Experimental investigation on the pull through failure of roof cladding to purlin connection considering overhang roof

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Abstract. The study on the effects wind loading to the roof cladding and purlin connection has raised a great interest among researchers. In some cases, the failure of roof cladding initiated at the overhang roof was due to the development of uplift force created by the strong wind. However, these studies are limited to the non-engineered building without considering overhang roof. This paper studies the effect of roof cladding types, overhang length and cladding thickness in term of pull through capacity of the overhang roof using simple pull through tests. The tests were conducted on two types of claddings namely, corrugated and trapezoidal roof cladding. In the case of corrugated cladding with 0.28 mm thickness, the specimen with 200 mm overhang length shows the highest pull through capacity with 1.534 kN followed by 300 mm overhang length with 1.083 kN. While, for trapezoidal cladding with 0.35 mm thickness, the 300 mm overhang length recorded the highest pull through capacity at 1.163 kN compared to 200 mm overhang length (1.068 kN). It was noted that shorter length of overhang developed stronger roof cladding to purlin connection. The most efficient connection for roof cladding to purlin connection was found to be 0.23 mm thickness of corrugated roof cladding with 200 mm overhang length.

1. Introduction

The wind is caused by different atmospheric pressure where air is moving from higher to lower pressure resulting in winds of various speeds. Malaysia experiences two monsoon seasons namely the Southwest Monsoon from late May to September and Northeast Monsoon from November to March where these seasons nominate wind and rainfall [1]. The structural response due to fluctuating nature of wind loads can cause large scale disaster across community [2]. During high wind events, light-gauge steel roofing system is highly susceptible to premature failures [3]. The roof of a house is usually the most vulnerable part to experience such large wind loading. The interaction between wind flow and building surfaces will give a significant effect on wind loads of a roof of a low rise building as stated by [4].

Uniquely, in the Northern region of Peninsular Malaysia, a study done by Majid et al. (2016) found that most of the rural houses are designated by having overhang roof [5] as shown in Figure 1. This part of roof is located at the edge of the roof and protruding outwards where its function is to protect the wall façade during heavy rain. However, due to inadequate support to hold the roofing system from uplift might initiate damage at overhang especially during strong wind events [6]. Inadequate connection strength, insufficient strength of structural member and fluctuation of high wind speed can be the reasons that cause damage to the roof system. Most of the houses in rural areas are non-engineered low rise
buildings. This type of house is easily damaged during strong wind events [7]. Hence, this issue should be further investigated focusing on the connection at the roof overhang and purlin connection. This study aims to compare pull through capacity of roof cladding to purlin connections assembled from different cladding thickness, roof cladding type, and overhang length.

![Figure 1. Example of overhang steel roof cladding on the rural houses roofing system](image)

Extreme wind events can cause extensive damage to residential buildings due to failure of the roof connection [8]. The worst failure of the roof connection occurred in roofing system might leads to accelerated damage to the whole building [9]. Generally, the roof connection failure can be split into two types namely pull through failure and pull out failure as shown in Figure 2. The pull through failures occurred when the fastener head is pulled through the thin cladding and pull out failure occurred when the fastener pulled out from the purlin as reported by Sivapathasundaram and Mahendran [10]. In addition, the study conducted by Maharaachchi and Mahendran [11] showed that the pull through failure of the connection system was initiated by the presence of large stress concentration due to wind loading around the fastener hole. As a result, the cladding failed locally within the vicinity of the fastener thus forming a sizeable hole that allows the fastener to pull through the cladding [12]. To address the drawback, this paper presents an experimental investigation on pull through failure of the steel roof cladding under simulated wind uplift loading considering overhang roof.

![Figure 2. Local failure of the steel roof cladding (a) pull through failure (b) pull out failure](image)

2. Methodology
The methodology in this study consists of two parts namely, rural house survey and experimental work. The rural house survey was carried out to obtain useful information pertaining to the roof dimensions especially on overhang roof length, roof cladding types and purlin spacing. This information was used in shaping the experimental work. The rural house survey covers several districts in Kedah, Penang and
northern part of Perak because this region showed to be among the highest recorded house damage due to strong wind event [13]. The survey in this study involved 64 number of non-engineered rural houses. The data was collected from 21st January 2019 until 3rd February 2019.

