THE IMPACT OF UPLIFT FORCES ON THE CONNECTION OF STEEL CLADDING FOR RURAL HOUSES IN MALAYSIA

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To Syria ….

ABSTRAK

Penyelidikan mengenai kesan kekuatan dan tekanan angin pada pelapis keluli dan tingkah laku pengikat untuk rumah luar bandar sebagai fokus kajian ini. Berdasarkan tinjauan terkini yang dilakukan terhadap sistem bumbung yang rosak di rumah luar bandar kerana ribut angin yang kuat memberi kesan dibeberapa lokasi di Malaysia, menunjukkan bahawa lembaran pelapisan bumbung keluli adalah bahagian bangunan yang paling terjejas. Kawasan luar bandar di Malaysia mempunyai sebilangan besar rumah yang tidak direkabentuk di mana bumbungnya diperbuat dari bahan dengan harga berpatutan terutamanya pelapisan bumbung keluli seperti trapezoid dan beralun. Hubungan antara pelapis purlin menggunakan penyambung iaitu paku atau skru. Sebilangan besar kajian terdahulu mengenai bidang ini memfokuskan pada bangunan bertingkat rendah yang memenuhi kod bangunan kejuruteraan, sementara kajian ini hanya memusatkan perhatian pada rumah yang dibina tanpa atau dengan teknik kejuruteraan terbatas. Kajian ini menggunakan kaedah kajian berangka dibantu perisian ANSYS workbench, dibawah subseksyen struktur statik untuk mensimulasikan pelapisan atap keluli dan pengikat. Model elemen terhingga dikenakan beberapa nilai daya angkat, iaitu 5, 6, dan 7kN untuk pelapisan keluli trapezoid, sedangkan untuk bentuk melengkung pelapisan keluli beralun, disebabkan oleh di mana daya angkat digantikan oleh tekanan angkat bernilai 3.8, 4.6, dan 5.3kPa. Kajian mencadangkan penambahan jalur dengan kelebaran 75mm, 100mm dan 150mm berdekatan penyambung utama, di mana tekanan paling kritikal biasanya berlaku dan pesongan tertinggi dicatatkan. Hasil yang diperolehi menunjukkan peningkatan yang mencukupi mengenai ubah bentuk pelapisan keluli dan daya tindak balas pengikat. Penggunaan kaedah jalur tambahan berjaya mengurangkan kesan daya angkat angin sebanyak 27% - 82% dan berupaya meningkatkan 22% - 54% daya tarikan untuk pengikat sambungan. Penambahan jalur bumbung menunjukkan kesan besar yang akan melindungi sambungan pelapisan bumbung keluli dari kegagalan di mana ia adalah bahagian paling kritikal sistem bumbung.

ABSTRACT

The research of the impact of wind uplift forces and pressures on the steel cladding and the fastener behaviour for the rural houses is the focus of the study. Based on a recent survey done on the damaged roofing system in the rural houses due to heavy windstorm affected many locations in Malaysia, showed that steel roof cladding sheets was the most affected part of the building. The rural areas in Malaysia have a huge number of non-engineered houses where the roof made out from the affordable material especially the steel roof cladding such as trapezoidal and corrugated. The connection between the purlin cladding used a fastener namely a nail or screw. Most of previous studies on this field were focusing on the low rise engineered building, which followed the engineering building codes, while this study only focused on the houses built with no or limited engineering guidance. The research adopted the numerical study method using ANSYS workbench software, via the static structure subsection to simulate the steel roof cladding and the fasteners. The finite element models subjected to several values of uplift forces, which are 5, 6, and 7kN for trapezoidal steel cladding, whereas, due to the curvy shapes of the corrugated steel cladding where the uplift forces were replaced by the uplift pressures which are 3.8, 4.6, and 5.3kPa. The study suggested adding a strip with different widths, 75mm, 100mm and 150mm near the central fastener, where the most critical stress usually occurred and highest deflection recorded.

