard, ANSI A58.1.

ANSI A58.1–1972 — Modern wind design in the United States started with ANSI A58.1–1972. The new provisions represented a quantum jump in sophistication in comparison with codes of practice at that time. However, the provisions were flawed with ambiguities, inconsistencies in terminology, and a format that permitted misinterpretation of certain provisions.

ANSI A58.1-1982 — A revised ANSI A58.1-1982 standard contained an innovative approach to wind forces for components and cladding of buildings. The wind-load specification was based on understanding the aerodynamics of wind pressure around building corners, eaves, and ridge areas, as well as the effects of area averaging on pressures. This standard was largely free of the ambiguities and inconsistencies of ANSI A58.1-1972 and began to be adopted by model code organizations.

ASCE 7-88 — The maintenance and update of the ANSI A.58.1 standard was taken over by ASCE in the mid-1980s. The first minimum-loads standard to appear under ASCE's banner was ASCE 7-88, in which only minor changes and modifications were made in the wind provisions of ANSI A58.1-1982.

ASCE 7-93 — No changes whatsoever were made to the wind provisions in the next edition of the standard, ASCE 7-93.

ASCE 7-95 — The first significant updates in the wind provisions since 1982 were made in ASCE 7-95. The most significant among a number of important changes was that "three-second-gust" wind speed rather than "fastest-mile" wind speed became the basis of design. The averaging time implicit in fastest-mile wind speed was the time it takes for a mile of wind to pass through the measuring instrument called an anemometer. This typically ranged between 30 and 60 seconds. The averaging time changed to a fixed three seconds when the three-second-gust wind speed was adopted. Since average wind velocity increases as the averaging time decreases, the design wind speed, which for the vast majority of the country had been 70 miles per hour (mph), now became 90 mph, except in the West (roughly in the Pacific time zone), where it typically became 85 mph. In order not to end up with significantly greater design wind pressures as a result of this change, numerous adjustments had to be made to coefficients. Some of the more important of these included velocity pressure exposure coefficients, gust-effect factors, and internal and external pressure coefficients that included gust effects.

Among other significant changes, provisions were added for wind speed-up over isolated hills and escarpments by including a topographic-effect factor in the expression for the design wind pressure.

New provisions were added for full and partial loading on the main wind force-resisting system (MWFRS) of buildings with a mean roof height greater than 60 ft, thereby requiring consideration of wind-induced torsion in all buildings other than low-rise buildings. Low-rise buildings, for purposes of the wind design provisions, are those with mean roof heights up to 60 ft.

Finally, an alternate (low-rise, analytical) procedure was added for determining external loads on the MWFRSs of buildings having mean roof height not exceeding 60 ft. This procedure had been adopted into the Standard Building Code (SBC), which was published by the Southern Building Code Congress International, from the Metal Building Manufacturers' Association (MBMA) manual and is based on testing carried out at the University of Western Ontario, in London, Ontario, many years earlier.

ASCE 7-98 — In ASCE 7-98, the basic wind-speed map was updated based on new analysis of hurricane wind speeds. As a result, wind speeds became significantly lower in inland Florida.

A wind-directionality factor, K_d, was introduced in the expression for the design wind pressure to account for the directionality of wind. Directionality refers to the fact that wind seldom, if ever, strikes along the most critical direction of a building — basically, because it cannot. Wind direction changes from one instant to the next. Wind can be only instantaneous along the most critical direction; at the very next instant, it will not be from the same direction. This fact used to be taken into account through a relatively low load factor of 1.3 on the effect of wind in strength design load combinations. But then, ASCE 7 received comments that engineers using allowable stress design (ASD) could not take advantage of the directionality of wind. The ASCE 7 decision to include K_d = 0.85 for buildings in the definition of the wind pressure was in response to these comments. In order not to design using lower-factored wind forces in strength design, the 1.3 load factor on wind was adjusted up. A load factor of 1.3/0.85 = 1.53 would have maintained status quo exactly. However, it was rounded up to 1.6, which resulted in an effective 5 percent increase in the wind-load factor. For ASD, the effect of this change was 15 percent lower wind forces.

The definitions of Exposures C and D were changed slightly to allow the shorelines in hurricane-prone regions to be classified as Exposure C rather than Exposure D.

A simplified design procedure was introduced for the first time for relatively common low-rise (mean roof height not exceeding 30 ft), regular-shaped, simple diaphragm buildings. New definitions were introduced for regular-shaped buildings and simple diaphragm buildings.

