DEVELOPMENT OF SITE SPECIFIC WIND HAZARD MAP FOR PENINSULAR MALAYSIA USING GEO-SPATIAL MODELLING

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by

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LIST OF ABREVIATION

AIJ	Architectural Institute of Japan
AS	Australia Standard
ASCE	American Society of Civil Engineering
BS	British Standard
CDF	Cumulative Distribution Function
DEM	Digital Elevation Model
DOA	Department of Agricultural
EMDAT`	The International Disaster Database
ENV	European Pre-Standard
ISO	International Organization for Standardization
LULC	Land Use Land Cover
MMD	Malaysia Meteorological Department
MS	Malaysia Standard
SDG	Sustainable Development Goals
SRTM	Shuttle Radar Topography Mission
TIN	Triangular Irregular Networks
UNISDR	United Nations International Strategy for Disaster Reduction

PEMBANGUNAN PETA BAHAYA ANCAMAN ANGIN SETEMPAT BAGI SEMENANJUNG MALAYSIA MENGGUNAKAN TEKNIK GEOSPATIAL

ABSTRAK

Penilaian ancaman bahaya adalah merupakan salah satu aktiviti dalam menangani dan mengurangkan kesan buruk dari sesuatu risiko. Didalam kejuruteraan angin penilaian bahaya angin dilakukan dengan bersandarkan kepada potensi halaju angin. Pada ketika ini halaju angin yang dirujuk adalah halaju angin asas (V_s). Kelajuan angin asas ditakrifkan sebagai kebarangkalian kelajuan angin maksimum dalam tempoh ulangan tahun. Walau bagaimanapun, kelajuan angin di lokasi tertentu yang dikenali sebagai kelajuan angin setempat (V_{site}) harus mempertimbangkan kesan penggunaan tanah dan kesan topografi. Selain itu, penilaian bahaya angin di kawasan spatial tidak dapat dilaksanakan kerana nilai V_{site} ditentukan berdasarkan titik lokasi. Oleh itu, matlamat utama kajian ini adalah untuk membangun peta bahaya angin setempat dengan menggunakan teknik *"geo-spatial"*. Kajian ini juga mengkaji kaedah penilaian bahaya angin yang besesuaian dengan membandingkan keberkesanan peta V_s dan peta V_{site} yang dihasilkan. Atas sebab itu, kejadian kerosakan bangunan akibat dari ribut di Semenanjung Malaysia digunakan untuk menilai keberkesanan peta bahaya angin yang dihasilkan. Didapati peta bahaya angin berdasarkan kelajuan angin setempat (V_{site}) sangat disyorkan berbanding dengan peta kelajuan angin asas (V_s). Ini kerana taburan kejadian kerosakan menunjukkan ia berlaku pada nilai V_s yang lebih rendah berbanding dengan V_{site}. Oleh itu, Berdasarkan tempoh ulangan 50 tahun untuk kes-kes kerosakan terhadap angin ribut, V_s dikenalpasti pada 31.66 m/s dimana 9.02%

lebih rendah berbanding dengan nilai yang dikenal pasti menggunakan V_{site} yang bersamaan dengan 34.80 m/s. Dapat disimpulkan bahawa pendekatan penilaian risiko semasa adalah tersasar dengan memberi maklumat yang kurang tepat terhadap bahaya ancaman angin disesuatu lokasi jika dibandingkan dengan potensi sebenar angin melalui kaedah kajian ini.

DEVELOPMENT OF SITE SPECIFIC WIND HAZARD MAP FOR PENINSULAR MALAYSIA USING GEO-SPATIAL MODELLING

ABSTRACT

Hazard assessment is one of the coping capacity activity in minimise the effect of risk. In wind engineering the wind hazard assessment are evaluated based on the value of wind speed. Currently the value of wind speed is referred to basic wind speed (V_s). Basic wind speed is defined as the probability of the maximum wind speed within the return period. However, wind speed at specific location which is known as site wind speed (V_{site}) should consider the effect of land use land cover and topography effect. Apart from that, wind hazard assessment on a spatial area is not feasible because of the V_{site} value determined based on the point location. Therefore, the main objective of this study to develop the site specific wind hazard map by using geo-spatial technique. In MS 1553:2002 V_{site} is calculated by multiplying the V_s with the Land Use Land Cover (LULC) factor denoted as $M_{z,cat}$, and topographic factor as M_h. In order to apply these formulae in a spatial area, Geographical Information System is used. This study also examined the wind hazard assessment by compare the performance of V_s map and V_{site} map produced. For that reason, the past windstorm damage in Peninsular Malaysia is used to validate the performance of the wind hazard map produced. From the result, wind hazard map based on the site specific wind speed (V_{site}) is highly recommended compared to the basic wind speed (V_s) map. The result showed that the damage

