A STUDY TO INESTIGATE THE CAUSE OF FAILURE OF PEDESTRIAN BRIDGE PASIR GUDANG, JOHOR

ELLIZA BINTI MARCELLUS

AA11079

BACHELOR OF CIVIL ENGINEERING & EARTH RESOURCES

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's full name	:	ELLIZA BINTI MARCELLUS
Date of birth	:	04 SEPTEMBER 1992
Title	:	A STUDY TO INVESTIGATE THE CAUSE OF FAILURE OF PEDESTRIAN BRIDGE IN PASIR GUDANG, JOHOR
Academic Session	:	2014/2015

I declare that this thesis is classified as :

☐	**CONFIDENTIAL**	(Contains confidential information under the Official Secret Act 1972)*
☐	**RESTRICTED**	(Contains restricted information as specified by the organization where research was done)*
☑	**OPEN ACCESS**	I agree that my thesis to be published as online open access (Full text)

I acknowledge that Universiti Malaysia Pahang reserve the right as follows:

1. The Thesis is the Property of University Malaysia Pahang
2. The Library of University Malaysia Pahang has the right to make copies for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified By:

(Student's Signature)	(Signature of Supervisor)
920915-12-5306	EN. NORAM IRWAN BIN RAMLI
New IC / Passport Number	Name of Supervisor
Date : 3 JULY 2015	Date : 3 JULY 2015

NOTES : *If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

A STUDY TO INVESTIGATE THE CAUSE OF FAILURE OF PEDESTRIAN BRIDGE

ELLIZA BINTI MARCELLUS

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

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

JULY 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	:	EN NORAM IRWAN BIN RAMLI
Position	:	LECTURER
Date	:	3 JULY 2015

STUDENT'S DECLARATION

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	:	ELLIZA BINTI MARCELLUS
ID Number	:	AA11079
DATE	:	3 JULY 2015

This thesis is a symbol of appreciation
for my most beloved parents
for making me be who I am today

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisor, En Noram Irwan Bin Ramli for his support, guidance, encouragement, effort, and comment during the preparation of this project.

I also would like to thank to all the lecturers in Universiti Malaysia Pahang, whom have taught me in every semester for the past four years. They have indeed helped me to reinforce my basic knowledge and theories in Civil Engineering courses.

I would like to thank my family especially my parents, Marcellus Charlie and Lusunim Malinggam who always support and motivate me. Not to forget, my siblings, Nelson Marcellus, Elvira Marcellus, Elvinie Netchelle Marcellus, Neirol Mitchelle Marcellus and Gerald Marcellus for their unconditional love and inspiration in order to be successful in life.

Not to forget, to all my friends especially, Fiona anak Gasing, Debbie Cynthia Clarence Botiti, Steny Chin Loong, Yap Yee Von and Costello Fifo Anak Nyuwus and and others for their kindness, advice and moral support.

ABSTRACT

Recently reported numbers of damage occurred to pedestrian footbridge in Malaysia. It had become significantly since there is affected loss in property and may also cause injury to people. On 12 October 2014, a pedestrian footbridge located at Perling – Pasir Gudang Highway was destructed by the wind storm. However wind speed at the nearest meteorological station are not showed any significant value that may damage the pedestrian footbridge. Therefore this study was carried out to investigate the effect of wind to the pedestrian footbridge. Computational Fluid Dynamic has been used in order to examine the effect of wind to structures. The model was examined with different direction of wind speed. From the result it obviously shows that the wind speed may increase suddenly when gust of wind reach to the structure. The interaction between the wind and the structure component might increase the wind speed up to 78% from the north direction. Additionally historical wind speed data at the nearest meteorological station was also examined. Past wind speed also shown that primary wind blow come from North Direction. Repetition of wind speed from same direction can also cause a fatigue failure to the structural component. It can be conclude that the consideration during the design stage are should be properly estimated. The orientation of footbridge may increase the potential of wind induce failure to the structure. Hence the wind speed direction and the interaction between the wind and structure need to be well recognized at design stage in order to reduce the wind risk to pedestrian footbridge component.

.

ABSTRAK

Baru-baru ini dilaporkan beberapa kerosakan berlaku kepada jambatan pejalan kaki di Malaysia. Ia menjadi ketara kerana telah berlaku kerugian dalam harta dan juga boleh menyebabkan kecederaan kepada orang ramai. Pada 12 Oktober 2014, sebuah jambatan pejalan kaki yang terletak di Perling - Lebuhraya Pasir Gudang telah dirosakkan oleh ribut angin. Namun kelajuan angin di stesen meteorologi yang terdekat tidak menunjukkan apa-apa nilai yang signifikan yang boleh merosakkan jambatan pejalan kaki. Oleh itu kajian ini dijalankan untuk mengkaji kesan angin kepada jambatan pejalan kaki. Perisian Computational Fluid Dynamic telah digunakan untuk mengkaji kesan angin untuk struktur. Model ini telah diperiksa dengan arah yang berbeza kelajuan angin. Dari keputusan itu jelas menunjukkan bahawa kelajuan angin boleh meningkatkan tiba-tiba apabila tiupan angin sampai kepada struktur. Interaksi antara angin dan komponen struktur mungkin meningkatkan kelajuan angin sehingga 78% dari arah utara. Selain itu sejarah data kelajuan angin di stesen meteorologi yang terdekat juga diperiksa. Kelajuan angin lalu juga menunjukkan bahawa pukulan angin utama datang dari Arah Utara. Pengulangan kelajuan angin dari arah yang sama juga boleh menyebabkan kegagalan lesu kepada komponen struktur. Ia boleh membuat kesimpulan bahawa kira semasa peringkat reka bentuk yang perlu dianggarkan dengan betul. Orientasi jambatan boleh meningkatkan potensi angin mendorong kegagalan struktur. Oleh itu, arah angin dan kelajuan interaksi antara angin dan struktur keperluan yang akan juga diiktiraf di peringkat reka bentuk untuk mengurangkan risiko angin untuk komponen jambatan pejalan kaki.

TABLE OF CONTENTS

	Page
SUPERVISOR'S DECLARATION	ii
STUDENT'S DECLARATION	iii
ACKNOWLEDGEMENTS	v
ABSTRACT	vi
ABSTRAK	vii
TABLE OF CONTENTS	viii
LIST OF TABLES	xi
LIST OF FIGURES	xii
LIST OF SYMBOLS	xiii
LIST OF ABBREVIATIONS	xiv

CHAPTER 1 INTRODUCTION

1.1	Background	1
1.2	Problem Statement	2
1.3	Objective of Study	3
1.4	Scope of Study	3
1.5	Significant of Study	4
1.6	Thesis Structure	4

CHAPTER 2 LITERATURE REVIEW

2.1	Introduction	5
2.2	Basic Wind Speed	5
2.3	Design Wind Speed	8
2.4	Wind Loading	9
2.5	Simulation of Wind using CFD	10

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction 11
3.2 Research Flowchart 12
3.3 Data Collection 13
3.3.1 Wind Data during Incident 16
3.4 Data Processing 17
3.4.1 CFD Simulation 17
3.5 Results 19
3.6 Summary 20

CHAPTER 4 RESULTS AND DISCUSSIONS

4.1 Introduction 21
4.2 Historical Wind Speed 22
4.3 Wind Data Estimation during Incident 26
4.4 CFD Simulation Results 29
4.5 Summary 33

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction 36
5.2 Conclusions 36
5.2.1 Objective 1: To study and investigate the characteristic of wind before and during the pedestrian bridge collapsed 36
5.2.2 Objective 2: To investigate and simulate the potential of cause of failure of the pedestrian bridge using Computational Fluid Dynamics. 36
5.3 Recommendations 38

REFERENCES 39
APPENDICES 41

LIST OF TABLES

Table No.	Title	Pages
2.1	Averaging Time of Basic Wind Speed (Zhou, 2002)	6
2.2	Basic Wind Speed for major towns in Peninsular Malaysia	7
3.1	Daily weather data for June 2014	13
3.2	Example table of calculated monthly maximum average wind speed with respect to wind direction for Year 2014	14
3.3	Range of each Wind Direction	18
3.4	The Orientation of the Pedestrian Bridge in CFD	18
4.1	Calculated average wind speed with respect to the wind direction in Year 2013	21
4.2	Calculated average wind speed with respect to the wind direction in Year 2014	22
4.3	Historical wind data on 12th October 2014	25
4.4	Percentage of Wind Speed Increase in Simulation	34

LIST OF FIGURES

Figure No.	Title	Pages
1.1	Location of the metal roofing landed	2
2.1	Basic Wind Speed for towns in Peninsular Malaysia (50 Years Return Period)	8
3.1	Wind Rose for Year 2013 based on MET Weather data	15
3.2	Wind Rose for Year 2014 based on MET Weather data	15
3.3	Graphs of wind speed and wind direction on 12 October 2014	16
3.4	The Position of the Pedestrian Bridge on Wind Rose	17
3.5	3D Model of Pedestrian Bridge	18
4.1	Wind Rose of Year 2013 based on MET Weather	21
4.2	Data Wind Rose of Year 2014 based on MET Weather Data	22
4.3	Wind from North Direction	23
4.4	Weather data for the day of the pedestrian bridge incident	26
4.5	Direction of wind for every hour on 12^{th} October 2014	26
4.6	Result of Wind blowing from North	29
4.7	Result of Wind blowing from North-East	30
4.8	Result of Wind blowing from East	30
4.9	Result of Wind blowing from South East	31
4.10	Result of Wind blowing from South	31
4.11	Result of Wind blowing from South West	32
4.12	Result of Wind blowing from West	32
4.13	Result of Wind blowing from North West	33

LIST OF SYMBOLS

%	**Percentage**
m/s	Meter per second
km/h	Kilometers per hour
°	Degree
Md	Wind Directional Multiplier
Mz,cat	Terrain/ Height Multiplier
Ms	Shielding Multiplier
Mh	Hill Shape Multiplier
Pa	Pascal
Vs	Basic Wind Speed
Vdes	Design Wind Speed
I	Wind Importance Factor

LIST OF ABBREVIATIONS

MS	Malaysia Standard
MET	Malaysian Meteorological Department
BS	British Standard
EN	European Standards
3D	3-Dimensional
CFD	Computational Fluid Dynamics
N	North
NW	North West
NE	North East
S	South
SE	South-East
SW	South-West
W	West
E	East
AS	American Standard
AIJ	Architectural Institute of Japan
ISO	International Organization for Standardization
ASCE	American Society of Civil Engineers
NBCC	National Buildings Construction Corporation

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

There had been reported numbers of damaged occurred to the pedestrian bridge in Malaysia. It had become significantly since there is affected loss in property and may also cause injury to people. According to the news reported on 12th October 2014, the metal roof of the pedestrian bridge in Perling-Pasir Gudang Highway flew off from its concrete foundation in a windstorm. The incident happened between 4.00pm to 5.00pm. Two cars, a lorry and a motorcycle were damaged due to the incident. It was also reported that 2 men and 3 women were injured. The incident had caused major traffic congestion along the highway as the metal roof of the pedestrian bridge landed on the road and blocked the traffic coming from both lanes of the highway. The pedestrian bridge links Taman Melati and Taman Kobena in Tampoi, Johor Bahru. The approximate location of the metal roofing after it was blown off from the concrete foundation of the pedestrian bridge is shown as in **Figure 1.1**.

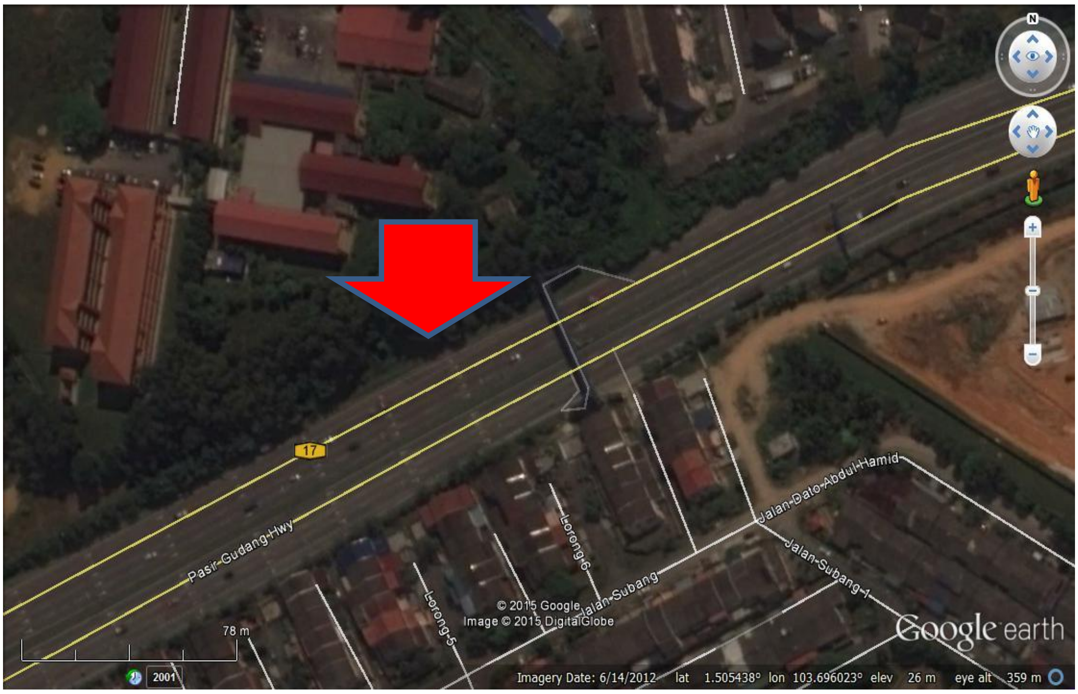


Figure 1.1: Location of the metal roofing landed

Source : Google Earth

Wind is able to produce three types of effect on a structure which is static, dynamic and aerodynamic. Consequently, the response of load depends on type of structure. Wind fluctuation during high wind events can have a serious effect on building envelopes, often with serious consequences such as roof failures (Morrison & Kopp, 2011) because wind uplift pressure makes roof membranes flutter or rapidly flap up and down (Baskaran et al., 2009). According to Suaris and Irwin (2010) the uplift pressure generated by corner vortices can create very high intermittent suction. A strong lifting force on the roof is created when wind flows over the roof of a structure which can cause it to break away. Hence, when wind flows over the pedestrian bridge it creates an aerodynamic pressure on its roof.

1.2 PROBLEM STATEMENT

Design stage is a very important step in constructing a structure which in this case a pedestrian bridge. The effect of wind on the intended location is not taken into consideration when designing the structure. As we know that wind is able to bring damage to the structure if it is not designed well and wind is considered as trivial.

In this developing world, people are competing with each other to advertise their products or services in order to attract more customers. One of their ways to advertise is to put advertisement on the billboard on the pedestrian bridge. By doing this, the additional structure might affect the sturdiness of the pedestrian bridge from its initial design. Thus, the effect of additional structure on the pedestrian bridge is should be inspected well.

1.3 OBJECTIVES OF STUDY

The objectives of this research are:

i. To study and investigate the wind characteristics before and during the pedestrian bridge's failure.

ii. To investigate and simulate the potential of cause failure of the pedestrian bridge using CFD software

1.4 SCOPE OF STUDY

This study is limited to the pedestrian bridge at Perling – Pasir Gudang, Johor. The type of pedestrian bridge is limited as to one type only which is the type of the pedestrian bridge of study. The weather data was collected from the nearest meteorological station in Malaysia specifically for the year 2013 and 2014.

Computational Fluid Dynamics software is used to simulate air flow around the 3D model and investigate the effect of wind on the pedestrian bridge. Sketch-Up software is used to build the 3D model of the pedestrian bridge. In addition, Google Earth software is used to study the location of the pedestrian bridge and surrounding the structure.

In this research, only the effects due to wind and direction are investigated. The impact due to rain was negligible. The obstruction of other existing trees or other structures was not considered in this research.

1.5 SIGNIFICANT OF STUDY

This research allows for exploration on the effect of wind to the pedestrian bridge by using Computational Fluid Dynamics to visualize graphically the airflow pattern and its behavior around the structures. Thus, it is a reliable method to conduct experiments without wasting more time or cost compared to using the wind tunnel approach.

1.6 THESIS STRUCTURE

The thesis is divided into five main chapters:

i) Chapter 1 : Introduction
   This chapter includes background of study, problem statement, objectives and scope of study.

ii) Chapter 2 : Literature Review
   This chapter reviews about the previous study material which related to the objectives.

iii) Chapter 3 : Methodology
   This chapter illustrates the flow of thesis production in a flow chart, from data collection until the production of the result.

iv) Chapter 4 : Result and Discussion
   This chapter displays the results and discussion based on the case study.

v) Chapter 5 : Conclusion and Recommendation
   This chapter discusses about the conclusion of the study based on thesis result and provides recommendations for future study.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

Wind load influence on the design of all kinds of civil engineering structure. Wind load have the ability to bring damage to buildings and other structures. Damage from wind speed force acting on building has been considered as act of god for many centuries (Senin, 2000). However, in the 18^{th} century many researchers have interest in wind characteristic. A lot of structures fail due to the inadequate consideration in the design stage. Development of construction method depends on the trial and error in building a wind-resist structure. Therefore, in order to build a stable structure and able to withstand the pressure from the wind, the impact of wind must be considered in the design.

