ANALYSIS THE EFI) ON ROOF TRUSSES OF
RESI 1553:2002

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ABSTRACT

Wind is a natural phenomenon that occurs in all regions and can be predicted. But nowadays, Malaysia experienced an extreme climate change and unexpected wind condition which is lead to severe damage to the building especially residential building and this case had increase in past few years. As this problem is forecasted to lead to the great amount of losses in term of money and can cause injuries to people, this paper is provide to study the characteristic of wind and to determine the maximum wind speed that can cause failure to roof, and hence provide the guideline of the safety design of roof truss for residential building. The research is focuses on standard roof trusses design of residential building with JKR standard as a guideline. As referring to the postdisaster investigation of major windstorm events that had been conducted in Unites States for past two decades prove that the failure of the roof structure is obviously because of the poor construction of the truss system and due to the construction itself that not following code. Based on the past research also shown that the presence of wind load in term of suction and uplift force that normally ignored in construction is the main cause of roof system to fail. The research is proceed by using data of various wind speed that lead to different potential damage to the building which is Fujita Scale and Tamura Scale. Basic wind speed of 33.5 m/s is set up as a benchmark in determining the standard size of the truss and the dimension of the truss itself. The value of wind speed from Tamura Scale is used in analysing the loading on the roof truss by using simplified procedure in MS 1553:2002 since the cases is investigated in Malaysia. The methodology of the research then projected by create a model of roof trusses in ANSYS CivilFEM where the roof truss is modelled using hot rolled cross section with the same truss span, truss spacing, purlin spacing as calculated using simplified procedure. At the end of the research, it found that the minimum size of truss that can support basic wind speed 33.5m/s is 75 x 75 x 8 and truss to fail when reach wind speed 140m/s when considering wind tunnel coefficient and 160m/s without considering wind tunnel coefficient. As a nutshell, this can be conclude that in designing for roof trusses, the value of wind speed that should be considered in the design is not only focusing on basic wind speed but also increase the design capacity of the trusses so that when unexpected high wind speed occur, the roof truss still can support the load without any failure.

ABSTRAK

Angin adalah satu fenomena semula jadi yang berlaku dalam semua wilayah dan boleh diramalkan. Tetapi sejak kebelakangan ini, Malaysia mengalami perubahan iklim yang melampau dan keadaan angin yang tidak dijangka yang menyebabkan kerosakan teruk kepada bangunan-bangunan terutamanya bagunan perumahan dan kes ini semakin meningkat. Masalah ini diramalkan boleh membawa kepada kerugian yang besar dan boleh menyebabkan kecederaan kepada penduduk. Kajian ini dijalankan untuk mengkaji ciri angin dan untuk menentukan kelajuan angin maksimum yang boleh menyebabkan kegagalan terhadap kekuda bumbung dan dengan itu menyediakan garis panduan reka bentuk keselamatan kekuda bumbung untuk bangunan kediaman. Kajian ini memberi tumpuan kepada jenis kekuda bumbung reka bentuk bangunan kediaman dengan piawaian JKR sebagai satu garis panduan. Merujuk kepada siasatan yang melibatkan peristiwa ribut angin yang telah dijalankan dalam oleh Amerika Syarikat pada dua dekad yang lalu membuktikan bahawa kegagalan struktur bumbung itu adalah kerana system pembinaan kekuda yang lemah dan kerana pembinaan itu sendiri yang tidak mengikuti piawaian. Berdasarkan penyelidikan yang lalu juga menunjukkan bahawa kehadiran beban angin dalam bentuk sedutan yang biasanya diabaikan dalam pembinaan adalah punca utama sistem bumbung gagal. Kajian ini diteruskan dengan menggunakan data kelajuan angina yang berbeza yang membawa kepada kerosakan kekuda bumbung iaitu Skala Fujita dan Skala Tamura. Kelajuan angin asas sebanyak 33.5 m/s digunakan sebagai penanda aras dalam menentukan saiz standard kekuda dan dimensi kekuda. Nilai kelajuan angin dari Skala Fujita dan Skala Tamura digunakan dalam menganalisis beban angin keatas kekuda bumbung dengan menggunakan prosedur dalam MS 1553:2002 memandangkan skop kajian adalah Malaysia. Metodologi kajian kemudian diteruskan dengan membina satu model kekuda bumbung menggunakan ANSYS CivilFEM dimana kekuda bumbung dimodelkan menggunakan 'hot rolled section' dengan panjang kekuda, jarak antara kekuda, jarak antara purlin yang sama dikira menggunakan prosedur dalam MS 1553:2002. Pada akhir kajian, ia mendapati bahawa saiz minimum kekuda yang boleh menyokong kelajuan angin asas, 33.5m / s adalah 75 x 75 x 8 dan kekuda gagal apabila kelajuan angina menjangkau 140 m/s untuk kelajuan angina yang mengambil kira pekali 'wind tunnel' dan 160 m/s bagi kelajuan angina tanpa mengambilkira pekali 'wind tunnel'. Kesimpulannya, dalam mereka bentuk kekuda bumbung, nilai kelajuan angin yang perlu dipertimbangkan dalam reka bentuk bukan sahaja memberi tumpuan kepada kelajuan angin asas tetapi juga meningkatkan kapasiti reka bentuk kekuda supaya apabila angin kuat yang tidak dijangka berlaku, kekuda bumbung masih boleh menyokong beban tanpa sebarang kegagalan.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Wind is a natural phenomenon that occurs in all regions and can be predicted. The function of wind can be categorized into two aspects which are as a phenomenon that give benefit in contribution of development of wind energy, sail boats and cool down the temperature and another part is can be seen as negative function which are the extreme of wind pressure can cause severe damage to the structure whether engineering structure or non-engineering structure. According to Mendis et al. (2007), wind is known as a complex phenomenon due to the condition of flow that is arising from the interaction of wind and the structure. With the increase of height, the average wind speeds over a time period also increase while the gustiness decreases due to height.

