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A Study of the Wind Speed Profile for Tall Building Design in Taiwan Area

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Abstract

Wind loads on high rise buildings have been widely studied for safety concerns. It is especially critical in modern metropolitan areas as newer high-rise buildings are needed due to limited habitable land. Typically, high-strength and light-weight material are used for the high-rise buildings. Wind loads therefore play an important role in design for both safety and comfort for the usage of such structures. The building codes provide guidelines of gradient height for various types of terrain. However, the actual wind speed distribution varies from the theoretical assumption because of either expansion or contraction above the gradient height. Previous studies indicate the gradient height in urban area is greater than the value of Terrain Type A in building codes. A further investigation of wind speed distribution for high rise buildings is conducted in this study.

Introduction

With the economic development of modern society and the utilization of land, a trend of forcing the metropolitan areas of buildings, as shown in Fig. 1, tends to increase the amount and height of floors, such as the Taipei 101 (510m), Tokyo Skytree (634m), Khalifa Tower (828m), Makkah Royal Clock Tower Hotel (601m) and recently the United States has just completed the One World Trade Center (541m). The structure of these sky-scraping buildings tends to take high-strength and light weight material. Thus, the effect of wind pressure force on the colossal buildings is very sensitive.

To understand the significance and influence of the wind speed on the vertical distribution and wind profile parameters as shown in Fig. 2 is very important for wind force calculation for tall building design. In this study, we used the data of the Central Weather Bureau cast by radiosonde to analyze the wind speed distribution along the elevation and find the coefficient of α and Zg above 500 meters of height. To provide a reference for specification revisions in the future, a further investigation of wind speed distribution for high-rise buildings is needed to be done in the near future.

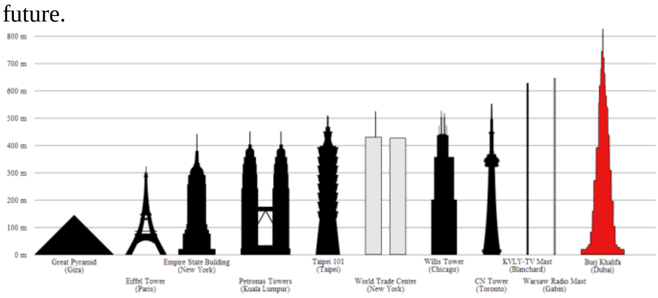

Figure 1. World-renowned Tall Buildings

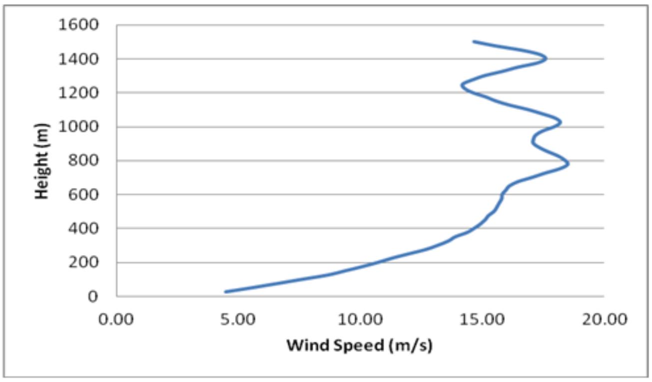

Figure 2: The Wind Velocity Profile of Banqiao Station (2011/12/30/20:00)

Wind Speed Profile Data Process

Because the height of the original data used by this research is not an elevation height above the ground level, it is the height above sea level. First, we need to adjust that. Consequently, we must take logarithms according to the revised elevation. The elevation changes rapidly and heightens depending on the height of the air balloon release position. After sounding the air balloon to release and rise from the ground, the elevation changes irregularly because of the perturbation of atmosphere and rising stabilization conditions. For increasing the credibility of data, we must check the original sounding data and revised it.

I. The original data process

1. The balloon sends back telegraphic signals to the air receiver, which may cause telegraphic signal data some time lag, produce disorderly data, or even lose contact, etc. because of the interference of the external world. The disorderly or abnormal wind speed data will not be used in this research.
2. If the data of the wind velocity distribution cross section deviates from the theory or normal wind speed profile assumptions, the data will not be included in this analysis. As displayed in the wind velocity profile of Fig. 3, the wind velocity distribution contains many miscellaneous and disorderly situations. Due to the wind velocity distribution diminishing from a point and jumping to another point, it is difficult to judge the profile model. The majority of the wind velocity data of the invalid wind velocity cross section profiles are all lower than 5 m/s.
3. This research uses two height definitions: the original data and the other takes the constant interval 25meter height by interpolation calculation of the original data and curve fitting analysis. Only the data of wind velocity greater than 15 m/s at

gradient height is used in this research.