The results show a sufficient improvement regarding the deformation of the steel cladding and the fastener reaction force. The use of additional strip method has

reduced the effect of wind uplift forces by 27% - 82% and the pull through capacity increases by 22% - 54% for the fastener. The additional strip presence showed a large impact which will lead to protect the steel roof cladding connection from failure where it is the most critical part of the roofing system.

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CHAPTER 1

INTRODUCTION

1.1 **Background**

Rural houses roof failure become a huge issue in Malaysia base on Media reports recently, the Peninsular Malaysia usually experience a strong windstorm during southeast monsoon and northwest monsoon (Wan Chik et al., 2019). Those wind strikes and the uplift forces have been the reason of the extensive damage to the rural houses roofing system (Myuran and Mahendran, 2017).

According to Ramli et al. (2010), 47% of the damage is in steel sheet roofing, where most of the rural houses are non-engineered and poorly designed without taking the design codes into consideration (Majid et al., 2020). Furthermore, connection failure of roof cladding- purlin may commence to the collapse of the whole structure (Majid et al., 2012).

The rural houses are usually a one or two storeys constructed in the rural areas, the building usually constructed with a combination of bricks, concrete, steel roofing cladding, and timber (Muhammad et al., 2015).

The use of the nail and screws are typical for the cladding-purlin connection of the steel system in the rural houses. The umbrella head nail and the self-drilling screw are the commonly types used in the rural houses (Majid et al., 2020).

Figure 1.1 Damaged roof cladding after windstorm in Kampung Likong, Kota Baru, source (NST, 2020).

1.2 **Problem Statement**

Previous studies carried out to examine the wind impact on the roofing system connection. However, the research on the connection capacity of the roofing system by taking into consideration the wind speed and the pressure distribution and pull through behaviour in the local plastic region are still limited, beside the lack into the research of proposing an enhancement method to the rural houses roof cladding-purlin connection.

Therefore, this study will provide an apparent purpose and a significance that the connection of sheet roofing needs to be investigated and provide an improvement approaches which can minimize the damage and reduce the risk.

1.3 **Objectives**

The main objectives of this study are:

1. To simulate pull through capacity of the fastener subjected to wind uplift load using FEM method.
2. To investigate the use of an enhancement technique to the connection between roof cladding and purlin.

1.4 **Scope of the study**

This study is emphasizing on the numerical model to investigate the roofing system failure between the steel cladding and the connection with purlin for rural houses in Malaysia. The data will be collected from different studies and investigations on the previous events of windstorm to review the damaged roofs. The finite element model using ANSYS static structural software will used to simulate the effect of wind uplift forces on the roofing system cladding connection.

The study will show the cladding and connection response under the pressure of wind uplift forces. The results will be analysed and clarify the pull through capacity for the connection subjected to various scenarios of cladding thickness and types like trapezoidal and corrugated roof steel cladding with different fastener types. The parameters chosen based on the common types available locally with affordable prices and the most types used in the damaged areas reviewed previously.

1.5 **Thesis outline**

There are five chapters in this thesis discussed and arranged as follows:

Chapter 2 discusses the previous work with regards to the roofing system of the rural houses and the windstorms events that had occurred recently. It also highlights the previous research work done on using the numerical modelling method for the roof steel cladding and purlin connection. The wind loading on the areas and the roof claddings and the pull through failure general knowledge are described in this chapter.

Chapter 3 identifies and explains the overall procedures and methodologies during the research work, including the data collection, the modelling development processes, and the parameters of finite element model. It shows the validation of finite element model, the potential enhancement procedures to the roofing system connection between the steel cladding and purlin.

Chapter 4 discusses the results collected from the finite element model and explain the impact of the wind uplift forces on the steel roof cladding and the pull through capacity of the fasteners. The suggested enhancement techniques results and its functionality on improving the steel cladding to purlin connection were analysed and discussed.

Chapter 5 concludes the study work findings and relates the main objectives with the results obtained and discussed. Also, some recommendations on the work and improvements may done for future studies are given.

