THE EFFECT OF WIND FORCE ON METAL DECK ROOF JOINT

MARSHILA BINTI MAEDIKA

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UNIVERSITI MALAYSIA PAHANG

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ABSTRACT

Wind related damage had been rapidly increase in Malaysia. Previous record most of the failure occurred at roof structure system. Roof metal decking is commonly used now in roof structure system in Malaysia. Pull through failure mostly occurred due to insufficient connection. Therefore this study is conducted to investigate the potential of failure and to provide the information related to connection in roof metal decking system. From previous study it was been identify that the maximum failures load of screw connection is 0.99 kN A general metal roof deck used in Malaysia were identified and been analysed. Two different connection type were used which is screw and nail in this study. The spacing between the connection been model are 300 mm, 600 mm, 900 mm and 1200 mm. Finite Element software were used to analyse the force acting to the connection. From the result it was shown that the maximum spacing of screw connection to resist wind speed at 32.5 m/s is 1100 mm. Result also shown that by increasing the spacing distance of connection will affect the risk to failure. It can be concludes that the spacing of the connection are very important in order to resist wind storm.

ABSTRAK

Kerosakan berkaitan angin semakin meningkat di Malaysia. Rekod sebelum in kebanyakan atau selalunya ialah kegagalan berlaku pada sistem struktur bumbung. Bumbung kepingan logam biasanya digunakan di sistem bumbung struktur di Malaysia. Kegagalan tarik melalui kegagalan kebanyakannya berlaku kerana sambungan yang tidak mencukupi. Oleh itu kajian ini dijalankan untuk menyelidik potensi kegagalan dan untuk menyediakan maklumat yang berkaitan dengan sambungan di bumbung sistem geladak logam. Daripada kajian sebelumnya ia telah mengenal pasti bahawa kegagalan beban maksimum sambungan skru ialah 0.99 kN logam umum dan lazim dek bumbung yang digunakan di Malaysia telah dikenal pasti dan dianalisis. Jenis sambungan yang digunaakan adalah skru.. Jarak di antara model sambungan menjadi 300 mm, 600 mm, 900 mm dan 1200 mm. Perisian Finite Element Software telah digunakan untuk menganalisis daya yang bertindak keatas sambungan skru. Dari hasil yang ia menunjukkan bahawa jarak maksimum sambungan skru untuk menahan kelajuan angin 32.5 m / s ialah 1100 mm. Keputusan juga menunjukkan bahawa dengan meningkatkan jarak jarak sambungan akan menjejaskan risiko kegagalan. Ia boleh membuat kesimpulan bahawa jarak sambungan yang sangat penting dalam usaha untuk menentang ribut angin.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Wind occurrences are because of existing of differing atmospheric pressure and the movement of the low pressure area of air towards high low pressure area of air lead to the various wind speeds produced. The wind load usually applied to the roof of the building while the wind speed cannot be control of human beings.

The phenomenon of disaster caused by wind shows increasingly and repeatable every year. Due to the reported case of the failure of the roof structure due to the wind blow during rainstorm we can find the way to reduce it by doing research. This problem always happens every year, but there is still no rigid solution to overcome the entire problem. The research is conducted due to the reported cases of the failure of the roof every year. The problem or the failure of the roof happens whenever the rainstorm or heavy wind blowing at a certain speed. This wind force phenomenon is very similar to Asian especially in Malaysia as the country which is in the area of Monsoon.

The phenomenon Monsoon in Peninsular Malaysia recorded the rainstorm and heavy wind from October until January. In between this period of monsoon seasons, the wind speed recorded in Methodology Department Malaysia. According to Malaysian Meteorological Department (MMD) the highest mean daily wind speed recorded at Johor which is 3.8 m/s while the highest maximum wind speed was recorded on 1992 located in Sarawak which is carry 41.7 m/s of the wind.

Wind climate in Malaysia is conquered by two main monsoon seasons, which is the North-east season and inter-monsoon period. The occurrence of tropical thunderstorm is slightly higher at inter-monsoon period. This period usually happens in April and May while another season of monsoon will take place in December to March. The tropical a thunderstorm is able to produce strong and gusty surface wind. The wind conceived from thunderstorm is relatively stronger and more turbulent than other monsoon winds (Choi, 1999). The wind speed produces during a thunderstorm will increased drastically and uncontrollable. During thunderstorm, the wind speed will increase approximate 592.9% (Yusoff, 2005)Thus, thunderstorm phenomenon could be dangerous and threaten to the building structure even potentially to kill people with its lighting produced.

