DEVELOPMENT OF TERRAIN HEIGHT MULTIPLIERS AND ROUGHNESS LENGTHS FOR SEBERANG PERAI REGION

by

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Dissertation submitted in fulfillment of the requirements
for the degree of
Master of Science (Structural Engineering)

School of Civil Engineering

Universiti Sains Malaysia **May 2010**

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ABBREVIATION

AIJ	Architectural Institute of Japan
AS	Australian Standard 1170.2 SAA Loading Code Part 2: Wind Loads
BS	British Standard Code of Practice on Wind Loading Structure
CIDB	Construction Industry Development Board Malaysia
MS	Malaysian Standard 1553:2002 Code of Practice on Wind Loading Structure
NBCC	National Building Code of Canada
a , b	Constant, depends on terrain category
$M_{z,cat}$	Terrain Height Multiplier
V_{ref}	Reference basic wind speed
$V(z)$	Wind speed at z (m) height
z	Height in meter (m)
z_0	Roughness Length (m)
z_{ref}	Reference height

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ABSTRACT

Malaysia has developed its own standard of practice in wind loading known as MS 1553:2002 Code of Practice on Wind Loading for Building Structure. During the development of this Malaysian Standard, reference was made to Australian Standard due to the similarity of wind climate between Malaysia and Australia. In the same time, researches have been carried out in order to update all parameters in MS 1553:2002 based on Malaysia wind climate. Seberang Jaya Telecommunication Tower was selected as the study area representing terrain Category 3: Suburban area for Seberang Perai region. An eight years period of data are recorded at three different levels by using the Ultrasonic Wind Sensor (UWS). Power Law profile is the best equation fit with the vertical wind speed profile at the study area as proven by *Ramli (2005)*. In this study, Terrain Height Multiplier, $M_{z,cat}$, and Roughness Length, z_o for all terrain categories in Seberang Perai region are defined by using statistical and mathematical method. From the results obtained, the proposed $M_{z,cat}$ for all terrain categories are much lower than the current values in MS 1553:2002. The difference up to 19% obtained due to the fact that Australia and Malaysia have different wind climate. A reasonable good agreement and a consistent result for $M_{z,cat}$ can be noted from the comparison of the proposed value to the other international codes and standards. The proposed z_o for all terrain categories are in range from 0.03 m to 1.13 m which is still in the overall range for all codes and standards.

PEMBANGUNAN PEKALI DEDAHAN DAN KETINGGIAN SERTA JARAK KEKASARAN BAGI DAERAH SEBERANG PERAI

ABSTRAK

Malaysia telah membangunkan satu kod piawaian beban angin terhadap bangunan yg dikenali sebagai Kod Piawai Beban Angin MS 1553:2002. Kod ini telah di adaptasi dari kod piawaian angin Australia 1170.2 kerana Malaysia dan Australia mempunyai keadaan iklim yang hampir serupa. Dalam masa yang sama, kajian giat dijalankan bagi mengemaskini semua pekali dan pembolehubah berdasarkan keadaan iklim sebenar di Malaysia. Menara Telekomunikasi Seberang Jaya telah di pilih sebagai lokasi kajian yang mewakil kawasan Kategori 3 bagi daerah Seberang Perai. Lapan tahun data pada tiga aras ketinggian yang berbeza telah dikumpul bagi menjalankan kajian ini. Data di rekod menggunakan "*Ultrasonic Wind Sensor*" *(UWS)*. Persamaan "*Power Law*" merupakan persamaan yang paling sesuai dengan profil angin di kawasan kajian dan ianya telah dibuktikan oleh *Ramli (2005)*. Di dalam kajian ini, kaedah statistik dan metematik digunakan bagi mencari Pekali Dedahan dan Ketinggian, *Mz,cat* dan Jarak Kekasaran Permukaan, z_0. Keputusan kajian mendapati bahawa nilai $M_{z,cat}$ yang diperolehi adalah lebih kecil nilainya berbanding nilai yang sediada yang digunakan di dalam MS 1553:2002. Perbezaan sehingga 19% di perolehi dan ianya berlaku disebabkan Australia dan Malaysia mempunyai iklim yang agak berbeza. Perbezaan yang sama juga dapat dilihat secara konsisten pada hasil perbandingan diantara kod dan piawaian antarabangsa yang lain. Nilai z_0 yang diperolehi untuk semua kategori kawasan adalah di antara 0.03 m hingga 1.13 m dan nilai tersebut berada di dalam lingkungan nilai bg keseluruhan kod dan piawaian antarabangsa yang diguna pakai.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Wind load in structural engineering can be defined as the natural horizontal load produced by air and it is the most important element because wind load has a great deal of influence on building design and the design of other kinds of civil engineering structures. Usually structure members fail because of inadequate consideration given to wind action at the design stage. The description of wind load has move from relatively simple, straightforward, notions of static drag forces to much more sophisticated model, structural mechanics, structural dynamics and reliability (Davenport, 2002).

