Assessment of out-of-plane failure of non-engineered masonry walls due to Typhoon Haiyan-induced storm surge

Master of Science in Civil Engineering
Gokongwei College of Engineering
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ASSESSMENT OF OUT-OF-PLANE FAILURE OF NON-ENGINEERED MASONRY WALL DUE TO TYPHOON HAIYAN-INDUCED STORM SURGES

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prepared and submitted by Jenes P. Borais in partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering been examined and is recommended for acceptance and approval for **ORAL EXAMINATION**.

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ABSTRACT

Typhoon Haiyan, in 2013, caused massive destruction in eastern Luzon and central Visayan region in the Philippines. Failure (collapsed) of non-engineered masonry walls were the most common failure experienced by residential structures in the area. Local government declared No Build Zone policy along coastal barangays, however this policy was not successfully implemented due to economic and social considerations.This exposed the high vulnerability of non-engineered masonry walls, as employed in residential structures in rural areas, against extreme events. Existing building codes for large reinforced concrete (RC) frame structures had performed well during Typhoon Haiyan, however, the current construction method for masonry walls for coastal structures has high vulnerability to out-of-plane (OOP) failures due to poor construction methodology and insufficient design considerations. On-site survey along the coastal barangays of Tacloban City was conducted mainly to investigate the construction and design process for masonry walls of the low-rise residential structures. Based on this survey, a common non-engineered design was established. Adequacy of the minimum design requirement for masonry walls based on NSCP 2015/ACI 530-02 was also verified. The estimated maximum pressure capacity using yield line method for the non-engineered masonry walls and NSCP 2015/ACI 530-02 compliant design was found to be below the possible lateral pressure due to storm surges. Thus, improved construction design was proposed and assessed against similar loads with consideration about the cost and suitability for the local worker’s skills and techniques. Improvements in design includes reducing spacing and increasing the size of steel reinforcements, increasing CHB thickness, and regulating masonry wall dimensions. Comparison in lateral pressure capacity per design consideration of masonry walls were established by finite element analysis using Staad Pro V8. Based on the comparison of the analytical results, it is concluded that the maximum pressure capacity of the improved masonry design increased significantly compared to the current non-engineered masonry design.

Keywords: Storm surge, typhoon Haiyan, out-of-plane failure, masonry walls

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Typhoon Haiyan (local code name Typhoon Yolanda) crossed the Philippines Area of Responsibility (PAR) on the 7th and 8th day of November, year 2013 (National Disaster Risk Reduction and Management Council, 2013). The aftermath of the typhoon has recorded more than 6,200 deaths, 28,000 injured and 4 million displaced (UK Aid, 2013). From 1970-2013, a total of 720 tropical cyclones entered the Philippine area of responsibility (PAR). Based on NDRRMC records, Typhoon Haiyan is the worst typhoon ever hit the Philippines to date. It is ranked No.1 among the top 10 worst typhoons in terms of damage to properties amounting to Php 93B (infrastructure, production, social and cross-sectoral). The estimated wind speeds is up to 314km/hr with an estimated forward speed of 41km/hr. Figure 1 shows the affected population in the path of Typhoon Haiyan. The typhoon caused excessive rainfall, landslides and flash floods throughout the region; however, the main cause of death is due to extreme storm surge. Storm surge is caused by irregular rise of ocean water caused by tropical cyclones. (National Geographic, 2017)

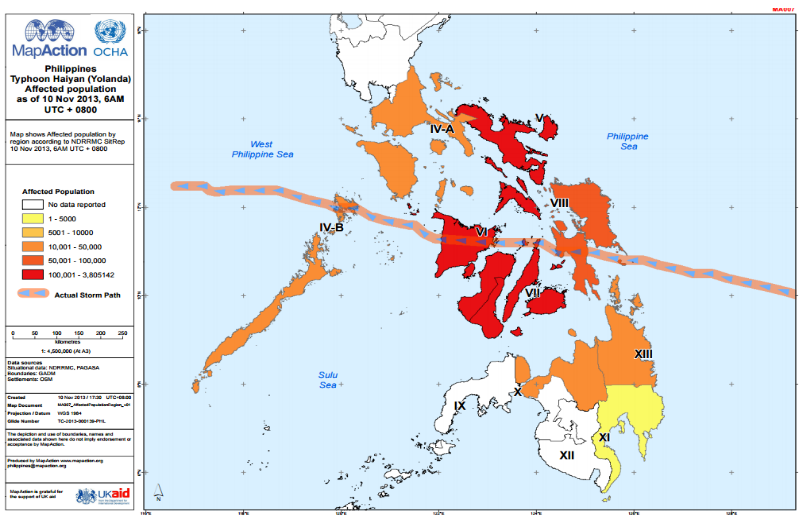


Figure 1: The affected population in the Philippines by affected by the Typhoon Haiyan and its actual storm path (UK Aid, 2013)

Confined masonry walls of several large RC frame residential and commercial structures have shown sufficiency to resist the lateral pressure of storm surge and extreme wind pressure. However, several low-rise structures have experienced significant damage to the masonry walls where only the RC frame remained intact as shown in the Fig. 2.

Figure 2: The aftermath of Typhoon Haiyan in the coastal areas of Tacloban City, Leyte: (a) Two-storey residential building with collapse masonry wall at the groundfloor, (Pedrasa, 2013) (b) A bungalow house with collapse exterior wall and damaged roof but RC frame is intact. (Edds, 2014)

This catastrophic phenomenon revealed the insufficiency of the structural design in the country's structure against extreme weather conditions like storm surge on the scale of Typhoon Haiyan. Structural codes and standards might be enough for larger RC frame structures since there is a significant number of structures that remained intact after the Typhoon. However, majority of the low-rise structures suffered from total damaged.

In this study, the researcher aims to mitigate the structural failure of non-engineered CHB masonry walls. It aims to lessen the failure of this non-structural member that may lead to damage to properties, injures occupants and even death. This research will complement the existing hazard maps in providing public safety.

Masonry is a general term that applies to construction using hand-placed units of clay, concrete, structural clay tile, glass block, natural stones and the like. One or more types of masonry units are bonded together with mortar, metal ties, reinforcement and accessories to form walls and other structural elements. The concrete hollow blocks(CHB) was the most common type of masonry used low-rise structures in the Philippines. Concrete hollow blocks(CHB) are standard size rectangular block made from cast concrete with hollow centers or cores to reduce weight. The CHB block may be produced in many sizes, the most common are 40cm long, 20cm tall and thickness varies from 10cm, 15cm and 20cm. A core also allows for the insertion of steel reinforcement, tying individual blocks together in the assembly. To hold the reinforcement in proper position and to bond the block to the reinforcement, the cores must be filled with grout or concrete. Steel reinforcement are inserted in cores vertically in a certain on-center distance and laid horizontally in between CHB layer. The intersection of the horizontal and vertical reinforcement was secured using galvanized iron (GI) wires.

Non-engineered structures in general are structures that are constructed without the proper supervision of a licensed engineers, architects, or other professional that has the technical knowledge and experience in designing and constructing such structures. By definition, non-engineered structures are those built without engineering input (Macabuag, Guraain, & Bhattacharya, 2010). Also, non-engineered structures are constructed spontaneously and informally constructed in the traditional manner without the intervention by qualified architects and engineers in their design (UNESCO, 2016). Masonry walls are also part of the structure that is constructed without the supervision of licensed engineer. Since the method for the standardized structural design has not been established yet for this structure, the quality of construction varies from one construction worker to other (Tanaka, et al., 2004). Generally non-engineered buildings in the Central Visayas, particularly in Tacloban City can be divided in two main categories: (1) Timber Houses constructed using wood and bamboo, (2) Concrete Houses with minimal reinforcement.

1.2 Problem Statement

Several structures had been severely damaged in the path of Typhoon Haiyan more particularly to the non-engineered structures in coastal areas in Tacloban City, Leyte. Structures had collapsed due to strong winds, and extreme storm surge resulting to injuries and casualties. Most of these structures are not designed to resist lateral forces caused by storm surge, thus, structural engineers must modify and enhance these structures capability to resist external forces due to different environmental occurrence such as storm surge. Non-engineered masonry walls are vulnerable to out-of-plane failure since they are not designed to carry lateral pressure. This type of structural failure can lead to major injuries and even death to the occupants.

Government agencies had provided hazard maps and determined "No Build Zone" Policy for areas with high risk based on storm surge height of 1.5 meters and above. However, the building and zoning laws state that the maximum "No Build Zone" is at most 40m from the shoreline. Surveys and studies show that several areas experienced storm surge heights of greater than 1.5 meters even if they are 40m away from shoreline. With this, structures along the coastline must be constructed with some consideration that the area would suffer from extreme storm surge like Typhoon Haiyan.

To achieve a much lower fatality and property damage, we must consider two points: (1) Warning and (2) Action/Response. Hazard maps and weather forecast greatly help in ensuring public safety by providing calamity advisory. As engineers, it is our mandate to provide structural safety. In this study, design and construction process of non-engineered masonry walls will be investigated to mitigate its catastrophic out-of-plane failure under lateral pressure due to storm surge.

1.3 Objectives

1.3.1 General Objectives

This study aims to find out the structural behavior in terms of bending of masonry wall of non-engineered structures when it is subjected to storm surge on a scale of Typhoon Haiyan with respect to its out-of-plane failure. The researcher conducted an interview survey in Tacloban City to determine the necessary information in the construction of the non-engineered masonry walls. With this, the researcher used this information to model, analyze and improve these structural systems. This study mainly aims to provide design recommendation and ideal construction design for non-engineered masonry wall that is more secure and sound.

1.3.2 Specific Objectives

Specifically, the researcher aim to:

a. Identify the current construction process, building design consideration, and materials used by interviewing the local construction workers, design and site engineers and residents of Tacloban City specifically in the coastal areas and gather maps/building plans of the low-rise structures from the local government unit.
b. Investigate the current construction method and current design provisions of NSCP by yield line method in masonry wall with varying parameters such as steel reinforcements, CHB thickness and wall dimensions.
c. Establish the present performance of the non-engineered masonry walls and determine its deficiencies in terms of material quality used, method of design and construction.
d. Improve the present design in order to increase its capacity and minimize its vulnerability due to bending by improving the following: (1) Size and spacing of steel reinforcements, (2) Thickness of CHB, (3) Regulating the wall dimension.
e. Develop and assess a better construction design of non-engineered masonry wall, to improve the storm surge capacity with minimal cost increase and at the same time, provide a generalized design applicable to the local worker's skills and techniques.

1.4 Significance of the Study

The findings of this study will redound to the benefit of the society considering that disaster risk mitigation is one of the priority of the Philippine government. One of the outputs of this study is the improvements in designing and constructing of non-engineered masonry walls. This can help in mitigating the disastrous effect of collapsed masonry walls that may lead to injury, damage to property and even casualties. Redesigning the structures itself is a must to cover the inaccuracy of hazard zoning. This study will also help the building officials to evaluate structures that are vulnerable when flooding/storm surge occurs. For the researcher, the study will be useful for his/her future study on improving the structural integrity of structures in the Philippines.

1.5 Scope and Limitations

This study is limited only the following scope and limitations.

- The study focused on Tacloban City, Leyte as the site of study since it was the most severely damaged municipality in Central Visayas. Residents/local workers of the coastal area of Tacloban City will be the correspondents to the interview and surveys conducted. Local builders and contractors were interviewed to determine the overall design and construction method for the masonry walls.
- The masonry wall was modelled based on the properties of locally available materials. In case of limited information, the minimum design requirements of the building code was used as a valid reference for material properties
- The study was limited only to the masonry walls. Concrete frames such as beam, columns and wall footing will be considered rigid. All masonry wall damage was assumed to be caused by extreme flooding or surge.
- Cracking pressure was estimated using Staad Pro V8 computer program. On the other hand, maximum pressure was estimated using yield line method for masonry walls. Different failure patterns were considered based on the damage assessments.
- Masonry wall was considered failed/insufficient when the maximum pressure capacity is less than the pressure load due to the storm surge in the scale of Typhoon

Haiyan. Pressure load calculation was based on the provision of FEMA Coastal Construction Manual and ASCE 7-10.

- Calculation of storm surge loads primarily requires information on the storm surge height. In this study, the storm surge heights used in the calculation of storm surge loads was based on the data from JSCE-PICE Typhoon Haiyan Joint Survey and Project Noah. The maximum storm surge height to be considered is 2.5-3m meters depending on the maximum height of the masonry wall of a low-rise structure.
- Sufficiency of anchorage was not considered in this study. It was assumed that the out-of-plane failure of the non-engineered masonry wall is mainly due to excessive bending and lateral deflection due to insufficient reinforcements and concrete flexural and bond strength.
- Out-of-plane failure on unreinforced masonry walls was not considered in this study. Although, survey results indicated that some houses have masonry walls without steel reinforcement.
- In this study, non-engineered masonry wall refers to the masonry wall of low-rise structures that were constructed without the supervision of a licensed engineer. Masonry wall is limited to concrete hollow blocks (CHB) that has a typical dimensions of 40cm long, 20cm tall and thickness varies from 10cm, 15cm and 20cm.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.0 Introduction

This chapter contains the discussion of important subjects, related research and experiments conducted that helped in the execution of this study. This includes researches in different subjects such as analysis of Typhoon Haiyan, the damaged structures, the existing design parameters and construction procedure for CHB masonry wall of non-engineered structures, out-of-plane (OOP) plane failure of masonry walls, yield line method, and FEM analysis.

2.1 Typhoon Haiyan and its aftermath

Typhoon Haiyan made landfall on the 7th day of November with estimated wind speeds up to 314km/hr. in the Philippines and then five other areas, including southern China and Vietnam. However, the Philippines was one of the worst affected. From 1970-2013, a total of 720 tropical cyclones entered the Philippine area of responsibility (PAR). Based on NDRRMC records, Typhoon Haiyan is the worst typhoon ever hit the Philippines to date. It is ranked No.1 among the top 10 worst typhoons in terms of damage to properties amounting to Php 93B (infrastructure, production, social and cross-sectoral). The historical distribution of maximum wind speeds in the Western North Pacific between 1951 to 2012 is shown in Fig. 3. It is evident that Typhoon Haiyan was one of the most powerful ever recorded. (Takagi, et al., 2015)

In terms of number of deaths, Typhoon Haiyan already outranked Typhoon Uring in 1993 with 6300. Typhoon Uring in 1993 which caused the Ormoc City tragedy killed 5,101 persons, followed by Typhoon Sendong in 2011 with 1,286, Typhoon Pablo in 2012 with 1,248, and Typhoon Nitang in 1984 with 1,029 (NDRRMC, 2013). Around 90% of all buildings were destroyed, trees were uprooted or flattened, debris covered the land, electricity supplies were cut and infrastructure and communications destroyed. Some 5 million people saw their homes destroyed or become uninhabitable, and the airport was unusable. Of the total 6340 fatalities (estimated), almost all were in Tacloban.

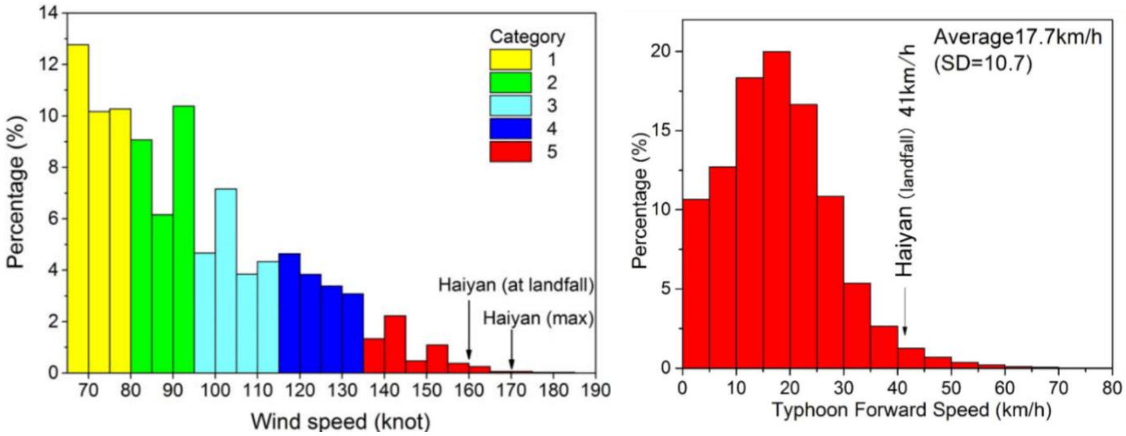


Figure 3: Historical distribution of maximum (a) wind speed and (b) forward speed in the Western North Pacific between 1951 and 2012, showing that Typhoon Haiyan was one of the most powerful ever recorded. The figure was obtained by reanalyzing the Joint Typhoon Warning Center (JTWC) best track data. (Takagi, et al., 2015)

The typhoon caused excessive rainfall, landslides and flash floods throughout the region; however, the main cause of death is due to extreme storm surge. Storm surge is caused by irregular rise of ocean water caused by tropical cyclones (National Geographic, 2017). Rise in sea water level is caused by high winds that push on the ocean's surface and the low pressure at the center of a storm system. High gusty winds ravaged the vegetation in the islands affected, leaving behind bare mountains and flattened fields. Adding to the wind damage, a large storm surge inundated most of the coastline of Leyte gulf, causing particularly large damage to the sea front of Tacloban City. Many papers assessing storm surge risks had been published in other countries that are typically affected by these events, such as United States and Japan. However, in recent memory, no large storm surge had affected the Philippines, and thus, there have been comparatively little research carried out along the coastline of the Philippines. Based on historical records, around 14-30 typhoons crossed in the October-November period, and thus Typhoon Haiyan was not unusual in terms of the season in which it took place. Number of research claimed that there is an increase in the intensity of tropical cyclones based on a 30-year analysis of satellite records. Such increases could have important consequence for coastal areas in the Philippines (Takagi, et al., 2015).

Several numerical simulations were carried out to demonstrate the distribution of storm surge in the Philippines, showing that the maximum storm surges occurred in Leyte Island, followed by Panay Island, Negros Island, and Cebu Island (see Figure 5). Based on storm surge simulations, the maximum storm surge was found to be 3-4 meters high in Tacloban City. Storm surge height based on the simulations (blue) was verified by on-site measurements (black) as shown in Fig. 4.