The consideration of uplift force, wind force and the sheathing material could be save and reduce the number of damage happen to the structure of the building. There are many factors will lead to the damaging on the roof structures. The roof structure, usually failed is the truss and the bonding including the rafter, connection between the roof and the truss such as inadequate nailing and screws of the roof.

The damage due to Wind Storm in Malaysia reported from January until August 2010 the reported cases regarding on roof damage shows 1012 houses are involved during a wind storm, (Ramli, et. al, 2010) as shown in **Table 1**. According to (Tamura, 2009) titled as wind-induced/damage if the wind speed, 10m above ground the speed below 30m/s will deal with some phenomenon or damage on structures such as overall roof lift-off, steel sheet roofing failure, the collapsing of wooden houses, RC block fences collapse and other damage could happen.

Table 1: Damage due to Wind Storm in Malaysia (January until August 2010)

	Place	Region	Number of Affected	Structure Damage
27 Jan 2010	Sungai Petani, Kedah	Roof and Truss	350 Houses	Roof and Truss
5 Apr 2010	Bukit Mertajam, Penang	Northern Peninsular	21 Houses	Roof and Truss
5 Apr 2010	Mergong, Kedah	Northern Peninsular	13 Houses	Roof and Truss
12 Apr 2010	Baling, Kedah	Northern Peninsular	200 Houses	Roof and Truss
13 Apr 2010	Merbuk, Kedah	Northern Peninsular	150 Houses	Roof and Truss
22 Apr 2010	Sg Besi- Kg Malaysia	Middle Peninsular	18 Houses	Roof and Truss
1 May 2010	Ulu Bernam, Selangor	Northern Peninsular	Secondary School	Roof and Truss
31 May 2010	Parit Buntar, Perak	Northern Peninsular	*	Roof and Truss
11 Jun 2010	Batu Gajah, Perak	Northern Peninsular	30 Houses	Roof and Truss
13 Jun 2010	Temerloh, Pahang	Eastern Peninsular	9 Houses and School	Roof and Truss
7 July 2010	Beaufort, Sabah	Eastern Borneo	50 House	Porch, Roof
15 July 2010	Kuala Perlis, Perlis	Northern Peninsular	150 Houses	Roof and Truss
12 Aug 2010	Temerloh Pahang	Eastern Peninsular	20 Houses Canopy Damage	Roof Night Market
13 Aug 2010	Malacca	Southern Peninsular	Canopy Damage 3 kills 30 injured	Night Market (Flying Debris)
14 Aug 2010	Jerlun, Kedah	Northern Peninsular	1 Houses, Crop	Roof
14 Aug 2010	Petaling Jaya, Selangor	Middle Peninsular	*	Roof and Truss
31 Aug 2010	Tanjung Malim	Middle Peninsular	Canopies Damage	Night Market

Source: (Ramli, 2010)

1.2 PROBLEM STATEMENT

The phenomenon of the disaster caused by wind shown increasing and repeatable every year will lead to the roof damage and some other problem related to the structure of the building. The damage will continuously occur if there is no wind hazard consideration during designing the structure.

The failure of the roof is the problems happen at least 3 times per year in Malaysia itself. The failure roof, damage roof, the 'fly roof' happens in Malaysia rapidly every year and reported at many channels of news. Berita Harian and Sinar Harian reporting at least 1 (one) cases in 2011, 2012 and in 2013 at least 6 (six) cases reported of the damage roof around Malaysia. In a mean time, institution of school usually will apply the metal deck roof as their some main part of the roof, and most of the cases involving the metal deck roof are from the school. The school reported is Sekolah Menengah Kebangsaan (SMK) Dol' Said, Melaka and SMK Tinggi Setapak Selangor.

