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# WIND INDUCED DAMAGE TO ROOFS

## A Comparative Study on Roofs in Bhutan and Japan



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### **Overview**

1. Background
2. Problem Statements
3. Scope and Objectives
4. Comparison of Japan and Bhutan Roofs
5. Recent Windstorm Damages
6. Analysis and Mitigations
7. Conclusions
8. Future Recommendations

## Background

- Bhutanese rural home are constructed by the carpenters based on their indigenous knowledge.
- Rural home in Bhutan is non-engineered construction

•Till early 1960's when Bhutan is not open the other world, people are using the wooden shingle or other local materials as roofing materials which is more eco-friendly and wind resistant



## Changing period.....

- Roofing materials started changing from are wooden shingles and corrugated galvanized Iron (CGI) sheets in early 1980s





## WHY THEY CHANGE?

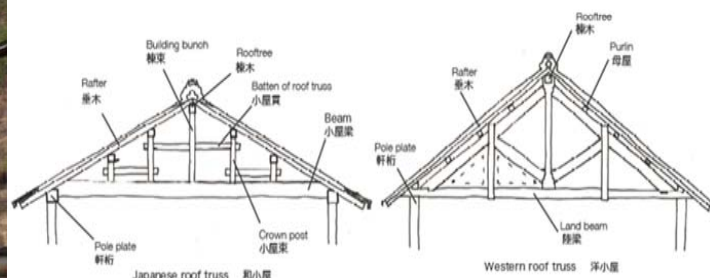
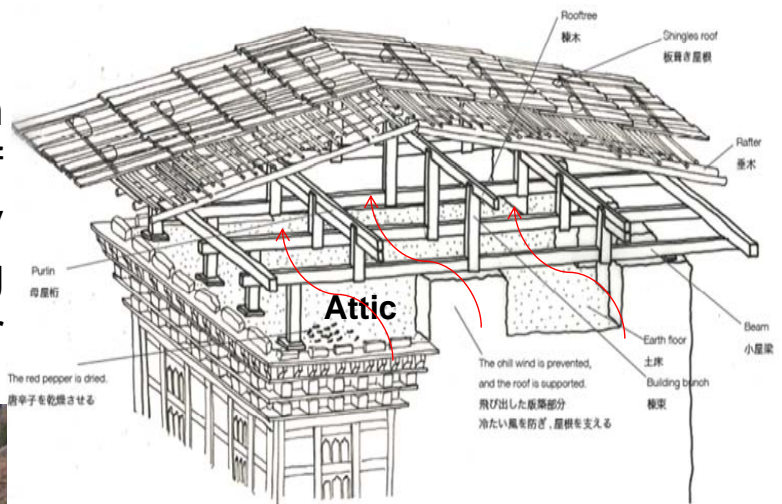
- Durability and affordability for the rural people
- Environment conservation
- Less maintenance cost



Hip-and-gable roof with CGI sheets

## Typical Bhutanese Rural Roof Configuration

- Roof slope  $12^{\circ} - 15^{\circ}$
- Space (attic) between roof floor and roof covering is use for hay and red pepper drying and use as open-air storage.



(source: Traditional Bhutanese Houses survey and research report, 2010)

## Problem Statement

- More than 60% of population lives in rural area in Bhutan but people lack understanding on rural home roofs failure during windstorm in Bhutan.
- In 2011 & 2013 windstorms, 2424 & 1017 rural home roofs were damaged respectively
- Lack of wind resistant features incorporation during **RECONSTRUCTION**



2013 Windstorm damage



Reconstruction

## Scope and Objective

- To assess the rural home roofs in Bhutan based on the roofs; configuration, shape, slope, overhang, support string, connections and roofing materials and comparing with the Japanese traditional roof
- To assess the rural home roofs failure based on the existing roof configuration during the windstorm based on the literature review.
- Aim of this research is to help the common people of Bhutan to reduce the rural homes roof damage, economy losses during windstorm and to preserve our traditional Bhutanese architectural by suggesting some mitigations.