The purpose of this research is mainly to investigate the coefficient α value and the gradient height as shown in Fig. 4. The gradient height is 500 meters and the value of coefficient α is 0.32 for terrain category A of Taiwan building code. Therefore, the wind speed profile of this research was divided into two parts. One is the gradient height Z_g greater than 500 meters and the other is the gradient height less than 500 meters.

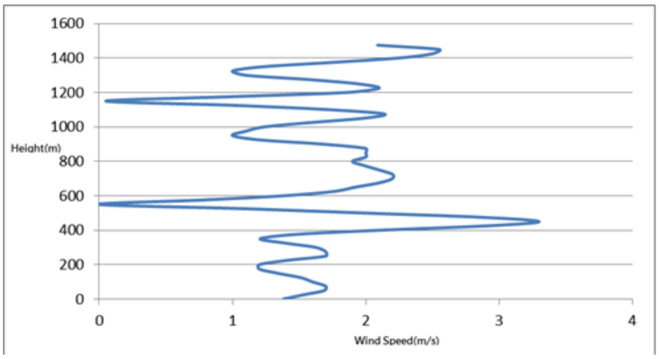

Figure 3: The Invalid Wind Velocity Profile of Hualien Station (2011/09/03/20:00)

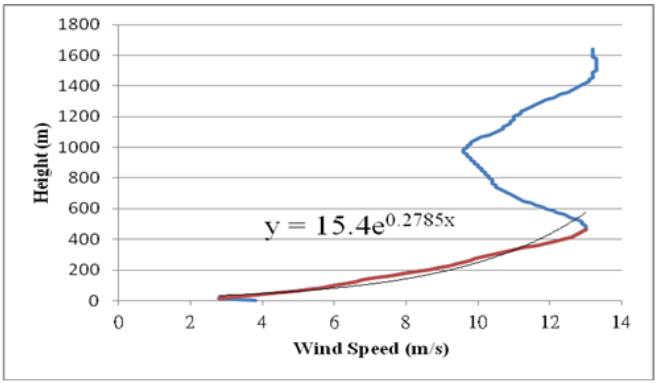

Figure 4: The Wind Velocity Profile of Banqiao Station (2012/08/06/08:00)

II. *Calculation and formulation of the wind speed profile*

1. The process of original sounding data

The gradient high Z_g may be defined and located from the first shrink point of the wind speed profile. Assume the wind speed profile is a logarithmic model as shown in Eq. (1). After taking logarithm of both sides of the Eq. (1), we can get Eq. (2).

$$\frac{V_Z}{V_{Z_g}} = (\frac{Z}{Z_g})^{\alpha} \qquad (1)$$

$$\ln(\frac{V_Z}{V_{Z_g}}) = \alpha \ln(\frac{Z}{Z_g}) \qquad (2)$$

After moving the item of Eq. (2), one can obtain the coefficientαas shown in Eq. (3). The value of α is calculated by this definition from all the wind speed data.

$$\alpha = \ln(\frac{V_Z}{V_{Z_g}}) \Big/ \ln(\frac{Z}{Z_g}) \qquad (3)$$

2. Take exponential regression of the original sounding data

The gradient high Z_g may be defined and located from the first shrink point of the wind speed profile. Taking Logarithm of wind speed data after the exponential regression, and change the index notation of formula. Eq. (4) is generated from Eq. (1).

$$\frac{V(Z)}{V(Z_g)} = (\frac{Z}{Z_g})^{\alpha_R} \qquad (4)$$

The meaning of the symbols is defined as follows:

V(Z): The wind velocity of data sample height. (After exponential regression)

$V(Z_g)$: The gradient wind velocity. (After exponential regression)

α_R: After index regression of α.

Z: The height of sample data

Z_g: The gradient height.

After taking logarithm of the Eq. (4), we can get Eq. (5).

$$\ln(\frac{V_Z}{V_{Z_g}}) = \alpha_R \ln(\frac{Z}{Z_g}) \qquad (5)$$

After moving the item of Eq. (5), one can get coefficient αR from Eq. (6)

$$\alpha_R = \ln(\frac{V_Z}{V_{Z_g}}) \Big/ \ln(\frac{Z}{Z_g}) \qquad (6)$$

3. Take interpolation of the originality sounding data

The height interval of this research is set to be 25 meters for easy calculation and regression. We may obtain the wind speed data of every 25 meters by interpolation of the original data sample. After obtaining a set of wind speed data base, we may find out the first the gradient high Z_g from the first shrink point of the wind speed profile. After notation substitution of Eq. (1) one can get the Eq. (7)

$$\frac{V_{Z25}}{V_{Z_{g25}}} = (\frac{Z_{25}}{Z_{g25}})^{\alpha_{25}} \qquad (7)$$