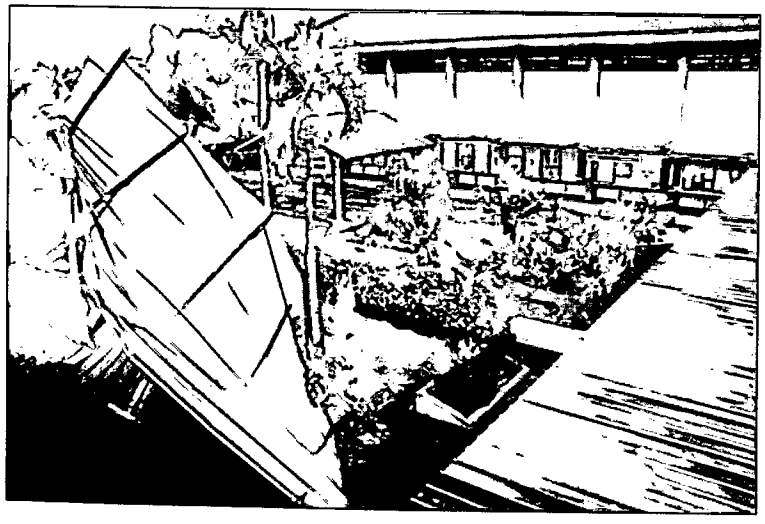

Figure 1.1: Metal deck roof damage in SMK Tinggi Setapak, Selangor.

Source: Berita Harian, (9 Oct 2013)

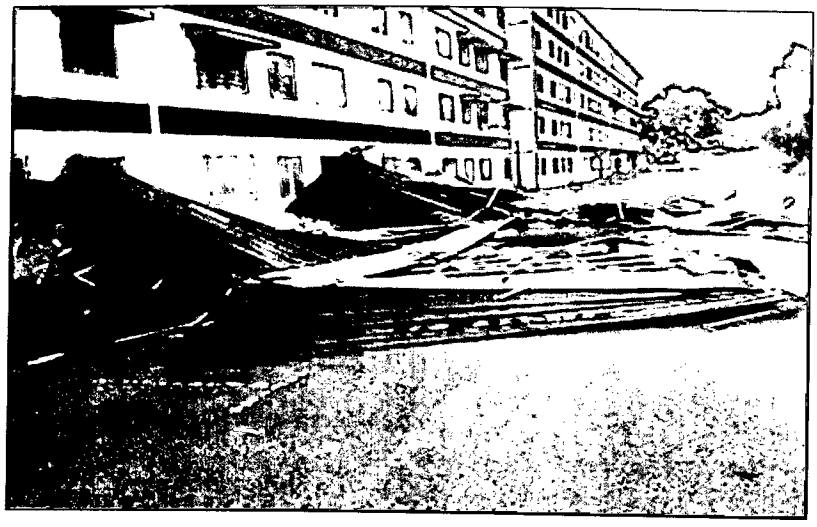

Figure 1.2: Roof structure damage at SMK Perempuan Pasir Mas

Source: Sinar Harian, (11 Oct 2013)

1.3 OBJECTIVE OF RESEARCH

This section contains the objectives for this research which are the wind force towards the metal deck roof.

1. To examine the effect of wind load to the metal deck roof.
2. To investigate the potential of failure and to provide the information related to connection in roof metal decking system.

1.4 SCOPE OF STUDY

Investigate what is the velocity of the wind needed to destroy the structure of the roof and also study about will the slope or gradient from the roof influence the risk damage to the roof by doing stimulation. To apply mitigation on the effect wind towards structure or building by applying the preventing step after analyzing the characteristic of wind and the wind hazard. Research on the pattern of the wind type apply to the structure of the roof

and know what is the effect of the uplift wind on the roof and the trusses. Guide a way to reduce the damage to a certain building, especially the rooftop either considering the distance of the trusses till it produce the gradient for the roof or the material and connection from the roof itself. The sheeting and the material of metal deck may influence the result for the speed limit to apply for it. The way of the constructing the roof is the most important things to avoid damage happen to the roof. By investigating the pattern of the wind towards the roof which is what type of the wind pattern will break the roof part.

The result from this study obtained by using programming on SAP software, through that the certain wind speed will be obtained. The data obtained from the programming will be analyzed until it can produce the data of wind speed limit for the roof to resist the load until it fail.

