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A Case Study To Investigate The Wind Load Factor That Possibly Cause The Failure Of Roof Stadium, Kuala Terengganu.

COSTELLO FIFO ANAK NYUWUS

Thesis submitted in fulfilment of the requirements
for the award of the degree of
B.Eng (Hons.) Civil Engineering

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JUNE 2015

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Civil Engineering (Hons.).

Signature :

Name of Supervisor : ENCIK NORAM IRWAN BIN RAMLI

Position : LECTURER

Date : 30 JUNE 2015

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature	:
Name of student	: COSTELLO FIFO ANAK NYUWUS
ID Number	: AA11169
Date	: 30 JUNE 2015

Dedicated to my parents, for their love and devotion making me be who I am today.

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ABSTRACT

Current records show numbers of building structure component failure due to wind storm. Mostly in the normal practice of design consideration during design stage are only considered on extreme wind speed that probably occurred rarely. However there are also claim that direction of wind and repeatable lower wind from same direction may reduce the strength of the building component. On 2nd June 2009, the roof of the stadium of Kuala Terengganu has been collapsed. In this study one of damaged stadium was investigated due to the effect of wind speed. Computational Fluid Dynamic has been used in order to examine the effect of wind to the stadium. From the result it clearly shows that wind load may increase up to 2.68 times at South East Direction from the normal wind act to the stadium. Historical wind speed also has shown foremost wind blow come from South East direction. The maximum increasing of wind speed are from South East direction. Additionally the data collected from nearest meteorological station show the most frequency of wind come from the South East direction. From the observation the triggering collapse of roof stadium is located on the south east side of the stadium. Therefore the collapse of roof stadium to experience the repeatable wind speed and increasing wind speed due to the direction are remarkably exposed. It can be conclude that the possibility of collapse roof are highly predictable due to wind speed. The effect of the geometrical shape of the structure may also increasing the wind load effect to the building component. Therefore consideration of the geometrical shape and the orientation of the building are vital at the design stage.

ABSTRAK

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Rekod semasa menunjukkan bilangan kegagalan komponen struktur bangunan akibat ribut angin. Kebanyakannya dalam praktikal pertimbangan reka bentuk semasa peringkat reka bentuk hanya mempertimbangkan kelajuan angin yang melampau yang mungkin jarang berlaku. Walau bagaimanapun, ada juga mendakwa bahawa arah angin dan angin berulang lebih rendah dari arah yang sama boleh mengurangkan kekuatan komponen bangunan. Pada 2 June 2009, sebahagian daripada bumbung stadium Kuala Terengganu telah runtuh. Dalam kajian ini salah satu stadium yang rosak telah disiasat kerana kesan kelajuan angin. *Computational Fluid Dynamis* (CFD) telah digunakan untuk mengkaji kesan angin ke stadium. Dari keputusan itu jelas menunjukkan bahawa beban angin boleh meningkat sehingga 2.68 kali pada Arah Tenggara dari perbuatan angin biasa ke stadium. Kelajuan angin Sejarah juga telah menunjukkan pukulan angin utama datang dari arah Tenggara. Maksimum peningkatan kelajuan angin adalah juga dari arah Tenggara. Selain itu data yang dikumpul dari stesen meteorologi yang terdekat menunjukkan kekerapan kelajuan angin datang dari arah Tenggara. Dari pemerhatian selepas kejadian menunjukkan keruntuhan stadium bumbung terletak di sebelah timur selatan stadium. Oleh itu keruntuhan bumbung stadium untuk mengalami kelajuan angin dan meningkatkan kelajuan angin berulang kerana arahan itu adalah amat terdedah. Ia boleh membuat kesimpulan bahawa kemungkinan bumbung runtuh adalah sangat diramal kerana kelajuan angin. Kesan bentuk geometri struktur juga boleh meningkatkan kesan beban angin terhadap struktur bangunan. Oleh itu pertimbangan bentuk geometri dan orientasi bangunan adalah penting di peringkat reka bentuk.

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LIST OF SYMBOLS

Km/h	Kilometers per hour
m/s	Meter per second
%	Percentage
Pa	Pascal

LIST OF ABBREVIATIONS

N	North
NE	North East
E	East
SE	South East
S	South
SW	South West
W	West
NW	North West

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Wind Engineering is best described as the rational treatment of interaction between wind in the atmospheric boundary layer and man and his works on the surface of earth (Cermak, 1975). It comprises a synthesis of knowledge from fluid mechanics, meteorology, structural mechanics, physiology and the like. Although aerodynamics is of central importance, most applications are non-aeronautical in nature. As far as structural engineering is concerned, the evaluation of wind-induced pressure loads on building surfaces, primary and secondary structural systems, and the consequent along wind, across wind and torsional response are clearly the most important applications. Good knowledge of fluid and structural mechanics is the fundamental background necessary for the understanding of details of interaction between wind flow and civil engineering structures or buildings.

The unsteady character of the wind regime, particularly in urban areas, combined with the additional unsteadiness generated by the separated flow after the wind impacts on a building generates highly fluctuating pressures depending on the flow characteristics and the building configuration. Naturally, the wind-induced pressure regime is more complex than the wind flow regime, so its evaluation becomes more cumbersome and analytical techniques fail in most cases. Consequently, boundary layer wind tunnels simulating atmospheric flows have been used and continue to use extensively for the evaluation of wind loads on buildings. Computational approaches have progressed through the last decade but they are still at a level that hesitation prevails when their results are suggested for use in practical applications

Local winds have minimal influence on primary and secondary circulations but, regardless, they may have high intensity. Thunderstorms, caused heavy precipitation (like wall jets) and tornadoes, which are the most powerful winds causing maximum damage, belong in this category.

Malaysia is located near the equator. In general, the wind climate is dominated by the two monsoon seasons and the inter-monsoon thunderstorms. The northeastern monsoon blows from December to March, usually accompanied by heavy rains. Around June to September, there blows the southwestern monsoon which is slightly tranquil. Thunderstorms frequently occur during the inter-monsoon periods. Although thunderstorms are localized phenomena, they often produce significant strong and gusty surface winds. These winds from thunderstorms are relatively stronger and more turbulent than those of monsoon winds. (Choi, 1999) Unlike in cyclone prone region, the thunderstorms in Malaysia occurs in micro scale (Yusoff, 2005). Despite their small size and short duration of thunderstorm which is about 15 to 30 minutes. Every thunderstorm produces lightning which has the potential to kill people. Heavy rain from thunderstorms can lead to flash flooding and landslides. Strong winds and hail are also dangers associated with some thunderstorms.

Currently in Malaysia, a wind-related disaster is not being given priority due to lack of expertise and awareness among the Malaysian. Incidences of damaged houses have been reported in daily Newspapers. From the reported news, it is observed that most of the damage occurs in northern region on peninsular Malaysia. The climate change in the world has resulted in significant increasing in the numbers of incidences of freak wind storm in Malaysia. It is of vital that study be carried out to under the characteristics of such freak wind storm. Damage due to wind occurs due to lack of concern regarding wind effect to building structure. Moreover most codes of practice do not reflect much the structural system and materials used in Malaysia practice. It is clearly shown that repeated type of damage occurs at different places in Malaysia. However, no concrete measure has been seen to be taken to address such potential dangerous hazard.

Frictional effects play an important role for wind near the ground surface. Stathopoulos (2007) reported that ground obstructions slow down the movement of air close to the ground surface causing reduction in wind speed. Thus, the mean wind speed may change in direction slightly with height, as well as magnitude (Holmes, 2001). Recently, Computational Fluid Dynamics (CFD) has become a powerful tool for the study of airflow through and around structures in built-up areas. CFD enables to see results almost immediately and allows exploring the effect of different wind speed and direction. CFD techniques may be used for determination of wind effects where Standards are sometimes not directly or as easily applicable, for instance when designing tall buildings and non-conventional structures. (Mendis et.al, 2007).

High-rise buildings are particularly influential to wind effects. Therefore, information regarding the wind flow pattern can be important for architects and engineers. However, with the advent of computational analysis using advanced modeling techniques like CFD, it is made possible to simulate the same condition in a virtual environment. CFD allows designers to analyze a full domain of the model and presents the results of analysis in an easy to understand graphical way.

Methods for reflecting directional wind characteristics have been proposed by Cook and Holmes. Matsui et al. has examined the effects of directional wind characteristics and the orientations of structures on wind loads on the basis of the Holmes method. It is important to decide the directional characteristics of strong winds at a construction site in order to achieve a resilient wind-resistant design. 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. In practice, it has been found useful to start with a reference wind speed based on statistical analysis of wind speed records obtained at meteorological stations throughout the country or near to the area of study.

1.2 PROBLEM STATEMENT

There are some wind characteristic that greatly influenced the cause of failure and collapse of roof of Sultan Mizan Zainal Abidin's Stadium at Gong Badak, Kuala Terengganu. Design and orientation of buildings did not consider the effect of repeatable load acting to the building at certain direction and speed at some point could lead to structural damage of the building. Besides that, the topographical condition of where the building situated have not been critically identified and geometry of the building that is not considering the condition of topography.

1.3 OBJECTIVES OF STUDY

The main objectives to investigate the cause of failure and collapse of roof of Sultan Mizan Zainal Abidin's Stadium at Gong Badak, Kuala Terengganu, Terengganu are:

1. To study the wind characteristics at the location after the construction until collapsing.
2. To simulate the building against wind speed by using CFD.

1.4 SCOPE OF STUDY

The Stadium of Sultan Mizan Zainal Abidin is located in the area of Gong Badak, kuala Terengganu, Terengganu Darul Iman. Thus, the area of study is limited in that particular area only. Data of wind from the particular area were obtained from the Malaysian Meteorological Department (MET) and has been compiled. The wind characteristics at particular are is examined in order to obtain an appropriate result. Base on the data collected, the problem that involved fluid flows are analyzed by using Computational Fluid Dynamic (CFD). Basically, CFD is used for simulation purpose in order to investigate the wind flow pattern acting to the structure of the stadium. The stadium has been drawn by using the software of Sketch Up to get the model of full-size scale of the real stadium. Google Earth was used in obtaining the geographical location of the stadium. In this research, only the effects due to wind and direction are investigated. The impact due to rain and thunderstorm were negligible.

1.5 SIGNIFICANT OF STUDY

The research provides a clearer study and analysis by using Computational Fluid Dynamics to visualize the pattern of wind flow and its behavior around the building. Hence, it is a reliable method chosen by many researchers to conduct their experiments without harming the environment, as opposed to relying on expensive and time consuming usually in the case with using a physical wind tunnel modeling.

1.6 THESIS STRUCTURE

This thesis is divided into five chapters:

i. Introduction : This chapter includes the overview of the studies, problem statement, objectives, and scopes of study, the significance of the study and study area.
ii. Literature Review : This chapter is the previous study material related to objectives.
iii. Methodology : The flow of the thesis from data collection to production of the result.
iv. Discussion : Discuss the result obtained based on the case study.
v. Conclusion : Conclusion of the discussion based on the thesis result and provides the future suggestion.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Wind having numerous characteristics of its own such as wind rose, turbulent intensity, type of anemometer and wind turbine performance. Wind-related disaster events have had significant impacts on our society, especially in terms of the shocking number of injuries and deaths to people and attendant property loss. Probabilistic and statistical methods become the basis to study wind characteristic based on historical recorded data. The determination of appropriate design wind speed is a vital step towards the calculations of design wind loads for structures. It is important to properly decide both the directional characteristics of strong winds at a construction site and the directional characteristics of wind loads on a structure in order to achieve a resilient wind-resistant design. Methods for reflecting directional wind characteristics have been proposed by Cook and Holmes 2001. Matsui et. al. 2001has examined the effects of directional wind characteristics and the orientations of structures on wind loads on the basis of the Holmes method. Whereas the former reflected directional wind speed characteristics, load effects such as directional aerodynamic properties were ignored. There are numbers of researchers have been conducted the case study to investigate the wind load factor that possibly cause the failure to the building structure. In this study, the wind load factor that possibly causes the failure to the building structure may refer to the wind speed due to topography, surface roughness and Computational Fluid Dynamics (CFD).

2.2 WIND SPEED

Wind speed or wind flow velocity, is a fundamental atmospheric rate. Wind speed is caused by air moving from high pressure to low pressure area which is usually due to changes in temperature. Wind speed is measured in meters per second or knots. Calm is measured when the wind speed is less than 0.5 meters per second or less than one knot. At great heights above the surface of the earth, where frictional effects are negligible, air movements are driven by pressure gradients in the atmosphere, which in turn are the thermodynamic consequences of variable solar heating of the earth. This upper level of wind speed is known as the gradient wind velocity (Mendis et al., 2007). The neutral data about the wind speeds is usually defined in terms of averaging period, return period, height above the ground, topography and ground roughness (Tony Gibbs, 2000).

2.2.1 Basic Wind Speed

Basic wind speed, Vs is used to determine the design wind pressure acting onto a structure. The definition of basic wind speed based on the OAS/NCST/BAPE "Code of Practice for Wind Loads for Structural Design", reads as "The basic wind speed V is the 3-second gust speed estimated to be exceeded on the average only once in 50 year at a height of 10 m (33 ft.) above the ground in an open situation…". The basic wind speed will then be adjusted for specific cases using various parameters including the averaging period, return period, ground roughness, height, topography and size of structure in order to obtain the design wind speeds for the particular cases.

According to Faridah et al. (2004), currently, a multitude of national wind loading codes and standards with a range of defined averaging periods and return periods exists that can be used for structural design purposes. However, to date, there is no single document that provides world-wide data on extreme wind speeds at present. Various research were conducted to determine the basic wind speeds with a range of defined averaging periods and return period. Holmes summarized briefly the sources of basic design wind speed for 56 countries, and classified these countries or territories into five levels, with respect to the magnitude of their extreme wind speeds. Design wind speeds for the Asia-Pacific Region have been summarized by Holmes and Weller (2002) based on national codes and standards and a five-level zoning system. Eurocode 1: Wind actions on Structure provides a harmonized code for winds but the basic wind speeds is provided by the national application documents of respective European member countries.

Before the establishment of the Malaysian Standard, MS1552 (2002), the common practice of determining the basic wind speed wad based on either the following step:

i. Obtaining wind speed data of the nearest meteorological station from Malaysian Meteorological Department (MET).
ii. Adopting any Code of Practice such as British Standard, CP3, Chapter V, Part 2 (1972) or BS6399, Part 2 (1995).

In practice, it is useful to start analysis with a reference wind speed based on statistical analysis of wind speed records obtained at meteorological stations throughout the country. This is due to the fact the definition of reference wind speed may varies from one country to another. Basic design wind speeds for different directions and different return periods can be derived using a rigorous analysis incorporating probability distributions for wind speed and direction. **Table 2.1** shows the typical value of the basic wind speed for 50 years return and 100 years return in 2013 for major towns in Peninsular Malaysia which is based on 3-sec gust. UMNO Tower located at George Town Penang. Therefore, Butterworth and Bayan Lepas station are referred to estimate the basic wind speed.