The past half century, self weights of structural members were heavier due to the relatively weak materials such as heavy masonry and stone. This type of structure frequently much stiffer and this situation did little emphasize the important of wind force (in question of overturning for example) in design consideration. The latent dynamic problems were effectively disguised. The development of new materials and construction techniques has resulted in the emergence of a new generation of structures that are frequently to a degree unknown in the past, remarkably flexible, low in damping and light in weight. Such structure exhibit an increased susceptibility to the action of wind (Scanlan, 1978). Change in stiffness, mass and damping in structure will lead to new requirements in dealing with wind effect (Davenport, 2002).

Wind engineering is a practical field looking for practical answers. It is not simply a catalogue of theoretical ideas. One way to meet this need is through case studies. Therefore, engineer needs to study the information regarding the wind environment, the relation between the environment and forces induced on the structure and the behaviour of the structure under the action of wind force (Davenport, 2002).

1.2 Background

Wind loading had significant research effort in many growth countries as well as Malaysia. This is because wind loading is the dominant environmental loading for structures that can influence on stability and safety. In structural engineering, building up to 10 stories are rarely affected by wind loads. The static approach assumes the structure to be fixed rigid body in the wind. Dynamics approach for slender and vibrations - prone structure.

Malaysia has developed its own standard of practice in wind loading known as MS 1553:2002 Code of Practice on Wind Loading for Building Structure. The development of this standard was carried out by the Construction Industry Development Board Malaysia (CIDB) which is the Standards-Writing Organisation (SWO) appointed by SIRIM Berhad to develop standard for construction industry (MS 1553:2002).

General requirements and design action in MS 1553:2002 was referred to AS/NZS 1170.2 Structural Design (MS 1553:2002). MS1553:2002 is fully adapted from Australian Standard due to the similarity of wind climate between Malaysia and Australia (Sundaraj, 2002). Parameters that have been adopted from Australian Standard may not be precisely accurate due to the different location which contributes to different wind pressure. Therefore it is necessary to establish a new Terrain Height Multiplier, $M_{z,cat}$ and new Roughness Length, z_o. In order to validate these parameters in MS 1553:2002, wind data collection must be based on the exact study location.

In year 2002, under research grant of wind profile study, three Ultrasonic Wind Sensors (UWS) were installed in Seberang Perai Communication Tower at three different heights. By having those Ultrasonic Wind Sensors, the objective of this study can be achieved.

1.3 Problem Statement

Wind loading is dependent on structure shape, location of the structure and the characteristics of wind such as wind direction and gradient wind speed. Therefore, according to MS 1553:2002 the design of wind speed is:

$$V_{des} = V_{site} \times I$$

Where the site wind speed,

$$V_{site} = V_{site} (M_d)(M_{z,cat})(M_s)(M_h)$$

The value of site wind speed is depending upon four multipliers which were adapted from Australian Standard (AS 1170.2) namely:

i. Wind Directional Multiplier, M_d

ii. Terrain Height Multiplier, $M_{z,cat}$

iii. Hill Shape Multiplier, M_h

iv. Shielding Multiplier, M_s

There are two main focus of this research, the first focus will be on the production of Terrain Height Multiplier, $M_{z,cat}$, for all terrain categories specified in MS 1553:2002. Terrain Height Multiplier, $M_{z,cat}$ is defined as the multiplier to obtain wind speed according to variation of height, z, in different type of terrain category (Ramli, 2005). The designers shall take account of known future changes to terrain roughness in assessment of terrain category (MS 1553:2002). Therefore, the second focus of this research will be on the production of Roughness Length, z_o, for terrain categories.

