Discussion of "Definition of Wind Profiles in ASCE 7" by Yin Zhou and Ahsan Kareem

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Zhou and Kareem's critical review of models used in the ASCE 7-98 standard for mean wind speed, turbulence intensity, and gust speed profiles "suggests notable inconsistencies" among the definitions associated with those models. We point out in this discussion a further inconsistency that, in our opinion, is sufficiently serious to warrant a major change in future versions of the ASCE 7 standard. This inconsistency is due primarily to the assumption that the power law describes the entire atmospheric boundary layer, from the ground surface up to the "gradient height."

The gust speed profile is expressed in ASCE 7-98 by Eq. (7) as follows:

$$\hat{V}(z)=\hat{V}_0\hat{b}(z/10)^{\hat{\alpha}}$$

where $\hat{V}_0$=basic wind speed; z=height above ground in meters; and $\hat{b}$ and $\hat{\alpha}$=constants depending upon terrain type. The basic wind speed specified for nonhurricane regions in the ASCE 7-95 standard is the 50-year peak gust speed at 10 m above ground in open terrain. It has exactly the same specified values—and therefore the same definition—in ASCE 7-98. For open terrain (Category C) $\hat{b}=1$, $\hat{\alpha}=1/9.5$ (Table 6-4, p. 58 of ASCE 7-98, and Table 1 of the authors' note). For built-up terrain (Category B) $\hat{\alpha}=1/7$, and $\hat{b}$ is obtained from the condition that the peak gust speeds at "gradient height" for each of the respective assumed boundary layers be the same over open terrain and over built-up terrain. The gradient height is specified in ASCE 7-98 as 274.3 m (900 ft) for open terrain and 365.8 m (1,200 ft) for built-up terrain. From Eq. (7) it follows that, for built-up terrain, $\hat{b}=0.847$ (see also Table 1 of the paper). We note that the elevation of the top of the boundary layer assumed in ASCE 7-98 is referred to improperly therein as the gradient height. Since the wind speeds are assumed to be "straight," that is, unaffected by centrifugal forces to any significant degree, it would be more correct to refer to that elevation as the geostrophic height.

The condition that the peak gust speeds are equal at the respective gradient heights is consistent with the definition that a boundary layer is a layer above which the flow is for practical purposes laminar, that is, turbulence-free.

The same condition requires that the mean hourly speeds be the same at the gradient heights of the assumed boundary layers over open terrain and built-up terrain. In this case, the governing equation for the mean hourly speed at elevation z is (original paper):

$$\bar{V}(z)=\bar{V}_0\bar{b}(z/10)^{\bar{\alpha}} \tag{1}$$

In Eq. (1), $\bar{V}_0$=mean hourly speed with a 50-year mean recurrence interval at 10 m above ground over open terrain; $\bar{\alpha}=1/6.5$ over open terrain; and $\bar{\alpha}=1/4$ over built-up terrain (ASCE 7-98, Table 6-4, p. 58 and Table 1, Zhou and Kareem). At the gradient height the turbulence intensity is for practical purposes nil. Therefore, the average wind speed is for practical purposes independent of the averaging time. In particular, under the assumption that the wind storm has a constant mean speed over an interval of 1 h or so—a common, if usually conservative assumption in wind engineering—at the gradient height the wind speed averaged over 3 s is equal to the wind speed averaged over 1-h. We also note that the gradient height is the same for the 3 s peak gust profile and the 1-h mean wind speed profile.

From Eqs. (7) and (1) we can estimate the ratio between the 3 s peak gust speed and the mean hourly wind speed at 10 m above ground in open terrain. Making use of the condition that the two speeds are equal at the gradient height, we have

$$\hat{V}_0\times 1.0\times\left(\frac{900\ \text{ft}\times 0.3048\ \text{m/ft}}{10\ \text{m}}\right)^{1/9.5}$$
$$=\bar{V}_0\times 1.0\times\left(\frac{900\ \text{ft}\times 0.3048\ \text{m/ft}}{10\ \text{m}}\right)^{1/6.5}$$

or

$$\frac{\hat{V}_0}{\bar{V}_0}=1.175$$

This is grossly inconsistent with Fig. C6-1 of the ASCE 7-98 commentary, in which $\hat{V}_0/\bar{V}_0\cong 1.52$, rather than 1.175, and is of course an aberrant result. That this is the case can in no way be attributed to Zhou and Kareem, but rather to the unnecessary constraint imposed on their work by the use of the power law in ASCE 7-98.

The authors state that the power law is "a more popular description" of the wind speed profile. We would like to take issue with this view. Meteorologists—the National Oceanic and Atmospheric Administration's (NOAA) Hurricane Research Center meteorologists are just one example among many—and knowledgeable engineers now routinely use the logarithmic law. Also, as pointed out by Zhou and Kareem, both the Eurocode and AS1170.2 (Standards Australia 1989) use logarithmic expressions to describe the wind profiles.