Table 2.1: Basic Wind Speed for major towns in Peninsular Malaysia

Stations	50 Year Return Period (ms^{-1})	100 Year Return Period (ms^{-1})	Period
Chuping	25.0	26.5	1979 – 2012
Alor Star	29.2	31.1	1939 – 2012
Butterworth	24.5	25.5	1985 – 2012
Bayan Lepas	27.2	28.6	1939 – 2012
Ipoh	30.8	32.9	1939 – 2012
Sitiawan	25.3	26.8	1939 – 2012
Batu Embun	26.8	28.7	1983 – 2012
Cameron Highlands	28.7	30.3	1983 – 2012
Subang	31.0	33.1	1966 – 2012
Petaling Jaya	31.0	33.0	1971 – 2012
KLIA Sepang	21.9	22.8	1998 – 2012
Malacca	28.5	30.4	1941 – 2012
Kluang	31.3	33.9	1974 – 2012
Senai	29.1	31.0	1974 – 2012
Mersing	31.6	33.5	1939 – 2012
Muadzam Shah	24.4	26.0	1983 – 2012
Temerloh	27.0	28.9	1978 – 2012
Kuantan	30.0	31.9	1950 – 2012
Kuala Terengganu	29.8	31.9	1985 – 2012
Kota Bahru	32.4	34.5	1939 – 2012
Kuala Krai	27.6	29.1	1985 – 2012

Source: Malaysian Meteorological Department (MET) 2013

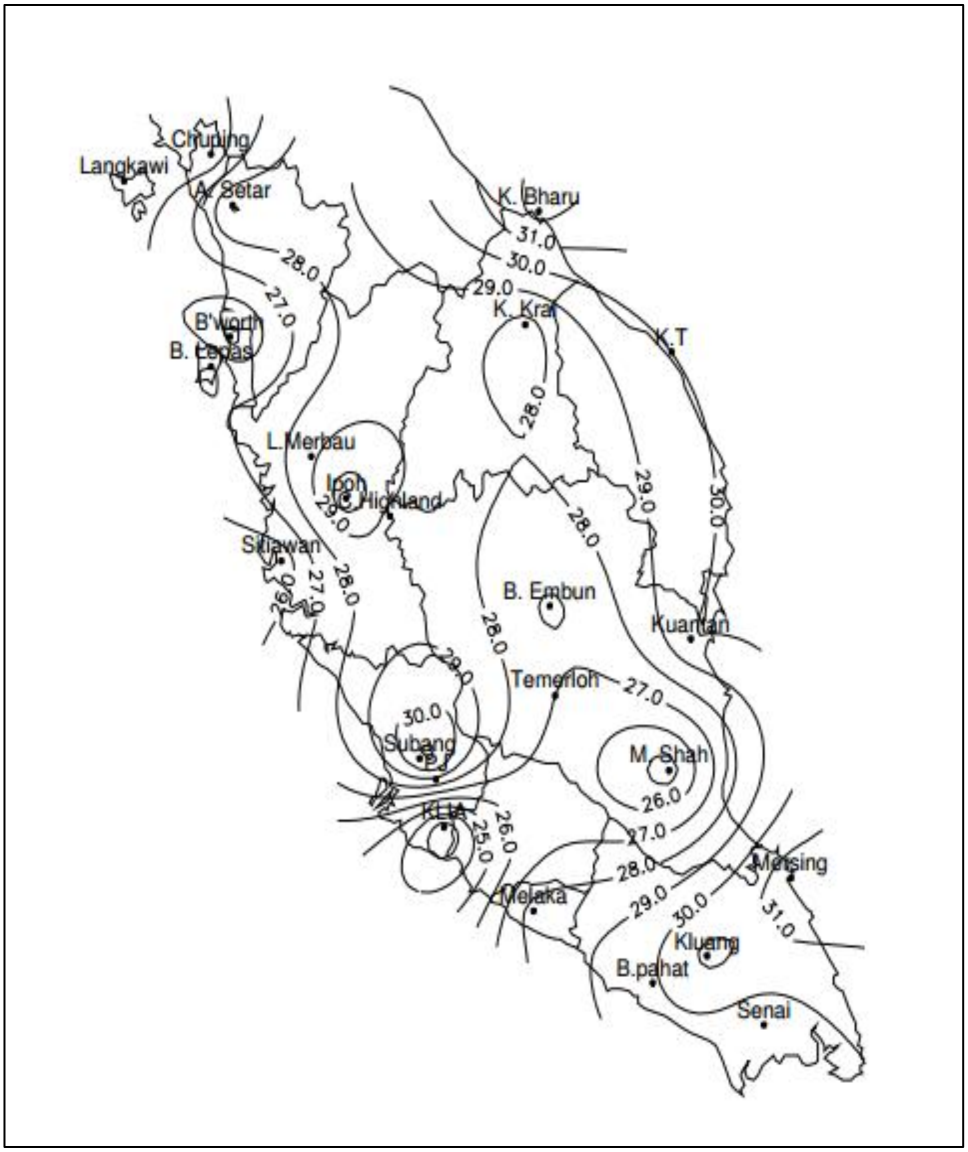


Figure 2.1: Basic Wind Speed for towns in Peninsular Malaysia (50 Years Return Period)

Source: Malaysian Meteorological Department (MET) 2013

2.2.2 Wind speed due to topography

Topography comprises of two English words, namely ‘topo’ that deals with earth surface and ‘grapho’ that represents information (Hurni, 1992). Investigation regarding the effect of wind speed due to hill and escarpment founded that wind speed can be increase due to topographic effect. (Davenport et. Al., 2000, Lubitz and White 2007, Lemelin et. Al., 1988, Miller and Davenport, 1998). The wind speed accelerates when the winds flow along with topographic features such as hills or ridges.

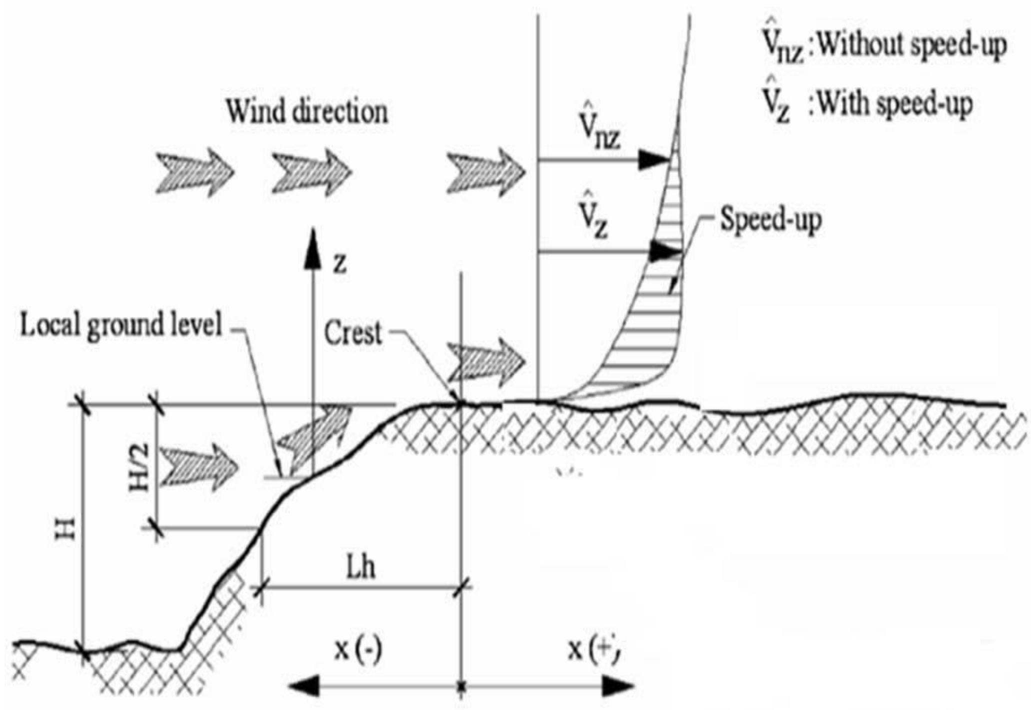


Figure 2.2: Wind speed accelerates when the winds flow along with topographic features.

Source: Ramli et. al, 2009

2.2.3 Wind speed due to surface roughness

Wind speed varies with height and the variation is related to the drag on the wind as it blows over upstream areas. Different types of terrain will produce different roughness effects. The approaching wind characteristics are largely controlled by the roughness of the upwind fetch over which it had blown. (Choi, 2009)

Table 2.2: Surface roughness lengths for different type of terrain.

Table 1: Surface roughness lengths for different type of terrain (Ramli et al., 2009)

Terrain description	Z_0 (m)	Surface
Open sea, fetch at least 5km	0.0002	Sea
Mud flats, snow: no vegetation, no obstacles	0.005	Smooth
Open flat terrain; grass, few isolated obstacles	0.03	Open
Low crops; occasional large obstacles	0.10	Roughly Open
High crops; scattered obstacles	0.25	Rough
Parkland, bushes; numerous obstacles	0.5	Very Rough
Regular large obstacle coverage (suburb, forest)	1.0	Closed
City center with high-and low-rise buildings	≥ 2	Chaotic

Source: Ramli et. al, 2009

2.2.4 Wind simulation using Computational Fluid Dynamics (CFD)

Methods for calculating wind flow around buildings and predicting pedestrian wind conditions. More efficient and its graphic presentation of wind flow fields is particularly attractive. Bottema (1993) has attempted the evaluation of pedestrian level wind conditions in the vicinity of an isolated building by using the CWE approach and a simple turbulence model but with only limited success.

Computational Wind Engineering (CWE) is the usage of Computational Fluid Dynamics (CFD) for the solution of problems encountered in wind engineering. Typical application examples are the prediction of wind comfort, pollution dispersion and wind loading on buildings, which is the main topic of this chapter. The loading is a result of the pressure distribution on the building or structure in general. The variation of the pressure is determined by the flow field around the structure which itself depends on the shape of the structure and its immediate surroundings, and on the approach flow characteristics. In structural engineering this dependence is described with the first three links of the wind load chain (e.g., Dyrbye and Hansen, 1997). The first link determines the regional wind climate of the site from meteorological data. The second link describes the conversion of these data in the profile of the wind at lower heights, which is determined by the terrain surrounding the structure. The transformation of the wind profile into the pressure distribution forms the third link. These last two links are increasingly examined by means of CFD and reviews for the stimulation of the flow over complex terrain and the computation of pressure are available (e.g, Stathopoulos, 1997; Stathopoulos, 2002; Bitsuamlak et al., 2004). With these application reviews available the present chapter tries to focus on the basics of CFD and therefore addresses novices to this field of wind engineering. The presented material is of very general nature, biased by the author's experience.

Like in all other applications of CFD, knowledge on several ingredients of the problems to be evaluated is required. First of all the user has to have knowledge of the area of application, here wind loading on buildings. Secondly, he or she must be aware of the assumptions made in describing the physics by a mathematical model. And finally the influence of the numerical approximations on the solution should be known.

In **Figure 2.3** is a typical flow chart of the numerical solution of an engineering problem by means of CFD is shown. First one has to decide which mathematical equations should be used to describe the physical problem. For these equations boundary and initial conditions are necessary, which are ideally available from measurements. Next one has to decide about the domain in which one wants to compute the flow field. The size of this computational domain is determined by the knowledge of the flow conditions on the boundaries and by the available resources of computer hardware, man power and time. Inside the computational domain and on its boundaries a grid then he has to be generated, which determines the discrete locations at which the flow is compared.

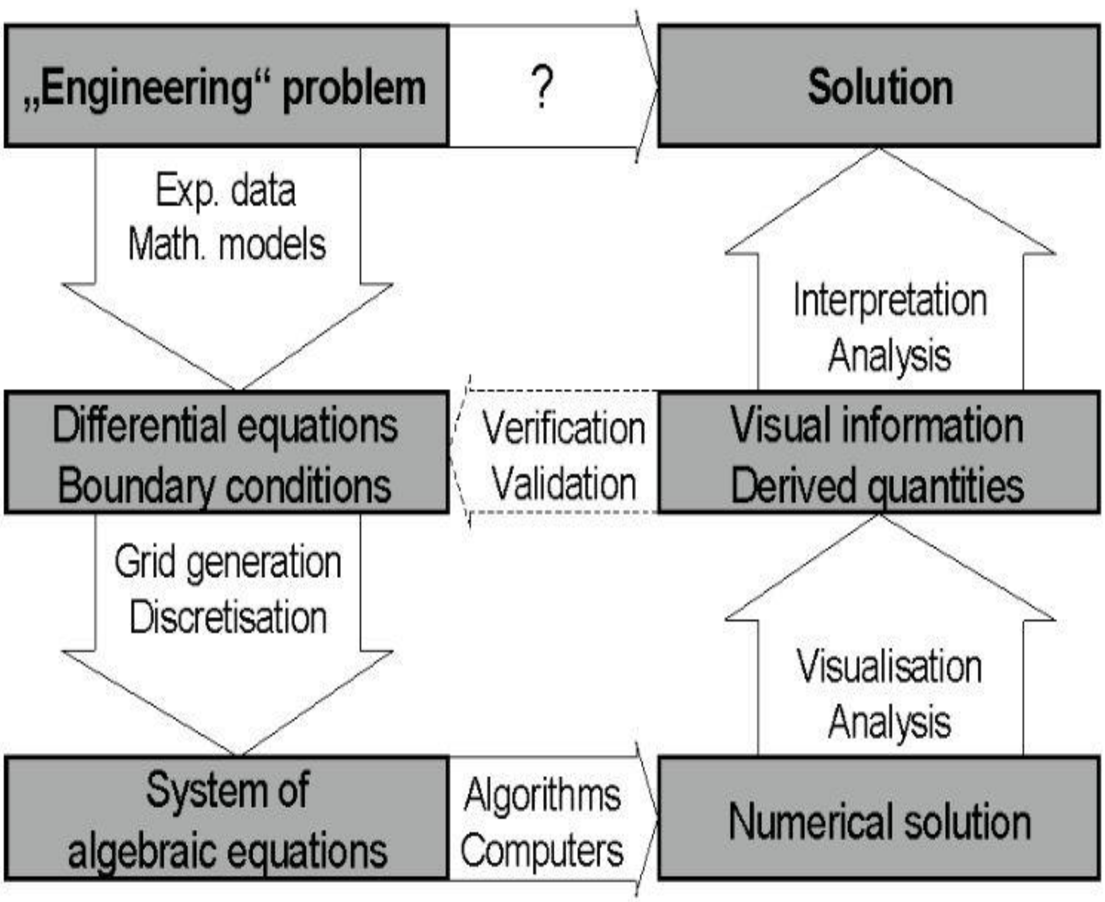


Figure 2.3: Flow chart of a CFD analysis

Source: After Schafer, 1999

2.3 WIND LOADING

2.3.1 Design Considerations

Windstorms pose a variety of problems in buildings, particularly in tall buildings, causing concerns for building owners, insurers, and engineers alike. Hurricane winds are the largest single cause of economic and insured losses due to natural disasters, well ahead of earthquakes and floods.

In designing for wind, a building cannot be considered independent of its surroundings. The influence of nearby buildings and land configuration on the sway response of the building can be substantial. The sway at the top of a tall building caused by wind may not be seen by a passerby, but may be of concern to those occupying its top floors. There is scant evidence that winds, except those due to a tornado or hurricane, have caused major structural damage to new buildings. However, a modern skyscraper, with lightweight curtain walls, dry partitions, and high-strength materials, is more prone to wind motion problems than the early skyscrapers, which had the weight advantage of masonry partitions, heavy stone facades, and massive structural members.

To be sure, all buildings sway during windstorms, but the motion in earlier tall buildings with heavy full-height partitions has usually been imperceptible and certainly has not been a cause for concern. Structural innovations and lightweight construction technology have reduced the stiffness, mass, and damping characteristics of modern buildings. In building experiencing wind motion problems, objects may vibrate, doors and chandeliers may swing, pictures may lean, and books may fall off shelves.

Following are some of the criteria that are important in designing for wind:

i. Strength and stability.
ii. Fatigue in structural members and connections caused by fluctuating wind loads.

iii. Excessive lateral deflection that may cause cracking of internal partitions and external cladding, misalignment of mechanical systems, and possible permanent deformations of nonstructural elements.
iv. Frequency and amplitude of sway that can cause discomfort to occupants of tall, flexible buildings.
v. Possible buffeting that may increase the magnitude of wind velocities on neighboring buildings.
vi. Wind-induced discomfort in pedestrian areas caused by intense surface winds.
vii. Annoying acoustical disturbances.
viii. Resonance of building oscillations with vibrations of elevator hoist ropes.

2.3.2 Nature of wind

Wind is the term used for air motion and is usually applied to the natural horizontal motion of the atmosphere. Motion in a vertical or nearly vertical direction is called a current. Movement of air near the surface of the earth is three-dimensional, with horizontal motion much greater than the vertical motion. Vertical air motion is importance in meteorology but is less importance near the ground surface. On the other hand, the horizontal motion of air, particularly the gradual retardation of wind speed and the high turbulence that occurs near the ground surface, are of importance in building engineering. In urban areas, this zone of turbulence extends to a height of approximately one-quarter of a mile aboveground, and is called the surface boundary effect. The wind speed at this height is called the gradient wind speed, and it is precisely in this boundary layer where most human activity is conducted. Therefore, how wind effects are felt within this zone is of great concern.

