

## WIND STRUCTURES OF MONSOON WINDS AND TYPHOONS NEAR THE GROUND

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### Abstract

The objective of the paper is to present the dependence of the wind profile of a monsoon on the depth of the layer, the ground surface roughness length, and the atmospheric stability. The paper also indicates that the wind profiles of the typhoon are composed of two layers, the upper one with the nearly constant velocity and the lower one in which the velocity decreases with the decrease in the height. The typhoon wind profiles are not stationary but changes abruptly.

**Keywords:** Monsoon wind; wind structures; turbulence; typhoon; movement path

### 1. Introduction

The depth of the boundary layer normally ranges in the case of the neutrally stratified flows from a few hundred meters to several kilometers, depending upon the wind intensity, the roughness of the terrain, and the angle of the latitude. The near-surface wind is the most variable of all meteorological elements. Due to the friction, the wind speed always vanishes at the ground. Approximately 50 percent of the transition in wind speed due to the frictional effects takes place in the first 2 meter above the surface. The adjustment in the wind direction takes place over a 1-to-2 km depth. These adjustments give rise to the wind profile; the profile of the wind speed in particular must be taken into account when the tall buildings or the stacks are being designed.

Under most conditions, the wind varies continuously in the near-surface layer. However, it usually can be expressed by a superposition of the high-frequency oscillations of the small amplitude in both the speed and the direction around a much more slowly varying sustained speed and a prevailing direction, respectively. The wind structures include the descriptions of the mean wind profiles, the relation between the wind speeds in the different roughness regimes, the turbulence and so on.

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## 2. Wind Structures of Monsoon Winds

The monsoons are the seasonal winds that form the cells of the general circulation and develop around thermally produced continental highs in winter and lows in summer. Owing to the vast landmass of Asian continent, the monsoon effects are developed most strongly in Asia, where they have a considerable influence on the seasonal changes of the weather patterns.

In a monsoon, the wind profile is dependent on the depth of the layer at which the wind speed is being extrapolated, the surface roughness length  $z_0$ , and the atmospheric stability. For monsoon, it may be assumed that in the large-scale storms, within a horizontal site of uniform roughness over a sufficiently large fetch a region exists over which the flow is horizontally homogeneous. There is a variety of ways to express the variation of the wind speed with height. Among these are the logarithmic law and the power law. Recently, the power law has been used widely in many engineering practices. In general, the power law exponent  $p$  increases as the layer becomes more stable. And it also varies from site to site. The exponent is also different during the different time in a day and different season. For example, Moses and Bosgner [1] found that in January the most frequent values of the power law exponent  $p$  during the daytime and nighttime hours were 0.11 or 0.14 while in July the most frequent values of the power law exponent  $p$  were 0.33 or 0.45. And De Marrais [2] found that the power law exponents  $p$  varied from 0.1 to 0.3 during the day when the super-adiabatic and the neutral lapse rates prevail and from 0.2 to 0.8 during the nighttime conditions when the stable and isothermal conditions exist. Panofsky et al. [3] investigate the stability and the surface roughness dependence of the profile exponent values. They concluded that during the stable conditions the power-law exponent  $p$  is mostly a function of stability and only a weak function of the surface roughness while during the unstable conditions, however, the power-law exponent is mostly a function of the surface roughness and only a weak function of stability. The power law appears to be a good approximation to use only during the neutral conditions since it is not valid for the other conditions (in fact, the exponent almost triples at very stable classes). In some engineering design applications, the high average wind speeds are of interest. It is during the conditions of the high wind speeds that the atmosphere is assumed to be well mixed and the neutral conditions are most likely to occur. In a word, the true power law relationship is highly variable and is dependent on the stability class at each site. Thus, it is suggested that a site-specific power law profile be developed and used when it is necessary. Logarithmic law is regarded by the meteorologists as a superior representation of the strong wind profiles in the lower atmosphere. It was found to be a good approximation of the data by many researchers in many sites with the different surface characteristics. Some studies suggested that the wind profile be logarithmic near the ground surface and be a power-law form further from the surface, i.e., the logarithmic form is seen to be best near the surface, with the power law a better fit at greater heights or over a large range of elevations and the power law exponent is a function of the boundary layer thickness and the surface roughness. A schematic representation of the respective wind profiles is shown in Figure 1.

