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BRACING FOR TYPHOONS: AN INITIAL STUDY OF TYPHOON RESILIENT
SINGLE-FAMILY HOUSES ALONG THE CENTRAL COAST OF VIETNAM

BY

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Abstract

The Central Coast of Vietnam has had a long history of severe typhoons and flooding. Efforts have been made to minimize the effects of these natural disasters on both people and properties. There are many approaches in minimizing the effects, including early warning and better evacuation plans, helping local residents prepare better for typhoons and living with them while a typhoon is going through an area, and building more resilient systems.

As an effort to contribute to a greater understanding and discussion over climate change adaptation and building resilient systems in face of natural disasters, the Institute for Social and Environmental Transition (ISET), a non-profit international organization that focuses on collaborative research and planning with regional partners concerning building resilient systems and climate change adaptation in many parts of the world, had organized a design competition to showcase innovative designs and solutions for building a more typhoon resilient house targeted for the residents along the Central Coast of Vietnam.

This project focuses on analyzing the effects of a Type 13 typhoon on a single-family residential house commonly found along the Central Coast. The design of the winner of ISET's Resilient Housing Design Competition was selected to be constructed and analyzed in SAP2000 (version 15), a structural analysis software. The ASCE 7-05 Design Manual and particularly Chapter 6-Wind Loads were consulted in determining the wind pressure distribution on a house of a wind with a wind speed of 85mph (wind speed corresponding to a Type 13 typhoon).

After constructing the model in SAP2000 and running the analysis, several conclusions were drawn from the model. The dead load effects, including the dead weight and the gutter loads, dominated over the wind loads. This was not the expected results. The maximum deflection on the model occurred at the connection between the top of the lower roof and the bottom of the emergency access window. The maximum stress concentration occurred at the exterior horizontal girder at the back of the house (where the upper roof tips down).

For future work, it is necessary to collect more data on the types and quality of the materials of the elements used in the model to better reflect the actual construction materials used in Vietnam in the model. A capacity check for all of the elements in the model is also needed to better quantify the degree of resilience of the model and to determine if the model is capable of producing resilient responses when subjected to a Type 13 typhoon.

Introduction

Vietnam's Central Coast Background

The area referred to as "Central Coast of Vietnam" actually consists of two areas: the North Central coast and the South Central coast. Figure 1 shows the map of Vietnam, with Vietnam's Central coastline highlighted in red.

Since these two areas have had a long history of severe storms and flooding, they are combined here and are the target area for this study. The central coastline spans 1000km (620mi) and consists of 14 cities. The largest city in the region is Da Nang. The Truong Son mountain range is to west of the region, and the east side of the region borders the sea. The general topography for the North Central coast is hilly or in some regions mountainous. The general topographic traits for the South Central coast are coastal farms and small mountains (Thong Tin 2013).

Figure 1: Map of Vietnam. The Central coastline is highlighted in red. Source: Google Earth

Based on photographs obtained from literature and from the news, the two most common types of houses in these areas are houses with brick walls and corrugated metal sheet roof or older brick roofs. (Bui 2013). Most of these houses are not designed to incorporate aspects of typhoon resilience and will most likely suffer significant amount of damages in case of a typhoon (Bui 2013). Some of the most affected cities in the region are Quang Binh, Quang Nam, Thua Thien Hue, Da Nang, and Quy Nhon.

How Typhoons are Categorized

As the focus of this study will be on analyzing the resilience of residential designs to typhoons, it is crucial to understand the criteria for classifying a typhoon. Based on a study done by the ISET titled "Sheltering from a Gathering Storm: Typhoon Resilience in Vietnam", the Beaufort scale is presented as the tool to categorize pacific storms. A table outlining the scales is shown below (ISET 2014). According to the study, in order for a tropical storm to be classified as a typhoon, it has to have a wind speed of at least 118 km per hour (73 mi per hour) (ISET 2014).

Table 1: Beaufort Scale Category. Source: ISET

Extended Beaufort scale category	Wind speed (kph)	Typhoon category
12	118	Typhoon
13-14	119-156	Strong typhoon
15-16	157-193	Very strong typhoon
17	≥194	Violent typhoon

Existing Protocol

For clarification purposes, it is noted here that in many publications in Vietnamese, the effects of typhoons and flooding are often combined since typhoons usually bring heavy rainstorms and cause severe flooding to the region. Therefore, in existing literature and in some cases, titles of government agencies associated with these events, these two words are often used together or interchangeably in some cases.