CHAPTER 2 LITERATURE REVIEW

2.1 Rural houses in Malaysia

The non-engineered houses in the rural area in Malaysia has suffered a various dangerous damages recently during the heavy windstorms according to Muhammad et al. (2015). Especially in the Peninsular Malaysia's northern part states, there were reports of a series of extremely strong windstorm events which mostly due to the season northeast Malaysia based on Zakaria et al. (2019). Between 2010 and 2013 the number of damaged low rise non- engineered houses were 1138 (Majid et al., 2016).

Most of the rural houses in Malaysia that that were damaged especially the roofing system were built without following any building codes and engineering guidance (Zainorizuan et al., 2017). As shown in Figure 2.1, the one story rural house commonly built in Malaysia was constructed using timber walls and timber truss with a steel cladding sheets for the roof.

Figure 2.1 A rural non-engineered house in Malaysia, source (Muhammad et al., 2015)

Malaysian rural houses usually made out of the affordable local materials available in the area, timber is the main component of the house, for the frame system, and wooden walls, beside the metal roof cladding sheets and nails for the roof connections (Muhammad et al., 2015).

2.1.1 Roofing system

Many variations of roofing system types exists in the rural areas in Malaysia, which are based on the different factors such as the area, culture, and the construction materials cost (Zainorizuan et al., 2017).

The author Zainorizuan et al. (2017) declared that most accustomed types of roofing system geometry are the simple gable roof geometry and the Dutch gable roof geometry (Figure 2.2).

Due to the simplest way of construction and the affordable materials can be found locally for these types of roofs compared to hip roof or valley roof.

Figure 2.2 Typical Dutch gable roof house in Malaysia, source (Flickr, 2010)

Roofing system were lead the most affected part of building during the windstorms (Majid et al., 2016). As shown in Figure 2.3, the roof was blown out due to very heavy storm in Kuantan 25 March 2021.

Due to early failure of roof steel cladding sheets and the connection, the roofing system are usually damaged and may collapse after experiencing high wind pressure (Sivapathasundaram and Mahendran, 2017).

Figure 2.3 Damaged roof after a heavy storm in Kuantan, source (BERNAMA, 2020).

Roofing system usually consists of the wooden truss frame, purlin, cladding sheets, and the connections. Trapezoidal and corrugated roof steel cladding are the most common and affordable types in Malaysia, while the umbrella head nail is the ordinary nail used based on Majid et al. (2020). According to Wan Chik et al. (2014), the thunderstorm report showed that 90% of the damaged low rise building components was the roofing system.

2.1.2 Cladding to purlin connection

Most of the low rise building roof system component were made out of thin roof sheets connected to purlin by fastener which was screwed or nailed (Myuran and Mahendran, 2017, Luan and Li, 2019). As shown in Figure 2.4, the greater number of rural houses were built out of timber, truss system in particular.

In Malaysia, most of the fasteners used for cladding purlin connection were Umbrella head nail and Umbrella head nail with rubber washer (Majid et al., 2020). The roof steel cladding are vulnerable during the typhoons or monsoons (Ji et al., 2018). The majority of the damaged cases in the roof were due to connection failure as compared to the roof frame (Kopp et al., 2012, Morrison et al., 2012).

Figure 2.4 Rural house under construction in Sabah, source (CEphoto, 2014).

Cladding purlin connection are very important to the roof system, Navaratnam et al. (2020) found that the pull out or pull through of the fastener cause a substantial damage and weak roof system, which may lead to very serious damages and human loss due to building collapse.

2.2 Windstorms in Malaysia

Peninsular Malaysia is located in the equator zone, which is known with numerous windstorms events. Those seasonal windstorms events are called monsoons (Sopian et al., 1995). The monsoon affects Malaysia three times annually, i.e. North East monsoon, South East monsoon, and the Inter monsoon (Zakaria et al., 2019).

Figure 2.5 shows the windstorm event based on the seasonal monsoon in 2018. Furthermore, it was observed that Kedah state experienced the highest number of windstorm events among other states. Each monsoon event is responsible for several damages by uplifting trees and roofs, and cause destruction of buildings and vehicles (Sabah et al., 2020). A study by Masseran and Razali (2016) explained that the speed of wind is much greater during the monsoon's comparing to the other periods.