Many researchers have conducted similar studies regarding wind-related effect on engineered structure such as this and there are many theories have been proposed to explain the effect of wind on the structures. This chapter of literature review will focus on major aspects of theories which emerge throughout this study.

2.1 BASIC WIND SPEED

Basic wind speed (V_s) can be defined as maximum wind speed that will occur one in a recurrent interval year (X_T), where X is the wind speed and T is the year. Usually, T is taken as 50 years and 100 years. The basic wind speed, V_s is used as reference wind speed that will be considered in calculation design load of building structure. The height of reference taken is at 10 m above ground level at all meteorological station. According to Zhou, (2002) basic wind speed is based on averaging time 10 minutes to 1 hour in several international codes and standards. Averaging time is wind speed measured over an interval time to provide basic wind speed. **Table 2.1** shows the averaging time of basic wind speed for different country.

Table 2.1: Averaging Time of Basic Wind Speed (Zhou, 2002)

COUNTRY	CODE	AVERAGING TIME
-	ISO 4354	10 minutes
European Country	ENV 1991-2-4	10 minutes
United States of America	ASCE 7-98	3 seconds
Japan	AIJ 1996	10 minutes
Australia	AS 1170.2	3 seconds
United Kingdom	BS 6399:PART 2	1 hour
Canada	NBCC 1996	1 hour
Malaysia	MS 1553:2002	3 seconds

Table 2.2 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. The pedestrian bridge is situated at Johor Bharu, Malaysia. Therefore, the basic wind speed will be referring to Senai station which the nearest meteorological station to the pedestrian bridge.

Table 2.2: 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 Station (MET), 2013

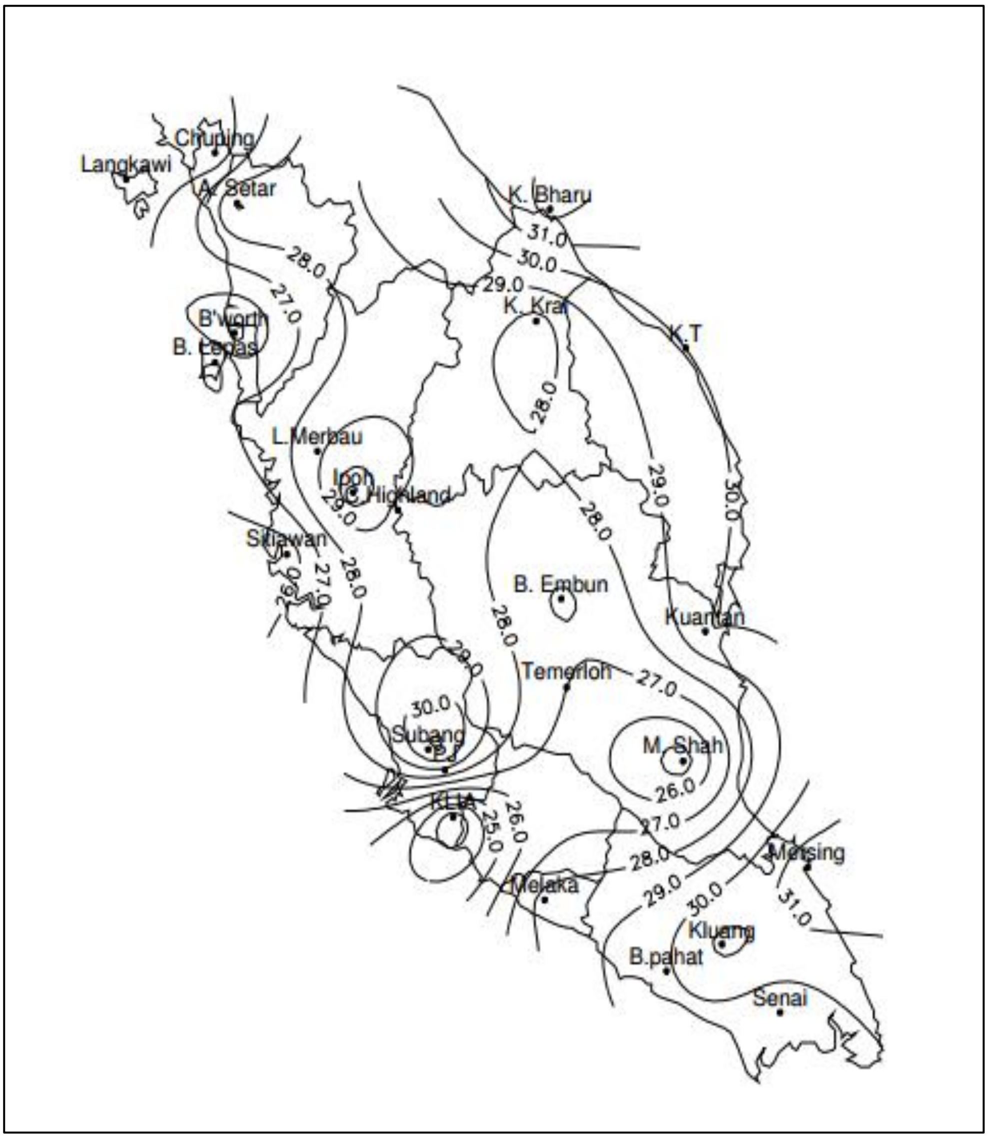


Figure 2.1 Basic Wind Speed for towns in Peninsular Malaysia (50 Years Return Period)

Source: Malaysian Meteorological Department (MET) 2013

2.3 DESIGN WIND SPEED

Design wind speed is derived from site wind speed multiplied with some parameter such as terrain categories and type of building. Design wind speed is one of the key components of any wind loading code. The calculation of design wind speed is based on basic wind speed information in the design codes. The variation with direction and height is determined using established techniques based on the roughness and topography of the site.

The equation of design wind speed:

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

Where,

V_{des}	=	Design Wind Speed
I	=	Wind Importance Factor

The value of site wind speed can be calculated using the following equation:

$$V_{site} = V_s(M_d)\left(M_{z,cat}\right)(M_s)(M_h)$$

Where,

V_s	=	Basic Wind Speed (m/s)
M_d	=	Wind Directional Multiplier
$M_{z,cat}$	=	Terrain /Height Multiplier
M_s	=	Shielding Multiplier
M_h	=	Hill Shape Multiplier

2.4 WIND LOADING ANALYSIS

The estimation of wind loading for structural design in Malaysia is based on MS1553: Code of Practice on Wind Loading for Building Structures, 2002. This code specifies the procedures to determine wind speed and resulting wind actions to be used in the design for structures subjected to wind loading. It also covers structures with criteria of (i) buildings of less than 200 m high, (ii) structures with roof span less than 100 m and (iii) structures other than offshore structures, bridges and transmission lines.

2.5 SIMULATION OF WIND USING CFD

CFD is now widely use in the prediction of flow fields due to the time and cost issues involved in wind tunnel testing. The first CFD techniques were introduced in the early 1950s, where it is made possible by the advent of the digital computer (Chung, 2002). CFD is a computer-based mathematical modeling tool capable of dealing with fluid flow problems and predicting physical fluid flows and heat transfer (Versteeg & Malalasekera, 1995).

CFD is used intensively as a tool for evaluating the indoor environment of a building and its interaction with the building envelope, as well as for analyzing the outdoor environment surrounding the building (Blocken et. al., 2009). CFD can used to analyze the wind loading on buildings, bridges and other structures as the prediction of external air flow. As an example, Sengupta et al. (2008) had simulated the effects of microburst and tornadic winds to quantify the resulting aerodynamic loading on a building. The simulation is to investigate the peak loads and stresses at various locations on a roof. Then, the results are compared to the corresponding values for the guidelines specified in ASCE 7-05.

CFD is more advantageous compared to traditional wind tunnel testing (Wainwright et al., 2004). It can generate full-scale simulations as opposed to scale models of many physical simulations as well as providing extensive data that can be measured in the lab and its results can be visualized clearly and in detail.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter will discuss about the method of collecting data and inputting the data to get results. Generally, the information of wind is obtained from the Meteorological Department (MET). The related wind data is collected and tabulated. Wind data on the day of the incident also taken to investigate the cause of pedestrian bridge failure. Three-dimensional pedestrian bridge model is made and then imported into the CFD software for simulation. This study is primarily consists of 4 phases, which are:

i) Data collection

Obtaining historical weather data from 2013 to 2014 and the weather data specifically on 12 October 2014 from nearby meteorological station

ii) Preparation

The collected data are tabulated in Microsoft Excel in the form of tables

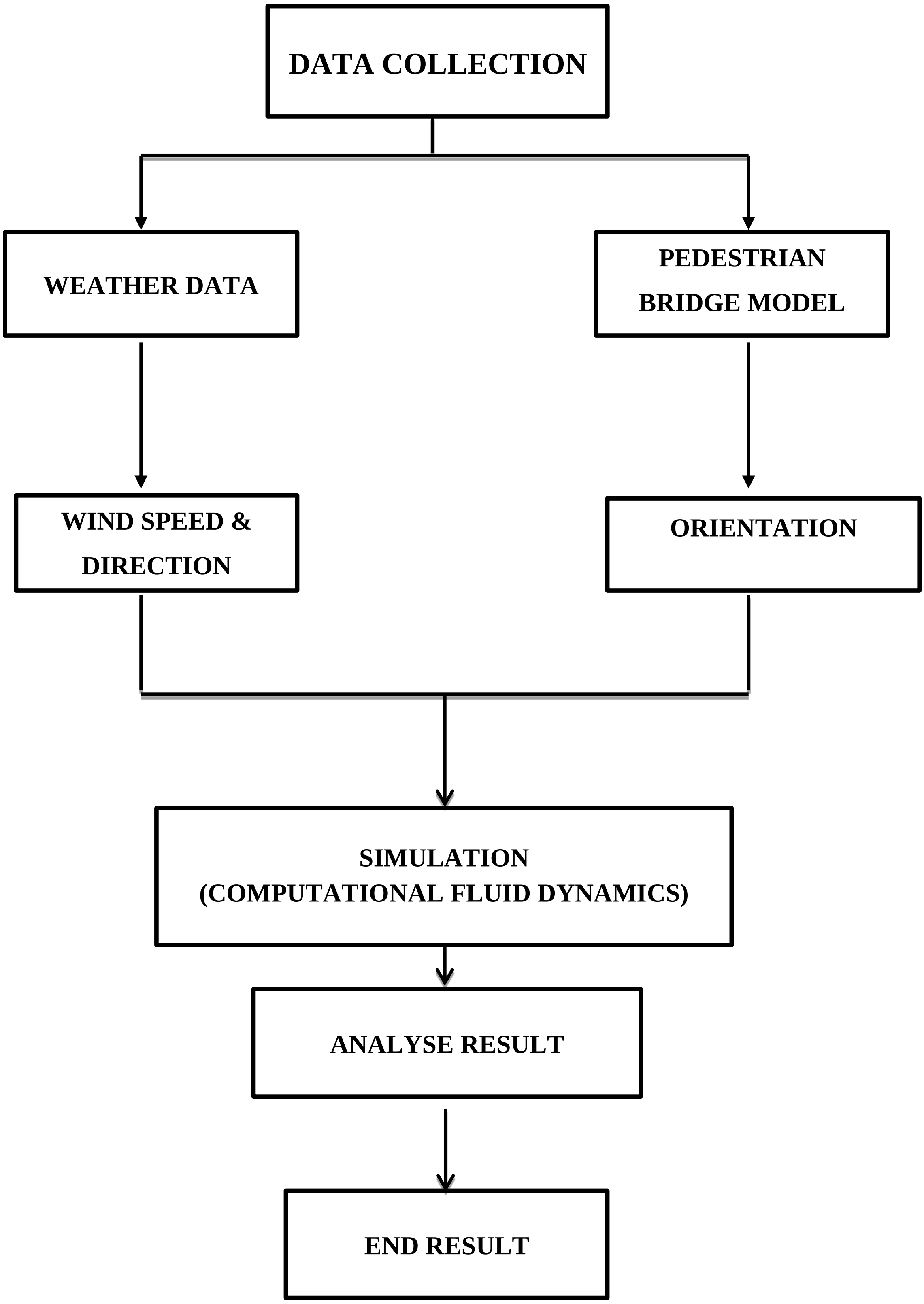
iii) Data Processing

Data are input into Computational Fluid Dynamics (CFD) and analysed

iv) Results

Results are being analysed and discuss

3.2 RESEARCH FLOWCHART



3.3 DATA COLLECTION

The pedestrian bridge incident happens on 12 October 2014 between 4.00pm to 5.00pm following a freak storm. The historical weather data were taken throughout the Year of 2013 and 2014. The weather data are collected from the nearest Malaysian Meteorological Department.

Wind speed and wind direction factors are the main factors for this study. The other data taken from MET will not be considered. The wind data for each year is tabulated using Microsoft Excel after collecting related information. 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.

The historical wind data are gathered on monthly basis throughout the year of 2013 and 2014. This is done in order to estimate the maximum average wind speed and the direction of wind frequently blows. Example information obtained from MET are as shown in **Table 3.1.**

Table 3.1 Daily weather data for June 2014

Daily Weather History & Observations

2014	Temp. (°C)			Dew Point (°C)			Humidity (%)			Sea Level Press. (hPa)			Visibility (km)			Wind (km/h)			Precip. (mm)	Events
Oct	high	avg	low	high	avg	low	high	avg	low	high	avg	low	high	avg	low	high	avg	high	sum	
1	33	30	27	26	24	20	94	71	46	1012	1010	1007	10	8	2	16	10	-	0.00	
2	32	29	27	26	23	18	94	67	43	1012	1010	1007	10	7	2	13	8	-	0.00	
3	33	30	27	24	23	22	84	68	52	1011	1009	1006	10	8	6	16	8	-	0.00	
4	30	27	24	25	24	23	100	79	66	1012	1010	1008	10	8	1	19	8	-	0.00	Rain , Thunderstorm
5	32	28	25	24	23	21	84	72	55	1012	1011	1009	10	10	10	16	10	-	0.00	
6	33	29	26	23	21	19	83	59	43	1012	1009	1007	9	5	1	19	10	-	0.00	
7	33	30	28	24	23	22	79	65	52	1011	1009	1007	10	9	5	16	11	-	0.00	
8	34	30	27	24	23	22	84	65	52	1011	1009	1007	10	8	5	16	8	-	0.00	
9	32	29	27	25	23	20	84	67	55	1011	1009	1007	10	10	8	21	10	-	0.00	Thunderstorm
10	33	30	28	24	22	19	79	63	43	1012	1009	1007	10	10	8	16	10	-	0.00	
11	33	30	27	25	23	20	84	70	52	1011	1009	1007	9	5	3	19	10	-	0.00	Rain , Thunderstorm
12	33	29	26	24	23	21	89	72	52	1012	1010	1008	10	7	3	16	6	-	0.00	Rain , Thunderstorm

Source: Malaysian Meteorological Stations, 2014

Table 3.2 Example table of calculated monthly maximum average wind speed with respect to wind direction in Year 2014

DIRECTION	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JULY**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**	**AVERAGE**
NORTH	17.4	20.1	17.2	15.4	15.7	16	0	16.38	16	14.44	23.88	22.57	16.26
NORTH EAST	22.9	19.3	19.3	13	13.3	13	12.2	15.4	16	17.25	19.25	0	15.08
EAST	0	0	0	14	13	13	13	19	13.25	13	16.5	16	10.9
SOUTH EAST	0	0	0	0	0	13.2	14	17.25	14	14	14.5	0	7.25
SOUTH	0	0	0	0	15	13.3	13.8	17.5	0	0	16	0	6.3
SOUTH WEST	0	0	0	0	13.8	13	12.7	11.5	14	14	17	21	9.75
WEST	0	0	0	14.5	10.5	13	13.5	12.75	13.33	15.33	21.75	16	10.89
NORTH WEST	16	0	0	14.9	13.3	13.5	15.3	12.67	12.33	15.33	20.25	18	12.63