At the end of the research, it will be a guideline about the wind speed limit that potentially damages the roof structure. After this research is done, the guideline will be provided to reduce the cases on roof damage. After the speed wind limit determined the people out there will know what they should do to avoid the failure of the roof constructed. The maximum spacing between connections that obtained from the research can be used as the reference before designing the roof structure, this result obtained from the stimulation will reduce the failure of roof structured due to the wind load action.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

According to the Roof Sheathing and Roof Damage Insurance Claim in North Carolina attachment, HUD (1993), roof sheathing as a critical component that locks all other roof members together to form a structural system the roof member. The component such as roof, trusses, column and frame will support the strength of the roof itself. The component at the joint or connection also will affect the toughness and endurance of the roof. The metal deck roofing is one of the materials used as the roof system major in Malaysia because its properties which is easy to produce and the price of the metal deck are affordable. When the higher wind uplift force or pressures are exist around the eaves of the model metal deck sheeting the pull-though failures often occur at its screws fasteners (Mahaarachchi, 2003).

There are so many cases related to the failure during a wind storm. The roof structure that exposed to the highest risk of failure because of a high wind event are discussed in this chapter and what the consequences of the high wind event on the metal sheeting, connection, truss as well as the wall cladding that support system for the roof structure.

2.2 WIND RELATED DAMAGE

2.2.1 Uplift Force

Uplift force happens when the wind acting inside the building located below the roof exerted which is it pressure much higher than the wind pressure outside the building. The wind hitting on the building will move around the building and pushes the air against the position of the building and will produce the pressure around it.

The uplift force of the wind will lead to the failure of roof sheeting pulling over the connection head called as 'pull through' failure (Mahaarachchi, 2003). Studies have handled before majorly taking the roof cladding in strong wind were focused on the uplift force of the wind (Xu & Teng , 1994).

When the pressure inside the building higher and the pressure above roof system decrease because the high winds flow will producing the uplift force? When the uplift force is higher than it should be or the system was designed for, the roof able to lift from the roof structure during rainstorm or heavy wind.

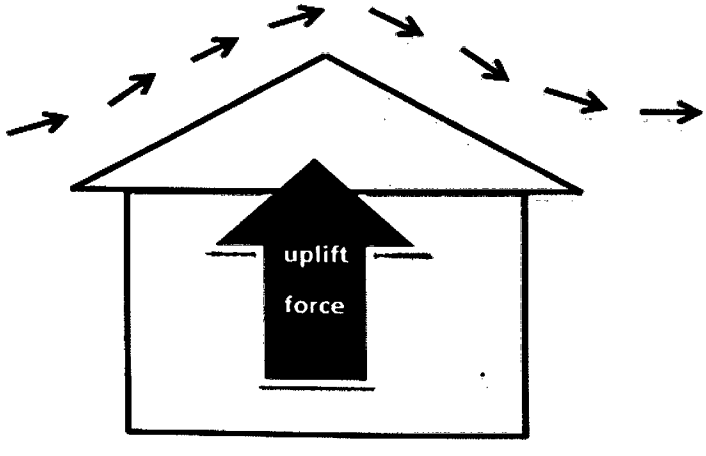

Figure 2.1: Uplift force of a House

The wind uplift force on the roof is usually fluctuating. Under fluctuating loading usually the roof system will undergo fatigues phase, which will lead to its connection of roof to fail. This statement is strengthened by the (Cook, 1990)under vary loading the thin crest-fixed steel cladding will suffered a fatigue failure of sheeting in the surrounding of the roof connection. When combining the wind load acting internally and externally of pressure to the panel will cause sufficient uplift on the panel to remove the fasteners and metal sheeting from the roof framing (Kyung & Rosowsky, 2009).

2.3 WIND DAMAGE TO BUILDING

2.3.1 Wind Loading

Malaysia usually used metal decking system for low-rise building which means it consisting low pitched roofs. The low pitched roofs are usually subjected to the uplift wind load during a wind storm. The low-rise buildings are always undergoing bad routine impacted by the speed-up effect from terrain category (Davenport, 1993.). The forced acting on the metal decking system may either in the form of negative pressure or positive pressure. This aspect needed to be concerned and consider during designing of the roof structure.