In an event when there is a typhoon warning, there is a brief period of about 1 to 2 days where local residents get busy with preparing for the upcoming typhoon. These tasks include anchoring down the roof with sand bags or other types of anchoring systems, buying extra food and supplies, cleaning up debris around the house to prevent flying objects from damaging the house or the surrounding area etc. Out of the anchoring methods used, putting sand bags on top of the roofs has been a common, inexpensive method of anchoring down the roof. This method however is not very effective because these roofs are typically made from materials that are brittle and often become hazardous in an event of a typhoon. Therefore, other innovative materials are now sought after in new housing designs to improve the resilience of houses in these areas.

ISET Involvement

ISET has been conducting researches related to climate change adaptation in South Asia and Southeast Asia in the past 20 years. Their main area of focus includes strategic research in carefully selected areas or cities to identify innovative strategies in responding to critical issues centered around climate change adaptation while providing technical support to local governments (ISET 2014). In the past, ISET has targeted both urban and sub-urban cities along the Central coast of Vietnam such as Da Nang and Quy Nhon. In 2013, as part of a study titled "Sheltering from a Gathering Storm", ISET, Hue College of Economics, Hue Planning Institute, and Da Nang University of Architecture announced a design competition called "Resilient Housing Design Competition" that seeks innovative designs of houses along the Central coast of Vietnam with focus on typhoon resiliency. The objective of the design competition was to design low-coast housing that is resilient to typhoons and climate change activities. The competition was open to engineers, architects, students and individuals interested in the topic of typhoon resilience. As stated, " the competition rules required each design to include two or three rooms, a kitchen, and a toilet with construction costs under \$10,000 USD; to consider climate resilience, environmental sustainability, and the sourcing of local materials and labor; to integrate innovative construction technology that meets building codes and bylaws; and make all design considerations for low-income households." (ISET 2013). The design competition was successful and one design by Team TT-Arch was selected as the first prize winner. Figure 2 below shows ISET's winning design. Innovative features of this design include the changes made to the roof design and the inclusion of a solid "safe room" in the house for sheltering in an event of a typhoon.

Figure 2: ISET's Winning Design Poster

This study will utilize this design to construct a model in a structural analysis program (SAP2000) in order to analyze the behaviors of this model when subjected to a Type 13 typhoon.

Overview of the Literature

There are many approaches in dealing with these extreme phenomena. These could be long term planning and preparation such as systematic urban planning concerning disaster preparedness and better warning system (in some cases). Post-event relief and recovery efforts are also crucial components in minimizing the effects of these extreme events. As outlined in the Introduction above, this study will target the short-term preparation task of bracing for houses once the typhoon warning has been generated.

In the earlier stage of this project, one of the goals was to develop a model for the most commonly found type of houses along the Central coast. In order to develop a model for this type of house, many documents have been consulted. The *Atlas Nhà Ở: Thực Tiễn Và Giải Pháp* (House Atlas: Reality and Solutions) put out by Quang Nam's Department of Construction serves as a great starting point. Quang Nam is one of the many cities along the Central coast that has encountered many typhoons and floods in the past. This publication provides ample evidence of the types of houses commonly seen in the flood-prone and typhoon-prone areas through a series of photographs of the houses and their existing conditions in these areas. The main load-carrying structural elements are shown clearly, including the footings, walls and roofs. These details will be useful in the analysis portion of this study. This publication also outlines the general approach in preparing for these extreme events that the city of Quang Nam has taken in the past. The last chapter of this publication proposes models and CAD drawings of new houses that meet the building code requirements for buildings in typhoon-prone and flood-prone areas, as well as detail drawings of the crucial structural elements of the bracing systems (Bùi 2013).

In the search for more technical information on the topic, one piece of literature stands out using a more qualitative approach. A case study done by Michael DiGregorio and Cao Van Huynh titled "Living with Floods: A Grassroots Analysis of the Causes and Impacts of Typhoon Miranae" provides dialogues between the local residents who were affected by a recent flood in the city of Quy Nhon and local

governments on the existing problems on urban and sub-urban planning concerning climate change effects in a coastal city. Even though this book focuses on sub-urban planning and its clash with climate change adaptation, it is an informing case study and gives a different insight and contextual background to the issue of typhoon resilience. Since disaster preparedness itself in general is an encompassing task, it is often the concerns and responsibilities of the national, local governments, the private sectors and many non-government organizations (NGOs) to try to minimize the effects of these natural disasters. In this case study, Quy Nhon is a city that is putting forward a proposal to be classified as a centrally-managed city (which essentially means more funding for the infrastructures and benefits for the local government). In order for the city to do this, one of the first criteria is that it has to meet the criteria for population and total area set forth by the national government. To do this, Quy Nhon would have to be merged with other neighboring cities. Development plans for many parts of the city would also need to be adopted quickly. Thi Nai Lagoon is a critical component in the flood management system in the region. If construction gets started in Thi Nai Lagoon, this will cause negative effects in terms of climate change adaptation and flooding in the region. Quy Nhon has suffered two recent severe flooding events in 2 years apart, and the local residents are getting more concerned about future extreme events similar to these events. There are many stakeholders in the problem of flooding and urban planning, and this case study illustrates one example of how urban planning can clash with climate change adaptation and flood management activities. As a side note, the idea of switching the focus of my research from tsunamis to typhoons and floods also originated from a talk by Dr. DiGregorio that I attended.