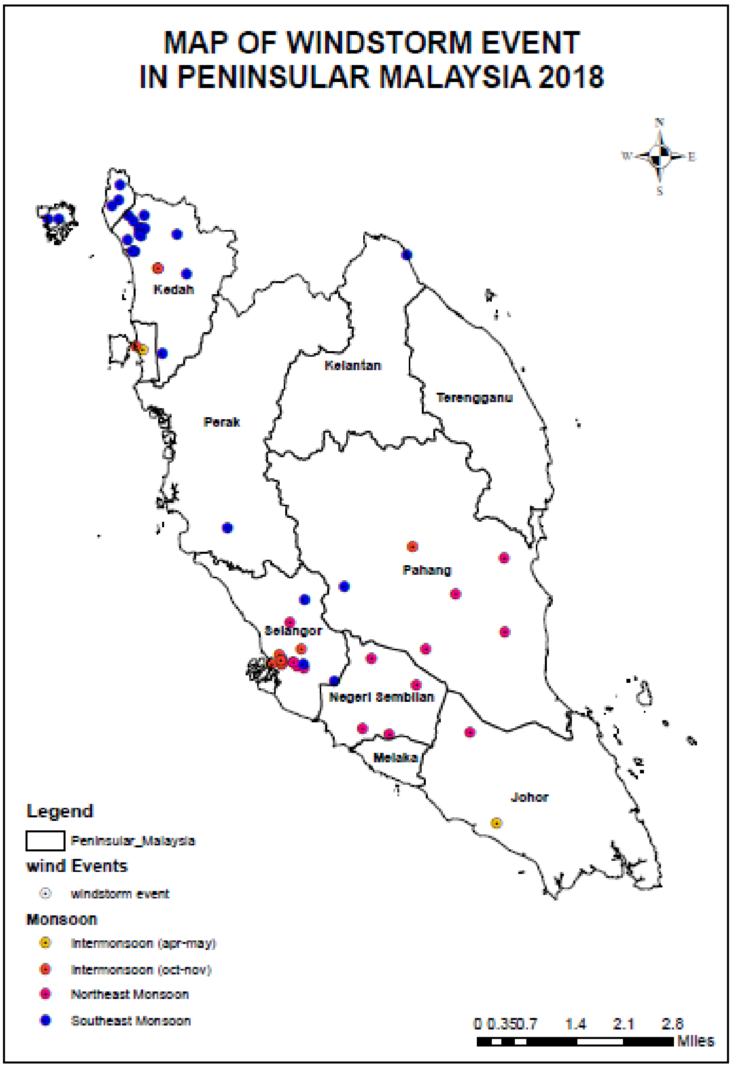

Figure 2.5 Windstorm event in Peninsular Malaysia 2018, from (Zakaria et al., 2019).

2.3 **Wind loading on roof.**

Monsoon's events have been one of the major reasons of the roofing system failure in peninsular Malaysia. Based on Zakaria et al. (2019), the roof system will be the worst among other parts of the buildings that are damaged after the windstorms. The study by Zakaria et al. (2019) shows that 80% of the damages were on the roof of the houses, precisely 47% of damages affected the steel roof cladding.

Wind uplift forces usually effect the roof in the low rise buildings, the wind forces will pull up the roof sheets and damage the fastener which may lead to the failure of the roofing system (Majid et al., 2014). The gaps in the building such as doors, windows or leak in the roof cladding may allow the wind to enter and cause the internal pressure (Kopp, 2013).

Usually, larger pressure and suction on the house roof especially the edges due severe pressure load (Tamura et al., 2001). Figure 2.6 shows the wind distribution schematic on the low rise building, the uplift forces caused by both external and internal pressures are the major reason for roof damages as presented in Figure 2.6. The net pressure hitting on the roof can be effective for the damages (Morrison et al., 2012); (Kopp, 2013).