For the first time, the wind design provisions were organized by the method of design: Method 1 – Simplified Procedure; Method 2 – Analytical Procedure; and Method 3 – Wind Tunnel Procedure. Method 2 contained two separate and distinct procedures under the same heading — the general analytical procedure, applicable to buildings of all heights, and the low-rise analytical procedure, applicable to buildings having mean roof height not exceeding 60 ft.

A very important provision was introduced, requiring that glazing in the lower 60 ft of Category II, III, or IV buildings (all buildings except those representing a low hazard to human life in the event of failure) sited in wind-borne debris regions be impact-resistant glazing or protected with an impact-resistant covering, or such glazing that receives positive external pressure be assumed to be openings. "Wind-borne debris region" was defined in ASCE 7-98.

ASCE 7-02 — In ASCE 7-02, the simplified design procedure, Method 1, of ASCE 7-98 was discarded. The simplified design procedure in Section 1609.6 of the 2000 IBC, with only a few relatively minor modifications, was adopted instead. This simplified procedure is based on the low-rise analytical procedure of ASCE 7 and bears strong resemblance to it. Its applicability is broader than that of the simplified design procedure in ASCE 7-98.

ASCE 7-02 required that a ground-surface roughness within each 45-degree sector be determined for a distance upwind of the site. Three surface-roughness categories were defined as shown in *Table 1*.

Three exposure categories were defined in terms of the three roughness categories, as shown in *Table 2*. The former Exposure A (centers of large cities) was deleted.

Method 2, Analytical Procedure for (MWFRS of) low-rise buildings, was revised to provide clarification. The different load cases were clearly delineated.

New pressure coefficients were provided for determination of wind loads on domed-roof buildings, and provisions for calculating wind loads on parapets were added.

The design-load cases for the MWFRSs of buildings designed by the general analytical procedure (as distinct from the low-rise analytical procedure) were different in ASCE 7-98 than in ASCE 7-02. Consideration of wind-induced torsion was now required for all buildings, not just buildings having mean roof height exceeding 60 ft.

In the table of roof pressure coefficients for the design of the MWFRS by the general analytical procedure, a low-suction coefficient of 0.18 was added for the windward roof in all cases where only a high-suction coefficient had been provided earlier. The

Table 1: Surface roughness categories of ASCE 7-02 and 7-05

Surface roughness category	Description
B	Urban and suburban areas, wooded areas or other terrain with numerous, closely spaced obstructions having the size of single-family dwellings or larger.
C	Open terrain with scattered obstructions having heights generally less than 30 feet. This category includes flat, open country; grandstands; and all water surfaces in hurricane-prone regions.
D	Flat, unobstructed areas and water surfaces outside hurricane-prone regions. This category includes smooth mud flats, salt flats, and unbroken ice.

Table 2: Exposure categories of ASCE 7-02 and 7-05

Exposure category	Description
B	Surface Roughness B prevails in the upwind direction for at least 2,630 feet or 10 times the building height, whichever is greater.
C	All cases where Exposure B or D does not apply.
D	Surface Roughness D prevails in the upwind direction for at least 5,000 feet or 10 times the building height, whichever is greater. Exposure D extends inland from the shoreline a distance of 660 feet or 10 times the building height, whichever is greater.

intent of the new low-suction coefficient was to require the roof to be designed for zero or a slightly positive (inward-acting) pressure, depending upon whether the building is enclosed or partially enclosed, respectively.

ASCE 7-05 — Several changes are made in the set of conditions that must be met by a building for its MWFRS to be qualified to be designed by Method 1 – Simplified Procedure. The restriction that the building not be subjected to topographic effects is omitted. These are now accounted for in the simplified design procedure by including a topographic-effect factor in the calculation of the design wind pressure.

The conditions that must be met by a building for its components and claddings to be eligible to be designed by Method 1 are not changed, except that the restriction concerning topographic effects is lifted, as in the case of the MWFRS.

Simplified design wind pressures and net design wind pressures can now be calculated for basic wind speeds of 105, 125, and 145 mph.

ASCE 7-05 now explicitly states that the basic wind speeds estimated from regional climatic data for special wind regions outside hurricane-prone areas can be lower than those given in ASCE 7-05, Figure 6-1. For estimation of basic wind speeds from regional wind data in special wind regions outside hurricane-prone areas, a minimum criterion is specified.