occurred at lower V_s value compared to V_{site}. Based on 50 years return period for windstorm damage cases, V_s is identified at 31.66 m/s which is 9.02% lesser when compared to value identified using V_{site} which is equal to 34.80 m/s. It can be concluded that the risk assessment by referring only to V_s are misleading. Thus, the current risk assessment approach may underestimate the real potential of wind hazard for site specific location.

CHAPTER ONE

INTRODUCTION

1.1 Background

The force of nature, wind has always been an essential part of human being. Ever since the existence of mankind the wind has played its vital role in daily life. For example, in some countries, the advantages of wind speed have been used as an energy source to benefit mankind. Nevertheless, it also may cause property damage and even to the extent of loss of life due to catastrophic natural event. In fact, in the last decades, losses caused by severe windstorm were higher compared to other disasters (Tamura & Cao, 2012a). Many structures or parts of structures failed because of inadequate considerations were given to wind action at the design stage (Sparks et al., 1994). Such failures can trigger crucial financial demand and burden to project owners and ever increase the construction risk. Therefore, it is necessary to highlight the issues surrounding wind-related hazards and its impact on infrastructure and facilities as well as society with cautious. Hence, it should also be noted that the wind hazard needs to be treated in a holistic manner rather than each in isolation. A full understanding of the effects of climate change on windstorm frequency and intensity is required in order to establish appropriate risks method (Baker, 2007a). There is a need to revisit some of the basic assumptions of disaster risk method in light of recent advances in measurement and analysis techniques (Paton, 2003). Thus, there is a persuasive need for pooling of expertise and cooperative actions to reduce losses from various types of those wind-related hazards. This approach can be achieved by the interactions among various groups with diverse backgrounds, but with a common focus on disaster reduction (Tamura & Cao, 2012a).

In record buildings and structures in Malaysia are also affected by wind action. As a result, Malaysia has developed its own code of practice MS 1553:2002 on wind loading for building structure. The MS: 1553:2002 was adapted from Australia Standard AS 1170.2 due to the similarity of wind climate (Sundaraj, 2002). The code was established by using data from 23 meteorological stations erected all over Malaysia. Based on previous studies, windstorm posed a significant impact that caused damages to building structures (Bachok et al., 2012; Deraman& Wan Chik, 2014; Majid et al., 2012; Wan Chik et al., 2014). It was also observed that most of the damages occurred in the northern region of Peninsular Malaysia (Bachok et al., 2012; Wan Chik et al., 2014). Wind related damages have the potential to be repeatable at the same location although in a different time frame.

1.2 Problem Statement

Risk management is currently one of the most important aspects in mitigating natural hazards. It has already been highlighted at the national level policy and is one of the Sustainable Development Goal (SDG) 2030 policies outlined by the United Nations in 2015. The main action listed in SDG is to conduct a post-disaster evaluation and developing the pre-disaster planning. One of the activities that needs to be carried out is by completing the studies up to the national level in order to identify the hazard potential. The management of the hazard potential is called risk management. Risk management includes the risk strategy which consists of activities such as avoid, control, reduce, accept or transfer the identified hazards. Effective risk assessment can only be accomplished by identifying the hazard and vulnerability clearly. Hazard is defined as a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.

A natural disaster is of the categories listed under hazard. In a strategy to manage the risk from natural disaster, hazard map needs to be established such as flood map, landslide map, earthquake intensity map, wind speed map and etc. Hazard maps are created and can be used in conjunction with several natural disasters. Different hazard maps have different uses by authority or by insurance companies for rate adjustments. Hazard maps can also be useful in determining the risks of living in a certain area. Additionally, hazard maps can help people become aware of the dangers they might face from natural disasters in a specific area. Hazard map is part of the mitigation strategies when dealing with natural disaster.