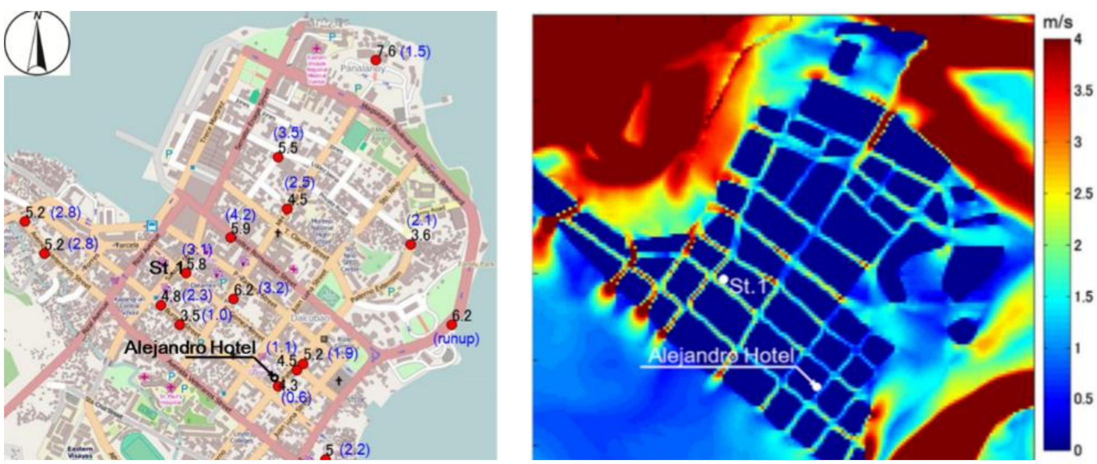
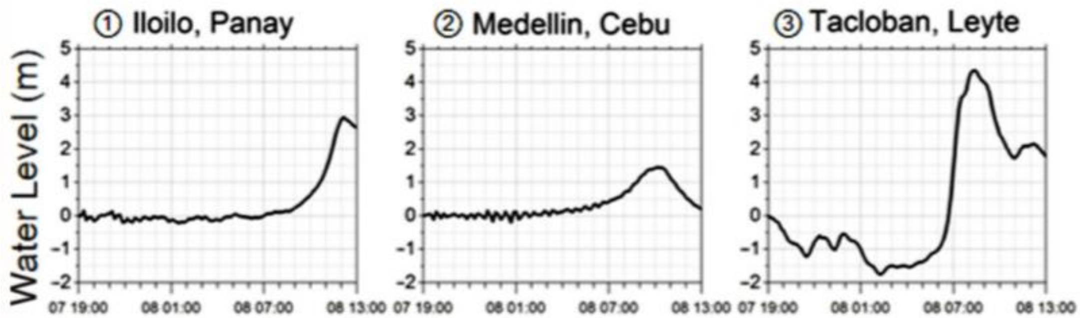


Figure 4: (a) Storm surge heights (black) adjusted to the tidal level at the time of passage of the typhoon, and inundation depths above ground level (blue) measured around Tacloban area (unit meters) along the streets of Tacloban Downtown. (b) Maximum flow velocity simulated along the streets of Tacloban Downtown. (Takagi, et al., 2015)



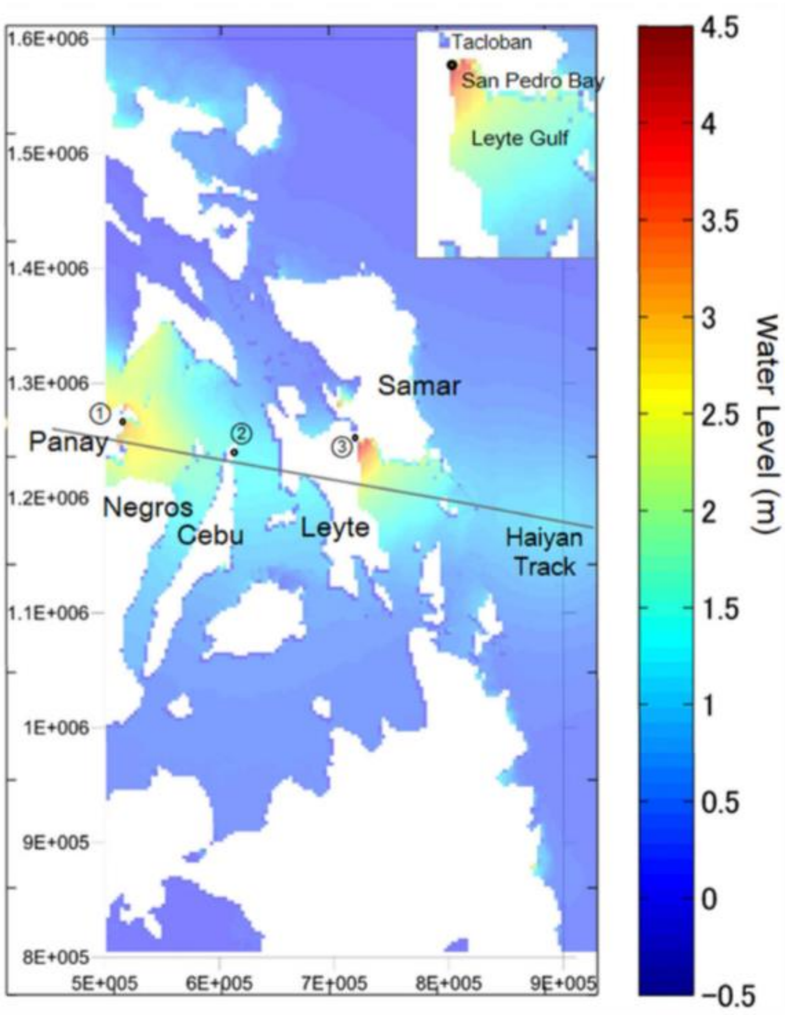


Figure 5: Maximum storm surge levels of the passage of Typhoon Haiyan through the Philippines. The graphs show the time history of the storm surge at its passage through (1) Tacloban City (Leyte Island), (2)Medellin (Cebu Island) and (3)Iloilo (Panay Isalnd). (Takagi, et al., 2015)

2.2 Building Damage Assessment

Damage patterns due to storm surge strongly correlated with inundation depth. The greatest damage was observed around Tacloban City where inundation levels were consistently beyond +5m, and in other places as high as +7m. Not only wooden houses were affected, but also more solid concrete constructions, ships, and oil tanks suffered heavy damage (see Fig. 6). The large wind speeds also contributed to the further devastation of the area. Throughout the entire region, roof of even the sturdiest houses and building were blown off, with everything else knocked down or reduced to rubble, including most of the vegetation. Failure modes for extreme wind and flood events are different than for seismic events. Out-of-plane failure becomes more significant because wind and floodwater push directly on the weak axis of the structures. Majority of timber houses are destroyed entirely. While houses, both one and two-storey, relying on a reinforced concrete (RC) frame system with infill walls performed poorly where only frames are left. This RC houses were unusable and often leaning hazardously. It is worth-mentioning that many larger RC frame structures, such as commercial and public structures, performed well in the Typhoon, indicating that the building permit and code enforcement process in the Philippines can work quite well, but is not sufficiently applied to housing. (Build Change, 2014). Based on NDRRMC (2013), the number of damaged houses (see Table 1) remained at 1,140,332 houses, where 550, 928 houses were totally damaged, and 589, 404 houses were partially damaged with a total damage cost of Php 95B (see Table 2). Figure 7 shows the damged map of Tacloban.

Table 1: Number of totally and partially damaged houses by region in the Philippines after Typhoon Haiyan (NDRRMC, 2013).

Region	Totally	Partially	Total
IV-A	34	806	840
IV-B	11,611	22,202	33,813
V	2,088	10,324	12,412
VI	229,326	253,023	482,349
VII	62,840	48,479	111,319
VIII	244,550	248,306	492,856
X	2	18	20
XI	11	8	1
XIII	466	6,238	6,704
TOTAL	**550,928**	**589,404**	**1,140,332**

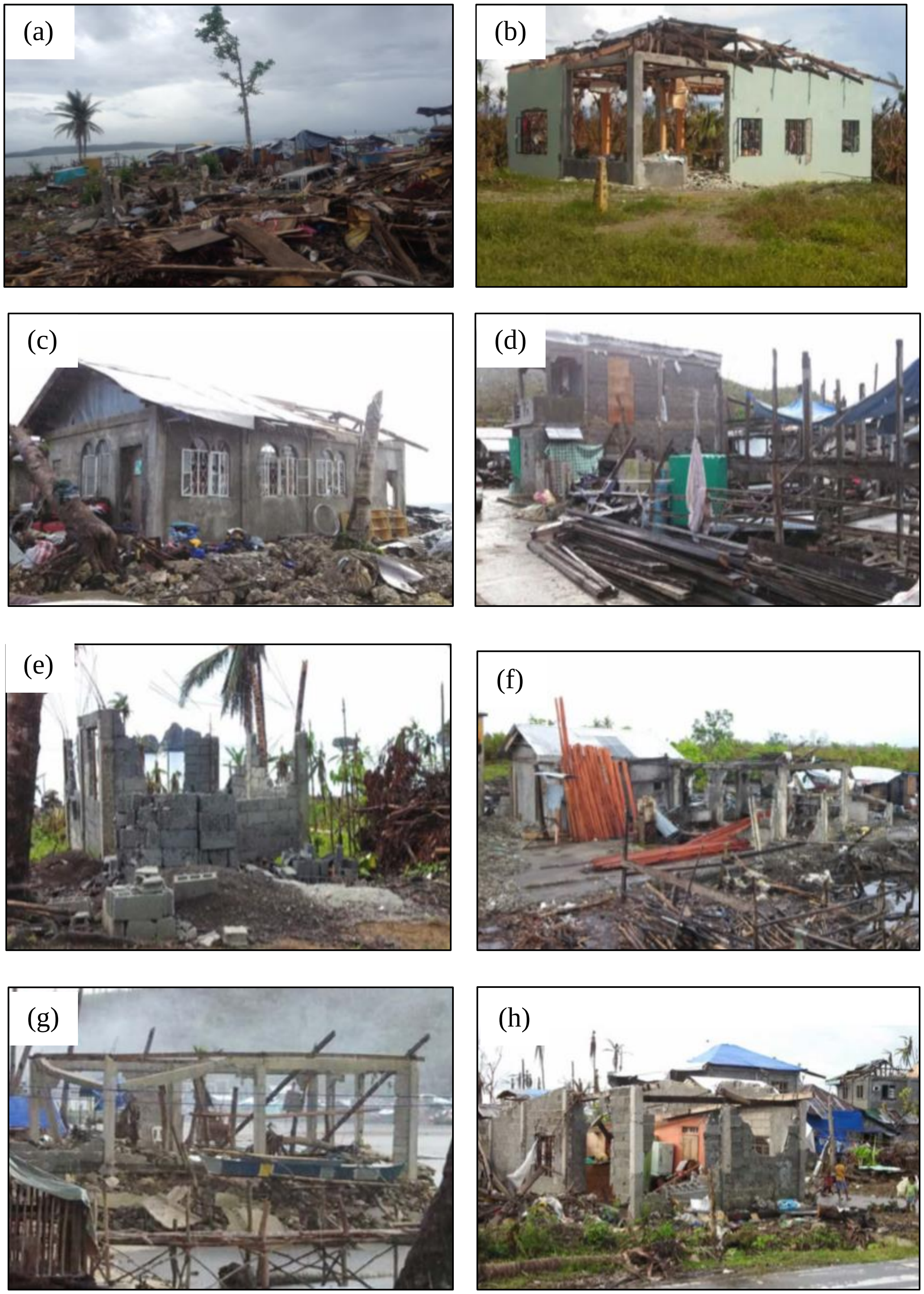


Figure 6: Examples of residential structures damaged by Typhoon Haiyan: (a) Timber houses near coasta areas, (b) RC House with damaged roofing system, (c) & (d) One-storey confined masonry house that survive the typhoon, (e) & (f) Destroyed masonry house, (f) & (g) Destroyed masonry house in intact RC frames (Build Change, 2014)

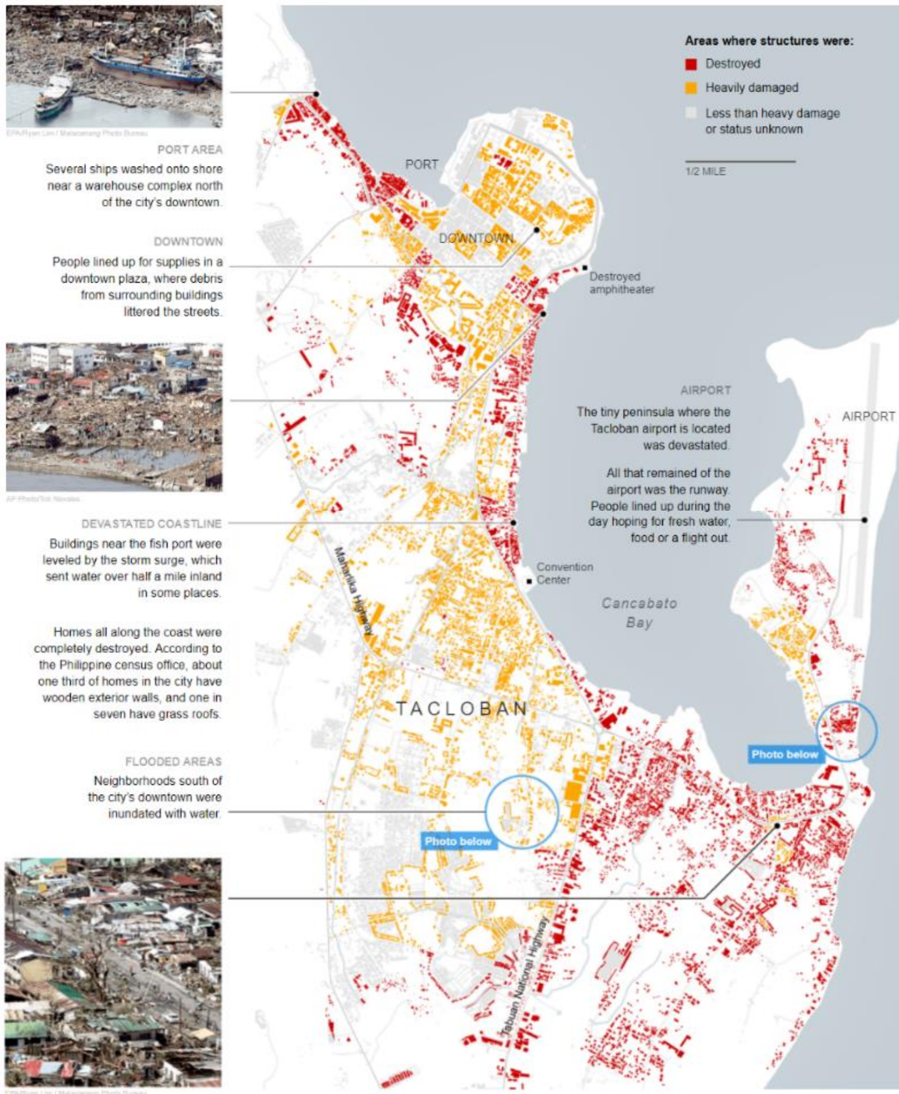


Figure 7: : Detailed map of areas with damaged structures inTacloban City after Typhoon Haiyan in 2013 (source: www.nytimes.com)

Table 2: Total cost of damaged structures in the by region in the Philippines after Typhoon Haiyan (NDRRMC, 2013).

Region	PDNA	NDRRMC Repport	Total
IV-A		65,235,774.00	65,235,774.00
IV-B	703,885,673.39	1,425,270,868.00	2,129,156,541.39
V		870,800,564.84	870,800,564.84
VI	14,618,785,150.19	3,204,295,195.45	17,823,080,345.64
VII	5,677,349,596.71	6,665,930.00	5,684,015,526.71
VIII	68,707,360,318.09		68,707,360,318.09
XIII		203,504.00	203,504.00
TOTAL	**₱89,707,380,738.38**	**₱5,572,471,836.29**	**₱95,279,852,574.67**

2.3 DRRM of Tacloban City

Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) continuously disseminates weather bulletins and advisories, and constantly monitors the situation. Department of Public Works and Highways (DPWH) conducted monitoring of critical infrastructures, major roads and bridges, and provide equipment assistance. Local Chief Executives of Department of Interior and Local Government (DILG) declared and announced the suspensions of classes in all school levels, public, and private in there area of responsibility on November 6, 2013 at 1:00 PM. Local Government Unit (LGU) warned residents living at coastal barangays to monitor situation. Department of Environment and Natural Resources (DENR) reiterated flood and landslide risk hazard maps to LGUs and issued advisories to local chief executives on possibility of landslides and flooding.

Under the Joint DENR-DILG-DND-DPWH-DOST Memorandum Circular No. 2014-01 entitled "Adoption of Hazard Zone Classification in Areas Affected by Typhoon Yolanda (Haiyan) and Providing Guidelines for Activities Therein" states that areas that are likely to experience storm surge flood heights greater than one and a half meters(1.5m) are considered as high storm surge susceptibility. Modern storm surge susceptibility areas are likely to experience storm surge flood heights of 0.5m to one and half meters (1.5m). On the other hand, low storm surge susceptibility are areas likely to experience storm surge with flood height of 0.5 meters or less (see Table 3). Under article 51 of a Marcos-era Presidential Decree No. 1067 signed into law in 1976, the Water Code of the Philippines, which reads:

> *Article 51. The banks of rivers and streams and the shores of the seas and lakes throughout their entire length and within a zone of three (3) meters in urban areas, twenty (20) meters in agricultural areas and forty (40) meters in forest areas, along their margins are subject to the easement of public use in the interest of recreation, navigation, floatage, fishing and salvage. No person shall be*

allowed to stay in this zone longer than what is necessary for recreation, navigation, floatage, fishing or salvage or to build structures of any kind.

Also, there are laws stating different parameters for no-build zone. Civil Code or RA 386 states that structures are not allowed within three (3) meters away from the banks of rivers and streams (Article 638). Under Forest Code or PD 705 states that structures are prohibited within twenty (20) meters away from rivers and streams with channels at least five (5) meters wide (Section 16).

Considering all existing provisions for no build zone (see Fig. 8) for hazardous areas, the maximum distance of no build zone is within 40m. Base on the conducted surveys and research, storm surge in Tacloban City reached 1.5 meters and above. The storm surge hazard map was updated based on the gathered data for Typhoon Haiyan-induced storm surges as shown in Fig. 9.

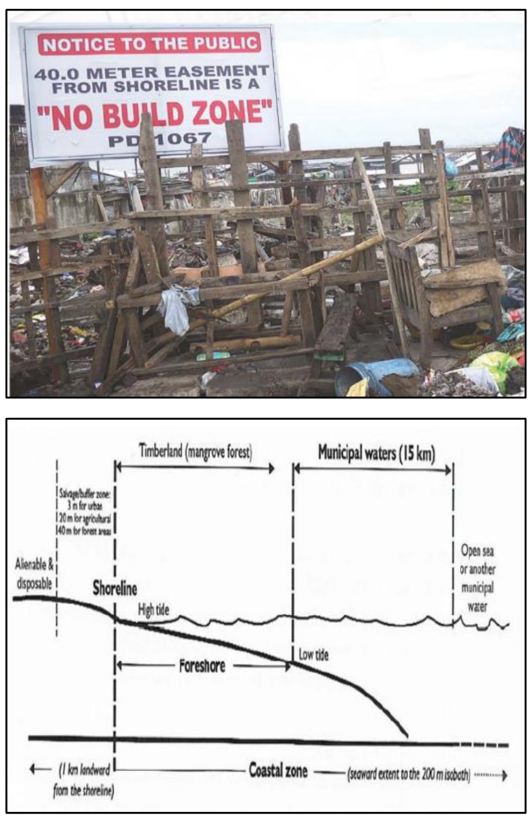


Figure 8: (a)Sign boards for 'No Build Zone" within 40.0 meter easement from the shoreline implemented after the Typhoon Haiyan. (Basilio, 2014), (b) Diagram for the reference of 40.0 meter "No Build Zone". (Basilio, 2014)

Table 3: Storm surge hazard zone classifications and recommended actions (Joint DENR-DILG-DND-DPWH-DOST Memorandum Circular No. 2014-01, 2014)

HAZARD	HAZARD ZONE		
	LOW	MODERATE	HIGH
STORM SURGE	Dwelling may be allowed and residents may stay in their homes during impending storm surge events provided that their houses have second floor and are structurally sound. Evacuation centers should not be established in this zone unless it has vertical evacuation capabilities.	Dwelling may be allowed but during impending storm surge events, all residents should not be in this zone. Evacuation centers should not be established in this zone.	During impending storm surge events, all people should not be in this zone. Evacuation centers should not be established in this zone. Natural and man-made coastal defenses, such as mangroves (soft interventions), breakwater (hard interventions), etc. should be established. Recommended as not suitable for commercial, industrial, residential(subdivisions), and institutional developments. Storm surge warning signage should be installed in this zone.

