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Fastener Pull-out Tests to Determine Threshold Values for Roof Failure Modes Observed After Typhoon Haiyan in the Philippines

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Abstract

Typhoon Haiyan slammed into the islands of the Philippines, devastating many coastal cities and communities along its path. Low-rise residential buildings and mid-rise buildings suffered different damages on their building envelope, almost none were spared. Although damage and deaths increased due to the storm surge, many inland towns experienced damage due to the severe wind loading. This paper identifies the different types of damage or modes of failure due to severe wind found during a survey of the areas ravaged by the typhoon. Static and cyclic pull-out tests of nails and screws for metal and wood were conducted to determine their resistance. The tests showed surprising results, with the wood screws providing the highest resistance contrary to the notion that the metal screws performs better. The low tearing capacity of GI sheets also reveals a weakness of the roof envelope which greatly contributed to its rampant failure.

Introduction

Typhoon Haiyan made landfall on November 8, 2013 over Guiuan, Eastern Samar in the Philippines. It affected Regions IV-A, IV-B, V, VI, VII, VIII, X, XI, and CARAGA. According to the National Disaster Risk Reduction and Management Council's (NDRRMC) last update the number of casualties reached 6,190 people, with 28,626 injured, and 1,785 still missing. The total cost of damages to infrastructure and agriculture is estimated at 834 (in million US$). Add to this the cost of damage by eight (8) tropical cyclones on average that annually make landfall and the running total could reach thousands of million US$ with thousands of people affected. Thus, there is a need for in-depth research on the effects of wind forces on existing structures due to tropical cyclones in order to reduce damages and save lives. In particular, the different modes of failure observed after a tropical cyclone should be identified and tests conducted to quantify the resistance provided by fasteners and the building envelope.

The damage survey identified the different types of failure on the building envelope which are normally not designed. It includes the roof, walls, doors and windows. Failure of one these components may lead to the decrease of the structural integrity of the building. The common failures that roofing experience are pull out of the connection from roof-to-wall, tearing of the roofing, and pull out of the fasteners in roof-to-purlin connections. The weakness in the building envelope appears to be in the connections of non-structural elements. Thus, pull out tests of different fasteners were conducted to determine their capacities.

The objective of the study is to conduct pull out tests on the commonly used fasteners in the roof-to-purlin connections and quantify uplift threshold values for the resistance of the fasteners under static and cyclic loadings. Threshold values are important since it is used in preliminary design or simulations of structures. Threshold values are included in the building database. Simulations use threshold values in order to predict possible failures in the parts of the system in developing fragility curves. Uplift threshold values vary depending on the type and properties of materials. The developed threshold values from this study will be suitable for the Philippine setting.

Damage Survey

A joint damage survey was conducted by the Institute of Civil Engineering - Philippine Institute of Civil Engineers - Japan Society of Civil Engineers (ICE-PICE-JSCE) in Leyte and Samar islands after Haiyan. Almost all buildings lost a part of their building envelope, especially roofs. Figure 1 shows a two-storey reinforced concrete building with damage to hip roof truss, complete loss of G.I. sheets, and damage to windows, walls, and doors. Figure 2 shows typical damage to a single-storey reinforced concrete residential house with damage to gable roof truss, complete loss of G.I. sheets, and damage to windows and doors.

Figure 1. Typical damage to a two-storey reinforced concrete building (photo from ICE-PICE-JSCE Joint Survey).

Figure 2. Typical damage to a one-storey reinforced concrete residential house (photo from ICE-PICE-JSCE Joint Survey).

Figure 3. Collapsed Steel roof of a multi-purpose covered court (photo from ICE-PICE-JSCE Joint Survey).

Figure 4. Typical damage to a one-storey CHB residential house with wooden truss (photo from ICE-PICE-JSCE Joint Survey).

Figure 5. Typical damage to a two-storey wooden residential house (photo from ICE-PICE-JSCE Joint Survey).

Figure 3 shows the complete collapse of the steel roof of a covered court multi-purpose hall; there was a complete loss of all G.I. sheets. Figure 4 shows the damage to a Concrete Hollow Block (CHB) building with wooden roof. The roof framing is damaged, and there is a complete loss of the roof cover and purlins, doors, and windows. Figure 5 shows the damage to a two-storey wooden house with partial loss of roof trusses, complete loss of purlins, G.I. sheets, and windows.