ASCE 7-02 required Exposure D to extend inland from the shoreline for a distance of 660 ft or 10 times the height of the building, whichever was greater. ASCE 7-05 requires Exposure D to extend into downwind areas of Surface Roughness B or C for a distance of 600 ft or 20 times the height of the building, whichever is greater. The multiplier of building height by which a certain terrain category has to extend in the upwind and the downwind direction of the building for qualification of an Exposure Category is changed from 10 to 20, as indicated above in the specific case of Exposure Category D. Other controlling distances are rounded off to the nearest 100 ft.

A definition for "eave height" is added. Footnote 8 to Figure 6-10 (Low-Rise Analytical Procedure), which concerns delineation of the boundary between windward zone pressures and leeward zone pressures, has been clarified.

Glazing in wind-borne debris regions that receive positive external pressure can no longer be treated as openings for design purposes, instead of making it impact-resistant or protected.

Provisions for wind loads on parapets are updated. Values of the Combined Net Pressure Coefficient are updated from +1.8 and -1.1 to +1.5 and -1.0 for windward and leeward parapets, respectively. Application of the provisions to low-slope roofs has been clarified.

Design wind loads on free-standing walls and solid signs are revised.

Design wind loads on open buildings with monoslope roofs are revised. Design wind loads on open buildings with pitched or troughed roofs are provided for the first time.

New provisions are added for rooftop structures and equipment when the roof height of the building is less than 60 ft.

Wind-borne debris requirements are clarified as being applicable to Method 3 (Wind Tunnel Procedure). The requirements are the same as those for Method 2 (Analytical Procedure).

Discussion of Changes from ANSI A58.1-1972 to ASCE 7-05

Of all the changes from ANSI A58.1-1972 through ASCE 7-05, there are only a few that are in the direction of more liberalism in design. The first of these is the adoption of the low-rise analytical procedure in ASCE 7-95 as an alternative design approach for the MWFRS. This procedure can reduce design wind pressures significantly. While generalizations are difficult since so many variables influence the determination of design wind pressures for a specific building, use of the alternate procedure can result in the total wind load being approximately 30 to 35 percent less than would be calculated using the primary procedure. It ought to be remembered that the low-rise analytical procedure was part of the Standard Building Code long before it was adopted by ASCE 7 and is based on comprehensive testing done at the University of Western Ontario.

In areas where the basic wind speed is low, the relative lack of conservatism of the low-rise procedure is mitigated somewhat by the requirement that all MWFRS be designed for a minimum pressure of 10 pounds per square foot applied to the area of the building projected onto a vertical plane. However, this provision is widely ignored and is not rigorously enforced by local jurisdictions. It needs to be taken more seriously by practitioners as well as local jurisdictions.

The second change was the introduction of the directionality factor, K_d, in ASCE 7-98. This led to a rounding up of the wind-load factor from 1.53 to 1.60 in strength design, which is conservative. However, this also decreased the design wind forces when using ASD methods, which are widely used in the design of structures made of materials other than concrete. Also, the three-second-gust speed map of ASCE 7-95 was prepared from data accumulated by the National Weather Service and not converted from the fastest-mile wind speed map of ASCE 7-93. While in most areas, 70 mph fastest-mile wind speed became three-second-gust speeds of 85 or 90 mph, and so forth, in certain areas, such as Denver, the numbers remained virtually unchanged. This meant that design wind pressures in those areas went down as ASCE 7-95 was adopted, even while using strength design, with incorporation of the rounded-up load factor of 1.6.

The only other change possibly in the direction of more liberal design was the redrawing of the basic wind speed map in ASCE 7-98, which decreased the basic wind speeds in inland Florida. Obviously, when National Weather Service data indicate that a change is warranted, ASCE 7 has no reason to resist making that change.

Standard Conclusions

By and large, the changes in ANSI A58.1/ASCE 7 have not been consistently in the direction of lower or higher design wind pressures. If there is a consistent trend to the changes, it is that the complexity of wind design has been steadily increasing.

WIND PROVISIONS IN THE MODEL CODES

The building codes of most jurisdictions within the United States used to be, and in some cases still are, based on one of three legacy model building codes: The BOCA National Building Code (BOCA/NBC), published by the Building Officials and Code Administrators International (BOCA) in Country Club Hills, Illinois; the Standard Building Code (SBC), published by the Southern Building Code Congress International (SBCCI) in Birmingham, Alabama; and the Uniform Building Code (UBC), published by the International Conference of Building Officials (ICBO) in Whittier, California. These three model codes, where still in effect, are in the process of being replaced by the International Building Code (IBC), published by the International Code Council (ICC), which has absorbed the former model code groups (BOCA, SBCCI, and ICBO). The following is an historical summary of wind design provisions in these model codes.