ISET has been the publishing organization for many of the works that I have examined concerning the topic of my research. One case study stood out for me as a great introduction and transition into the topic of typhoon resilience- the focus of my study right now. Titled "Sheltering from a Gathering Storm: Typhoon resilience in Vietnam", the document studies typhoon resilience in the Central coast of Vietnam, even though it is written to incorporate studies on the economic aspects in typhoon resilience study as well. The paper is written by three authors, one of which is the direct contact person from ISET at Vietnam. ISET is also the main organizer of the Resilient Housing Design Competition. The design of the first winner is the design that my project will utilize in constructing the design in structural analysis software (SAP2000) to analyze.

Methodology

As the focus of this initial study is to create a model in the structural analysis software SAP2000 to analyze the behavior of this house when subjected to Type 13 typhoon loadings, it is necessary to explain and summarize the assumptions and constraints in modeling this design.

Modeling the House

Constraints and Assumptions

DIMENSIONS

From the poster of the winning design (Figure 2), it was possible to obtain some basic dimensions of the model. Figure 3 shows one of the figures obtained from the poster. This figure shows the longitudinal cross section along the length of the house along with some basic dimensions of the house. Since the original design utilized the Metric unit system, the model was also created in SAP2000 using Metric units to stay as close to the original dimensions as possible.

Figure 3: Dimensions obtained from the poster

Figure 4 shows the 3D model of the house obtained from the ISET poster with the dimensions labeled.

Table 2 shows some of the fundamental dimensions of the model. The house in the original design is 12.5m long, about 4.9m wide and 7.8m high, measured from the ground level. The footings were estimated to be 1.4m high. The column spacings are about 3m in average. The ground floor is 3.3m high and the second floor is 4.5m high. It is noted here that the dimensions marked with asterisks in Table 2 were assumed values (obtained by scaling the drawing based on the dimensions provided).

Figure 4: 3D design obtained from the ISET poster with dimensions labeled

Table 2: List of dimensions used in SAP2000

Components	Dimensions (m)
a	3.6
b	3.3
c	2
d	3.6
e	4.9*
f	3.3
g	4.5
h	1.4*
i	0.06*
j	0.2*
k	0.4*

As mentioned in the Introduction, one concern and a weakness for most of the houses in this area is the roof system. Most of the households still have roofs that are not securely or properly anchored to the house as a whole. The roofs are typically corrugated metal sheets or fibro sheets that are both brittle and hazardous to the health of the occupants. In the event of a typhoon, these metal or fibro roof sheets have detached from some houses and caused serious hazards. Therefore, the author of this design has incorporated an overhang gutter (which can be covered to avoid added loads to the structure as a whole) that acts as a shield to the roof and decreases the uplift effect of the wind generated from the typhoon that gets applied to the roof. This innovative feature is shown in Figure 5 with the labels. The roof was designed to have a slope of about 41°.

Figure 5: Overhang gutter to shield the roof and decrease the uplift effect of the wind that gets applied to the roof

Other innovative features in this design include

- Living room and bathroom are designed with reinforced concrete frame and slabs, “forming a safe box for occupants to shelter in case of a severe typhoon” (ISET 2013)
- Bedrooms are located on the second floor and serve as shelters for occupants if the first floor is flooded
- Escape area on the 2nd floor to access emergency rescuers in case flood water rises to the second floor

MATERIALS SELECTION

Based on reference materials found on construction materials in Vietnam, the columns in SAP were set to be 8’’x 8’’ reinforced concrete (R/C) columns with steel reinforcement. Four #4 rebars were placed at four corners of the column. Figure 6 shows the cross section of the columns (not to scale).

Figure 6: Cross Section of the Columns Showing Reinforcement

The roofs on the second floor were modeled to be supported by R/C girders. It is worth noting that this selection might not be realistic for typical house construction in Vietnam. Timber girders would be a better selection. However, for the simplicity of this initial model, the girders were kept as reinforced concrete.