## Comparison of Japan and Bhutan Roofs

- **Common rural home roofs in Bhutan:**

- Gable roof (Kirizuma)
- Hip-and-gable roof(Irimoya)
- Jamthok roof
- Lean-to roof
- Drangrim roof



Lean-to and drangrim roof



Gable roof



Hip-and-gable combined



Jamthok roof

## Comparison of Japan and Bhutan Roof

- **Common rural home roofs in Japan:**

- Gable roof (Kirizuma)
- Hip-and-gable roof(Irimoya)
- Hip roof (Yosemune)



Gable roof



Hip-and-gable roof

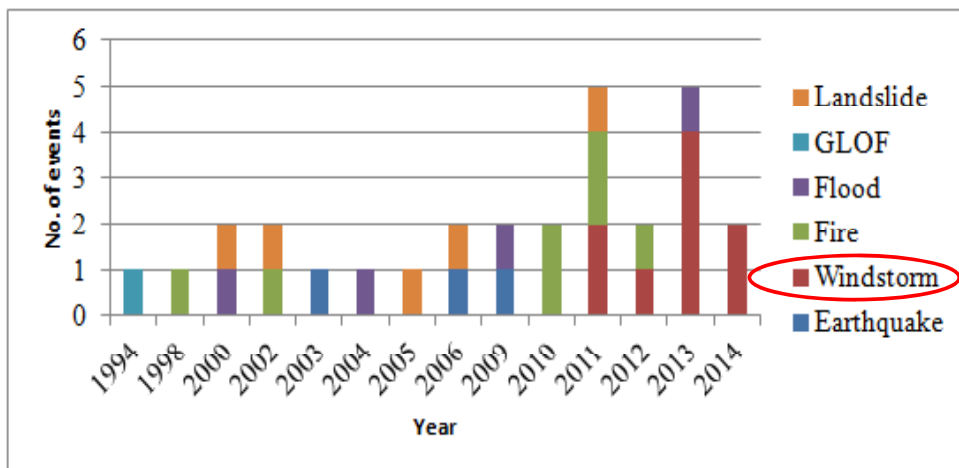


Hip roof

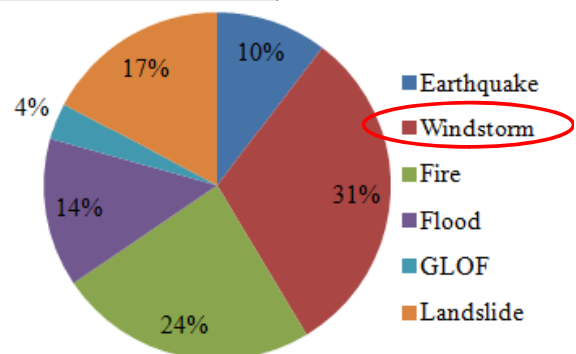
# Comparison of Japan and Bhutan Roof

Sl No.	Descriptions	Bhutan	Japan
1	Type of roof	gable, gable + hip roof (combined), lean roof, Jamthok (monitor) roof & etc.	gable(kirizum), hip(yosemune), gable + hip (irimoya), hogyo roof and etc.
2	Type of roof material	corrugated galvanized iron (CGI) sheet metal, shingles, thatch, banana leaves, bamboo, slates & etc.	tiles, thatch, plank, shingles, bark & etc..
3	Roof configuration	roof members act independently and no rigid connections between members.	members are connected rigidly using the screws or bolt or nails
4	Roof overhang	large roof overhang (500mm-2500mm)	less roof overhang (around 0 – 1500mm) usually around 600mm
5	Roof angle	roof slope between 12 ° - 15 °	roof slope various based on the location, e.g. in the snowy areas, roof slope is steep
6	Trusses specification	square or rectangular shape tie beam, timber batten purlin, circular rafters	most members are circular timber in traditional roof and batten in modern houses
7	Roof-to-wall connection	simply supported	rigid connections using bolt or nails

