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PROPOSAL FOR UNIFIED TERRAIN CATEGORIES EXPOSURES AND VELOCITY PROFILES

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ABSTRACT

In the last APEC-WW meeting, it was observed that there are significant differences in the way that terrain types and wind profiles for difference terrains are being handled by different wind codes. A sub-group was set-up to look into this issue. In this paper, roughness classification, terrain category and wind profiles are being discussed. A set of terrain category and the corresponding wind profile are proposed.

KEYWORDS: TERRAIN CATEGORY, ROUGHNESS, WIND PROFILE

Introduction

For any kind of wind study, be it wind loading, environmental wind or pollution dispersion problem, a precise knowledge of the characteristics of the approaching wind is necessary. The approaching wind characteristics are largely controlled by the roughness of the upwind fetch over which it had blown (assuming the fetch is relatively flat). The way that wind speed profiles of the approaching wind is being taken care of by various wind codes can be very different. This paper looks at what is currently provided for in the various wind codes. A set of terrain roughness category is proposed.

Terrain category

It has long been recognized that wind speed varies with height and that the variation is related to the drag on the wind as it blows over upstream areas. As the drag, among other things is related to the roughness of the ground; and different types of terrain produces different roughness effects. In order to cater for these varying roughness conditions, different terrain categories are specified in different wind load codes. However, the number, as well as the types of terrain specified in different codes is very different. For example, Hong Kong has only one terrain type whereas Japan has five types. This sometimes creates different wind load of the same targeted problem calculated from different wind codes. Table 1 gives a summary of some major wind codes.

Looking at the range of roughness specified in the various wind codes (Log or Deaves & Harris model) which spread from 0.002m to 3.0m, a few points can be observed. 1) The smooth end of most codes has roughness of around 0.002m – 0.003m. 2) The rougher terrains specified in the codes are having values of 2.0m to 3.0m. In order that codes with wind profiles specified using Power Law can also be compared, the following approximate equation is used for conversion.

$$\alpha \approx \frac{1}{\ln\left[\sqrt{z_1 z_2} / z_0\right]} \qquad (1)$$

As the conversion is height dependent, in the present calculation Z_1 & Z_2 are set to 10m and 100m respectively; the Zo values for the Codes AIJ, ASCE, GB and NBCC are estimated and also given in Table 1. It can be seen that the coverage is comparable. Except that the smooth end for NBCC is large at Z_0=0.025m, and the rough end for ASCE-7 is small at Z_0=0.58m.

The spread of the Zo value in the different codes is perhaps expected. However, there are some discrepancies among the codes. For example 'Open terrain' the largest Zo is the NBCC having a value 0f 0.025m; as compared with the smallest in the Chinese GB5009 of 0.0076m. Values given for the very rough 'city' type of terrain also differed a lot; there is the 1.0m of the EN 1991, 1.13m of the GB5009, 1.82m of the Japanese AIJ, 1.97 of NBCC, 2.0 of the AS/ZNS1170 and the 3.0m of the ISO 4354. Also the terrain categories in ASCE-7 are in order of rough to smooth, whereas others are from smooth to rough. Thus it would be desirable to have a common set of typical terrain type and with Zo values.

Table 1 Summary of terrain category information for various wind codes

Code/Standard	Number of terrain categories	Velocity and turbulence intensity profiles	Power exponent α	roughness length $z_{0\ (m)}$
AIJ 2004	5	Power Law	0.1 to 0.35	(0.0014 to 1.82)
AS/NZS1170.2:2002	4	Deaves and Harris		0.002 to 2.0
ASCE-7-02	3	Power Law	1/9 to 1/4	(0.0039 to 0.58)
BS6399:Part 2:1997	3	Deaves and Harris		0.003 to 0.3
EN 1991-1-4.2005	5	Log Law		0.003 to 1.0
GB 50009-2001	4	Power Law	0.12 to 0.30	(0.0076 to 1.13)
ISO/FDIS 4354: 2008	4	Deaves and Harris		0.003 to 3.0
NBCC (1995)	3	Power Law	0.14 to 0.36	(0.025 to 1.97)

Values of z_0 given in brackets are estimated from Equation 1(in height range 10m to 100m)

In general it seems that wind codes usually specified three to five categories of terrain. But what is the optimal number of terrain categories that should be specified? In order to answer this question, the following two points are to be satisfied.