Although one cannot see the wind, it is a common observation that its flow is quite complex and turbulent in nature. Imagine taking a walk outside on a reasonably windy day. You no doubt experience the constant flow of wind, but intermittently you will experience sudden gusts of rushing air. This sudden variation of wind speed, called gustiness or turbulence, plays an important part in determining building oscillations.

2.3.3 Types of wind

Winds that are of interest in the design of buildings can be classified into three major types: prevailing winds, seasonal winds, and local winds.

i. Prevailing winds. Surface air moving toward the low-pressure equatorial belt is called prevailing winds or trade winds. In the northern hemisphere, the northerly wind blowing toward the equator is deflected by the rotation of the earth to become northeasterly and is known as the northeast trade wind. The corresponding wind in the southern hemisphere is called the southeast trade wind.

ii. Seasonal winds. The air over the land is warmer in summer and colder in winter than the air adjacent to oceans during the same seasons. During summer, the continents become seats of low pressure, with wind blowing in from colder oceans. In winter, the continents experiences high pressure with winds directed toward the warmer oceans. These movements of air caused by variations in pressure difference are called seasonal winds. The monsoons of the China Sea and the Indian Oceans are an examples.

iii. Local winds. Local winds are those associated with the regional phenomena and include whirlwinds and thunderstorms. These are caused by daily changes in temperature and pressure, generating local effects in winds. The daily variations in temperature and pressure may occur over irregular terrain, causing valley and mountain breezes.

All three types of wind are of equal importance in design. However, for the purpose of evaluating wind loads, the characteristics of the prevailing and seasonal winds are analytically studied together, whereas those of local winds are studied separately. This grouping is to distinguish between the widely differing scales of fluctuations of the winds; prevailing and seasonal wind speeds fluctuate over a period of several months, whereas the local winds vary almost every minute. The variations in the speed of prevailing and seasonal winds are referred to as fluctuations in mean velocity. The variations in the local winds are referred to as gusts. The flow of wind, unlike that of other fluids, is not steady and fluctuates in a random fashion. Because of this, wind loads imposed on buildings are studied statistically.

2.3.4 Characteristic of wind

Wind having numerous characteristics of its own such as wind rose, turbulent intensity, type of anemometer and wind turbine performance. Wind-related disaster events have had significant impacts on our society, especially in terms of the shocking number of injuries and deaths to people and attendant property loss. Probabilistic and statistical methods become the basis to study wind characteristic based on historical recorded data. The determination of appropriate design wind speed is a vital step towards the calculations of design wind loads for structures. It is important to properly decide both the directional characteristics of strong winds at a construction site and the directional characteristics of wind loads on a structure in order to achieve a resilient wind-resistant design.

The flow of wind is complex because many flow situations arise from the interaction of wind with structures. However, in wind engineering, simplifications are made to arrive at design wind loads by distinguishing the following characteristics:

- Variation of wind velocity with height
- Wind turbulence
- Statistical probability
- Vortex shedding phenomenon
- Dynamic nature of wind-structure interaction

2.3.5 Variation of wind velocity with height

The viscosity of air reduces its velocity adjacent to the earth’s surface to almost zero, as shown in Figure 1.1. A retarding effect occurs in the wind layers near the ground, and these inner layers in turn successively slow the outer layers. The slowing down is reduced at each layer as the height increase, and eventually becomes negligibly small. The height at which velocity ceases to increase is called the gradient height, and the corresponding velocity, the gradient velocity. This characteristic of variation of wind velocity with height is a well-understood phenomenon, as evidenced by higher design pressures specified at higher elevations in most building codes.

At heights of approximately 1200 ft (366m) above ground, the wind speed is virtually unaffected by surface friction, and its movement is solely dependent on prevailing seasonal and local wind effects. The height through which the wind speed is affected by topography is called the atmospheric boundary layer. The wind speed profile within this layer is given by

$$V_z = V_g \left(Z/Z_g\right)^{1/\alpha}$$

Where

V_z = mean wind speed at height Z aboveground

V_g = gradient wind speed assumed constant above the boundary layer

Z = height aboveground

Z_g = nominal height of boundary layer, which depends on the exposure (values for Z_g are given in Figure 1.1)

α = power law coefficient

With known values of mean speed at gradient height and exponent α, wind speeds at height Z are calculated by using Eq. (1.1). The exponent $1/\alpha$ and the depth of boundary layer Z_g vary with terrain roughness and the averaging time used in calculating wind speed. α ranges from a low of 0.087 for open country of 0.20 for built-up urban areas, signifying that wind speed reaches its maximum value over a greater height in an urban terrain that in the open country.

Methods for reflecting directional wind characteristics have been proposed by Cook [1] and Holmes [2]. Matsui et. al. [3] has examined the effects of directional wind characteristics and the orientations of structures on wind loads on the basis of the Holmes method. Whereas the former reflected directional wind speed characteristics, load effects such as directional aerodynamic properties were ignored. According to the timeline, the roof of Sultan Mizan Zainal Abidin Stadium located at Gong Badak, Terengganu was collapsed on June 2nd 2009 at 9:30 in the morning.

In designing for wind, a building cannot be considered independent of its surroundings. The influence of nearby buildings and land configuration on the sway response of the building can be substantial. In building experiencing wind motion problems, objects may vibrate, doors and chandeliers may swing, pictures may lean, and books may fall off shelves. In this case, the potential failure of roof of the stadium might come from the wind itself. Though we know that during the day of incident, the wind speed recorded was not high enough to bring the roof of the stadium down but the wind speed and storm that acted constantly and with repeatable wind speed on the roof of stadium from different angle of wind direction will give some additional pressure onto it.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter includes a review of the data analysis, design appropriateness, and a discussion of the wind load factor. In this study, the data of wind occurrences scenario of the region, state, district, main city, year, date, duration, diurnal distribution and geographical. Stadium was designed using software of sketch up. Topography around the stadium was determined. Stadium roof failure simulated using Computational Fluid Dynamics (CFD) software. By using CFD, we are able to have a quick analysis, efficient simulation of fluid flow and heat transfer of wind speed and direction onto the structure. This simulation offers a wide range of physical models and fluid flow capabilities. This study is primarily consists of 4 phases, which are;

i. Data collection : Obtaining historical weather data from year 2008 to 2009 and the weather data specifically on 2nd June 2009 from the station of Kuala Terengganu.
ii. Preparation : The data collections are to be readied in Microsoft Excel.
iii. Data Processing : Data then processing through Computational Fluid Dynamics (CFD) and analyzed.
iv. Results : Simulation of the wind flow and pressure in CFD.

3.2 RESEARCH FLOW CHART

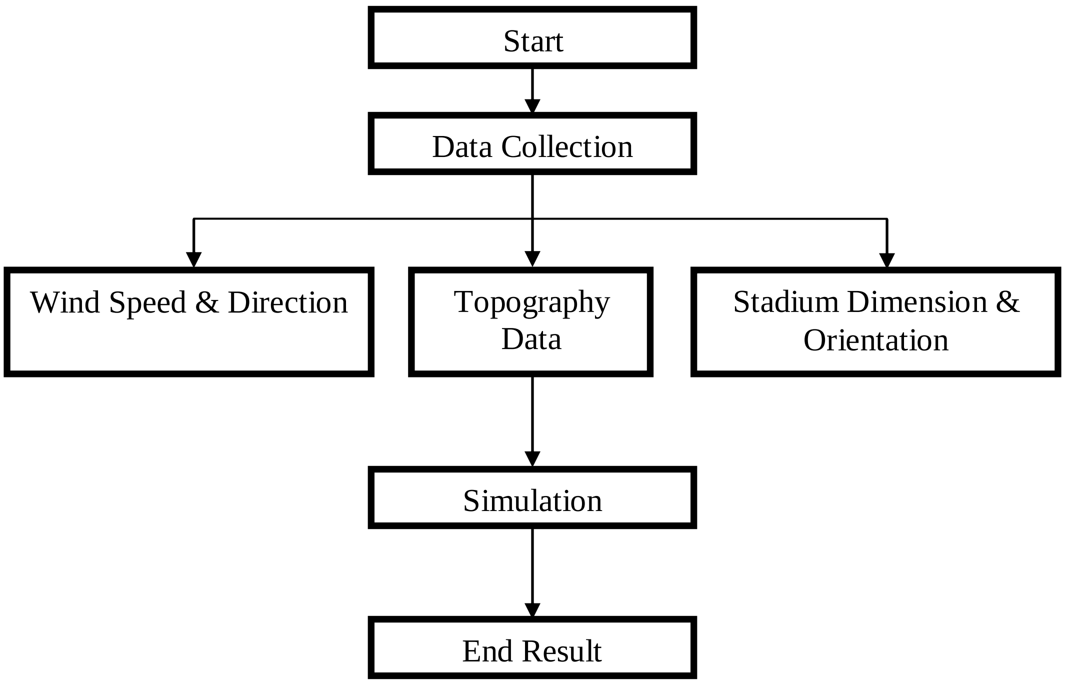


Figure 3.1: Flow chart

3.3 DATA COLLECTION AND PREPARATION OF DATA

Data collection is the process of gathering and measuring information on variables of interest, in an established systematic fashion that enables one to answer stated research questions, test hypotheses, and evaluate outcomes. The data collection was started with collecting the wind speed and direction of the particular area from Malaysian Meteorological Department (MET). **Figure 3.2** shows the map of the Peninsular Malaysia while **Figure 3.3** shows the location of the stadium at Kuala Terengganu, Terengganu Darul Iman.

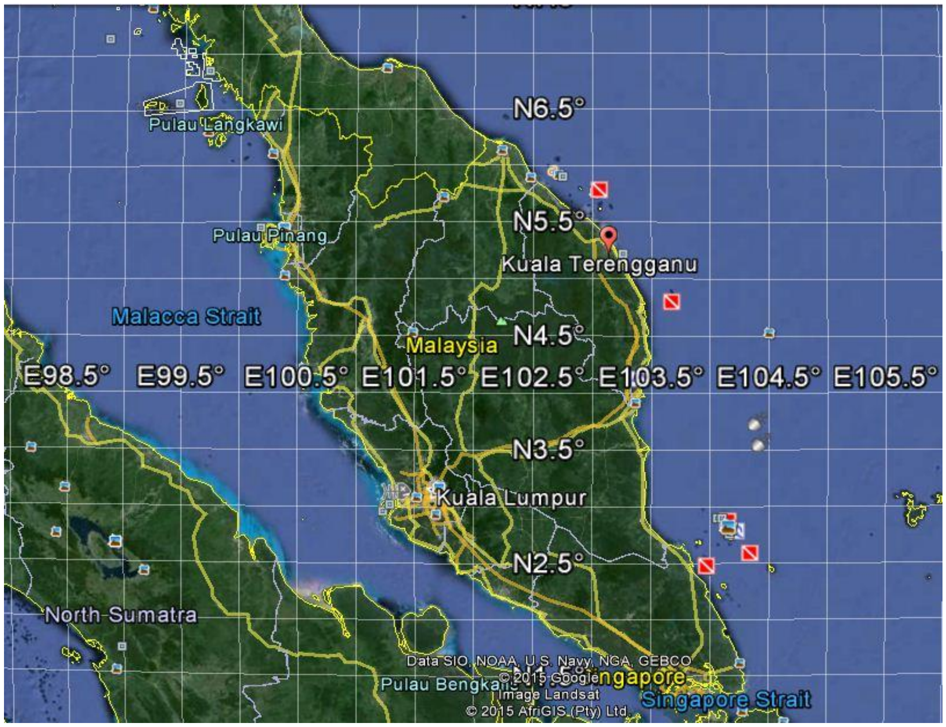


Figure 3.2: Map of Peninsular Malaysia.

Source: Google Earth.

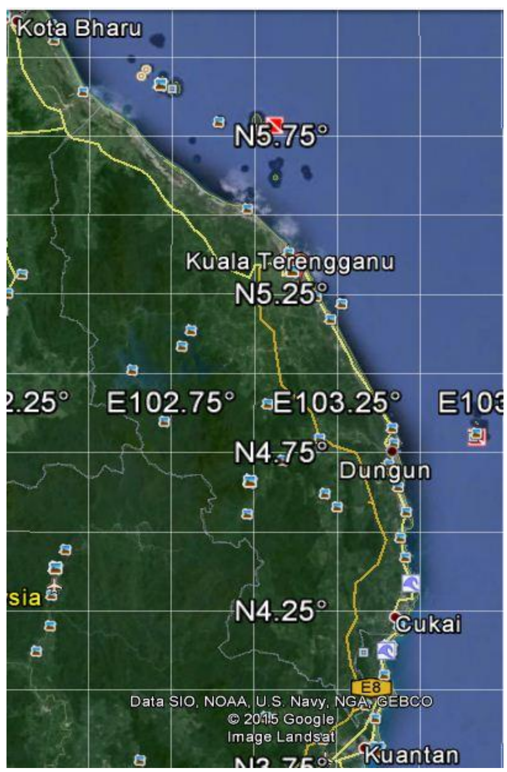


Figure 3.3: Map of State of Terengganu Darul Iman.

Source: Google Earth.

Figure 3.4: Location of Stadium Sultan Zainal Abidin, Kuala Terengganu.

Source: Google Earth.

3.3.1 Wind speed and direction data.

In order to estimate the maximum average wind speed and which direction of wind blows foremost for the particular year given, historical wind data are gathered by monthly starting from January 2008 until December 2009.

In this research, only two main factors will be considered which are wind speed and wind direction. Microsoft Excel is then used to re-arrange the wind data by according to months of Year 2008 and 2009 into tabulated form as shown in **Appendix A and B**. Average wind speeds for each month are calculated with respect to the wind direction. Wind direction which is measured in degree is divided into 8 azimuths namely North, North-East, East, South-East, South, South-West, West and North-West. **Table 3.1** shows the range of wind direction with respect to the azimuth used in this research.

Table 3.1: Range of wind direction with respect to azimuth.

AZIMUTH	RANGE IN DEGREE (˚)
North	337.5 - 22.5
North-East	22.5 - 67.5
East	67.5 - 112.5
South-East	112.5 - 157.5
South	157.5 - 202.5
South-West	202.5 - 247.5
West	247.5 - 292.5
North-West	292.5 - 337.5

Wind speed and wind direction are parameters that has been taken into account to calculate the average wind speed (m/s). The data of wind speed and wind direction in year 2008 and 2009 are taken from the Malaysian Meteorological Department (MET).

3.4 SIMULATION

3.4.1 Computational Fluid Dynamics (CFD) Simulation

The dimension of the building model used in this simulation is in accordance to the full-scale size of the Stadium of Sultan Mizan Zainal Abidin, Gong Badak, Kuala Terengganu, Terengganu. To simulate the actual condition of wind flow surrounding the area, the size of computational domain used for this model must satisfy the allowable range referred to Osman (2005) which has also been used by other researchers such as Gary Easom (2000) and Delaunay et al. (1995). **Figure 3.6** shows the building model of stadium.

