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CASE STUDY: POST DISASTER INVESTIGATION ON WIND DAMAGE FOR RURAL HOUSING ROOFING SYSTEM IN NORTHERN PENINSULAR MALAYSIA

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A R T I C L E I N F O

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Rural roofing
Windstorm
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A B S T R A C T

Rural roofing houses will like endure tremendous damage because of windstorms in several parts of Malaysia. This study aims to identify the post disaster structural impacted factor on rural roofing system. Post disaster observations is performed to measure the damage extent on-site based on terrain category, wind speed and roofing damage at several locations in northern Peninsular Malaysia. Other contribution factors such as wind speed and terrain category, rural housing and roofing characteristic also discussed in this study. The result shows damage was induced by the wind speed and local topography itself. The double storey house experienced the tremendous roofing damage. The roof pitch, cladding type, anchorage or ties and connection placement impacted on the high wind event. Thus, structural improvement requires as one of proactive effort on disaster mitigation to resolve recurring damage in the future.

1. Introduction

Natural disasters are a global issue. Windstorm is an example of a natural disaster categorized under geophysical risk (Shaluf and Ahmadun, 2006). Malaysia is located in tropical regions where heavy rains occur almost all year long. Windstorms mostly occur in the northern region of Peninsular Malaysia during the inter monsoon period. There are two phases of inter monsoon period. The first phase begins from month of April to May while the second phases are from October to November.

Windstorms can be broadly classified as tropical cyclones, thunderstorms, tornadoes, monsoons, and gales according to their meteorological parameters (Henderson, 2008). Extensive damage and badly affected roofing systems in rural houses are observed in the housing sector. Kousky et al. (2014) provided a summary of natural disaster occurrence results in direct and indirect effects. Subsequently, damage to homes and infrastructures and their contents are categorized as direct effect. Previous research findings by Majid et al. (2011) indicated that windstorms in the country tend to occur in the northern region of Peninsular Malaysia. About 80% of these cases cause damage to roofing systems. The damage breakdown indicates that 47% damage occurred in steel sheet roofing, 30% in truss system, 13% damage on roof tiles, and another 20% for other related damages.

The wind speed affected by terrain exposure, elevation, by local topography and probability occurrence. Topography or large vertical displacements of the ground surface can have a significant effect on wind speed profile (Yohana et al., 2009). The northern region is mostly classified as terrain category 1, which is an open terrain. The wind speed normally referred to Beaufort scale which summarized the wind effect on people. In the case of hurricane, Saffir-Simpson Scale is used to characterize the intensity. Meanwhile, the Fujita Scale provide a scale to classify tornado based on damage extension.

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This study focuses on post disaster investigation on wind damage for non-engineered rural roofing houses located in the northern region of Peninsular Malaysia.

2. Problem Statement

Rural housing roofing system in Malaysia generally not design to cater load during any cases. Rural houses in Malaysia were constructed using wood or masonry or in combination of wood and masonry. In terms of house settings, it may be low-set, double storey and of combination. Meanwhile, for roofing most probably covered by trapezoidal zinc, asbestos and metal deck. The damage usually starting to one of the components forming the building envelope (typically the roof) and which, if it progress far enough, can lead to failure of the complete structure.

Wind disaster occurrence is influenced by several factors. Geographical due to terrain category, transition of season were identified and may contribute to the event occurrence. There is no particular study emphasize in Northern region as well in Malaysia in broad view.

Mitigative adaptation is one of the disaster risk phase involved structural and non-structural measures undertaken to limit the adverse impact of hazard. Build back better highlighted by Clinton in 2006 on improvement on structural design is one of risk reduction principles. Thus, mitigation requires from post disaster assistance to pre disaster readiness thus, lessen the damage from wind occurrence.

3. Objectives

1. To identify post wind disaster structural impacted factor on rural roofing system.

4. Methodology

The states of Perlis, Kedah, Penang, and Perak are located in the northern part of Peninsular Malaysia and chosen as study area. Perlis shares marine and land borders with Thailand. Perak situated very closely, and shares the state borders of Kedah and Penang.

