

# Wind load effects on high rise buildings in Peninsular Malaysia

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**Abstract.** Wind is a randomly varying dynamic phenomenon composed of a multitude of eddies of varying sizes and rotational characteristics along a general stream of air moving relative to the ground. These eddies give wind its gustiness, creating fluctuation and results in a complex flow characteristics. The wind vector at any point can be regarded as the sum of mean wind vector and the fluctuation components. These components not only vary with height but also dependant on the approach terrain and topography. Prevailing wind exerts pressure onto the structural surfaces. The effects of wind pressure in the form of shear and bending moments are found to be a major problem in structural failure. This study aims to study the effects of wind load on a fifteen-storey high rise building using EN 1991-1-4 code and MS1553:2002. The simulation results showed that by increasing the wind speed, the storey resultant forces, namely storey shear and storey moment increases significantly. Furthermore, simulation results according to EN 1991-1-4 yield higher values compared to the simulation results according to MS1553:2002.

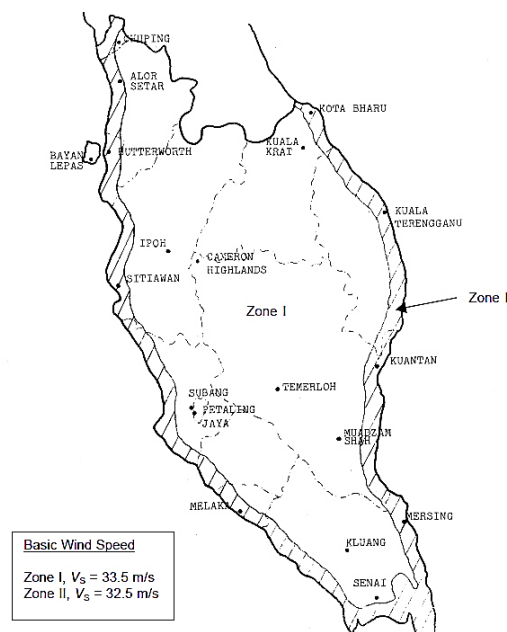
## 1. Introduction

Wind loads exerted on a building are not steady, but dynamic and highly fluctuating. The fluctuating pressure could bring severe damage to building other than the wind force itself. One of the ways to safely assume wind pressures is through the quasi-steady assumption in which the building is assumed to be fixed rigid body in wind and the wind pressure exerted on the building is a steady lateral force. This method is only applicable if the building height is less than 50 meters [1]. Due to demand of high rise buildings in Malaysia, there is a need to understand the behavior of wind loads. Moreover, climate change has vindicated the idea of designing the building against wind loads. Resultantly, high rise buildings consider as a solution to reduce the urban sprawl as it will provide greater density per unit area [2]. Currently, Malaysia construction industry follows Eurocode since year 2010. As a result, the revised version of Uniform Building By-Laws (UBBL) in year 2012 had announced that Eurocode is included and has replaced the British Standard in construction industry [3].

The European Standard, Eurocode 1: Actions on structures – Part 1-4: General Actions – Wind Actions give guidance on the determination of natural wind actions for structural design [4]. The code



is applicable to land structures with height up to 200m, bridges up to 200m spans require an availability of local data such as terrain type, wind speeds, building type and general structural configurations. On the other hand, Malaysia's Department of Standards Malaysia has developed the National Annex for wind loading, namely MS1553:2002. The Malaysian Standard of Code of Practice on Wind loading for building structure [5] sets out procedures for determining wind speeds and wind actions to be used in structural design. The standard applies to structures with height less than 200m, with roof spans less than 100m and structures other than off-shore structures, bridges, and transmission towers. The basic wind speeds taken in MS 1553:2002 is obtained from the Gringorten Method Analysis for 50 years return period, which there are two main zones considered. Zone I is the inland area of Peninsular Malaysia which basic wind speed taken as  $V_s = 33.5$  m/s, where Zone II is the on-shore outer perimeter of Peninsular Malaysia, which basic wind speed taken as  $V_s = 32.5$  m/s as shown in Figure 1. The designed structure is a reinforced concrete office building with fifteen (15) storey 45m (3m per story) above the ground, with 30m square in shape on each side (x,y-directions). The designed structure is located in Kuala Lumpur, Malaysia. The focus of this study is to observe the effects of increasing wind speed onto a high-rise building and to compare the simulation results of design according to Eurocode and Malaysian Standard.