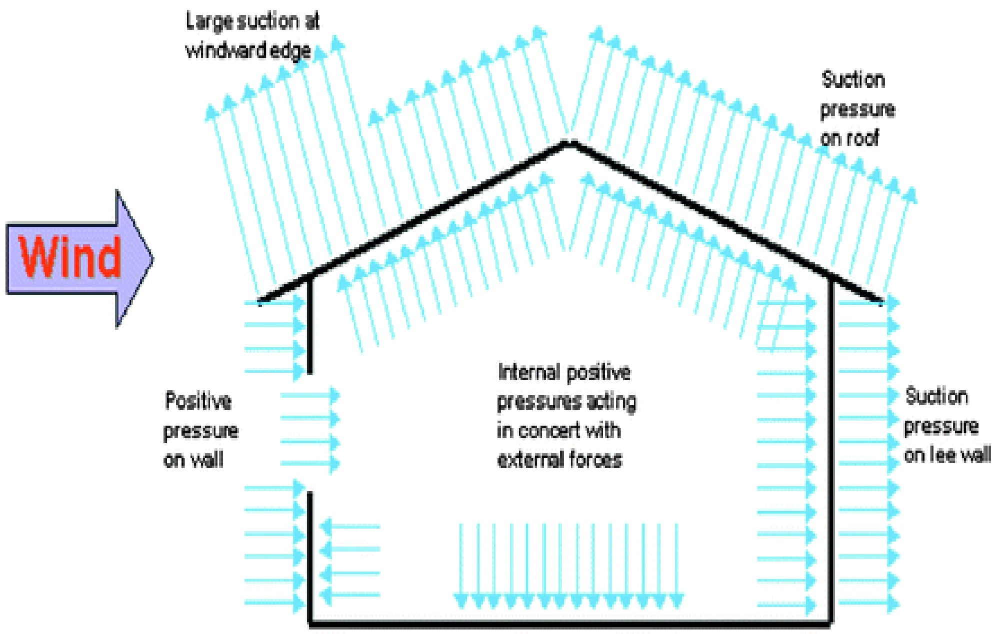

Figure 2.6 Wind load acting on low rise building, source (Kopp, 2013).

2.4 **Wind flow effect on low rise building**

Low rise building can be considered a target for the high speed wind, especially in the rural areas where the roof system are one of the major component were affected during the windstorms (Henderson and Ginger, 2011); (Wan Chik et al., 2013). As shown in Figure 2.7, a study in 2014 by (Wan Chik et al., 2014) shown the number of damaged building in Peninsular Malaysia's states where Kedah and Terengganu have suffered the greatest number of damaged building due to windstorms.

However, not only the wind velocity have the influence on the effect on low rise buildings, According to Goyal and Datta (2013), the wind direction was also played a huge rule on damaging the low rise building.

The wind pressure in both types external and internal caused huge damage to the low rise building (Morrison et al., 2012). Although it depends on many factors such as connections strength, duration of windstorm, wind velocity, the direction of wind flow, and other potential considerations (Kopp, 2013).

