Definition of Wind Profiles in ASCE 7

Yin Zhou, M.ASCE,[1] and Ahsan Kareem, M.ASCE[2]

Abstract: One of the major changes in the recent versions of ASCE 7 concerns the introduction of three-second gust as the reference wind speed. The three-second gust speed is derived using Durst's model in terms of the mean wind speed and turbulence intensity given in the former versions of ASCE 7. A review of these profiles suggests a notable inconsistency in the embedded relationship among the wind profiles in ASCE 7-98, which is also apparent when these are compared to the profiles in major international codes and standards. To overcome this inconsistency in the definition of wind profiles, this paper proposes a modified turbulence intensity profile and suggests retaining the current mean wind and gust speed profiles. This modification not only ensures consistency in the definition of wind profiles in ASCE 7-98, but also renders the definition of these profiles consistent with those in major international codes and standards.

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Introduction

One of significant features of ASCE 7-95 and ASCE 7-98 (ASCE 1999) that separates them from their earlier versions concerns the introduction of a three-second (3 s) gust as the reference wind speed. The 3 s gust speed is derived using Durst's model in combination with the mean wind speed and turbulence intensity given in the former versions of ASCE 7 (Solari and Kareem 1998).

This note first reviews the models used in determining the mean wind speed, turbulence intensity, and gust speed profiles. The wind profiles defined in ASCE 7-98 are compared to major international codes and standards, e.g., AS1170.2 (Standards Australia 1989), NBCC [National Research Council of Canada (NRCC 1996)], RLB [Architectural Institute of Japan (AIJ 1996)] and Eurocode (1995) and related information available in the literature. The comparison suggests notable inconsistencies among the definitions of the wind profiles in ASCE 7-98. Furthermore, the wind profiles used in ASCE 7-98 exhibit a departure from similar profiles in other international codes and standards. A modified scheme that primarily involves a new definition of the turbulence intensity profile is proposed here in an attempt to unify the description of wind profiles in ASCE 7-98.

[1]Engineer, Malouf Engineering International, Incorporated, 275 West Campbell Road, Suite 611, Richardson, TX 75080; formerly, Research Associate, NatHaz Modeling Laboratory, Dept. of Civil Engineering and Geological Science, Univ. of Notre Dame, Notre Dame, IN 46556. E-mail: yzhou@nd.edu

[2]Robert M. Moran, Professor and Chair, Dept. of Civil Engineering and Geological Sciences, Univ. of Notre Dame, Notre Dame, IN 46556. E-mail: kareem@nd.edu

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Wind Profiles

Mean Wind Speed Profiles

The mean wind speed as a function of height above the ground can be computed by a logrithmic profile

$$\overline{V}(z) = u_*/k \ln(z/z_0) \quad (1)$$

where k = von Karman constant that is approximately equal to 0.4; u_* = friction velocity; z_0 = surface roughness length; and z = height above the ground. An alternative and more popular description is given by a power law

$$\overline{V}(z) = \overline{V}_0 E(z) = \overline{V}_0 \overline{b}(z/10)^{\overline{\alpha}} \quad (2)$$

where $\overline{V}_0$ = mean basic wind speed; E = wind speed exposure coefficient; and $\overline{b}$ and $\overline{\alpha}$ = constants depending on terrain type. For exposure C (open country terrain), the basic wind speed is defined at 10-m elevation, which results in $\overline{b} = 1.0$. In several international codes and standards, the mean wind speed is based on averaging time of 1 h or 10 min. In the cases where the reference wind speed has a shorter averaging time than the mean, such as ASCE 7-98, which uses a 3 s gust basic wind speed, $\overline{b}$ is less than unity. This feature will be discussed in the following sections. A summary of definitions of mean wind speed profiles in major international codes and standards is provided in Table 1. The mean wind speed profiles for exposures A (large city center) and C in major codes and standards, expressed in terms of the basic wind speed of 1 h or 10 min averaging time, are plotted in Fig. 1. A reasonably good agreement among these profiles can be noted.