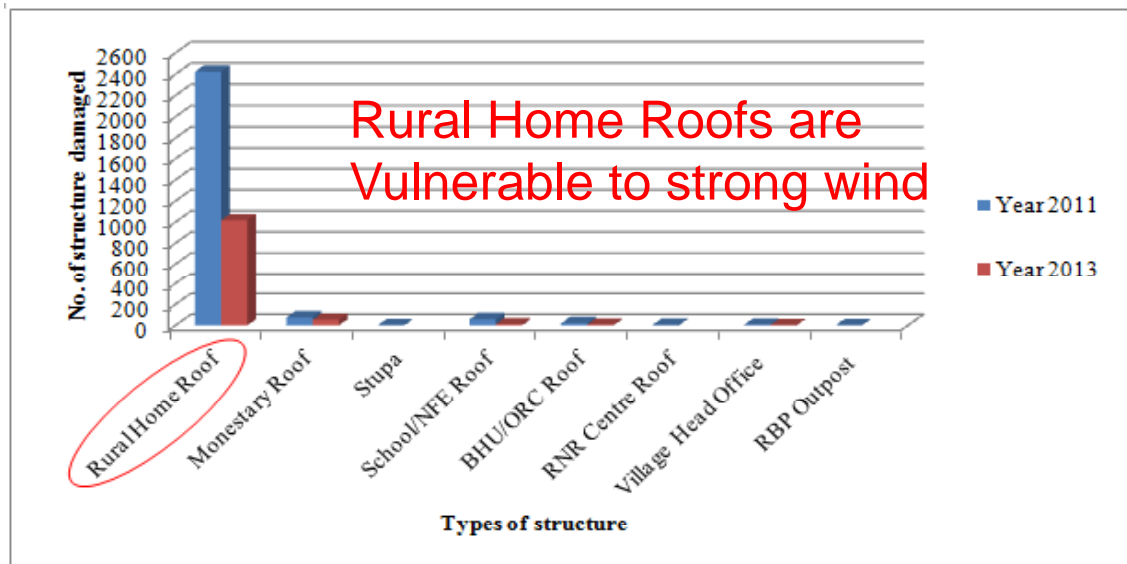
## Recent Natural Disasters in Bhutan



•Compared to other natural disasters WINDSTORM events are more frequent in Bhutan