1. There should be enough types such that the error induced when wrongly selecting the adjacent category would not be too large.
2. Each type should be distinctly identifiable such that the possibility of selecting a wrong category could be minimized.

Looking at the roughness categories specified, it spreads from say the very smooth of 0.002m to the very rough of 3.0m (power exponent of 0.1 to 0.36). To have an understanding of the error in wind speed estimation for wrongly selecting the adjacent category, Table 2 gives an indication for smooth, medium and rough terrains (exponent of 0.1, 0.2 and 0.3). The error was calculated for the 10m wind speed base on the same upper level speed. It can be seen that, with the same discrepancy in the value of the power exponent, the error of wind speed estimation is larger for rough terrain than smooth terrain. From the table, it seems to keep the wind speed error to about 10%, we will need 6 to 7 terrain categories.

Criteria 2 above requires that the types of terrain can be clearly specified, and furthermore can be distinctly identified. There have been many studies on terrain roughness and different terrain types have been proposed e.g. Davenport[1960], Deaves[1981], Cook[1985], Schmid & Oke[1990], and Wieringa[1992]. In Wieringa's paper the Davenport revised classification was presented. It was mentioned that the Zo values were checked and conformed to results of "good experiments" (Wieringa[1992]). It was also mentioned that the descriptions given to the various types of terrain were obtained with the help of 'Geographers' so as to be reasonably unambiguous. The description for each terrain type of the Revised Davenport classification asis reproduced in Table 3.

Table 2 Exponents for 10% speed estimation error

Terrain Cateogory	Error in wind speed	Exponent
Smooth (target exponent=0.1)	-10%	0.586
	+10%	0.146
Medium (target exponent=0.2)	-10%	0.172
	+10%	0.231
Rough (target exponent=0.3)	-10%	0.277
	+10%	0.326

Table 3 Revised Davenport roughness classification (Wieringa[1992])

Type	Z_0 (m)	Landscape description
1 – sea	0.0002	Open sea or lake (irrespective of the wave size), tidal flat, snow-covered flat plain, featureless desert, tarmac and concrete, with a free fetch of several kilometers.
2 – smooth	0.005	Featureless land surface without any noticeable obstacles and with negligible vegetation; e.g. beaches, pack ice without large ridges, morass, and snow-covered or fallow open country.
3 – open	0.03	Level country with low vegetation (e.g. grass) and isolated obstacles with separations of at least 50 obstacle heights; e.g. grazing land without windbreaks, heather, moor and tundra, runway area of airports.
4 – roughly open	0.10	Cultivated area with regular cover of low crops, or moderately open country with occasional obstacles (e.g. low hedges, single rows of trees, isolated farms) at relative horizontal distances of at least 20 obstacle heights.
5 – rough	0.25	Recently-developed "young" landscape with high crops or crops of varying height, and scattered obstacles (e.g. dense shelterbelts, vineyards) at relative distances of about 15 obstacle heights.
6 – very rough	0.5	"Old" cultivated landscape with many rather large obstacle groups (large farms, clumps of forest) separated by open spaces of about 10 obstacle heights. Also low large vegetation with small interspaces, such as bushland, orchards, young densely-planted forest,
7 – closed	1.0	Landscape totally and quite regularly covered wlth similar-size large obstacles, wlth open spaces comparable to the obstacle heights; e,g, mature regular forests, homogeneous cities or villages.
8 - chaotic	>= 2	Centres of large towns with mixture of low-rise and high-rise buildings. Also irregular large forests with many clearings.

From Table 2, for a uniform spread of error, the exponents for the targeted terrain categories should be around 0.1, 0.15, 0.2, 0.24, 0.28 and 0.31 (Zo of about 0.0014, 0.04, 0.21, 0.49, 0.89 and 1.26). Taking into account of the roughness value and the description of the Davenport roughness classification and the roughness used by the current codes, it would be desirable to adjust the targeted categories to suit. Table 4 presents six types of roughness giving the Zo as well as the corresponding Power Law Exponent values. The category name has been modified. The roughness of current codes are also given in the Table.