Turbulence Intensity Profiles

The longitudinal turbulence intensity profile is defined as

$$I(z) = \sigma_v(z)/\overline{V}(z) \quad (3)$$

where $\sigma_v(z) = \sqrt{\beta} u_*$ = root-mean-square (rms) value of the longitudinal fluctuating wind speed at height z, in which β = terrain

Table 1. Wind Speed Profiles in Codes and Standards [Eqs. (2) and (7)]

	ASCE 7-98				AS 1170.2[a]				NBCC		RLB		Eurocode[a]	
	3 s[b]		1 h[b]		3 s[b]		1 h[b]		1 h[b]		10 min[b]		10 min[b]	
	$\hat{b}$	$\hat{\alpha}$	$\bar{b}$	$\bar{\alpha}$	$\hat{b}$	$\hat{\alpha}$	$\bar{b}$	$\bar{\alpha}$	$\bar{b}$	$\bar{\alpha}$	$\bar{b}$	$\bar{\alpha}$	$\bar{b}$	$\bar{\alpha}$
A	0.64	1/5	0.30	1/3	0.76	0.14	0.29	0.28	0.43	0.36	0.39	0.35	0.55	0.29
B	0.84	1/7	0.45	1/4	0.91	0.10	0.45	0.20	0.67	0.25	0.58	0.27	0.77	0.21
C	**1.00**[c]	1/9.5	0.65	1/6.5	**1.04**[c]	0.07	0.58	0.16	**1.00**[c]	0.14	0.79	0.20	**1.00**[c]	0.16
D	1.07	1/11.5	0.80	1/9	1.18	0.04	0.69	0.13			**1.00**[c]	0.15	1.17	0.12
E											1.23	0.10		

[a]These two codes use logarithmical description, which is fitted with power law here.
[b]Averaging time.
[c]The basic wind speed in individual code or standard refers to the exposure where coefficient b is equal to unity that is written in bold.

Table 2. Turbulence Intensity Profiles in Codes and Standards [Eq. (4)]

	ASCE 7-98				AS1170.2[a]		NBCC[b]		RLB		Eurocode[a]	
	Current		Proposed									
Terrain	c	d	c	d	c	d	c	d	c	d	c	d
A	0.45	0.17	0.45	0.33	0.42	0.28	0.62	0.36	0.40	0.40	0.43	0.29
B	0.30	0.17	0.30	0.25	0.24	0.20	0.34	0.25	0.36	0.32	0.29	0.21
C	0.20	0.17	0.20	0.15	0.18	0.16	0.20	0.14	0.26	0.25	0.19	0.16
D	0.15	0.17	0.15	0.11	0.16	0.13			0.20	0.20	0.15	0.12
E									0.16	0.15		

[a]These two codes use logarithmical description, which is fitted with power law herein.
[b]The turbulence intensity profile is not apparently available in NBCC (NRCC 1996). Some mathematical manipulation is performed to obtain these coefficients (Zhou et al. 2002).

Table 3. Comparison of Gust Factors in ASCE 7-98

	$G_{V\text{-Durst}}$[a]				$G_{V\text{-Code}}$[b]				$G_{V\text{-Code}}/G_{V\text{-Durst}}$			
Height (m)	D	C	B	A	D	C	B	A	D	C	B	A
5	1.446	1.595	1.892	2.339	1.381	1.592	2.029	2.413	0.966	1.012	1.092	1.055
10	1.398	1.530	1.795	2.193	1.358	1.539	1.884	2.2	0.982	1.019	1.067	1.025
20	1.354	1.472	1.708	2.062	1.336	1.488	1.749	2.006	0.996	1.024	1.041	0.992
40	1.316	1.421	1.631	1.946	1.313	1.439	1.624	1.829	1.007	1.025	1.01	0.957
70	1.287	1.383	1.575	1.862	1.296	1.4	1.529	1.697	1.015	1.024	0.984	0.928
100	1.271	1.361	1.542	1.812	1.285	1.376	1.472	1.618	1.019	1.021	0.968	0.908
150	1.253	1.337	1.506	1.759	1.272	1.349	1.409	1.533	1.022	1.018	0.948	0.886
200	1.241	1.322	1.483	1.724	1.263	1.331	1.367	1.476	1.026	1.016	0.934	0.87
210[c]	1.239	1.319	1.479	1.718	1.264	1.328	1.36	1.466	1.028	1.015	0.931	0.867
250	1.232	1.310	1.465	1.697	1.266	1.316	1.334	1.432	1.034	1.014	0.922	0.857
270[c]	1.230	1.306	1.459	1.688	1.266	1.311	1.323	1.418	1.037	1.013	0.918	0.853
300	1.226	1.301	1.451	1.677	1.266	1.266	1.309	1.398	1.041	0.981	0.912	0.847
350	1.220	1.293	1.440	1.659	1.266	1.266	1.287	1.369	1.045	0.987	0.904	0.838
370[c]	1.218	1.290	1.436	1.653	1.266	1.266	1.277	1.359	1.046	0.989	0.9	0.835
400	1.215	1.287	1.430	1.645	1.266	1.266	1.266	1.345	1.049	0.992	0.895	0.83
460[c]	1.210	1.280	1.420	1.630	1.266	1.266	1.266	1.32	1.053	0.997	0.902	0.822
500	1.207	1.276	1.414	1.621	1.266	1.266	1.266	1.266	1.056	1	0.905	0.792