1.4 Scope of Study

The scopes of study of this research are as follows:

i. Analyse local wind speed from year 2002 until year 2009 by using SPSS 11.5 Software to determine the best fit equation represents the vertical wind speed profile for terrain Category 3; suburban area, Seberang Perai region.

ii. Terrain Height Multiplier, $M_{z,cat}$ for terrain Category 3 will be determined using the best fit equation represents the vertical wind speed profile for suburban area, Seberang Perai region. In this study Power Law equation will be used as verified by Ramli (2005) and Husain (2007).

iii. Terrain Height Multiplier $M_{z,cat}$ for terrains Category 1, Category 2 and Category 4 will be obtained by interpolating the proposed $M_{z,cat}$ for Category 3.

iv. Terrain Roughness Length, z_o for all terrain category will be calculated base on the proposed Terrain Height Multiplier, $M_{z,cat}$ for all terrain categories.

1.5 Objectives

The objectives of this research are:

i. To determine and propose Terrain Height Multiplier, $M_{z,cat}$ according to MS 1553:2002 for terrain Category 3; suburban area, Seberang Perai region.

ii. To interpolate and propose Terrain Height Multiplier, $M_{z,cat}$ for terrains Category 1, Category 2 and Category 4 according to MS 1553:2002.

iii. To determine and propose the Terrain Roughness Length, z_o for terrains Category 1, Category 2, Category 3 and Category 4.

iv. To compare the proposed Terrain Height Multiplier, $M_{z,cat}$ and propose Terrain Roughness Length, z_o with other codes of practice.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Wind engineering is the discipline that has evolved, primarily during the latest decades, from efforts aimed at developing such tools. It is the task of the engineer to ensure that the performance of structures subjected to the action of wind will be adequate during their anticipated life. In order to achieve this end, the designer needs information regarding the wind environment, the relationship between that environment and the forces induced on structure and the behavior of the structure under the action of these forces. The information on the wind environment normally includes elements derived from meteorology, micrometeorology and climatology (Simiu, 1996).

Meteorology provides a description and explanation about the fundamental features of atmospheric flows. Such features may be of considerable significance from a structural design viewpoint. Micrometeorology attempts to describe the detailed structure of atmospheric flows near the ground such as the variation of mean wind speeds with height above ground, the description of atmospheric turbulence and the dependence of the mean speeds and of turbulence upon roughness of terrain. Climatology is concerned with the prediction of wind condition at given geographical location (Simiu, 1996).

2.2 Monsoon in Malaysia

The term ''monsoon'' stems from seasonal variations in winds but it is now more generally applied to tropical and subtropical seasonal reversals in both the atmospheric circulation and associated precipitation. These changes arise from reversals in temperature gradients between continental regions and the adjacent oceans with the progression of the seasons, and the extremes are often best characterized as ''wet'' and ''dry'' seasons rather than summer and winter (Trenberth, 2000).

Malaysia lies in the equatorial region and its climate is governed by the monsoons (Zaharim,2009). Malaysia does not experience typhoon, and has very low extreme winds from weak thunderstorm and monsoonal wind. Monthly maximum wind data are available from more than thirty stations in the country. Analysis for this data for 50-years return period gust by Malaysian Meteorological Department gave value between 24 m/s and 32m/s. Therefore, Malaysia can be classified as low extreme wind climates (Holmes, 2001).

The wind over the country is generally light and variable but there are some uniform periodic changes in the wind flow patterns. Based on these changes, four seasons can be distinguished, namely;

i. Southwest monsoon
ii. Northeast monsoon
iii. Two shorter periods of inter-monsoon seasons.

According to Malaysian Meteorological Department, the southwest monsoon season is usually established in the latter half of May or early June and ends in September.

During this period, the wind flow is generally southwesterly and below 15 knots. In early November, the northeast monsoon season usually commences and ends in March. During this period, steady easterly or northeasterly winds of 10 to 20 knots prevail. In the east coast states of Peninsular Malaysia, the wind may reach 30 knots or more during periods of strong surges of cold air from the north.

Hurricanes often occur in the west pacific in April and November. This phenomenon will eventually move towards the Philippines from the west and then move towards Sabah and Sarawak in Malaysia by the southwest wind (Hussain, 2007). During this transition, higher wind speed can be experienced along the coastal areas and the life span of a hurricane usually averaging about 10 days (Liu, 1991).

2.3 Atmospheric Boundary Layer (ABL)

Wind is fundamentally caused by variable solar heating of the earth atmosphere. It is initiated, in a more immediate sense, by different of pressure between points of equal elevation. Such differences may be brought about by thermodynamic and mechanical phenomena that occur in the atmosphere nonuniformly both in time and space (Simiu, 1996).