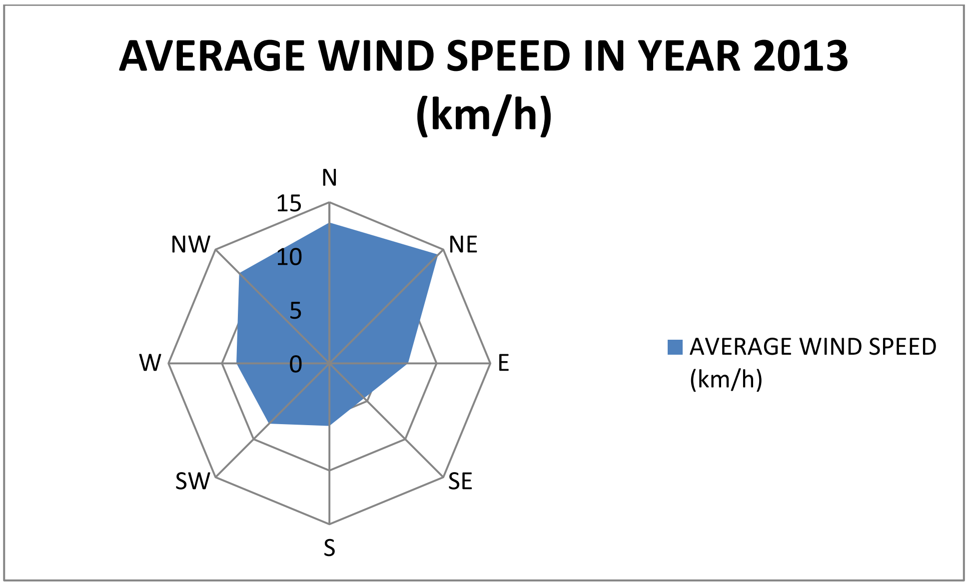


Figure 3.1 Wind Rose for Year 2013 based on MET Weather data

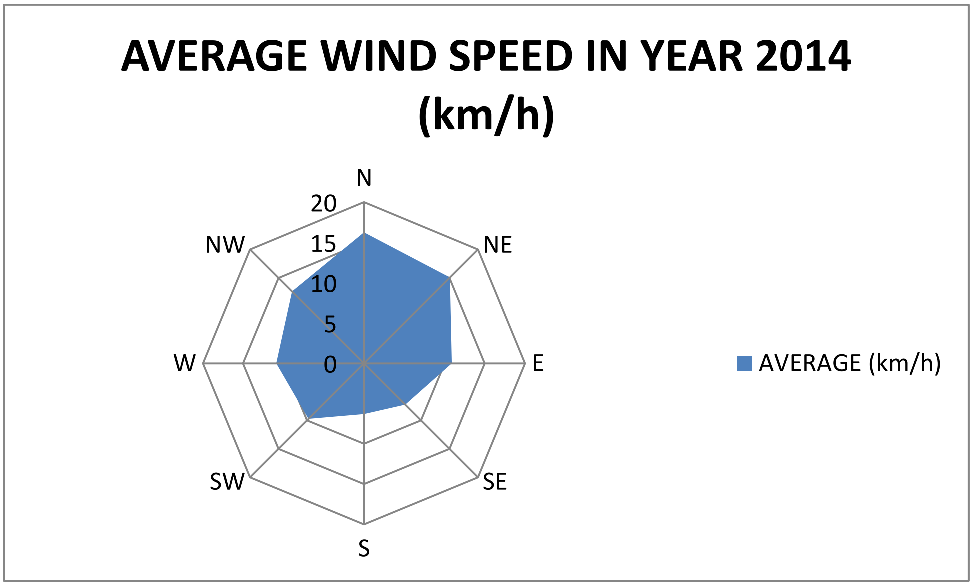


Figure 3.2 Wind Rose for Year 2014 based on MET Weather data

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 that particular year. **Table 3.2** shows the example table of calculated maximum average wind speeds for Year 2014 (refer to **APPENDIX E** for year 2013).

APPENDIX A & B shows the historical weather data which will be extracted into **APPENDIX C & D**. Based on **APPENDIX C & D**, the average maximum wind speed will be calculated based on their respective direction of wind. Wind rose of the average wind speed for each year can be constructed based on the data in **Table 3.2**. **Figure 3.1** and **3.2** shows the wind rose for the year 2013 and 2014 respectively**.** **Appendix G & H** shows the monthly wind rose for year 2013 and 2014.

3.3.1 Wind Data during incident

The pedestrian bridge is located at Perling – Pasir Gudang Highway, Johor Bahru, Malaysia. On 12 October 2014 around 4.00pm to 5.00pm, a storm occurred causing the metal roofing of the pedestrian bridge to fly off from its concrete foundation. The wind speed and direction of wind on that day is determined from the nearest meteorological station which is Senai station.

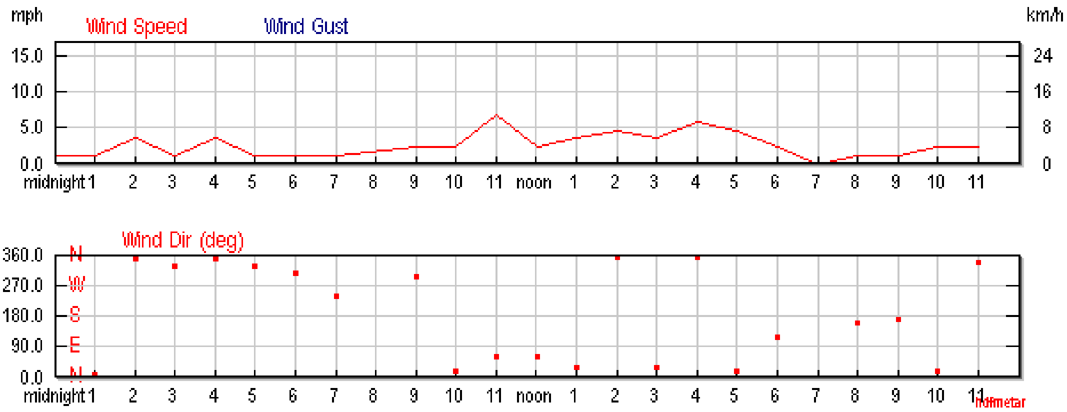


Figure 3.3: Graphs of wind speed and wind direction on 12 October 2014

Source: Malaysian Meteorological Stations, 2014

3.4 DATA PROCESSING

3.4.1 CFD Simulation

CFD is used to simulate air flow around the pedestrian bridge in a virtual wind tunnel. CFD is to aid in understanding the behaviour of the air flow when it flows over the pedestrian bridge. Furthermore, it allows for exploration on the effect of wind on structures of different conditions.

Before importing the model into the software, the zero degree of the pedestrian bridge is determined using the image from Google Earth and wind rose as shown in the **Figure 3.4**.

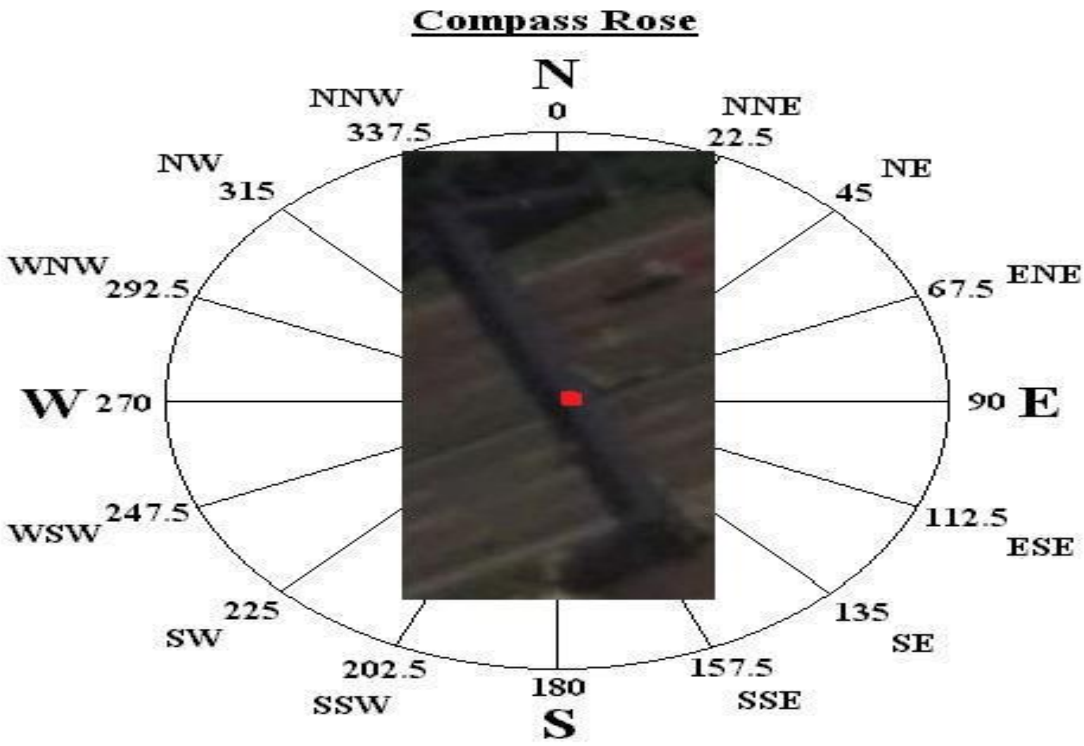


Figure 3.4: The Position of the Pedestrian Bridge on Wind Rose

The position of the pedestrian bridge model is determined before it was simulated in CFD as shown above. The position of the pedestrian bridge is determined according to the image taken from Google Earth and it shows that the structure tilted to the left around 22.5^o. Thus, when simulating the pedestrian bridge in CFD, the North-North-West (NNW) is set up as the North (zero degree).

Table 3.3: Range of each Wind Direction

WIND DIRECTION	**RANGE^O (DEGREE)**
NORTH	315 - 0
NORTH EAST	0 - 45
EAST	45 - 90
SOUTH EAST	90 - 135
SOUTH	135 - 180
SOUTH WEST	180 - 225
WEST	225 - 270
NORTH WEST	270 - 315

The wind speed of the air flow around the pedestrian bridge is set up as 10 m/s. The wind is simulated from the North, North East, East, South East, South, South West, West, and North West direction. The image of the simulation is saved as the result. The velocity of the wind when it flows over the pedestrian bridge is tabulated.

Table 3.4: The Orientation of the Pedestrian Bridge in CFD

WIND DIRECTION	**RANGE^O (DEGREE)**
NORTH	22.5
NORTH EAST	67.5
EAST	112.5
SOUTH EAST	157.5
SOUTH	202.5
SOUTH WEST	247.5
WEST	292.5
NORTH WEST	337.5

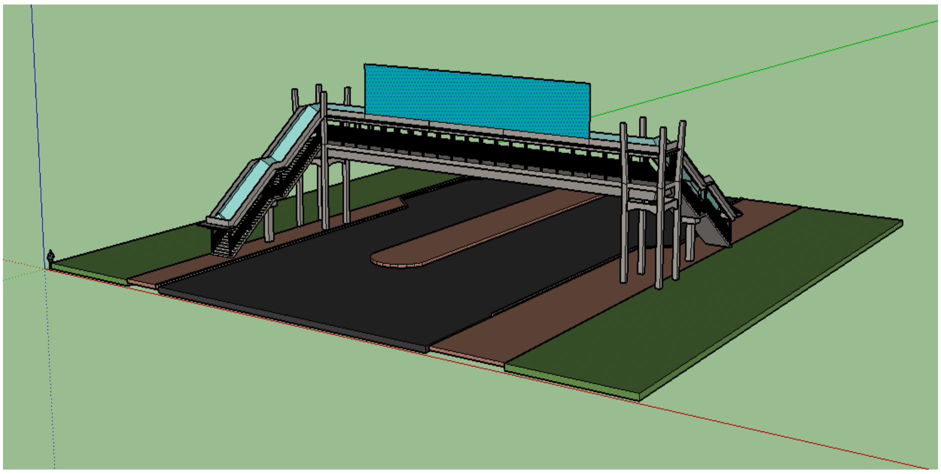


Figure 3.5: 3D Model of Pedestrian Bridge

Source: Sketch-up, 2014

The range of wind direction used in CFD is adjusted in order to display the correct orientation of the pedestrian bridge based on the real situation. **APPENDIX I** shows the steps of making the 3D model of pedestrian bridge. The 3D model is simulated from every direction based on the normal wind speed of 10 m/s. The velocity of the wind flow over the pedestrian bridge is recorded and tabulated to get the difference in velocity of the wind. Percentage of velocity increase is calculated based on the difference of velocity.

3.5 RESULTS

From the result, the predicted wind pressure on the pedestrian bridge is produced using Computational Fluid Dynamics software. **Figure 3.6** shows an example of the predicted wind pressure on the pedestrian bridge. From the data, analysis and discussion can be concluded.

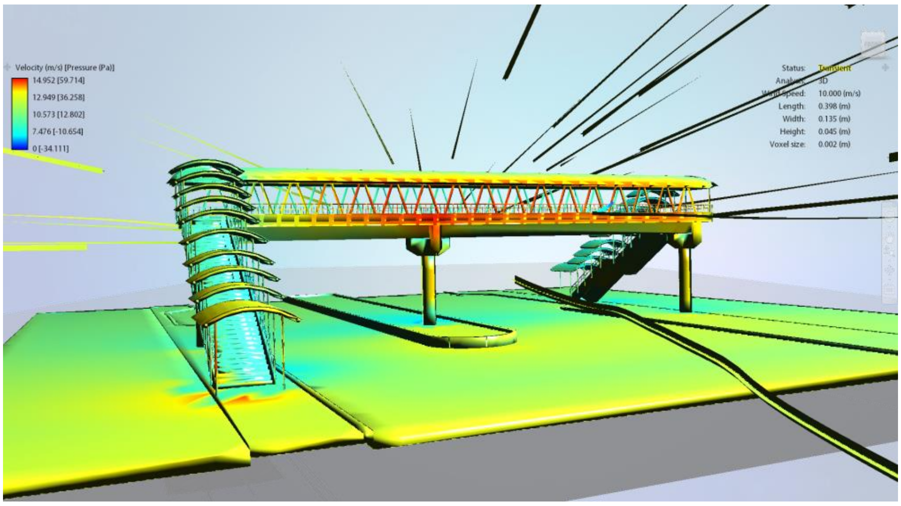


Figure 3.6: Predicted Wind Pressure on Pedestrian Bridge

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 Dynamic (CFD). This chapter also shows the sequences of steps in doing the research.

CHAPTER 4

RESULT & DISCUSSION

4.1 INTRODUCTION

This chapter consists of result and discussion after the collected data being analyzed and simulated using Computation Fluid Dynamics (CFD) software. The topics that will be discussed are analysis on the day of incident, monthly wind analysis and simulation using CFD software. The result and comparison will be further discussed.

4.2 HISTORICAL WIND SPEED

Table 4.1: Calculated average wind speed with respect to the wind direction in Year 2013

DIRECTION	AVERAGE WIND SPEED (km/h)
N	13.12
NE	14.33
E	7.33
SE	4.59
S	5.84
SW	7.96
W	8.66
NW	11.88

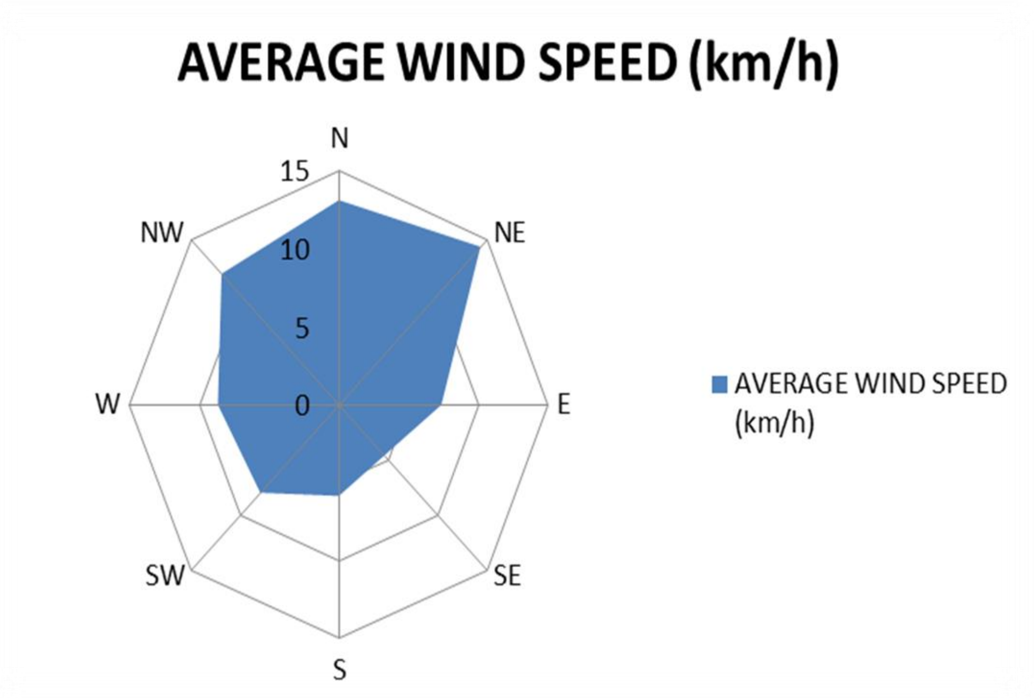


Figure 4.1 : Wind Rose of Year 2013 based on MET Weather Data

Table 4.2: Calculated average wind speed with respect to the wind direction in Year 2014