The power law as a description of the wind profile up to the gradient height was proposed for use in a structural engineering context about 40 years ago. At about that time it was stated that "The idea is attractive, but it suffers from a number of practical disadvantages" (Shellard 1965). Among the disadvantages, Shellard noted the fact—of definite interest in engineering practice—that results based on that description "are not consistent with actual measurements," as shown by a detailed analysis of measurements at Cardington, U.K.

In the 1960s and 1970s extensive studies of the atmospheric boundary layer yielded remarkably useful results that clearly support the use of the logarithmic law and were brought to the attention of the structural engineering community—see, for example, Simiu (1973), and Simiu and Scanlan (1996).

It may be argued that no model of the atmospheric boundary layer is adequate for all possible situations with which a code must contend, including situations where there is an internal boundary layer near a change of roughness, or where topographic effects come into play, or the terrain roughness is not homogeneous, or the stratification of the flow is not neutral. This is true. But a canonical model for wind profiles is necessary for standard conditions (i.e., at locations sufficiently far removed from roughness changes, in horizontal terrain, in terrain with homogeneous roughness, and in sufficiently strong flows that neutral stratification occurs for practical purposes). In the present state of the art there is no doubt that the power law is an inferior model that should be discarded in favor of the scientifically substantiated logarithmic law. For the strong winds of interest in structural engineering, the logarithmic law can be shown to apply to sufficiently high elevations (up to hundreds of meters). The discussers heard the argument that the power law ''is easier to use.'' This may have been an issue in the 1970s, but is no longer relevant today. Another argument is that engineers would be confused by the use of a logarithmic function, which again is not the case, since in fact engineers are sufficiently knowledgeable; besides, the standard provides pressure tables that remove the need for the less knowledgeable engineers to even use the function describing the increase of wind speeds with height. Moreover, as we pointed out earlier, other building codes already use logarithmic laws.

We therefore believe that the unacceptable contradictions inherent in the ASCE 7 use of the power law warrant a reconsideration of the latter's use in future versions of the Standard. The authors deserve credit for pointing out in their fine work that such contradictions exist, and for providing a dependable and solid framework for a fruitful discussion of wind speed profiles.

References

Simiu, E. (1973). ''Logarithmic profiles and design wind speeds.'' *J. Eng. Mech. Div.*, 99(5), 1073–1083.

Simiu, E., and Scanlan, R. (1996). *Wind effects on structures*, 2nd Ed., Wiley, New York.

Shellard, H. C. (1965). ''The estimation of design wind speeds.'' *Proc., Symp. on Wind Effects on Buildings and Structures*, Vol. 1, National Physical Laboratory, Her Majesty's Stationery Office, London, 29–51.

Closure to ''Definition of Wind Profiles in ASCE 7'' by Yin Zhou and Ahsan Kareem

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The writers are thankful to the discussers for raising this issue, as discussions like these may dispel any misconception that may otherwise continue to exist and be a source of confusion to those not conversant with the background and history of development of codes and standards, or may help to bring useful changes. The main objective of this technical note was primarily to suggest a revision of the wind profiles in ASCE 7 standard, i.e., turbulence intensity, since we noted that there was an inconsistency in our initial development of the gust loading section for the standard.

In the writers' opinions, one of the most attractive features of building codes and standards is the capturing of complex loading features and presenting these in a very simple and convenient format for expedient use in design practice. In this regard, several years back, the senior writer was asked to provide a closed-form expression for the gust loading factor to reduce uncertainty in the existing procedure involving use of a chain of busy figures often requiring interpolations or extrapolations. The choice of velocity profile at that time was made to remain consistent with the remaining part of the standard and to facilitate convenient integration with sufficient transparency since the velocity profile does appear in many integrals involving the gust loading factor. The writer collaborated with Prof. G. Solari from Italy who had earlier developed closed-form expressions for the dynamic wind loading (Solari and Kareem 1998). The most difficult task at that time was to distill information and data concerning velocity profiles from a host of sources and to provide the best fit to the data for application to the standard. A major source of difficulty was related to switching of wind speeds, in the standard for the calculations of dynamic effects, from the gust wind to mean hourly wind. Despite many constraints, the major effort was to ensure that the mean velocity profile and turbulence close to the ground were matched with the data.