Site observation survey is careful conducted from year 2012 to 2015 basically to measure the wind damage extend after a windstorm strike. This covers on terrain category in compliance to MS1553:2002 and wind speed based on Beaufort Scale in miles per hour unit (mph) are explored on-site. The Beaufort Scale relate the local mean wind speed and the wind effects on people rather than the peak gust on individual. In addition, a survey is conducted to the damaged houses by measuring the structural layout and identifying structural failures. Furthermore, below section will be further discussed on terrain category, wind speed and roof damage identified to recap the whole research objective. Furthermore, identification of rural housing characteristics also was made. For example, building age, roof type, roof pitch, roof element, cladding type and connection type to gather information on rural housing that may contribute to the extensive damage extent.

5. Result and Discussion

5.1 Terrain Category

Most of the houses are situated in an open terrain or terrain category 1 at respective locations in Kedah, Penang and Perak (i.e., Alor Nan, Bandar Baharu, Kampung Terap, and Sungai Nonang). Very least locations affected by windstorm are located at hilly topography.

Referring to Figure 1, it is shown that houses located in terrain category type 2 frequently hit by the windstorm. According to MS1553:2000, terrain category 2 describes water surface, open terrain, grassland with few well scattered obstruction having height generally from 1.5 m to 10.0 m. In contrast, terrain category 3 refers to terrain with numerous closely spaced obstructions 3 m to 5 m height such as areas of suburban housing. There was twenty one (21) numbers of rural roofing houses damage in the windstorm event located in terrain category 2. Meanwhile, only 11 number of houses located in terrain category 3 involved in the event. Observation shown that most probably house surrounded by vacant area prone to have great impact in windstorm event. These vacant area in this research context is referring to paddy field and grassland and least obstruction.

Marshall et al. (2003) strongly supported that homes located in an open, unobstructed terrain, on hills, beside lakes or oceans, on street corners, or at the end of city blocks are more exposed to wind compared with homes in urban or suburban, settings or forests. Meanwhile, Keul et al. (2005) and Sioutas (2011) stated that topography do influence thet windstorm occurrence.

5.2 Wind Speed

A wooden frame house is fragile against windstorm. The roofing system rises during high winds. Wind speed is measured using the Beaufort scale. The magnitude of Beaufort scale is an empirical measure that employs wind speed to observe conditions at sea and land in unit miles per hour (mph). Majority of the result indicate magnitude 11 in the Beaufort scale with a wind speed value of 64 to 72 mph. The result of wind speed conversion from mph to m/s is between 28.60 and 32.19 m/s. Based on the Beaufort scale, this range can be considered a storm, which refers to the seaman's term. Hence, these rural non-engineered houses cannot resist high wind speed, which usually causes widespread damage to houses built below basic wind speed consideration in reference to MS1553:2002.

5.3 Rural Housing and Roofing Characteristics

Certain characteristics such as the built age, building type, terrain category, cladding type, roof pitch, roof geometry, and purlin to fastener connection are identified factors that leads to detrimental of structural elements on the windstorm event.

As illustrated in Figure 2 shows the range of house built age identified was from 13 to 55 years. These findings shows that damage house occurred majority involved housing more than 20 years constructed. Building age range from 10 to 20 years and 21 to 30 years shown the dominant building age represent 29% number of total house damage. Subsequently, this one of the factor shall be taken into consideration contribute towards the wind disaster impact. (Goyal et al., 2012) described the house age less than 10 years is new. It was shown that the least number of damage in the windstorm involving only 6% of total house for age constructed less than 10 years. However, the least damage also observed on rural house constructed age more than 51 years at 6%. This result indicate that small number of house existence also at 6% with built age more than 51 years old in the rural area.

There are three types of rural house built within these study area involved in the windstorm event as shown in Figure 3. The house type observed was double-storey landed, single-storey; and elevated and landed. The common construction material use for the house is concrete or in combination of concrete and wood. Generally, it was observed the double-storey house and elevated and landed house was made of combination of concrete and wood rather than single-storey house only constructed from concrete and masonry. The total numbers of 29 of rural house observed during post-wind disaster visit. Majority windstorm damage prone to double-storey landed house which is about 13 numbers of house (45%) in this case study. Hence, followed by the single-storey house involved 11 number of house (38%) most probably the second highest house ranked type impacted by the windstorm followed by elevated and landed house shown 5 damage houses represent 17%.