DIRECTION	AVERAGE (km/h)
N	16.26
NE	15.08
E	10.9
SE	7.25
S	6.3
SW	9.75
W	10.89
NW	12.63

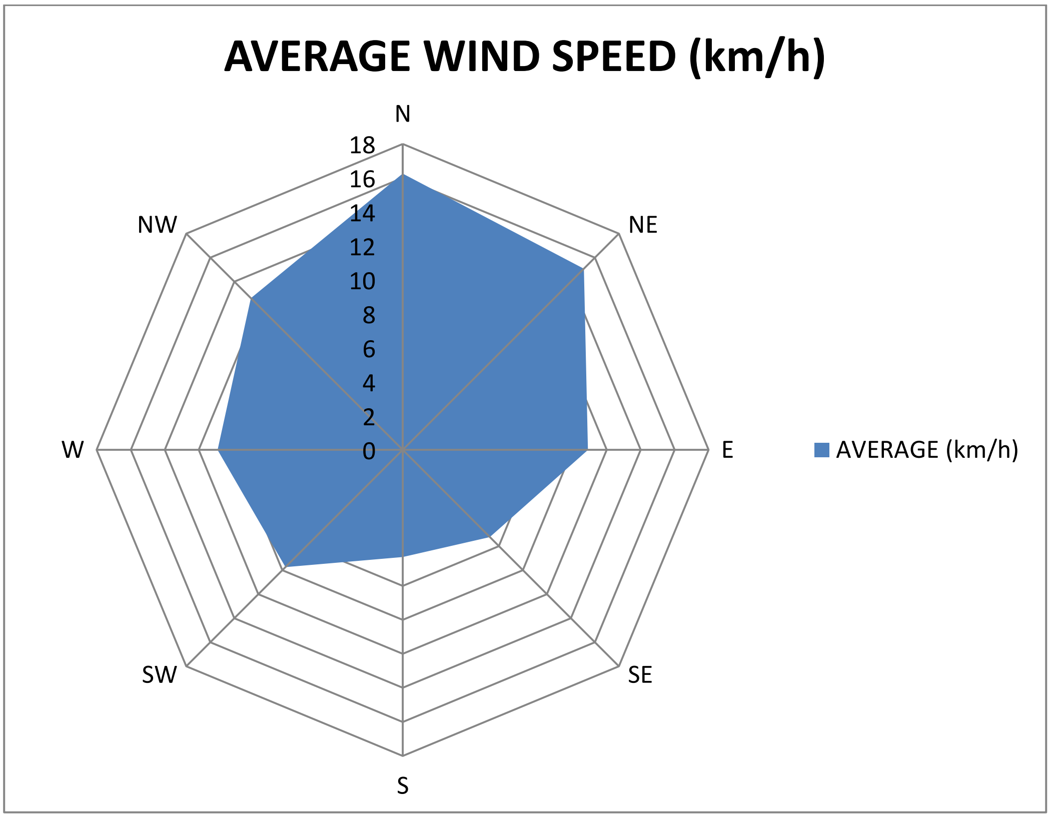


Figure 4.2 : Wind Rose of Year 2014 based on MET Weather Data

The data of wind speed and wind direction of year 2013 and year 2014 is tabulated as shown in the **Table 4.1** and **Table 4.2**. Then, the average of wind speed for every direction of wind is calculated and represented in wind rose as shown in **Figure 4.1** and **Figure 4.2**.From the data in **Table 4.1** above, it shows that the wind direction that has the highest average velocity is from the North East direction. The highest average velocity is in month of April which is 18 km/h and in the North East direction.

From the data in **Table 4.2** above, it shows that the wind direction that has the highest average velocity is from the North direction. The highest average velocity is in month of November which is 23.88 km/h and in the North direction.

Based on the wind roses, throughout the year 2013 and 2014 the wind frequently blows from the North and North-East direction. The wind load acting on the pedestrian bridge is repeatable throughout the year which causes the structural component become weak.

Figure 4.3 : Wind from North direction

The wind frequently hit the pedestrian bridge from the North direction throughout the year as shown in the **Figure 4.3** according to the data collected. The impact of wind from same direction affects the pedestrian bridge. Thus, this could possibly resulting of weaken joints between the components of the pedestrian bridge.

4.3 WIND DATA ESTIMATION DURING INCIDENT

Table 4.3 : Historical wind data on 12th October 2014

Time	Wind Direction (Degree)	Wind Speed (Km/h)
12:00 AM	300	1.9
1:00 AM	10	1.9
2:00 AM	350	5.6
3:00 AM	330	1.9
4:00 AM	350	5.6
5:00 AM	330	1.9
6:00 AM	310	1.9
7:00 AM	240	1.9
9:00 AM	300	3.7
10:00 AM	20	3.7
11:00 AM	60	11.1
12:00 PM	60	3.7
1:00 PM	30	5.6
2:00 PM	360	7.4
3:00 PM	30	5.6
4:00 PM	360	9.3
5:00 PM	20	7.4
6:00 PM	120	3.7
7:00 PM	0	Calm
8:00 PM	160	1.9
9:00 PM	170	1.9
10:00 PM	20	3.7
11:00 PM	340	3.7

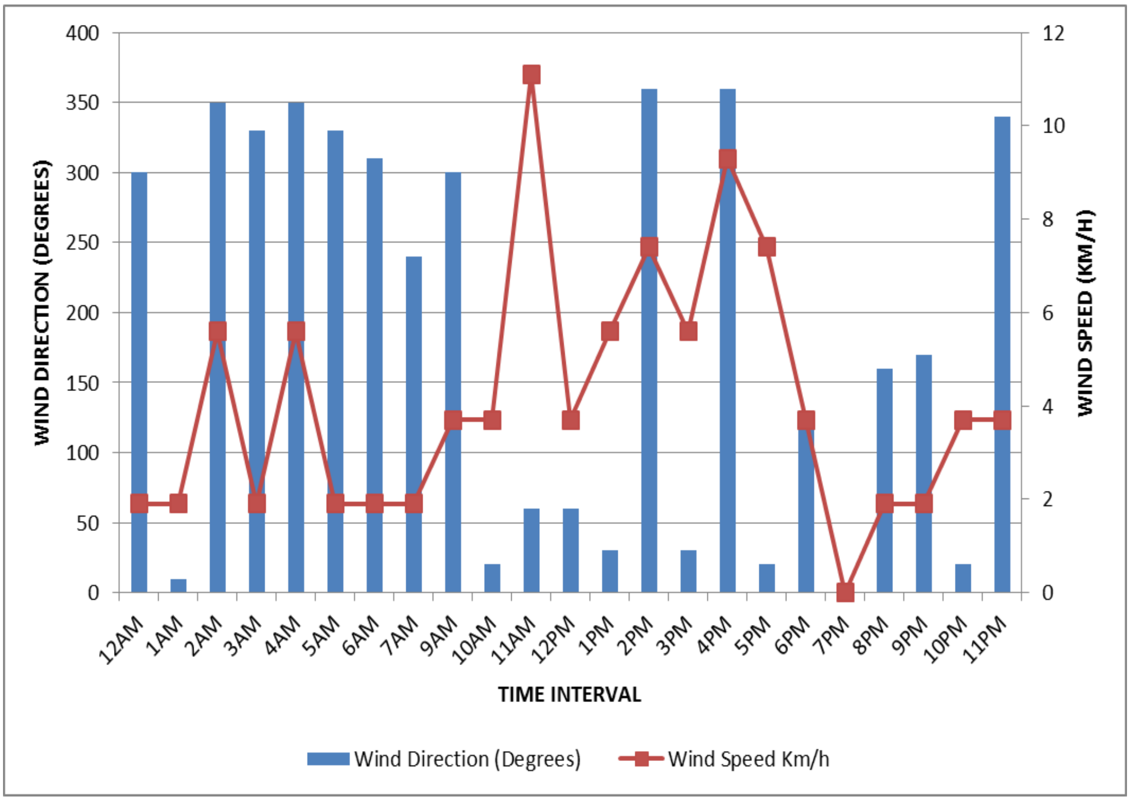


Figure 4.4: Weather data for the day of the pedestrian bridge incident

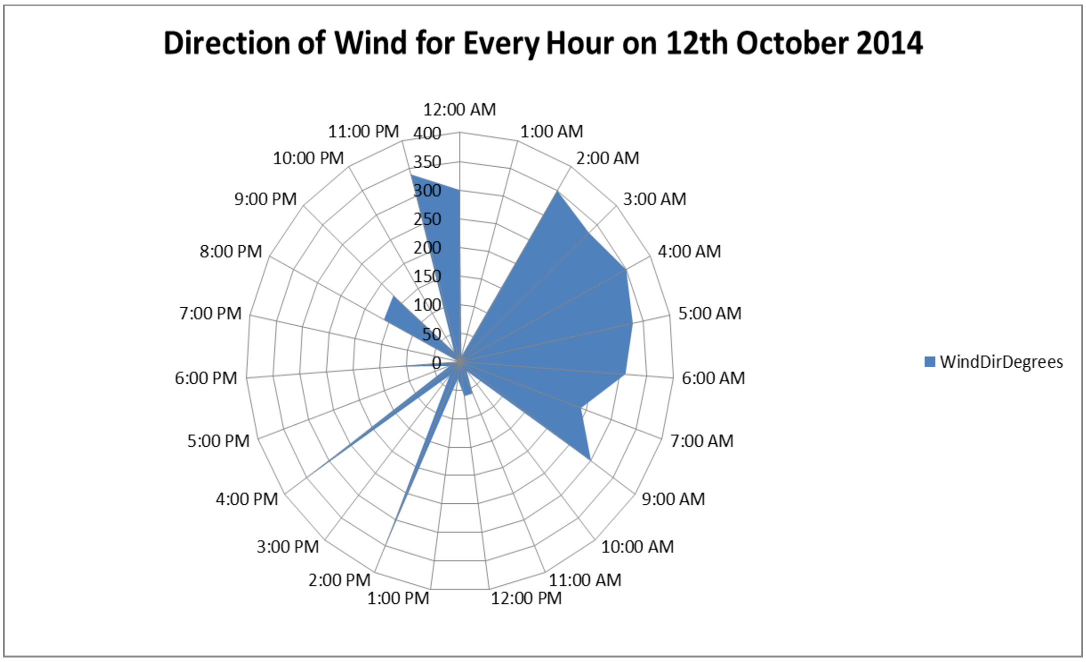


Figure 4.5: Direction of wind for every hour on 12th October 2014

The historical data is taken from the nearest meteorological station which is Johor Bharu, on 12th October Malaysia. For every hour, the wind speed and wind direction is tabulated into table form in Microsoft Excel as shown in **Table 4.1**. It is then represented into combined graph as shown in **Figure 4.2** and **Figure 4.3** for better visualization of the data and easier analysis.

The incident of metal roofing of pedestrian bridge blown off is happened between 4.00pm to 5.00pm. Based on the data taken on the day of the incident, it is shown that during the incident, there is a sudden increase of wind speed between 4.00pm to 5.00pm from 5.6 km/h to 9.3 km/h and the wind blew from the North direction. However, the speed of wind shows that it was not significantly high enough to damage the pedestrian bridge. It also shows that the highest speed of wind on that day is 11.1 km/h and the direction of wind blow is from the North-East.

Furthermore, it is noted that there is an additional structure on the pedestrian bridge which is a big billboard built on top of the metal roofing. Based on Figure 4.3, the wind frequently blows from the North North-East, East and South-East direction. The wind repeatedly acted on the pedestrian bridge on that day from these directions which are perpendicular to the billboard on the pedestrian bridge. Consequently, this resulting the metal roofing to blown off from the concrete foundation of the pedestrian bridge and landed on the other side of the road (refer to **Figure 1.1**).

4.4 CFD SIMULATION RESULTS

The structure is then simulated with wind blowing from North, North East, East, South East, South, South West, West and North West direction. The wind speed in the CFD is constant with value of 10 m/s. Afterwards, the effect on the pedestrian bridge model is observed and the value is recorded.