In the case of the experimental work, two types of roof cladding was used namely corrugated and trapezoidal steel roof cladding. Table 1 shows a summary of the overall specimen. Umbrella head nails were used to secure the tested steel roof cladding to the timber purlin. The diameter of umbrella head nail, the shaft and length are 16 mm, 3.90 mm and 50.8 mm length, respectively. The type of timber purlin used in this experimental work is Dark Red Meranti from Strength Group 5 based on MS544 Part 2. This type of wood is common for the construction of roof truss in the rural area of Malaysia due to the relatively low cost compared to metal purlin.

| Material     | Type                  | Dimension                      |
|--------------|-----------------------|--------------------------------|
| Roof cladding| Corrugated Thickness: | 0.18 mm, 0.23 mm               |
|              | Trapezoidal Thickness:| 0.23 mm, 0.35 mm               |
| Timber purlin| Dark Red Meranti (SG5)| 50.8 mm × 50.8 mm × 914 mm     |
| Fastener     | Umbrella head nail    | Head diameter: 16 mm           |
|              |                       | Shaft diameter: 3.90 mm        |

The steel roof cladding was fastened to the two timber purlins (50.8 mm × 50.8 mm) and adjusted to achieve a 750 mm span length. The roof cladding was secured using umbrella head nails at the crest and inversely assembled to the steel frame. This type of arrangement is adopted in order to simulate the uplift wind loading acting on roof cladding as shown in Figure 3(a) and the schematic diagram of the experiment is shown in Figure 3(b). The reaction force of the central nail fastener was measured using 5kN load cell attached to the central umbrella head nail at the center timber purlin. Moreover, the deflection of the roof cladding overhang was measured using three Lateral Vertical Displacement Transducer (LVDT). In this case, two were located at unscrewed crest and one was located at screwed crest. The loading pad was designed such that it is able to distribute uniform load from the hydraulic testing machine to the steel roof cladding. The test was proceeding until pull through failure occurred where the roof cladding pullover from the fastener head.
3. Results and discussions

3.1. The rural house survey result

The rural house survey activity involving a total of 64 houses measured the important parameters such as types of claddings, purlin spacing and steel roof cladding overhang length. Figure 4.1 shows the percentage distribution for two types of steel roof cladding found for the damaged rural houses. A number of 36 houses (56%) used corrugated and 28 houses (44%) used trapezoidal as the roof cladding. The result indicates all surveyed houses used steel roof cladding compared to tiles or other types of roofing materials. This finding is particularly true because this material is cheap and requires less number of purlins for the roof assembly. However, the lightness of thin steel cladding compared to tiles or asbestos makes this type of roof material prone to be uplifted during strong wind.

The variation in terms of the purlin spacing of rural houses is shown in Figure 5. The result showed that 34 houses (53%) were built with purlin spacing between 600 mm to 900, 19 houses (30%) with purlin
spacing more than 900 mm and 11 houses (17%) used purlin spacing of less than 600 mm. It is thought that the variation of purlin spacing observed in this survey is merely due to the general practice of the traditional tradesman and has no technical relationship. However, it is well understood that higher purlin to purlin span can result in larger tributary area to the cladding connection hence imposing more wind load to the connections. As a result, the risk of connection failure is increased. As for the experimental set up, a value of 750 mm was selected (average length of 600 mm and 900 mm) to be the span length of the roof cladding for the pull through test. The main function of purlins is to carry roof cladding.

![Figure 5](image)

**Figure 5.** Number of rural houses respected to the purlin spacing

Figure 6 shows the overhang length of the steel roof cladding for the surveyed rural houses. It is apparent from the bar chart that 53 houses (83%) adopted the length of overhang roof between 200 mm to 300 mm. In addition, 6 houses (9%) used the length of less than 200 mm and 9 houses (8%) constructed the overhang roof having more than 300 mm length. The selection of the overhang cladding length in the experimental work done by choosing the dominant length based on-site survey data.

![Figure 6](image)

**Figure 6.** Number of rural houses according to the length of overhang cladding
3.2. Pull through test results
The result for the pull through test was determined based on the average value of the maximum pull through capacity and maximum applied load. The pull through capacity was recorded at the central fastener using 5 kN load cell and the maximum applied load was obtained from the hydraulic jack. The summary of the experimental results is shown in Table 2. It can be seen that, with the same cladding overhang length, the highest thickness of the steel roof cladding shows the increased of pull through capacity and maximum applied load. The results are particularly true for both types of steel roof cladding.

Table 2. Summary of experimental results.

| Type of cladding | Thickness (mm) | Cladding overhang length (mm) | Pull through capacity (kN) | Max. applied load (kN) |
|------------------|----------------|------------------------------|---------------------------|------------------------|
| Corrugated       | 0.18           | 200                          | 0.764                     | 2.270                  |
|                  |                | 300                          | 0.548                     | 2.350                  |
|                  | 0.23           | 200                          | 1.534                     | 3.391                  |
|                  |                | 300                          | 1.083                     | 2.830                  |
|                  | 0.23           | 200                          | 0.944                     | 3.578                  |
|                  |                | 300                          | 0.951                     | 3.444                  |
| Trapezoidal      | 0.35           | 200                          | 1.068                     | 3.738                  |
|                  |                | 300                          | 1.163                     | 3.578                  |