Atmospheric boundary layer can be defined as the height where the wind speeds affected by topography. The depth of the boundary layer normally depending on three factors;

i. The wind intensity
ii. The terrain roughness
iii. The angle of latitude

The atmospherics boundary layer is within approximately 1 kilometer from ground surface. This layer grows from ground surface with zero wind speed and gradually increase until it reaches the gradient wind level (Liu, 1991).

2.4 Basic Wind Speed

The basic wind defined as the 3-second peak gust at 10 m above ground surface in open terrain with sufficiently long fetch in all direction (Simiu, 2006). In other hand, the basic wind speed can be in different mean recurrence intervals and averaging times. It is actually the maximum wind speed that is predicted in 50 or 100 years of return period depending on the standards and codes of practice. The basic wind speed is converted to the design reference velocity for a particular site by introducing the influence of local environment, directionality, mean recurrence interval, and significance factors associated with the planned structure (Zhou, 2002).

2.5 Averaging Times

Wind speeds over horizontal terrain with uniform roughness over a sufficiently long fetch depend on averaging time in a well established way. If the flow were laminar, wind speeds would be the same for all averaging times. However, owing to turbulent fluctuations as shows in Figure 2.1, the definition of wind speeds depends on averaging time (Smiu, 2006).

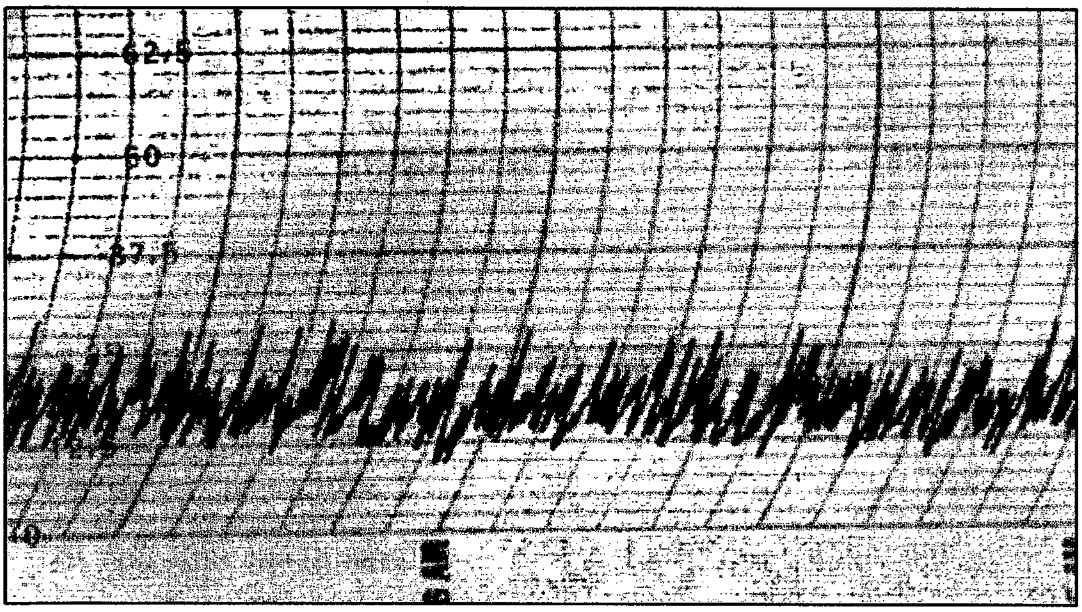

Figure 2.1: Extra-tropical Wind Speed Record (Smiu, 2006)

The longest averaging time is 50 years which used for wind speed is the operational period of measuring station. This long-term average is often referred to as the annual mean or long-term average. Although information on this speed is important for wind energy utilization, it is useless for wind load on structure because only high winds of short durations are of interest in this case. The longest averaging time for peak values used in structural design is an hour and the shortest is 2 to 3 seconds (gust speed). Generally, as the averaging time decreases, the peak wind speed for a given return period increases (Liu, 1991).

In MS 1553:2002, averaging time for basic wind speed is based on three-second gust (3s gust) while the averaging time for other standards and codes of practice are shown in Table 2.1.