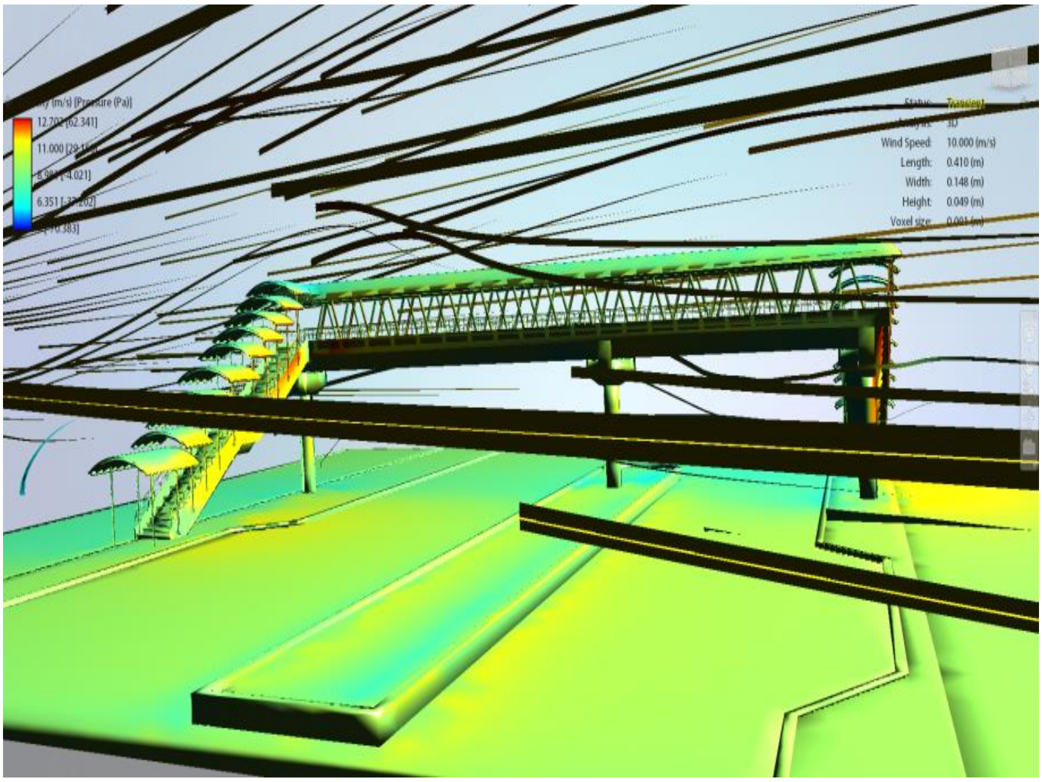


Figure 4.6: Result of Wind blowing from North

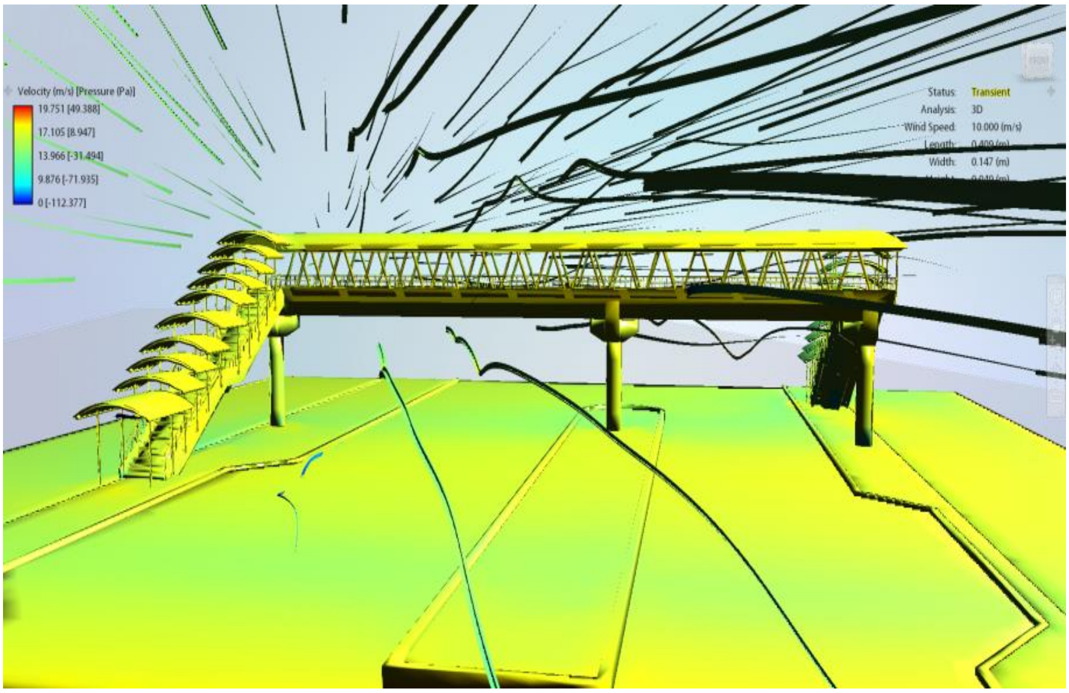


Figure 4.7: Result of Wind blowing from North East

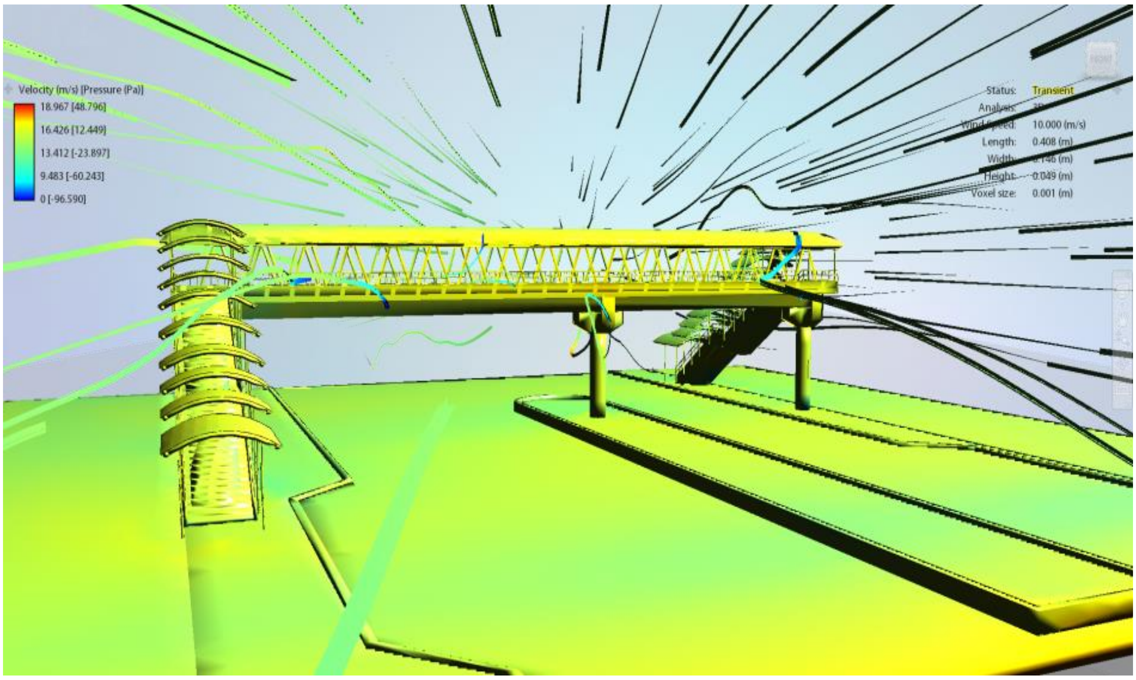


Figure 4.8: Result of Wind blowing from East

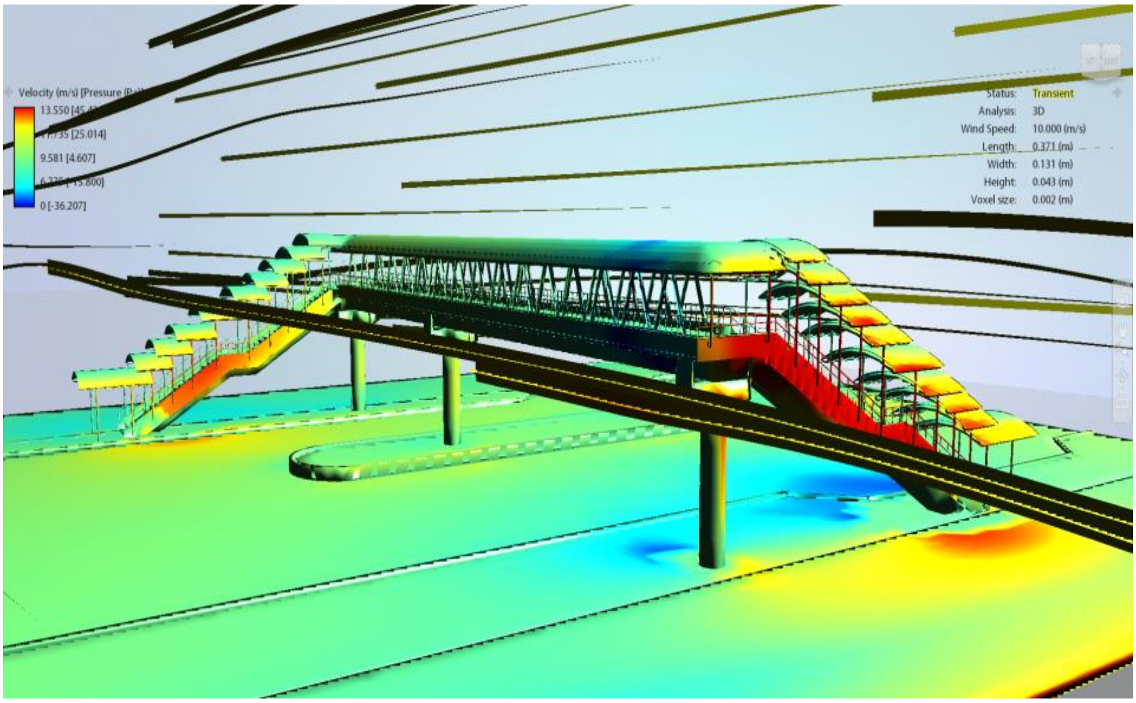


Figure 4.9: Result of Wind blowing from South East

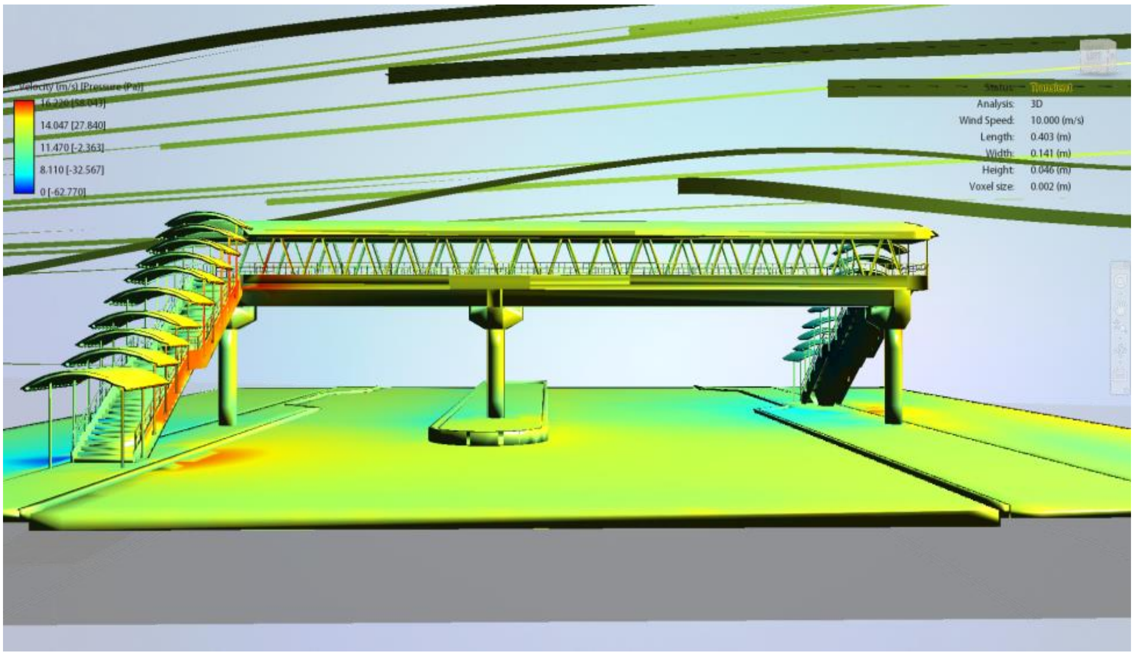


Figure 4.10: Result of Wind blowing from South

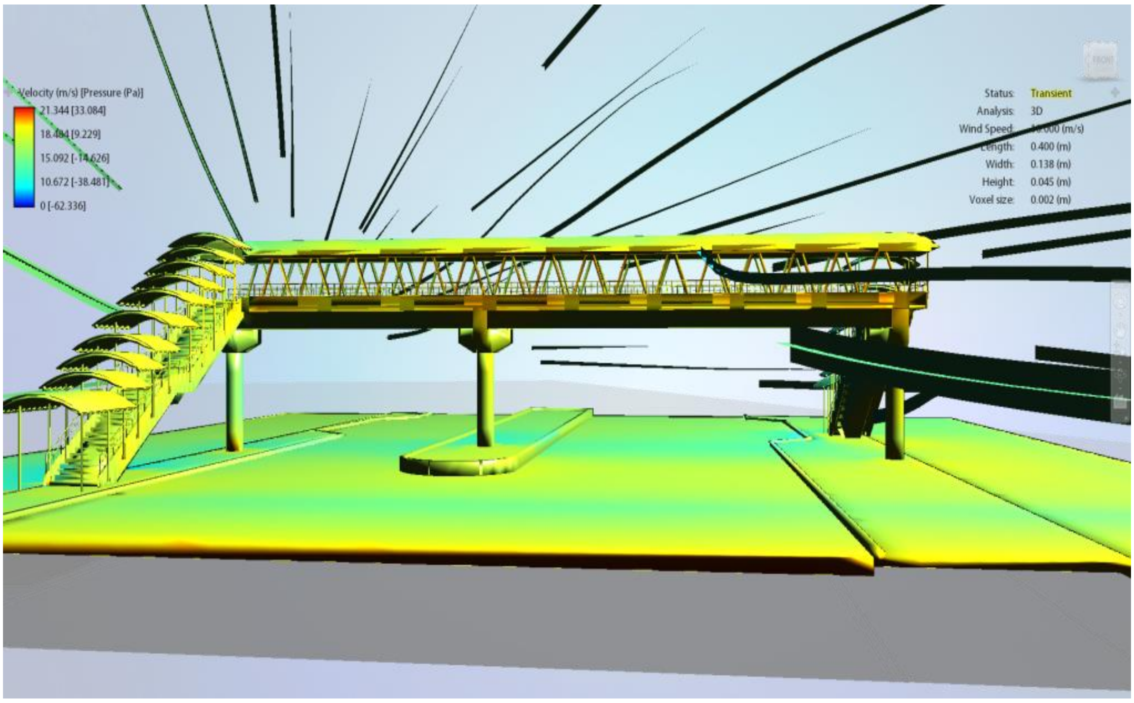


Figure 4.11: Result of Wind blowing from South West

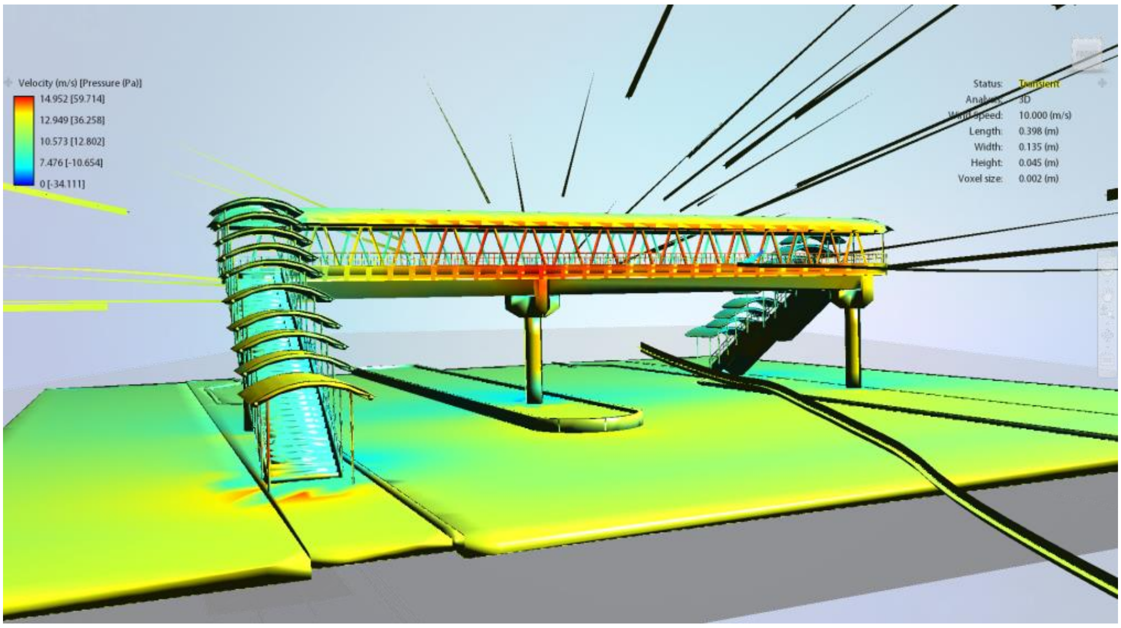


Figure 4.12: Result of Wind blowing from West

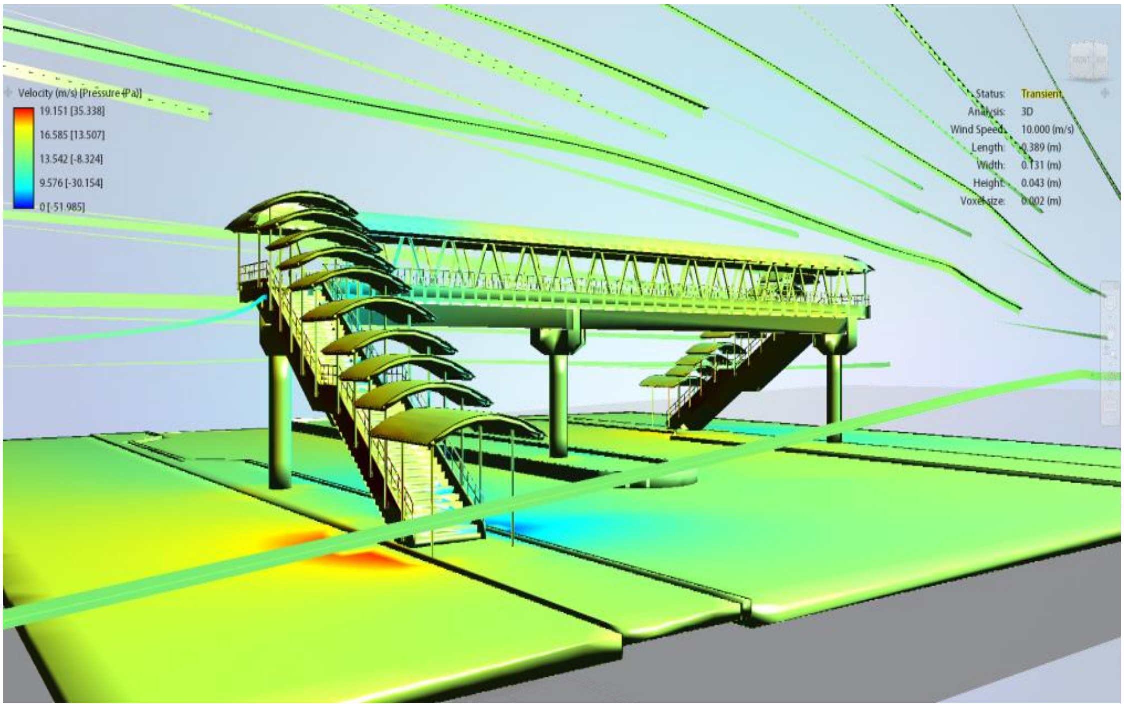


Figure 4.13: Result of Wind blowing from North West

Figure 4.6 until **Figure 4.13** shows the image of results of simulated pedestrian bridge using CFD software. The velocity of the simulated pedestrian bridge are analysed and tabulated as in Table 4 below. The difference of velocity is the difference between the constant wind speed and the resulted velocity when the wind hit the pedestrian bridge model. Percentage velocity increases for all the direction of wind are also the calculated.

Table 4.4: Percentage of Wind Speed Increase in Simulation

Wind Direction	Relative Velocity	Relative Wind Speed	Difference in Velocity	Percentage Velocity Increase, %
North	1.2702	1	2.702	78.73
North East	1.9751	1	9.751	50.63
East	1.8967	1	8.967	52.72
South East	1.355	1	3.55	73.8
South	1.622	1	6.22	61.65
South West	2.1344	1	11.344	46.85
West	1.4952	1	4.952	66.88
North West	1.9151	1	9.151	52.22

Based on the table 4, the wind blowing from North direction created the highest percentage velocity increase among all wind direction. It shows that when the wind reached the structure it increase up to 1.78 times greater than the normal wind speed which in this case is 10 m/s.