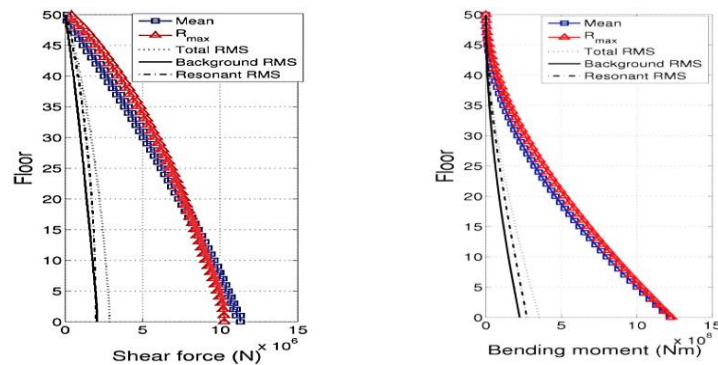


**Figure 1.** Basic wind speed in Peninsular Malaysia (MS 1553: 2002)

The designed building in this study is expected to reach 45m of height. The standard wind speed value ( $V_s$ ) obtained from the Malaysian Standard [5] is stated to be in between the range of 32.5 m/s to 33.5 m/s, was recorded at 10m of height. The wind speed at desired height is expected to increase. Power Law is used to get the wind speed at the desired height.

## 2. Literature Review

According to Guoqing, the base shear of a building increases as the building height increases and the bending moment of a building increases as the building height increases as shown in Figure 2 [6]. A recent study has shown that the results of base shear and base bending moment acquired from design according to Eurocode is slightly greater compared to the design using Malaysian Standard. The calculated base shear and base bending moment were approximately 6% and 20% higher for Eurocode than Malaysian Standard respectively [7].



**Figure 2.** Relationship of number of floors vs. storey shear force and storey moment [6]

### 2.1 Wind Patterns in Malaysia

Wind over the country is generally variable and light, however, there are some periodic changes in flow patterns, which from these wind flow patterns, four seasons can be distinguished, namely, the southwest monsoon, northeast monsoon, and two shorter periods of inter-monsoon seasons. The prevailing wind during the southwest monsoon is generally light, below 15 knots (7.7 m/s). During the northeast monsoon, steady winds of 10 to 20 knots prevail (5.2 to 10.3 m/s), the wind over the east coast states of Peninsular Malaysia may reach 30 knots (15.4 m/s) or more during this period while strong surges of cold air from the north. During the two inter-monsoon seasons, the winds are generally light and variable. According to the Malaysia Meteorological Department (MetMalaysia), the highest mean daily wind speed is 3.8 m/s, recorded at Mersing, Johor, while the highest maximum wind speed is 41.7 m/s, recorded at Kuching, Sarawak on 15<sup>th</sup> September 1992 [8].

### 2.2 Basic Wind Speed

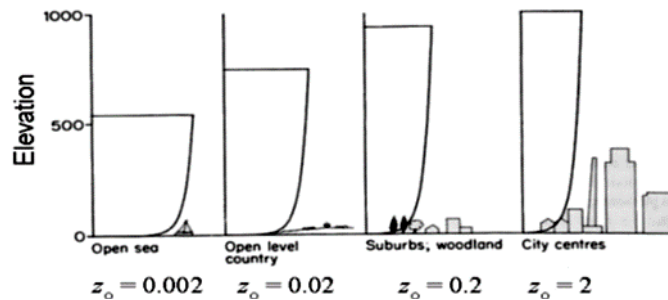
The basic wind speeds are usually taken at 10m height above ground at all meteorological stations and are used as reference wind speed considered in calculation design load to building structure [9]. The wind speed measuring height of meteorological stations and averaging time of various codes are shown in Table 1. The design wind speed is obtained by multiplying the basic wind speed with some considered parameters such as terrain categories, direction factors, and building type, the equation is dependant to code of practice [9].