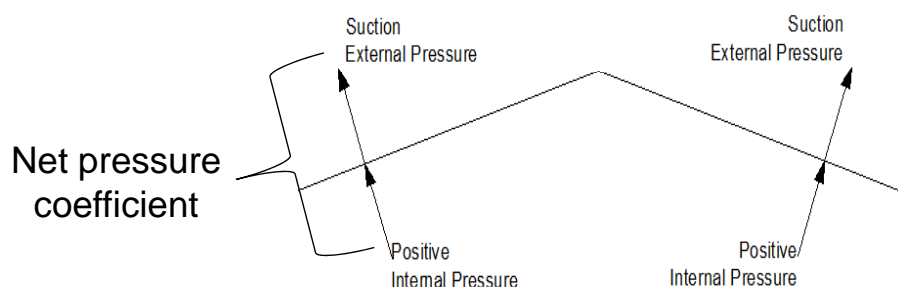
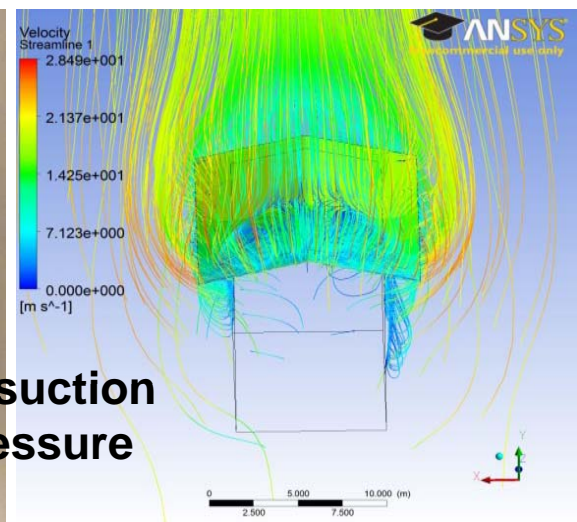
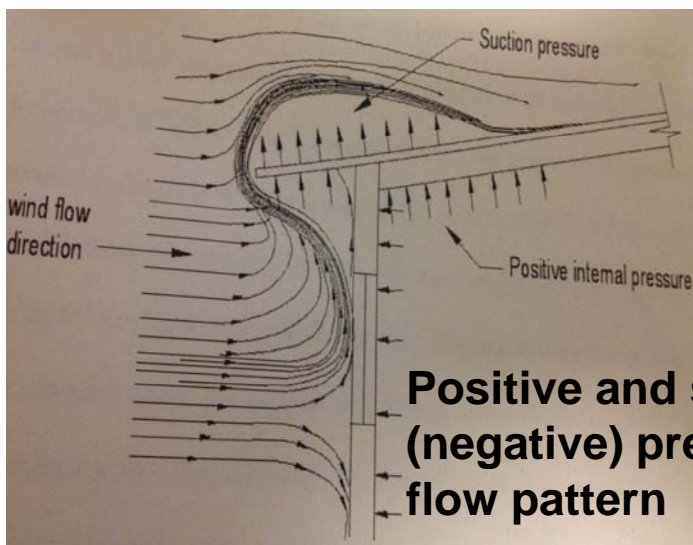


## 2011 & 2013 Windstorm Damages



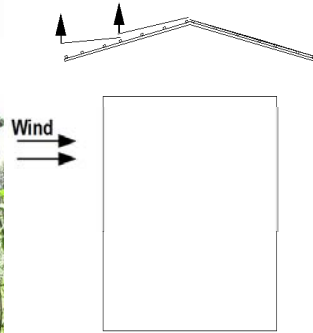
- In 2011 windstorm damage, 2424 rural home roofs damaged out of 2598 total damaged structures (93.30%)
- In 2013 windstorm damage, 1017 rural home roofs damaged out of 1093 total damaged structures (93.05%)

## Wind Effect on Roof System





## Common Type of Roof Failure - 1

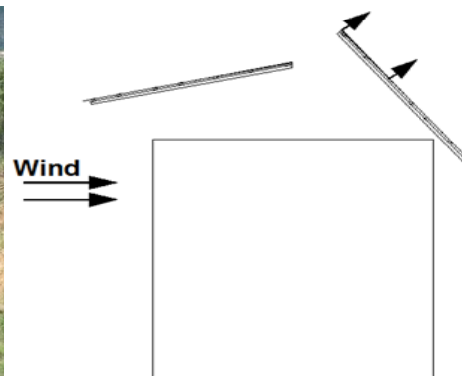


CGI sheet lift/loss at roof edges and gable roof end



- Failure in timber section
- CGI sheets are intact on batten
- Timber batten section are not adequate to withstand wind pressure

## Common Type of Roof Failure - 2



Failure at roof ridge connections

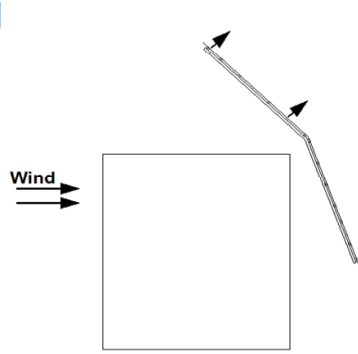
Toe-nails



- Timber lap joint with single 4-5inch toe-nail connection at roof ridge
- Poor connection