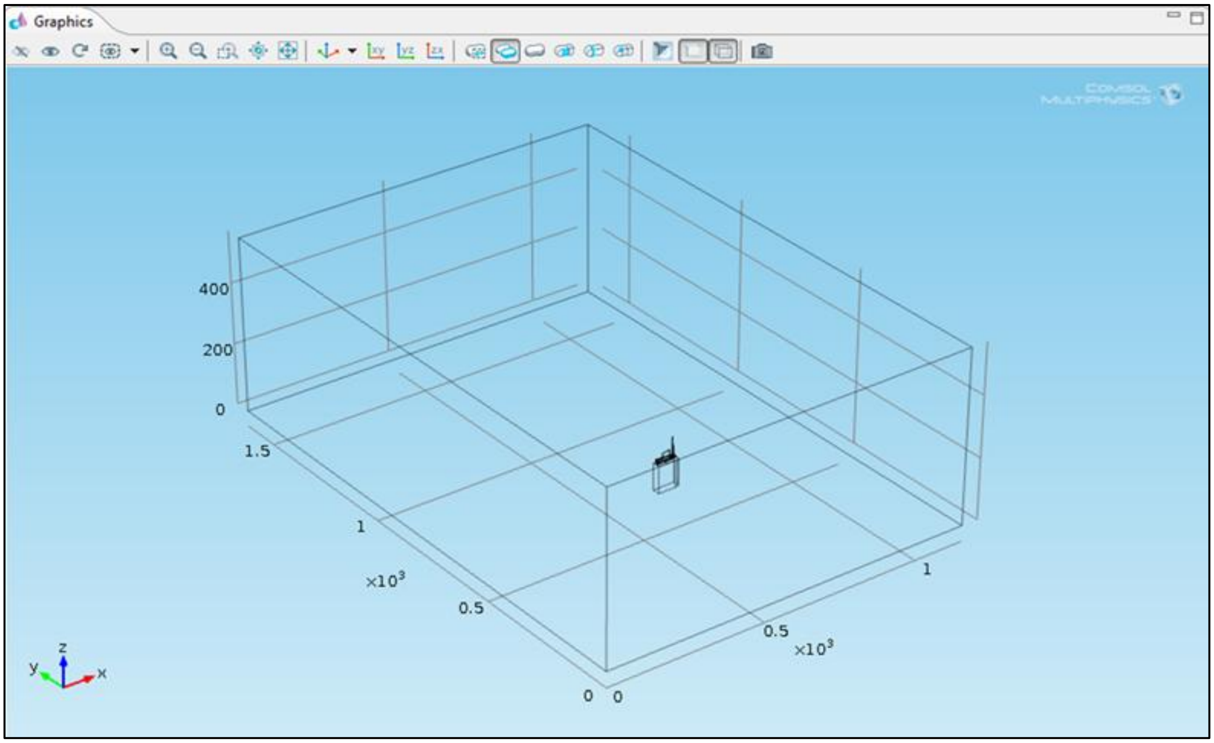


Figure 3.5: The computational domain of the building model

Source: Dr Siti Aminah Osman, 2013

CFD are used to predict pressure around the building when a certain wind speed hits the building model. Therefore, in this research, CFD is used to predict wind loading of the stadium. The wind speed used is based on the maximum wind speed close to the time of incident which was obtained from the nearest meteorological station, whereby in this case, the Kuala Terengganu Station. The dimension of the building model used in this simulation is in accordance to the full-scale size of the stadium which was drawn by using Sketch Up Software.

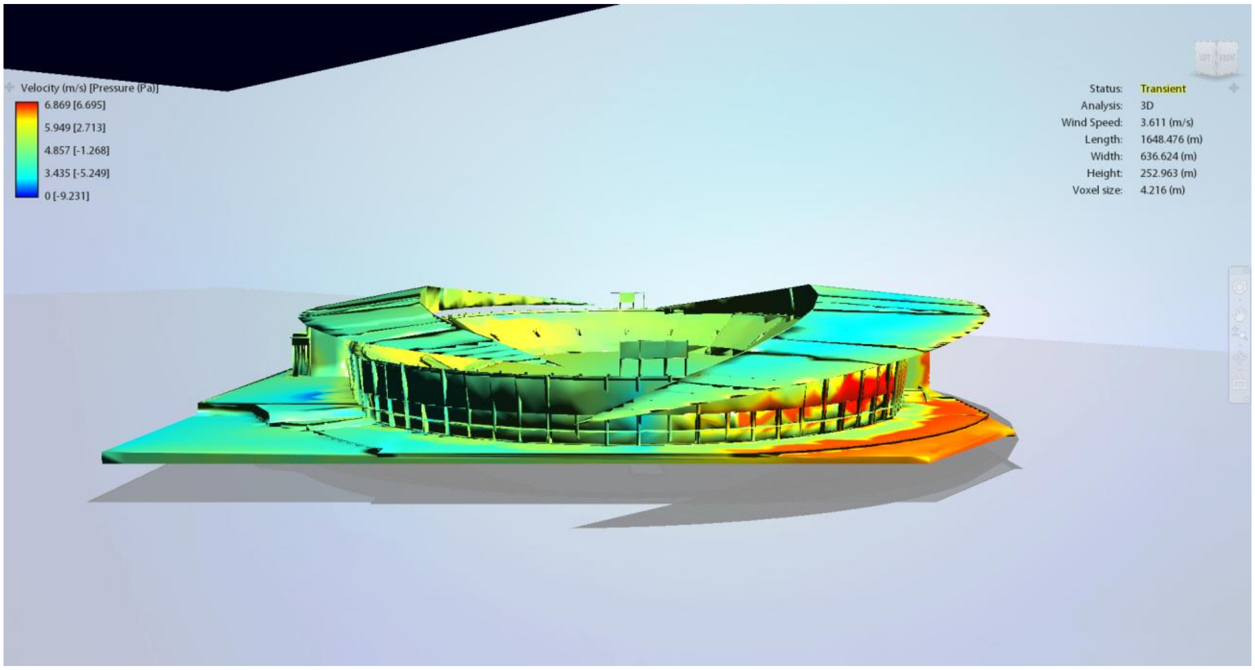


Figure 3.6: The Schematic drawing of the building model.

Source: Sketch up software, 2013.

Based on the initial result, the maximum wind speed taken for the closest time to the incident which is just before 9:30am at station of Kuala Terengganu is 3.611 m/s from South-East Direction. During the incident, the highest wind speed was collected from the direction of 112.5˚ - 157.5˚, South-East Direction. Therefore the simulation of the stadium is done by using wind speed of 3.611 m/s from range of 112.5˚ - 157.5˚, South-East Direction

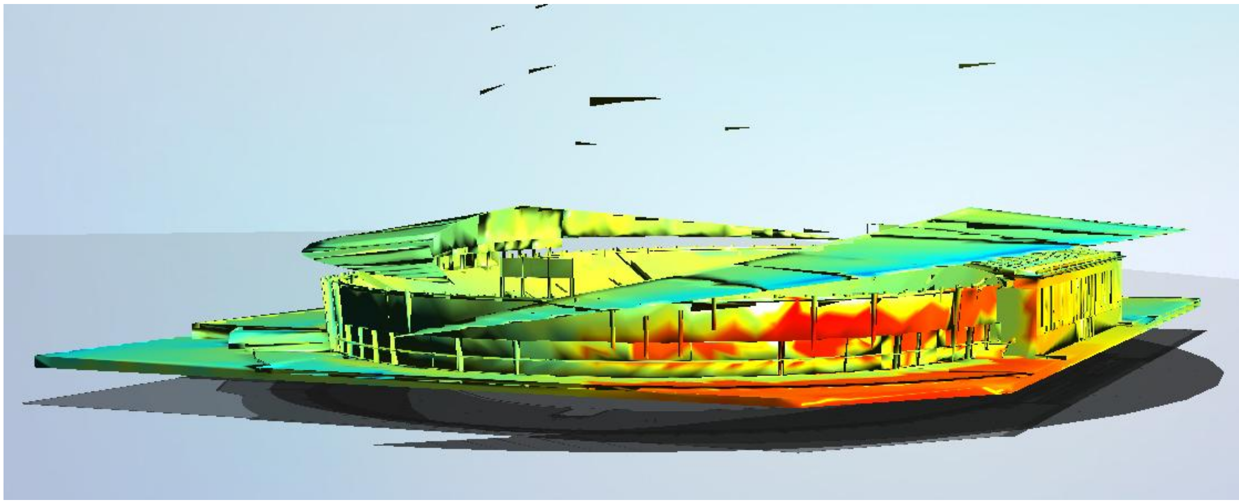


Figure 3.7: The predicted wind pressure on the surface of the stadium at 3.611 m/s from SE direction.

Source: Autodesk Flow Design, 2015

Simulation on different wind speeds with different angles have also been carried out and then summary of wind pressure on the stadium is tabulated in **Appendix C. Table 3.2** shows the range of wind direction with respect to the azimuth used in CFD simulation only. Some adjustment on the range of wind direction used in CFD is made in order to display the correct orientation of the tower based on real situation.

Table 3.2: Range of wind direction with respect to azimuth used in CFD

Actual AZIMUTH	AZIMUTH in CFD	Wind Degree
N	S	0'
		0' - 22.5'
NE	SW	22.5' - 45'
		45' - 67.5'
E	W	67.5' - 90.0'
		90.0' - 112.5'
SE	NW	112.5' - 135'
		135' - 157.5'
S	N	157.5' - 180'
		180' - 202.5'
SW	NE	202.5' - 225'
		225' - 247.5'
W	E	247.5' - 270'
		270' - 292.5'
NW	SE	292.5' - 337.5'
		337.5' - 360'

3.5 RESULTS

By using Computational Fluid Dynamics software, the predicted wind pressure on the stadium is produced as shown in Figure 3.7 and 3.8. From these simulations, analysis and discussion can be made.

3.6 SUMMARY

The whole progress of this research project has been mapped based on the simplified research flowchart. The main software used for this research is Computational Fluid Dynamics (CFD). This chapter also shows the sequences of steps in doing the research.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter shows the results obtained from the data collection. The results was obtained from the test conducted was recorded, analyzed and simulated using Computational Fluid Dynamics (CFD). The topics that will be discussed in this chapter are analysis of the day of incident, monthly wind and simulation using Computational Fluid Dynamics software. Objectives of the study were carried out successfully.

4.2 HISTORICAL WIND SPEED

Based on this case, it was shown that the roof of stadium was collapsed at the right side of the stadium. Specifically, the orientation of the stadium is in between North and South. Logically, we knew that probability of the highest accuracy of wind speed blew up the structure was from that direction. By referring to the initial result before this, it was claimed that the highest wind speed (m/s) probably came from the right side of the stadium. Figure 1 below shows the location of the stadium, captured from the Google Earth. It was identified that the topographical location of the stadium is at open flat terrain, nearby the sea shore with value of Z_0 is 0.03m.

Figure 4.1: Plan view of stadium

Source: Google Earth

Based on the case study, it shows that the highest wind speed recorded during the incident was at 3.611 (m/s). **Table 4.1** shows that the data of average wind speed (m/s) were collected and analyze onto different direction on each month in year 2008. The highest average wind speed (m/s) was recorded at 2.65 (m/s) comes from the direction of South East. **Table 4.2** shows the data of average wind speed (m/s) were collected and analyze onto different direction on each month in year 2009. The highest average wind speed (m/s) was recorded at 2.945 (m/s) and it is also comes from the direction of South East. It may also seem that this value is not the worst that can cause the structure to collapse. Historical wind speed also had shown foremost wind blow come from direction of South East. From that it can determined, at which direction of wind that can affect the failure of building structure. Thus, it can be conclude that the trend of the wind speed having highest average velocity is both from the direction of South East.

Table 4.1: Data of Average Velocity Wind Speed (m/s) in Year 2008

DIRECTION	RANGE	MONTHS/AVERAGE												AVERAGE (km/h)	AVERAGE (m/s)
		JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DISEMBER		
N	337.5' - 22.5'	16	12.33	0	13	0	0	0	0	0	0	17	15	6.11111	1.698
NE	22.5' - 67.5'	14.76	16.38	14.813	0	0	0	0	0	0	0	8	16.8333	5.89879	1.639
E	67.5' - 112.5'	12.33	12.75	13.778	13	0	0	0	0	0	0	11	0	5.23843	1.455
SE	112.5' - 157.5'	16	0	12.833	12.3	11.8	11.2	10.5	11.71	0	12.25	0	16	9.54147	2.65
S	157.5' - 202.5'	0	0	0	11	11.4	11.6	11.76	14.05	11.941	11.636	10.6	0	7.83192	2.176
SW	202.5' - 247.5'	12	0	0	10	13	0	10	18	12	13	11.5	6	8.79167	2.442
W	247.5' - 292.5'	18.5	0	0	9	0	13	0	11.33	11.333	14.333	12	11.6	8.425	2.34
NW	292.5' - 337.5'	0	12	0	11	0	10	0	0	0	12	10.75	12.1429	5.65774	1.572

Table 4.2: Data of Average Velocity Wind Speed (m/s) in Year 2009

DIRECTION	RANGE	MONTHLY AVERAGE WIND SPEED (km/h)												AVERAGE (Km/h)	AVERAGE (m/s)
		JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DISEMBER		
N	337.5' - 22.5'	12.8333	10.5	12.6667	23	13	0	0	0	0	0	23.5	11.5	8.91666667	2.47685185
NE	22.5' - 67.5'	16.9444	12.8333	12.8333	0	0	0	0	0	0	0	26	17.3571	7.16402116	1.99000588
E	67.5' - 112.5'	11.3333	13.8182	13.8182	0	0	0	0	0	13	0	0	13.4545	5.4520202	1.51445006
SE	112.5' - 157.5'	0	13.25	13.25	11.571	12	12.571	13.4	11.667	12.3333	11	16.17	0	10.6007937	2.9446649
S	157.5' - 202.5'	0	0	0	13.923	12.9	13.048	13	14.043	12.2778	12.625	17	0	9.07204759	2.52001322
SW	202.5' - 247.5'	0	0	0	13.667	15.25	12.5	11.6	13.5	13	12.2	10	0	8.47638889	2.35455247
W	247.5' - 292.5'	0	0	0	11	0	0	0	21	12	11.3333	12.67	11	6.58333333	1.8287037
NW	292.5' - 337.5'	9	11.5	11.5	8	0	0	0	0	0	0	12.13	10	5.17708333	1.4380787

From the table given, it shows that in year 2008 the direction of South East (Range: 112.5’ – 157.5’) recorded the highest average wind speed (km/h) with 2.65 (m/s) and in year 2009, the direction of South East (Range: 112.5’ – 157.5’) recorded the highest average wind speed (km/h) with 2.944 (m/s). **Figure 4.2 and 4.3** shows the wind rose of average wind speed (m/s) in year 2008 and 2009 respectively. It shows that direction of South East having the highest average of wind speed with 2.6504 m/s in year 2008 and 2.9666 m/s in year 2009 compare to others. The average wind speed data for each month are calculated in order to estimate the maximum average wind speed with respect to the foremost wind direction for year 2008 and 2009 in **Table 4.1** and **4.2** respectively. **Appendix C and D** shows the monthly wind rose for year 2008 and 2009.

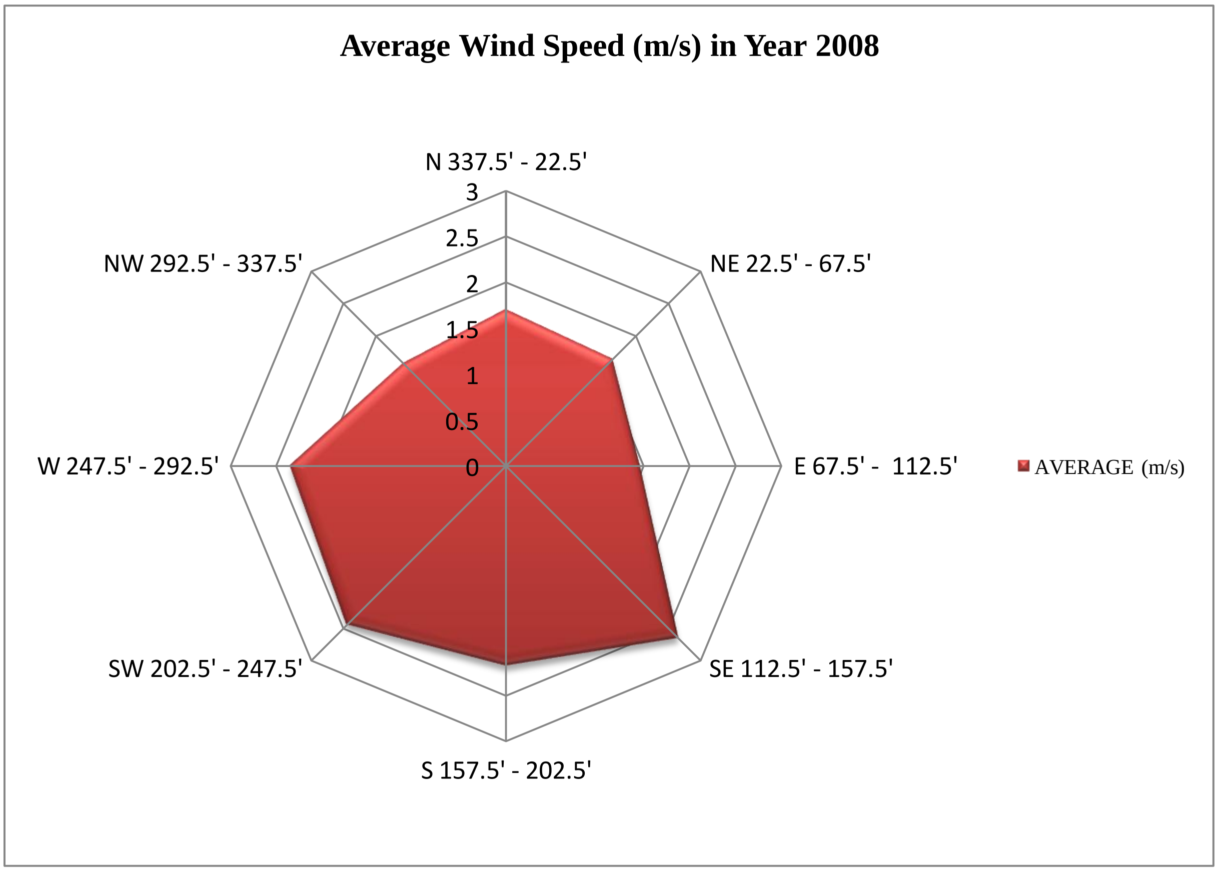


Figure 4.2: Wind rose of Average Wind Speed (m/s) in Year 2008.