[a]Gust factor computed using Eq. (6) and the ASCE 7-98 turbulence intensity definition.
[b]Gust factor derived by dividing the 3 s gust speed with the mean wind speed.
[c]Gradient heights.

dependent coefficient. It is commonly assumed that β does not vary along the height, which implies that the rms turbulence fluctuations at all levels are constant in each terrain (Simiu and Scanlan 1996). Similar to the description of the mean wind profile, the turbulence intensity profile can be expressed in terms of a power law

$$I(z)=c(z/10)^{-d} \tag{4}$$

where c and d = terrain dependent coefficients. These coefficients that describe the turbulence profiles in different codes and standards are summarized in Table 2.

It is noteworthy that the assumption of a constant rms turbulence fluctuation at any height requires coefficient d to be equal to the mean wind speed exponent $\bar{\alpha}$. This is indeed reflected in some codes and standards, e.g., Eurocode (1995) and NBCC (NRCC

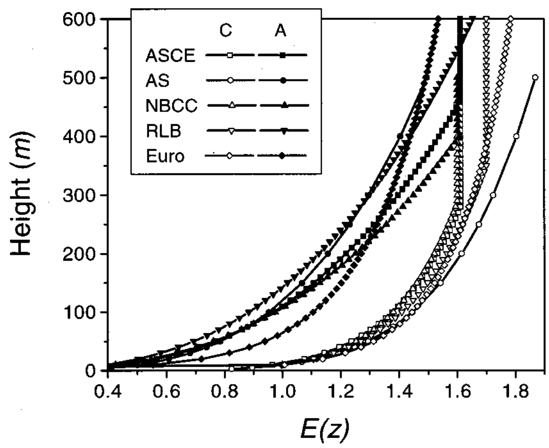

Fig. 1. Mean wind speed profiles in major codes and standards (based on basic wind speed at averaging time of 1 h or 10 min. See Table 1 for coefficients involved)

1996). RLB (AIJ 1996) includes a 0.05 adjustment factor based on $\overline{\alpha}$ for all terrains. Whereas AS1170.2 (Standards Australia 1989) employs a logarithmic expression for wind speed profiles. By expressing these in terms of a power law, the aforementioned equivalence between the exponents of the mean wind speed and turbulence profiles can also be observed.

A significantly different description of turbulence intensity is noted in ASCE 7-98 in which d is assigned a constant value of 1/6 for all exposure categories. A comparison of turbulence intensity profiles in codes and standards is illustrated in Fig. 2, which suggests that the turbulence intensity in ASCE 7-98 is much higher than those in other codes and standards for exposures A and B (urban or suburban).

3 s Gust Speed Profiles

The peak gust speed at height z in ASCE 7-98 is computed using Durst's statistical model (Durst 1960)

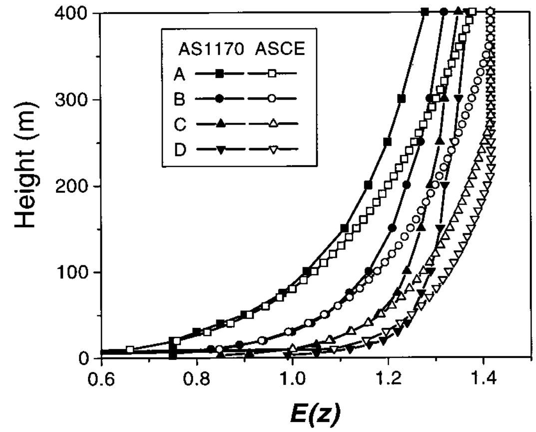

Fig. 3. 3 s gust speed profiles in AS1170.2 and ASCE7-98

$$\hat{V}_t(z)=\overline{V}(z)+g(T)\sigma_v \tag{5}$$

where T = averaging time which is 3 s in ASCE 7-98 and $g(T)$ = peak factor which is a function of T. This corresponds to the following gust factor for the wind speed:

$$G_V(t)=\hat{V}_t(z)/\overline{V}(z)=1+g(T)I(z) \tag{6}$$

For 3 s gust in an open country terrain at 10-m height, G_V (3 s) is equal to 1.53 as provided by Durst (1960). Considering $I(10)=0.2$ as in ASCE 7-98 for open country terrain, the peak factor $g(3\text{ s})=2.65$ can be obtained.

The 3 s gust speed profile can also be expressed in terms of a power law

$$\hat{V}(z)=\hat{V}_0\hat{b}(z/10)^{\hat{\alpha}} \tag{7}$$

where $\hat{V}_0$ = basic 3 s gust wind speed and $\hat{b}$ and $\hat{\alpha}$ = constants depending on the terrain type, which are given in Table 1. Among major codes and standards, only ASCE 7-98 (ASCE 1999) and AS1170.2 (Standards Australia 1989) provide expressions for the 3 s gust profile. A comparison of 3 s gust profiles in these two standards is shown in Fig. 3. Generally, a reasonably good agreement can be observed at relatively low heights.

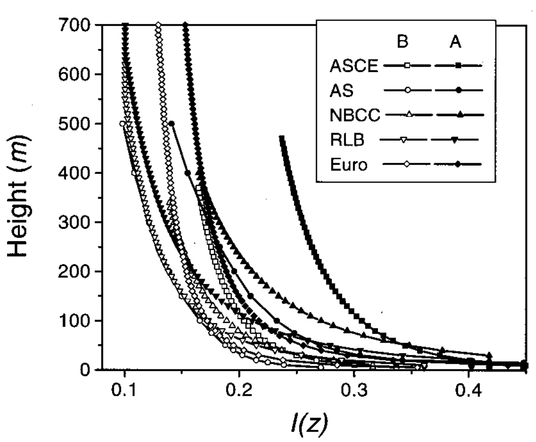

Fig. 2. Turbulence intensity profiles in major codes and standards (see Table 2 for coefficients involved)