According to the Malaysian Code of Practice, the maximum wind speed that a structure can sustain is around 30 m/s. Beyond recommended maximum wind speed, the structure are vulnerable to the load causes by the wind and might not able to withstand the pressure exerted by the wind. Consequently, if the wind speed of that day is 20 m/s, the velocity of the wind may increase up to 35.6 m/s when it reached the structure. This will cause the pedestrian bridge to be damaged.

4.5 SUMMARY

Based on the results, the wind direction on the day of incident is perpendicular to the orientation of the pedestrian bridge, which may produce the maximum force on the pedestrian bridge as well as the additional structure. The wind load may increase up to 1.78 times from the normal wind speed acting on the pedestrian bridge from the North direction. However, this value may not the worst that can cause the metal roof the pedestrian bridge to blown off but it can be conclude that the possibility of the failure are highly foreseeable due to repeatable wind speed. Repeatable load acting to structural component of the pedestrian bridge may have weakened the structural component. Therefore, to ensure the pedestrian bridge to be able to withstand the load causes by the wind consideration of wind load direction is highly recommended during the design stage.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 INTRODUCTION

This chapter will discuss about the conclusion for each of the objectives outline for this study. For future study, several recommendations also included at the end of the chapter to improve the study for this research.

5.2 CONCLUSION

5.2.1 Objective 1: To study and investigate the characteristic of wind before and during the pedestrian bridge collapsed.

The first objective of this research is to study and investigate the characteristic of wind before and during the pedestrian bridge collapsed. Data of wind was collected for two years which is in the year of 2013 and 2014. From the tabulated data, we get the result that throughout the years, wind mostly blowing from North and North East direction. The wind frequently acted on the pedestrian bridge from the same direction could possibly weaken the components of the pedestrian bridge. Hence, even average speed of wind on that day of incident could damage the weakened pedestrian bridge.

5.2.2 Objective 2: To investigate and simulate the potential of cause of failure of the pedestrian bridge using Computational Fluid Dynamics.

The second objective of this research is to investigate and simulate the potential of cause of failure of the pedestrian bridge using CFD software. The pedestrian bridge model is simulated using CFD software by taking 10 m/s as the constant wind speed. From the simulation, we get the result that the wind blowing from North direction would give the highest velocity increase when it passed through the pedestrian bridge model. Therefore, it shows that the wind from North direction mostly affect the pedestrian bridge due to its fixed orientation.

As a conclusion, the objectives of this study had been achieved. The characteristic of the wind is the speed of the wind change when it passed an obstacle or a structure. Hence, the consideration during the design stage are should be properly estimated. The orientation of the pedestrian bridge may increase the potential of wind induce failure to the structure. The pressure of wind on the structure increases when the structure is built by not considering the orientation.

In order to reduce wind risk to the pedestrian bridge component the wind speed direction and the interaction between the wind and structure need to be well recognized at the design stage. In addition, wind data should be well analyzed before designing a structure. The characteristic of the wind on the particular location should be examined in order to design a stable pedestrian bridge. Moreover, design wind pressure for the geographic location of a new pedestrian bridge must be determined and be included in the calculation of the load applied on the pedestrian bridge.

5.3 RECOMMENDATION

Several recommendations can be made to further study the potential cause of pedestrian bridge failure. The materials used to construct the pedestrian bridge or the design of the pedestrian bridge also should be taken into consideration in determining the cause of failure of the pedestrian bridge. In addition, the effect of additional structure on the pedestrian also could possibly be the cause of failure. Thus, the other factors should also be investigated to get the precise cause of pedestrian bridge failure.

There are recommendations that can be done to improve the findings and validity of the result for future researchers. The data of wind should be taken at least five years for a more reliable analysis. The factor of wind causing the pedestrian bridge to be damaged should be analyzed in more details.

REFFERENCE

[1] Baskaran, B., Murty, B., Wu, J. (2009). Calculating roof membrane deformation under simulated moderate wind uplift pressures. *Engineering Structures*, 31 (3), 642-650.
ISSN 0141-0296, http://dx.doi.org/j.engstruct.2008.10.013.

[2] Bastiaansen WGM, Menenti M, Feddes R.A. and Hotslag A.A.M. (1998) "A remote sensing surface energy balance algorithm for land (SEBAL) Formulation." *Journal of Hydrology* 212-213, pp, 198-212

[3] Blocken, B., & Persoon, J. (2009). Pedestrian wind comfort around a large football stadium in an urban environment: CFD simulation, validation and application of the new Dutch wind nuisance standard. Journal of Wind Engineering and Industrial Aerodynamics, 97 (5-6), 255-270. ISSN 0167-6105, http://dx.doi.org/j.jweia.2009.06007

[4] Chung, T. (2002). *Computational fluid dynamics*. New York, NY: Cambridge University Press.

[5] E. Badiu, Gh. Bratucu, The Effect of Wind on Roof Systems for Building, 2014

[6] Gergely Szabo, Numerical and experimental based aerodynamic stability study of bridge decks, 2013

[7] J.D. Holmes, Winds Load of Structures, Spon. Press, 2001

[6] Morrison, M., & Kopp, G. (2011). Performance of toe-nail connections under realistic wind loading, *Engineering Structures*, 33(1), 69-76. ISSN 0141-0296, http://dx.doi.org/10.1016/j.engstruc.2010.09.019.

[8] MSS1553: Malaysian Code of Practice on Wind Loading for Building Structure, 2002.

[9] Sengupta, a., Haan, F., Sarkar, p., & Balaramudu, V. (2008). Transient loads on buildings in microburst and tornado winds. *Journal of Wind Engineering and Industrial*

Aerodynamics, 96 (10-11), 2173-2187. ISSN 0167-6105, http://dx.doi.org/10.1016/j.jweia.2008.02.050.

[10] Suaris, W., & Irwin, P. (2010). Effect of roof-edge parapets on mitigating extrema roof suctions. *Journal of Wind Engineering and Industrial Aerodynamics*, 98 (10-11), 483-491. ISSN 0167-6105,http://dx.doi.org/10.1016/j.jweia.2010.03.001.

[11] Wainwright, J. & Mulligan, M. (Eds.). (2004). *Environmental Modelling Finding Simplicity in Complexity*. England: John Wiley & Sons Ltd.

[12] Wieringa J., 'Updating the Davenport roughness classification''. *Journal of Wind Engineering and Industrial Aerodynamics* Vol.41, pp, 357-368

[13] Versteeg, H. & Malalasekera, W. (1995). *An introduction to computational fluid dynamics*: The finite volume method. England: Pearson Education. Ltd.

[14] Zhou, Y., and Kareem, A. (2001), Gust loading factor: A new model. *Journal Structural Engineering*,127~2

APPENDIX A: Historical Weather Data for October 2013

MYT	Temperature, C			Dew Point, C			Humidity			Sea Level Pressure, Pa			Visibility, km			Wind Speed, km/h		Gust Speed, km/h	Precipitationmm	CloudCover	Events	WindDirDegrees
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Max				
10/1/2013	33	28	24	26	25	23	100	82	63	1011	1009	1006	10	10	10	16	5		0	6		92
10/2/2013	31	27	24	25	24	23	100	84	62	1014	1011	1008	10	10	10	13	5		0	6		214
10/3/2013	32	28	24	26	24	23	100	87	62	1013	1011	1009	10	10	7	13	3		0	6	Rain-Thunderstorm	349
10/4/2013	34	29	24	25	24	23	94	82	59	1012	1010	1008	10	10	7	13	5		0	6		246
10/5/2013	33	28	24	25	24	23	94	81	59	1013	1010	1007	10	10	10	14	3	35	0	6	Rain	273
10/6/2013	33	28	23	26	24	21	100	79	55	1012	1009	1006	10	9	4	23	5	45	0	6	Rain-Thunderstorm	232
10/7/2013	33	28	23	26	24	22	100	80	52	1012	1010	1007	10	9	3	14	5		0	6	Rain	270
10/8/2013	34	29	25	25	24	23	94	75	52	1012	1010	1008	10	10	10	11	3		0	6		228

10/9/2013	33	28	24	25	24	23	94	82	55	1013	1011	1008	10	9	0	13	5		0	6	Rain-Thunderstorm	89
10/10/2013	33	28	24	26	24	24	100	88	59	1013	1011	1009	10	10	6	16	3	29	0	6	Rain-Thunderstorm	4
10/11/2013	31	28	25	26	24	24	94	86	66	1013	1010	1007	10	9	4	11	3		0	6	Rain-Thunderstorm	215
10/12/2013	31	27	24	25	24	23	100	84	70	1012	1010	1007	10	8	3	13	3		0	6	Rain-Thunderstorm	264
10/13/2013	32	28	24	26	24	23	100	86	70	1012	1009	1007	10	10	8	11	3		0	6	Rain-Thunderstorm	277
10/14/2013	31	28	25	25	24	23	94	85	66	1012	1010	1007	10	10	10	14	5		0	6	Rain-Thunderstorm	256
10/15/2013	30	27	24	26	24	23	100	85	70	1012	1009	1007	10	10	3	13	5		0	6	Rain-Thunderstorm	179
10/16/2013	34	29	25	26	25	24	100	83	59	1011	1009	1007	10	10	10	14	3		0	6		121
10/17/2013	33	28	24	26	24	23	100	82	55	1011	1009	1006	10	9	1	16	5		0	6	Fog	29
10/18/2013	31	28	25	27	26	24	94	87	70	1012	1009	1007	10	10	8	14	5		0	6	Rain-Thunderstorm	10
10/19/2013	34	29	24	26	24	24	100	88	63	1012	1010	1008	10	9	6	8	3		0	6	Rain-Thunderstorm	317
10/20/2013	32	28	24	26	24	23	94	86	66	1012	1010	1006	10	10	9	10	5		0	6	Rain-Thunderstorm	314
10/21/2013	31	27	24	25	24	24	100	85	70	1011	1009	1006	10	10	8	11	3		0	6		288
10/22/2013	31	27	24	26	24	23	100	85	70	1012	1010	1008	10	10	9	11	5		0	6	Rain-Thunderstorm	275
10/23/2013	32	28	24	26	24	23	94	83	62	1012	1010	1008	10	10	10	11	3		0	6		286

10/24/2013	32	28	24	25	24	23	100	85	66	1012	1010	1007	10	10	6	8	2		0	6	Thunderstorm	339
10/25/2013	33	28	24	25	24	23	94	86	59	1013	1011	1008	10	10	6	11	3		0	6	Rain-Thunderstorm	332
10/26/2013	33	28	23	25	24	23	100	88	59	1012	1011	1007	10	9	1	21	5		0	6	Rain-Thunderstorm	345
10/27/2013	33	28	23	26	24	23	100	88	59	1013	1011	1009	10	10	6	21	5		0	6	Rain-Thunderstorm	354
10/28/2013	33	28	24	26	24	23	100	88	59	1014	1012	1009	10	9	1	14	3		0	6	Rain-Thunderstorm	318
10/29/2013	33	28	23	26	24	23	100	85	66	1014	1012	1008	10	10	10	14	3		0	6		339
10/30/2013	33	28	24	26	24	23	100	87	62	1014	1011	1009	10	9	3	11	2		0	6	Rain-Thunderstorm	359
10/31/2013	34	28	23	26	24	23	100	87	59	1013	1011	1008	10	9	3	10	3		0	6	Thunderstorm	337

APPENDIX B: Historical Weather Data for October 2014

MYT	Temperature, C			Dew Point, C			Humidity			Sea Level Pressure, Pa			Visibility, km			Wind Speed, km/h		Gust Speed , km/h	Precipitationmm	CloudCover	Events	WindDirDegrees
	Max	Mean	Min	Dew PointC	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Max				
10/1/2014	34	29	24	25	24	21	94	78	46	1012	1010	1006	10	9	3	13	5		0	6	Thunderstorm	70
10/2/2014	34	29	24	25	24	22	94	78	52	1012	1010	1007	10	9	3	13	5		0	6		84
10/3/2014	34	29	24	26	24	23	94	80	52	1011	1009	1006	10	9	5	13	3		0	6		54
10/4/2014	30	28	25	25	24	23	94	86	70	1012	1010	1008	10	9	6	14	5		0	6	Rain	287
10/5/2014	31	27	23	25	23	22	94	83	66	1013	1011	1009	10	10	10	19	8		0	6	Rain	265
10/6/2014	33	28	24	25	23	21	94	76	49	1013	1010	1007	10	9	6	19	5		0	6	Rain	212
10/7/2014	33	28	24	26	24	23	94	80	63	1011	1009	1007	10	8	3	14	5		0	6		121
10/8/2014	33	28	24	26	25	22	94	82	66	1011	1009	1007	10	9	6	13	3		0	6		212

10/9/2014	33	28	24	27	24	23	100	88	66	1011	1010	1007	10	8	3	27	3		0	6	Rain-Thunderstorm	31
10/10/2014	34	29	25	26	24	23	94	79	52	1012	1009	1006	10	10	8	13	3		0	6		91
10/11/2014	33	29	25	27	24	24	94	87	63	1011	1009	1007	10	9	6	16	5		0	6	Rain-Thunderstorm	24
10/12/2014	32	28	24	26	24	23	94	84	70	1012	1010	1008	10	8	3	11	3		0	6		1
10/13/2014	34	29	25	26	24	23	94	83	63	1012	1010	1007	10	9	1	23	5		0	6	Rain-Thunderstorm	343
10/14/2014	33	28	24	26	24	23	100	88	66	1012	1010	1008	10	10	6	23	3		0	6	Rain-Thunderstorm	343
10/15/2014	32	28	24	26	24	23	100	88	70	1012	1010	1008	10	9	3	19	3		0	6	Rain	355
10/16/2014	31	27	24	26	25	23	94	89	74	1012	1010	1008	10	9	6	14	2		0	6		32
10/17/2014	33	28	24	27	24	23	100	87	66	1011	1009	1006	10	9	2	11	3		0	6	Rain-Thunderstorm	17
10/18/2014	31	27	24	26	24	23	100	91	75	1011	1009	1007	10	9	1	21	3		0	6	Rain-Thunderstorm	326
10/19/2014	32	28	24	25	24	23	100	87	66	1011	1009	1007	10	5	1	14	3		0	6	Rain-Thunderstorm	322
10/20/201	33	28	24	26	24	23	10	87	59	101	101	100	10	6	1	10	3		0	6	Fog-	35

4							0			2	0	7									Thunderstorm	9
10/21/2014	29	27	24	26	24	23	100	91	79	1013	1012	1010	10	9	6	11	3		0	6	Rain-Thunderstorm	348
10/22/2014	29	26	23	25	24	22	100	89	74	1014	1012	1010	10	9	4	10	3		0	6	Rain	234
10/23/2014	32	27	23	25	24	23	100	82	62	1013	1011	1008	10	7	0	13	3		0	6	Fog	292
10/24/2014	34	28	23	25	24	23	100	81	56	1012	1010	1007	10	9	5	13	3		0	6		81
10/25/2014	34	29	24	26	24	23	94	81	55	1013	1011	1008	10	9	3	19	3		0	6	Thunderstorm	40
10/26/2014	33	28	24	26	24	23	94	84	63	1013	1011	1008	10	10	10	14	5		0	6	Thunderstorm	37
10/27/2014	31	27	24	26	24	23	94	89	74	1012	1010	1008	10	10	10	19	3		0	6	Rain-Thunderstorm	24
10/28/2014	33	28	23	26	24	23	100	86	66	1012	1010	1007	10	9	3	11	3	32	0	6	Rain-Thunderstorm	348
10/29/2014	34	29	24	25	24	23	100	83	56	1011	1009	1007	10	9	6	16	3		0	6	Rain-Thunderstorm	33
10/30/2014	34	29	24	26	24	23	100	87	59	1011	1009	1006	10	9	1	11	3		0	6	Rain-Thunderstorm	335
10/31/2014	33	28	24	26	24	23	100	87	66	1010	1008	1006	10	9	5	11	3		0	6	Rain-Thunderstorm	348

APPENDIX C: Monthly Wind Speed and Wind Direction for Year 2013

Jan			**Feb**			**Mar**			**Apr**			**May**			**Jun**			**July**			**Aug**			**Sept**			**Oct**			**Nov**			**Dec**		
Max Wind SpeedKm/**h**	WindDirDegrees		Max Wind SpeedKm/h	WindDirDegrees		Max Wind SpeedKm/h	WindDirDegrees		Max Wind SpeedKm/h	WindDirDegrees		Max Wind SpeedKm/h	WindDirDegrees		Max Wind SpeedKm/h	WindDirDegrees		Max Wind SpeedKm/h	WindDirDegrees		Max Wind SpeedKm/h	WindDirDegrees		Max Wind SpeedKm/h	WindDirDegrees		Max Wind SpeedKm/h	WindDirDegrees		Max Wind SpeedKm/h	WindDirDegrees		Max Wind SpeedKm/h	WindDirDegrees	
14	352	N	23	19	N	13	344	N	11	6	N	16	283	W	16	338	N	14	272	W	11	179	S	8	332	SW	16	92	E	14	356	N	11	336	NW
21	329	NW	21	6	N	14	20	N	16	4	N	16	33	NE	10	349	N	10	173	S	13	182	S	13	295	NW	13	214	SW	10	344	N	11	301	NW
14	342	N	13	1	N	23	14	N	19	318	NW	11	85	E	11	346	N	8	255	W	13	167	S	14	328	NW	13	349	N	10	345	N	8	317	NW