The roofs were modeled in SAP as an aluminum shell (thin plate) with a thickness of 1.5mm. Also, according to previous research, the floor material for the second floor was assumed to be either R/C slabs or thick plywood (about 3cm thick). For simplicity, both the second floor and the ground floor were modeled as reinforced concrete slabs using shells in SAP (thick plate) with a slab thickness of 4cm thick.

Below are some technical information regarding the materials selected for the structural elements in the model:

❖ R/C columns and beams

- Normal weight concrete; unit weight=150 lb/ft³ (pcf)
- $f'_c=2500 \text{ lb/in}^2$ (psi)

- 8'' x 8'' cross section
- 4 #4 rebars at corners
- ❖ **Concrete masonry walls**
  - Modeled as a shell (thick plate) 10.5cm thick (width of a typical Concrete masonry unit)
  - Unit weight=125pcf for normal weight units
  - E=2000MPa (290ksi)
- ❖ **Metal sheet roofs**
  - Model as an aluminum shell (thin plate) with a thickness of 1.5mm
  - Unit weight=175pcf
- ❖ **Concrete slabs**
  - Modeled as a shell (thick plate) 4cm thick
  - Unit weight=150pcf
  - $f'_c=2500\text{psi}$
  - E=3000ksi

Omissions

There are several details included in the ISET poster that were not included in the SAP2000 model. These include the steel connection close to the innovative overhang gutter that anchors the roof into the timber girder. Underneath the roof close to the gutter, steel hollow structural sections connecting to the R/C anchor and attached to the timber girders by ties were omitted in the model. These omissions were made to simplify the model and make the construction of the model in SAP seamless.

Modeling the Load Effects

Dead Loads

The dead loads applied on the model include the dead weights of all the elements in the model and the gutter loads which were applied along the length of the two exterior girders to mimic the overhang gutters from the original design. Locations of the gutter loads are shown in Figure 6 below.

Figure 7: Locations of Gutter Loads in the Model

Wind Loads

The typhoon will be modeled based solely on the wind effect that gets applied to the faces of the house. The wind loads will be applied to four faces of the house and to the house's roof. The wind loads are applied orthogonally onto the concrete masonry walls. They are applied on the roof in the upward direction to mimic the uplift effect of the wind.

ASCE 7-05: Minimum Design Loads for Buildings and Other Structures was consulted in determining the wind pressure distribution for the model. Chapter 6: Wind Loads was the primary focus. Using Method 1-Simplified Procedure and assuming the model is a "Building, or Other Structure, with Regular Shape", based on Figure 6-2 in the manual (page 37), for a wind speed of 85mph (equivalent to 137 km/hr) and a roof angle of 30° to 45° (the original design's roof angle is approximately 40°), the horizontal and vertical wind loads are shown in Figure 6 (marked in yellow). Figure 7 shows the locations where the wind loads are typically applied according to the manual.

Main Wind Force Resisting System – Method 1								h ≤ 60 ft.				
Figure 6-2 (cont'd)		Design Wind Pressures						Walls & Roofs				
Enclosed Buildings												
Simplified Design Wind Pressure, p _{s30} (psf) (Exposure B at h = 30 ft., K _{zt} = 1.0, with I = 1.0)												
Basic Wind Speed (mph)	Roof Angle (degrees)	Load Case	Zones									
			Horizontal Pressures				Vertical Pressures				Overhangs	
			A	B	C	D	E	F	G	H	EoH	GcH
85	0 to 5°	1	11.5	-5.9	7.6	-3.5	-13.8	-7.8	-9.6	-6.1	-19.3	-15.1
	10°	1	12.9	-5.4	8.6	-3.1	-13.8	-8.4	-9.6	-6.5	-19.3	-15.1
	15°	1	14.4	-4.8	9.6	-2.7	-13.8	-9.0	-9.6	-6.9	-19.3	-15.1
	20°	1	15.9	-4.2	10.6	-2.3	-13.8	-9.6	-9.6	-7.3	-19.3	-15.1
	25°	1	14.4	2.3	10.4	2.4	-6.4	-8.7	-4.6	-7.0	-11.9	-10.1
		2	-----	-----	-----	-----	-2.4	-4.7	-0.7	-3.0	-----	-----
	30 to 45	1	12.9	8.8	10.2	7.0	1.0	-7.8	0.3	-6.7	-4.5	-5.2
		2	12.9	8.8	10.2	7.0	5.0	-3.9	4.3	-2.8	-4.5	-5.2

Figure 8: Figure 6-2 in Chapter 6- Wind Loads for the Applicable Wind Speed and Roof Angle.