Numbers of severe damage and injuries that caused by the wind hazard in past few years had increase in Malaysia currently. Most of the respective peoples aware about this issue but the big problem is the number of people or expertise that involved in wind engineering activities still fewer (Majid et al., 2010). Case (2011) claims that non-engineered buildings and low rise buildings is the majority of type of buildings that will damage due to extreme wind speed because most of this buildings are residential and constructed using timber and light-frame construction.

Roughly, the function of the roof is only to cover the building, but the failure of the connection system of the roof will caused severe damage and the entire building will suffered with same consequences. So that, during the early stage of construction process, the design should be in details in order to ensure the roof system can restrain any burden from wind pressure in various condition. Because of this consideration, MS 1553:2002, Code of Practice on Wind Loading for Building Structure is developed in Malaysia as our own standard. This standard is developed by referring Australian Standard, AS/NZS 1170.2 due to the same climate in Australia and Malaysia (Sundaraj, 2002).

Mahendran (1995) states that low rise building especially house suffer severe damage due to high wind event such as storms and hurricanes. Low rise building is normally including house, school, industrial building, commercial building, and also farm building. This kind of building can be categorized as country's assets and if these kind of building damage, it will give a huge amount of losses to the country.

1.2 PROBLEM STATEMENT

Nowadays, there are many reported cases on failure of roof due to the extreme wind load. The issue needs on deep analysis of the effect of wind load on any structure especially for non-engineered building. This kind of analysis is compulsory and cannot be taken for granted because extreme wind is one of the factors that can cause failure in structure due to the unpredictable wind condition in Malaysia.

Sinar Harian Newspaper had highlighted about the issue in Kuala Terengganu which is roof that made from 65 meters iron at Supermarket Xiri that located at Batu 2 Jalan Kuala Berang was collapsed due to extreme winds heavy rain on 1 October 2013. Examples of cases reported to media normally cases about the severe damage of properties such as homes and vehicles.

Although not involve in death as the cases reported in the Berita Harian on 15 August 2004, but about 20 vehicles damaged because of the roof that crushed by the storm from the 20th floor of Rumah Pangsa Desa Wawasan, Bukit Mertajam. Berita Harian also reported the same incident that happened in Kuala Lumpur on 12 April 2005 which is at least about 40 houses and 10 unit apartments severely damages when hit by strong wind, and about 39 cars destroys because of the roof that fall from the apartment.