In wind engineering field, wind risk for specific site are denoted based on the potential of wind speed for the specific site location. A few wind hazard maps around the world were produced based on the basic wind speed (V_s). V_s is used in determining the wind load on a structure before deciding other factors such as height above the ground, the effects of topographic and the aerodynamic shape factors are taken into account. These wind hazard which referred based on V_s are assessed by only using probabilistic method of the past recorded wind speed data. The possibility of underestimates the risk of wind speed may occurred. This is due to the incompetent interpretation of real potential of wind speed. For example for $M_{z,cat}$ which are related to land use and land cover (LULC) condition may increase the wind speed up to 12%, while for the wind

M_h which related to topographical condition might increase up to 71%. Consequently, the community in general may underestimated the risk due to inappropriate method used to interpolate. At the moment most of the risk assessment methods available are visualized using map as a guide. Currently, V_s specified in the Malaysian Standard (MS1553:2002) are divided into 2 main zones for Peninsular Malaysia (in the form of a map) and there are also a tabulated value of V_s for specific 30 site locations. Unfortunately the map was also not interpolated by using spatial analysis techniques. Thus the information available may reduce the accuracy in judging the potential risk.

V_s is denoted as potential of wind speed for the specific location without considering the effect of geographical factors. The potential of wind speed is more realistic when the geographical factors are taken into consideration. Two major factors which are widely used in determining the potential of wind speed at specific site location which are the Land Use Land Cover (LULC) and the topographical condition. Wind speed will change its characteristics when passing over a specific site location. Thus the wind speed which considered the effects of LULC and the topographical conditions are represented as site wind speed (V_{site}). In the Malaysian Standard, wind speed at a specific location is notified as site wind speed (V_{site}). V_{site} is universally used in the wind loading code to determine the potential of wind speed. It is more meaningful and realistic wind speed since, the wind speed at specific site location are determined by incorporating the LULC and topographic conditions. V_{site} is calculated by multiplying the V_s with the LULC factor denoted as $M_{z,cat}$ and topographic factor as M_h. V_s are also determined only for the specific location which are based on meteorological station location. Locations other than the specified place need to be referred to the nearest station for determining the V_s. This method was commonly used in identifying the potential of wind speed. Interpolation of wind speed in spatial area cannot be simply calculated using this approach. Previous method also cannot be physically visualized in the spatial manner hence making it almost impossible to perform an accurate evaluation of the risk.

Therefore, this study enhanced the potential of V_{site} by using spatial analysis technique for other areas which have not been a reference for meteorological station. In fact, that wind hazard information is crucial for many agencies in the construction industry, hence any wind hazard map must be able to provide reliable information pertaining to potential risk of wind hazard at a specific area. To date, not many studies have been conducted to produce the wind hazard map based on V_{site}. Guo (2005) has been conducting an V_{site} assessment of wind hazard combining the V_s , M_h and $M_{z,cat}$ for Perth City. While Chock et.al. (2006) also tried to produce micro-zonation wind hazard map that includes the topographical model for sub-portion of Hawaii island. Furthermore, Lee et. al. (2009) introduced a method by considering the local wind characteristics such as hill shape multiplier and LULC multiplier for Jeju island in determining the V_{site} . This study also enhanced the wind hazard map with up to date data with regards to the site changes and the methods used. Therefore, this study is conducted with the intentions to improve the existing wind hazard map which is merely based on V_s and establish a realistic methodology with the updated wind speed data. The society in general will benefit in terms of understanding the specified level of safety to their existing and future facilities due to the risk from the wind.

Nevertheless, previously attempted effort to produce the wind hazard map based on V_{site} data was not supported with further verification. Therefore, this method is not extensively used as a reference to assess wind hazard at a specific site location. The validity of this method are being queried since there is no evaluation performed for past studies. In order to verify the soundness of the wind hazard map produced in this study, past recorded damages are significantly used to verify. Previously, there was no significant database related to windstorm damages. For that purpose, the database related windstorm damage were produced. The damage cases related to windstorm was collected. Due to the limitation of access to data, all the damage cases considered in this study was for non-engineered building only.