Thus, the typical damages observed can be classified according to four (4) types:

1. Complete or Partial Loss of Roof Cover - that can be attributed to failure of roof fasteners or tearing of G.I. sheets.
2. Damage to or Loss of Purlins or Trusses - that can be attributed to failure of connections of purlins to the top chord or connection of trusses to columns or beams.
3. Damage to or Loss of Windows and Doors - that can be attributed to failure of windows or connection between windows and walls.
4. Damage to or Loss of Walls - that can be attributed to failure of walls or connections to beams and columns.

It is easy to conclude that most of the damage occurred on the building envelope; these are non-structural elements that are seldom checked in design computations. With the modes of failure identified tests can be conducted to quantify the resistance of connections that fail during severe wind loading.

Methodology for the Experiment

For the study, there were 5 types of tests conducted. The first two were static and cyclic loading of single fasteners (Single Fastener Test). The purpose of these two types of tests is to determine whether there is significant decrease in Fastener Pull-out Resistance (FPR) of the fasteners if subjected to series of progressive cycles. The third type of test, Static loading for GI Roof (Roofing Test), was done to determine the strengths of GI roofing when upward pressure is applied on it. After the third test, it was then compared to the first test in order to determine what kind of failure most likely occurs depending on the maximum pull out resistances. The fourth test (combination test), was a combination of the first and third, was used to determine whether synergy exists when the strengths of roofing and purlin were combined. Lastly, the fifth test is the Multiple Fastener Tests. This test was made to observe the behavior of group of fasteners during pull out, especially the sequence of pull out and the maximum resistance the group can hold.

Test Specimen

Fastener Properties

Figures 6 to 8 show the three types of fastener were used in the experiment. First is the wood nail, second is the metal screw and lastly is the wood screw. Table 1 shows the dimensions of the fasteners that were used.

	Inner Diameter	Outer Diameter	Head Diameter	Threaded Length	Total Length
Wood Nail	N/A	4mm	20 mm	N/A	75 mm
Metal Screw	2.5 mm	4 mm	12 mm	35 mm	80 mm
Wood Screw	3 mm	5 mm	13 mm	60 mm	85 mm

Table 1. Specifications of Fasteners Used

Figure 6. Wood Nail used in the experiment

Figure 7. Metal Screw used in the Experiment

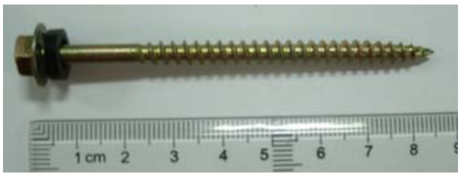

Figure 8. Wood Screw used in the Experiment

Purlin Properties

The purlin sample dimensions are 2 x 3 x 6 in. per sample. Two types of material were used for the purlin: Wood S4S and galvanized iron C channel (thickness: 1mm)

Figure 9. Test Specimen Types used in the Experiment

Roof Properties

The roofing used in the experiment was gauge 24 galvanized iron with a size of 200 x 200 mm. The thickness of the roof is 0.76 mm. The fastener is placed on the crest of the wave of the roof.

Figure 10. Roofing used in the Experiment

Design and Test Set Up

Since the Universal Testing Machine's wedge grips are not capable of holding the specimen, attachments were designed such that they are capable and flexible enough to conduct different types of tests. The following pictures are the designed attachments labeled with the corresponding test they were used.

Figure 11. Single Fastener Test (Static Loading Set-up)

Figure 12. Single Fastener Test (Cyclic Loading Set-up)

Figure 13. Static Loading for Roofing Test Set up

Figure 14 Combination of Roofing, Fastener, Purlin Test Set-up

Testing Process and Parameters

Since there are five types of testing, each of the test needs specifications for loading that will be set in the Bluehill software in order to operate the UTM. Therefore the researcher made some protocols for testing. These protocols are based from ASTM D1761 – 06, ASTM D7332/D7332M – 09 and modified CSA Loading Cycles from (Baskaran et al, 2008).

For static loading, the loading rate is 2mm/min. The movement of the crossbeam is constant until the fastener reached total pull-out. For cyclic loading, the crossbeam moves up and down with progressive amplitude. The loading rate for the crossbeam is 75mm/min. For certain amplitude, there is a certain number of cycles applied on the specimen. The sequence is similar to Baskaran but amplitude and number of cycles were modified.