BOCA/National Building Code — ANSI A58.1-1972 was adopted by the BOCA/NBC in its 1978 edition, and retained in the 1981 and 1984 editions. Then, ANSI A58.1-1982 was adopted in the 1987 edition, and retained in the 1990 edition.

In the 1993 edition, ASCE 7-88 was adopted, and was retained in the 1996 and 1999 editions. The 1999 edition was the last edition published before the integration of BOCA into the ICC.

Standard Building Code — The SBC adopted ANSI A58.1-1972 in the 1977 revisions to the 1976 SBC. The adopting language then appeared in the 1982 edition. Wind design using ANSI A58.1-1972 was permitted only for one- and two-story structures, provided the basic wind pressures from SBC Table 1205.1 were used. The 1982 SBC also adopted alternate wind-load provisions (those of the MBMA or Metal Building Manufacturers' Association, MBMA) in Section 1206. This section was permitted for the design of buildings with flat, single-slope, and gable-shaped roofs with mean roof heights of 60 ft or less, provided the eave height did not exceed the least-horizontal dimension of the building.

The 1985 edition had three procedures that could be used. Two of the procedures were contained in Section 1205, Wind Loads, and the third was in Section 1206, Alternate Wind Loads for Low-Rise Buildings. The first option allowed under Section 1205 was use of the provisions within the section. The second option permitted by Section 1205 was to use the wind design provisions of ANSI A58.1-1982, provided the basic wind pressures of Table 1205.1 were used. Table 1205.1 was based on the basic wind speed map of Figure 1205.1 (same as the 100-year mean recurrence interval basic wind speed map contained in ANSI A58.1-1972), which differed from the 50-year mean recurrence interval map in ANSI A58.1-1982.

The alternate wind-load provisions of Section 1206 (MBMA procedures) were permitted to be used for the design of buildings with flat, single-slope, and gable-shaped roofs with mean roof heights of 60 ft or less, provided the eave heights did not exceed the least horizontal dimensions of the buildings. Section 1206 contained its own basic wind speed map, which was taken from ANSI A58.1-1982.

The 1988 SBC permitted any building or structure to be designed using the provisions of ANSI A58.1-1982. In addition, Section 1205.2 had provisions based on the MBMA procedures for buildings with flat, single-slope, and gable-shaped roofs whose mean roof heights were less than or equal to 60 ft. This edition did not require that the roof eave heights be less than or equal to the least horizontal dimension of the buildings.

Section 1205.3 applied to buildings exceeding 60 ft in height, but not more than 500 ft in height, provided the roof slopes did not exceed 10 degrees or were not arched roofs. Buildings between 60 and 500 ft in height and not meeting these limitations, and all buildings over 500 ft in height, had to be designed according to ANSI A58.1-1982. The basic wind speed map within Section 1205 was the ANSI A58.1-1982 map.

The 1991 edition was essentially the same as the 1988 edition, except that ANSI A58.1-1982 was updated to ASCE 7-88. The basic wind speed map within Section 1205 remained unchanged from the 1988 edition, because the basic wind speed map did not change within ASCE 7-88 from what was in ANSI A58.1-1982.

In the 1994 SBC, ASCE 7-88 was adopted by reference to apply to all buildings and structures. An exception continued to permit the MBMA procedures in Section 1606.2 to be used for buildings with flat, single-slope, hipped, and gable-shaped roofs with mean roof heights not exceeding 60 ft or the least-horizontal dimension of the buildings.

The 1997 edition was essentially the same as the 1994 edition, except that ASCE 7-88 was updated to ASCE 7-95. The basic wind speed map within Section 1606.2, Alternate Wind-Loads for Low-Rise Buildings, remained unchanged from the 1994 edition. It is necessary to point this out because the basic wind speed map of ASCE 7-95 was based on the three-second-gust wind speed.

The 1999 edition remained unchanged from the 1997 edition and was the last edition of the SBC.

Uniform Building Code — The wind design provisions of the UBC, through its 1979 edition, were based on ANSI A58.1-1955, the predecessor document to ANSI A58.1-1972.

The wind design provisions became based on ANSI A58.1-1972 in the 1982 edition of the UBC. The calculation procedure was simplified. Also, important changes proposed for ANSI A58.1-1982 were incorporated. Few changes were made in the 1985 and 1988 editions of the UBC.

The UBC wind design provisions became based on ASCE 7-88 in the 1991 edition. The calculation procedure was once again simplified. Minor changes were made in the 1994 edition, and no changes were made in the 1997 edition, the last edition of the UBC.