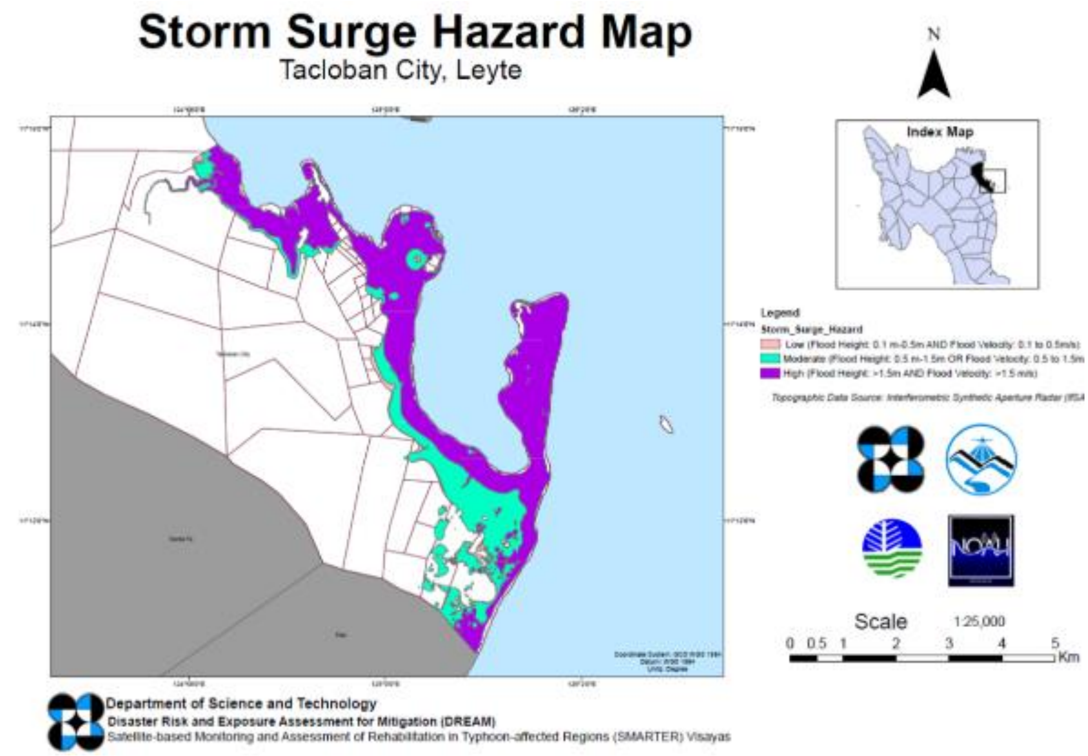


Figure 9: The storm surge hazard map of Tacloban City (DOST).

2.4 Regulatory Requirements, Building Codes and Design Standards

Preparing for storm surges induced by tropical cyclones is one of the most important challenges that many coastal areas in the world are currently facing. In Asian countries, many destructive storm surges were reported in recent years. These events have high-lighted the importance of cyclone shelters, which can save the lives of those living in vast expanses of low-lying grounds and the importance of preparation for rare cyclone tracks. In addition, the storm surge disaster in New York City caused by the 2013 Hurricane Sandy showed that although early evacuation can save lives, urban waterfront infrastructure, and especially underground facilities, can be vulnerable against a storm surge. Furthermore, sea level rise and tropical cyclone intensity change. Hence, in order to establish adequate adaptation strategies for places at risks, it is important for storm surge-prone countries to raise awareness about the nature of such phenomena which needs to be adequately transmitted to the local population in a language that they understand (Mikami, et al., 2016).

Coastal structures have higher risks of impact from natural hazards. However, coastal residential buildings that are properly sited, designed and constructed have generally performed well during natural hazard events. The design process includes consideration of the type of natural hazard that occur in the area where the building site is located and the design elements that allow a building to effective withstand the potential damaging effects of the natural hazards.

The minimum design requirements for loads, materials, and material resistances for a given building design are normally specified in the locally adopted building code. In case of the Philippines, building codes are mainly an adaptation with American Standards like ASCE 7-10, which is the reference load standard in model building codes. Figure 10 shows the process of determining site-specific loads for three natural hazards. The process includes identifying the applicable building codes and standards for selected site, identifying building characteristics that affect loads, determining factored design loads using applicable load combinations (FEMA, 2011).

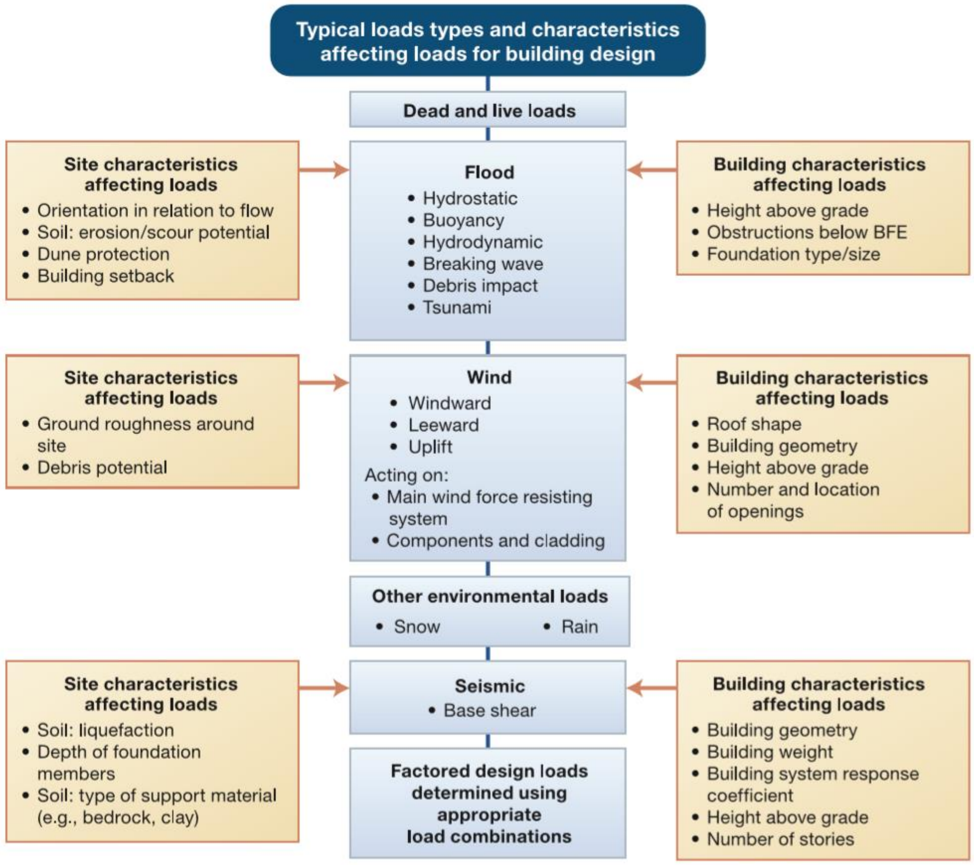


Figure 10: Summary of typical loads and characterstics affecting the determination of design load (FEMA,

The National Structural Code of the Philippines (2010) is one of the main reference of the structural design and analysis for the Philippine structures. This code is based on the ASCE/SEI 7-10. A detailed design and analysis is also provided by the Building Code Requirements for Masonry Structures or the ACI 530-02/ASCE5-02/TMS 4020-02 reported by the Masonry Standards Joint Committee (MJSC). This codes focus on larger buildings not with the low-rise residential structures. Implementation of the said codes can provide safe and resilient design for Philippine structure but not economical to the low-rise residential structures. The Philippines could ensure the safety of structures by creating a simplified residential code for low-rise houses or buildings. The existing standards for CHB and CHB wall construction in the Philippines is shown in Table 4.

Table 4: Existing standards for CHBs and CHB masonry wall construction in the Philippines.

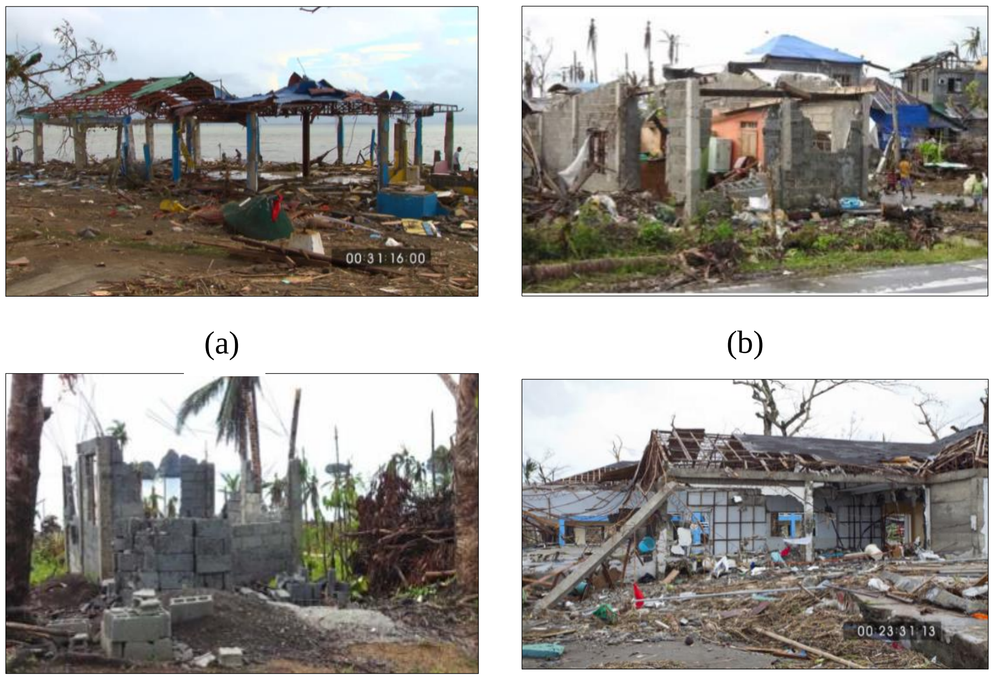
National Building Code of the Philippines and National Structural Code of the Philippines	
Load bearing walls	6" CHBs
	CHBs used must be Type I Class A or B unit, confirming with ASTM C-90-70
Minimum compressive strength	5.41 Mpa (800 psi)- For individual CHBs 6.89 Mpa (1000 psi)- Based on the average gross area of 5 units
Non- load bearing walls	4" CHBs
	Applications include: walls, partitions, fences, dividers
Steel bars	To be laid in mortar 1 part of Portland Cement and 3 parts of sand (1:3) Vertical and horizontal spacing as specified by a structural engineer.
Mortar and grout	Type 1, 2, 3 or Type 4 Portland Cement confirming to ASTM C-150. Standard mix to the building code specifications

2.5 Masonry walls: OOP Failure and Analysis

The mode of failure of the masonry structure in Tacloban can be categorized into two, based on the characteristics of applied load. These two categories are: (1) In-plane failure, (2) Out-of-plane failure. In-plane lateral loads induce shearing deformations in masonry wall. This deformation elongates one diagonal, including tension, and shortens the other, including compression perpendicular to the tension. Since masonry materials have much lower strength in tension than compression, in-plane forces typically induce diagonal cracking perpendicular to the tension axis. On the other hand, masonry walls subject to lateral forces can suffer from instability and collapse laterally. For walls which carry light gravity loads, out-of-plane loading typically induces a stability failure where a wall bursts outward or topples over.

The out-of-plane (OOP) behavior of masonry walls has not been studied as well as the corresponding in-plane behavior, however, some research has been carried out on the OOP behavior. For example, Rivera et al. (2011) constructed six full scaled masonry walls tested against out-of-plane (OOP) loading. The variable studied was the wall support conditions; four sided and three sided simple supported walls were considered. The observed maximum pressures and failure cracking pattern for the walls with three side support were similar to those with four-sided supports. Masonry walls are vulnerable to out-of-plane failure during high seismic activities. Most of the research conducted focuses on out-of-plane failure of masonry due to ground motion. Simsir et al. (2004) conducted a study on the OOP behavior of unreinforced masonry bearing walls in buildings subjected to earthquake motions. The validated models are useful for establishing the permissible limits on wall slenderness as prescribed by the current seismic guidelines. There are also studies conducted to compare reinforced and unreinforced masonry walls. Bui et al. (2010) investigated the OOP of masonry walls under normal pressure by constructing three 2.9x2x0.2m test specimen. Two of which is unreinforced masonry wall, while the third specimen is reinforced to withstand a pressure induced by a snow-avalanche of 300mbars. Crack patterns are similar to those predicted by the field line theory adapted from that for reinforced concrete slabs. Steel reinforcements are the main component that resist the tensile stresses in masonry walls. Noor-E-khuda et al. (2016) examined the OOP behavior of mortared and mortarless masonry walls with various forms of reinforcement including unreinforced masonry in order to overcome the vulnerability of masonry to seismic and cyclonic lateral loads. Masonry walls is a composite structure. Based on Mohamad et al. (2012) who conducted experimental tests of masonry walls to get the deformability, failure modes and compressive strength of the masonry. It is possible that the vertical mortar joint was the main responsible for initiated the failure mechanism of masonry.

The masonry wall is an anisotropic composed resulting from the interaction between block and mortar. This material under loads could be subjected to a complex stress state that produce failure by reaching the tensile strength of the block or, even, mortar crushing. The failure mechanism of masonry is caused by the initiation and propagation of cracks, which start often induced by the mortar that exhibits high porosity and different sizes of voids, with a possible initial decrease in volume caused by closing of flaw and voids. The lateral deformability between block and mortar is the main responsible for failure of masonry walls and it is important to understand the stress and strain mechanisms developed on block and mortar, It is possible to conclude that the interface between block and mortar was the weakness point of the masonry wall. (Mohamad, Lourenco, Rizatti, Roman, & Nakanishi, 2012)**.** Some of the damaged structure in Tacloban after Typhoon Haiyan(Yolanda) is shown in the Fig.11.



(a) (b) (c) (d)

Figure 11: : Structures in Tacloban City whose masonry walls had been damaged by Typhoon Haiyan (Yolanda): (a) multi-purpose hall with total damage to walls but intact RC frames and roof truss, (b) partial damage to masonry wall but roof is totally damaged, (c) totally damaged roof system with walls partially damage, (d) intact RC frames but total damaged to masonry walls. (Build Change, 2014)

2.5.1 Yield line method for masonry walls

Yield line method is a well-established and a highly effective method used in determining the load bearing capacity of concrete slabs and plates. Several experimental studies show that the development of crack pattern of masonry walls is similar with reinforced concrete slabs. Yield line method is considered as economical, simple and versatile design method. It is economical because it considers features at the ultimate limit state. (Kennedy & Goodchild, 2004).

The ACI Code contains no specific provisions for limit or plastic analysis of slabs, however yield line theory for the design of slab is an acceptable approach based on the successful use, analysis and tests. Yield line theory is an example of plastic analysis method derived from the general theory of structural plasticity. Based on this theory, the collapse load of a structure lies between an upper bound and a lower bound of the true collapse load (Nilson, Darwin, & Dolan, 2003) . The British Code for the design of masonry (BS5628) uses yield-line theory as a plastic method to predict the ultimate load capacity of reinforced concrete slabs. Haseltine et al. (1978) assessed the ability of the method to predict the cracking pattern and strength of masonry panels (Maluf, Parsekian, & Shrive). The similarity of the failure pattern in masonry walls and reinforced concrete slabs has been driven to apply Johansen's yield line method to laterally loaded masonry walls.

Yield line method requires the technical knowledge on how the masonry panels will fail. Several crack patters have been observed based on experimental studies conducted and based on historical records for masonry failures. With these, all possible failure mechanisms for any masonry wall must be investigated to confirm the correct solution that will give the lowest failure load (Nilson, Darwin, & Dolan, 2003). The failure pattern of masonry panel subject to out-of-plane forces is similar to the failure mechanism of reinforced concrete slab based on several tests. This kind of failure is characterized by the propagating diagonal, horizontal and vertical cracks that divides the masonry panel into smaller portions. Bakeer, et al (2009) proposed a modified yield line method in determining the maximum pressure capacity of masonry walls. They introduce a reduction factor into the moment resistance at the first crack. Rivera, et al (2010) used yield line method in determining the out-of-plane behavior of confined masonry walls subjected to uniform pressure.

The analysis using virtual work method can be used to determine the relationship between the applied loads and the resisting moments. Moments and loads are in equilibrium when the yield line pattern has formed, an infinitesimal increase in load will cause the structure to deflect further. The external work done by the loads to cause a small arbitrary virtual deflection must equal the internal work done as the masonry wall rotates at the yield lines to accommodate this deflection. The masonry wall is therefore given a virtual displacement, and the corresponding rotations at the various yield lines can be calculated. (Nilson, Darwin, & Dolan, 2003)

Lawrence, et al (2000) evaluated the effectivity of the yield line method to estimate the lateral pressure capacity of masonry wall by verifying the results against the data collected from throught the world, covering both clay brick and concrete block masonry. This includes paper of Baker, Gairns, Anderson, Drysdale, West, Haseltine, Candy, Carrick and Shackel in year 1976 to 1989 with a total number of 207 masonry wall tests.

2.5.2 FEM analysis of masonry walls

Finite element modelling is a state-of-the art numerical analysis that can be used to estimate the pressure capacity of masonry walls under lateral loading. A number of research, both experimental and numerical analysis had been conducted to determine the behavior of masonry walls. Each research used unique numerical analysis validated by a corresponding experimental analysis of masonry walls. Based on these studies, it can be generalized that masonry is a heterogeneous structural material obtained by composition of natural or artificial blocks connected by dry or mortar joints following a regular or irregular arrangement. However, masonry may be modelled as a homogeneous material by means of FE models, for performing analysis at macro scale level or modelling a masonry structure as a whole (Baraldi & Cecchi, 2016).The flexural load bearing behavior of masonry is determined by a large number of influences such as material properties of its component masonry unit and mortar, the bond behavior between the masonry unit and the mortar, the dimensions of the units, the length of the overlap, the masonry thickness. (Schmidt, Hannawald, Koster, Graubohm, & Brameshuber, 2012).

CHAPTER THREE

THEORETICAL FRAMEWORK

3.0 Introduction

This chapter includes the systematic procedure conducted in this study. It also includes all the theories and concept used in conducting the research.

3.1 Conceptual Framework

The adequacy of masonry wall design was assessed in terms of the following design specification: (1) Spacing of steel reinforcement, (2) Thickness of CHB, (3) Size of Steel Reinforcement, (4) Wall Dimensions. Storm surge pressure load was estimated in accordance of the FEMA Coastal Construction Manual and ASCE 7-10. Different flood loads were considered such as: (1) hydrostatic load, (2) breaking wave load, (3) hydrodynamic load, (4) debris impact load, and (5) wind pressure load. On the other hand, the lateral pressure capacity of the masonry wall was estimated using the yield line method and FEM analysis (Staad Pro V8). The general conceptual framework is shown in Figure 12.

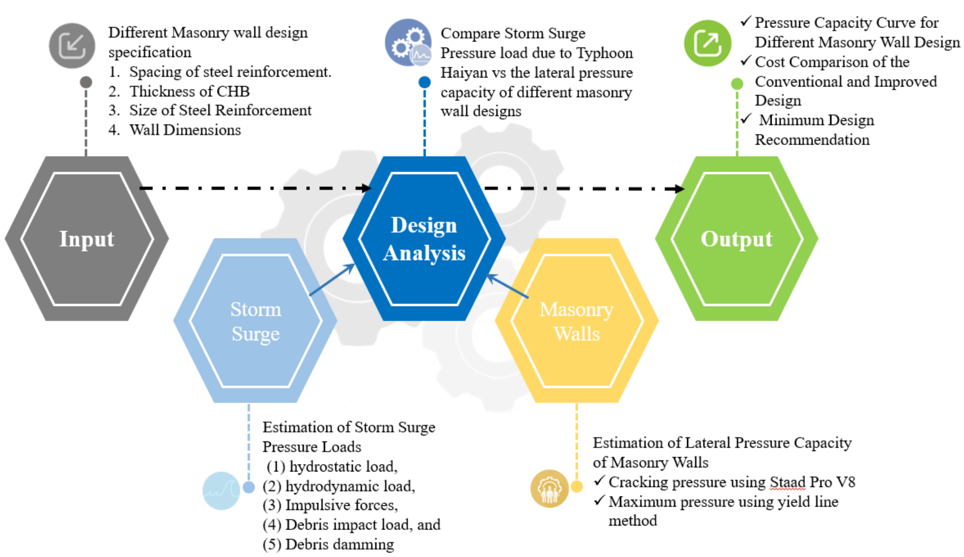


Figure 12: Conceptual Framework

In order to attain sufficient design, the masonry wall must have adequate lateral pressure capacity to resist different flood loads due to storm surge. The performance of the masonry wall will be based on the maximum pressure capacity, bending behavior and the pressure load due to Typhoon Haiyan-induced storm surges. A simple comparison of cost of different masonry models was provided. The cost to be considered are only based on the material cost and labor cost. With this, the researcher presented a design analysis and provided design recommendation.