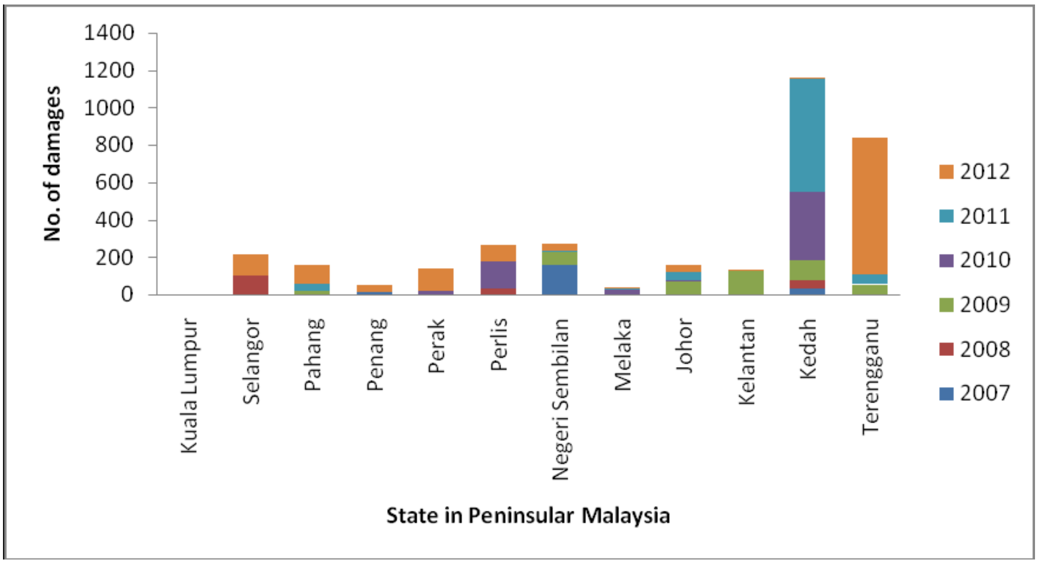

Figure 2.7 Number of building damages in Peninsular Malaysia 2007-2012, from (Wan Chik et al., 2014).

2.5 Steel roof cladding failure

The failure of steel roof cladding was relied upon various factors, such as geometry of roof system, fastener type, cladding thickness, and connection positions. Figure 2.8 shows the failure caused by the form of pull through of the fastener.

Wang et al. (2017) studied the damaged steel roof cladding and investigated the reason behind the failure stated that fastener joint can be considered as the weakest part of the roofing system against the windstorms.

The shaking and lifting the cladding sheets upward caused by wind against the thin layer of the cladding put a huge load on the fastener and may conduct a pull through or pull out failures under the effect of uplift forces (Ou et al., 2020).

Figure 2.8 Damaged roof due to windstorm in Kuala Juru, Penang, source (NST, 2019).

2.6 **Pull through failure.**

The pull through failure is a term associated with the local failure of steel cladding roof and the fastener head, the initiated existence of this form is generally related to splitting of the roof steel cladding (Mahendran, 1994); (Ramli et al., 2014).

During the huge wind pressure on the steel cladding purlin connection, the failure occur when the fastener hole experience very large stresses due to splitting in longitudinal direction (Mahendran and Tang, 1998). Figures 2.9 and 2.10 show a pull through failure occurred where the fastener hole expanded after the failure of the fastener which failed to resist the uplift forces.

Lovisa et al. (2013a) described the static pull through failure occurrence by the radial splitting after facing the peak suction pressure and the deep drawing of the fastener. The author also stated that the fatigue failure may result in some cases due to variations in the pressure applied.

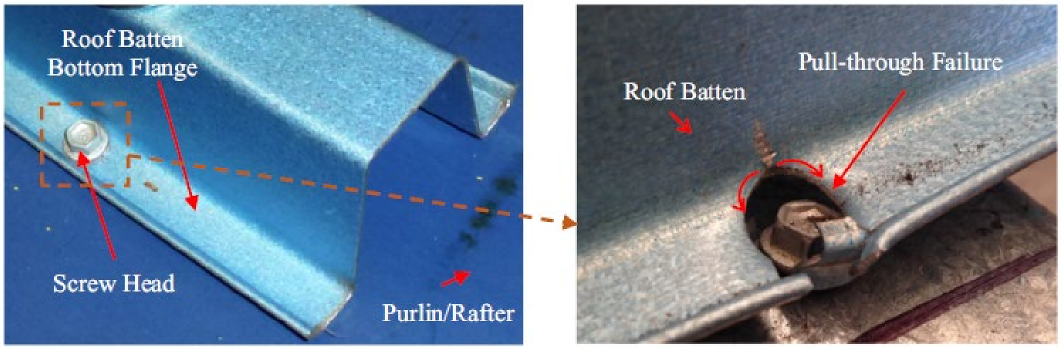

Figure 2.9 The form of pull-through failure in the connection, from (Sivapathasundaram and Mahendran, 2018).