1.3 Research Aim

The main aim of the study is to develop a wind hazard map for Peninsular Malaysia. The wind hazard map is established by considering the V_{site} *data.* V_{site} was determined by an equation that comprises V_s, LULC and topography condition. The potential of wind hazard for a specific location is identified through spatial analysis techniques. The main interest is focused on the performance of this method in establishment of a wind hazard map that considers the effect of LULC and topographic condition. The wind hazard map is evaluated based on past recorded wind damage data using statistical analysis.

1.4 Objectives

The research focuses on four objectives in establishing the wind hazard map for Peninsular Malaysia. The objectives of this research are:

1. To create and build a database of wind related damages in Peninsular Malaysia.
2. To construct the Geo-database consisting of all the related parameters for wind hazard map.
3. To develop the wind hazard map for Peninsular Malaysia.
4. To analyse the site specific wind hazard in Peninsular Malaysia.

1.5 Scope of Work

In this study, related wind damage data within Peninsular Malaysia is identified in order to construct the past damage database. Windstorm occurrences for the study were collected from several sources but the primary source was from the mainstream newspaper. The data summarizes the general features of the windstorm occurrences, damage type and level, the scenario of the region, state, district, the central city, year, date, duration, diurnal distribution and geographical. Apart from that, the parameters contributing to the wind speed characteristics such as wind speed return period, topographic features and the Land Use Land Cover (LULC) type were identified.

All accumulated data were transformed into Geographical Information System (GIS) Layer. Data layers were converted accordingly to the specific classification and assigned to the specific value explicitly in order to investigate the potential wind speed in Malaysia. ArcGIS 10.3 was used to establish the data layer.

Wind hazard map was established using spatial modelling method. Mathematical modelling method was introduced to identify the site wind speed on specific site location based on V_{site} equation. V_{site} equation is defined as follows.

$$V_{site} = V_s \times M_{z,cat} \times M_h \tag{1.1}$$

The detailed explanation of the equation (1.1) are discussed further in Chapter Two and Three. For the purpose of development of the wind hazard map for the spatial area the GIS methods were introduced. Numerous geographical scales were introduced to establish the magnitude of the specific site wind speed at a specific location.

Wind Hazard Map were validated accordingly. The relationship between potential wind speeds on site and damage location were produced in order to verify the reliability of the wind hazard map.

1.6 Thesis Organisation

This thesis consists of five chapters and organised as follows:

Chapter One presented the introduction of this study. It generally consist the background of the research, problem statement, research aim, objectives, scope of work and thesis outlines.

Chapter Two covered a Literature Review for this study. This chapter briefly reviews the past and recent damages related to a windstorm. In further, the risk assessment model is also reviewed. Additionally, hazard map criteria were elaborated. The international code practice related to wind also been underlined. The impact of a hazard map also highlighted.

In Chapter Three, a complete research methodology used were presented. This chapter describes the detailed methodology of this study and how it was conducted. For example how the related windstorm damage data was collected using a proper method. All relevant data were also digitised into the geo-database. Wind hazard map was produced using the ArcGIS software.

Chapter Four covers the results and discussions accordingly. The outline of this chapter was arranged as such to presents the results based on the objective of this study. The past damages related to windstorms are discussed in detailed. Damages are also categorised and analysed based on the geographical location. Wind hazard map are produced and evaluated in detail.

Finally, Chapter Five presents the conclusions and recommendations. This chapter concludes the main finding based on the objectives of the research. Some recommendations for future work to enhance the wind hazard map are also presented in this chapter.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter aims to generate a framework to provide guidance for the preparation of this study. Wind loads are essentially an influencing factor during the stage of structural design, such as for buildings and civil engineering structures. The loss of buildings and other structures by wind has been a reality of natural disaster. For many centuries, it is stated that the damage to buildings due to forces by wind has been considered as an act of god. Only after the eighteenth centuries, wind specifically has become the new area of interest for many engineers , scientists and researchers (Baker, 2007; Pacheco et al., 2007; Tamura & Cao, 2012; Vickery et al., 2009). Failure of building structures could be due to inadequate consideration of wind factor during the stage of structural design. Trial and error has played an essential part in the development of construction methods to design building structures to resist wind loads (Holmes, 2015). Therefore the impact of wind speed is among the significant loadings that must be considered in the structural design.