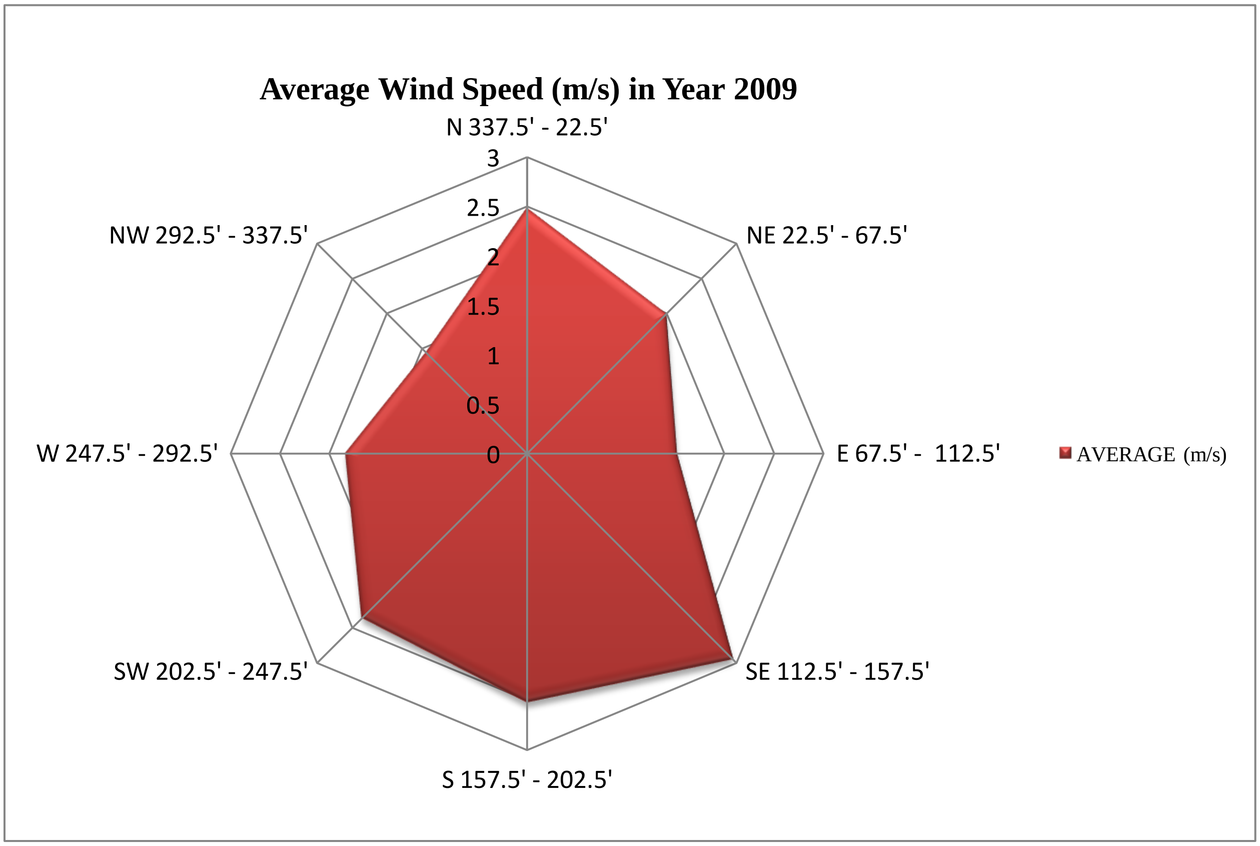
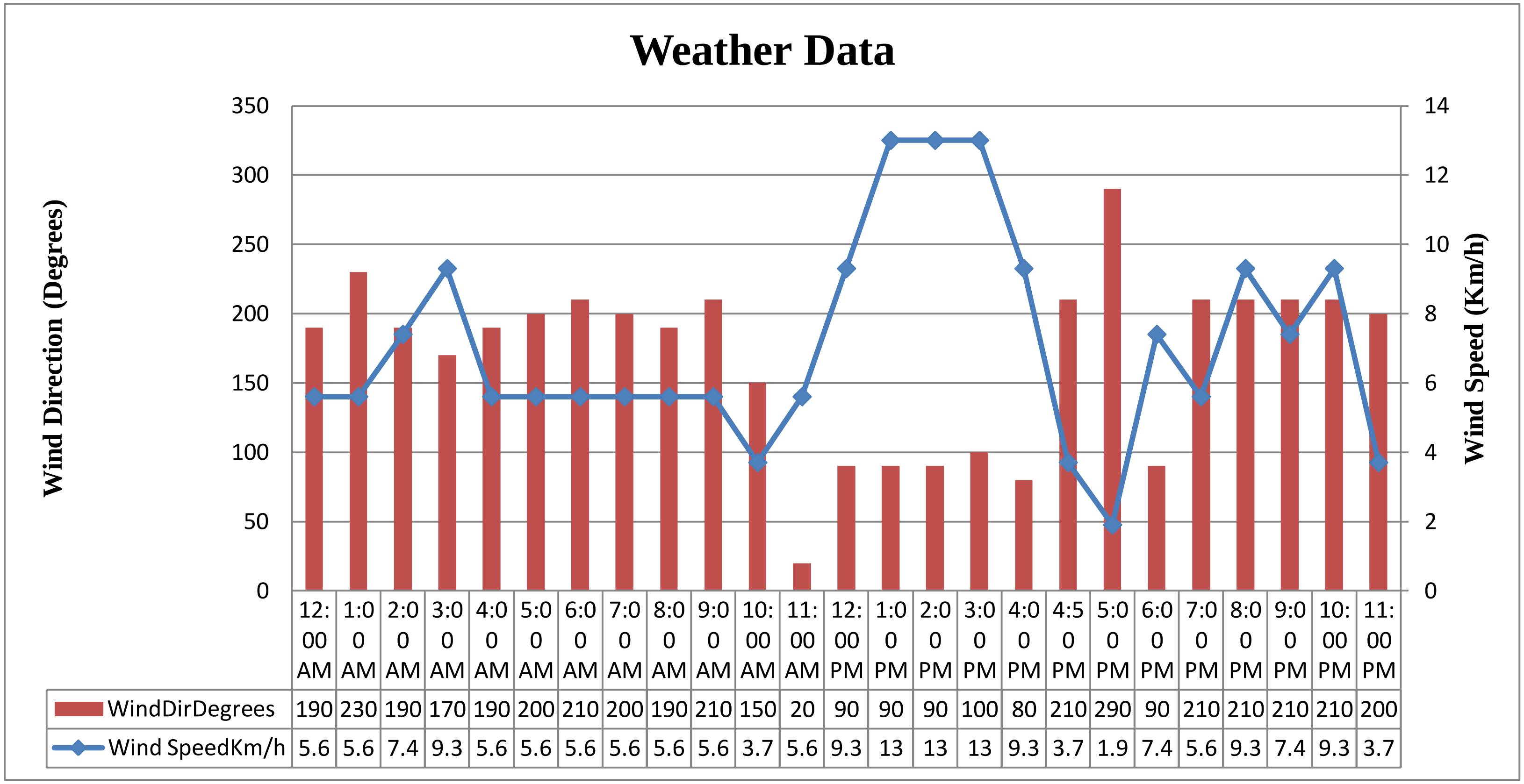


Figure 4.3: Wind rose of Average Wind Speed (m/s) in Year 2008

4.3 WIND DATA ESTIMATION DURING INCIDENT

Table 4.3: Summary of Wind Speed Data for 2nd June 2009 at station of Kuala Terengganu.

Time (24 hours)	**Velocity (km/h)**	**Wind Direction (Degree)**
0000	5.6	190 S
0100	5.6	230 SW
0200	7.4	190 S
0300	9.3	170 S
0400	5.6	190 S
0500	5.6	200 S
0600	5.6	210 SW
0700	5.6	200 S
0800	5.6	190 S
0900	5.6	210 SW
1000	3.7	150 SE
1100	5.6	20 N
1200	9.3	90 E
1300	13	90 E
1400	13	90 E
1500	13	100 SE
1600	9.3	80 E
1700	1.9	290 W
1800	7.4	90 E
1900	5.6	210 SW
2000	9.3	210 SW
2100	7.4	210 SW
2200	9.3	210 SW
2300	3.7	200 S



	12:00 AM	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	4:50 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM
WindDirDegrees	190	230	190	170	190	200	210	200	190	210	150	20	90	90	90	100	80	210	290	90	210	210	210	210	200
Wind SpeedKm/h	5.6	5.6	7.4	9.3	5.6	5.6	5.6	5.6	5.6	5.6	3.7	5.6	9.3	13	13	13	9.3	3.7	1.9	7.4	5.6	9.3	7.4	9.3	3.7

Graph 4.1: Weather data on the day of incident

Wind speed and wind direction from nearby meteorological station are used to estimate the maximum wind speed taken for the closest time to the incident which is just before 9:30am. From there, the data are used to estimate the wind pressure of the building by using CFD software.

Malaysian Meteorological Department (MET) is referred to obtain the weather data at Kuala Terengganu stations. Based on **Table 4.3**, Kuala Terengganu stations recorded maximum surface wind speed of 13 km/h or 3.611 m/s. The wind direction on the day of incident is almost perpendicular to the largest exposed surface of the stadium, which may produce the maximum force on the roof as shown. It may also seem that this value is not the worst that can cause the structure to collapse but highly foreseeable that the collapse was due to repeatable wind speed.

4.4 COMPUTATIONAL FLUID DYNAMICS (CFD) SIMULATION RESULTS

The wind speed used for simulation is based on the maximum wind speed close to the time of incident which was obtained from the nearest meteorological station, whereby in this case, the station of Kuala Terengganu. Based on the **Table 4.3**, hourly surface wind speed taken for the closest time to the incident which is just before 9:30am at Kuala Terengganu Station and the highest wind speed is recorded at 13 km/h or 3.611 m/s from South East Direction. Based on historical data in **Table 4.1 and 4.2**, the maximum average wind speed also shown that foremost wind blow comes from South East Direction. Therefore, wind speed of 13 km/h or 3.611 m/s from South West Direction is chosen for the simulation. The summaries of wind pressure of different angle using wind speed of 3.611 m/s are tabulated in **Table 4.5.**

Figure 4.4 shows the plan view of stadium by using Computational Fluid Dynamics (CFD). Apparently, by using CFD, the orientation of the angles was different. It shows that the angle having 0 degree was located at South direction.

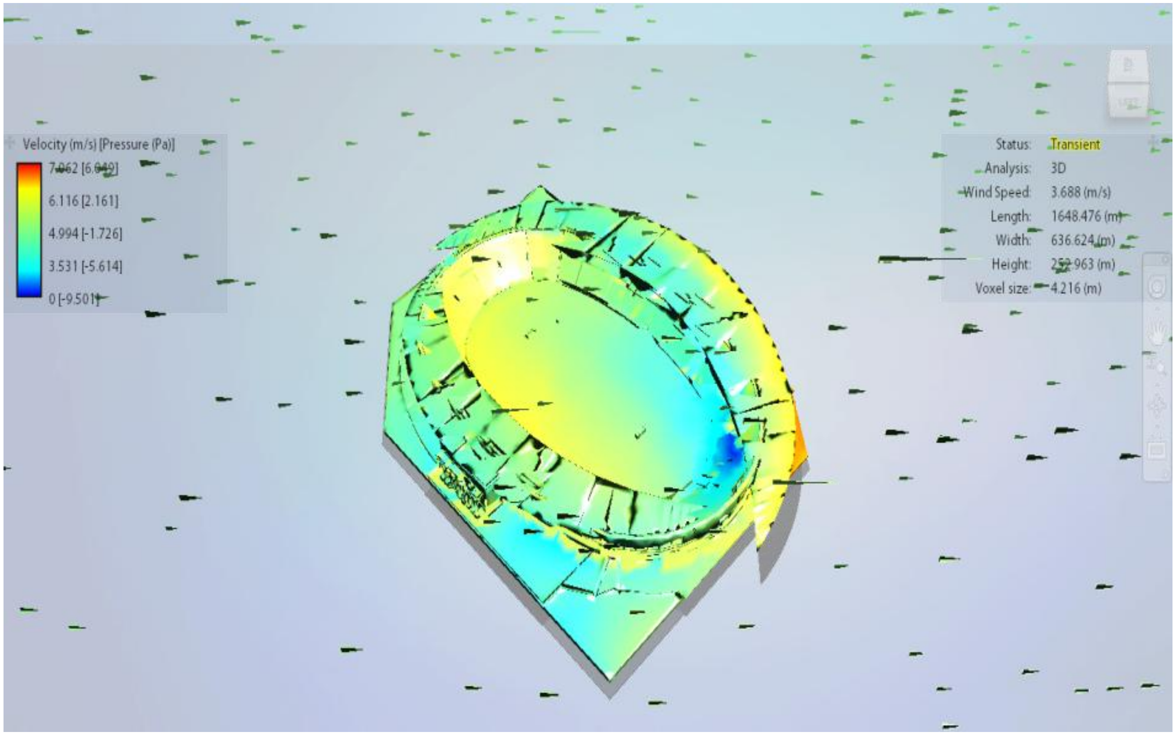


Figure 4.4: Plan view of the stadium in Computational Fluid Dynamics, (CFD Software 2015)

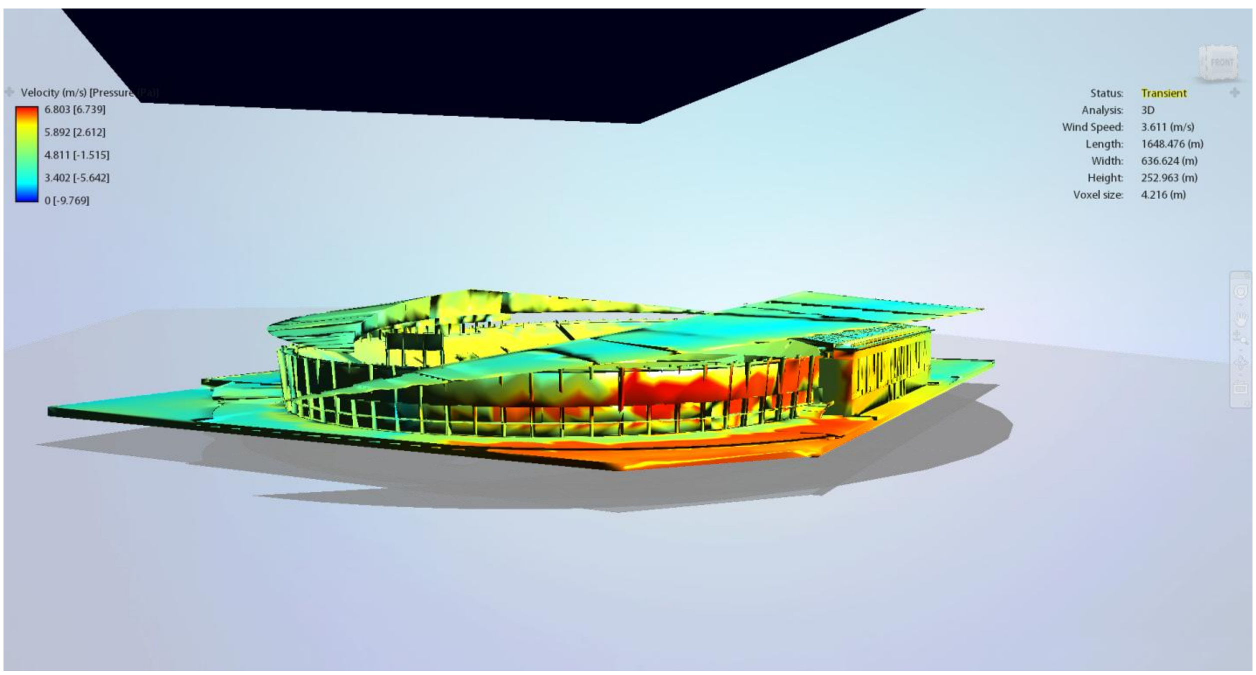


Figure 4.5: The predicted wind pressure on the stadium at speed of 3.611 m/s from angle of 135, South East direction, (CFD Software 2015)

Thus, the South direction at 0 degree was chosen as a new orientation following other directions simultaneously. **Figure 4.6** and **4.7** shows the wind rose of average wind speed (m/s) in year 2008 and 2009 respectively. As a result, it shows that the highest average of wind speed (m/s) was at the South East direction.