3.2 Theoretical Framework

Figure 13 shown is the detailed theoretical framework that includes all necessary equations and step-by-step procedure to determine the adequacy of lateral pressure capacity of the masonry walls and the necessary procedure to estimate the storm surge pressure. The analysis is subdivided into two major analyses: (1) masonry wall design analysis, and (2) storm surge pressure analysis. The design was considered adequate once the estimated lateral pressure capacity of the wall is greater than the estimated storm surge pressure load. On the other hand, the design is considered inadequate when $\boldsymbol{W_u} < \boldsymbol{P_{SL}}$. When the design is inadequate, the masonry wall design was improved by: (1) Higher steel reinforcement ratio, (2) Thicker CHB thickness, (3) Larger size of steel reinforcement, and (4) Minimize distance of column support. This alteration was terminated once the desired lateral pressure capacity was attained.

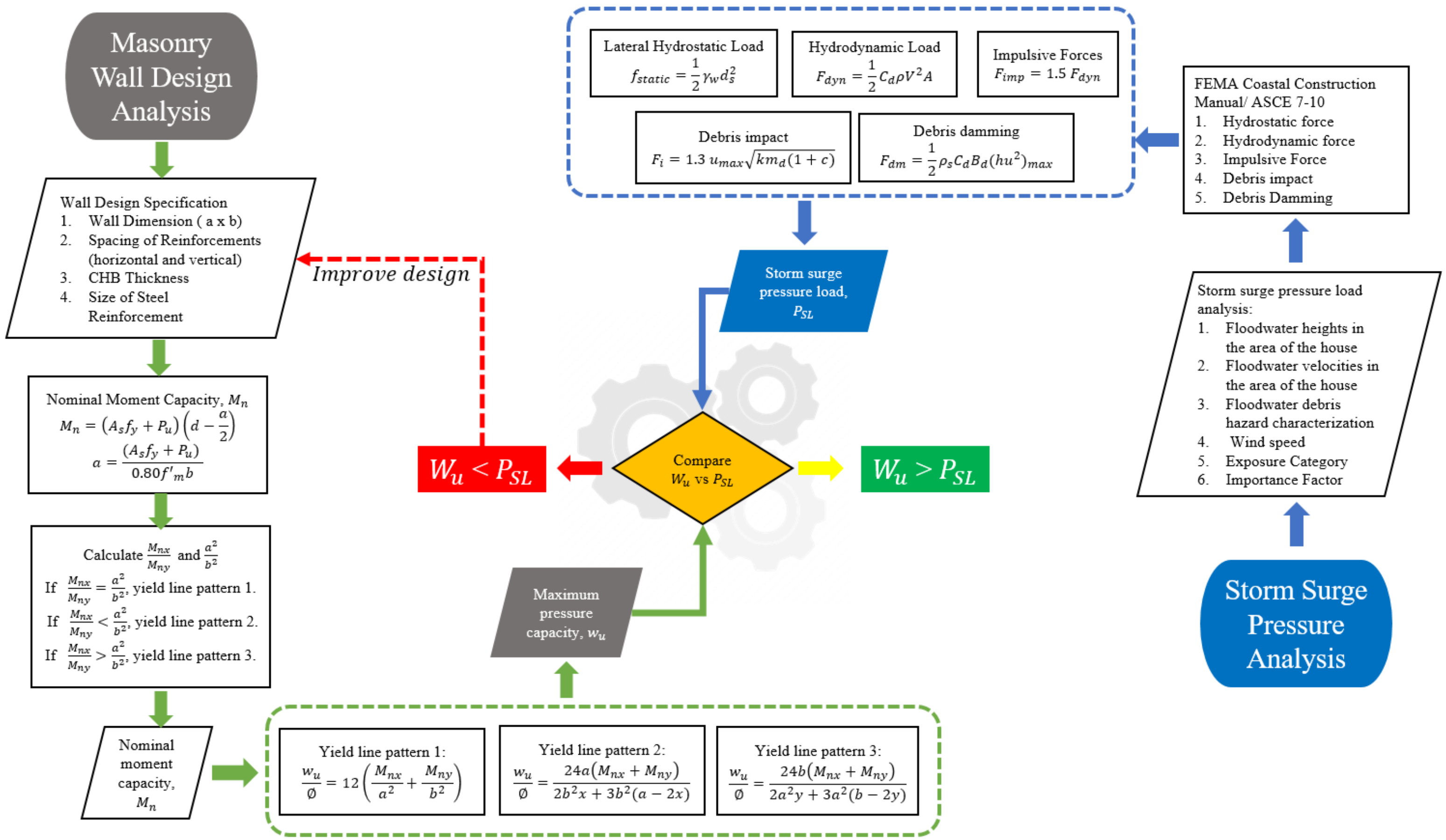


Figure 13: Theoretical Framework

CHAPTER FOUR

MATERIALS AND METHODOLOGY

4.0 Introduction

This chapter includes all the necessary methods conducted in this research. This includes the procedure for interview survey, identifying storm surge heights, estimation of lateral pressure capacity of masonry walls using FEM software Staad Pro V8 and yield line method and estimation of storm surge pressure load.

4.1 Research Methodology

To assess the damage of masonry walls in Tacloban City after Typhoon Haiyan, the researcher identified the barangays and structures damaged by Typhoon Haiyan using available data from NDRRMC, LGU and other international agency. Based on the data gathered in the interview, the researcher identified the following:(1) Common design used, (2) Method of construction, (3) Type of material Used, (4) Damaged created by Typhoon Haiyan. Pressure load capacity of the masonry walls was analytically estimated using FEM analysis with the aid of Staad Pro V8 and yield line method. The storm surge pressure load was calculated based on the design procedure stated in FEMA Coastal Construction Manual. Since the current design is insufficient, the researcher conducted some alteration on the design to provide improvement to the structural integrity of the non-engineered masonry wall. Some of the alterations to be made are limited to: (1) Spacing of steel reinforcement, (2) Thickness of CHB, (3) Wall dimensions and (4) Size of steel reinforcement. After the analysis of different wall design, the researcher provided design recommendation. This research methodology is shown in the Fig.14.

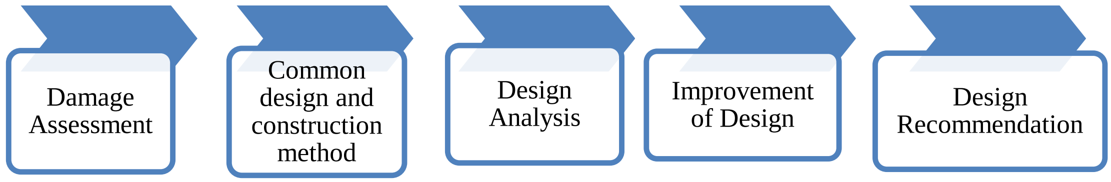


Figure 14: Schematic diagram of the research methodology

4.2 Conduct of Interview Survey

The schematic model on how to determine the construction process and design parameters of non-engineered masonry walls in Tacloban City is illustrated in the Fig. 15. It is a structured interview using the questionnaire sheet (see Appendix A)

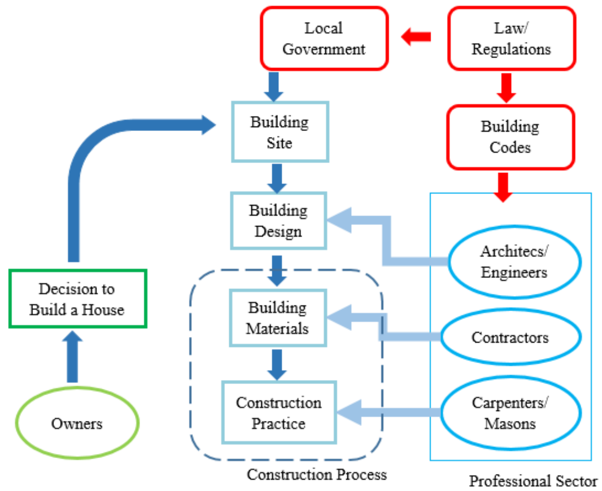


Figure 15: Schematic diagram of the interview process

Figure 16: (Upper) Photos taken during interview process: (a) Contractor, (b) House Owner, (3) Mason/ Carpenter. (Below) Example of non-engineered houses in the coastal barangays

The researcher conducted on-site survey (see Fig. 16) in Tacloban City to determine the following: (1) Common design used, (2) Method of construction, (3) Type of material Used, (4) Damaged created by Typhoon Haiyan. Some of the main questions asked were the following:

1. Who built or designed my house?
2. How old is my house?
3. Has my house been damaged by past Typhoon Yolanda last 2013?
4. Has my house been totally flooded during Typhoon Yolanda?
5. How far is my house from the shoreline?
6. What is the shape of the house?
7. Has my house been extended to two storey?
8. Are the external walls of my house 6-inch (150mm) thick CHB?
9. Are steel bars of standard size and spacing used in walls ?
10. What material is used as your column?
11. What part of the house is damaged?
12. What is the foundation of my house?
13. What is the soil conditions under my house?
14. What is the overall condition of my house?

Sample questionnaire form was provided in Appendix _. The detailed result of the on-site survey was documented in Appendix _.

4.3 Estimation of storm surge pressure load

Floodwaters can exert a variety of load types on building elements. Both hydrostatic and depth-limited breaking wave loads depend on flood depth. Different flood loads were considered in the estimation of storm surge pressure loads, these includes: (1) hydrostatic load, (2) breaking wave load, (3) hydrodynamic load, (4) debris impact load.

Lateral hydrostatic loads are given by Equation (4.4.1). Note that f_{static} is equivalent to the area of the pressure triangle and acts at a point equal to 2/3 d_s below the water surface.

$$f_{static} = \frac{1}{2}\gamma_w d_s^2 \qquad (4.4.1)$$

where γ_w is the specific weight of floodwater, d_s is the floodwater depth.

Hydrodynamic load is a function of flow velocity and structural geometry. In the Coastal Construction Manual of FEMA, the velocity of floodwater is assumed to be constant or steady-state flow. Hydrodynamic loads can be calculated using Equation (4.4.2).. The drag coefficient used in Equation # can be determined by one of the following ratios (see Table 6).

$$F_{dyn} = \frac{1}{2} C_d \rho V^2 A \tag{4.4.2}$$

where C_d is the drag coefficient, ρ is mass density of floodwater, V is velocity of floodwater, and A is the surface area of obstruction normal to flow.

Table 5: Drag Coefficient for Ratios of Width to Depth (FEMA, 2011)

Width-to-Depth Ratio (w/h)	Drag Coefficient (C_d)
01-Dec	1.25
13-20	1.3
21-32	1.4
33-40	1.5
41-80	1.75
81-120	1.8
>120	2

The impact force when waterborne debris can be a cause of building damage.. This can be estimated using Equation (4.4.3).

$$F_i = 1.3\, u_{max} \sqrt{k m_d (1 + c)} \tag{4.4.3}$$

where F_i is the impact force, 1.3 is the importance coefficient for Risk Category IV structures that is specified by ASCE 7 Chapter 5 for debris impact, u_{max} is the maximum flow velocity carrying the debris at the site (the debris is conservatively assumed to be moving at the same speed as the flow), c is the hydrodynamic mass coefficient which represents the effect of fluid in motion with the debris (see Table #), k is the effective net combined stiffness of the impacting debris and the impacted structural elements deformed by the impact, m_d is the mass of the debris.

Table 6: Mass and Stiffness of Some waterborne floating debris

Type of Debris	*Mass (m_d) in kg*	*Hydrodynamic Mass Coefft. (c)*	*Debris Stiffness (k_d) in N/m*
Lumber or Wood Log – oriented longitudinally	450	0	2.4×10^6 *
20-ft Standard Shipping Container – oriented longitudinally	2200 (empty)	0.30	85×10^6 **
20-ft Standard Shipping Container – oriented transverse to flow	2200 (empty)	1.00	80×10^6 **
20-ft Heavy Shipping Container – oriented longitudinally	2400 (empty)	0.30	93×10^6 **
20-ft Heavy Shipping Container – oriented transverse to flow	2400 (empty)	1.00	87×10^6 **
40-ft Standard Shipping Container – oriented longitudinally	3800 (empty)	0.20	60×10^6
40-ft Standard Shipping Container – oriented transverse to flow	3800 (empty)	1.00	40×10^6

* Haehnal and Daly, 2002; ** Peterson and Naito, 2012

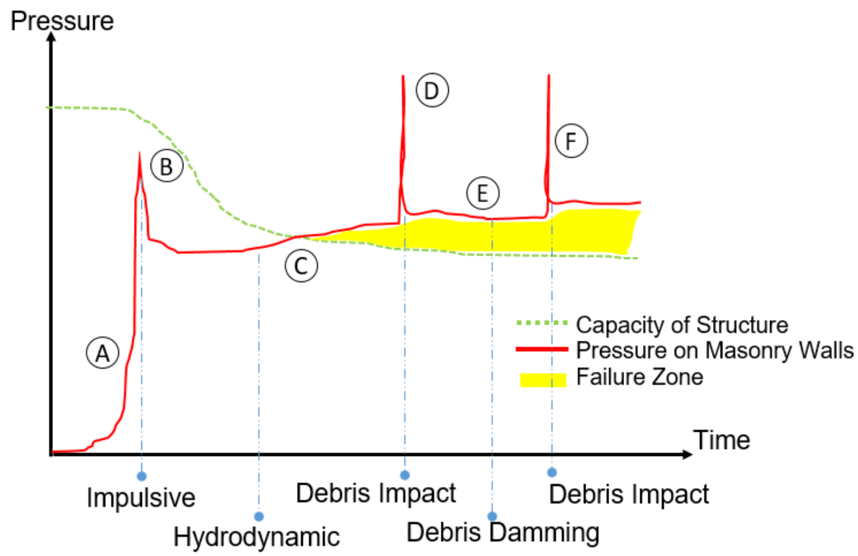
The damming effect caused by accumulation of waterborne debris can be treated as a hydrodynamic force enhanced by the breath of the debris dam against the front face of the structure. The damming forces can be estimated using Equation (4.4.4).

$$F_{dm} = \frac{1}{2}\rho_s C_d B_d (hu^2)_{max} \tag{4.4.4}$$

where ρ_s is the fluid density including sediments, C_d is the drag coefficient, B_d is the breadth of the debris dam, h is the flow depth, and u is the flow velocity at the location of the structure. It is recommended that the drag coefficient be taken as $C_d = 2.0$.

In the estimation of storm surge pressure load, the FEMA Coastal Construction Manual provided some load combination based on the typical time series of the complex combination of storm surge pressure loads (see Fig. #). Point A is characterized by the rising floodwater and estimated as hydrostatic. Point B is the time where the flood water attained its maximum depth where the flow is impulsive. This impulsive pressure is estimated to be 150% of the hydrodynamic pressure. Point C is characterized where the flow of floodwater is hydrodynamic. The critical pressure typically occurs due to the impact of debris as characterized by Point D and F. After the initial debris impact, debris tends to accumulate on the face of the structures. This leads to an increase of pressure due to the increased in contact area and weight of debris.

Summary of different load combination where considered based on FEMA Coastal Consruction Manual. These combination where based on the typical time series of the complex combination of storm surge pressure loads (see Fig. 17).



		Pressure (kPa)
A	Rising Floodwater	Hydrostatic
B	Floodwater with surge (Impulsive)	Combined Hydrostatic with Impulsive
C	Floodwater with surge	Combined Hydrostatic with hydrodynamic
D	Floodwater with Debris	Combined Hydrostatic and hydrodynamic with debris impact
E	Debris Damming	Combined Hydrostatic with hydrodynamic
F	Increasing Debris Impact	Combined Hydrostatic and hydrodynamic with increase debris impact

Figure 17: Typical time series of the complex combination of storm surge pressure loads.

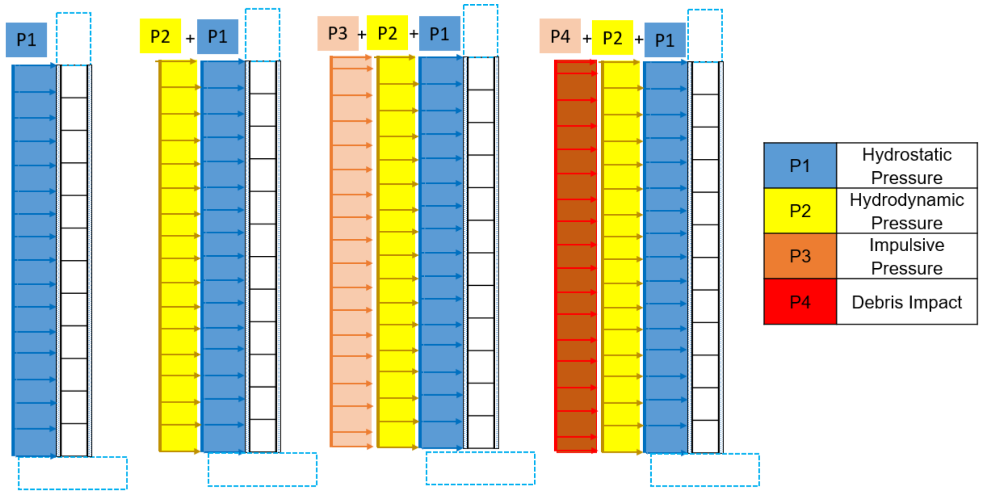


Figure 18: Load combination of flood loads.

4.4 Estimation of lateral pressure capacity of masonry walls

The structural analysis for the maximum pressure capacity of the masonry wall used yield line method. Maximum pressure (W_{max}) was predicted using yield line method. Equations 4.4a, 4.4b, 4.5c are used to calculate the maximum pressure capacity of masonry walls with varying yield line pattern (see Fig. 19).

Yield line pattern 1 $\quad \frac{M_{nx}}{M_{ny}} = \frac{a^2}{b^2} \quad \frac{w_u}{\emptyset} = 12\left(\frac{M_{nx}}{a^2} + \frac{M_{ny}}{b^2}\right)$ (4.4a)

Yield line pattern 2 $\quad \frac{M_{nx}}{M_{ny}} < \frac{a^2}{b^2} \quad \frac{w_u}{\emptyset} = \frac{24a(M_{nx} + M_{ny})}{2b^2x + 3b^2(a - 2x)}$ (4.4b)

Yield line pattern 3 $\quad \frac{M_{nx}}{M_{ny}} > \frac{a^2}{b^2} \quad \frac{w_u}{\emptyset} = \frac{24b(M_{nx} + M_{ny})}{2a^2y + 3a^2(b - 2y)}$ (4.4c)

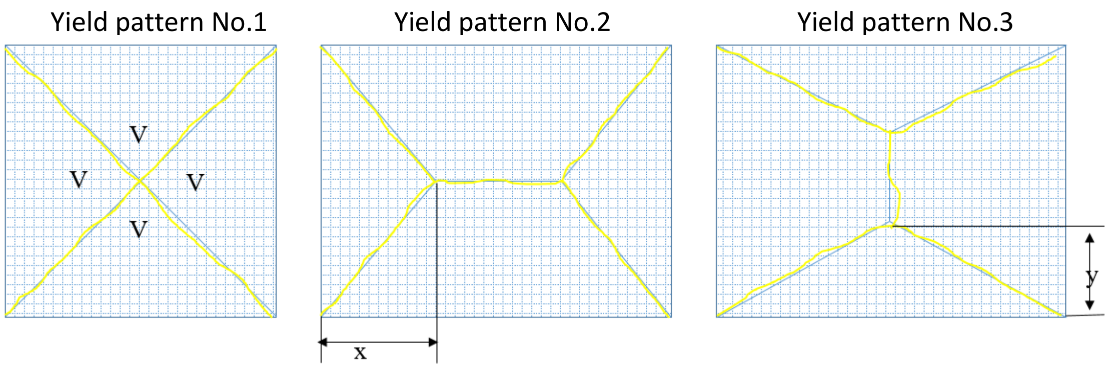


Figure 19: Most common yield line pattern for masonry OOP failure (Wang, Salmon, & Pincheira, 2007.)

where w_u is the maximum pressure capacity, $\emptyset$ is reduction factor, M_{nx} and M_{ny} are the nominal moment strength in x and y direction respectively, a and b are the width and height of the masonry walls. Nominal moment capacity of the masonry walls, M_{nx} and M_{ny} was calculated in accordance with the design procedure stated in the Building Code Requirements for Masonry Structures (ACI 530-02/ASCE5-02/TMS 402-02). The design nominal moment strength for out-of-plane wall loading was calculated in accordance with Equation (4.4d).

$$M_n = \left(A_s f_y + P_u\right)\left(d - \frac{a}{2}\right) \tag{4.4d}$$

where A_s is the area of steel reinforcement, f_y is the specified yield strength of steel reinforcement, P_u is the factored axial load, d is the distance from extreme compression fiber to centroid of tension reinforcemen, f'_m is the specified compressive strength of masonry, and b is the width of section. The width of section, b in Equation # is the least value of the following: (1) center to center bar spacing, (2) six times the wall thickness, and (3) 72 inches or 1829mm, a is the depth of an equivalent compression zone at nominal strength which can be calculated using Equation (4.4e).

$$a = \frac{(A_s f_y + P_u)}{0.80 f'_m b} \tag{4.4e}$$

The fundamental principle of yield line method is that work done internally and externally must balance. In other words, at failure, the expenditure of external energy induced by the load on the masonry walls must be equal to the internal energy dissipated within the yield lines. The detailed derivation of maximum pressure capacity for the three common yield line pattern was documented in Appendix #.