Nowadays, the trial and error method has been replaced due to development of modern approach in designing structures especially in resisting wind loads. Probabilistic and statistical methods become the basis to study the characteristics of wind using historically recorded data. The determination of appropriate design wind speed is a vital step towards the calculations of wind loads for structures.

2.2 Historical Review of Wind-Related Damage in Malaysia

According to the International Disaster Database (OFDA/CRED, 2004), windstorm was listed as top 10 natural disasters affecting Malaysia. On the 6th of November 2004, 40000 people on the east coast of Peninsular Malaysia have suffered from windstorm. Another windstorm event on the 26th of December 1996 has killed 270 people in Sabah. Windstorm events have been a major headline in the newspaper at all times in Malaysia.

Figure 2.1: Roof Structures of an Apartment Landed on top of Vehicles (Archive (Utusan, 2004)

Identifying historical data could be used as the first step in any disaster reduction effort. This could help to identify hazards that are typically recurrent (Falkiner, 2003; Khanduri & Morrow, 2003; Gunasekera et al., 2015a; Hong et al., 2016). In fact, one of the idea of this study is to come up with a strategy for developing resilient community due to wind hazard. A historical review of wind-related disaster is being discussed here. Wind related historical data that have been conducted from as early as 1968 up to recent years from new research works are included in this chapter. This review provides insights into future directions for developing and improving the activity related to wind disaster risk reduction in Malaysia.

Malaysia is a country situated near to equator and famously known for its rainforest. It is important to study the flow pattern of wind across Malaysia which is controlled by two major monsoons. According to researchers the characteristic features in the climate of Malaysia are mostly situated in uniform temperature, high humidity and frequent rainfalls, and they arise mainly from the maritime exposure of the country. The climate in this nation is found to be almost the same throughout the year. Nevertheless, the characteristic of wind over the country is generally light and variable. Over the year there are some uniform periodic changes in the wind flow patterns in Malaysia. The flow pattern of the wind system across Malaysia is dominated by two major monsoons. Normally the Southwest monsoon will flow from mid-April until September and the Northeast monsoon flow from early November until March. A specific period occurs between two major monsoons which is called as the inter-monsoon seasons. During this inter monsoon season, frequent thunderstorm events occur. Although thunderstorms are localized phenomena, they often produce significantly strong and gusty surface winds. The winds from thunderstorms are relatively strong and more turbulent than those winds which occur during the monsoon period. The windstorm is classified as Meteorological sub disaster type which is defined as events caused by short-lived from small micro-scale to meso-scale atmospheric processes (in the spectrum from minutes to days) (Guha-Sapir, Vos, & Below, 2012).

2.3 Historical Event Review

The number of damages have been widely reported in newspapers and mass media. However there is no single or any detail database was established from relevant agencies, regarding the disasters and damages caused by windstorm (Bachok, 2012). By referring to The International Disaster Database, windstorm has been categorised as one of the top ten natural disasters in Malaysia. According to EMDAT, disaster is defined as a situation or event which overwhelms local capacity, necessitating a demand to a national or international level for external assistance where an unexpected and often sudden event that causes great damage, destruction and human suffering. Before any situation and event of disaster to be recorded into the database, the following criteria should be complied. Disaster only classified after at least one of the following criteria fulfilled. Where ten or more people reported killed or more than 100 people reported affected. From the year of 1960 to 2016 EMDAT recounted that there were seven major events related to windstorm disaster. Two events were recorded as a tropical cyclone, one as convection storm and another four as other storm types.