It was shown in Figure 4, there are 15 number of house approximately constructed with the roof pitch between $7° < \alpha < 27°$. None of rural house observed has steep roof pitch which is less than 7° ($\alpha < 7°$). Previous scholar highlight that roof pitch less than 22° (<22°) is susceptible to wind damage. This research finding was in line with previous scholar that rural housing roofing damage due to low pitch. This leads to strong uplift force form outside the house. The principles of typhoon-resistant construction suggested to build the roof angle at an angle of 30° to 45° by (Ahmed, 2011).

Observation made on rural housing on roof geometry build in rural roofing system is occupied by gable and dutch-gable. None of the roof shape witnessed from hip. The gable roof sustained more damage than other roof types. This is one of probable contribution factor leads to the severity of wind damage impacts to the rural roofing system itself. These non-engineered rural roofing housing system is not design to resist the strongest windstorm thus, wind loading is not catered to the roof itself. This research findings encountered that gable and dutch-gable roof shape contribute to severe wind damage. Researched by Agarwal, (2007) and Marshall et al., (2003) highlighted that hip roof is stronger than gable and flat roof in terms of wind resistance towards uplift force. This is because the hip roofs are more streamlined and are structurally stronger as each slope is supported by intersecting planes on the roof.

As shown in Figure 5, roofing cladding type frequent used for rural house is metal deck which is corrugated and trapezoidal, asbestos and tile profile. From the observation, metal deck corrugated type is the most preferred cladding in the rural roofing system among the homebuilder. These may due to material used for cladding is substandard, poor installation and workmanship, connection failure between cladding and purlin. Common occurrence observed is loss of cladding during windstorm event.