International Building Code — The first edition of the IBC, the 2000 edition, adopted ASCE 7-98 for wind design. However, Method 1, Simplified Design from ASCE 7-98, was not adopted. Included in Section 1609.6 of the IBC code was a different, simplified design procedure based on the low-rise analytical procedure (part of Method 2) of ASCE 7-98 and applicable only

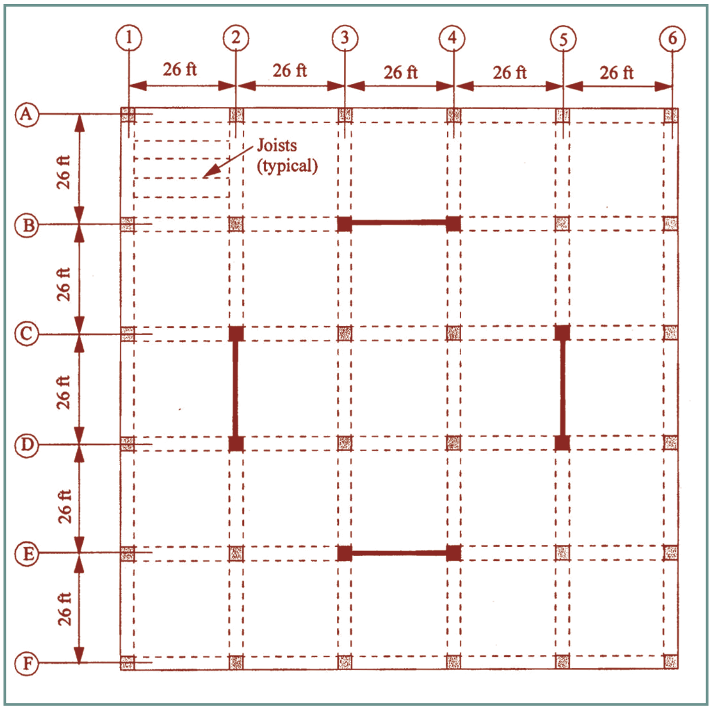

Figure 1 – Plan of example concrete building.

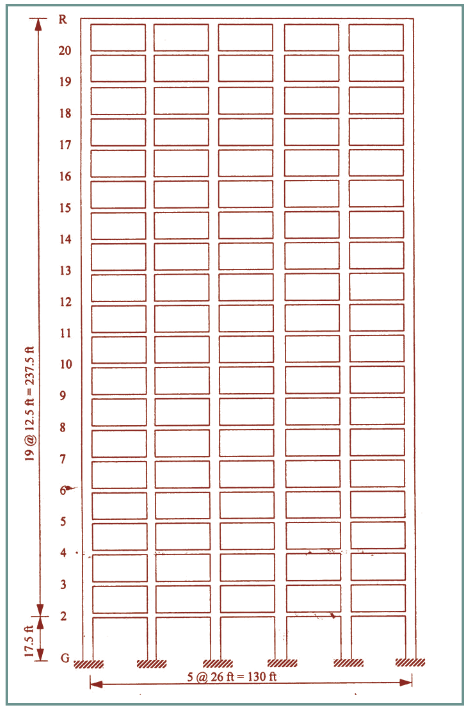

Figure 2 – Elevation of example concrete building.

to simple diaphragm buildings, as defined in the code. For qualifying residential buildings free of topographic effects, the SBCCI deemed-to-comply standard SSTD 10, Standard for Hurricane-Resistant Residential Construction, and the American Forest & Paper Association's (AF&PA) *Wood Frame Construction Manual* (WFCM) also were allowed to be used. The 2000 IBC also added an alternative way of providing opening protection in one- and two-story buildings, included a conversion table between fastest-mile wind speed and three-second-gust wind speed, and provided an optional design procedure for rigid tile roof coverings.

The second edition of the IBC, published in 2003, adopted ASCE 7-02 for wind design. There was still a simplified design procedure, applicable to simple diaphragm buildings, in Section 1609.6 of the IBC. But it was now very close to Method 1, Simplified [Design] Procedure of ASCE 7-02, because (as mentioned earlier,) ASCE 7-02 discarded Method 1 of ASCE 7-98, and adopted instead the simplified design procedure in Section 1609.6 of the 2000 IBC with some modifications. Qualifying residential buildings free of topographic effects could still be designed by SBCCI's SSTD 10 or AF&PA's WFCM. The alternative way of providing opening protection in one- and two-story buildings, the conversion table between fastest-mile wind speed and three-second-gust wind speed, and the optional design procedure for rigid tile roof coverings remained essentially unchanged.