Table 2.1: List of Windstorm Disaster in Malaysia 1960-2005 (EMDAT, 2017)

Start Date	End Date	Location	Disaster Subtype	Total Death	Total Affected	Associated Disaster
07/01/1968	7/1/1968	Johore	Nil	21	10000	
26/12/1996	28/12/1996	Sabah - Keningau, Sulaman, Tamparuli, Kiulu, Kota Kinabalu	Tropical Cyclone	270	4176	Flood
23/8/1997	27/8/1997	Kedah, Perlis, Penang	Tropical Cyclone	2	2115	Flood
23/8/1997	27/8/1997	Kedah, Perlis, Penang	Tropical Cyclone	2	2115	Flood
27/9/2000	27/9/2000	Penang	Nil	-	500	Nil
30/3/2002	30/3/2002	Klang Valley (Sepang, Setapak Jaya, Jalan Pinang, Jalan Semarak, Jalan Tun Razak, Pudu Boroughs, Petaling District	Convective Storm	2	155	
16/7/2004	16/7/2004	Kedah State	Nil	-	1000	Nil
06/11/2004	06/11/2004	Kuala Lumpur	Nil	1	40000	Flood, Land Slide, Mud

2.3.1 Tornado in Malaysia

For some reason Tornado events have been closely watched g and recorded in Malaysia (Abdul Shukur & Raihan, 2015). Tornadoes in Malaysia was recorded in localised form. In comparison to other countries tornado faced in Malaysia is shorter in duration. The frequency of the tornado in Malaysia is influenced by the monsoonal season. Based on Table 2.2, the number of cases has been recorded from the year 2010 to 2014. Records are divided into two cases, which are landspout and waterspout. It was found that the highest cases of landspout and waterspout were recorded during the northeast monsoonal season, which were 12 cases and 13 cases, respectively. Likewise, the second highest was found to occur during the southwest monsoonal season, which has recorded 6 landspout cases and 12 waterspout cases. However, the lowest case was recorded during the monsoonal transition period (April), which had two landspout cases and four cases of waterspout. During the monsoonal transition period (October), the number of cases recorded was with five landspout cases and seven waterspout cases.

Table 2.2: Tornado frequencies from the year 2010 to 2014 according to Monsoonal changes in Malaysia (Abdul Shukur & Raihan, 2015)

Monsoon	**Landspout**	**Waterspout**
	Number of Cases	
North East (Nov –Mac)	12	13
Transition (April)	2	4
South West (May-Sept)	6	12
Transition (October)	5	7

Table 2.3 shows an analysis of tornado events which was classified according to the state. For Peninsular Malaysia, Kedah shows the highest number of tornado occurrences with 11 cases. All tornado events in Kedah was classified as landspout. Pahang and Terengganu show the lowest record of tornado events which only had one case between 2010 to 2014. From Table 2.3 the northern state region of Peninsular Malaysia which consist of Perlis, Kedah, Penang and Perak cumulatively show the highest number when compared to other state region in Peninsular Malaysia.

According to statistics shown in Table 2.1, it seriously notable that Malaysia is a country which cannot be excluded from the windstorm disaster. Most of the windstorm disasters were also accompanied by other types of disasters such as floods, landslides and mudslides. Due to geographical position of Malaysia, it is always considered as safe from direct tropical cyclone hit. However, from Table 2.1, it clearly shows that Malaysia has also experienced tropical cyclone for two times. Even though there were only records with two events of tropical cyclones for the last 50 years, it has caused remarkable loss. For example, Tropical Storm Greg recorded in December 1996 caused a landfall near Kota Kinabalu Sabah. It carried heavy rains and subsequently triggered floods , which were caused by the overflow of river banks. The storm affected a total of 17,000 people and 226 villages along the Sabah's southwest coast. It destroyed 4,925 houses and killed 270 people. Tropical Storm Greg was the most devastating tropical storm ever recorded in Malaysia, with an estimated economic loss of around USD 280 million. Another significant tropical cyclone which hit Malaysia was Typhoon Vamei in December 2001. It caused a landfall near south-east of Malaysia. This uncommon event was first noticed through typhoon strength winds from a US Navy ship, and it was then confirmed by satellite images (Chang & Wong, 2008). It caused floods in the southeast part of Johore. Typhoon Vamei claimed 2 casualties and the estimated economic loss was approximately USD 4.2 million. Although the tropical cyclone is uncommon in Malaysia this phenomena still could cause substantial damage and loss of lives and therefore should not be taken lightly.