The power law profile with a long history has earned its place in codes and standards for its simplicity and convenience. In the earlier work by Davenport (1967) and that which followed, the use of this profile was further reinforced based on measurements in several locations. An examination of the data does point at variations in the boundary layer height or the gradient height due to the very nature of full-scale measurements as well as the transients in wind speed and direction that tend to contaminate otherwise reliable information. Furthermore, the question of fully developed flows contribute to the scatter as different data sets may have been obtained at different levels of the flow development as opposed to being fully developed. The depth of a boundary layer among other factors depends on the latitude, the reference wind speed, and the terrain roughness. These depths may reach around 1–4 km in some cases. In the earlier work by Davenport, the issue of relating gradient level winds in different exposures was resolved by choosing an approximate level, which facilitated the transfer of winds between different terrains (roughness surfaces). Although these numbers may vary in the literature, ASCE 7 currently implies values of 1,200, 900, and 700 ft for exposures B, C, and D, respectively. These are not necessarily the true gradient heights and therefore may not satisfy the textbook definition of gradient height at which turbulence may vanish. Yet, these levels provide a convenient transfer level for establishing equivalence in wind speeds in different terrains. Observation of data or profiles suggested in Engineering Science Data Unit (ESDU) points out that at elevations, which have been remarkably successful in performing wind speed transfers between boundary layers for differing surface roughness, the turbulence intensity is around 10%. The turbulence intensity may indeed vanish at the boundary layer height around 2–4 km.

Now, concerning the question of log law versus power law as raised in the discussion specifically, the following response is offered. The log law originally due to Prandtl for boundary layer flows over flat plates, to describe the mean velocity profile, has been found to be valid for most strong wind conditions in fully developed flow conditions. This is primarily valid for the inner boundary layer, which may range from 100–200 m. Extensions to higher elevations may be achieved by simply extending the log law, which may not represent the velocity profile accurately, or some other theory or model must be used to ''patch'' it to the remainder of the profile in the boundary layer, e.g., ESDU model based on the initial work by Deaves and Harris (1978) as adopted by the Australian Standard. The log law alone, as proposed in the discussion, is inadequate to cover the range of heights used in ASCE 7 based on the reported formulation in ESDU. Comparison of ASCE 7 profiles with ESDU data suggest that the power law used in ASCE 7 is a reasonable approximation of the ESDU profiles and preserves the simplicity of profile description that historically has been a part of ASCE 7.

It is also important to note that though the log law has a firm theoretical basis for fully developed flows in the inner boundary layer, it does not necessarily represent a 3-s gust profile, which is the basic wind speed used in ASCE 7.

In the discussion, it has been shown that ratio of 3-s wind gust to mean hourly wind at reference height leads to an aberrant result. This observation is based on trying to approach the reference level from the equivalence of a 3-s gust and the mean hourly winds at the gradient height. The discussers are implying that the gradient height has zero turbulence, which may be true at higher elevations, but these gradient heights implied in the standard, may, on the one hand, serve their intended purpose of providing satisfactory transfer between boundary layers, but, on the other hand, may not satisfy the textbook definition of the gradient height. This lack of meeting the zero turbulence criterion does not affect the velocity profile nor does it aberrantly violate the ratio between the gust and mean wind at the reference height. Rather, the current formulation does indeed accurately reflect the ratio of the 3-s gust to the mean hourly wind at the reference height and the level of turbulence one expects based on the available data at upper elevations.

The turbulence intensity in the standard (for C exposure) at the gradient height as specified in the standard is given by $I(z_g) = 0.2\times(274.3\text{ m}/10\text{ m})^{(-0.16)} = 0.12$. Therefore, the real relationship between the 3-s gust wind and mean at that elevation is $\hat{V} = G_v \times \overline{V}$, where G_v is the gust factor given by $G_v = 1 + 2.65 \times I(z_g) = 1.32$. Applying this factor to the relationship at the gradient height given in the standard yields the ratio of the 3-s gust and the mean hourly wind equal to 1.54, which is a normal result consistent with Durst's value of 1.52.

In light of the preceding discussion, arguably the definition of wind profile with power law does not necessarily contribute to the inconsistency as noted by the discussers. If equivalence between the gust and mean at the gradient height (as specified in the standard) needs to be emphasized, it should be viewed in the context of the turbulence level at that elevation.

Now, the question of the need to reconsider the use of power law in ASCE 7 in light of the unacceptable contradictions inherent in the ASCE 7, noted by the discussers, is not very likely because a log law may not be a proper law for describing the 3-s gust profile, which is the basic wind speed description in the standard. However, should there be other alternative formats that better describe the 3-s gust profile without resorting to fitted profiles with polynomials of high order; the writers would fully support such an exercise.

References

Davenport, A. G. (1967). ''Gust loading factor.'' *ASCE J. Struct. Div.*, 93, 11–34.

Deaves, D. M., and Harris, R. I. (1978). ''A mathematical model of the structure of strong winds.'' *Report 76*, Construction Industry Research and Information Association, U.K.

Solari, G., and Kareem, A. (1998). ''On the formulation of ASCE 7-95 gust effect factor.'' *J. Wind. Eng. Ind. Aerodyn.*, 77-78, 673–684.