On 17 April 2004, another incident happened is involving failure of asbestos type roof structure that occurred at Police Training Centre (Pulapol), Muar where caused damage to the roof of Information Technology Centre, cafeteria, club house, and some quarters as reports in Metro Ahad. Most recently, on 11 May 2013 at 6.45 pm, Harian Metro reported about the damage of roof of 23 houses in Kampung Manjoi due to strong wind. Fortunately, no death was reported.

Most of the reported incidents show the roof structure failures occur due to the inability of the connection system to support high wind load. There are two possible failure of the roof which is if the roof sheets lifted its mean that because of the weak connections between the roof and truss cover. If the truss structure that dislodged, this is because of the weak connection between the structure of the roof trusses and the roof beams.

However, no action was taken even if the cases start to be serious from 2004 until now in order to identify the causes and solutions to these issues. Therefore, this research is conduct to investigate whether the roof system that practiced is safe to be used or should be change especially for residential building.

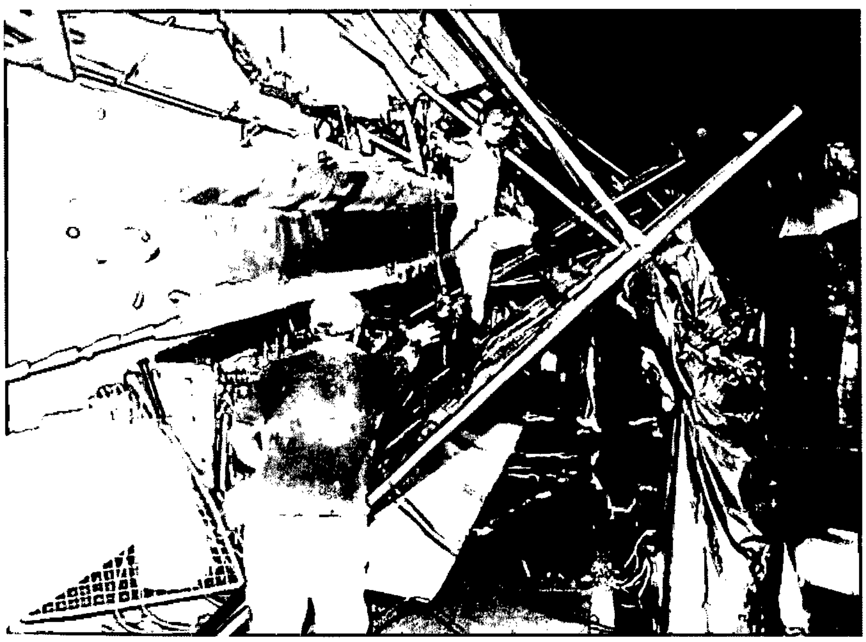


Figure 1.1: Common example of roof failure

1.3 OBJECTIVES

The goal of this research is to determine the effect of variable wind speed on roof truss. To achieve this goal, several objectives are determined:

i) To study the characteristic of wind which is suction force.
ii) To analyse the maximum wind speed that can cause failure to the roof truss
iii) To propose the safety design parameter of building in construction of roof truss

1.4 SCOPES OF RESEARCH

The scope of this research is focused on the effect of wind speed to the non-engineered building which are low rise building and residential building. The roof structure of non-engineered building has high risk to fail due to strong wind. High speed of wind that causes the high wind pressure had been expected to be the cause of the failure of the roof structure of non-engineered building. By focusing on this case, this research is conducted to determine the maximum wind speed that occurs in Malaysia that caused failure on the roof structure of non-engineered building.

The result decided through the simulation using ANSYS software and with manual calculation use Malaysian Standard, MS 1553:2002. The determination of these data must be only focused on MS 1553:2002 since this case occurs in Malaysia. Any other probabilities of failure of non-engineered building have been neglected by using the same model of building and the height of land from sea level where the building is demonstrated in this research.