Source: ASCE 7-05 Design Manual

Figure 9: Locations Where the Wind Loads are Applied. Source: ASCE 7-05 Design Manual

Table 3 summarizes magnitudes and directions of the wind loads that were applied to the model.

Wind Load Case	Magnitude (psf)	Direction
Front	12.9	Positive Global Y
Back	12.9	Negative Global Y
Left	12.9	Positive Global X
Right	12.9	Negative Global X
Roof (both roofs)	7.8	Positive Global Z (uplift)

Load Combinations

In order to better model the load effects on the model, especially the wind loadings, load combinations were created to combine the different load cases. A total of nine load combinations were created with the different wind load cases combined. The dead load (dead weights and gutter load) was part of all of the load combinations. The ninth load combination was an envelope of all the eight cases to determine the governing load combination that produces the maximum effects on the model.

Results

The model was created in SAP2000. Figure 8 shows the 3D model of the house in SAP2000.

Figure 10: 3D Model of the House in SAP2000 (Extrude View)

Figure 11: Deformed Shape of the Model after Applying the Loads (Envelope Load Combo)

The wind loads were applied to the model using the maximum values obtained from the Manual for conservativeness. Figure 10 shows the deformed shaped of the house after the loads were applied.

Hand Calculations

Hand calculations were performed as a check to determine if the values obtained from SAP2000 were reasonably accurate. Vertical load (gravity) was calculated by summing the dead weights of all members in the model. It was then compared to the sum of vertical support reactions in SAP. The horizontal load (wind) was calculated multiplying the areas being loaded by the corresponding applied wind loads and summing them. It was then compared to the sum of horizontal support reactions from SAP. Table 5 shows the comparison between the hand calculated values and the values obtained from SAP.

Loads	Hand Calculations (kips)	SAP Values (kips)
Horizontal loads	135.68	273.14
Vertical Loads	0	0

Hand calculated value for vertical loads (gravity) was smaller than SAP value.

Based on initial checks of the deformed model, no significant deformation was found. The dead load was found to be the dominating load over the wind loads. The maximum deflection occurred at the connection between the top of the lower roof and the bottom of the emergency access window (shown in Figure 11 below).

Figure 12: Location of Maximum Deflection

The maximum stress concentration occurred at the exterior horizontal girder at the back of the house (where the upper roof tips down). The stress diagram of all the elements and the table with values of stresses of the most stressed element are shown in Figure 12.

Figure 13: Location of Maximum Stress Concentration

Discussions

As mentioned above, the dead loads dominated over the wind load. This was not the expected results. The hand calculated value for the gravity loads was also smaller than the value obtained from SAP. A thorough check is therefore needed to ensure that all values were entered in SAP correctly as intended.

Material selection is important in modeling these types of constructions. Due to the lack of data and detailed drawings of the original design, many assumptions had to be made. More data need to be collected to reflect a more realistic set of materials for the model.

Capacity checks for each element should be carried out by comparing the capacity of each element to the total loads applied on each element. These checks are necessary to better quantify the degree of resilience of the model and to determine if the model is capable of producing resilient responses when subjected to a Type 13 typhoon.

The addition of the overhang gutter, even though helped with the uplift effect from the wind, might prove redundant and could even cause adverse effects on the structure as a whole since it added dead weight to the building.

The model was created in SAP2000 that bear a lot of simplifications and might not have accurately constructed the house as intended. For future iteration of this model, the connections between the brick walls and the columns would need to be analyzed more rigorously. The shell elements used in modeling the walls and the roofs in this model need to be studied more thoroughly and selected appropriately.

Other loads on the model, including dead loads, live loads (potential flood loadings) should be incorporated into the model for a more complete analysis of the structure. Also, the wind loads on the model should be distributed varyingly and also at oblique angles instead of uniformly as done here to represent more realistic cases.

All the components under the “Omission” section should be incorporated wherever applicable to the model. Structural details that were specified from the design such as the steel connection anchor and the R/C anchor should be included in later iterations of this model.

Conclusions and Recommendations

The Central Coast of Vietnam has had a long history of severe typhoons and flooding. Efforts have been made to minimize the effects of these natural disasters on both people and properties. This project focuses on strengthening the houses along the Central Coast by initially analyzing the effects of a Type 13 typhoon on a single-family house commonly found along the Central Coast.

The design of the winner of ISET’s Resilient Housing Design Competition was selected to be constructed and analyzed in SAP2000, a structural analysis software.

The ASCE 7-05 and particularly Chapter 6-Wind Loads were consulted in determining the wind load effects from wind with a wind speed of 85mph on the house.

A more refined approach should be used in determining the wind loads on the house. Also, the structural components that were omitted from the SAP model should be incorporated in the later iterations of this model.

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