Table 4.4: The range of wind direction with respect to the azimuth used in CFD simulation

Actual AZIMUTH	AZIMUTH in CFD	Wind Degree
N	S	0'
		0' - 22.5'
NE	SW	22.5' - 45'
		45' - 67.5'
E	W	67.5' - 90.0'
		90.0' - 112.5'
SE	NW	112.5' - 135'
		135' - 157.5'
S	N	157.5' - 180'
		180' - 202.5'
SW	NE	202.5' - 225'
		225' - 247.5'
W	E	247.5' - 270'
		270' - 292.5'
NW	SE	292.5' - 337.5'
		337.5' - 360'

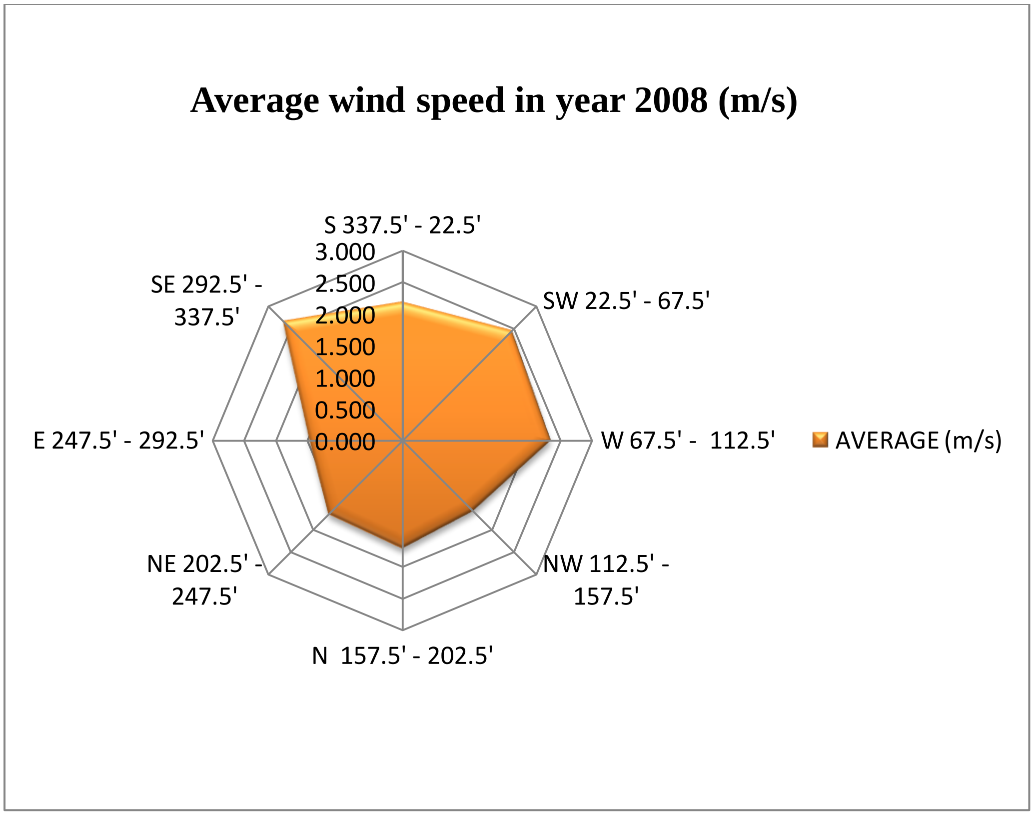


Figure 4.6: Wind Rose of Average Wind Speed (m/s) in year 2008 by using Computational Fluid Dynamics.

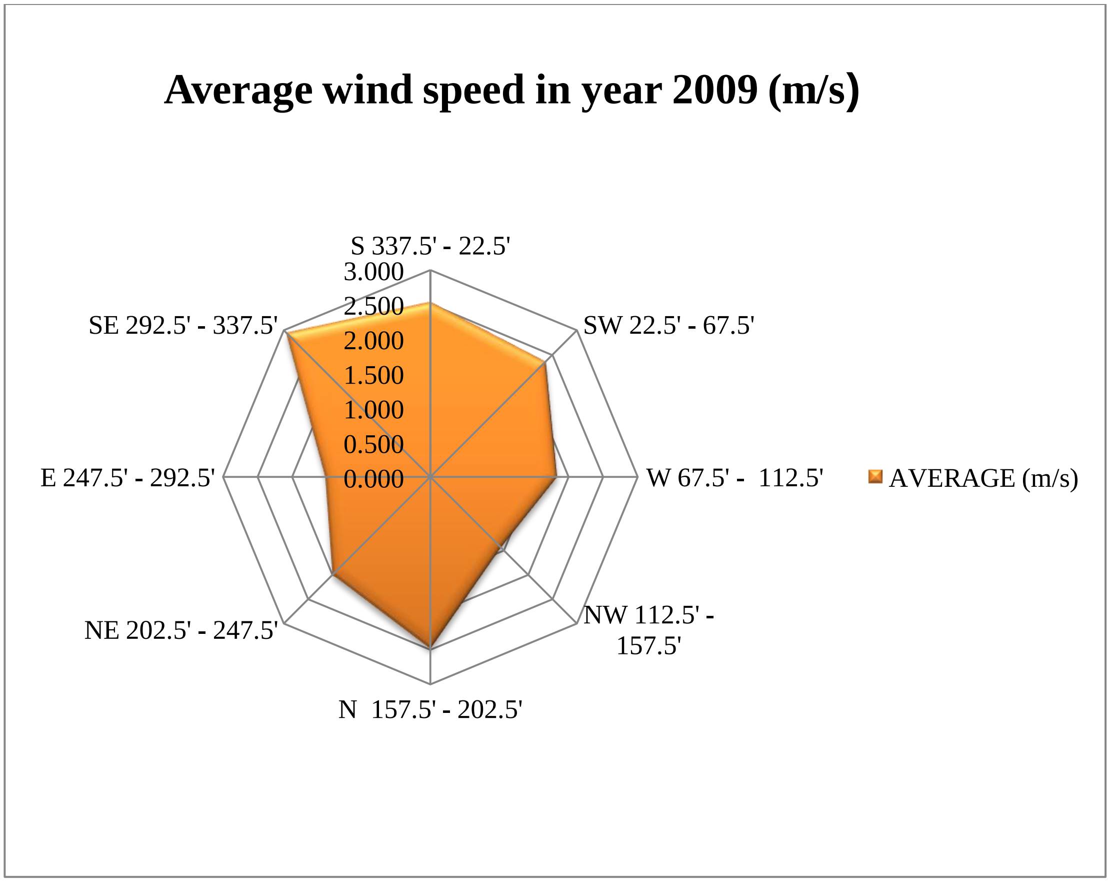


Figure 4.7: Wind Rose of Average Wind Speed (m/s) in year 2009 by using Computational Fluid Dynamics.

Besides that, **Table 4.5** is focusing on the difference in velocity and wind factor by using the initial wind speed velocity at 3.611 m/s. As a result, it shows that the highest difference in velocity was recorded at South East direction with 6.073 m/s. The value of wind speed was chosen based on the data recorded during the day of incident. From the result obtained each of the direction given the different value of wind pressure to roof of the stadium. It clearly shows that most the result show increasing of wind load pressure between the ranges of 70% to 168% from the normal wind that act to the stadium. It also clearly shows that wind load may increase up 2.68 times from South East Direction from the normal wind act to the stadium. Previously, it stated that the maximum increasing of wind speed were from the south east direction. Additionally, the data collected from nearest meteorological station shows the most frequently of wind came from the south east direction. From the observation the triggering collapse of roof stadium is located on the south east direction of the stadium

Table 4.5: Wind Load Factor

Direction	**Wind Degree**	**Initial Wind Speed, V0 (m/s)**	**Wind Speed, V (m/s)**	**Difference in velocity**	**Percentage Increase (%)**	**Wind Factor**	**Pressure (Pa)**
S	0'	3.611	9.045	5.434	150.4846303	2.504846303	7.584
S	0' - 22.5'	3.611	8.307	4.696	130.0470784	2.300470784	6.180
SW	22.5' - 45'	3.611	8.428	4.817	133.3979507	2.333979507	12.631
SW	45' - 67.5'	3.611	9.072	5.461	151.2323456	2.512323456	16.960
W	67.5' - 90.0'	3.611	8.697	5.086	140.8474107	2.408474107	5.598
W	90.0' - 112.5'	3.611	7.274	3.663	101.4400443	2.014400443	7.736
NW	112.5' - 135'	3.611	6.144	2.533	70.14677375	1.701467737	11.275
NW	135' - 157.5'	3.611	8.129	4.518	125.1176959	2.251176959	15.800
N	157.5' - 180'	3.611	8.169	4.558	126.2254223	2.262254223	16.675
N	180' - 202.5'	3.611	7.698	4.087	113.1819441	2.131819441	16.159
NE	202.5' - 225'	3.611	7.747	4.136	114.5389089	2.145389089	18.118
NE	225' - 247.5'	3.611	8.786	5.175	143.3121019	2.433121019	16.227
E	247.5' - 270'	3.611	7.634	4.023	111.4095818	2.114095818	4.803
E	270' - 292.5'	3.611	8.74	5.129	142.0382166	2.420382166	5.455
SE	292.5' - 337.5'	3.611	7.564	3.953	109.4710606	2.094710606	7.074
SE	337.5' - 360'	3.611	9.684	6.073	168.1805594	2.681805594	10.530

The results of predicted pressure around the building shown in **Figure 4.5** are based on wind speed of 3.611 m/s at 135 degrees. The figure also shows the maximum pressure of 18.118 Pa (0.018118 kN/m^2) was developed at the roof of the stadium.

From **Table 4.5,** it shows that with a wind speed of 3.611 m/s flows towards the building, the possibility of wind load may increase are up to 2.68 times from South East Direction from the normal wind act to the tower. However, it may also seem that this value is not the worst that can cause the structure to collapse but it can be conclude that the possibility of the collapse are highly foreseeable due to repeatable wind speed.

Simulations on different wind speeds with different angles have also been carried out and the summaries of wind pressures on the tower are tabulated in **Appendix D**. The range of wind direction with respect to the azimuth used in CFD simulation is shown in **Table 4.2**. Some adjustment on the range of wind direction used in CFD is made in order to display the correct orientation of the tower based on real situation.

Figure 4.8 shows the wind rose of percentage increase of velocity (%) and the highest percentage increasing in velocity was recorded at the South East direction with 168% increasing in velocity. While in **Figure 4.9** shows the wind rose of wind factor and the highest factor was recorded at the South East direction with 2.6818.

Last but not least, **Graph 4.2** shows the interaction between the initial wind speed, V_0 (m/s), wind speed after acted on the building, V (m/s), difference in velocity of wind speed (m/s) and the pressure acted on the building (Pa). The graph shows that the direction of South East is having the most critical section because of the all of the factors are highest than the others. This result can be related to other results that stated the highest direction of wind speed velocity (m/s) was come from South East.

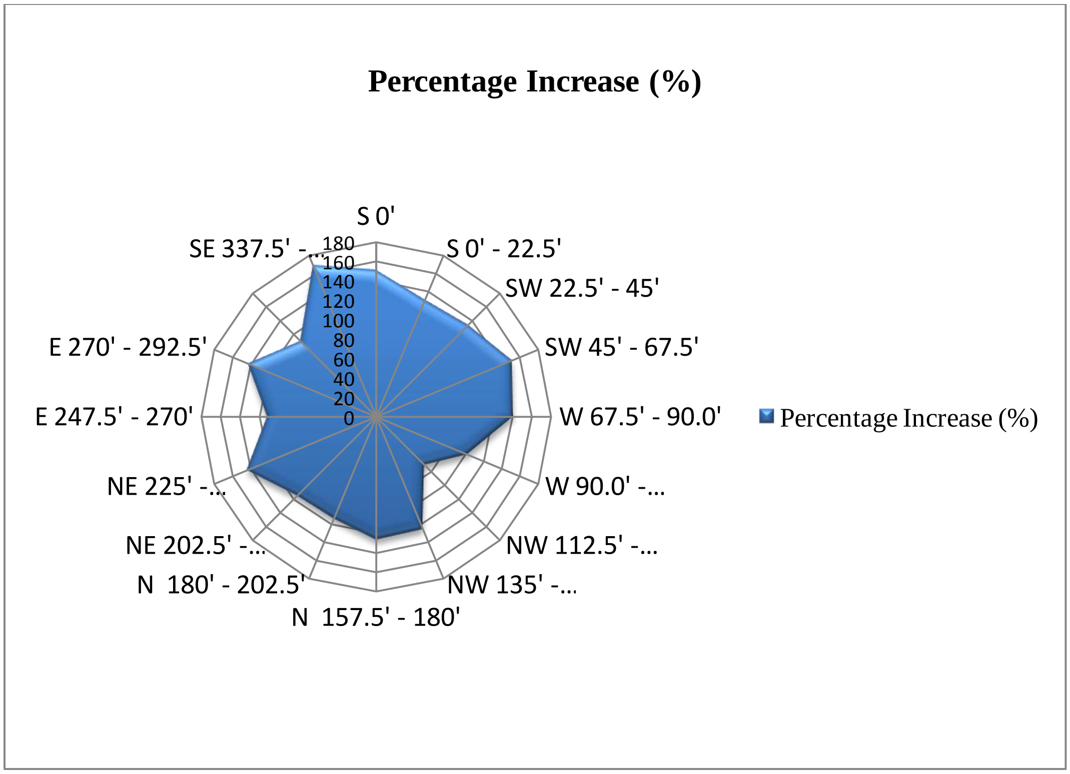


Figure 4.8: Wind Rose of Percentage Increasing of Velocity (%)