According to the (Holmes, 1993) during their study using wind tunnel and field measurement proved that the uplift force or suction of wind will focus on roof and wall cladding during the wind storm occurrence. This uplift loading produced on the metal deck is transferred to the purlin under the metal deck so, then followed by the trusses to the column and lastly the uplift loading will transferred to the foundation. There are two load paths during transfer load (Mahaarachchi, 2003). During transferring using both paths which are uplift load path and racking load path the member and connection should not undergo failure (Mahendran M. , 1995)because if either one of the path experience failure, which means that the path unable sustain the wind loading will lead to the collapsing entire building (Mahaarachchi, 2003).

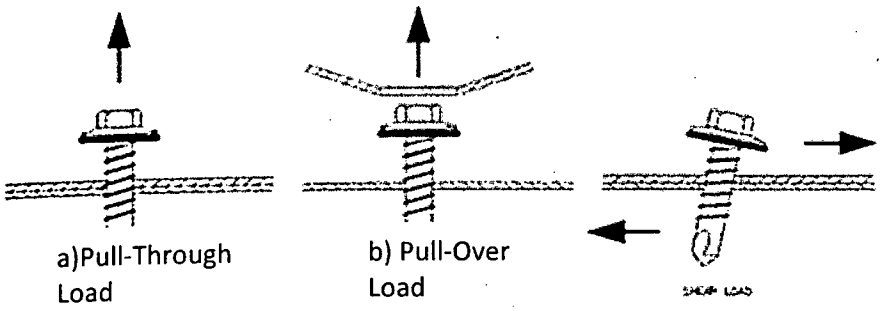

Figure 2.2: Common loads on roof system

Source: http://roofdek (16 Feb 2014)

Roof sheathing basically are affected by three major factors which are resistance capacity from the nail, wind load referring to uplift pressure acting on the panel and dead load are the self-weight of the sheathing panel. (Kyung, & Rosowsky, 2005)

2.3.2 Typical Failures for Metal Deck

There are two common failures on the roof sheeting such as pulling through failure and pulling over failure. The failure often occurred at the connection subjected to head of the screw. Most cases of roof damage are caused by the failure of pulling through, but the pull out failure also happen when the fasteners or called as the screw pulling out from the steel batten. **Figure 2.2** shows the common load always occurred at the fastener of the roof while in **Figure 2.3 (a, b, c)** shows the common failures of metal decking system.

During high large uplift pressure acting on the roof system such as at eave, hips and edges of the roof will cause the failure as shown in **Figure 2.3**. The **Figure 2.3 (a, b)** clearly shows the nail are detached from the metal deck. This failure happens whenever the uplift wind force acting as well as the pull through load as shows in **Figure 2.2** was taking over the roof system. Beside from the failure as shown before there are also some of thw

failures happen due to the higher racking loads. The example of failure due to the racking load are bending of the screw and tearing of sheeting.

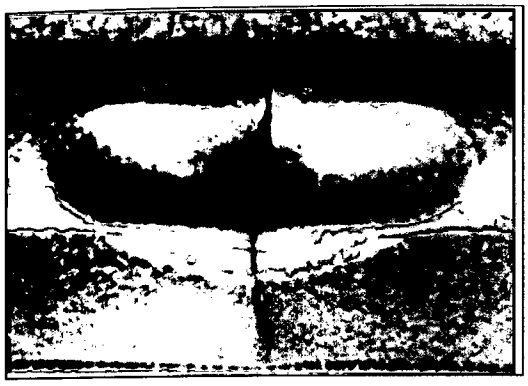

Figure 2.3(a): Pull through failure

Figure 2.3(b) Static dimpling failure

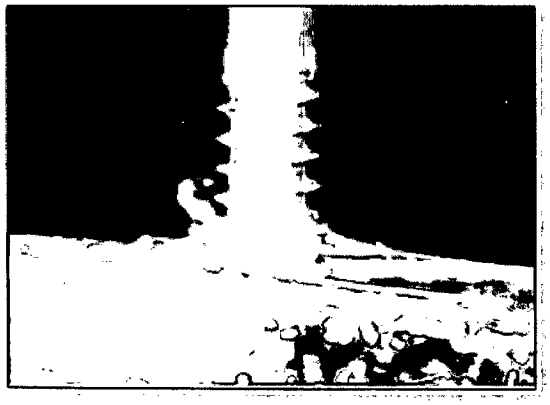

Figure 2.3(c): Pull-out failure

Figure 2.3(a, b, c): Common Failure of Metal Deck (Mahaarachchi, 2003)