Table 2.3: The occurrence of (landspout / waterspout) in Malaysia by the State from the Year of 2010 to 2014 (Abdul Shukur & Raihan, 2015)

	Year	2010		2011		2012		2013		2014		**Total**
State	**Type**	**L**	**W**	**L**	**W**	**L**	**W**	**L**	**W**	**L**	**W**	
Perlis		1	0	0	0	0	0	1	0	1	0	**3**
Kedah		1	0	3	0	1	0	1	0	5	0	**11**
Pahang		0	0	0	0	0	0	0	0	0	1	**1**
N.Sembilan		0	0	0	0	0	0	0	0	0	1	**1**
Sabah		0	1	0	3	0	2	2	2	0	1	**11**
Sarawak		1	2	0	1	0	0	0	1	0	1	**6**
Selangor		1	0	0	0	0	1	0	1	2	0	**5**
Perak		0	0	1	0	0	0	1	0	1	0	**3**
Johor		0	1	0	4	0	1	0	2	0	0	**8**
Melaka		1	1	0	0	0	1	0	1	0	0	**4**
Penang		0	5	0	0	0	0	1	1	0	0	**7**
Terengganu		0	1	0	0	0	0	0	0	0	0	**1**
Total		**5**	**11**	**4**	**8**	**1**	**5**	**6**	**8**	**9**	**4**	**61**
L = Landspout **,** **W** = Waterspout												

2.3.2 Thunderstorm in Malaysia

MMD has been monitoring and recording Thunderstorm Day (T_D) in Malaysia for more than 30 years. Since1990s, the majority of weather stations have conducted these observations in 24-hours basis. Table 2.4 shows the MMD data that have been obtained from the 24-hour stations for the year 1993 until 2002 (Abidin & Ibrahim, 2003).

The thunderstorm day is defined as in local calendar day during which thunder is heard at least once at a specified station. Nevertheless, this process of calculation is not precise since the period and intensity of the lightning activity on a given day is not taken into consideration. The available information for T_D in Malaysia has so far been erratic. Several maps that indicated with the T_D level were presented in several local seminars and conferences. It is found to be inaccurate when compared to the actual data provided by the MMS (Abidin & Ibrahim, 2003).

Nonetheless, these data could provide some useful information for readers in estimating the value of T_D for their particular locations. If it is not located at the major towns/cities recorded in the Table 2.4, then approximate values can be determined considering the values of T_D with the nearest location, or by interpolating the values between two known adjacent locations. Hence, reliable information on the thunderstorm is required to estimate the risk of a storm. According to Table 2.4, the variation of T_D for Peninsular Malaysia is between 90 at Langkawi and 239 at Bayan Lepas. For Sabah, the variation ranged between 45 at Tawau and 193 at Sandakan. Meanwhile for Sarawak, the variation range between 68 at Miri and 231 at Kuching. Thunderstorms in Malaysia are considered as localised phenomenal event which potentially poses damage to building structure. Most of the related damages are concentrated in small buildings or small structures, which are almost non-engineered building (Majid et al., 2010). Thunderstorm is found to be frequent in Malaysia. Unlike in cyclone-prone regions, the thunderstorms in Malaysia occured in microscale. Despite their minor size and short duration of a thunderstorm which is about 15 to 30 minutes yet it still may cause some serious damage to building structures. (Irwin, 2009).

Table 2.4: Annual Thunderstorm Day values for The Period 1993 – 2002. (Abidin & Ibrahim, 2003)

Major Town / City	10 – year T_D Average	Max T_D	Min T_D
Langkawi	101	136	90
Alor Setar	165	197	145
Butterworth	172	183	164
Ipoh	165	239	185
Sitiawan	165	200	135
Subang	188	195	180
Melaka	137	165	103
Kluang	191	222	165
Senai	172	206	159
Mersing	171	188	151
Kuantan	154	173	128
Temerloh	112	156	92
Kuala Terengganu	163	184	141
Kota Bahru	115	146	94
Kuala Krai	161	177	149
Kuching	184	231	151
Sibu	103	115	85
Bintulu	103	180	102
Miri	88	101	68
Labuan	147	164	112
Kota Kinabalu	139	158	113

2.4 Windstorm Assessment

Based on the recent wind-induced damage to buildings and structures in Malaysia, most of the possible risk of wind hazard is due to thunderstorm. There is very little emphasis on the design of building structures such as roof and cladding to minimize the wind-induced damage to buildings. From the information gathered through the literature review, some of the past studies conducted by researchers in Malaysia are included here.