Table 2.1: Averaging Time of Basic Wind Speed for Different Standards and Codes of practice (Holmes, 2001)

Standards / Codes	Averaging Time
ISO 4354	10 minutes
ASCE 7-98	3 seconds
AIJ	10 minutes
AS 1170.2	3 seconds
BS 6399: Part 2	3 seconds
NBCC 1996	1 hour

2.6 Vertical Wind Speed Profile

Vertical wind speed profile can be clearly defined as a profile of average wind speed versus height. The average wind speed increases as the height increases. Different terrain category will created different vertical wind speed profile because frictional force playing important role when dealing with vertical wind speed profile (Ramli, 2005). Vertical wind speed profile commonly expressed in term of Logarithmic Law or Power Law profile. There are no exact correspondent between the Power Law and Logarithmic wind profile, because the two profile shapes are different (Zoumakis, 1993). Both profile equation have been used by international standards and codes of practice and it summarized in Table 2.2.

Table 2.2: Profiles Used by International Standards and Codes of Practice (Holmes, 2001)

Standard / Code	ASCE 7-02	AS 1170.2	NBCC 1996	AIJ 1996	BS 6399: Part 2	EuroCode 1995
Wind Profile	Power	Logarithmic	Power	Power	Logarithmic	Logarithmic

2.6.1 Logarithmic Profile

The Logarithmic Law was originally derived from the turbulent boundary layer on flat plate (Prandtl). This law has been found to be valid in unmodified form in strong wind conditions in the atmospheric boundary layer near the surface (Holmes, 2001). Logarithmic Law equation describes the vertical wind speed profile as a function of height above the ground which can be expressed in Equation 2.1. This equation has been derived from Equation 2.2 known as exponential equation.

$$V_z = \left({U_*}/{k} \right) ln\left({z}/{z_o} \right) \qquad \ldots (2.1)$$

$$z = z_o e^{\left(V_z\, {k}/{U_*} \right)} \qquad \ldots (2.2)$$

Where,

V_z = Wind speed function of height

U_* = Friction velocity

k = Von Karman constant usually taken as 0.4

z = Height above the ground surface

z_o = Roughness length.

Tieleman (2003) and Hsu (1994) have stated that in the atmospheric surface boundary layer extending to not more than 100 meter above the surface, the logarithmic wind profile has been used extensively. Tieleman (2008) has proved that the velocity profile is logarithmic up to at least the 50 m level.

2.6.2 Power Law Profile

The power law has no theoretical basis but is easily integrated over height. It is more convenient when determining bending moments at the base of tall structure (Holmes, 2002). Power Law equation describes the vertical wind speed profile as a function of height above the ground which can be expressed in Equation 2.3.

$$V_z = V_{ref}\left(b\left({}^{z}/_{z_{ref}}\right)^{\alpha}\right) \qquad \ldots (2.3)$$

Where,

V_{ref} = Basic wind speed at 10 m height

b = Constant value depending on terrain category (b = 1.0 for open terrain category)

α = Constant value depending on terrain category

z = Height above the ground surface

z_{ref} = Reference height taken as 10 m above the ground surface

Since most of the available wind speed measurements have been made close to the ground, it is necessary to extrapolate the wind speed profile within the surface boundary layer. The most common extrapolation is based on the Power Law equation. It is also preferred by engineer for mathematical simplicity and also provided reasonable fit to observed wind velocity profile for the lowest part of the planetary boundary layer (Zoumakis, 1993).

The Power Law is often used compared to the Logarithmic Law. This is because the mathematics characteristic in Logarithmic Law will conveys inexistence value of the negative numbers. Therefore, for z which is below the zero displacement will not be able to evaluate. Due to this mathematic characteristic, negative wind speed is obtained (Holmes, 2002). In addition, with the Power Law no direct method is available for the prediction of the turbulence intensity contrary to the Logarithmic Law. Tieleman (2008) found that in spite of its shortcomings, the Power Law does a reasonable job predicting the velocity profile but its weak link is the determination of the power law exponent. Ramli (2005) has proved that the Power Law equation is the best equation represents vertical wind speed profile for Seberang Perai region compared with Logarithmic equation. This result is obtained by the goodness test or correlation and Sum Square Error (SSE).

2.7 Variation of Wind Speed with Height and Roughness

It has 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 things is related to the roughness of the ground (Choi, 2009). The wind speed is zero at ground surface and it increase with height above the ground within the atmospheric boundary layer (ABL). Above the ABL, the wind speed does not vary with height called gradient wind as shown in Figure 2.2.