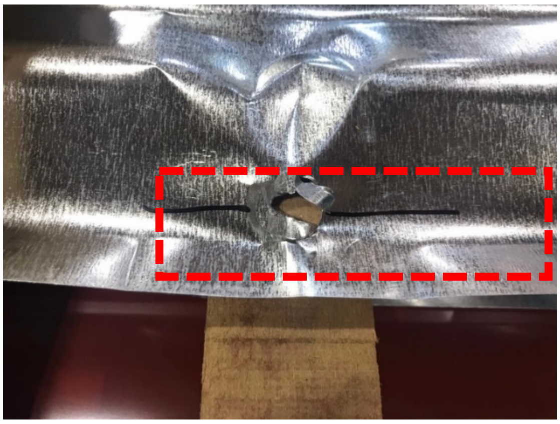

Figure 2.10 Pull through failure occurred between steel cladding and Purlin, from (Muhammad, 2020).

The failure because of the great stresses may happen as dimpling failure form, depends on the forces direction on the fastener hole, the dimpling of crest under the wind pressure will result the presence of pull through failure (Mahendran, 1994); (Sivapathasundaram and Mahendran, 2017).

The investigation done by Mahendran and Mahaarachchi (2004) found that the main cause of the pull through failure can be back to the fastener load capacity, where the largest recorded on the centre support. Majid et al. (2020) examined the relation between the cladding thickness and the pull through capacity of the fastener, where the thicker steel cladding sheets will result a higher pull through capacity for both trapezoidal and corrugated cladding types.

2.7 **Finite element analysis of steel roof cladding**

Finite element model (FEM) method has been used for many years in many fields, by offering more effectively options reduces the human error, and reduces the experimental time.

Previous studies FEM studies for many cases were successful and provided a realistic result especially for simulating the wind uplift forces on the roof which previously done by many researchers such as Tamura et al. (2001), Mahaarachchi and Mahendran (2009), Lovisa et al. (2013a), Lovisa et al. (2013b), Masseran and Razali (2016), Sivapathasundaram and Mahendran (2017), and Wang et al. (2017).

Figure 2.11 shows the FEM of a trapezoidal steel cladding, the connection hole and fastener head. It also shows the most critical area where the most effect from the wind load forces my concentrate. The meshing in different size were presented also, the meshing size depends on the most critical and important areas (Mahaarachchi and Mahendran, 2004).