**Table 1.** Measuring height and averaging time of basic wind speed

| Code         | Measuring Height | Averaging Time  |
|--------------|------------------|-----------------|
| EN1991-1-4   | 10 m             | 10 minutes mean |
| MS 1553:2002 | 10 m             | 3 seconds gust  |

### 2.3 Changes of Wind Speeds in Increasing Height

At the surface of the earth, prevailing wind velocity reduced to nearly zero then begin to increase with height, and at some height, the prevailing motion could be considered to be free from the earth's frictional influence and will attain its gradient velocity [1]. Figure 3 shows the relationship of height above earth surface and the prevailing wind speed, which is an exponentially growing wind speed curve, where  $z_o$  represents the surface roughness length which affects the wind profile.



**Figure 3.** Relationship of height above ground against prevailing wind speed [1].

#### 2.4 Power Law

According to Hamizah, the reference wind speed used in most construction codes are recorded at a height of 10m, but wind speed increases as height increases [9]. The vertical wind speed profile can be extrapolated using the power law Equation (1), which is an empirical expression for extrapolation of wind speeds up to the desired height [3].

$$v = v_0 \left( \frac{z}{z_0} \right)^\alpha \quad (1)$$

where:  $v$  : the wind speed estimated at desired height  $z$ ;

$v_0$  : the wind speed measured at reference height  $z_0$  (generally 10m).

$\alpha$  : ground surface friction coefficient expressed as per Equation (2)

$$\alpha = \frac{\ln(v/v_0)}{\ln(z/z_0)} \quad (2)$$

According to Touma,  $\alpha$  is good to be approximated as 1/7 for neutral conditions [10].

#### 2.5 Design Wind Loads

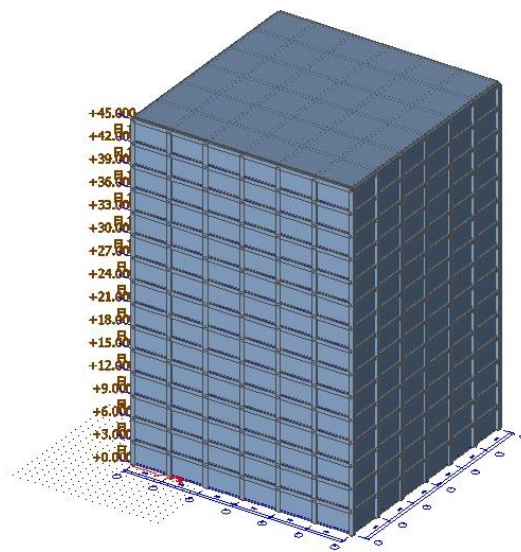
The wind loading codes used in this study, Eurocode [4] and Malaysian National Annex of Wind Loading [11], provide guidance in the computation of design wind pressure. The design wind characteristics considered in the codes are the basic wind speeds measured at meteorological stations. The designed structural geometry should be simplified in the sense that the wind codes generally cannot accurately access the design loads for complex building shapes [1]. Eurocode covers the design wind load calculations for rectangular, polygonal, sharp edge prism, circular, sphere, and lattice shaped structures (p. 31, p 32). Malaysian National Annex covers the design wind load calculations for rectangular, sharp-edge prism, lattice and circular shaped structures (p. 29-96). The terrain characteristics are important due to the shelter of wind loading from permanent objects will reduce wind load experienced by the building [11].

### 3. Methodology

This process involves the understanding of wind load calculation provided in MS 1553:2002 and EN1991-1-4, model simulation of wind load effects on design building using SCIA Engineer v15.3. The general building description is shown in Table 2. The design model is assumed to be a reinforced concrete office building. The three-dimensional view ( $x$ ,  $y$ ,  $z$ -axis) of the design model is shown in Figure 4. The concrete grade used in this study is G25/30 with the properties shown in Table 3. The chosen reinforcement steel in this study is B 400A with the properties shown in Table 4.