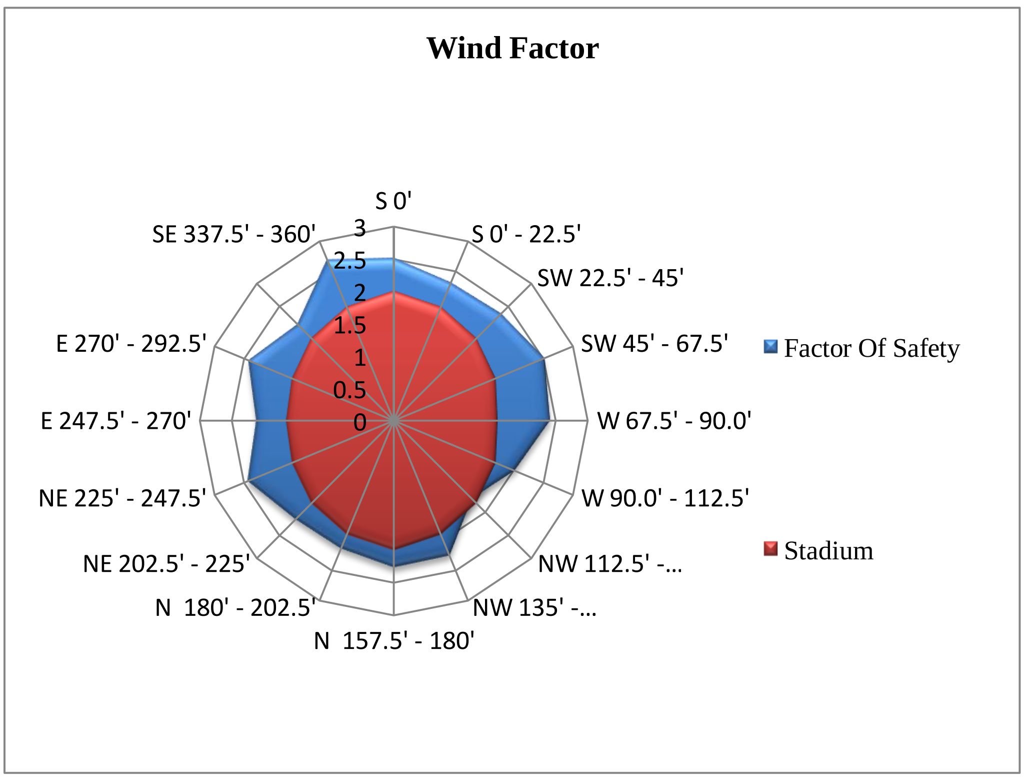
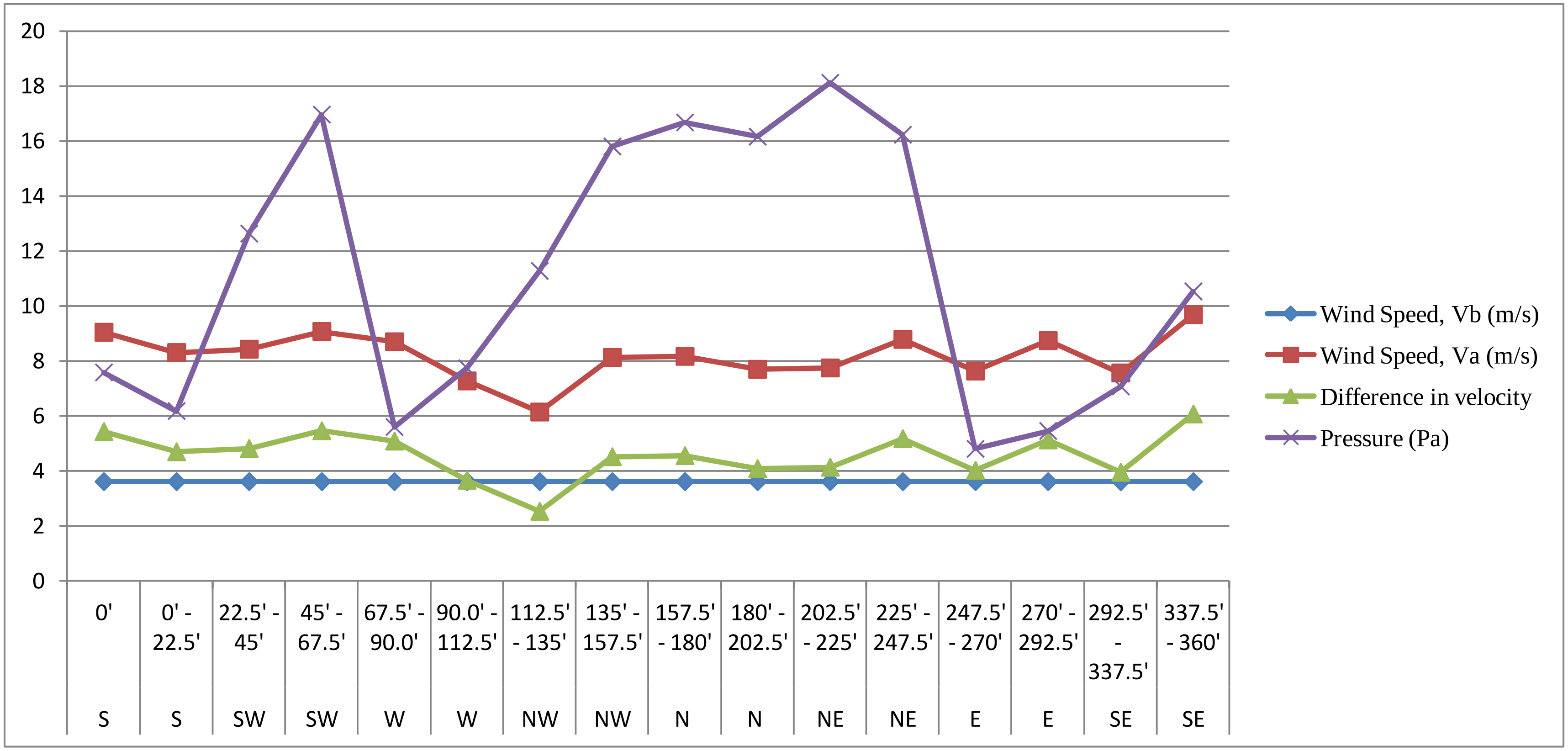


Figure 4.9: Wind Rose of the Wind Load Factor



Graph 4.2: Difference in Velocity against Angle Orientation of Stadium.

4.5 SUMMARY

As a conclusion, the possibility of wind load may increase up to 2.68 times from the South East Direction from the normal wind act to the stadium. However, it may also seem that this value is not the worst that can cause the structure to collapse but it can be conclude that the possibility of the collapse are highly foreseeable due to repeatable wind speed.

Based on the result, it can be conclude that the repeatable load acting to structural component of the tower may weaken the structural component. Therefore consideration of wind load direction is highly recommended during the design stage.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

In this chapter, it concluded the result obtained about the test conducted in the research and the recommendation towards the future research related in this field is also provided.

5.2 CONCLUSIONS

Wind-related disaster had become significant impacts in our society which responsible for the tremendous physical destruction, loss of life, injury and economic damage. The severity and increased frequency of wind-related disaster events over the past few years in malaysia has shifted the attention from several researchers towards investigating the effect of wind effect on building structure in Malaysia.

From all the result obtain, it can be conclude that wind characteristic is differs from place to place. Consequently, the wind speed and direction is influenced by the geographical position at the specific location. To conclude this project, it is basically based on the objectives of the study.

5.2.1 Objective 1: To study of the wind characteristics at the location after the construction until collapsing.

The flow of wind is complex because many flow situations arise from the interaction of wind with structures. Some of the wind characteristics have been made to arrived at design wind loads including the variation of wind velocity with height and wind turbulence.

5.2.2 Objective 2: To simulate the building against wind speed by using Computational Fluid Dynamics (CFD).

CFD was used to predict the behavior of structures. This simulation technique allows the wind flows around or through the building or structure to be analyzed in a great detail.

In order to simulate the building, a constant wind speed and a range of wind direction has been decided. Base on those results, a dynamic 2D and 3D of flow line animations are generated and the wind load acting on the surface of the building had been determined. The objective is achieved by determining the wind loading acting on the surface of the building tower from which direction of the wind blows. By simulating wind speed from different orientation acted on the surface of the building will give different value in wind speed. The collapse of roof stadium to experience the repeatable wind speed and increasing wind speed due to the direction are remarkably exposed. It can be concluding that the possibility of collapse roof is highly predictable due to wind speed. The effect of the geometrical shape of the structure may also increase the wind load effect to the building component. Therefore consideration of the geometrical shape and the orientation of the building is vital at the design stage.

5.3 RECOMMENDATION

This study is recommended to do a research extension because some of improvement needs to be taken to obtain more accurate results.

The first recommendation is to collect more data of wind speed to be input in Computational Fluid Dynamics (CFD). In this study, monthly average wind speed data and two years periods only were used. In other to improve the future work research studies, so it is recommended to collect more data of longer study period and use daily wind speed data.

Second recommendation is to have more data connecting and multiple sources to be input in the chart in Microsoft Excel to determine the relationship between wind speed and wind direction. In this study, wind speed and direction data are collected from website news and articles. In order to improve the future work research studies, it is recommended to have more data connecting and multiple sources.

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APPENDICES

Appendix A: Weather data obtained from Malaysia Meteorological Station (MET) for June 2008

MYT	Temperature, C			Dew Point, C			Humidity			Sea Level Pressure, Pa			Visibility, km			Wind Speed, km/h		Gust Speed, km/h	Events	Wind Direction Degrees
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Max		
6/1/2008	31	27	24	27	24	22	94	84	70	1010	1008	1005	10	10	10	10	5			165
6/2/2008	31	27	23	26	23	22	94	83	66	1010	1008	1006	10	10	10	11	6			160
6/3/2008	31	27	23	29	23	22	94	82	58	1011	1010	1008	10	10	10	13	6			163
6/4/2008	31	27	24	23	22	20	94	75	55	1011	1010	1007	10	10	10	13	5			149
6/5/2008	31	27	24	24	23	22	89	76	62	1010	1008	1005	10	10	10	11	5			155
6/6/2008	32	28	24	23	23	21	94	77	59	1009	1008	1005	10	10	10	11	6			174
6/7/2008	31	27	23	23	23	22	94	79	62	1010	1008	1006	10	10	10	10	5			165
6/8/2008	30	27	24	24	23	22	94	81	62	1010	1009	1007	10	10	10	11	6		Rain	165
6/9/2008	30	27	24	24	23	21	94	81	62	1010	1008	1007	10	10	5	10	5		Rain	300
6/10/2008	30	26	22	24	22	21	94	85	62	1011	1009	1007	10	10	8	13	5		Rain-Thunderstorm	224
6/11/2008	28	24	22	24	22	21	100	88	79	1011	1009	1007	10	10	10	13	6		Rain-Thunderstorm	166
6/12/2008	31	27	23	24	23	22	94	82	58	1012	1008	1006	10	10	6	13	6		Rain-Thunderstorm	183
6/13/2008	30	27	23	24	23	22	94	81	70	1010	1009	1007	10	10	10	10	5		Rain	114
6/14/2008	31	27	23	25	23	21	94	82	66	1010	1008	1006	10	10	10	11	6		Rain-Thunderstorm	160

6/15/2008	31	27	23	25	23	21	94	82	70	1010	1009	1006	10	10	10	10	6		Thunderstorm	164
6/16/2008	31	27	23	25	22	20	94	78	66	1010	1009	1006	10	10	10	10	6		Thunderstorm	166
6/17/2008	30	27	23	24	22	21	94	79	66	1010	1009	1007	10	10	10	11	6			140
6/18/2008	30	27	24	24	23	23	94	81	70	1011	1010	1007	10	10	10	10	5			176
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6/23/2008	30	27	23	24	23	22	94	83	66	1010	1008	1005	10	10	10	10	5		Rain-Thunderstorm	181
6/24/2008	30	26	22	24	22	21	100	83	66	1010	1008	1007	10	10	10	14	6		Rain-Thunderstorm	184
6/25/2008	31	27	23	24	23	21	94	81	55	1011	1009	1007	10	10	10	11	6			179
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6/29/2008	31	27	23	24	23	21	94	82	66	1012	1009	1007	10	10	10	11	6		Rain	184
6/30/2008	30	26	22	24	22	21	94	81	66	1012	1010	1008	10	10	10	10	5			180

Appendix B: Weather data obtained from Malaysia Meteorological Station (MET) for June 2009

MYT	Temperature, C			Dew Point, C			Humidity			Sea Level Pressure, Pa			Visibility, km			Wind Speed km/h		Gust Speed km/h	Events	Wind Direction Degrees
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Max		
6/1/2009	31	27	24	24	23	22	94	79	62	1011	1009	1006	10	9	2	11	5			161
6/2/2009	31	27	24	25	24	23	94	81	62	1010	1008	1007	10	10	8	13	5		Rain-Thunderstorm	168
6/3/2009	31	27	23	25	23	22	94	83	70	1011	1008	1006	10	10	6	13	6		Rain-Thunderstorm	188
6/4/2009	31	27	24	25	24	23	94	82	62	1010	1008	1005	10	10	10	11	5			165
6/5/2009	31	27	24	25	24	22	94	81	62	1010	1008	1005	10	10	10	14	6			158
6/6/2009	31	27	24	25	24	22	94	80	66	1010	1008	1006	10	10	10	13	5			152
6/7/2009	31	26	22	25	23	21	94	81	66	1011	1009	1007	10	10	10	11	6		Rain	216
6/8/2009	32	28	24	24	23	22	94	78	59	1012	1010	1008	10	10	10	11	6			147
6/9/2009	31	27	24	26	24	23	94	83	70	1012	1010	1008	10	9	7	11	6			155
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6/13/2009	32	28	24	24	23	22	89	77	59	1012	1011	1009	10	10	10	13	6			144
6/14/2009	32	28	24	25	23	22	89	76	62	1012	1010	1007	10	10	10	14	6			189
6/15/2009	31	27	24	25	24	22	94	82	66	1010	1008	1005	10	10	10	13	5		Rain-Thunderstorm	161
6/16/2009	31	27	24	25	24	23	94	82	62	1009	1007	1006	10	10	10	11	5			161
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6/19/2009	31	27	23	25	23	21	94	82	70	1010	1008	1007	10	10	8	13	5			173