After taking logarithm of the Eq. (7), we can get Eq. (8).

$$\ln(\frac{V_{Z25}}{V_{Z_{g25}}}) = \alpha_{25} \ln(\frac{Z_{25}}{Z_{g25}}) \qquad (8)$$

The value of α_{25} can be calculated from Eq. (9).

$$\alpha_{25} = \ln(\frac{V_{Z25}}{V_{Z_{g25}}}) \Big/ \ln(\frac{Z_{25}}{Z_{g25}}) \qquad (9)$$

4. Take exponential regression of the original sounding data

Take every 25 meters as one to be apart from the sounding data and take interpolation. Get a set of each data base to be apart from to 25 meters. The gradient height Z_g can be defined from the first shrink point of the wind speed profile. Taking logarithm and perform exponential regression of the data. Eq. (10) can be obtained by changing the index of formulation of Eq. (1).

$$\frac{V(Z_{25})}{V(Z_{g25})} = (\frac{Z_{25}}{Z_{g25}})^{\alpha_{R25}} \qquad (10)$$

After taking logarithm of the Eq. (10), we can get Eq. (11).

$$\ln(\frac{V(Z_{25})}{V(Z_{g25})}) = \alpha_{R25} \ln(\frac{Z_{25}}{Z_{g25}}) \tag{11}$$

The value of α_{R25} can be calculated from Eq. (12)

All data are all reckoned by above-mentioned method to find the value of α_{R25}

$$\alpha_{R25} = \ln(\frac{V(Z_{25})}{V(Z_{g25})}) \Big/ \ln(\frac{Z_{25}}{Z_{g25}}) \tag{12}$$

III. The measuring results of Banqiao station

As shown in Table 1 to 6, the result of the coefficient α_R of this research from the original sounding data in the Banqiao station by exponential regression method is very close to the specification of Taiwan building code. At Banqiao station, the three-year average gradient height Z_g is 628.0 m. The gradient height Z_g is 745 meters for wind speed data with sample gradient height more than 500 m, which is 245 meters higher than the Taiwan specification. The number of sample data set with gradient height above 500 m is much more than the samples of gradient height under 500 m, the ratio is 66% of total data sets. In this study, the wind speed profile value of α is 0.3353, which is larger than standard ground terrain category A, α = 0.32.

Table 1: Gradient Height and Coefficient α of the Original Sounding Data

Year	Time (Month)	<500m of Zg (m)	<500m of α	<500m of α_R	>500m of Z_g (m)	>500m of α	>500m of α_R
2010	8~12	407	0.376	0.3341	749.5	0.4154	0.3252
2011	1~12	393.3	0.414	0.3527	745	0.4456	0.3331
2012	1~12	396	0.4009	0.3299	743.2	0.4472	0.3359
Three-year average		397.3	0.4008	0.3399	745	0.4414	0.3329

Table 2: Gradient Height and Coefficient α Taking Exponential Regression

Year	Time (Month)	<500m of Zg (m)	<500m of α_{25}	<500m of α_{R25}	>500m of Zg (m)	>500m of α_{25}	>500m of α_{R25}
2010	8~12	391.7	0.3402	0.3392	730.0	0.3840	0.3502
2011	1~12	399.1	0.4036	0.3846	765.6	0.4386	0.3553
2012	1~12	406.0	0.3925	0.3645	762.5	0.4419	0.3507
Three-year average		400.7	0.3882	0.3685	759.1	0.4318	0.3527

Table 3: Gradient Height and Coefficient α of Original Three-year Average Data

Year	Time (Month)	Gradient height Z_g (m)	α_R
2010	8~12	610.7	0.3288
2011	1~12	635.6	0.3392
2012	1~12	627.4	0.3339
Three-year average		628.0	0.3353

Table 4: Gradient Height and α of Three-year Average Data Taking Interpolation

Year	Time (Month)	Gradient height Z_g (m)	α_{R25}
2010	8~12	603.1	0.3460
2011	1~12	647.5	0.3647
2012	1~12	638.0	0.3555
Three-year average		636.7	0.3581

Table 5: The Number of Samples of Each Year Taking Interpolation

Year	Time (Month)	Gradient height under 500 m	Gradient height above 500 m
2010	8~12	12	20
2011	1~12	29	61
2012	1~12	29	54
The sum of 3 years		70	135

Table 6: Research Values Compared with Different Country Specification

	Research value of three-year average	Research value > 500m	Taiwan (ground category A)	ASCE7-98 (ground category A)	AIJ-2004 (ground category V)	GB5009-2001 (ground category D)
α	0.3353	0.3329	0.32	1/3	0.35	0.3
Z_g	628.0m	745.0m	500m	457.2m	650m	450m

Table 6 shows the research results with gradient height Z_g and α and compared with other countries specification. In this study, the coefficient of wind speed profile α is 0.3353, which is close to all specifications and a little lower than the Japanese AIJ-2004 specification. The gradient height of wind speed profile Z_g is 628.0m for all three years data, and the gradient height Z_g is 745.0m for sample data with gradient height above 500m, both of values are larger than the specification of Taiwan, the United States and China and close to Japanese specification.