Different masonry design was considered based on the following: (1) non-engineered masonry, (2) NSCP 2015 Compliant, (3) ACI 530-02 Compliant, and the (4) recommended design. The design specification for the non-engineered masonry walls was verified based on the on-site survey conducted. The maximum pressure capacity of NSCP2015/ACI 530-02 Compliant design was also investigated using yield line method.

Based on the survey, non-engineered masonry walls are walls with horizontal reinforcement spaced every 4th CHB layer and whose vertical reinforcements are spaced at 80cm O.C. It is also worth-mentioning that some masonry walls do not have steel reinforcements mainly because of financial incapability of the occupants. However, unreinforced masonry is not considered in this study. Some houses also used 40 x 20x

10cm thick CHB even if the desired designed CHB thickness for exterior walls are 40 x 20 x 15cm CHB. This has been verified during the survey since around 65% of the 380 houses confirmed that their house is not made of 6” CHB (40 x 20 x 15cm). According to some construction hardware, majority of the locals purchased/used 10mmØ for the construction of their houses.

In terms of the NSCP 2015 and ACI 530-02 Compliant provides a maximum spacing of 1.20 meter for a minimum diameter of 10mm steel reinforcements, both vertical and horizontal. Based on NSCP 2015 and ACI 530-02, the minimum CHB thickness for masonry walls are 10cm and 15cm, respectively (see Fig. 20).

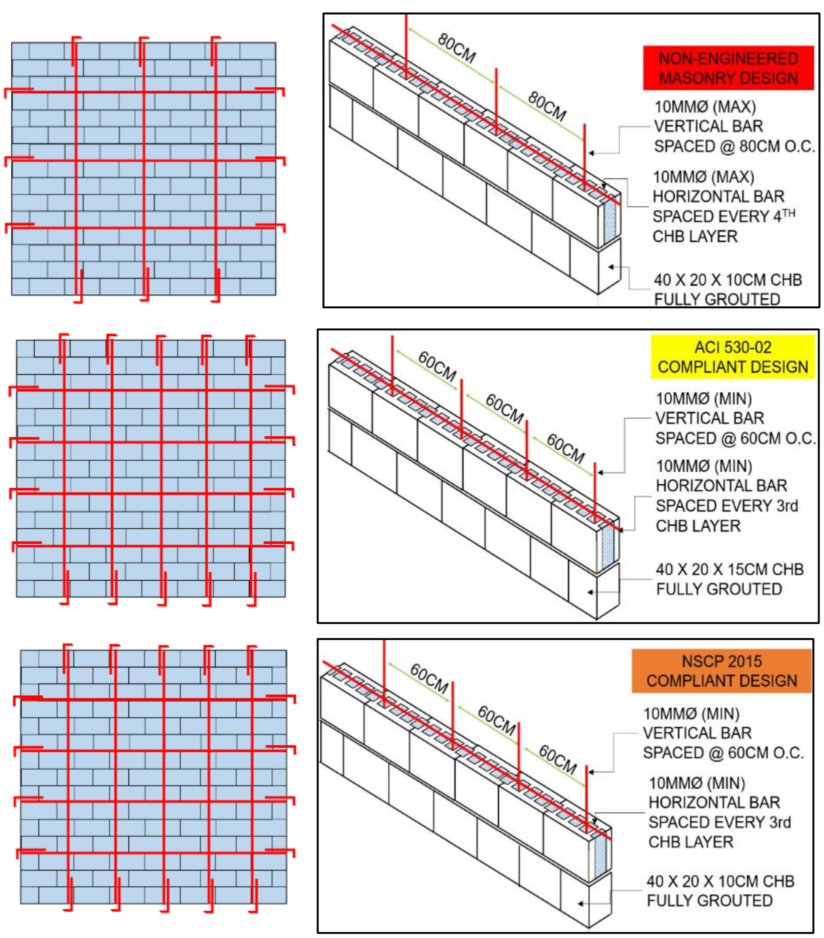


Figure 20: Structural details of: (a) Non-engineered design, (b) NSCP 2015 Compliant Design, (c) ACI 530-02 Compliant Design.

4.5 Macro-modelling using finite element analysis for masonry walls

To estimate the cracking pressure of masonry walls per design consideration, macro-modelling using finite elemet analysis was conducted. The study used Staad Pro V8 in the structural analysis. The said software was used because of its easy to understand features and flexibility in modelling that is very useful in the analysis of several design consideration.

The masonry wall was modelled by structural meshing of 20cm by 20 cm square shell elements of 4 nodes and 6 degrees of freedom per node. The thickness of masonry wall was modelled using the corresponding CHB thickness per design consideration. Masonry walls was modelled as isotropic linear elastic. For the steel reinforcement with varying diameter of 10 to 12mm was modelled using stick or linear model. The endpoints of the reinforcements were considered fixed to consider the effects of embedment to the supports. Hinge supports were located along the confining elements to simulate the presence of columns and ring beams (see Fig. 21). Modulus of elasticity of masonry wall was $550f'_m$, where f'_m was 6.89Mpa based on the minimum compressive strength of masonry required. Modulus of elasticity and yield strength of steel reinforcement was 200 GPa and 275 Mpa, respectively. Poisson's ratio was assumed equal to 0.20. Increasing uniform lateral pressure was applied perpendicular to the face of the masonry walls and the corresponding maximum lateral displacement was determin

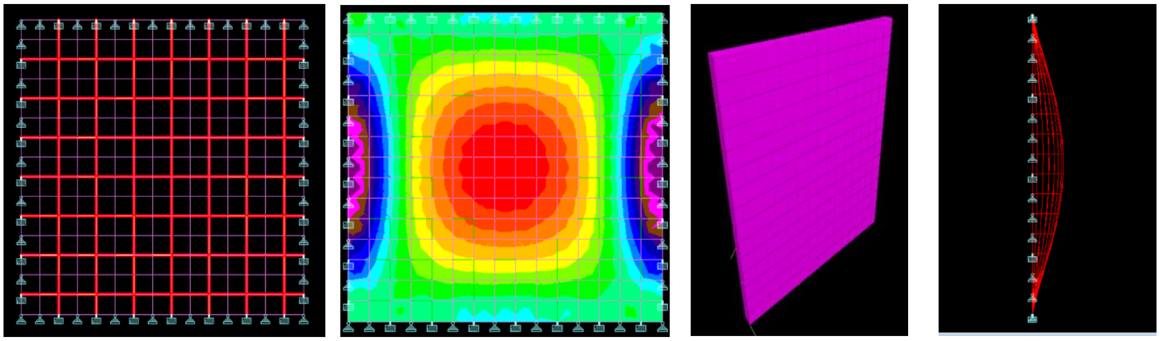


Figure 21: : Staad Pro V8 model for masonry wall subjected to uniform pressure: (a) details of reinforcement, (b) stress contour, (c) 3D model, and (d) lateral displacement.

STAADPro is equipped with a plate/shell finite element, solid finite element and an entity called the surface element. The features of each is explained in the following sections. "Surface structures" such as walls, slabs, plates and shells may be modeled using finite elements. For convenience in generation of a finer mesh of plate/shell elements within a large area, a mesh generation facility is available.

The STAAD plate finite element is based on hybrid finite element formulations. An incomplete quadratic stress distribution is assumed. For plane stress action, the assumed stress distribution (see Fig. 22) is as follows.

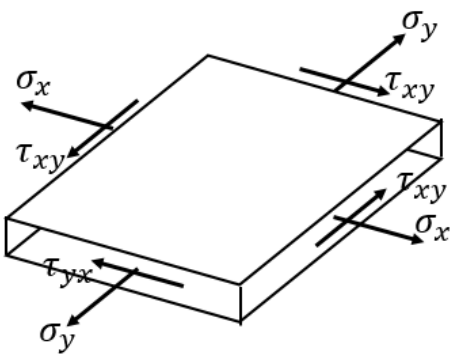


Figure 22: Assumed stress distribution

The incomplete quadratic assumed stress distribution:

$$\begin{pmatrix} \sigma_x \\ \sigma_x \\ \tau_{xy} \end{pmatrix} = \begin{pmatrix} 1 & x & y & 0 & 0 & 0 & 0 & x^2 & 2xy & 0 \\ 0 & 0 & 0 & 1 & x & y & 0 & y^2 & 0 & 2xy \\ 0 & -y & 0 & 0 & 0 & -x & 1 & -2xy & -y^2 & -x^2 \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix}$$

a1 through a10 = constants of stress polynomials.

The following quadratic stress distribution(see Fig. 23) is assumed for plate bending action:

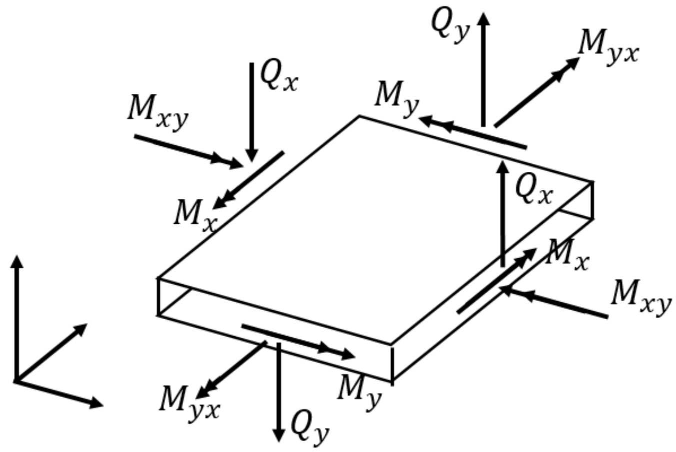


Figure 23: Quadratic stress distribution assumed for bending

The incomplete quadratic assumed stress distribution:

$$\begin{pmatrix} M_x \\ M_y \\ M_{xy} \\ Q_x \\ Q_y \end{pmatrix} = \begin{pmatrix} 1 & x & y & 0 & 0 & 0 & 0 & 0 & 0 & x^2 & xy & 0 & 0 \\ 0 & 0 & 0 & 1 & x & y & 0 & 0 & 0 & 0 & 0 & xy & y^2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & x & y & -xy & 0 & 0 & -xy \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & x & y & 0 & xy \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & -y & 0 & x & y \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_{12} \\ a_{13} \end{pmatrix}$$

a1 through a13 = constants of stress polynomials

The distinguishing features of this finite element are:

1. Displacement compatibility between the plane stress component of one element and the plate bending component of an adjacent element which is at an angle to the first (see the following figure) is achieved by the elements.
2. This compatibility requirement is usually ignored in most flat shell/plate elements. The out of plane rotational stiffness from the plane stress portion of each element is usefully incorporated and not treated as a dummy as is usually done in most commonly available commercial software.

3. These elements are the simplest forms of flat shell/plate elements possible with corner nodes only and six degrees of freedom per node. Yet solutions to sample problems converge rapidly to accurate answers even with a large mesh size.
4. These elements may be connected to plane/space frame members with full displacement compatibility. No additional restraints/releases are required.
5. Out of plane shear strain energy is incorporated in the formulation of the plate bending component. As a result, the elements respond to Poisson boundary conditions which are considered to be more accurate than the customary Kirchoff boundary conditions.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.0 Introduction

This chapter includes the the results and discussion of this study. The results of on-site surveys, estimation of lateral pressure due to Typhoon Haiyan, estimation of lateral pressure capacity of the non-engineered masonry walls and the recommended masonry wall design are discussed thoroughly in this chapter.

5.1 Interview Survey

Based on the damage assessment of Tacloban City after the Typhoon Haiyan, barangays along the coastal areas were identified (see Fig.20). On-site interview survey was conducted on this areas to determine the necessary information needed to assess the OOP failure of masonry walls. Additional questions were also asked to determine the current status of the houses along the coastal barangays.

A total of 380 low-rise residentialcommercial houses were interviewed. This houses are located mostly at Brgy. 36, 37, 66, 67, 68, 69 and 70 in Anibong, at Brgy. 30, 48-B, 52, 54, 58 and 60-A along Esperas Avenue and Real St., at Brgy. 83 and 85 at San Jose. Almost 84% of the 380 houses were built without the proper supervision of a licensed civil engineer or professional architect (see Fig.24). Since coastal areas are the most vulnerable to high storm surges, around 79% of the houses surveyed were categorized as totally damaged after Typhoon Haiyan (see Fig.24). The number of houses that were considered as totally damaged is directly proportional to the number of houses that are totally flooded.

Around 58% out of the 380 houses surveyed are within the 40meter No Build Zone implemented by the local government of Tacloban City. Almost 69% of the houses within the No Build Zone areas are single storey houses and the remaining 31% has the capabilities to move on higher grounds since their houses were two storey structures. On the other hand, 65% of the total houses within 40-100metermeter from shoreline are considered as single storey structures and the remaining 35% are two storey structures (see Fig.25).

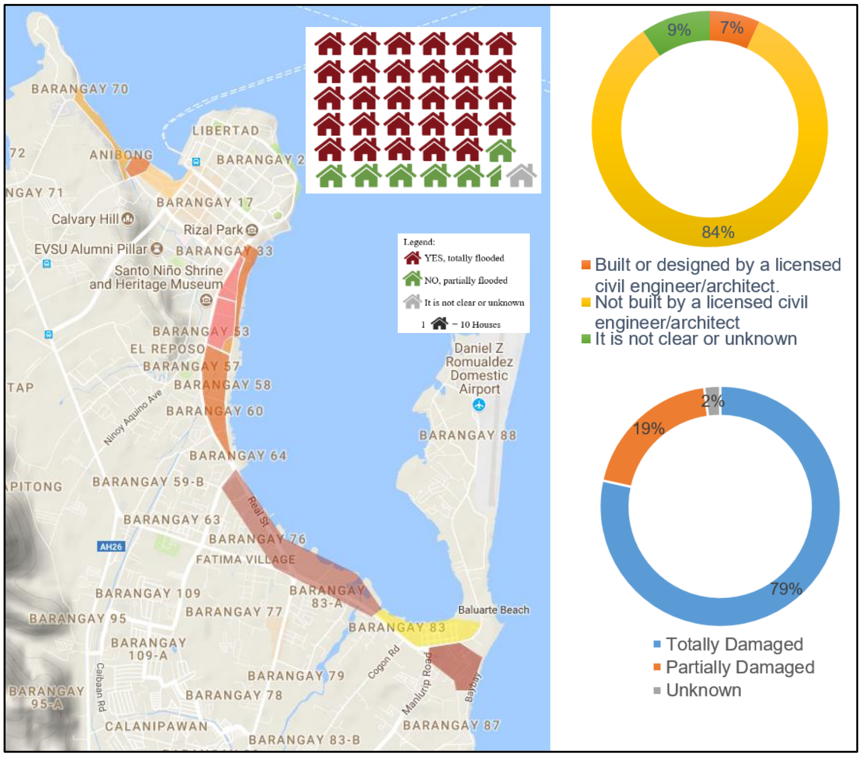


Figure 24: (a)Percentage of houses per designer in the coastline of Tacloban City , (b) Percentage of houses along the coastline of Tacloban City that are partially and totally damaged by Typhoon Haiyan(2013), (c) Number of houses along the coastline of Tacloban City that are partially or totally flooded during Typhoon Haiya (2013).

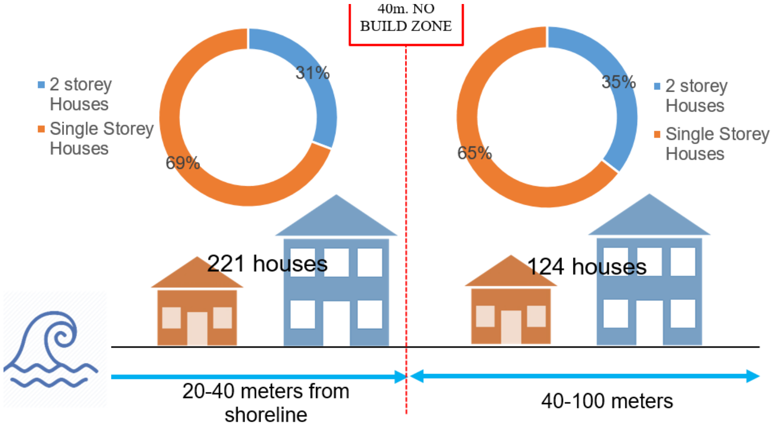


Figure 25: Number of houses within/beyond the No Build Zone in the coastal areas of Tacloban City. (survey conducted March, 2018)

5.2 Current Construction Method and Structural Details

Based on the survey of the housing structures in the coastal area, a typical house, named House E shown in Fig. 26, is selected for investigating the current construction method and structural details of masonry walls. House E is a 2 stories non-engineered RC framed with masonry wall structure and is constructed 2 years ago. The plan, cross section and structural details of House E is shown in Fig. 27.