# Common Type of Roof Failure - 3

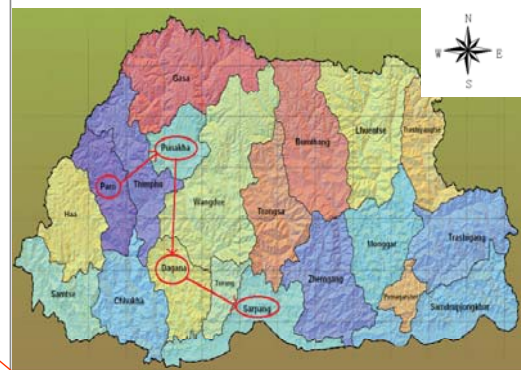
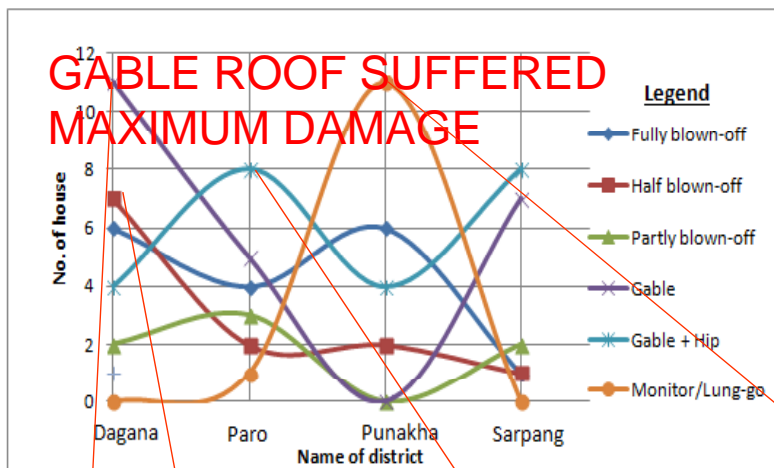


Full blown-off or overturning of roof failure



- No connection roof-to-wall connection
- No connection between struts and attic floor