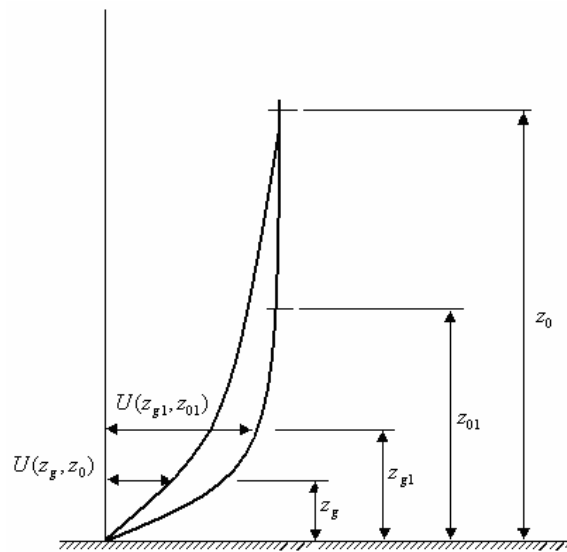


Figure 1. Wind velocity profile. ( $z_0$  and  $z_{01}$  denote the height above the ground,  $z_g$  and  $z_{g1}$  denote the gradient height)

### 3. Monsoon Winds Turbulence

The information on the features of the turbulence is useful in the structural engineering applications, such as the turbulence intensity, the integral scales of the turbulence, and so on. Some observations indicate that the standard deviations are almost constant up to approximately half the height of the internal boundary layer. The surface winds at 10 meter height often have the turbulence intensity of the order of 20% or 30%. The turbulence intensity increases with the ground roughness and decreases with the height. It also varies with the duration used in determining the mean velocity: the longer duration yields the smaller mean velocity and hence the larger value of turbulence intensity. Some studies indicate that the estimates of the standard deviation, and correspondingly, the turbulence intensity, from the modeled or the measured wind shear in the inhomogeneous terrain using the factors valid for the flat and homogenous terrain involves a high degree of inaccuracy. Correspondingly, the formulas using this relation cannot give the precise results in such terrain. The integral length scales are a measure of the sizes of the vortices in the wind. The integral scales depend on the height  $z$  above the ground and on the roughness of the terrain. The mean wind speed may also influence the integral scales at a site. The purely empirical expression for the  $x$  longitudinal integral length scale at a height  $z$  in the range of 10~240 meter is written as

$$L_u^x = Cz^m \quad (1)$$

Where  $C$  and  $m$  depend on the roughness of the terrain. The spectral peak for the

turbulence in the monsoon winds is usually at rather low frequencies.

In order to describe the dependence of the wind speed profile and the turbulence on the ground roughness, a parameter is introduced, which is named as the roughness length. The roughness length is a measure of the eddy size at the ground. In reality, a site is limited in size; the flow near its boundaries is therefore affected by the surface roughness of the adjoining sites.

#### 4. Wind Structures of Typhoons

A few times each year, from early June through October, the low-pressure systems termed the tropical cyclones form over warm ocean waters in the tropics. Occasionally, where the sea-surface temperatures are greater than 22°C and when the winds high in the atmosphere are supportive, one of these systems will become more organized and intensify to become a typhoon. The typhoons are the storms that derive all their energy from the latent heat released by the condensation of the water vapor. Their diameters are usually of the order of several hundred kilometers. The depth of the atmosphere involved is of the order of ten kilometers. The vertical scale is much less than its horizontal scale. They normally travel as whole entities at speeds of 5 to 50 km/hr. As seen in a vertical plane section, the structure of a typhoon in the mature stage consists of five main regions, represented schematically in Figure 2, in which the approximate dimensions are also shown. Region I consists of a roughly circular, a relatively dry core of the calm or the light winds, called the eye, around which the storm is centered. The aircraft and radar studies have shown that some of the more intense typhoons have contained a double concentric eye-wall structure and a related double maximum in the wind speeds. Region II consists of a vortex in which the warm moist air is convected at the high altitudes and forms the tall convective clouds. Consideration of the water vapor occurs as the moist air rises, and this results in the intense rainfall and the release of the vast amounts of the latent heat. It has been estimated that the condensation heat energy released by a typhoon in one hour may be equivalent to the electrical energy used in the entire U.S.A. in one week. The air flows out the region II into an outflow layer (region III). In region IV the flow is vortex-like and settles very slowly into the boundary layer region V. Below region II, where the strong updrafts are present, the separation of the boundary layer may occur. According to the studies of Graham and Hudson [4] an expression of the following form

$$\frac{1}{\rho} \frac{dp}{dr} = \left( \frac{p_N - p_o}{\rho} \right) \frac{R_m}{r^2} e^{-R_m/r} \quad (2)$$