**Table 2.** Building description

|                    |           |
|--------------------|-----------|
| Length X Width     | 30m x 30m |
| Number of storeys  | 15        |
| Storey height      | 3m        |
| Column dimension   | 600x600mm |
| Beam dimension     | 500x500mm |
| Slab thickness     | 125mm     |
| Wall thickness     | 115mm     |
| Foundation support | Fixed     |

**Figure 4.** Three-dimensional view of design model.**Table 3.** Concrete properties

| Properties                     | Unit                   |
|--------------------------------|------------------------|
| Concrete unit mass             | 2500 kg/m <sup>3</sup> |
| E modulus                      | 3.1500E4 MPa           |
| G modulus                      | 1.3125E4 MPa           |
| Compressive strength, $f_{ck}$ | 25.00 MPa              |

**Table 4.** Reinforcement steel properties

|                                    |                          |
|------------------------------------|--------------------------|
| Steel unit mass                    | 7850.0 kg/m <sup>3</sup> |
| E modulus                          | 2.0000E5 MPa             |
| G modulus                          | 8.3333E4 MPa             |
| Yield strength, $f_{yk}$           | 400 MPa                  |
| Maximum tensile strength, $f_{tk}$ | 420 MPa                  |

### 3.1. 3-Second Gust to 10-Minute Mean Conversion

The wind speed averaging method used in Malaysian Standard is the 3-second gust wind speed, while the wind speed averaging method used in Eurocode is 10-minute mean wind speed. Conversion is done as per Equation (3) for 10-minute mean wind speed input for model simulation according to Eurocode. The recommended conversion factors are shown in Table 5.

$$V_{t,T_o} = G_{t,T_o} \times V \quad (3)$$

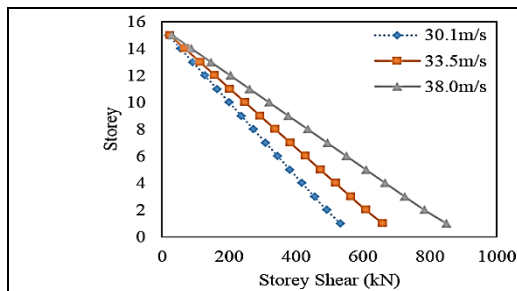
**Table 5.** Recommended conversion factors (WMO).

| Exposure at 10m |                                     | Reference           | Gust Factor $G_{t,T_o}$ |      |      |      |      |
|-----------------|-------------------------------------|---------------------|-------------------------|------|------|------|------|
| Class           | Description                         | Period<br>$T_o$ (s) | Gust Duration $t$ (s)   |      |      |      |      |
|                 |                                     |                     | 3                       | 60   | 120  | 180  | 600  |
| In-Land         | Roughly<br>open terrain             | 600                 | 1.66                    | 1.21 | 1.12 | 1.09 | 1.00 |
|                 |                                     | 180                 | 1.58                    | 1.15 | 1.07 | 1.00 | -    |
|                 |                                     | 120                 | 1.55                    | 1.13 | 1.00 | -    | -    |
|                 |                                     | 60                  | 1.49                    | 1.00 | -    | -    | -    |
| Off-Land        | Offshore<br>winds at a<br>coastline | 600                 | 1.52                    | 1.16 | 1.09 | 1.06 | 1.00 |
|                 |                                     | 180                 | 1.44                    | 1.10 | 1.04 | 1.00 | -    |
|                 |                                     | 120                 | 1.42                    | 1.08 | 1.00 | -    | -    |
|                 |                                     | 60                  | 1.00                    | -    | -    | -    | -    |
| Off-Sea         | Onshore<br>winds at a<br>coastline  | 600                 | 1.38                    | 1.11 | 1.05 | 1.03 | 1.00 |
|                 |                                     | 180                 | 1.31                    | 1.05 | 1.00 | 1.00 |      |
|                 |                                     | 120                 | 1.28                    | 1.03 | 1.00 |      |      |
|                 |                                     | 60                  | 1.23                    | 1.00 |      |      |      |
| At-Sea          | > 20 km<br>offshore                 | 600                 | 1.23                    | 1.05 | 1.02 | 1.00 | 1.00 |
|                 |                                     | 180                 | 1.17                    | 1.00 | 1.00 | 1.00 |      |
|                 |                                     | 120                 | 1.15                    | 1.00 | 1.00 |      |      |
|                 |                                     | 60                  | 1.11                    | 1.00 |      |      |      |