## Analysis of Rural Home Roof



Site location



Gable Roof



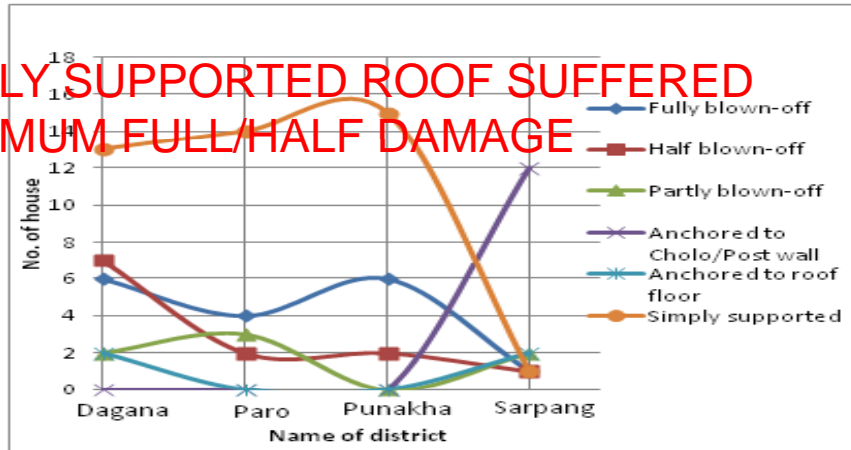
Hip-and-gable Roof



Jamthok Roof

# Analysis of Rural Home Roof

**SIMPLY SUPPORTED ROOF SUFFERED MAXIMUM FULL/HALF DAMAGE**



Half blown-off



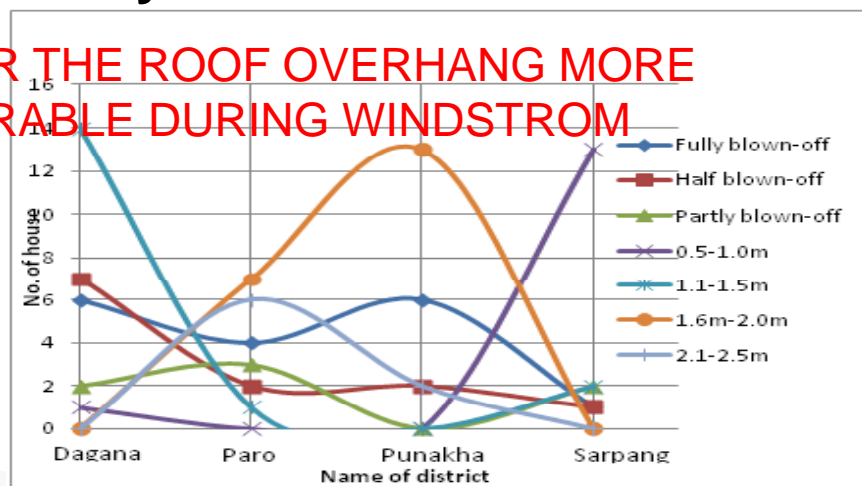
Fully blown-off



Partly blown-off

# Analysis of Rural Home Roof

**LARGER THE ROOF OVERHANG MORE VULNERABLE DURING WINDSTROM**



Overhang (2.1-2.5m) 2014 09 24

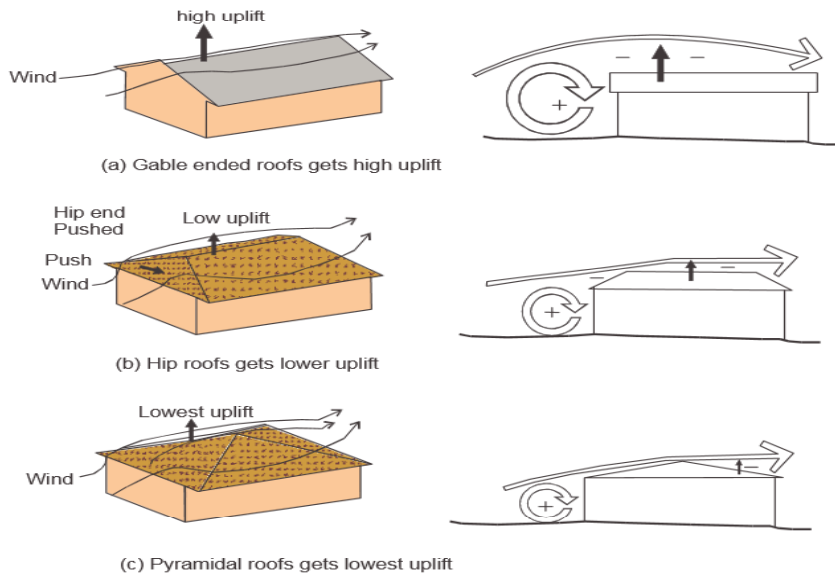


Overhang (0.5 - 1.5m)