Table 4 Proposed terrain categories

category	Exposure (description)	roughness length $z_{0\,(m)}$	Power exponent α	Current code specifications ($z_{0\,(m)}$)
Cat I	Open water (open sea or lake and coastal areas with few obstructions)	0.002	0.103	AIJ Cat I – open sea (0.0014) AS/NZ Cat 1 – open terrain (0.002) BS6399 – Sea (0.003) EN Cat 0 – Open sea (0.003) ISO Cat 1 – open sea (0.003) ASCE Exp D – flat area & water (0.0039) GB Cat A – Sea, island, desert (0.0076)
Cat II	Open country (terrain with scattered obstructions up to 10m high. Rural areas with a few low rise building)	0.04	0.15	EN Cat I – lake & area without obst. (0.01) AS/NZ Cat 2 – open, few small obst. (0.02) NBCC Exp A – Open terrain (0.025) BS6399 – Country (0.03) ISO Cat 2 – open country (0.03) AIJ Cat II – open, few obstruction (0.04) ASCE Exp C – open, few med. obst.(0.048) EN Cat II – area with few obst. (0.05) GB Cat B – village, countryside (0.061)
Cat III	Forest/Sub-urban scattered low(3-5m) buildings (Numerous closely space 3-5m obstructions)	0.2	0.198	AS/NZ Cat 3 – many medium obst. (0.2) AIJ Cat III – suburban (0.21) BS6399 – Town (0.3) EN Cat III – suburban, forest (0.3) ISO Cat 3 – Suburban (0.3)
Cat IV	Urban, large town (many medium height(10-50m) buildings)	0.5	0.241	GB Cat C – City (0.34) ASCE Exp B – Urban (0.58) NBCC Exp B – Suburban & urban (0.58)
Cat V	City, (medium height buildings mixed with tall(50m+) buildings)	1.0	0.289	AIJ Cat IV – City medium height bldg. (0.78) EN Cat IV – Area 15% Bldg >15m (1.0) GB Cat D – City iall bldg (1.13)
Cat VI	City centre (concentration of very tall buildings mixed with other buildings)	>=2.	0.362	AIJ Cat V – City tall bldg. (1.82) NBCC Exp C – City centre (1.97) AS/NZ – city (2.0) ISO Cat 4 Urban (3.0)

With the terrain categories defined as given in Table 4, the next important thing that is required is to help designers to identify the correct category. Descriptions for the various categories are also given in Table 4. Such descriptions can only be approximate, rough and covering generic situation. It would be useful for designers to have other means for helping them to correctly identify the terrain category. In some codes, rules for quantitative calculation are given, for example, a ratio of the frontal area of obstruction to ground area. However, such rules are difficult to apply and also difficult to define. A handy way would be to have typical pictures of the various types of terrain. With a few representative pictures for each category, designers could have a better visual and mental perspective of the category. There are some good representative pictures given in various codes. The ones representative of the proposed six terrain categories are extracted and presented here for reference (please refer to the original Codes for better quality pictures).

Figure 1a: Category I (source *1)

Figure 1b: Category II (source *1)

Figure 1c: Category III (source *2)

Figure 1d: Category IV (source *3)

Figure 1e: Category V (source *1)

Figure 1f: Category VI (source *3)

*1 AIJ Wind Load recommendations & Commentary 2004
*2 AS/NZ 1170.2 Structural Design actions – wind actions-commentary (sup1:2002)
*3 ASCE7-98 Wind Load Commentary

Besides defining the roughness length Zo, or the power exponent α for each category, two other parameters are needed to completely specify the wind speed profile. The gradient height Zg, at which the wind speed is approaching constant and little affected by the ground roughness and Zb, the base height, below which the profile has little meaning where wind speed is assumed to stay constant at V(Zb). Values of Zg and Zb for the six categories are given in Table 5. With this set of parameters, the velocities at different heights for different terrain categories are calculated corresponding to a unit wind speed at a standard height of 10m for a Cat.II terrain. The velocity ratios are given in Table 6.