in which  $p_N$  is the pressure that is approached as the radius  $r \rightarrow \infty$ ,  $p_o$  is the pressure at the center of the typhoon eye,  $(p_N - p_o)/\rho$  is assumed independent of height, and  $R_m$  is twice the radius of the maximum  $dp/dr$ , is fairly representative of the typical typhoon pressure fields. If this description of the pressure gradient field is used, the gradient wind velocity field results from the expression of the gradient wind. There results from Eq. (2) that the gradient

velocity reaches a maximum at a radius of the order of  $R_m$ . From this radius the velocity decreases rapidly to zero at the center of the eye, and more slowly to the relatively small values that obtain at large distances from the center. It is displayed in Figure 3. The maximum value of the surface wind speed is found inside the radius of the maximum wind  $R_m$ , as is often observed in the surface wind data during a typhoon. A fairly strong convergent flow exists in the vicinity of the ground surface, which causes the transport of the momentum in the radial direction owing to the existence of the spatial heterogeneity of the wind field in the typhoon boundary layer.

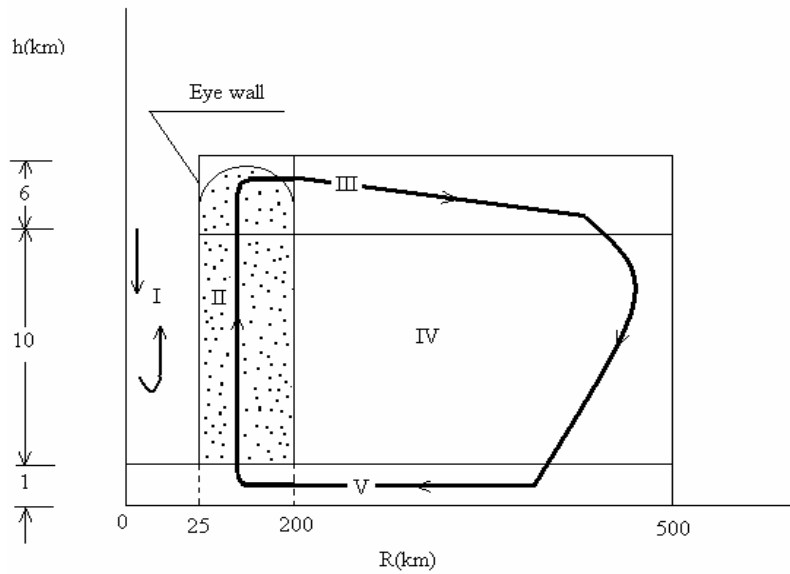


Figure 2. Structure of a typhoon

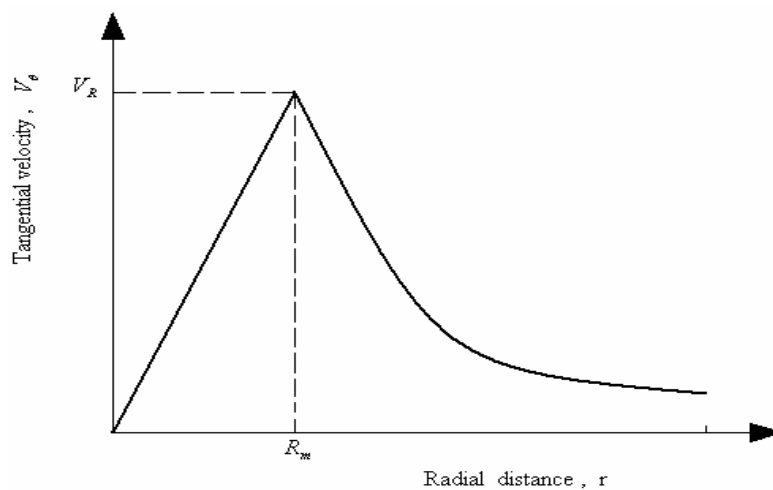


Figure 3. Velocity distribution of a typhoon

Several analytical solutions of the typhoon boundary-layer problem have been attempted, all of which apply to the steady axisymmetric mean flows. The solutions are based on the assumption that the eddy viscosity is constant, and they *cannot* provide a reliable detailed description of the flow near the ground. According to Simiu et al. [5], in the lowest 400 meter of the boundary layer the mean wind profiles differs only insignificantly from the logarithmic profiles. The surface wind speeds in the eye can be comparable with or higher than the estimated speeds at the gradient height level. However, whether the logarithmic profile holds in the case of the mature typhoons remains an open question cause such information is still insufficient. In the measurements carried out by Choi [6], it indicates that the certain relationship exists between the wind speed  $v_z$  and the gradient wind speed  $v_g$ . A simple exponential expression has been used to represent the variation and after curve fitting the following equation is established:

$$\frac{v_z}{v_g} = e^{-\frac{6.64}{v_z}} \quad (3)$$

If the power-law is used to represent the wind speed profile, the relationship between the height above the ground  $z$  and the gradient height  $z_g$  can be expressed as

$$\frac{z}{z_g} = e^{-\frac{6.64}{\alpha z}} \quad (4)$$

Where  $\alpha$  is the exponent of the power-law. In the past years, the measurements and researches on the typhoon characteristics have been carried out by some people. The power exponent for the variation of the wind speed with height at the lower 100 meter of the atmosphere has been established and published. For instance, Choi [6] found the values ranging from 0.18 to 0.28. Mackey and Ko [7] postulated a mean value of 0.19. As can be seen in the above equation, the gradient height  $z_g$  is changing with the wind speed  $v_z$ . The higher the value of  $v_z$ , the lower will be the value of  $z_g$ . Some observations indicate that the wind profiles of the typhoon are composed of two layers, the upper one with the nearly constant velocity and the lower one in which the velocity decreases with the decrease in the height. The velocity profile in the lower layer is well fitted by the power law and the height to distinguish the two layers seems to represent the gradient height. It should be emphasized that the wind profiles are not stationary but changes abruptly. It is surprising that the gradient height can descend to a height less than 100 meter, whether the variation of the gradient height is large or not. When the low gradient height is predominant, the stronger downward flow with the slightly larger fluctuation is observed in all heights except the lower height of less than 50 meter.

## 5. Typhoon Turbulence

According to the research of typhoon Mireille, the turbulence intensity during the period of

the strongest 10-min wind (about 25 m/s) was over 25%. The turbulence scale was estimated to be 780 meter during that period and 280 meter during the 10-min period preceding it. The von Karman spectrum, with the turbulence scales just indicates, matched the measured spectra well, except for the range of about 0.025 to 0.15 Hz, where it underestimated the measured spectra by as much as 100% for the certain frequencies. Certainly in a typhoon, the turbulence intensity is varying with the mean wind speed. In general, the turbulence intensities are scattered in the range of the low wind speeds, and converge on a certain value with an increase of the wind speeds. For example, the values are scattered around 15% in the case of the Typhoon Caitlin, while the turbulence intensities above 30% can be seen in the case of the Typhoon Kinna and Mireille. For Typhoon Mireille, the values of more than 20% were observed even in the range over 20 m/s. The variation of the turbulence intensity with the height has been studied by many researchers. Most people used an exponential law to describe the relationship. For the typhoon conditions, Choi [6] gave an exponent of -0.31. It was found the values ranging from -0.01 to -0.26 for 50 meter height and above and much higher values for the levels below 50 meter. Based on the data of typhoon Freda, the following expression is obtained

$$\frac{I_z}{I_g} = \left(\frac{z}{z_g}\right)^{-0.25\left(\frac{z_g - z}{z_g}\right)} \quad (5)$$

## 6. Typhoon Movement Paths

It is confirmed that the typhoon movement is often erratic: a typhoon on the move can slow down, remain nearly stationary, speed up, or changing direction. Actually the wind direction keeps changing in a typhoon and it should be noted that the wind speed changed rapidly with the wind direction. It is obvious that the roughness length  $z_o$  depend strongly on the wind direction in the typhoon case. It indicates that the values of  $z_o$  should be identified in every wind direction from the observations or the wind tunnel tests in order to simulate the typhoon-induced wind field accurately. In a word, the typhoon wind speed depends not only on the radial distance from the typhoon center but also on the wind direction, because of the heterogeneity of the surface roughness and the topography around the site.

The surface wind has traditionally been measured by the instruments mounted on the masts and the towers extending upward from the surface of the earth. The traditional techniques suffer from a number of the shortcomings. For example, the observations from many observing stations are available only hourly and from some stations for only the selected hours of the day. Many surface observations rely on the human observations visually estimating a sustained speed and a prevailing direction. Where the continuous data are available, they are often in the analog or strip chart form and therefore the labor intensive to reduce. Few data are available from many remote sites. What's more, there are very few wind-recording stations located in the coastal areas that are in the path of the typhoons. Moreover, the wind-recording instruments are often damaged or without the power during the passage of severe typhoons. As a result, the recorded data of the typhoon

winds are sparse. It is extremely important to improve the current methods for collecting the typhoon wind-speed data if the reliable predictions of the wind speeds are to be obtained. The wind speeds also affected by the wind climate and by the topography. They can significantly affect the wind speed at various locations. The data gathered at many stations can help to estimate the regional zonation of the design wind speeds.

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