Recently, highlight of damages and injuries due to windstorm events are reported frequently (Majid et al., 2010). Roof truss failure due to a windstorm was frequently reported. Clay roof tile also found to be uplifted during the storm and create flying debris hazard. Most damages to roofs themselves was caused by local high suctions and large pressure fluctuations around the roof periphery and protruding portions. Temporary structures such as canopy tent were damaged due to windstorm. Fatal incident was recorded during the event. For building structure damage caused by strong wind was mainly concentrated on the roof structures. Damages was associated with windstorm event due to the building structure which is not designed accordingly. The study also identified flying debris issues which should be given priority in reducing the impact of windstorm-related damages.

Improvement of standards and building codes related to wind-related disaster need to be addressed intensively (Majid et al.,2012). At present wind related disasters is not being highlighted due to lack of expertise and awareness among the Malaysian.

Number of damaged houses have been reported in daily newspapers. From the reported news, it was identified that most of the damage occurs in the northern region of Peninsular Malaysia. Damage due to windstorm was caused by the lack of concern regarding the wind effect on structural system. It was also reported that most of the codes of practice does not not reflect much on the structural system and materials that is widely used in Malaysia.

Interestingly, Bachok et al. (2012) has evaluated and reviewed windstorm occurrences all over Malaysia from the year 2000 to 2012. The windstorm occurrences were collected from several sources such as mass media and reports published by government agencies. Summaries of 681 occurrences which contains 681 locations and dates, 463 times and 147 durations indicated that windstorms could be expected in Malaysia each year. From the study it was concluded that windstorm occurred throughout the year was highly influenced by the monsoon.

Furthermore, Wan Chik et al., (2014) identified the total number of windstorm occurrences in Peninsular Malaysia between the year 2007 until 2012. The study found that the occurrences have shown slight increment from the year 2007 to 2012. State of Kedah state was found to experience 19 cases of maximum event of occurrences in six years duration. The minimum event of occurrences was found to be only 3 cases in Melaka state.

Majid et al., (2015) extensively observed the cause of wind related damage caused by localized thunderstorm event. Increased in severe windstorm events continuously increases damage, losses, and even mortality was also observed. Serious damage was observed in rural non-engineered buildings in Malaysia. It was found out that approximately 80% of the cases of damages to the roofing systems were caused by thunderstorms in Peninsular Malaysia. Damage breakdown shows that 47% damage on the steel sheet roofing, 30% on the truss system, 13% on the roof tiles, and 20% on other related components. A good example for damage in roofing system was also reported after the windstorm event at the Macalister Road which is located on Penang Island. The construction industry and other stakeholders in Malaysia requested an immediate study and inputs form wind engineering expert to clarify this uncertainty. Further studies and research works have been carried out to gather more information for better understanding of wind characteristics in Malaysia.

Majid et al. (2016) presented an examination reports for the past windstorm occurrence trend, including damage and losses, in Penang districts from 2010 to 2013. Windstorm likely to occurs during March, May, and November annually. The windstorm occurrence indirectly contributed to the damage and losses in that particular area. Extensive damage was observed in rural non-engineered buildings in Penang. It was also found that failure is influenced by several factors, such as missing or poorly installed fasteners, insufficient fasteners, and sub-standard roof sheathing, fasteners, and nails.

From the numerous studies conducted, several factors were found to contribute to damage of building components. It can be concluded that most of the failures caused by lack of the consideration due to wind effect during the design stage. Furthermore, it is clearly stated that most structure failure was on the roof and truss

2.5 Wind Damage Database

Currently, there is no single reliable database which could be referred. However, a number of past researchers had taken the initiative to establish the database. Bachok et al (2012) has proposed a method of collecting data for windstorm event more appropriately. Windstorm damage can be identified from several sources, but the primary source is from the newspaper. Figure 2.2 shows the details about windstorm occurrence extracted from a newspaper report. The data summarized general features of the windstorm occurrences scenario based on several categories such as, state, district, the central city, year, date, duration and estimation loses.

Based on Abdul Shukur & Raihan (2015) work, the data collecting information related to damage could be classified into three categories as shown in Table 2.5. All cases have been recorded based on time, location, and type. The study recommended that only strong and very strong classification could recognised and valid to use.