# MITIGATIONS

## Roof Type Selections

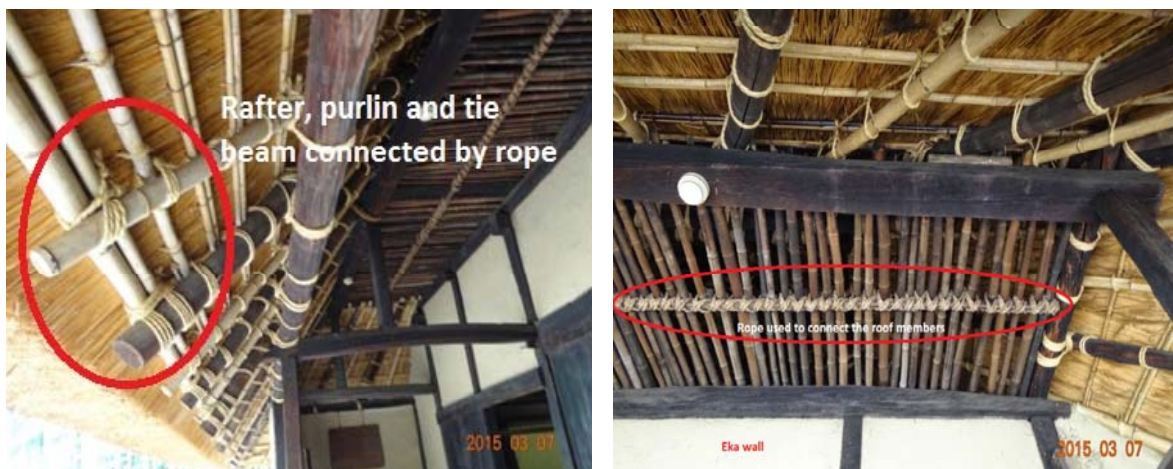


(Source: Roof type effect on uplift pressure (Bhandari et al., 2005))

**HIP ROOF PERFORM BETTER THAN OTHER ROOF**

# MITIGATIONS

## Rope Connection like Japanese roofs



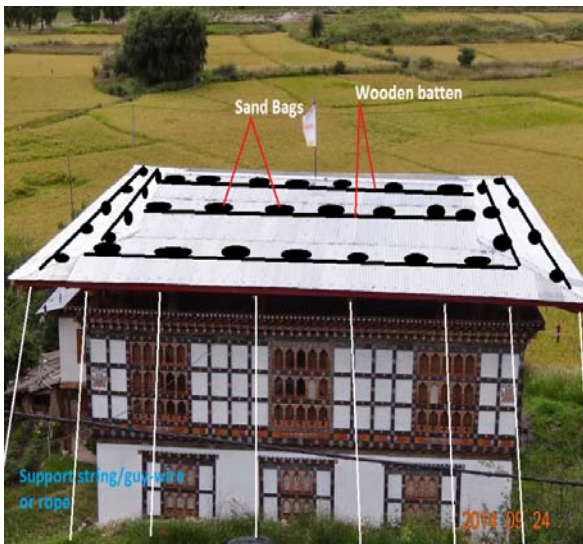
Connect the rafters and purlins using rope/GI wires