NW	N	NE	N	N	NW	N
332	356	57	345	353	334	359
10	10	16	13	13	11	11
NW	N	W	W	NW	N	SW
328	340	274	284	330	343	235
14	16	13	13	13	24	13
SW	W	SW	W	SW	E	N
246	273	232	270	228	89	4
13	14	23	14	11	13	16
NE	SW	SW	SW	SW	W	W
45	240	217	233	246	270	262
10	11	13	13	13	11	14
SE	SW	SW	W	S	E	SW
155	203	224	284	192	98	203
11	14	11	14	19	13	16
W	NW	S	E	NE	SW	SW
283	333	164	109	30	215	205
11	8	13	13	11	11	13
NW	N	N	N	NW	W	W
317	356	1	356	306	241	245
19	16	13	16	13	14	13
NE	NW	N	NW	NW	N	NE
15	317	354	316	312	357	43
14	8	32	13	23	14	19
NW	NW	NW	NW	NW	N	N
321	249	273	281	334	10	352
11	13	13	13	23	13	11
N	N	NE	N	NE	NE	N
2	7	23	20	23	28	22
27	23	14	16	21	16	16
N	N	N	NE	NW	N	N
8	354	350	43	315	358	356
14	14	14	14	10	8	11
N	N	NW	NW	NW	NW	NW
358	340	337	323	314	330	335
13	**14**	**11**	**13**	**16**	**26**	**11**

N	NE	N	N	N	NW	N
357	23	1	8	9	306	351
14	19	13	14	14	19	19
W	N	NE	NW	NW	NE	N
269	22	23	304	337	29	341
11	13	13	11	10	14	10
SW	W	W	W	S	SE	NE
215	264	277	256	179	121	29
11	13	11	14	13	14	16
SW	SE	E	NW	NW	SE	NE
196	131	76	337	312	115	42
13	14	10	13	14	11	13
W	S	SE	SE	SE	S	E
250	184	156	130	155	170	91
8	19	19	14	16	14	11
W	NW	SW	W	S	NE	S
285	326	245	267	174	42	196
10	16	13	8	13	19	13
W	W	W	SW	SW	SW	W
222	254	248	240	228	247	281
16	14	14	14	14	13	14
SE	SE	E	NE	E	SW	W
139	164	93	41	70	214	291
14	14	10	14	11	13	11
N	N	E	N	NW	NW	W
345	18	106	13	294	307	241
13	11	10	21	10	11	19
NE	NE	NE	NE	NE	NE	NE
32	41	24	30	42	32	23
16	14	16	13	21	21	19
NW	N	N	NW	N	NW	N
315	22	16	333	348	326	7
13	19	16	6	14	14	13
N	N	N	N	N	N	N
355	341	8	8	19	12	5
16	**16**	**13**	**21**	**19**	**21**	**23**

N	N	NW	N	N	N	N
4	1	320	354	358	7	343
16	23	16	19	23	14	24
N	NW	W	W	NW	NE	NW
359	312	282	264	331	51	320
32	11	11	14	11	10	10
N	NW	NW	W	W	W	N
10	317	314	288	275	286	339
14	8	10	11	11	11	8
SW	E	S	S	S	S	S
205	95	187	163	172	177	188
13	16	14	19	19	13	16
E	S	N	E	SE	SW	SE
96	164	4	77	152	228	157
23	14	13	13	13	13	16
S	SW	W	W	SW	S	E
167	208	277	271	237	161	111
13	13	13	11	14	14	14
W	W	W	W	SW	SW	NE
273	280	273	253	242	215	55
19	16	13	16	13	10	8
SE	W	NE	N	SW	W	NW
126	269	39	347	234	258	334
10	13	13	10	21	11	8
NW	W	S	NE	NW	N	NE
294	276	172	53	326	360	24
14	11	13	27	13	14	16
NE	NE	E	NE	E	NE	N
28	37	86	65	69	43	13
16	13	10	16	14	14	14
N	NW	N	NW	N	N	N
351	334	11	336	345	342	345
21	10	19	13	16	23	16
N	NW	NW	N	N	N	N
346	323	321	353	357	4	356
21	**13**	**13**	**16**	**13**	**19**	**16**

N	N	N	N	N	N	N
7	5	8	7	358	2	348
19	19	19	24	19	16	19
NE	NW	NW	W	N	NW	
56	310	325	287	342	326	
10	10	13	13	11	13	
NW	N	N	NW	N	N	NW
332	345	354	318	339	359	337
11	21	21	14	14	11	10
W	SW	SW	NW	W	SW	
271	243	219	318	271	219	
16	13	14	10	11	13	
SE	SES	S	N	N	W	N
136	128	173	14	344	260	14
19	19	14	21	13	14	16
S	NE	S	S	SW	E	S
199	62	198	196	207	69	189
13	13	13	13	11	11	13
NE	N	W	SW	SW	NW	
23	360	290	234	225	337	
21	11	10	13	13	11	
NW	N	NW	NW	NE	NW	NW
324	16	328	310	30	303	328
10	11	13	16	10	16	24
N	N	NW	S	N	NE	
1	341	302	162	1	35	
10	10	16	14	16	11	
NW	NW	N	NE	N	N	NE
321	312	345	24	354	19	42
16	13	10	13	24	13	11
NW	N	N	N			
324	348	339	352			
13	16	14	16			
N	NE	N	N	N	N	NE
8	26	22	12	14	22	26
16	**16**	**19**	**16**	**21**	**21**	**19**

APPENDIX D: Monthly Wind Speed and Wind Direction in Year 2014

JAN			FEB			MAR			APR			MAY			JUNE		
Max Wind	WindDirDegrees		Max Wind	WindDirDegrees		Max Wind	WindDirDegrees		Max Wind	WindDirDegrees		Max Wind	WindDirDegrees		Max Wind	WindDirDegrees	
19	11	N	21	2	N	23	23	NE	13	27	NE	11	238	W	10	141	SE
19	22	N	19	7	N	16	16	N	13	46	NE	11	360	N	10	37	NE
19	360	N	14	23	NE	21	28	NE	13	67	NE	11	44	NE	13	12	N
16	322	NW	14	14	N	14	16	N	19	326	NW	21	29	NE	11	122	SE

JULY			AUG			SEPT			OCT			NOV			DEC		
Max Wind	WindDirDegrees		Max Wind	WindDirDegrees		Max Wind	WindDirDegrees		Max Wind	WindDirDegrees		Max Wind	WindDirDegrees		Max Wind	WindDirDegrees	
13	53	NE	14	193	S	10	98	E	13	70	E	11	236	SW	24	227	SW
14	262	W	16	130	SE	14	90	E	13	84	E	16	179	S	13	233	SW
13	311	NW	11	210	SW	23	355	N	13	54	NE	16	152	SE	16	252	W
16	313	NW	16	138	SE	10	281	W	14	287	W	19	71	E	26	243	SW

E	NW	NW	N	N	N	N
76	308	332	350	11	9	15
16	21	32	16	21	24	24
NE	NW	W	SW	SE	E	N
40	298	265	235	141	86	10
24	26	24	29	13	14	21
W	SW	SE	SW	NE	E	NE
265	212	121	212	31	91	24
19	19	14	13	27	13	16
W	W	N	NW	NE	N	NE
251	249	359	296	41	345	30
14	16	14	13	10	14	14
SW	SW	W	SE	E	NE	N
237	217	275	154	81	60	351
14	8	13	14	19	14	16
SW	W	SW	SW	S	E	NW
232	257	227	206	183	71	332
10	13	13	14	10	13	13
W	N	SE	SE	E	NE	S
281	347	110	136	94	30	184
16	19	16	14	13	16	14
N	NE	N	NE	NE	N	N
359	47	353	30	35	12	359
14	11	32	11	10	11	19
NW	N	N	N	N	NW	N
294	2	4	355	356	332	350
8	14	10	19	19	11	14
N	NE	NE	NE	NE	NE	N
12	34	31	25	30	24	19
21	24	23	19	23	23	23
N	N	NE	NE	N	N	N
16	13	24	23	17	12	16
16	21	14	14	13	14	16
N	N	N	N	N	N	N
347	4	342	356	343	351	355
13	**14**	**13**	**19**	**6**	**8**	**21**

N	N	N	N	N	NW	N
12	4	7	4	340	322	4
23	26	19	24	13	19	26
W	NW	NW	N	NW	N	NE
259	318	295	22	320	11	47
24	16	13	29	32	29	11
N	N	N	N	NE	N	NW
1	343	343	355	32	17	326
11	23	23	19	14	11	21
SE	NW	W	S	E	E	NE
129	329	264	181	86	76	54
14	13	16	19	16	14	21
N	SW	S	N	NW	NE	NE
351	218	164	343	335	38	66
13	13	21	14	14	11	14
SW	S	SW	SE	NE	S	S
246	200	216	115	47	193	187
13	14	13	14	14	16	14
SW	SW	S	SW	SW	SE	SW
239	210	191	218	215	157	208
19	10	10	11	13	14	16
N	W	SW	W	SW	NW	NW
17	282	240	289	225	293	310
13	10	16	10	19	13	14
NW	N	N	N	N	E	N
315	354	350	347	352	75	341
8	24	13	14	19	14	16
NE	N	N	NE	N	N	N
24	16	15	26	350	15	342
21	13	24	26	8	16	11
N	N	N	N	N	NE	NE
22	18	22	20	22	34	26
23	23	23	26	23	19	16
N	N	N	N	N	N	N
1	20	5	9	7	3	14
16	**23**	**23**	**19**	**23**	**21**	**24**

NW	N	N	NW	W	NW	NW
324	348	347	335	286	345	315
11	27	29	14	16	21	14
N	NW	N	NE	W	NW	NW
1	334	359	37	267	327	309
21	16	24	23	13	14	29
NW	N	N	SW	W	E	NE
322	359	348	234	292	81	40
14	10	11	10	13	13	19
NE	N	SW	E	E	N	E
39	351	227	103	78	3	99
21	13	14	14	14	13	13
N	NE	N	NE	NW	N	NW
20	42	13	63	335	343	324
26	19	16	19	11	11	13
S	S	S	SE	NE	S	S
162	176	184	146	37	173	183
11	14	16	14	10	14	14
SW	S	SW	W	NW	NW	SW
215	185	215	265	293	297	204
10	13	14	10	13	14	16
S	W	NW	W	N	E	NE
172	269	327	284	16	91	40
11	8	13	13	14	13	16
NW	NW	NW	N	N	N	N
337	315	328	342	7	339	16
8	19	13	16	8	14	16
N	N	N	NE	NE	N	NE
353	3	1	28	32	16	23
16	19	11	16	19	21	19
NE	NE	NE	N	NE	N	N
41	40	24	17	28	20	4
16	23	23	27	26	19	21
N	N	N	N	N	N	NE
1	355	7	7	13	14	28
24	**23**	**21**	**21**	**21**	**19**	**19**

W	NW	N	W	NW	N
286	330	348	289	319	360
14	16	23	16	14	21
NW	N	NE	W	SW	
304	12	27	268	232	
16	19	19	26	11	
NE	NE	N	NE	NW	N
37	24	348	33	335	348
14	19	11	16	11	11
N	NE	NE	E	NW	
359	41	63	112	331	
19	14	16	11	11	
W	W	W	SE	N	N
249	242	256	141	14	356
14	11	13	23	14	21
S	NW	SW	NE	NE	S
184	323	207	60	42	178
16	19	13	10	14	13
SE	SW	SW	SW	S	
144	243	246	216	193	
14	11	13	13	16	
N	SW	SW	N	SW	S
2	265	226	341	245	158
11	10	11	16	13	19
NW	W	W	NW	NW	
334	289	288	320	329	
26	19	10	14	23	
NE	NE	NE	N	NE	N
26	23	25	13	33	21
16	14	11	21	11	24
N	NE	NE			
20	27	31			
23	24	23			
N	N	NE	N	N	N
9	19	27	20	9	15
16	**23**	**24**	**23**	**21**	**21**

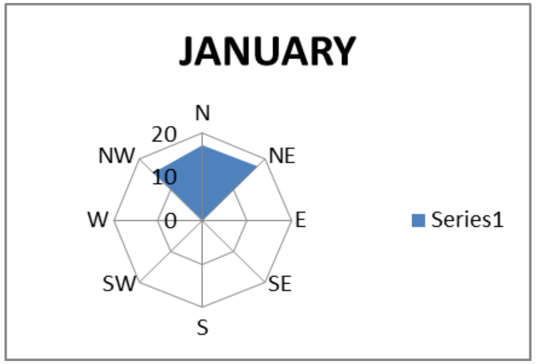
APPENDIX E: Average Maximum Wind Speed with respect to the Wind Direction in Year 2013

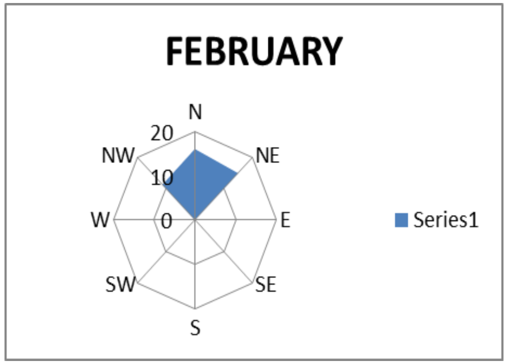
DIRECTION	JAN	FEB	MAC	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	AVERAGE (km/h)
N	17.2	16.1	17.5	13.3	16.8	13.3	0	15.8	0	14.8	15.6	17	13.12
NE	17.5	15	15.9	18	14.3	14.5	14.3	0	11.5	16	17.5	17.5	14.33
E	0	0	12	10	10.7	0	12.7	15	13	14.5	0	0	7.33
SE	0	0	0	0	12.7	0	0	15.9	12.5	14	0	0	4.59
S	0	0	0	13.5	0	0	12.8	14.6	16.2	13	0	0	5.84
SW	0	0	0	0	17	12.9	12.5	13.5	12.4	14.2	13	0	7.96
W	0	0	0	15	12.8	14.5	10.7	13	13	12.4	12.5	0	8.66
NW	15.5	11.3	14.5	14.2	13.4	14.3	12	0	12.8	10.6	11.6	12.3	11.88

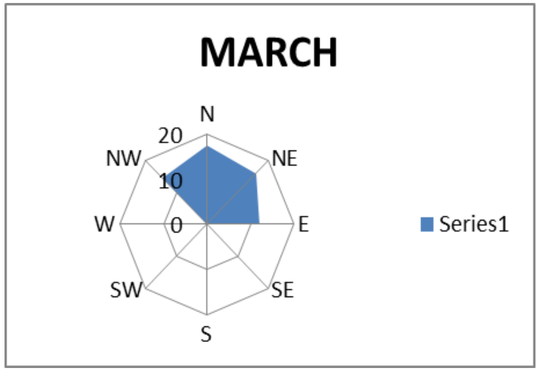
APPENDIX F: Average Maximum Wind Speed with respect to the Wind Direction in Year 2014

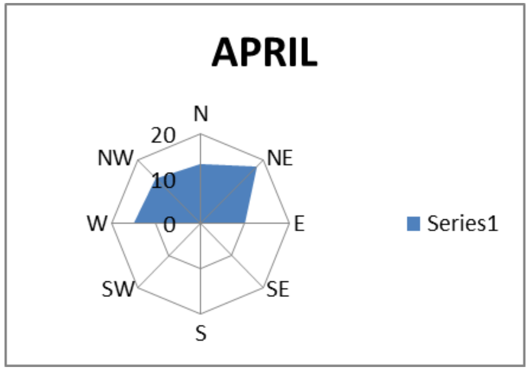
DIRECTION	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	AVERAGE (km/h)
N	17.4	20.1	17.2	15.4	15.7	16	0	16.38	16	14.44	23.88	22.57	16.26
NE	22.9	19.3	19.3	13	13.3	13	12.2	15.4	16	17.25	19.25	0	15.08
E	0	0	0	14	13	13	13	19	13.25	13	16.5	16	10.9
SE	0	0	0	0	0	13.2	14	17.25	14	14	14.5	0	7.25
S	0	0	0	0	15	13.3	13.8	17.5	0	0	16	0	6.3
SW	0	0	0	0	13.8	13	12.7	11.5	14	14	17	21	9.75
W	0	0	0	14.5	10.5	13	13.5	12.75	13.33	15.33	21.75	16	10.89
NW	16	0	0	14.9	13.3	13.5	15.3	12.67	12.33	15.33	20.25	18	12.63