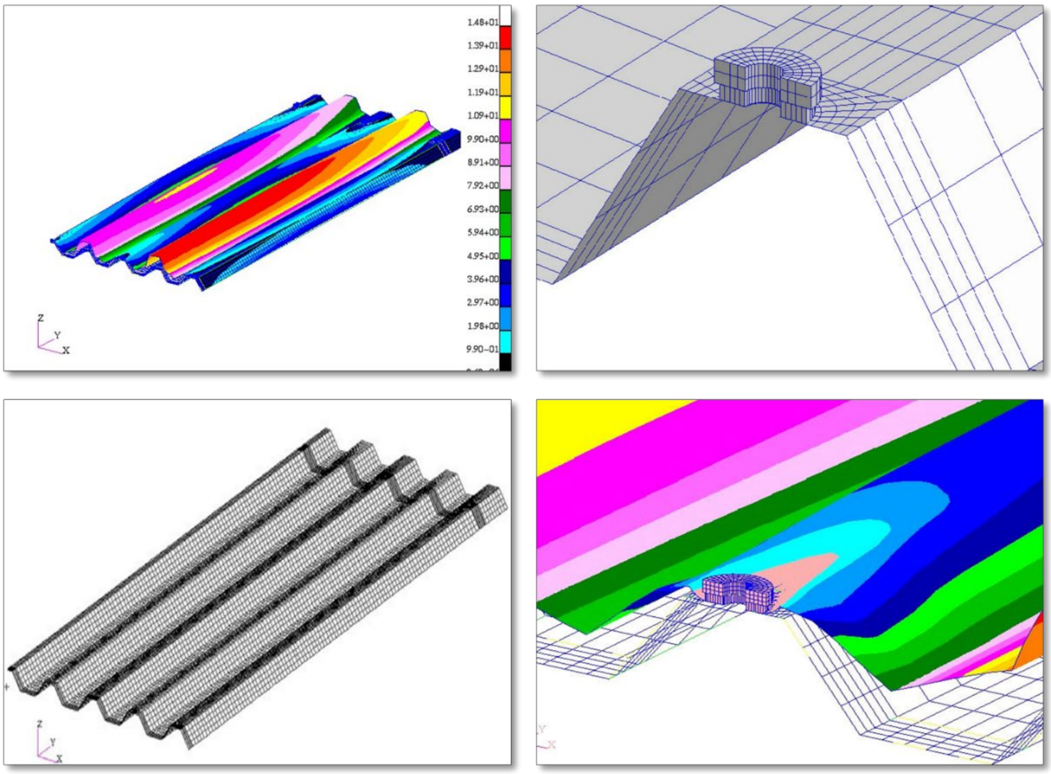

Figure 2.11 FEM for Trapezoidal Cladding Connection, from (Mahaarachchi and Mahendran, 2004)

The quarter of the model where used in previous studies in order to reduce the numerical test time and due to symmetrically conditions of the models (Lovisa et al., 2013b), some researchers stated that the use of purlin which support the roof cladding can in the FEM can be neglected (Majid et al., 2020); (Mahaarachchi and Mahendran, 2009).

2.8 **Summary**

Based on the research work done by previous researchers on the effect of wind uplift forces during windstorms on the roof cladding purlin connection of low rise non-engineered houses in rural areas, a significant research work has been done on this field and many experimental works were conducted to investigate the pull through capacity and the pull out capacity of the fasteners in the cladding purlin connection, in addition, some researchers used finite element model to support the experimental data and to further understand the behaviour of the fastener under the impact of wind uplift forces. Table 2.1 summarised related work on this field using both experimental and finite element model methods. However, limited study was carried out for the enhancement techniques to a cladding and fasteners of rural houses in order to avoid the problem of roof failure during the windstorms.

Table 2.1 Summary of the previous studies

Authors	Type of Project	Cladding type and Thickness	Fastener type	Summary
Mahaarachchi and Mahendran (2009)	Experimental	Trapezoidal (0.42 mm)	Screw	Described an investigation into the structural behaviour and design of crest-fixed trapezoidal steel claddings with closely spaced ribs under wind uplift/suction forces.
Majid et al. (2020)	Experimental	Trapezoidal (0.35 mm)	Screw	The highest pull through capacity and applied load was shown by the 0.35 mm thickness trapezoidal roof cladding. The pull through resistant can be significantly contributed by the cladding thickness.
Mahaarachchi and Mahendran (2005)	FEM	Trapezoidal (0.42 mm)	Screw	Improved design formulae have been developed to determine the local failure loads of trapezoidal steel cladding of any geometry under static wind uplift loading.
Lovisa et, al. (2013)	FEM	Corrugated (0.42 mm)	Screw	The local response of the cladding is very similar when a uniform pressure is applied to the whole cladding sheet and when a localised pressure is only applied to the fastener tributary area.

Majid et al. (2014)	FEM	Trapezoidal (0.30 mm)	Screw	The used of finite element analysis would ultimately enable a cost effective and efficient means of studying the behaviour and response of steel cladding subject to a variety load.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The main goals during this research study are to study the effect of wind uplift forces on the steel roof cladding-purlin connection in the rural houses and to suggest the affordable enhancement measure might be taken to improve the connection's pull through capacity.

The methodology of this research was divided into two phases, firstly the development and verifying the finite element model, and the second phase is focusing on the proposed enhancement techniques to reduce the impact of uplift forces on the roofing system. Detail about the process of simulating the finite element model in the software were discussed in the following sections.

3.2 **Study area**

The study is focusing on the northern part of Peninsular Malaysia where the most of damaged after windstorms recorded in recent years. The Study is focused on the previous surveys performed by Muhammad (2020) on the roof in the state of Penang, Kedah, Terengganu, Kelantan, and Perak.

35 locations were investigated for data such as commonly used materials and types of connections were collected from the study conducted on the rural houses roof damages due to uplift forces.