6/20/2009	32	28	24	25	23	22	89	81	59	1011	1009	1007	10	10	10	11	6		Thunderstorm	196
6/21/2009	32	28	24	25	23	22	89	81	66	1010	1009	1007	10	10	8	11	5		Thunderstorm	190
6/22/2009	31	27	23	25	23	20	94	80	58	1010	1008	1006	10	10	8	13	6		Thunderstorm	180
6/23/2009	32	27	23	25	23	21	94	77	62	1010	1008	1005	10	10	9	14	6		Rain-Thunderstorm	199
6/24/2009	30	26	22	24	22	21	94	81	66	1011	1009	1007	10	10	6	13	6		Rain-Thunderstorm	167
6/25/2009	31	27	23	25	23	21	89	77	66	1011	1008	1005	10	10	10	13	6			153
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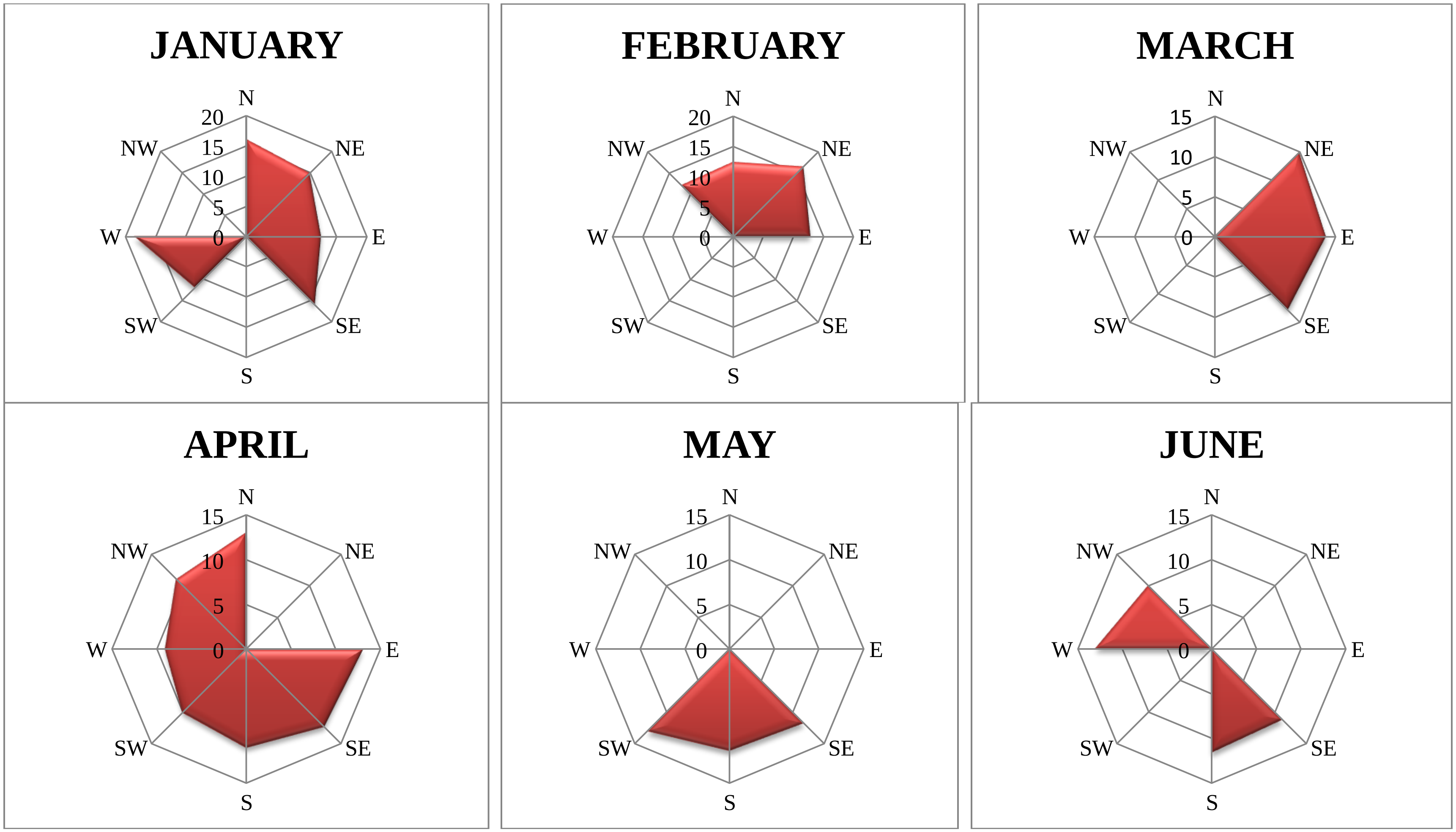
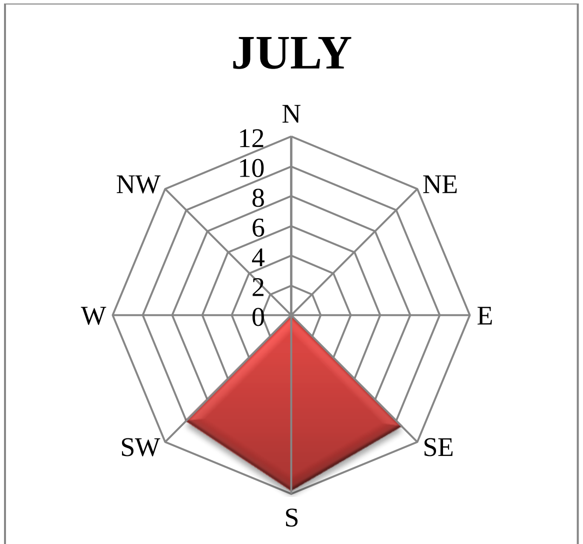
6/27/2009	31	27	23	25	23	22	94	82	66	1010	1008	1007	10	10	10	13	6	29	Thunderstorm	189
6/28/2009	31	27	24	24	23	21	94	80	62	1010	1009	1007	10	10	10	11	5		Thunderstorm	201
6/29/2009	31	26	22	25	23	20	94	83	66	1012	1009	1007	10	9	1	11	6		Rain-Thunderstorm	199
6/30/2009	29	26	22	24	22	20	94	83	70	1012	1010	1007	10	10	10	13	5		Rain	186

Appendix C: The average wind speed data for each month in year 2008

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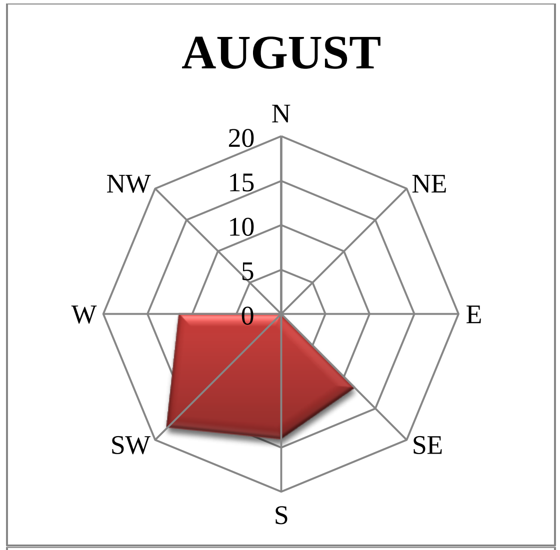
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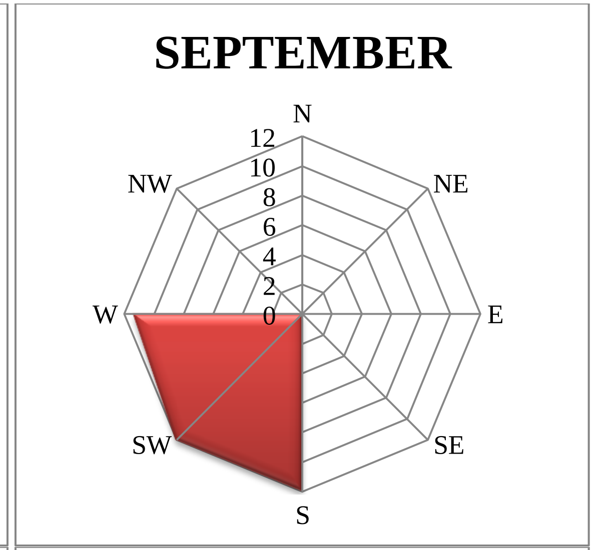
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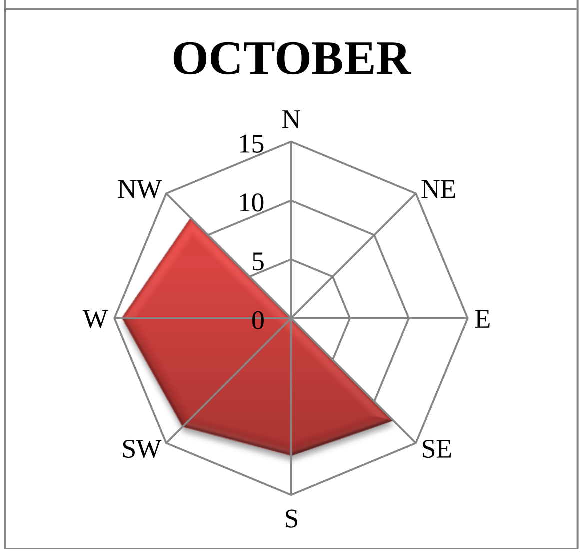
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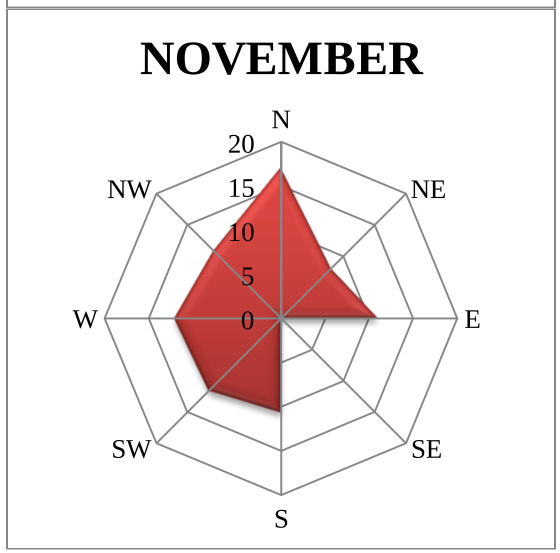
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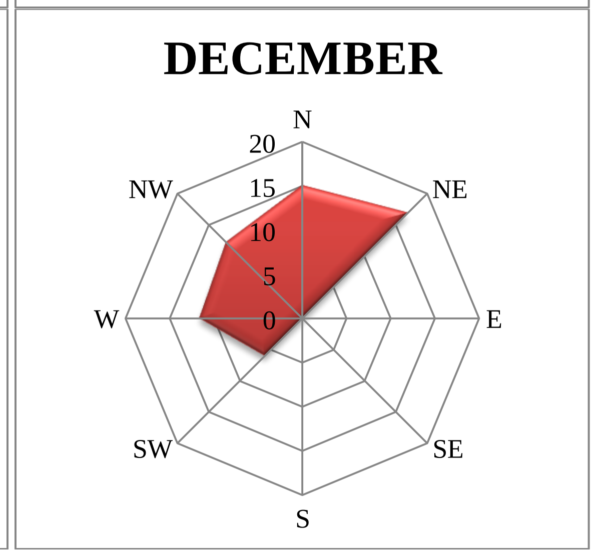
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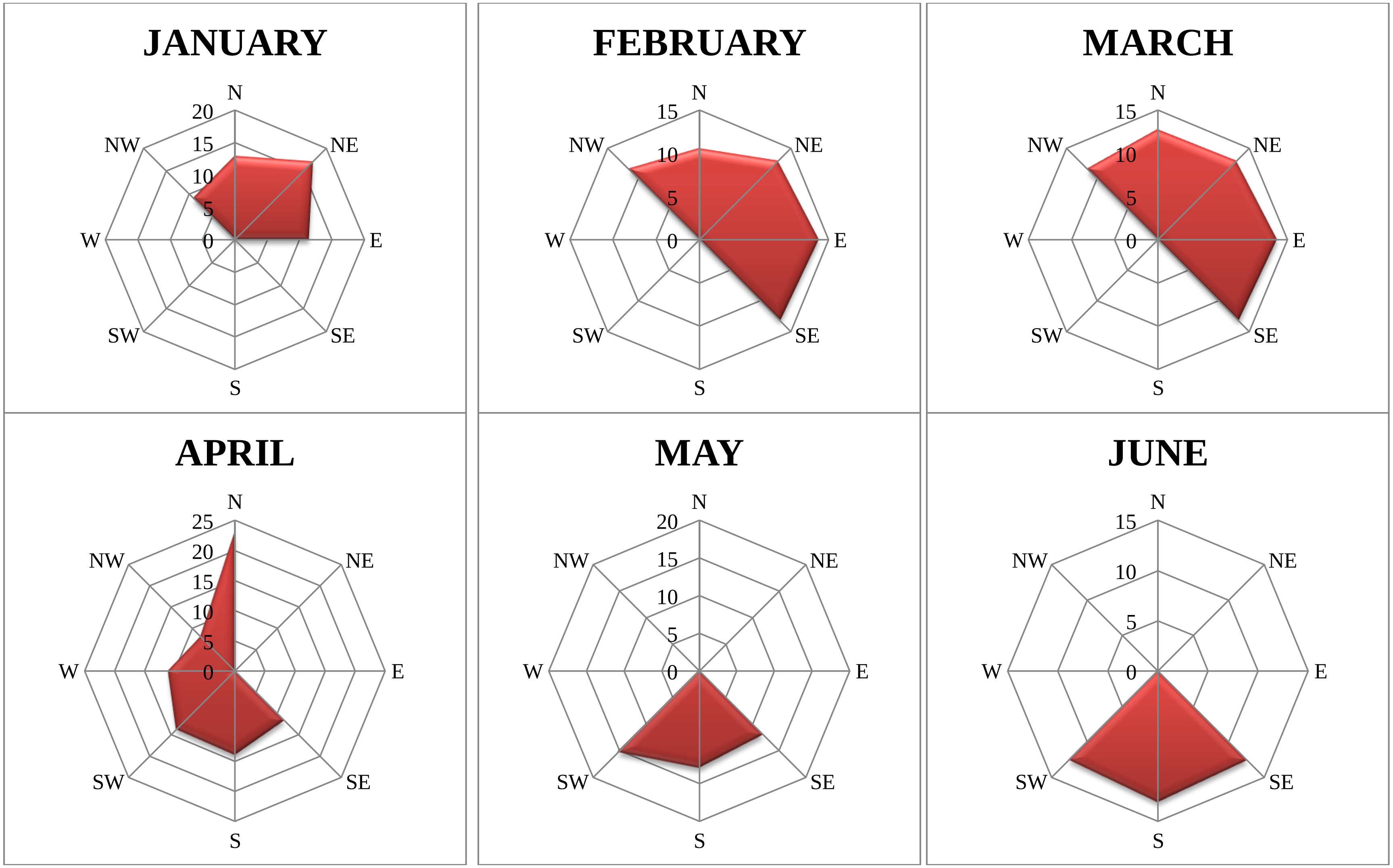
Appendix D: The average wind speed data for each month in year 2009



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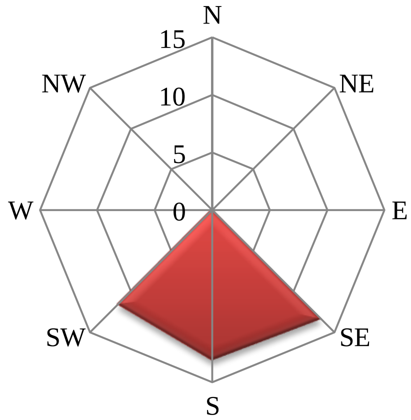

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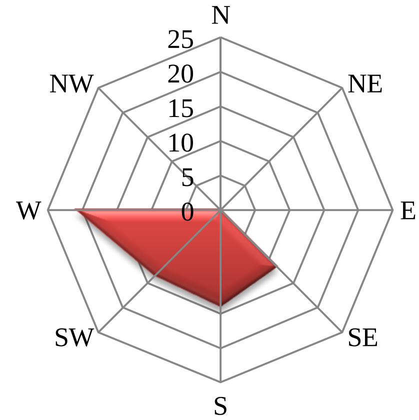

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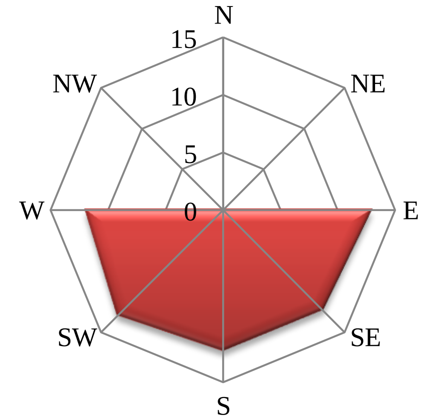

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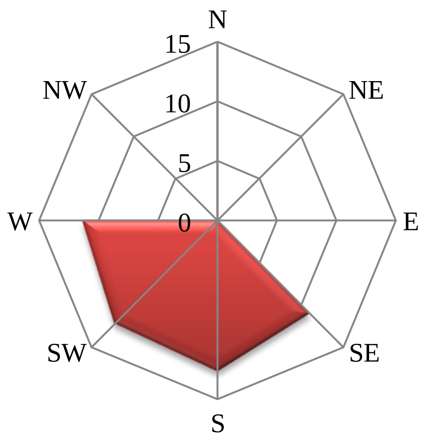

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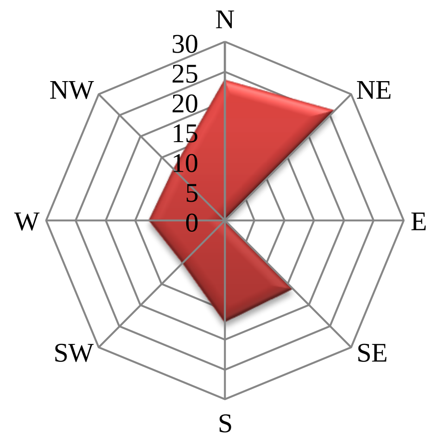

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