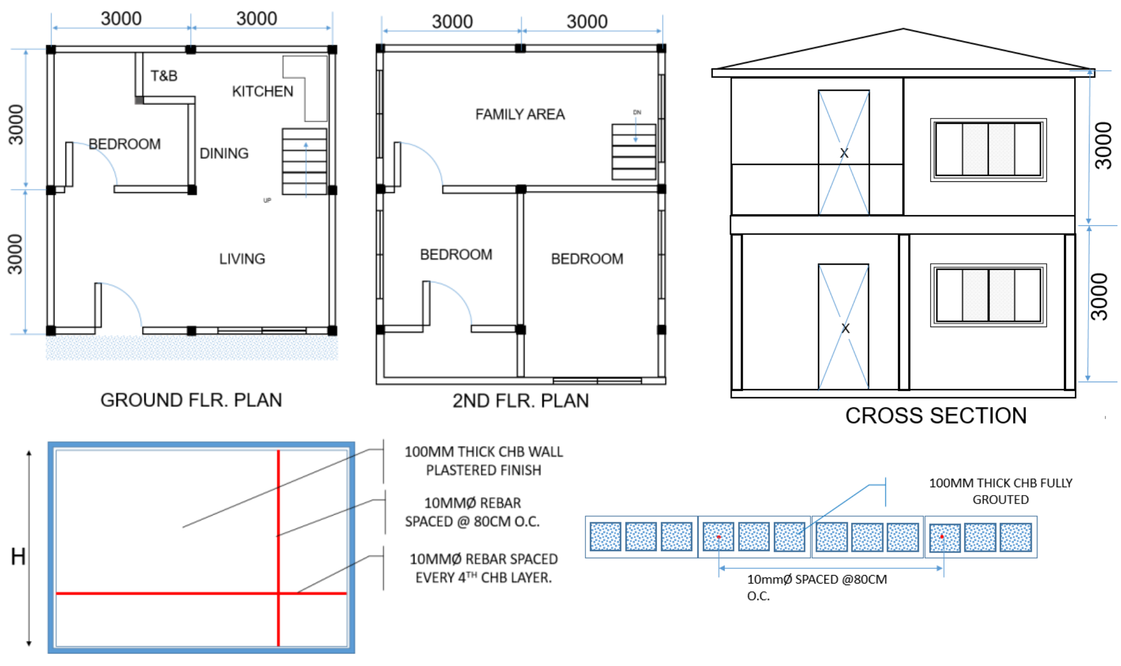


Figure 26: Structural details of House E, a two-storey residential RC frame house located within flood storm surge prone areas along the coastline of Tacloban City

Figure 27:. Actual photos of House E, with flood depth, located at Brgy. San Jose, Tacloban City, Leyte

5.3 Storm Surge Pressure load

To estimate the pressure load imposed by the storm surge during Typhoon Haiyan, different flood was calculated. Different flood loads include hydrostatic load, breaking wave load, hydrodynamic load and debris impact load. Wind load calculation was based on ASCE 7-10. ASCE 7-10 is the procedure most commonly used for designing low-rise residential buildings. Figure # illustrates a typical time series of the complex combination of storm surge pressure loads. In this figure, a dashed line represents the actual capacity of the structure. There is a decrease in capacity that can be attributed to the buoyancy force reducing the resistance of the structure to global failure. In this research, it was difficult to calculate the exact pressure load on the masonry walls as a function of time, thus, the researcher determined the estimated pressure ranges or the possible maximum values of pressure load considering the maximum estimated values for flood depth, flow velocity, specific weight of flood water, weight of debris and other factors.

The hydrostatic pressure is a force under static condition. Considering a flood depth ranges from 2 to 3 meters high, the estimated hydrostatic pressure on masonry wall was 16.19 kPa.

$$P_{static} = \gamma_w h_s = (1.1)\left(\frac{9.81kN}{m^3}\right)(1.5m) = 16.19\ kPa \tag{5.3.1}$$

The impulsive force is caused by the impingement of a leading edge of initial surging floodwater onto the structure. The impulsive force acts only on the front side of the structure. Presently, there is no established and rational method available to predict the force. Based on two independent laboratory studies of Ramsden (1993) and Arnason (2005), the upper limit of the impulsive force is approximately 150% of the subsequent maximum hydrodynamic force in a quasi-steady flow.

When the floodwater is in motion around the structure, the hydrostatic condition no longer exists. However, the deviation caused by the initial flow of floodwaters is mainly small in comparison with the hydrostatic state. For the hydrodynamic forces considering drag coefficient: C_d=2.0, flood water velocity ranges from 2-3 m/s, Surface Area, *A*: is a 3 x 3meter walls, floodwater density is approx. $1000kg/m^3$, the estimated maximum hydrodynamic force was 29.70 kN acting at mid-height of the masonry walls.

$$F_{dyn} = \frac{1}{2} C_d \rho (hu^2) = \frac{1}{2}(2.0)(1100\frac{kg}{m^3})\left(\frac{3m}{s}\right)^2 (3m) = 29.70kN \tag{5.3.2}$$

The impulsive forces was estimated to be 150% of that of hydrodynamic forces based on experimental results, the the estimated maximum impulsive forces was 44.45KN.

$$F_{imp} = 1.5F_{dyn} = 1.5\ (29.70kN) = 44.45kN \tag{5.3.3}$$

Debris impact forces are difficult to estimate. Several engineering attempts have been made previously, and they are summarized in Appendix D of FEMA P-646 (2012). Unlike other forces, debris impact forces occur locally at the point of contact when debris is smaller than the building. Theoretically, debris impact forces can be evaluated with impulse-momentum principle. Nonetheless, application of the theory in practice is difficult due primarily to uncertainty in the determination of impact time duration. The magnitude of this forces depends on the weight of the debris. Based on the local condition of Tacloban City, debris may include woods, garbage, stone, etc.

The estimated debris impact was 128.17 KN considering flow velocity, u_{max} ranges from 2-3m/s., hydrodynamic mass coefficient, c = 0, debris stiffness, k=2.4 x 10^6 N/mm, mass of the debris, m_d= 450 kg.

$$F_i = 1.3\ u_{max}\sqrt{km_d(1+c)}$$
$$F_i = 1.3\left(\frac{3m}{s}\right)\sqrt{(2.4x10^6)(450kg)(1+0)} = 128.17kN \tag{5.3.4}$$

The debris damming forces are due to the jamming effect of debris on a structure, which increases the hydrodynamic forces by increasing the surface area exposed to the flow. This force follows after the initial impact force of the debris. This can be calculated by replacing the width of the structure with the width of the jammed debris, thus increasing the force.

Different load combination was considered based on the typical time series of th complex combination of stor surge pressures. Table 7 show the estimated pressure per masonry dimensions. For example, point A in Fig. is characterized by rising floodwater at the face of the masonry wall. It was assumed that the floodwater exerts a hydrostatic pressure of 16.19 kPa. This load combination was based on the FEMA Coastal Construction Manual.

Table 7: Storm surge pressure load for different wall dimensions.

		Load Combination	3x3m wall (kPa)	3x4m wall (kPa)	3x2.5m wall (kPa)
A	Rising Floodwater	Hydrostatic	16.19	16.19	16.19
B	Floodwater with surge (Impulsive)	Combined Hydrostatic with Impulsive	21.14	19.90	22.13
C	Floodwater with surge	Combined Hydrostatic with hydrodynamic	19.49	18.67	20.15
D	Floodwater with Debris	Combined Hydrostatic and hydrodynamic with debris impact	33.73	29.35	33.28
E	Debris Damming	Combined Hydrostatic with hydrodynamic	-	-	-
F	Increasing Debris Impact	Combined Hydrostatic and hydrodynamic with increase debris impact	>33.74	>29.35	>33.28

5.4 Lateral Pressure Capacity of Masonry Walls

In order to organize the difference between each masonry wall design. Design specifications were categorized as: S-Category, C-Category, B-Category, and D-Category as shown in the Table 8. To investigate the maximum pressure capacity of masonry walls using yield line method, different combination per category was considered. For example, the non-engineered masonry walls are under S1-C1-B2 Category. The NSCP 2015 Compliant design is under S2-C1-B2 and the ACI530-02 is under S2-C2-B2. Yield pattern defends on the nominal moment capacity (see Eq. 4.4d) and dimensions of the masonry wall under D-Category (see Table 8). Masonry wall under D1 exhibits yield line patter 1, D2 for yield line pattern 2, and D3 for yield line pattern 3.

Table 8: Category per design specification of masonry wall

Spacing of Rebar			CHB Thickness		Rebar Diameter		Wall Dimension (w x h)	
S-Category			C-Category		B-Category		D-Category	
S1	HOR.	Every 4th CHB Layer	C1	10cm	B1	8mmØ	D1	3 x 3m
	VERT.	Every 80cm O.C.						
S2	HOR.	Every 3rd CHB Layer	C2	15cm	B2	10mmØ	D2	4 x 3m
	VERT.	Every 60cm O.C.						
S3	HOR.	Every 2nd CHB Layer	C3	20cm	B3	12mmØ	D3	2.5 x 3m
	VERT.	Every 40cm O.C.						

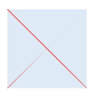
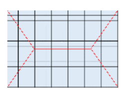
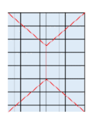
The list of different masonry design was organize in Table #. The effective compression width per bar is the least of the following: (a) Center-to-center bar spacing, (b) six times the wall thickness, (c) 72 inches (1829mm). For masonry design with 10cm thick CHB (C1) or steel reinforcement spaced at 60cm O.C. (S2), the governing effective compression width per bar is 600mm. For masonry design with steel reinforcement with steel reinforcement spaced at 40 cm O.C. (S3), the effective compression width per bar is 400mm. Tensile force can be calculated using $T = A_s f_y$, where A_s is the cross-sectional area of a single steel bar and f_y is the yield strength equal to 27 MPa. Once the effective width and tensile force per bar has been calculated, the depth of the compression block can be calculated by $a = \frac{(A_s f_y + P_u)}{0.80 f'_m b}$, where f'_m is equal to 6.89 MPa. With these, the nominal moment capacity can now be calculated by $M_n = (A_s f_y + P_u)\left(d - \frac{a}{2}\right)$. The results of analytical analysis is provided in Appendix.

Table 9: Specification per masonry wall

			Wall Design Specifications					
			Spacing of Reinforcement		CHB Dimensions			Rebar
			Horizontal	Vertical	Length (mm)	Height (mm)	Thickness (mm)	Diameter (mmØ)
S1	C1	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	8
S1	C1	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	10
S1	C1	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	12
S1	C2	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	8
S1	C2	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	10
S1	C2	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	12
S1	C3	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	8
S1	C3	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	10
S1	C3	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	12
S2	C1	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	8
S2	C1	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	10
S2	C1	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	12
S2	C2	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	8
S2	C2	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	10
S2	C2	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	12
S2	C3	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	8
S2	C3	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	10
S2	C3	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	12
S3	C1	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	8
S3	C1	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	10
S3	C1	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	12
S3	C2	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	8
S3	C2	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	10
S3	C2	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	12
S3	C3	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	8
S3	C3	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	10
S3	C3	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	12

Yield line pattern is governed by the following criteria (see Table #) where $\frac{M_{nx}}{M_{ny}}$ is the ratio of the nominal moment capacity along x and y. While $\frac{a^2}{b^2}$ is the ratio of the squared of the width and height of the masonry wall. Masonry walls under D1: 3x3m has yield line pattern 1. Masonry walls under D2: 4x3m has yield line pattern 2 . Masonry walls under D3: 2.5x3m has yield line pattern 3 as shown in Table 10.

Table 10: Maximum pressure capacity using yield line method

Yield Pattern		Criteria	Wall (a x b)	Maximum Pressure
Pattern 1		$\frac{M_{nx}}{M_{ny}} = \frac{a^2}{b^2}$	D1: 3 x 3m:	$\frac{w_u}{\emptyset} = 12\left(\frac{M_{nx}}{a^2} + \frac{M_{ny}}{b^2}\right)$
Pattern 2		$\frac{M_{nx}}{M_{ny}} < \frac{a^2}{b^2}$	D1: 4 x 3m	$\frac{w_u}{\emptyset} = \frac{24a(M_{nx} + M_{ny})}{2b^2x + 3b^2(a - 2x)}$
Pattern 3		$\frac{M_{nx}}{M_{ny}} > \frac{a^2}{b^2}$	D1: 2.5 x 3m	$\frac{w_u}{\emptyset} = \frac{24b(M_{nx} + M_{ny})}{2a^2y + 3a^2(b - 2y)}$

Once the yield line pattern has been identified by using the given criteria, the maximum pressure capacity using yield line method was calculated (see Table 10). Derivation of equations for Table 10 is provided in Appendix B. This analytical analysis was performed in all the masonry walls with varying design specification. The maximum pressure capacity per masonry wall design was shown in Table 11. In order to determine the sufficiency of the design, Fig. 28 provides a comparison in the maximum pressure capacity and storm surge pressure for each masonry wall design.

Two compressive strength of CHB, f'_m were considered: (1) Non-load bearing, (2) Load bearing CHB. Non-load bearing CHB has less compressive strength compared to load bearing CHB since there are design to function differently. The minimum f'_m

required for load bearing CHB was 6.89 MPa, for non-load bearing CHB, it is 2.10 MPa (ASEP, 2016).

Considering load bearing CHB, non-engineered masonry walls under S1-C1 category CHB have an estimated maximum pressure capacity below the estimated pressure due to flood loads caused by storm surge. For example, S1-C1-B2 has an estimated pressure capacity of 10.32 kPa, 7.97 kPa and 12.53 kPa for wall dimension of 3x3m, 4x3m, and 2.5x3m respectively. This masonry design is not capable of resisting a lateral hydrostatic pressure of 16.19 kPa. The NSCP 2015 Compliant design, S2-C1-B2 has an estimated pressure capacity of 10.32 kPa, 7.97 kPa and 12.53 kPa for wall dimension of 3x3m, 4x3m, and 2.5x3m respectively. The ACI-530-02 Compliant design has an estimated pressure capacity of 15.65 kPa, 12.10 kPa and 19.01 kPa for wall dimension of 3x3m, 4x3m, and 2.5x3m respectively. Based on these result, the ACI530-02 Compliant design can sustain floodloads under static condition. Additional improvements must be considered against hydrodynamic and impulsive forces during storm surge events.

A summary of maximum pressure load for different masonry wall design is provided in Table 11. There is a minimal difference in the pressure capacity considering two different compressive strengths. A maximum of 20.93% difference in maximum pressure capacity (S3-C1-B3) between the non-load bearing and load bearing CHB.It can be generalized that the strength of the masonry wall is dependent to the spacing of reinforcement.

Table 11: Result of yield line method per masonry design

Wall Design			Non-Load Bearing CHB, (A) Maximum Pressure Capacity			Load Bearing CHB, (B) Maximum Pressure Capacity		
			D1	D2	D3	D1	D2	D3
			3x3m	4x3m	2.5x3m	3x3m	4x3m	2.5x3m
S1	C1	B1	6.36	4.91	7.72	6.68	5.17	8.12
S1	C1	B2	9.52	7.36	11.57	10.32	7.97	12.53
S1	C1	B3	12.99	10.04	15.78	14.64	11.31	17.78
S1	C2	B1	7.42	5.73	9.01	7.60	5.87	9.23
S1	C2	B2	11.36	8.78	13.80	11.80	9.12	14.34
S1	C2	B3	15.95	12.32	19.37	16.87	13.04	20.50
S1	C3	B1	9.98	7.71	12.12	10.16	7.85	12.34
S1	C3	B2	15.36	11.87	18.65	15.80	12.21	19.20
S1	C3	B3	21.71	16.78	26.37	22.63	17.49	27.49
S2	C1	B1	6.36	4.91	7.72	6.68	5.17	8.12
S2	C1	B2	9.52	7.36	11.57	10.32	7.97	12.53
S2	C1	B3	12.99	10.04	15.78	14.64	11.31	17.78
S2	C2	B1	9.77	7.55	11.87	10.10	7.80	12.27
S2	C2	B2	14.86	11.48	18.05	15.65	12.10	19.01
S2	C2	B3	20.67	15.98	25.11	22.32	17.25	27.11
S2	C3	B1	13.18	10.19	16.02	13.51	10.44	16.41
S2	C3	B2	20.19	15.60	24.53	20.98	16.22	25.49
S2	C3	B3	28.35	21.91	34.44	30.00	23.18	36.44
S3	C1	B1	9.19	7.10	11.16	9.92	7.67	12.05
S3	C1	B2	13.43	10.38	16.31	15.22	11.76	18.48
S3	C1	B3	17.71	13.69	21.51	21.41	16.55	26.01
S3	C2	B1	14.31	11.06	17.38	15.04	11.62	18.27
S3	C2	B2	21.43	16.56	26.03	23.21	17.94	28.20
S3	C2	B3	29.23	22.59	35.50	32.93	25.45	40.01
S3	C3	B1	19.43	15.01	23.60	20.16	15.58	24.49
S3	C3	B2	29.43	22.74	35.75	31.21	24.13	37.92
S3	C3	B3	40.75	31.49	49.50	44.45	34.36	54.00

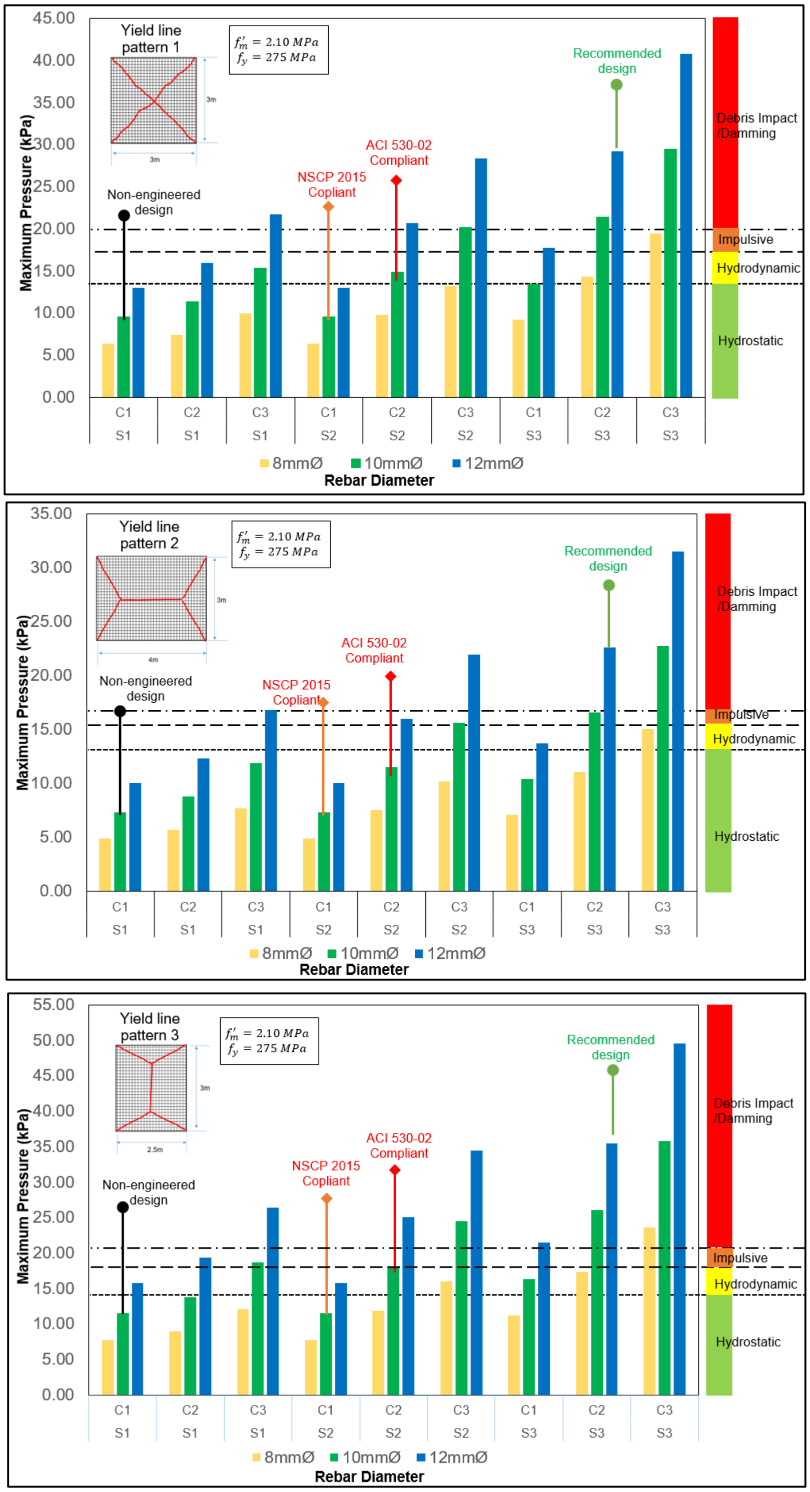


Figure 28: Maximum pressure capacity of masonry walls with load bearing CHB, $f'_m = 2.10\ MPa$: (a) 3x3m, (b) 4x3m and (c)2.5x3m using yield line method.