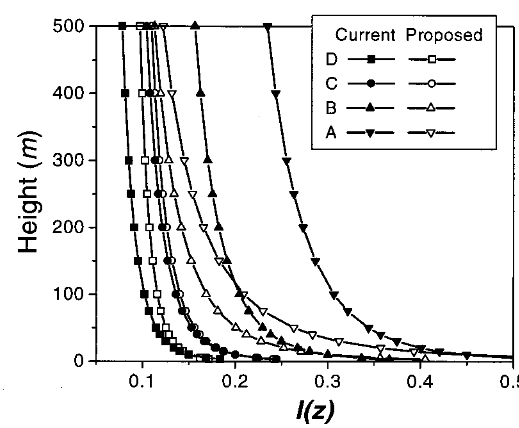

Fig. 4. Turbulence intensity profiles

Table 4. Comparison of Gust Factors based on Proposed Turbulence Intensity

Height z (m)	$I(z)$[a]				$G'_{V\text{-Durst}}$[b]				$G_{V\text{-Code}}/G'_{V\text{-Durst}}$			
	D	C	B	A	D	C	B	A	D	C	B	A
5	0.162	0.223	0.357	0.567	1.429	1.59	1.945	2.502	0.966	1.001	1.043	0.964
10	0.15	0.2	0.3	0.45	1.398	1.53	1.795	2.192	0.972	1.006	1.049	1.003
20	0.139	0.18	0.252	0.357	1.368	1.476	1.669	1.946	0.977	1.008	1.048	1.031
40	0.129	0.162	0.212	0.283	1.341	1.428	1.562	1.751	0.979	1.007	1.04	1.044
70	0.121	0.148	0.184	0.235	1.32	1.393	1.489	1.623	0.981	1.005	1.028	1.046
100	0.116	0.14	0.169	0.209	1.308	1.372	1.447	1.554	0.982	1.003	1.017	1.042
150	0.111	0.132	0.152	0.182	1.294	1.349	1.404	1.484	0.983	1	1.004	1.033
200	0.108	0.126	0.142	0.166	1.285	1.334	1.376	1.439	0.983	0.997	0.993	1.026
210	0.107	0.125	0.14	0.163	1.283	1.332	1.371	1.432	0.985	0.997	0.991	1.024
250	0.105	0.122	0.134	0.154	1.278	1.323	1.356	1.408	0.991	0.995	0.984	1.017
270	0.104	0.12	0.132	0.15	1.276	1.319	1.349	1.398	0.992	0.994	0.981	1.014
300	0.103	0.119	0.128	0.145	1.272	1.314	1.34	1.384	0.995	0.963	0.977	1.01
350	0.101	0.116	0.123	0.138	1.268	1.307	1.327	1.365	0.999	0.969	0.97	1.004
370	0.1	0.115	0.122	0.135	1.266	1.304	1.322	1.358	1	0.971	0.966	1.001
400	0.1	0.113	0.119	0.132	1.264	1.3	1.316	1.349	1.002	0.974	0.962	0.997
460	0.098	0.111	0.115	0.126	1.26	1.294	1.305	1.333	1.005	0.978	0.97	0.991
500	0.097	0.11	0.113	0.122	1.257	1.29	1.299	1.324	1.007	0.981	0.975	0.956

[a]Proposed turbulence intensity, see Eq. (4) and Table 2 for coefficients involved.
[b]Gust factor computed using Eq. (6) and the proposed turbulence intensity definition.

Comparison of Wind Profiles in ASCE 7-98

Based on this model, there is a strong interdependence among the definitions of mean wind speed, gust speed, and turbulence intensity profiles. A crosscheck of these wind profiles in ASCE 7-98 is performed in the context of the gust factor as shown in Table 3. In Table 3, $G_{V\text{-Durst}}$ is the gust factor using Eq. (6), which indicates that the gust factor is a function of coefficient $g(3\text{ s})$ and the turbulence intensity. $G_{V\text{-Code}}$ is obtained by dividing the gust speed with the mean wind speed in ASCE 7-98. Except for exposures C and D, a notable departure can be observed for exposures A and B. Obviously, this difference in gust factors brings out an inconsistency in the definition of wind profiles in current ASCE 7-98.

Proposed Turbulence Intensity Profile

To eliminate the inconsistency in the definition of wind profiles in ASCE 7-98, a modified turbulence intensity profile is proposed in this section. As mentioned earlier, the definition of turbulence intensity profile in ASCE 7-98 appears to be in an apparent disagreement with the fundamental principles (e.g., Simiu and Scanlan 1996). Following the assumption of constant turbulence fluctuations as shown in Eq. (4), a modified definition of the turbulence intensity profile is proposed

$$I(z)=c(z/10)^{-\bar{\alpha}} \tag{8}$$

The coefficients involved in Eq. (8) are listed in Table 2 for all terrain categories. The proposed turbulence intensity is significantly different from those in ASCE 7-98, especially for exposures A and B as shown in Fig. 4. However, good agreement can be noted in the proposed turbulence intensity description when compared to major international codes and standards as shown in Table 2.

With the modified turbulence intensity profile, a crosscheck of wind profiles in terms of gust factors is performed in Table 4. In Table 4, $G'_{V\text{-Durst}}$ is the gust factor computed using Eq. (6) and the proposed turbulence intensity in Eq. (8). As shown in Table 4, the ratio between $G'_{V\text{-Durst}}$ and $G_{V\text{-Code}}$ is either unity or with difference from unity usually within 5% for almost all heights and all terrain categories. This comparison demonstrates that the modified turbulence intensity profile provides consistent results.

Concluding Remarks

This note reviews definitions of wind profiles in ASCE 7-98. Through a comparison of wind profiles with major international codes and standards, a notable inconsistency is observed. In order to eliminate this discrepancy, a modified definition of the turbulence intensity profile is proposed. The proposed turbulence intensity profile results in a consistent relationship among the mean wind speed, turbulence intensity, and gust speed profiles without altering the current descriptions of the mean and gust speeds. Furthermore, the proposed definitions of wind profiles are all consistent with those in other major international codes and standards. Like other parameters used to define wind characteristics, the proposed turbulence intensity definition calls for further verification and improvement based on field measurements.

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