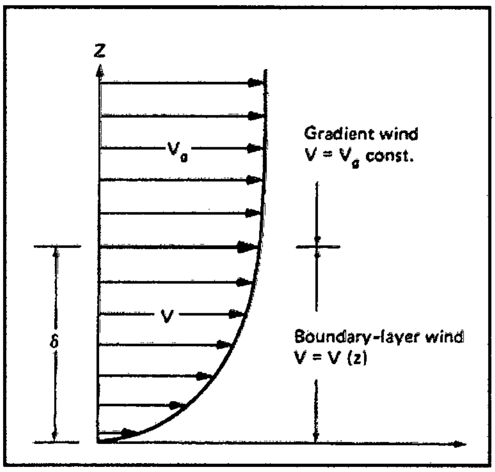

Figure 2.2: Wind Velocity Profile in atmospheric boundary layer (Liu, 1991)

The Malaysian Standard, MS 1553:2002 has clearly classified four types of terrain category as describe in Table 2.3. Selection of terrain category made based on the permanence of obstructions which constitute the surface roughness, in particular some vegetation and buildings in tropical regions shall not be relied upon to maintain surface roughness during wind events (MS 1553:2002).

Table 2.3: Terrain Category Descriptions (MS 1553:2002)

Terrain Category	Descriptions
Category 1	Exposed open terrain with few or no obstructions. (Note; For serviceability considerations, water surfaces are included in this category.
Category 2	Water surface, open terrain, grassland with few well scattered obstructions having height generally from 1.5 m to 10.0 m.
Category 3	Terrain with numerous closely spaced obstructions 3.0 m to 5.0 m high such as areas of suburban housing.
Category 4	Terrain with numerous large, high (10.0 m to 30.0 m high) and closely spaced obstruction such as large city centers and well-developed industrial complexes.

Different types of terrain will produce different roughness effect. The rougher the terrain is, the more retards the wind within the ABL. According to Davenport (1960, 1963), the variation of velocity with height is best considered as a gradual retardation of wind nearer to the ground due to surface friction. Figure 2.3 shows vertical wind speed profile for three different terrains at one particular time which create different vertical wind speed, Z_g.

The city centre terrain reaches gradient wind speed at 500 m while woodland or suburban and open country reaches gradient wind speed at height 400 m and 270 m respectively. As declared before, the rougher a terrain is, the more retards the wind within the ABL. Therefore, wind speed at 100 m in the city centre is less than half of open country.

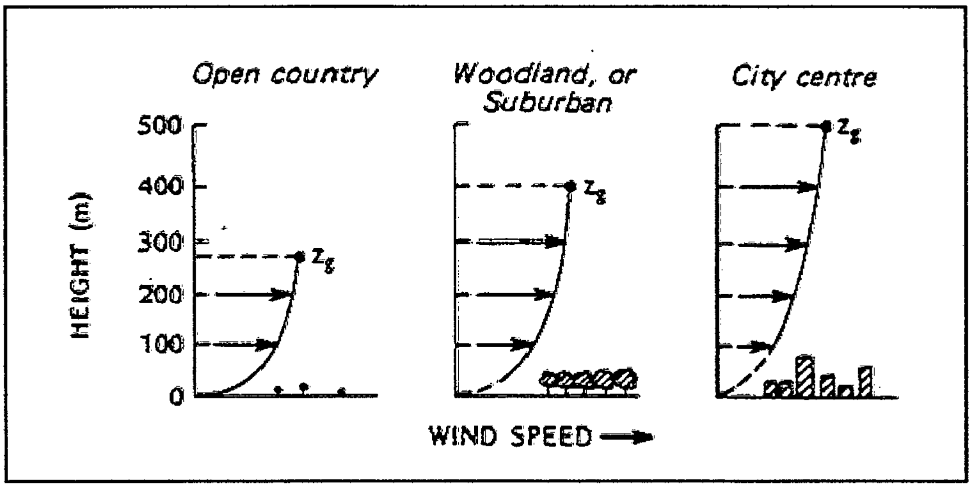

Figure 2.3: Vertical Wind Speed Over Different Level of Terrain Category

Davenport (1960, 1963)

2.8 Terrain Height Multiplier

Malaysian Standard, Ms 1553:2002 has clearly defined the Terrain height multiplier, $M_{z,cat}$ as the variation with height of the effect of terrain roughness on wind speed. Values of Terrain Height Multiplier $M_{z,cat}$ are based on terrain category.

This multiplier can be determined from both vertical wind speed profile either from Power Law profile or Logarithmic Law profile. ISO 4353 has suggested guidelines to use either power law or logarithmic law to define terrain height multiplier. AS 1170.2 and BS 6399:2 used the Logarithmic Law to define the Terrain Height Multiplier while ASCE 7-98, NBCC 1996 and AIJ 1996 used the Power Law to define their Terrain Height Multiplier.