# MITIGATIONS



Use of metal strap and strong support string

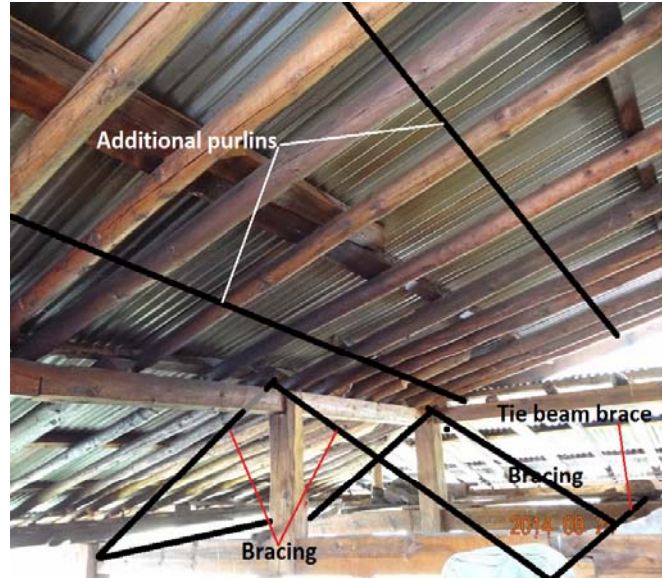
# MITIGATIONS



Use of sand bag (10-20kgs)  
Use of stone over the CGI sheet

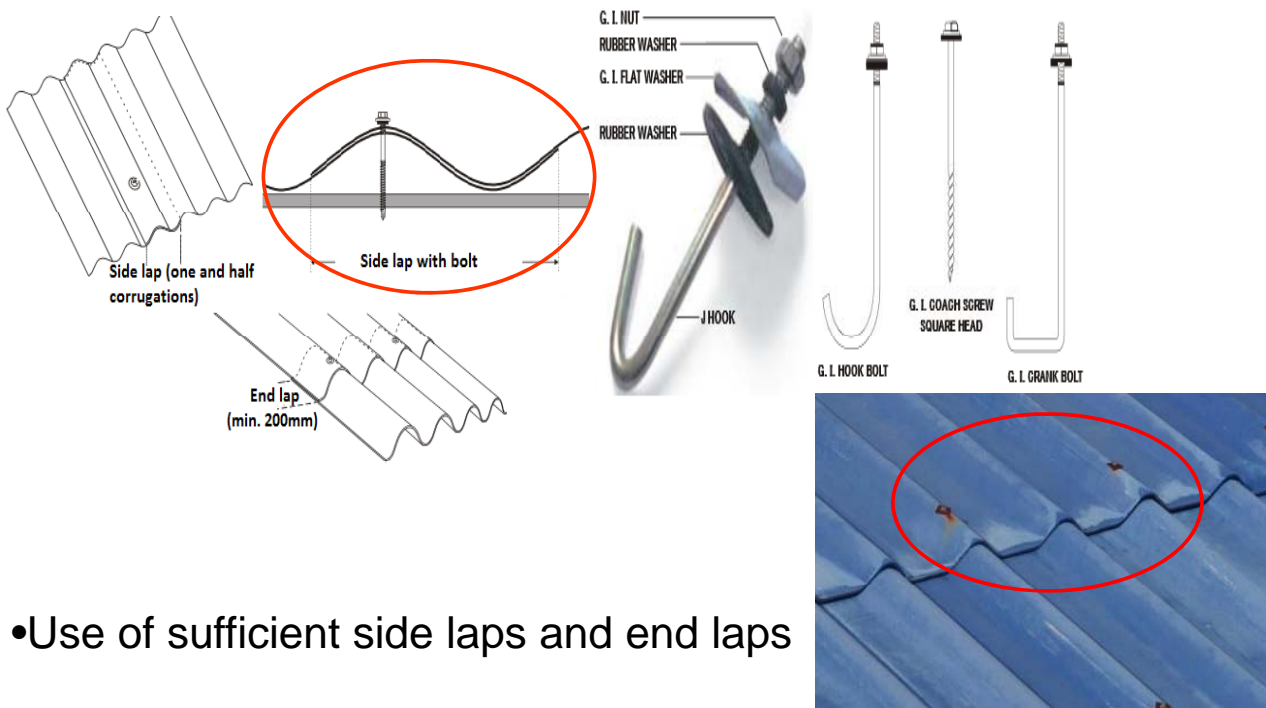


# MITIGATIONS



- Use of gable end stiffener and overhang ties
- Use of additional purlin and bracing

# MITIGATIONS



- Use of sufficient side laps and end laps
- Use of rubber washer instead of bitumen washer



## **Conclusions**

- Bhutanese roof is highly vulnerable to strong wind because most of the Bhutan rural home roofs were gable roof type with large roof overhang between 500mm and 2500mm. It was found that gable roof is weak during the windstorm especially with the large roof overhang.
- Bhutanese roofs act independently and roof configurations is very flexible and weak during windstorm
- Japanese roofs are wind resisted as compared to Bhutanese roofs

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## **Conclusions**

- Most common rural home roofs failure during the recent windstorms are gable end failure, ridge failure, roof-to-wall connection, timber section and pull through failure.
- Western part of Bhutan rural home roofs with large roof overhang are more vulnerable to strong wind as compared to southern region roof with smaller overhang.

## Recommendations

- In this study, Bhutan rural home roof was assessed based on the literature review and damage reports of 2011 and 2013 windstorms. But it is not sufficient to conclude that Bhutan rural home roofs are still unsafe during the windstorm. Therefore, in the future study, more experimental test is required to conclude the behavior of Bhutan rural home roofs.
- More study need to carry out on the roof joinery and connection details.