The **Figure 2.3 (c)** always happens due to usage of steel batten. Pull out failure recently happened because of the usage thin steel and high strength steel purlin for residential housing. But there is no arise problem about pull out failure could happen if the purlin and batten used are based on timber material. When the membrane stresses reached

yielding, the transverse fracture will occurr at the screw fasteners' hole by considering the limited ductility of the high strength steel (Mahaarachchi, 2003) as shown in **Figure 2.3 (a).**

Beside pull-though failure and pull out failure the fatigue failure also occurred in roofing system for metal deck. Fatigue behaviors will show up followed by fatigue failure in presence of cyclonic wind before the pull through failure happen. These failures usually happen in consequences of having high stress at the vicinity of the fastener holes under the wind uplift loading. The fatigues cracking happen at surrounding of the connection fasteners when the wind loading fluctuates. The cracking continuously happens until the sheeting pull through the fastener head.

2.4 ROOF SYSTEM/STRUCTURE

The screws/nail and metal straps are used as the connector between the roof purling but when the number of connections used is insufficient, the connection part of the roof will tend to fail during a wind storm, especially around the fastener hole. The purlin such as cold form is used majorly on metal deck roofing system, but this type of batten may suffer fatigue failure. The fatigue failure is contributed by the material of the purlin. The purlin used of thin walled high tensile steels may cause the failure of the roof in term of pull through failure.

The fastener holes are the critically undergo failure under the fluctuations of wind uplift but by applying the high strength metal strap able to reduce the risk of failure by improving the strength of the connection between the roof structures (Mahendran, 1995c) However, the failure also unable to resist to be happen at the connection of the roof structure as shown in the below **Figure 2.4**.

Figure 2.4: Failure of Connection at roof structure

Source: http://failures.wikispaces.com/ (2 March 2014)

In the case of the inadequate connector between rafters or the batten was not connected properly may lead to the bigger failure such as the damage for whole roof system as seen in **Figure 2.5.**

Figure 2.5: Damage for whole roof structure.

Source: http://www.asce.org/

During high wind event such as thunderstorm or wind storm the most damage recorded are for residential and institution type of building. The common failure is the losses of the metal sheeting while the school usually using metal deck as its roof sheeting.

2.4.1 Wall Cladding

The previous wind disaster investigation shows that the damage involving walls is lesser compared to the damage happen to the roofs (Mahaarachchi, 2003) However, the statistic will not guarantee the damage to the wall cladding is not critical. Thus, the design of the wall cladding should not neglect the wind loading consideration. The failure could happen when the top plate of the wall frame is not properly connected to the studs as shown in the **Figure 2.6**.

During the wind blowing usually the windward wall will subjected to the positive pressure while the negative pressure or know as suction will act on the leeward wall frame. This pressure will produce if the wind blowing to the structure is in the perpendicular towards building while the pressure negative and negative will be experienced by the structure when the wind blowing is parallel.

Figure 2.6: Damage at wall cladding (Mahaarachchi, 2003)

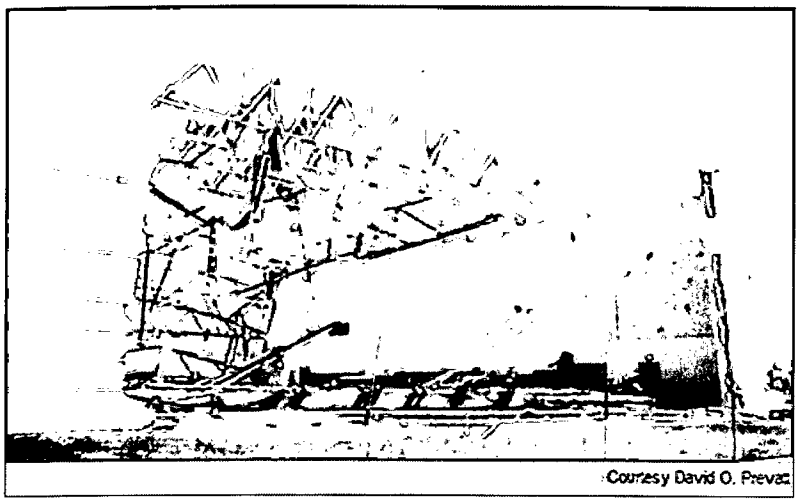

Figure 2.7: Wall Collapsed Inward

Source: http://www.asce.org/ (13 Nov 2013)