1.5 SIGNIFICANCE OF RESEARCH

As the technologies expand in modern age, the enhancement of the structure of building should be take concern in order to ensure the uniformity of design standard for all types of building. Because of the unpredictable of weather condition in Malaysia nowadays, an aspect of wind load cannot be neglected in any design of structure in order to avoid any failure that will cause losses and bring to death. At the end of the research, the maximum of the wind pressure that will occur on roof structure and cause it to be failed due to the wind speed in Malaysia's weather will be provided. With the final result of this research will provide an understanding and awareness to the involved parties especially to the engineers, contractors and also to the people about the importance the proper design of the building by not taking for granted of the wind factor in Malaysia. With this, whenever the residents know about the current wind speed, they will know the consequences of roof structure failure. To avoid the tragedy again, repairing and strengthening of roof structure and also determination of the probabilities of the maximum wind speed caused the structure to fail are strongly needed.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

One of the most significance current discussion in legal and moral philosophy is regarding the extreme wind load that cause failure to the building especially non-engineered low rise building. Even if roof is physically functioned to cover the upper part of the building, but actually roof play an important role in structure. The failure of the roof system will cause failure to the whole structure. Selection of roof type is based on characteristics of stability, strength, durability, heat resistance, supply of light and air and also aesthetic value.

The construction of roof system should be strong and able to support loads and stress applied. Loads is categorized into dead load which is comes from roof tiles, purlin and trusses, live load and wind load. Wind load is a major load that experienced by the roof but is difficult to predict due to unpredictable weather in Malaysia. Roof stability depends on it supporters such as roof frame, column, walls, beams and foundations.

2.2 RESIDENTIAL BUILDING

Anand S Arya (2000), states that residential buildings as a building that are informally or spontaneously constructed in almost all countries by using traditional method without any involvement of any qualified engineers and architects during design until construction phase. Non-engineered building mostly constructed using materials such as clay, concrete block, wood, and clay bricks and the construction is normally by using experience or rules of thumb that is passing from one generation to the next generation.

As the development of the construction field, non-engineered reinforced concrete frame buildings is also as a part of the non-engineered building nowadays that constructed by semi-skilled professional builders. Normally this type of building use low quality of concrete and placement of reinforcement. The moment resisting frame normally constructed from wall with no reinforcement that made of hollow clay bricks or hollow concrete blocks.

Non-engineered buildings normally do not have specific design, and do not have to get any approval from expertise such as professional engineers before been constructed. According to Lizzarralde's study (as cited in Papanikolaou & Taucer, 2004), before construction, non-engineered building do not have to go through the permit process and this kind of building normally constructed in rural areas.

Normally, non-engineered building that constructed in all over the world is according to minimum reference to standards or codes. Almost all house owners did not take concern to check whether their house is complying with standards or not. This is because these types of buildings are constructed by workers or labors with no or maybe less skills and less knowledge about the standards or codes. This type of building also constructed without any design as a guideline and without provision and inspection by the engineers or any expertise in construction field and also using local materials and traditional methods. With this reasons, this building surely have low quality and have great possibilities to have severe damage due to strong wind (Kusumastuti, Pribadi, & Rildova, 2008).

The problems that occur on these buildings is normally due to improper structural design of the buildings which are normally based on owner's or worker's aspiration. During the traditional age, the house is build using wood and bamboos, with the design and the arrangement of the structure is adequate with the materials. But nowadays, the traditional workers choose to use masonry wall and reinforcement concrete frame which are considered to be more modern. But the problem is, by changing the materials of the building, the structure's arrangement, plan layouts, building shape and the design of the building itself should be change and cannot be maintained. This will cause the structure to have very low qualities and will damage due to strong wind (Kusumastuti et al., 2008). Normal damage of the building that occur in Malaysia due to strong wind are roof covering dislodged and roof separate from its supports.

2.3 ROOF STRUCTURE SYSTEM

Roof is the upper part of the building or shelter that function to covered them and give protection to the building from the rain, snow, heat, wind and also sunlight. The characteristic of the roof is different for every building depends on its function and the purpose of the building constructed. Almost all of the building has its roof functioning to protect against rain. But now in Malaysia, due to unstable and unpredictable weather, the characteristic of the roof not only should be considered about the rain intensity, but wind speed also cannot be taking for granted.

According to Lee Sid Hwa (2008), roof structure can be defined as the combination of roof truss which is made of timber, purlin, batten connection, rafter and roof sheeting or tiles. Trusses typically has a pin type bearing on one end and a roller bearing on the opposite end which is allowed the trusses to move laterally in response to the load that its support. This movement is a normal response in most residential and light commercial construction due to the flexibility of the structure's construction.