3.3. Effect of type of roof cladding
Figure 7 shows the relationship between the pull through capacity and the displacement of corrugated and trapezoidal roof cladding for 0.23 mm thickness and 200 mm roof cladding overhang length. It can be seen that the pull through capacity of corrugated profile is higher compared to trapezoidal profile. The maximum value of pull through capacity for the corrugated and trapezoidal roof cladding was recorded at 1.534 kN and 0.944 kN, respectively. The difference in pull through capacity is calculated to be approximately 62.5 %.
3.4. Effect of length of overhang cladding

This section discusses the effect of roof cladding overhang length based on pull through capacity and maximum applied load. Figure 8 shows the relationship of pull through capacity with respect to the recorded deformation for 0.23 mm thickness corrugated roof cladding with different overhang cladding length. In this case, the maximum pull through capacity of the specimen with 200 mm and 300 mm overhang length was recorded to be 1.534 kN and 1.083 kN, respectively. This shows that corrugated roof cladding with 200 mm overhang cladding length has better connection strength compared to 300 mm overhang cladding length. In this study, it can be seen that, by reducing 33% of the overhang length, the pull through capacity can be increased up to 41.6%.

Figure 8. Effect of roof cladding overhang length for corrugated steel roof cladding

Figure 9 shows the results of applied load against displacement with different overhang length for the corrugated roof cladding with 0.23 mm thickness. Similar to the above finding, the magnitude of the maximum applied load for corrugated roof cladding with 200 mm overhang cladding length was found
to be higher than corrugated roof cladding with 300 mm overhang cladding length. The maximum applied load for 200 mm overhang length was recorded to be 3.391 kN compared to 2.83 kN for the 300 mm overhang length. It can be seen that by reducing the overhang length 100 mm, the resistant is able to withstand an additional of 19.8% prior to failure.

Figure 9. Load-displacement curve for 0.23 mm corrugated steel roof cladding with different roof overhang length

Figure 10 shows the effect of roof cladding overhang length on the pull through capacity for trapezoidal roof cladding with 0.23 mm thickness. The results show that the pull through capacity for the 300 mm overhang length is 0.951 kN and 0.944 kN for the specimen with 200 mm overhang length. Unlike the trapezoidal cladding, the magnitude of the pull through capacity for 200 mm overhang length was found to lower than the 300 mm overhang length. However, the difference was calculated to be 0.74% and can be classified as insignificant.

Figure 10. Pull through capacity-deformation curve for 0.23 mm trapezoidal steel roof cladding with different roof cladding overhang length

Figure 11 shows the effect of roof overhang length to the applied load for trapezoidal roof cladding with 0.23 mm thickness. The graph shows that the maximum applied load for the specimen with 200 mm overhang cladding length is marginally greater than 300 mm overhang cladding length. The maximum
applied load for the 200 mm and 300 mm overhang length is recorded to be 3.578 kN and 3.445 kN, respectively. The difference in the maximum applied load is calculated to be approximately 3.86%. Theoretically, the overhang cladding length contributes to the maximum applied load where the shorter the overhang length, the higher the maximum applied load will be.

Figure 11. Applied load-deformation curve for 0.23 mm trapezoidal steel roof cladding with different roof cladding overhang length

3.5 Effect on the thickness of the roof
Figure 12 shows the pull through capacity and displacement of corrugated roof cladding with 0.18 mm and 0.23 mm thickness, both having 300 mm roof overhang length. It can be seen that the corrugated roof cladding with 0.23 mm thickness is significantly higher than 0.18 mm thickness corrugated roof cladding. The value of pull through capacity for 0.23 mm thickness corrugated roof cladding is recorded at 1.083 kN while for 0.18 mm thickness is 0.548 kN. The difference between the two values is calculated approximately 97.7%.

Figure 12. Comparison on roof cladding thickness for pull through capacity-displacement relationship
4. Conclusion
Rural house survey was carried out to determine the length of the overhang roof typically used in northern region of Peninsular Malaysia and the experimental work was carried out to determine the maximum pull through capacity for two overhang length (200 mm and 300 mm) of roof cladding to purlin connection. The tests were carried out using in-house modified frame and hydraulic jack machine. Based on the experimental results, the following conclusion can be drawn:

- The length of the roof overhang produced significant effect on the roof cladding to purlin connection. Shorter overhang length is able to resist higher wind load and manifested via the increase in the pull through capacity and applied load compared to the longer overhang length.
- The highest pull through capacity and applied load was shown by the 0.35 mm thickness trapezoidal roof cladding with 200 mm overhang length. However, in the case of roof cladding thickness and overhang length, the 0.23 mm thickness corrugated roof cladding with 200 mm overhang length produced the highest value. The pull through resistant can be significantly contributed by the cladding thickness.
- Shorter overhang improved the pull through capacity by increasing the stiffness and reducing the tributary area that accumulate the wind pressure.

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