Table 5 Values for Zg and Zb

Category	I	II	III	IV	V	VI
Zg (m)	250	350	450	500	550	650
Zb (m)	5	5	10	15	20	30

Table 6 Velocity ratios for different terrain categories

Height (m)	Velocity Ratio					
	I	II	III	IV	V	VI
10	1.22	1.00	0.80	0.73	0.65	0.56
50	1.44	1.27	1.10	0.98	0.85	0.67
100	1.55	1.41	1.26	1.16	1.04	0.87
150	1.62	1.50	1.37	1.28	1.17	1.00
200	1.67	1.57	1.45	1.37	1.27	1.11
250	1.70	1.62	1.52	1.44	1.36	1.21
350		1.70	1.62	1.56	1.50	1.36
450			1.70	1.66	1.61	1.49
500				1.70	1.66	1.55
550					1.70	1.60
650						1.70

When directional wind is taken into consideration in the design, the sector of the terrain ±45° of the intended wind direction is to be considered. If there are variations in terrain category within the nominal 90° sector, select the sector with the less rough category, i.e. the category producing the higher wind speed. If the upwind terrain is in-homogenous and mixed, it may be possible to proportionally average between adjacent categories. However, if there are large patches or sectors of terrain being different, the category producing the higher wind speed should be selected.

Profiles for typhoon wind

The variation of wind speed with height for typhoons has been studied for a long time. It was observed that for cyclonic wind coming over the sea, the wind profile changed with the strength of the wind. It seemed the stronger wind would increase the wave height and spray density and generally increased the roughness length. Measurements in Hong Kong (Choi 1978 and Hui et.al. 2009) gave exponent of 0.19 for typhoon wind from sea fetch. The Australian code AS/NZ 1170.2 suggested for extreme wind coming over from open water, a rougher Zo of 0.02m should be used instead of Zo=0.002m.

There were also measurements using GPS drop-sondes from reconnaissance flights through hurricane eye-walls reported (Powell et.al. 2003) that at U_{10} above 40m/s, streaks of bubbles were created on the sea surface; and when above 50m/s, the sea completely covered by a layer of foam which impeded momentum transfer. This resulted an apparent low roughness giving an exponent value of 0.1 – 0.11. However it was mentioned in the paper that the result applies to deep-water and open-ocean conditions. And, that indications are for shallow water, a higher roughness would be expected.

It seems further research is required to confirm the profile during typhoon wind. With the current knowledge, for deep-water, open-ocean a Category I profile is suitable. Whereas, for coastal areas with typhoon wind coming from the sea, a Category II profile may be used.

Profiles for thunderstorm wind

Winds generated by a thunderstorm downburst have very different characteristics from those of the synoptic or cyclonic winds which are boundary layer in nature. The column of cold air falling down in a thunderstorm cell spreads out radially as it reaches the ground. The waind at the gust front can be very strong. As the wind is in contact with the ground for a relatively short while, the roughness effect has little chance to influence the wind flow. The shape of the wind profile of a thunderstorm downburst as shown in Figure 2 is very different from that of a boundary layer wind.