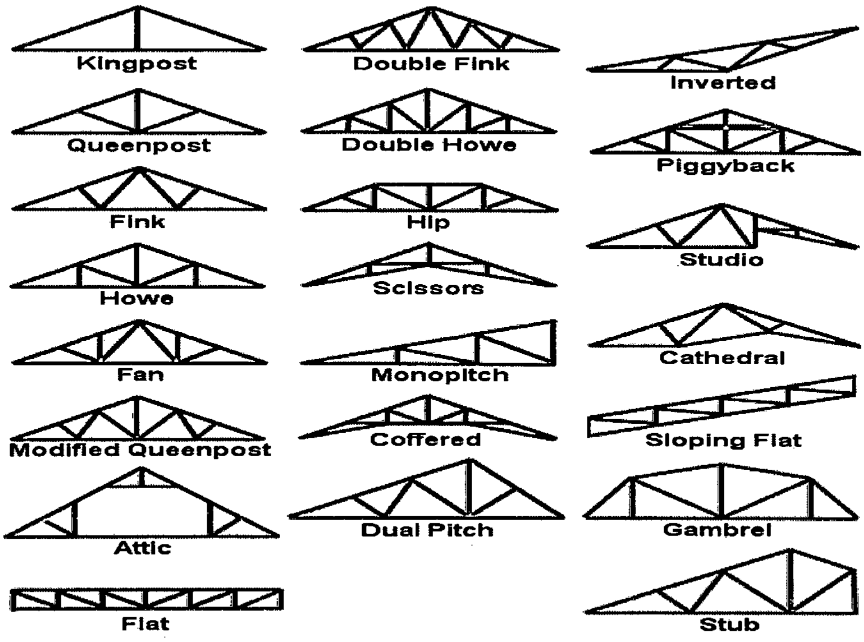


Figure 2.1: Common example of truss shapes

2.3.1 Material of Truss

Timber roof truss can refers as the term light-frame, it is generally applied to assemblies framed using dimension lumber or wood of varying widths having a nominal thickness of 51mm. Conventional light-frame residential structures evolved with little concern for aerodynamics. These buildings generally comprise straight flat walls which meet at 90° corners. Roof overhangs have been accepted as a means of shading windows and protecting siding from the sun during the hot seasons. Most wood-frame structures are residential buildings, including both single family homes and low-rise apartment buildings. In general failure of the structure is usually due to the lack of a continuous load path able to transfer the wind loads to the foundations. Timber roof structure has such advantages:

- Easy to erect
- No job site waste
- Lowest overall cost
- Have a good appearance
- Engineered product
- Do not required skilled labor

- Virtually any roof and ceiling is possible
- Do not required ordinary tools Project fast track

In residential construction, when additional strength is needed or greater free spans is required, light gauge steel roof system available in the market even if timber trusses are dominating the industry. The advantages of the steel truss structure are:

- Free from termite attack and material decomposition as in organic timber
- Simple fastening/installation method allows for minimum manpower and rapid installation time frame
- A durable and long lasting roof structure
- No welding works which leads to minimum wastage, creating a neater environment
- No coating, painting or treatment required on the steel components. Construction period is thus reduced including cost saving and workmanship consistency

In the nutshell, both systems are equally good but timber truss is widely used because of the availability of the materials. Unfortunately, high quality of timber is hard to find nowadays, and those timbers that used in construction need to be treated with chemicals first in order to protect them from termite attacks and for long lasting uses and the chemical used is harmful to human's health. In order to overcome the problems of lacking of high quality if timber, steel trusses is introduced in the market but can be obtained with high cost. Even if steel trusses are high in cost, but these materials are more durable and reliable.

2.4 WIND CONDITION IN MALAYSIA

The characteristic of climate in Malaysia are normally uniform in temperature, high humidity, and abundant rainfall. Winds are generally light. Malaysia is located in the equatorial region so that it's very rare to have clear sky even in periods of severe drought. Malaysia is also rare to have a few days with sunshine except during the northeast monsoon season.

Wind event is caused by changes in temperature. Warm temperatures on the mainland will be replaced by the cold temperature of the ocean. A wind condition in Malaysia is different depending on the cycle of seasons in Malaysia, there are four seasons can be distinguished, namely the southwest monsoon, northeast monsoon and monsoon transition season which is much shorter. The southwest monsoon usually starts in the second half of May or early June and in the end of September. Prevailing winds are generally from the southwest with a low speed which is below 17.25 mph. Northeast monsoon usually starts in early November and in the end of March. During this season, the prevailing winds are from the east or northeast with speeds of 11.5 to 23 mph. East coast states of Peninsular Malaysia is most affected by the wind at the speed of 34.5 mph or more during strong surge of cold air from the north (Malaysian Meteorological Department).