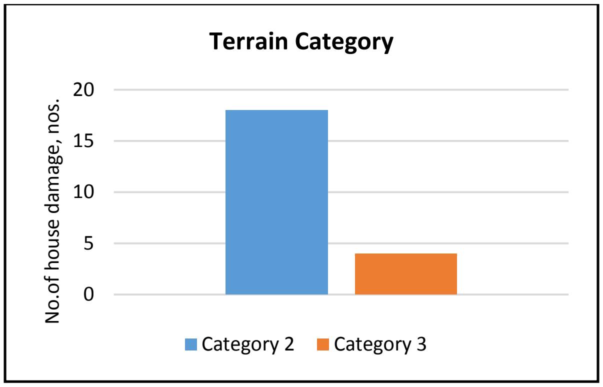

Figure 1: Terrain category

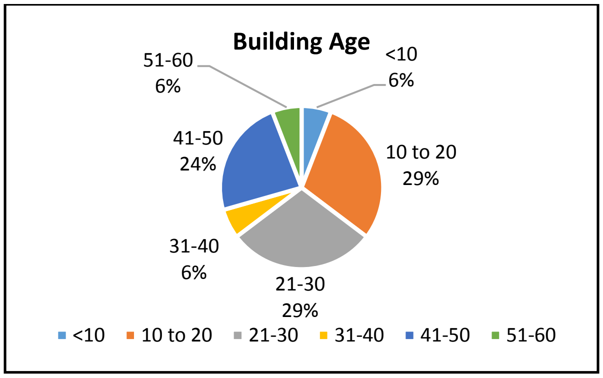

Figure 2: Building age

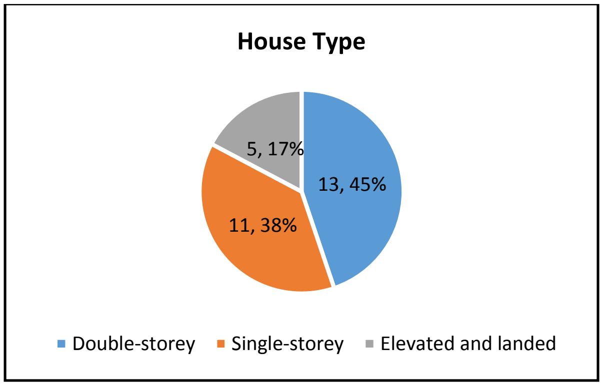

Figure 3: House type

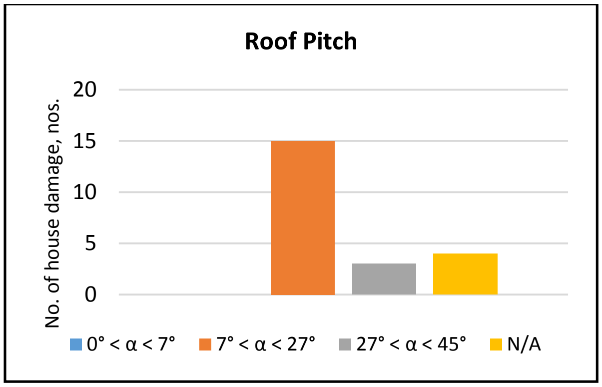

Figure 4: Roof pitch

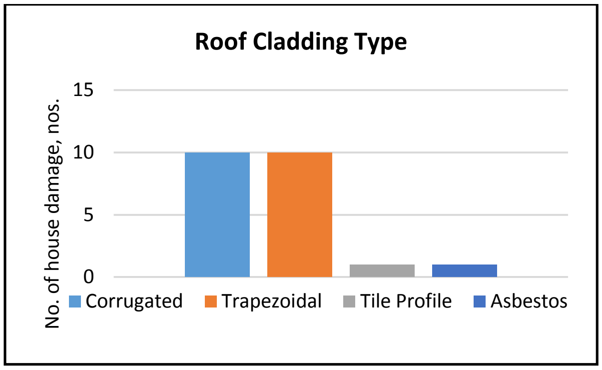

Figure 5: Roof cladding type

5.4 Damage to Rural Roofing System

Majority of rural house roofing are blown off during a heavy windstorm. The sources of damage to the roofing system are identified from several factors, such as low or high buildings, failed joints or fasteners, inadequate anchorage or ties, roof types, engineered or non-engineered buildings, and wooden or timber house. The rural houses severely damaged by windstorm are low-rise buildings, non-engineered rural houses made from timber, and houses made of wood or a combination of concrete and wood.

According to Wan Chik et. al, (2014), the number of houses damaged by windstorm events annually increases throughout the four-year data period from 2010 to 2013 located in Northern Peninsular Malaysia. Most of rural housing located in northern Peninsular Malaysia are low set and constructed in combination of concrete and timber. From post disaster investigation observed that the gable roof sustained more damage than other roof types. These non-engineered rural roofing housing system is not design to resist the strongest windstorm thus, wind loading is not catered to the roof itself. Furthermore, the roofing system experiences inadequate anchorage or ties to the wall and weak joints and fasteners, especially at the corner of the house.

Below listed description for item no. 1 to 5 shows the example of frequent failure modes and post windstorm damage occurred on the rural roofing system.

1. Edge of the cladding is the risky part on the roof structure to lift off and damage. This damage can be considered as only light damage.
2. Partially damage of roof cladding and can be considered as light damage.
3. Severe damage to roof and loss of roof cladding. This damage involved other non-structural elements such as purlin and rafter.
4. Lost all the roof cladding.
5. Loss of roof structure.

It was identified most common problem due to windstorm was severe damage to roof and caused loss to roof cladding. This damage also involve purlin and rafter the non-load bearing member elements. Consequent damage observed was loss of roof structure. Least loss of roof structure experienced and these can be considered as minimal structural damage on post disaster investigation. Meanwhile, others damage observed was roof partly uncovered and these can best referred as light damage. From the observation, damage occurred at the corner of roof structure also considered as light damage and ranked second lowest structural damage compared to top five listed damage from the illustrated graph in Figure 6.

Most of the damage to actual roofs is caused by local high suctions and large pressure fluctuations. Referring to Figure 7 and Figure 8, site observations are made for fastener failure based on two major aspects, namely, screw and nails, and location of connection. Location of connection is divided into three categories, that is, rafter to purlin (R-P), purlin to purlin (P-P), and Purlin to wall (P-W). Screw gives significant values at 59% failures compared to nail at only 50% failures. This is a very good finding whereby local homebuilder utilized screw understood that this fastener riveted performed better than nail at rural roofing system based on their previous experience. Observation made at all affected rural roofing damage concluded inadequate anchorage or ties probably occurred at location between rafter and purlin at 86% and the lowest at purlin to wall at 41%. Probability the connection failure between purlin to purlin is moderate, at 50%. The result indicates that roof damage is probably influenced by failure of fasteners which is screw and inadequate anchorage or ties of roofing located at rafter to purlin.