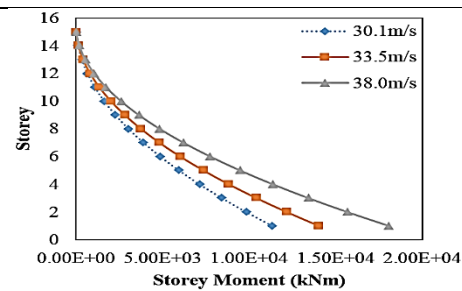
#### 4. Results and discussion

This research is aimed to study and analyze the structural behavior of a reinforced concrete high-rise building under wind loads. The design building is a symmetrical office building with 30m of width and length, 45m height divided into 15 storeys. The results of this study are acquired from the design software SCIA Engineer v15.3. The basic wind speeds considered in this study are 30.1m/s, 33.5m/s, and 38.0m/s. The graphical representations of storey shear and storey moment simulation results according to Eurocode [4] are shown in Figures 5-6 respectively. The graph of storey shear variation of different wind speeds shows a relatively steady increase of storey shear as the storey approaches the ground level. This implies that the storey horizontal shear is at the maximum at the base and decreases as height increase. In the comparison of storey shear in Y-direction, storey shear values of 33.5m/s increase approximately 1.24 times that of 30.1m/s, and storey shear values of 38.0m/s increase approximately 1.60 times that of 30.1m/s. The maximum storey shear occurs at 1<sup>st</sup> floor. The graph of storey moment variation of different wind speeds shows a logarithmically increase of wind speed with respect to storey number. The higher the wind speed, the greater the storey moment. In the comparison of storey moment in X-direction, storey moment values of 33.5m/s increase approximately 1.24 times that of 30.1m/s, and storey moment values of 38.0m/s increase approximately 1.60 times of that 30.1m/s. The maximum storey moment occurs at 1<sup>st</sup> floor.





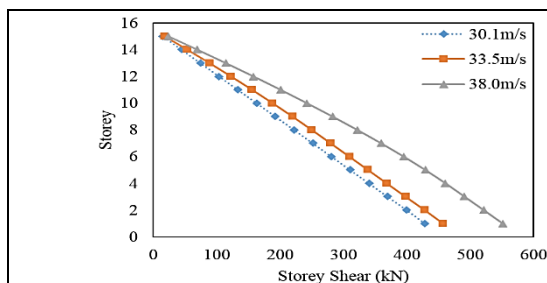
**Figure 5.** Storey shear variation of different wind speeds (EN1991-1-4 design)



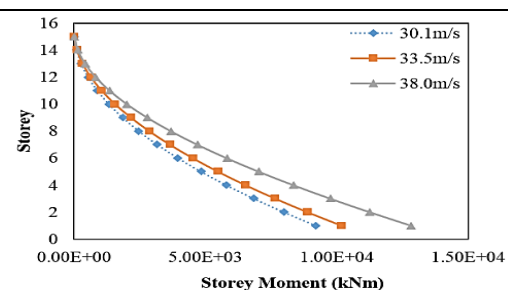
**Figure 6.** Storey moment variation of different wind speeds (EN1991-1-4 design)

#### 4.1 Design According to Malaysian Standard

The graphical representations of storey shear and storey moment simulation results according to Malaysian National Annex [11] are shown in Figures 7-8 respectively. Similar to the Eurocode simulation, the graph of storey shear variation of different wind speeds shows a relatively steady increase of storey shear as the storey approaches the ground level. In the comparison of storey shear in Y-direction, storey shear values of 33.5m/s increase approximately 1.22 times that of 30.1m/s, and storey shear values of 38.0m/s increase approximately 1.57 times that of 30.1m/s. The maximum storey shear occurs at 1<sup>st</sup> floor. The graph of storey moment variation of different wind speeds shows a logarithmically increase of wind speed with respect to storey number. The higher the wind speed, the greater the storey moment. In the comparison of storey moment in X-direction, storey moment values of 33.5m/s increase approximately 1.21 times that of 30.1m/s, and storey moment values of 38.0m/s increase approximately 1.56 times of that 30.1m/s. The maximum storey moment occurs at 1<sup>st</sup> floor.