During the transition seasons, winds are generally light and variable. It is worth mentioning here that in the period from April to November, when typhoons frequently develop in the western Pacific and moving westward across the Philippines, southwesterly winds in the northwest coast of Sabah and Sarawak region stronger and can reach 23 mph or much more. As a country surrounded by the sea, the effects of land and sea breezes of wind flow pattern is great especially during days with clear skies. In the bright afternoon sunshine, ocean breezes with a speed between 11.5 to 17.25 mph and the wind usually happens could reach several tens of kilometers into the interior. During clear nights, the reverse process occurs and land breezes weaker strength can occur in coastal areas.

2.5 NATURE OF WIND AND WIND SPEED

Zainudin Abu Bakar (2000) states that, air movement at the surface is hindered due to surface roughness and wind speed will be slow. On the surface wind speed is reduced leading to a value of zero. At a high altitude, wind movement is independent of the surface vibration and wind speed will be increased under the effect of pressure gradients up to speed gradients. The movement of wind in the atmosphere does not directly flow from high pressure to low pressure, as Geostrophic of Coriolis effect and the spin of the earth to produce the resultant force causes the wind is blowing parallel to the isobars.

Orchard (2011) agreed that direction of the local wind and its direction are strongly influenced by the adjacent building and the roughness of the surrounding buildings. According to him, the condition of wind normally reported in terms of direction of the wind and also the speed of wind that can be determine about a period of time from five minutes to ten minutes up to an hour or more. According to Simiu's study (as cited in Norhaiza Ghazali, 2010), the definition of basic wind speed is as the 3 second peak gust at 10 m above ground level and located in open terrain.

The difference speeds of wind leads difference conditions of land or sea which explained in the Fujita Scale. According to Wikipedia, Fujita Scale is an empirical measure that relates wind speed to observed conditions at sea or on land. Wind-induced Phenomena/Damage Table (Tamura, 2005), also proof that different wind speed will lead to different phenomena and different levels of damage.

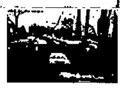
Scale	Estimated wind speed[3]		Relative frequency[citation needed]	Average Damage Path Width (meters)[citation needed]	Potential damage[3]	
	mph	km/h				
[illegible]	40–73	64–117	38.9%	10–50 (approx. 32–164 ft)	Light damage. Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.	
F1	74–112	118–180	35.6%	30–150 (approx. 98–493 ft)	Moderate damage. The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.	
F2	113–157	181–253	19.4%	110–250 (approx. 360–820 ft)	Significant damage. Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; highrise windows broken and blown in; light-object missiles generated.	
F3	158–206	254–332	4.9%	200–500 (approx.655 ft-1/3 mile)	Severe damage. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.	
[illegible]	207–260	333–418	1.1%	400–900 (approx. 1/4-1/2 mile)	Devastating damage. Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown and large missiles generated.	
[illegible]	261–318	419–512	<0.1%	1100 ~(approx. 3/4 mile or more)	Incredible damage. Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile sized missiles fly through the air in excess of 100 m (110 yd); trees debarked; steel reinforced concrete structures badly damaged.	

Table 2.1: Fujita Scale

Wind Speed (10m above ground)		Phenomenon/Damage
10min-mean	**3s gust**	
5 m/s	7 – 10m/s	- Vortex resonance/fatigue damage of truss members
10 – 15 m/s	15 – 20 m/s	- Handrail vibration/wind-induced noise - Vortex resonance of steel chimneys - Vibration perception in flexible high-rise buildings
20 m/s	30 m/s	- Seasickness and discomfort in high-rise buildings - Damage to garage shutters - Falling down of pedestrians
25 m/s	40 m/s	- Damage to roof tiles - Damage to window panes due to wind-borne debris
30 m/s	45 m/s	- Collapse of RC block fences - Damage of steel sheet roofing - Overall roof lift-off - Collapse of wooden house - Falling down of gravestones
35 m/s	50 m/s	- Damage to window panes due to wind pressure of high-rise buildings - Blown over of heavy tombstones
40 m/s	60 m/s	- Damage to cladding of high-rise buildings - Limit of allowable distortion of external sealing compounds
45 m/s	70 m/s	- Main frame stresses in high-rise buildings exceed elastic limit

Table 2.2: Tamura Scale

According to Ilgin (2006), the behavior of wind can be different due to some features which are variation of wind speed with height, turbulent and dynamic nature of wind and vortex shedding phenomenon.