IV. The shrink and external expansion phenomenon of the wind speed profile

In fact, the true nature of wind field vertical wind speed distribution is different from the theories and the building code assumption; in general, the real wind speed does not maintain a uniform value after reach the gradient height. Contrastingly, it will vary with height either with shrink or external expansion phenomenon. Table 7 to Table 9 shows the results of the analysis of data collected with the shrink and external expansion of the phenomenon for the past three years.

The gradient height Z_g is 451.8 meters for external expansion phenomenon samples for the three-year average. The gradient height Z_g is 645.3 meters for shrink of the phenomenon samples for the three-year average. The probability of shrink phenomenon occurrence is higher than the external expansion phenomenon, as shown in Table 10 to Table 11.

The external expansion phenomenon most likely with the gradient height less than 500 meters, the samples ratio is up to 70.2%. The probability of external expansion phenomenon occurrence is higher than the shrink phenomenon. The external expansion phenomenon most likely with the gradient height less than 500 meters, the samples ratio is up to 70.2%.

The shrink phenomenon, most likely with the gradient height, is above 500 meters. The proportion of shrink phenomenon samples is up to 75.7%. For the gradient height below 500 meters, the wind speed radiosonde data for up to 1000 meters of altitude, the probability occurrence of the external expansion phenomenon is higher than the shrink phenomenon.

On the contrary, for the gradient height of above 500 meters, the wind speed radiosonde data for up to 1000 meters height of altitude, the probability occurrence of the shrink phenomenon is higher than the external expansion phenomenon.

Table 7: The Values of External Expansion Phenomenon

Year	Gradient height Z_g (m)	Angle θ(°)	The wind speed of change every 1000m V_C(m/s)
2010	455.1	0.3272	2.9960
2011	439.5	0.2485	2.4485
2012	460.3	0.3253	3.1482
Three-year average value	451.8	0.2979	2.8660

Table 8: The Values of Shrink Phenomenon

Year	Gradient height Z_g (m)	Angle θ(°)	The wind speed of change every 1000m V_C(m/s)
2010	654.2	-0.3948	-2.4100
2011	671.9	-0.3593	-1.9997
2012	611.7	-0.3561	-2.2579
Three-year average	644.2	-0.3636	-2.1711

Table 9: The Values of Constant Phenomenon

Year	Gradient height Z_g (m)	Angle θ(°)	The wind speed of change every 1000m V_C(m/s)
2010	579.5	-0.0037	0.0813
2011	618.1	-0.0034	0.0384
2012	645.8	-0.0170	-0.0943
Three-year average	619.2	-0.0078	0.0045

Table 10: The Number of Typhoon Samples of All Phenomenon

Year	External expansion phenomenon	Shrink phenomenon	Constant phenomenon	Invalid data	Total
2010	5	3	2	2	12
2011	5	5	1	0	11
2012	13	4	7	1	25
Sum	23	12	10	2	48

The results of all shrink and external expansion of the phenomenon are shown in the following Table 11.

Table 11: The Gradient Height and Coefficient α

	Gradient height Z_g (m)	α_R
Shrink phenomenon	644.2	0.3343
External expansion phenomenon	451.8	0.3289
Constant phenomenon	619.2	0.3388

Conclusions and Discussions

This paper analyzes the values of coefficient α and gradient height Z_g for wind speed profile of the Taipei area using data obtained from Banqiao Station of Central Weather Bureau. The analysis focuses on the expansion and shrink phenomenon of wind speed profile for height above the gradient height.

The results of this study are listed as follows: The value of α_R is 0.3353 and the value of Z_g is 628.0 m. When gradient height is above 500m, the value of α_R is 0.3392 and the value of Z_g is 745.0 m. The values ofα_R is greater than the value 0.32 per building code for Terrain Type A. The gradient height indicated in this study also is greater than the value 500 m in Taiwan building code for Terrain category A.

It is concluded in this study that the taller the high-rise building is, the greater the difference occurs between the actual wind speed/wind pressure/wind power and those specified in the building codes when the phenomenon of wind speed expansion is taken into consideration. This exposes a potential safety concern for those high-rise buildings with extreme height. Deficient safety factors for wind speed and excessive floor deflection could likely occur under current building codes. It is the author's hope that such findings could help bring the wind speed calculation of high rise building in the future up to date.

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