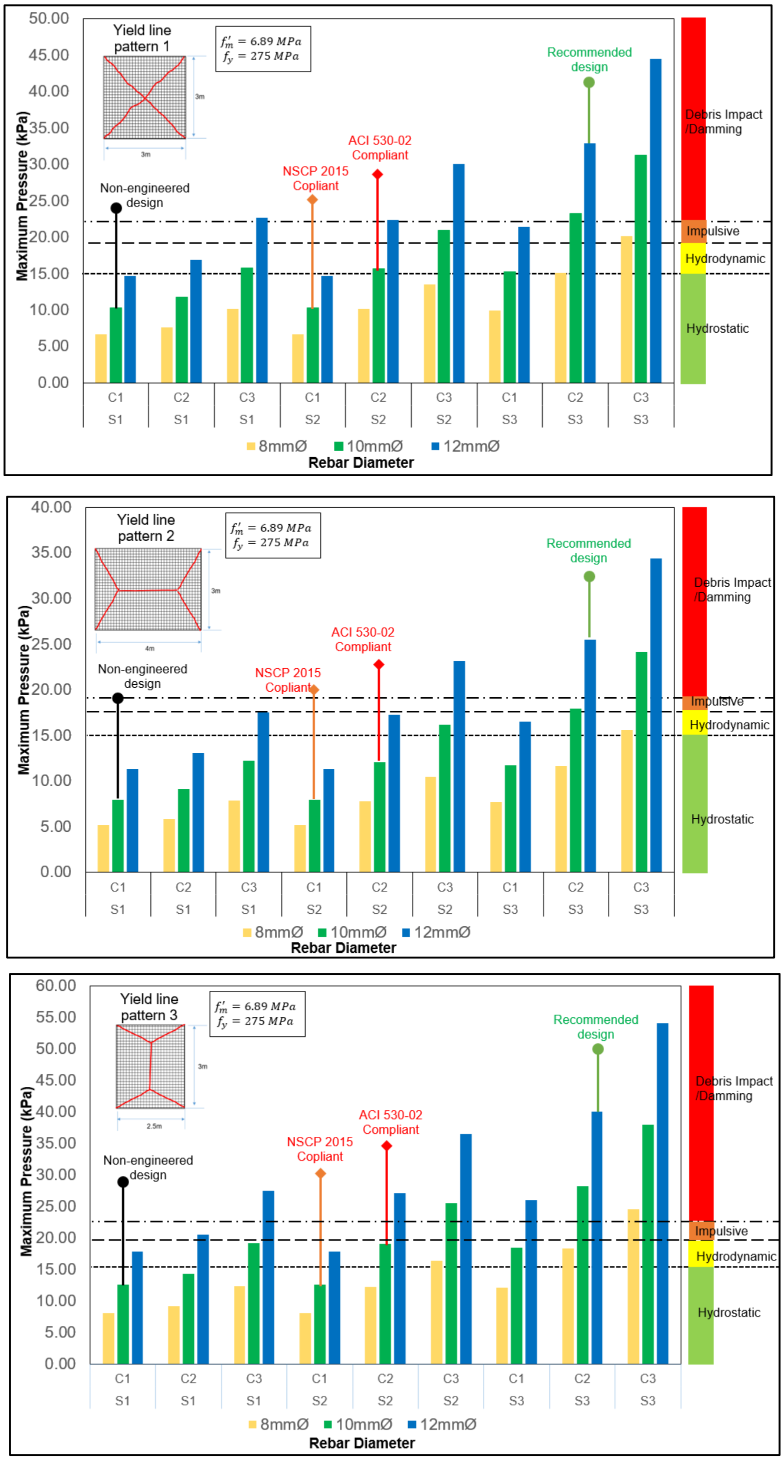


Figure 29: Maximum pressure capacity of masonry walls with load bearing CHB, $f'_m = 6.89\ MPa$: (a) 3x3m, (b) 4x3m and (c)2.5x3m using yield line method.

5.5 Development of the Improvement

Considering the estimated maximum pressure capacity of the non-engineered masonry walls using yield line method, it is evident that this current masonry wall design has experienced difficulty in sustaining lateral pressure due to floodwater induced by storm surges. The researcher conducted several attempts to improve the lateral pressure capacity of the masonry walls by: (1) Minimizing the on-center distance of the steel reinforcements, (2) Increasing the CHB wall thickness from 4" to 6" and 8" thick, (3) Providing a larger steel rebar diameter (see Fig. 29).

Comparing all the estimated lateral pressure capacity of each masonry wall design, the recommended design is S3-C2-B3 because of the following reason: (1) Capacity to sustain impact forces, (2) minimal addition in construction works, (3) architectural consideration, and (d) minimal cost increase.

The S3-C2-B3 is masonry design whose vertical and horizontal reinforcements are 12mmØ spaced @ 60cm, CHB thickness of 150mm or 6" and the column distance is from 2.5 to 3meters (see Fig. 29). The S2-C2-B3 has the estimated lateral pressure capacity that is sufficient enough to resist impulsive forces and debris impact. The S3-C2-B3 can be upgraded to C3 category to improve resistance to sever debris impact. Based on the information obtained from the results of the investigation and analytical analysis, the points of improvement to upgrade the lateral pressure capacity of masonry walls are identified. The concept of improvement is to reinforce the strength of the masonry walls with minimum cost increase. The proposed improvements are listed in Table 13.

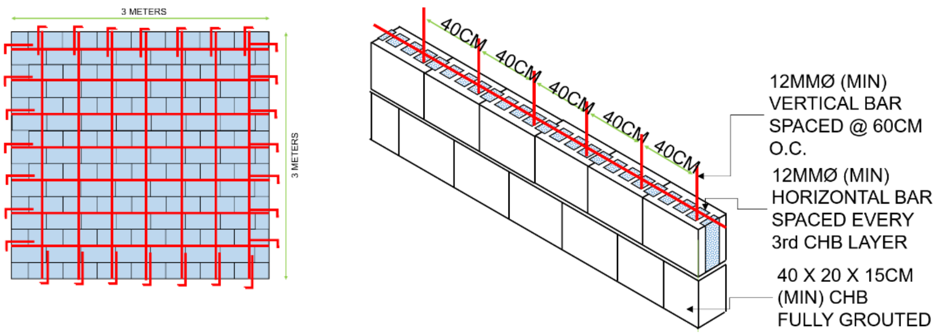


Figure 30: Detail plan of the recommended design for a 3x3m. masonry walls.

Table 12: Structural details of different masonry wall as per design consideration

Part	**Non-engineered design**	**NSCP 2015**	**ACI 530-02**
Horizontal Reinforcement	Every 4th CHB Layer	Max. of 1.2meter or as specified by a structural engineer.	Max. of 1.2meter or as specified by a structural engineer.
Vertical Reinforcement	Every 80cm O.C.	Max. of 1.2meter or as specified by a structural engineer.	Max. of 1.2meter or as specified by a structural engineer.
Thickness of CHB	10 cm Thick CHB	10 cm Thick CHB or 1/30 the lesser of the unsupported length and unsupported height (NSCP 2015 Table 411.3.1.1)	Minimum of 6" or 152mm (ACI 530-02 Sec. 5.6.2)
Bar Size	Max. of 10mmØ	Min. of 10mmØ	Min. of 10mmØ
Spacing of Support (Column)	Min of 3 m.	l/t or h/t is 18 to 20 or 2.7 to 3meters	l/t or h/t is 18 to 20 or 2.7 to 3meters
Joint Mortar for CHB	Partially	Partially/Fully	Partially/Fully
Masonry wall Covering	Not plastered		
CHB Layout	Running and Stack Bond	Running and Stack Bond	Running and Stack Bond

Table 13: Structural details of recommended masonry design per hazard zone.

Part	**Recommended design per hazard zone**		
	Low	Moderate	High
Horizontal Reinforcement	Every 3rd CHB Layer	Every 3rd CHB Layer	Every 2nd CHB Layer
Vertical Reinforcement	Every 60cm O.C.	Every 60cm O.C.	Every 40cm O.C.
Thickness of CHB	15 cm Thick CHB	15 cm Thick CHB	15 cm-20cm Thick CHB
Bar Size	Min. of 12mmØ	Min. of 12mmØ	Min. of 12mmØ
Spacing of Support (Column)	2.5 to 3 meters	2.5 to 3 meters	2.5 to 3 meters
Joint Mortar for CHB	Fully	Fully	Fully
Masonry wall Covering	20mm plastering	20mm plastering	20mm plastering
CHB Layout	Running Bond	Running Bond	Running Bond

Cracking pressures were estimated using the Staad Pro V8 computer program; four models of 3 x 3m masonry walls were developed, one for each design considerations studied namely: (1) non-engineered masonry, (2) NSCP 2015 Compliant, (3) ACI 530-02 Compliant, and the (4) recommended design. Material properties per masonry design is summarized in Table 14.

Table 14: Summary of the design parameters per masonry design consideration.

Model	Non-engineered design	NSCP 2015 Compliant	ACI 530-02 Compliant	Recommended design
Rebar Diameter	10mmØ	10mmØ	10mmØ	12mmØ
Spacing of Rebar	80cm O.C.	60cm O.C.	60cm O.C.	40cm O.C.
CHB Thickness	10cm	10cm	15cm	15cm
Wall Dimension	3x3m	3x3m	3x3m	3x3m

The masonry wall was modelled as a surface meshed by square elements of 0.20x0.20m of 4 nodes and 6 degrees of freedom per node exactly in the same way for all masonry design. Figure 30 show the details of reinforcement in each masonry design. Reinforcement for non-engineered design was spaced at 80cm O.C. both vertical and horizontal. Both NSCP2015 and ACI530-02 Compliant design has reinforcement spaced at 60cm O.C. both vertical and horizontal. For the recommended design, reinforcement was spaced at 40cm O.C. both vertical and horizontal.

Figure 31: Detailig of reinforcement is Staad Pro V8 per masonry as per (a) non-engineered, (b) NSCP2015/ACI530-02, and (c) recommended design.

For the boundary condition, hinge supports were located along the confining elements to simulate the presence of columns and ring beams. The endpoints of the reinforcements were considered fixed to consider the effects of embedment to the supports. The mortar joints are not modelled directly as elements. The interface between blocks are assumed to be perfectly bonded. For the blocks, the behavior is considered elastic. Horizontal and vertical reinforcements are modelled using 1D elements and their behavior is considered as elastic perfectly plastic (see Fig. 31).

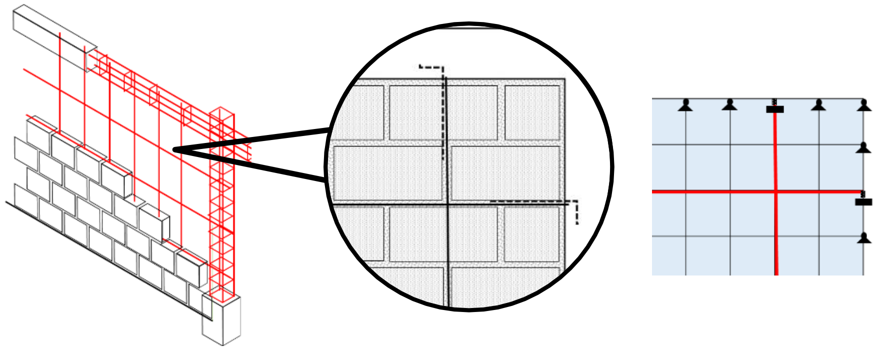


Figure 32: Support condition

The masonry walls were modelled using a structures mesh with square shell elements of 4 nodes and 6 degrees of freedom per node. The masonry wall was modelled using the corresponding CHB thickness per design consideration. Constitutive model used for the masonry walls was isotropic linear elastic; modulus of elasticity of masonry wall was $550f'_m$, where f'_m was 6.89Mpa based on the minimum compressive strength of masonry required. Modulus of elasticity and yield strength of steel reinforcement was 200 GPa and 275 Mpa, respectively. Poisson's ratio was assumed equal to 0.20.

Increasing uniform lateral pressure was applied perpendicular to the face of the masonry walls and the corresponding maximum lateral displacement was determined (see Fig. 32). These procedures were performed with increasing pressure to the four masonry wall design. In each pressure load, the corresponding maximum midheight deflection is determined. The results were graphically represented in Fig. 33. Based on the ACI 530-02 Sec. 3.2.5.6, the maximum midheight displacement is limited to 0.007h or 21mm where h is the height of the masonry wall.

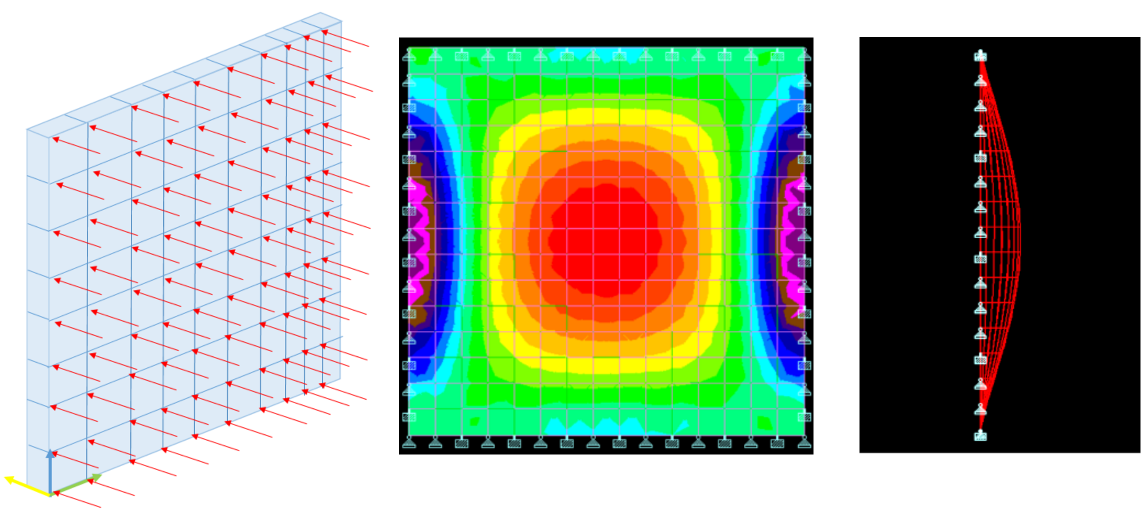


Figure 33: (a) Loading, (b) stress distribution, (displacement) for masonry walls using Staad Pro V8.

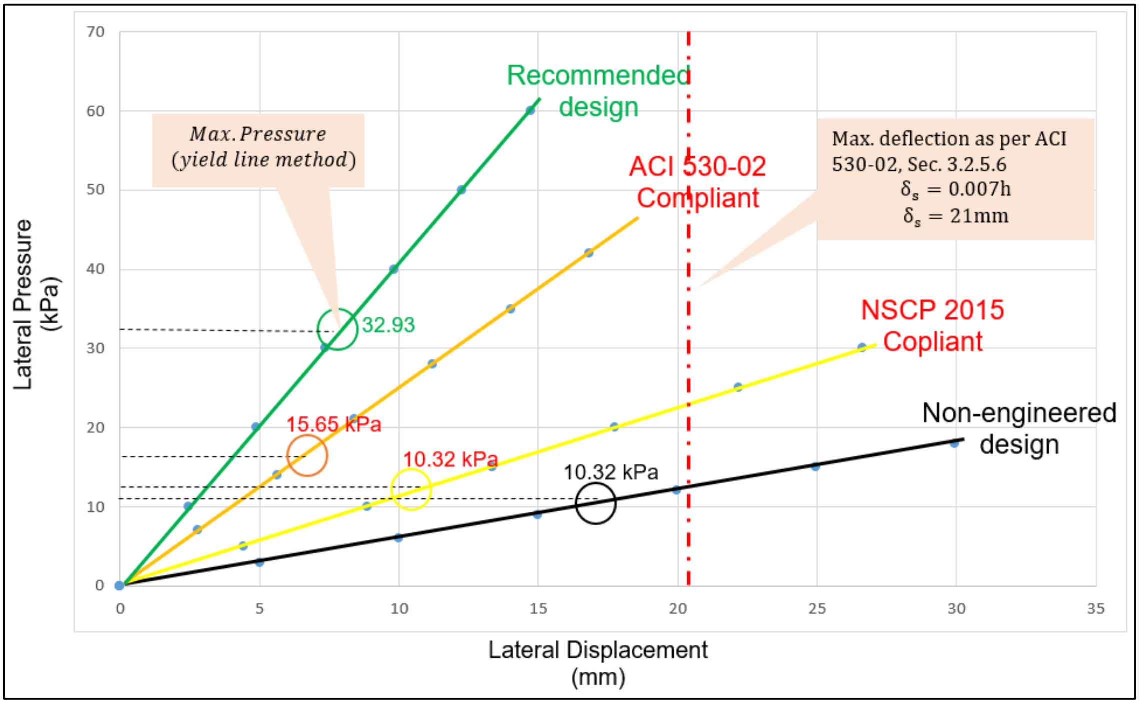


Figure 34: Lateral Pressure-displacement curve for different design consideration.

	Non-engineered design							NSCP 2015 Compliant Design						
Max. midheight deflection (mm)	0.00	4.99	9.99	14.98	19.98	24.97	29.96	0.00	4.44	8.88	13.33	17.77	22.21	26.65
Lateral Pressure (kPa)	0	3	6	9	12	15	18	0	5	10	15	20	25	30

	ACI 530-02 Compliant Design							Recommended design						
Max. midheight deflection (mm)	0.00	2.80	5.62	8.42	11.22	14.04	16.84	0.00	2.46	4.90	7.36	9.82	12.26	14.72
Lateral Pressure (kPa)	0	7	14	21	28	35	42	0	10	20	30	40	50	60

Increasing the CHB wall thickness and reducing the spacing of reinforcement significantly improves the lateral pressure capacity and reduce the lateral displacement of the masonry walls. The recommended design can sustain lateral pressure 2 to 3 times of the non-engineered masonry walls considering a 10mm lateral displacement. This may represent the difference in lateral pressure capacity for fully grouted, well-plastered masonry walls with different design considerations. Although it refers to a wide range of structural details and construction works, the key points of the improvements are as follows:

1. Increase steel reinforcement ratio
2. Increase the strength of the concrete by controlling the concrete mixture and the amount of water
3. Minimize the distance of column to provide adequate lateral support.
4. Adequate rebar joint lapping length.
5. Use 12mm rebar to minimize the cost increase.

Sample detail plan for the recommended masonry wall design is shown in Fig. 34. The concrete hollow block must be 40x20x15cm fully grouted with mortar that complies with ACI standards. The reinforcement must by spaced at 40cm on center. Intersection of steel bars must be tied by galvanized iron wire with adequate gauge number. The first CHB layer must be laid on a wall footing designed by the structural engineer.

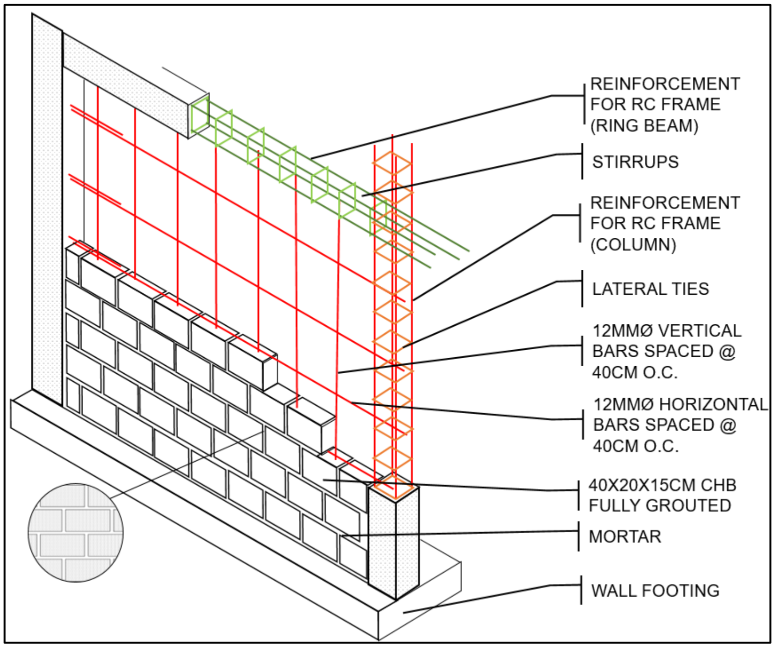


Figure 35: Detailed plan for the recommended masonry wall design.