2.5.1 Variation of Wind Speed with Height

The winds that occur 10 km above the earth's surface which is known as jet stream is the steadiest, strongest and most persistent winds. At the height of 100m of the atmosphere, the speed and the condition of the wind are heavily affected by the surface, and wind speed become lower through the friction. The area below 1 to 2 km, where the wind is strongly dependent on the friction between the wind and surface is known as planetary boundary layer or atmospheric boundary layer. This fact is agreed by Taranath (2008), (as cited in Ilgin, 2006), states that when the region is about 366m from the earth's surface, the friction between the surface and the wind is almost negligible. According to him, the atmospheric boundary layer is the height of the area which the wind condition is affected by the surface and the change of the wind speed due to height is called wind shear.

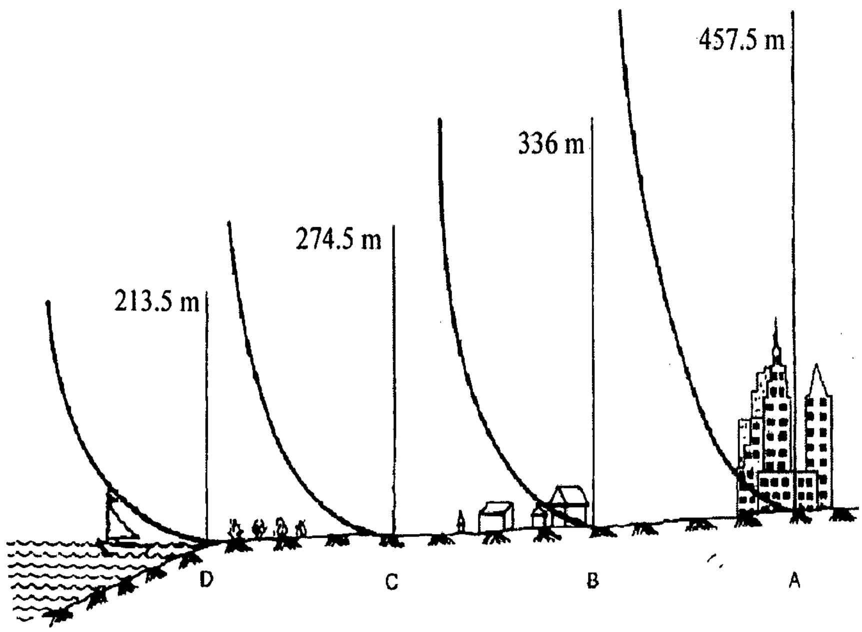


Figure 2.2: Variation of wind speed with height

2.5.2 Turbulent and Dynamic Nature of Wind

Taranath (2008) states that when wind hit an object on its path, its will transfer some amount of energy and this kind of energy is called as gust response factor. Wind turbulence which are also known as gustiness is depending on the variety of the height above ground level and also the terrain roughness. Turbulence can be defined as the movement of air at speed which is greater than 0.9 m/s to 1.3 m/s. Norhaiza Ghazali (2010), conclude that two components can be considered in wind speed which are a mean speed of wind can be increase with the height and the fluctuation of turbulence speed.

2.5.3 Vortex Shedding Phenomenon

Vortex shedding can be defined as the oscillation movement of air or water when flow over an object at certain velocities. When wind flow passing through a building, the stream flow of the wind will be split on both side of the building and the forces that form at every side of the building is known as vortices. There different behavior of the vortices varies with the speed of the wind. For low wind speed, the vortices that form will be equal or symmetrical for both side of the building and this will cause no vibration of the building when the wind passing through. But, when high speed of wind hit the building, the vortices firstly forms at only one side of the building and then followed by another side. This unsymmetrical of vortices formation will cause the building to vibrate (Taranath, 1998 as cited in Ilgin, 2006).