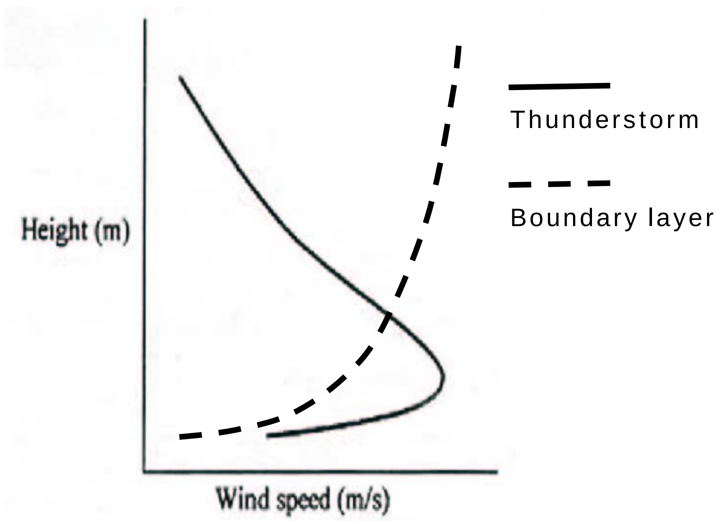

Figure 2 Thunderstorm wind profile

There were many field measurements of thunderstorm wind; most notable are the studies by Fujita. Some of the result were used by Oseguera (Oseguera & Bowles 1988) to develop a thunderstorm wind profile. However the profile is not quite suitable for Codes application, as one of the parameter in the profile equation is the height of occurrence of peak wind speed which varies from storm to storm. There are other field measurements, for example, Choi ((2004) and Chen & Letchford (2005), and some preliminary results are available. For design purpose, thunderstorm wind profile is given in only a few wind loading codes/draft codes, the ISO 4354:2008(E) 'Wind Action on Structures' and the draft 'Overhead line design standard AS/ZN'. Table 7 gives the "Height Exposure Factor for peak wind speed' for ISO and the 'Terrain Height Multiplier' for AS/NZ for thunderstorm downdraft winds. While both present the general shape that after the maximum speed, the wind speed decreases with height; the location of the maximum is quite different. AS/NZ has the maximum speed at or below 50m and the speed drops very fast from 50m to 100m to half the value. On the other hand, the ISO has the maximum at about 100m to 200m and drops slowly as the height increases. Much more field measurements are required to cofirm one way or the other.

Height (m)	ISO Height Exposure Factor	AS/NZ Terrain Height Multiplier
3	0.86	1.00
5	0.93	1.00
10	1.00	1.00
20	1.06	1.00
50	1.15	1.00
100	1.20	0.50
200	1.20	0.50
500	1.02	
1000	1.00	

Table 7 Thunderstorm wind profile

Conclusions

This paper pointed out some in-consistencies in the way that terrain categories are specified in the various wind codes and summarized information on the various types of terrain. Based on a uniform distribution of "would be" selection error, six terrain types have been proposed as the unified terrain exposure. They are proposed so as to minimize the error when wrongly identifying the site category. Pictures for terrain identification are also given. This paper also discussed on wind profiles for typhoon and thunderstorm wind.

References

ASCE 7-98: Minimum design loads for buildings and other structures, Revision of ANSI/ASCE 7-98, 2000

AS/NZS 1170.2: Australian/New Zealand Standard, Structural design actions, Part 2 : Wind actions, 2002

AIJ Recommendation for Loads on Buildings, 2004.

BS6399-2: British Standard, Loading for buildings, Part 2. Code of practice for wind loads, 1997

Chen, L., C.W. Letchford, 2005, Proper orthogonal decomposition of two vertical profiles of full-scale nonstationary downburst wind speeds, JWEIA, Volume 93, Issue 3, March 2005, Pages 187-216

Choi E.C.C., (1978), Characteristics of Typhoons over The South China Sea, Journal of Industrial Aerodynamics, Netherlands, 3, 1978, pp.353-365.

Deaves, D.M., Harris, R.I., 1978. A mathematical model of the structure of strong winds, CIRIA Report 76.Construction Industry Research and Information Association, London.

Eurocode 1: Actions on structures, BS EN 1991-1-1-4:2005

GB50009-2001, Load code for the design of building structurers, PRC.

Hui M.C.H. A. Larsen, H.F. Xiang, 2009, Wind turbulence characteristics study at the Stonecutters Bridge site: Part I—Mean wind and turbulence intensities, JWEIA, Volume 97, Issue 1, January 2009, Pages 22-36

ISO:FDIS 4354:2008(E) Wind Actions on Structures.

NBC2005 Structural Commentaries –IRC-NRC-CNRC

Powell, M. D., Vickery, P. J., Reinhold, T. A., 2003, Reduced drag coefficient for high wind speeds in tropical cyclones, Nature, Vol 422, March 2003, pp279-283.

Wieringa, J., 1992, Updating the Davenport roughness classification, J. Wind Eng. Ind.Aerodynam., 41-44 (1992) pp 357-368

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