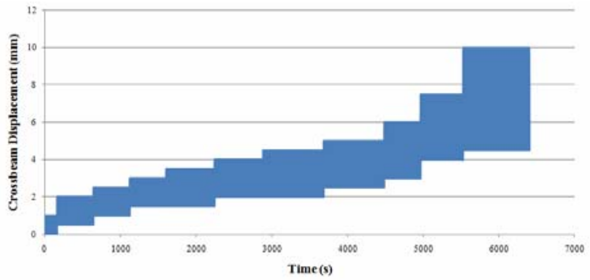

Figure 15. Cyclic Loading Sequence for Wood Nail

Results

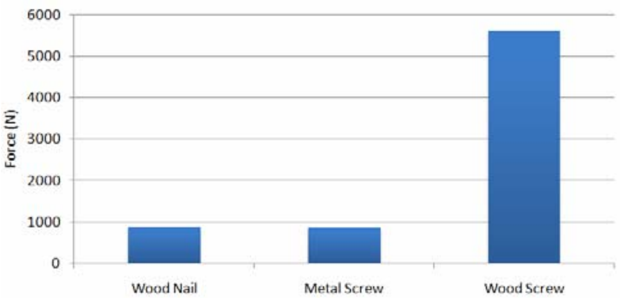

Figure 16. Comparison of Average Resistances between Different Fasteners

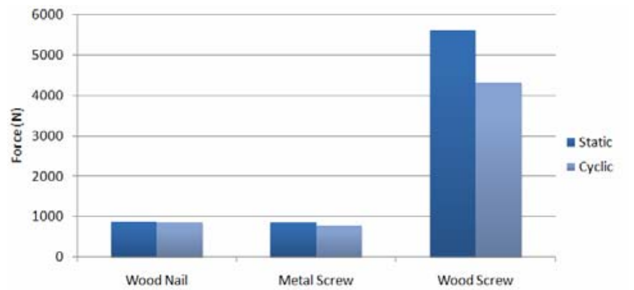

Figure 17. Comparison of Average FPR (Static and Cyclic Loading) per Fastener Type

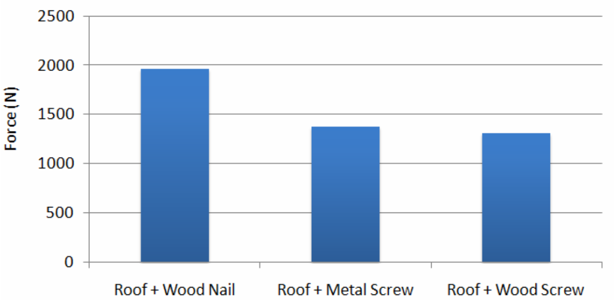

Figure 18. Comparison of Average Maximum Loads on Roofing Test

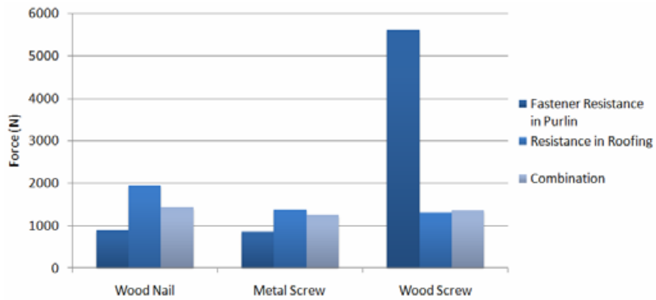

Figure 19. Comparison of Average Maximum Loads on Fastener, Roofing and Combination Test

Observations and Conclusions

Figure 16 shows the FPR (Static loading), wood screw has the highest (5.5 kN) while wood nail and metal screw are the almost the same (0.9 kN). Figure 17 shows the decrease on FPR due to 1500-2000 cycles for wood nail, metal screw and wood screw was 2.8%, 9.4% and 23% respectively. The mode of failure in the roofing connection depends on what type of fastener is to be used shown in Table 2.

Type of Fastener	Mode of Failure	Average Maximum Load (kN)
WOOD NAIL	PULL-OUT	1.43
METAL SCREW	MOSTLY TEARING	1.26
WOOD SCREW	TEARING	1.37

Table 2. Modes of Failure per Fastener Type

These results show that the high pull-out resistance of the wood screw is not achieved because tearing failure of the G.I. sheets controls the mode of failure. Whereas the wood nail does not allow tearing failure because of its wide head. However, its low FPR caused a pull-out mode of failure.

Acknowledgments

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