ASCE 7-05 is adopted for wind design in the third edition of the IBC, which was published in 2006. Simplified wind design is no longer in the code; it is by reference to ASCE 7-05. Qualifying residential buildings free of topographic effects can still be designed by SBCCI's SSTD 10 or AF&PA's WFCM. The alternative way of providing opening protection in one- and two-story buildings is retained in a modified form in the 2006 IBC. The conversion table between fastest-mile wind speed and three-second-gust wind speed is revised. The optional design procedure for rigid tile roof coverings remains unchanged.

1997 UBC Versus 2006 IBC — A Comparison

Design wind forces at the various floor levels of an example concrete building, the plan and elevation of which are shown in *Figures 1* and *2* respectively, were calculated using the general analytical procedure (Method 2) of ASCE 7-05 (which has been adopted into the 2006 IBC) and the wind design procedure of the 1997 UBC, which is a simplified version of that in ASCE 7-88. The building is assumed to be located in suburban Los Angeles (three-second-gust wind speed of 85 mph) and the exposure category is assumed to be B. The simplification of the analytical procedure of the 1997 UBC was the result of a joint effort by the Structural Engineers Association of California (SEAOC) and the Structural Engineers Association of Washington (SEAW).

It can be seen in *Table 3* that the UBC procedure produces slightly, but not overly, conservative results, as it should. The efforts involved in the two cases were not comparable, with the ASCE 7-05 design taking considerably more time and being more complex (even though the different load cases in Figure 6-9 of ASCE 7-05, other than Load Case 1, were not even con-

Floor Level	Wind Forces (plf)		2006 IBC/
	1997 UBC	2006 IBC	1997 UBC
R	235	214	0.91
20	314	286	0.91
19	310	284	0.92
18	306	281	0.92
17	302	278	0.92
16	298	275	0.92
15	293	272	0.93
14	290	269	0.93
13	285	265	0.93
12	282	262	0.93
11	277	258	0.93
10	272	254	0.93
9	267	249	0.93
8	261	244	0.94
7	253	239	0.94
6	247	233	0.94
5	239	226	0.94
4	229	218	0.95
3	218	208	0.95
2	243	233	0.96

Table 3 – Comparison of computed wind forces for example building.

sidered). The primary reason that accounts for the additional time is that the simplifications made by SEAOC/SEAW to the provisions of ASCE 7-88 are not available to the user of Method 2 of ASCE 7-05. Also, as outlined in preceding sections, many complexities have been added to the wind design provisions of ASCE 7 between the 1988 and 2005 editions. One example of the added complexity is the prescribed procedure for the computation of gust-effect factors for flexible buildings. The example building being flexible, the gust-effect factor had to be calculated. The calculation involves a large number of complex equations and took an experienced engineer more than an hour and a half to complete. Ironically, the factor turned out to be 0.87, which should be compared with the 0.85 prescribed for rigid buildings. While no generalization is possible on the basis of one example, the UBC procedure, which has been in the UBC since 1991, has been used in the design of a large population of structures located west of the Mississippi, in Indiana, and elsewhere. There is no record of distress that has been attributed to any deficiency in that design procedure.

When the state of Oregon adopted the 2003 IBC as the basis of the 2004 Oregon Structural Specialty Code, it made an amendment to the 2003 IBC allowing continued usage of the 1997 UBC wind design procedure (as adopted into the 1998 Oregon Structural Specialty Code). The state of Washington did not make a similar amendment when it adopted the 2003 IBC as the basis of the state code a few months ahead of Oregon. A simplification of the analytical procedures of ASCE 7-98 and -02 was under development by the SEAW for quite some time. The simplified procedure — SEAW's *Handbook of a Rapid Solutions Methodology for Wind Design* — has recently been published. This procedure, however, does not appear ready for codification.

Conclusion

There is an urgent need for a design procedure in the IBC that is similar to the one included in the 1997 UBC. Its applicability, of course, would be somewhat restricted. The UBC design procedure itself cannot be used as it is. It will need to be updated because, for one thing, it is based on fastest-mile wind speed, which is no longer recorded by the National Weather Service. It is outdated in some other ways, as well. The most effective way of accomplishing an update would be through collaboration among groups, such as the Structural Engineers Associations of California, Oregon, and Washington. Early action to bring about such collaboration is strongly urged.

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