**Figure 7.** Storey shear variation of different wind speed (MS1553:2002 design)



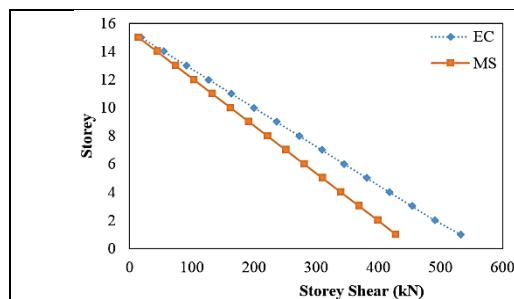
**Figure 8.** Storey moment variation of different wind speed (MS1553:2002 design)

#### 4.2 Storey Results of Eurocode and Malaysian Standard

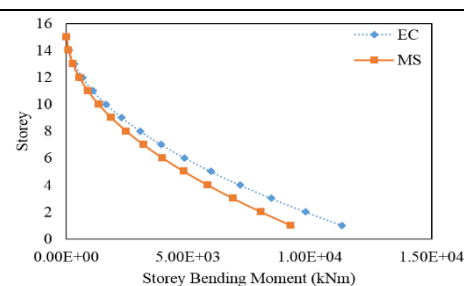
The comparison between the Malaysian National Annex of Wind Loading [11] and Eurocode [4] is done for the wind speeds of 30.1m/s, 33.5m/s, and 38.0m/s. The differences between these two standards are presented in this section.

##### 4.2.1 Wind Speed of 30.1m/s

The graphical representations of storey shear and storey moment simulation results are shown in Figures 9-10 respectively. The model simulation is based on the basic wind speed of 30.1m/s for both Eurocode and Malaysian National Annex. The graph of storey shear variation of different design standards show a relatively steady increase of storey shear as the storey approaches the ground level. The difference of storey shear for Eurocode design is approximately 1.23 times higher than the design of Malaysian National Annex. The maximum storey shear occurs at 1<sup>st</sup> floor. In the comparison of a moment in X-direction, storey moment values of Eurocode design is approximately 1.23 times that of Malaysian National Annex design. The maximum storey moment occurs at 1<sup>st</sup> floor.



**Figure 9.** Storey shear variation of different design standards (30.1m/s)



**Figure 10.** storey moment variation of different design standards (30.1m/s)

## 5. Conclusion

The effects of varying wind speeds on storey shear and storey moments are determined and comparison of Malaysian National Annex [11] and European Standard [4] is done in this study. The increase of storey number increases the storey shear and storey moment due to the cumulative increase of wind pressure up height. The increase of wind velocity increases storey shear and storey moment significantly as wind pressure is a square function of wind velocity. The design according to Eurocode yields results which values are approximately 30% higher compared to Malaysian National Annex. The difference is significant as Eurocode is widely used in Malaysian construction industry. This study shows that Eurocode design yields slightly higher values as compared with Malaysian National Annex. The storey shear is approximately 29% higher and the storey moment is approximately 31% higher for Eurocode design compared to the design according to Malaysian National Annex.

In the future study, increasing the wind speed up to 41.7m/s which is the highest recorded wind speed in Malaysia (Kuching, Sarawak) as the wind speeds in this study is assumed to be occurring in Peninsular Malaysia. Studies can be done to understand the effect of increased wind speed on different structural elements of high rise buildings such as beams, columns, and slabs. Furthermore, dynamic wind loading and non-linear analysis could be done to understand how the building behaves in the presence of fluctuation component of wind loading. With such information, it is particularly useful in the real industry where buildings with a height lower than 45 meters are designed in the mainland of Malaysia. By increasing the wind speed, especially beyond the maximum design wind speeds defined by construction code of practices, high rise building designs can be more reliable and thus provide safer design in the long run.

## Acknowledgments

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