Usually the wall cladding will experience less fluctuation of wind load compared to the roof structure, thus the failures will front the static pull through failure or Pull out failures rather than failure are caused by fatigue cases. The lateral bracing of the wall has been collapsed and as the result the wall collapsed inward caused by the high internal pressure. The opening in the structure during wind storm may affect when the flying debris occur. When this opening broken during high wind events, the internal pressure may arise in the building and as the result it will influence the other opening, then the cladding and the other structures as shown in **Figure 2.7**.

2.4.2 Roof Trusses

Good roof trusses are the roof trusses are designed as it can resist the uplift force from the wind suction. There are several types of trusses but in roof construction, truss the pitched truss is usually used. The type of flat truss is usually used in the industry's building while for residence's building usually using slope truss such as fink, howe, fan and modified queen post.

Truss system can be defined as that system consisting framed element with both axial tension and compression. The member in the truss is arranged and fitted so that the tension or compression can be distributed to other members equally. Usually the roof trusses will act to support the load as supporting structure if the truss are installed in vertical position, the truss is braced thus will prevent the incident of overturning and buckling. Besides the truss need to tie with support so it will able to resist the uplift force. So, the truss as supporting structure are functioning for supporting on external load bearing and truss also need to be installed correctly to avoid the truss to buckle and fail.

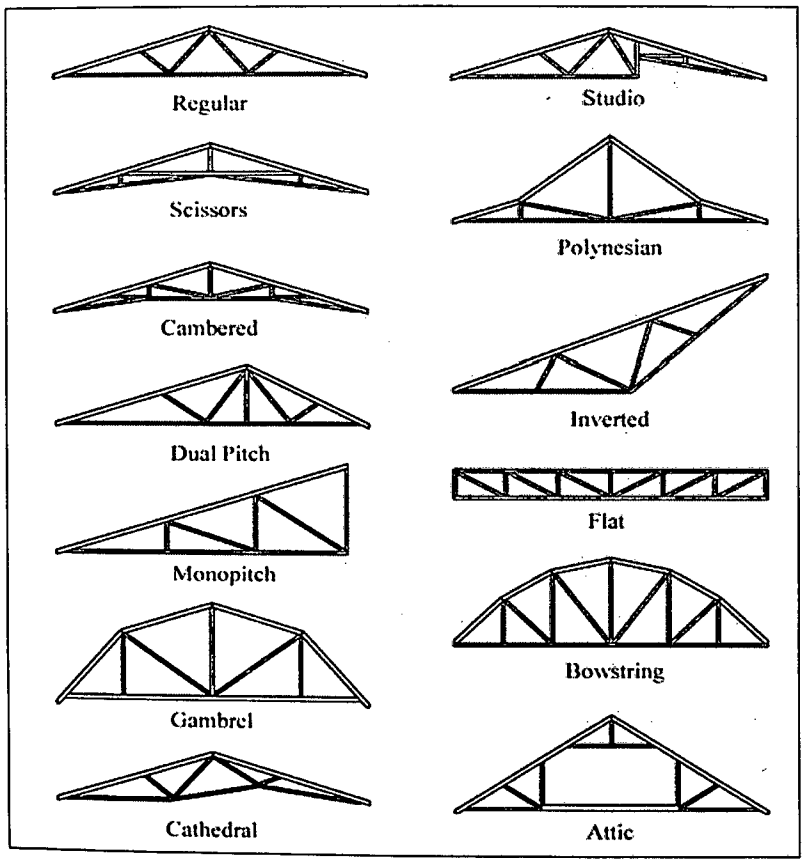

Figure 2.8: Common example truss shape for roof truss

Source: barntoolbox.com