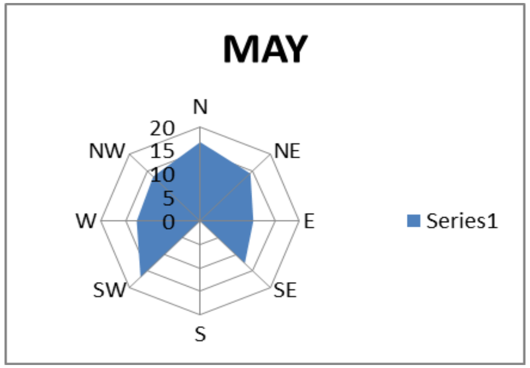
APPENDIX G: Monthly Wind Rose in the Year 2013

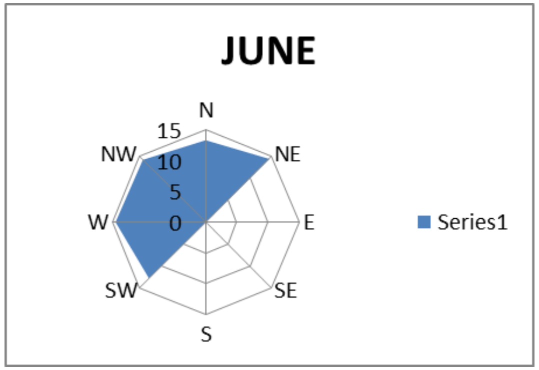


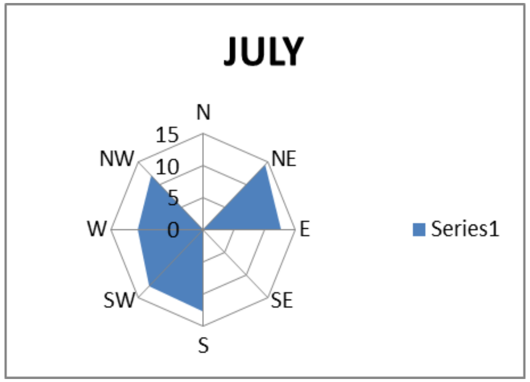


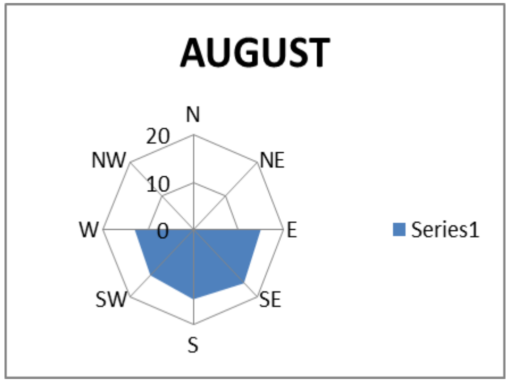


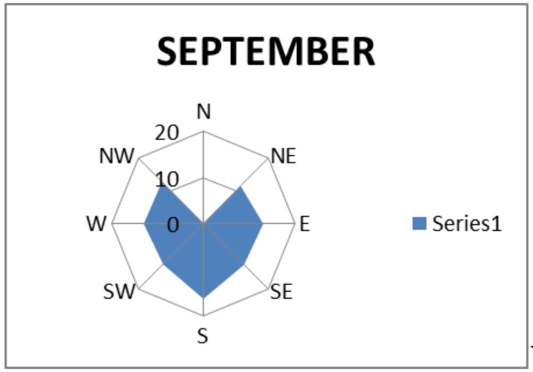


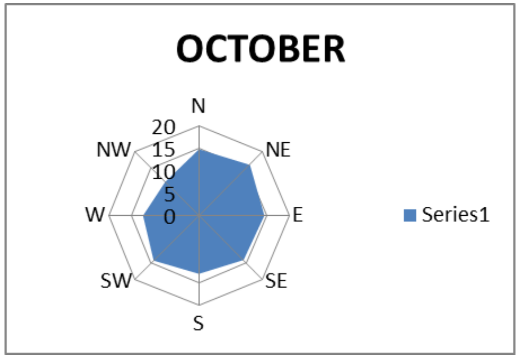


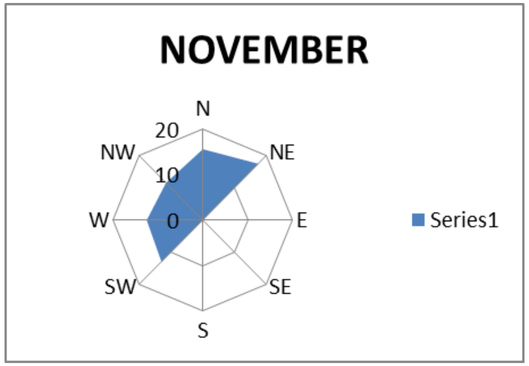


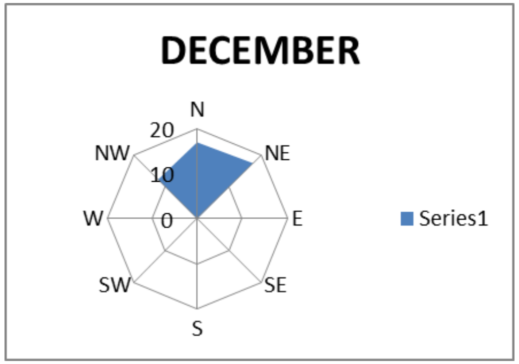

JULY
N
NE
E
SE
S
SW
W
NW
15
10
5
0
Series1


AUGUST
N
NE
E
SE
S
SW
W
NW
20
10
0
Series1

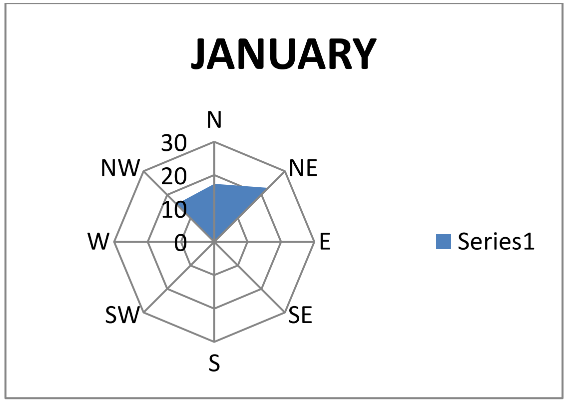

SEPTEMBER
N
NE
E
SE
S
SW
W
NW
20
10
0
Series1

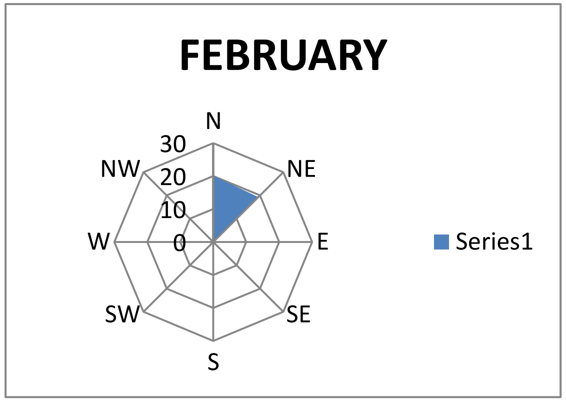

OCTOBER
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Series1

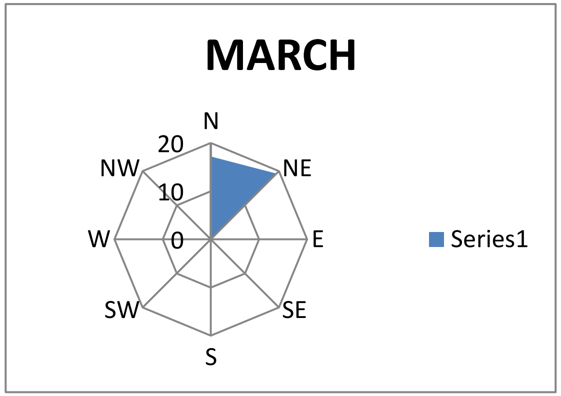

NOVEMBER
N
NE
E
SE
S
SW
W
NW
20
10
0
Series1

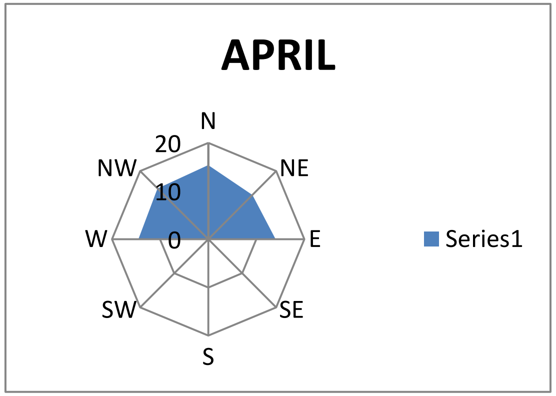

DECEMBER
N
NE
E
SE
S
SW
W
NW
20
10
0
Series1

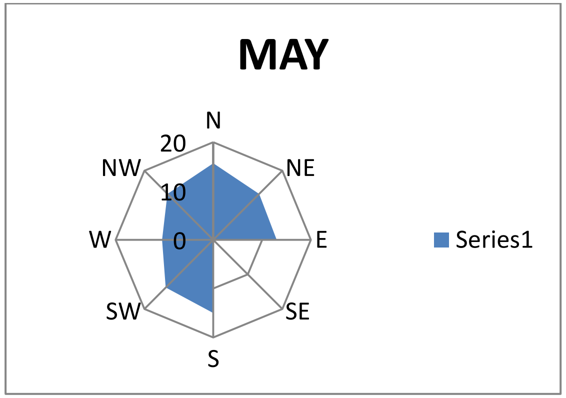
APPENDIX H: Monthly Wind Rose in the Year 2014

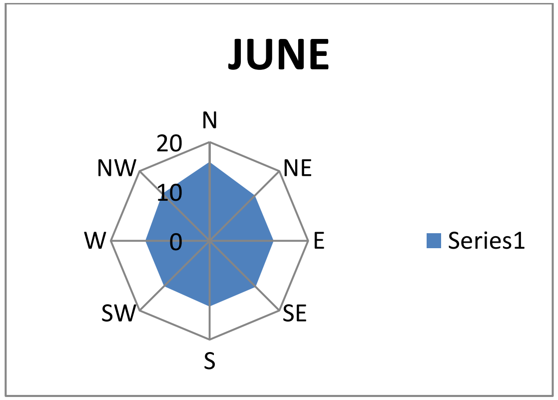


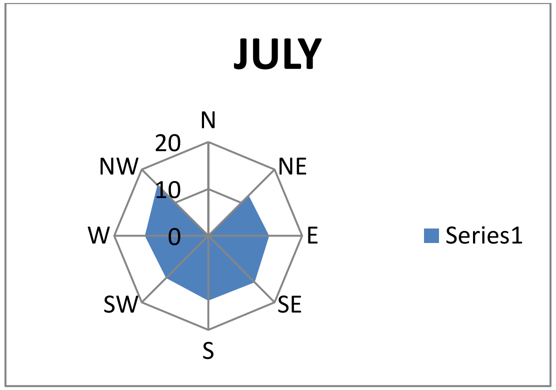


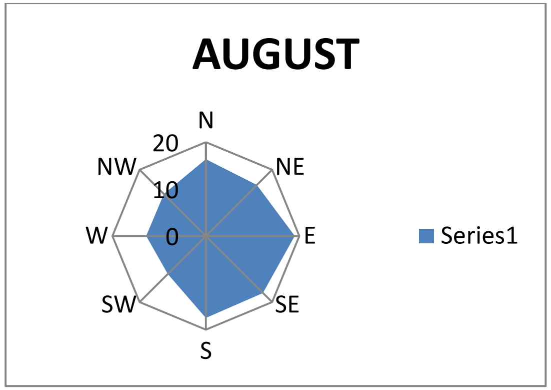


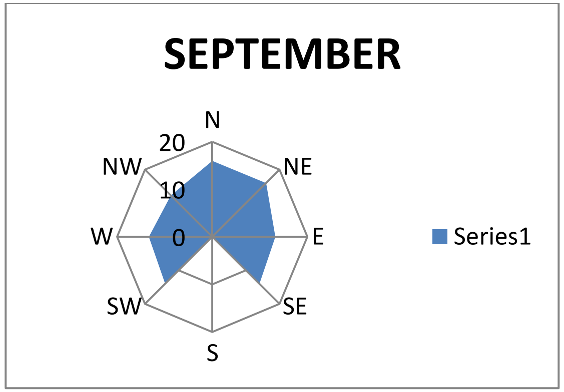


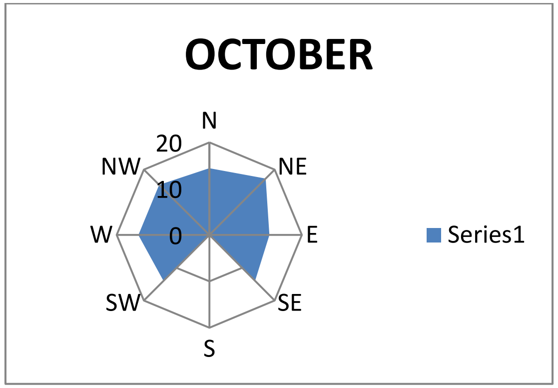


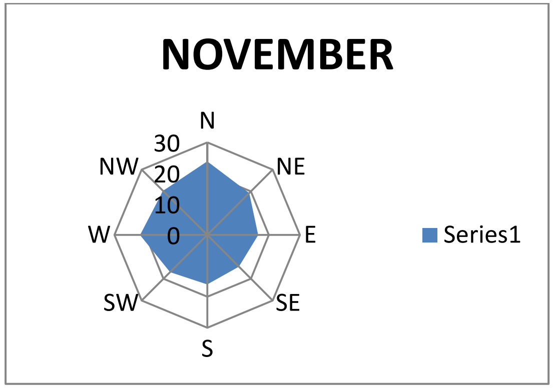


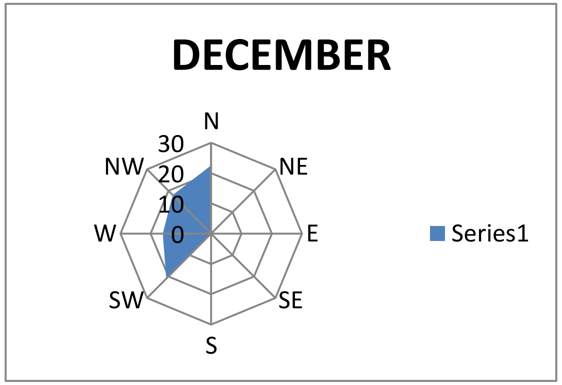

JULY
N
NE
E
SE
S
SW
W
NW
20
10
0
Series1


AUGUST
N
NE
E
SE
S
SW
W
NW
20
10
0
Series1


SEPTEMBER
N
NE
E
SE
S
SW
W
NW
20
10
0
Series1


OCTOBER
N
NE
E
SE
S
SW
W
NW
20
10
0
Series1


NOVEMBER
N
NE
E
SE
S
SW
W
NW
30
20
10
0
Series1


DECEMBER
N
NE
E
SE
S
SW
W
NW
30
20
10
0
Series1

APPENDIX I: Steps of Making 3D Model

There are several steps to download the pedestrian bridge using 3D Warehouse using SketchUp Component Browser. First, click on the Get Models button to access the 3D Warehouse from within SketchUp. Then, Enter the type of model you're looking for in the "search" field which in this case a pedestrian bridge. After that, click on the “Search” button. Thumbnail icon representations of models are displayed on the screen. Click on the thumbnail image of the model that you like to view the model. Click on the Download Model button to download the model into SketchUp. The message "Load this directly into your SketchUp model" appears. Click “Yes” to download the model directly into SketchUp. Then, the downloaded model is placed on the ground plane at the axes origin. The solid green axis points north, the solid red axis points west, and the solid blue axis points up.

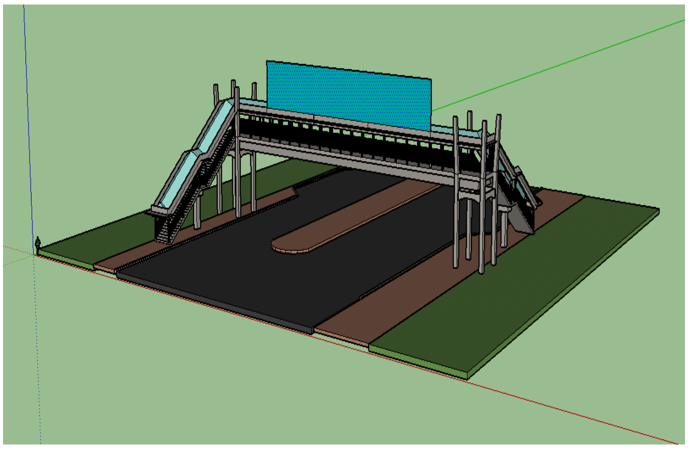


Figure 1: 3D Model of the pedestrian bridge