The common mistakes that contribute to the failure of the roofing system are due to poor workmanship by carpenters, poor installment of the fasteners and joint, and substandard roofing materials, such as fasteners used (i.e., screw and nails, roof sheathing, trusses, and purlins). Timber house weakness is on proper connection detailing. This has often led to tremendous disaster impact .

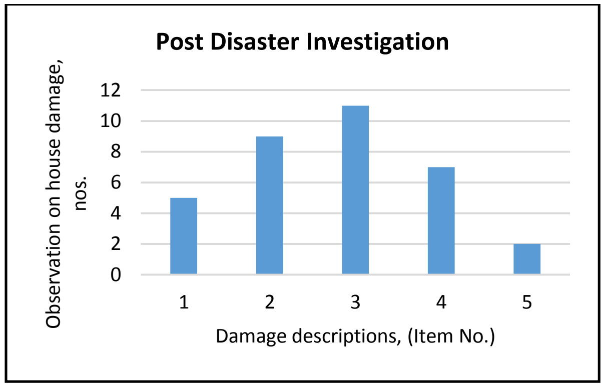

Figure 6: Wind impacted rural roofing damage

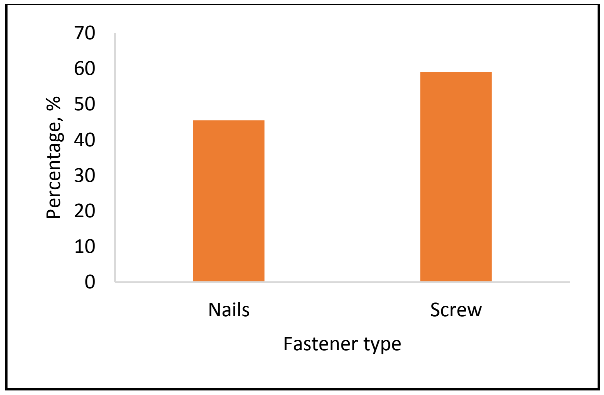

Figure 7: Fastener type

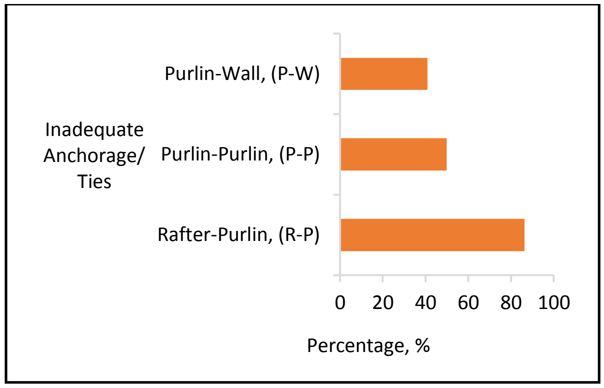

Figure 8: Inadequate anchorage or ties

6. Conclusions

Structural improvement need to cope future recurrence wind damage especially on the rural roofing system. Building especially house in rural region is not disaster proof. The roof must be given priority because it had to withstand the heavy wind and rain during the hot sun and rainy season.

It can be concluded that all the above factors discussed has to be considered in housing reconstruction. Improvement shall complies to building codes and regulation, depends on budgeted cost and time frame allocated and also built good quality of house.

Build the roof angle at an angle of 30° to 45° decrease wind damage impact. Further collaboration among consultant, contractor or homebuilder is very helpful to ensure that the roof pitch for rural roofing is design and constructed accordingly at site. Otherwise, severe damage was observed to roof and loss of roof sheathing. This damage involved other non-structural elements such as purlin and rafter. Rafter to purlin connection must be secured tightly to minimize the damage risk. Output from this study provides basic idea for the design improvement need to be taken place based on the existing guideline and code of practice.

Thus, new rural roofing housing must built to wind-resistant standard with an appropriate adaptation to windstorm and extensive damage impact. Further labwork shall be carried out to justify on roofing material testing, connection and fastener relationship, analysis on roof pitch which is out of this study scope. Recommendation on future research shall collaborate this findings and labwork to optimize the result output towards the risk reduction in wind disaster.

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