As for the cost of the construction, a construction foreman calculated the direct cost both for the non-engineered design vs the recommended design for a 3 x 3-meter wall. Figure 35 shows that the cost increase is about 15%. According to the interview to the local residents, some of the people answered that 15% cost increase is in the acceptable level. It means that the more cost reduction is necessary for promoting a better construction.

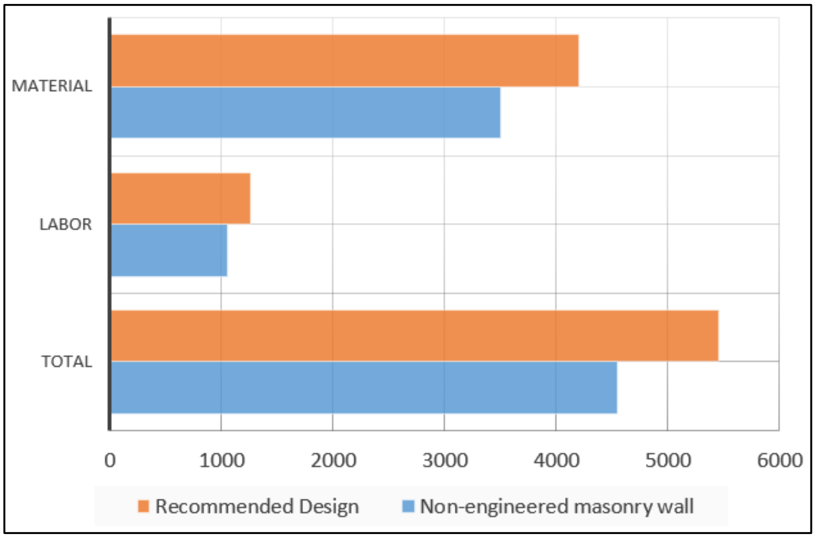


Figure 36: Comparison of Direct Construction Cost of a 3 by 3-meter masonry wall using the non-engineered design and the recommended .design.

Chapter Six

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the field surveys and the corresponding analytical results of the assessment of the out-of-plane failure of non-engineered masonry walls due to Typhoon Haiyan-induced storm surges, the following conclusions and recommendations are presented:

- Existing codes for large RC frame structures had performed well during Typhoon Haiyan, however, the current construction method for masonry walls for coastal structures has high vulnerability to OOP failures due to poor construction methodology and insufficiend design considerations.
- NO Build Zone Policy along coastal barangays was not totally implemented due to economical and social considerations. The existing 40m. (max) is not enough to guarantee that coastal structures are safe against structural damage due to impending storm surges.
- A standard design for masonry walls was established. Additional improvements must be considered for structures with high exposure to heavy debris. The resultscan be used as simple basis for evaluating coastal low-rise structures that are vulnerable to total failure during extreme typhoons.
- The out-of-plane pressure capacity of the recommended masonry wall design was observed to range 2 to 3 times of the current non-engineered masonry walls. The results of the analytical model show that reducing the spacing of reinforcement can increase the strength and ductility of the masonry walls. However, further experimental investigations are required to investigate the real OOP deformation on masonry walls.
- Based on the analytical analysis, the OOP lateral strength of the masonry walls is directly proportional to the compressive strength of masonry block, and inversely proportional to the ratio of height to thickness. Comparison between the yield line

method and FEM model resulst shows that there is a direct and acceptable results in terms of pressure capacityies. However, future researches on both static and dynamic OOP behavior of masonry walls is still needed.

6.2 Recommendations

To achieve a much lower fatality count, there is a need to strengthen the structures against natural hazards. Building codes and hazard zoning may be enough for large structures, however this must be implemented at the barangay level and develop a culture of preparedness. Although this is already embodied in our laws, its actual implementation leaves must be desired.

The Philippines is visited by 20 cyclones each year and storm surges are common. The one that happened in the central Philippine region during Typhoon Haiyan is perhaps the most powerful in recent history and it will not be the last of its kind. The sooner the implementation of the improvements of hazard proof designs , the better the people and the structure can respond to any warning if an impending storm surge hazard.

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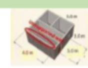
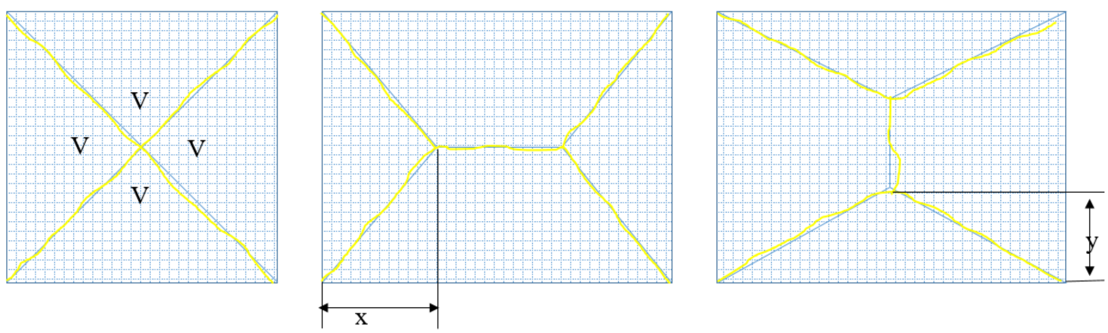
APPENDIX A
Survey Questionnaire

PERSONAL NG INPORMASYON		HOUSE NO:
PANGALAN:		
TIRAHAN:		
Street	Barangay	
EDAD:		

No.			
1	Who built or designed my house?		
	A	Built or designed by a licensed civil engineer/architect.	
	B	Not built by a licensed civil engineer/architect	
	C	It is not clear or unknown	
2	How old is my house?		
	A	Built in or after 2013	
	B	Built before 2013	
	C	It is not clear or unknown	
3	Has my house been damaged by past Typhoon Yolanda last 2013?		
	A	YES, totally damaged	
	B	YES, but partially damaged	
	C	It is not clear or unknown	
4	Has my house been totally flooded during Typhoon Yolanda?		
	A	YES, water reaches roof level	
	B	NO, partially flooded	
	C	It is not clear or unknown	
5	How far is my house from the shoreline?		
	A	20-40 meters	
	B	40-100 meter	
	C	It is not clear or unknown	
6	What is the shape of the house?		
	A	Regular (symmetrical, rectangular, box-type, simple	
	B	Irregular/Complicated	
	C	It is not clear or unknown	
7	Has my house been extended to two storey?		
	A	YES	
	B	NO	
	C	It is not clear or unknown.	
8	Are the external walls of my house 6-inch (150mm) thick CHB?		
	A	Yes, it is a 6-inch	
	B	NO, it is thinner than 6-inch	
	C	It is not clear or unknown.	
9	Are steel bars of standard size and spacing used in walls ?		
	A	YES (10mm diameter, tied and spaced correctly).	
	B	NO, fewer and smaller than 10mm.	
	C	It is not clear or unknown.	
10	What material is used as your column?		
	A	Made of timber	
	B	Made of concrete	
	C	It is not clear or unknown.	
11	What part of the house is damaged?		
	A	Roofing	
	B	Walls	
	C	It is not clear or unknown.	
12	What is the foundation of my house?		
	A	Reinforced concrete	
	B	Stones or unreinforced concrete	
	C	It is not clear or unknown.	
13	What is the soil conditions under my house?		
	A	Hard (rock or stiff soil)	
	B	Soft (muddy or reclaimed)	
	C	It is not clear or unknown.	
14	What is the overall condition of my house?		
	A	Good condition	
	B	Poor condition	
	C	It is not clear or unknown.	

APPENDIX B
Derivation for yield line method

Some of the three most common yield line patterns based on some research and experiements conducted are shown in the Fig.23. In Yield pattern No.1 , there is no unknown position of yield line patterns. Thus, the nodal forces V need not to be predetermined, and their value is dictated by statics alone. The unknowns x and y in yield line patterns Nos. 2 and 3 must be determined by means of differential calculus in the virtual work method.



Yield pattern No.1 Yield pattern No.2 Yield pattern No.3

Figure 37: Most common yield line pattern for masonry OOP failure
(Wang, Salmon, & Pincheira, 2007)

Analysis for yield line pattern No.1

Assuming a vertical deflection of Δ at the intersection of the diagonal yield lines in Fig.24, the deflection at the centroids of the four triangles A-B-C-D is $\Delta/3$. The work done at the collapse condition by the uniform load is the product of the total load on the entire panel and $\Delta/3$; thus

$$W = \frac{w_u}{\emptyset} ab\left(\frac{\Delta}{3}\right) \qquad (4.6.4.1)$$

The work done by the yield moments on the boundaries of all four slab segments, referring to Fig. 37, is

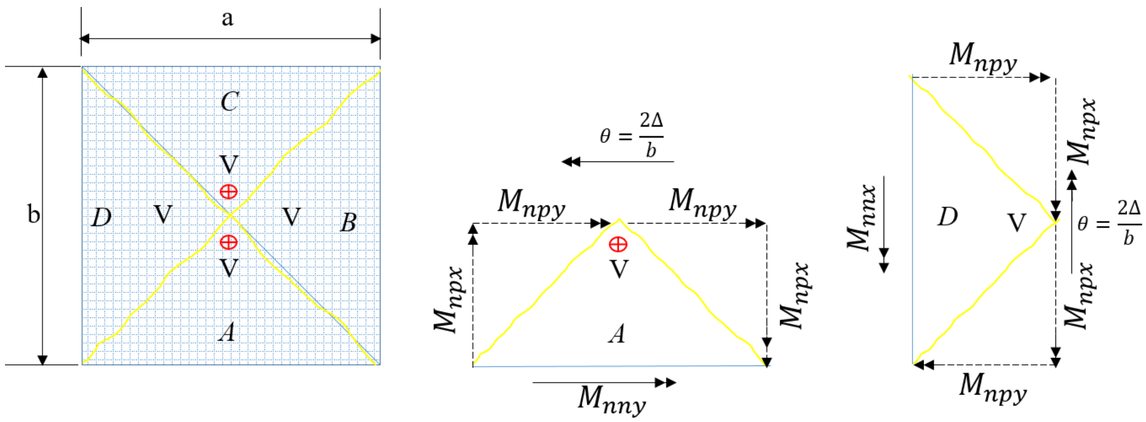


Figure 38:Analysis of yield line pattern No.1

$$W = 2(M_{nny} + M_{npy})(a)\left(\frac{2\Delta}{b}\right) + 2(M_{nnx} + M_{npx})(b)\left(\frac{2\Delta}{a}\right) \qquad (4.6.4.2)$$

Equating Eq.(4.6.4.1) to Eq.(4.6.4.2), and solving for w_u;

$$\frac{w_u}{\emptyset} = 12\left(\frac{M_{nnx} + M_{npx}}{a^2} + \frac{M_{nny} + M_{npy}}{b^2}\right) \qquad (4.6.4.3)$$

Alternately, the same solution is obtained using the equilibrium method. Taking moments about the lower edge of masonry segment *A* in figur#,

$$\frac{1}{2}\left(\frac{w_u}{\emptyset}\right) a \left(\frac{b}{2}\right)\left(\frac{b}{6}\right) + V\left(\frac{b}{2}\right) = (M_{nnx} + M_{nny})(a) \qquad (4.6.4.5)$$

Taking moments about the left edge of masonry segment *D* in Fig.24,

$$\frac{1}{2}\left(\frac{w_u}{\emptyset}\right) a \left(\frac{a}{2}\right)\left(\frac{a}{6}\right) = (M_{nnx} + M_{nny})(b) + V\left(\frac{a}{2}\right) \qquad (4.6.4.6)$$

Eliminating V between Eqs.(4.6.4.5) and (4.6.4.6) and solving for $\frac{w_u}{\emptyset}$, the same expression for $\frac{w_u}{\emptyset}$ as Eq.(4.6.4.3)

Analysis for yield line pattern No.2

Assuming a vertical deflection of Δ at the two points of intersection of the yield lines in Fig. 25, the work done at the collapse condition by the uniform load on the entire panel is

$$W = 2W_D + 2W_{A1} + 4W_{A2}$$

$$= 2[\frac{1}{2}\left(\frac{w_u}{\emptyset}\right)bx](\frac{2\Delta}{b}) + 2\left(\frac{w_u}{\emptyset}\right)(a-2x)(\left(\frac{b}{2}\right)\left(\frac{\Delta}{2}\right) + 4[\frac{1}{2}\left(\frac{w_u}{\emptyset}\right)x\frac{b}{2}]\left(\frac{\Delta}{3}\right)$$

$$= \frac{w_u}{\emptyset}\left(\frac{\Delta}{6}\right)(3ab - 2bx) \tag{4.6.4.7}$$

The work done by the yield moments on the boundaries of all four masonry segments is, referring to Fig.25

$$W = 2(M_{nny} + M_{npy})(a)\left(\frac{2\Delta}{b}\right) + 2(M_{nnx} + M_{npx})(b)\left(\frac{\Delta}{x}\right) \tag{4.6.4.8}$$

Equating Eq.(4.6.4.7) to Eq.(4.6.4.7) and solving for $\frac{w_u}{\emptyset}$,

$$\frac{w_u}{\emptyset} = \frac{12[b^2(M_{nnx} + M_{npx}) + 2ax(M_{nny} + M_{npy})(b)(\frac{\Delta}{x})}{b^2(3ax - 2x^2)} \tag{4.6.4.8}$$

Setting to zero the derivatice of Eq.(4.6.4.8)with respect to *x* gives the quadratic equation in *x*,

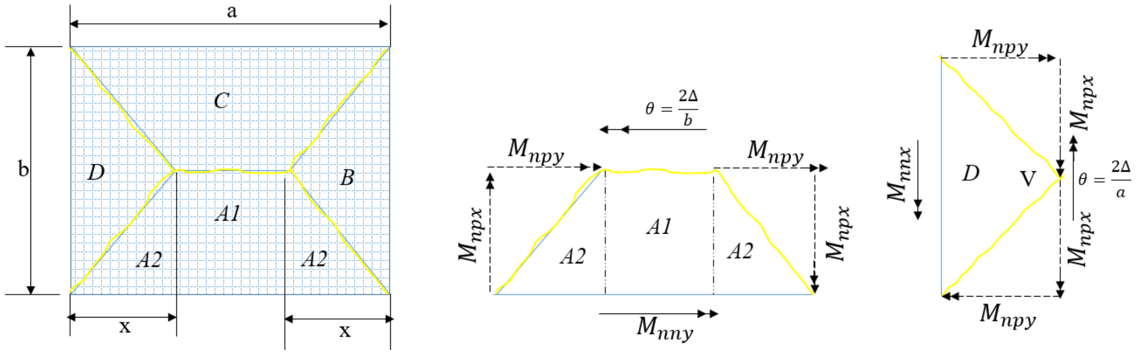


Figure 39:Analysis of yield pattern No.2

$$4a(M_{nny}+M_{npy})x^2+4b^2(M_{nnx}+M_{npx})x-[3ab^2(M_{nnx}+M_{npx})]=0 \quad (4.6.4.9)$$

Using the equilibrium mehod with *V=0* because there are three intersecting yield lines and taking the moments about the lower edge of masonry segments *A* in Fig.25,

$$2\left[\frac{1}{2}\left(\frac{w_u}{\emptyset}\right)x\frac{b}{2}\right]\left(\frac{b}{6}\right)+\left(\frac{w_u}{\emptyset}\right)(a-2x)\left(\frac{b}{2}\right)\left(\frac{b}{4}\right)=(M_{nny}+M_{npy})(a)$$

$$\frac{w_u}{\emptyset}=\frac{24a(M_{nny}+M_{npy})}{2b^2x+3b^2(a-2x)} \quad (4.6.4.10)$$

Taking moments about the left edge of masonry segment *D* in Fig.25.

$$\frac{1}{2}\left(\frac{w_u}{\emptyset}\right)bx\frac{x}{3}=(M_{nnx}+M_{npx})(b)$$

$$\frac{w_u}{\emptyset}=\frac{6(M_{nnx}+M_{npx})}{x^2} \quad (4.6.4.11)$$

Equating Eq.(4.6.4.10)to Eq.(4.6.4.11) gives the same quadratic equaition in *x* as Eq. (4.6.4.9)

The condition for *x=a/2* in Eq. (4.6.4.9) can be shown to be

$$\frac{M_{nnx}+M_{npx}}{M_{nny}+M_{npy}}<\frac{a^2}{b^2} \quad (4.6.4.12)$$

$$for\ x=\frac{a}{2}$$

which means that if the sum of positive and negative reinforcements in the *a-direction,* each per unit width of masonry wall, is equal to $\frac{a^2}{b^2}$ times the sum of positive and negative moment reinforcement in the *b-direction*, each per unit width of masonry wall, yield pattern No. 1 prevails.

The condition for $x<\frac{a}{2}$ in Eq.(4.6.4.9) can be shown to be

$$\frac{M_{nnx} + M_{npx}}{M_{nny} + M_{npy}} < \frac{a^2}{b^2} \qquad (4.6.4.13)$$

$$for\ x < \frac{a}{2}$$

which means that in order for yield pattern No. 2 to prevail, the reinforcement in the *a-direction* is less thab that for yield pattern No. 1 control.

Analysis for yield line pattern No.3

By interchanging the subscripts *x* and *y* as well as the quantities *a* and *b* in Eq.(4.6.4.8),(4.6.4.9),(4.6.4.10),and (4.6.4.11), the following equations applicable to yield line pattern No. 3 are obtained. The quadratic equation in *y* (Fig.25) is

$$4b(M_{nnx} + M_{npx})y^2 + 4a^2(M_{nny} + M_{npy})y - [3ba^2(M_{nny} + M_{npy})] = 0 \qquad (4.6.4.14)$$

Similarly, the expressions analogous to Eq…(4.6.4.8),(4.6.4.10),and (4.6.4.11) for $\frac{w_u}{\emptyset}$ in terms of *y* are

$$\frac{w_u}{\emptyset} = \frac{12[a^2(M_{nny} + M_{npy}) + 2by(M_{nnx} + M_{npx})]}{a^2(3by - 2y^2)} \qquad (4.6.4.15)$$

$$\frac{w_u}{\emptyset} = \frac{24b(M_{nnx} + M_{npx})}{2a^2y + 3a^2(b - 2y)} \qquad (4.6.4.16)$$

$$\frac{w_u}{\emptyset} = \frac{6(M_{nny} + M_{npy})}{y^2} \qquad (4.6.4.17)$$

The condition for $y < \frac{b}{2}$ in Eq.(4.6.4.14) can be shown to be

$$\frac{M_{nnx} + M_{npx}}{M_{nny} + M_{npy}} > \frac{a^2}{b^2} \qquad (4.6.4.18)$$

$for\ y < \frac{b}{2}$which means that in order for yield pattern No. 3 to prevail, the reinforcement in the *a-direction* is more than that for yield pattern No. 1 control . (Wang, Salmon, & Pincheira, 2007)

APPENDIX C
Result of On-site Survey in Tacloban City

NO	NAME	LOCATION	AGE	1			2			3			4			5			6			7			8			9			10			11			12			13			14		
				A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	Emanuel Collardo	Brgy 37, Reclamation Area	54		1			1			1		1				1			1			1			1				1	1			1					1		1			1	
2	Liezel Cahingcon	Brgy 37, Reclamation Area	51		1		1			1			1				1		1				1			1				1	1			1					1		1			1	
3	Enrico Consultado	Brgy 37, Reclamation Area	48		1			1		1			1			1			1			1				1			1				1	1					1		1			1	
4	Jane Fabi	Brgy 37, Reclamation Area	30			1		1		1			1			1					1		1			1				1	1			1					1	1				1	
5	Manuel Abugado Jr	Brgy 37, Reclamation Area	40		1		1			1			1				1			1			1			1		1			1				1				1			1		1	
6	Carlito Egonio	Brgy 37, Reclamation Area	46	1					1	1					1		1				1		1			1		1					1		1				1		1			1	
7	Christian Yman	Brgy 37, Reclamation Area	37		1			1		1			1				1			1		1			1			1				1			1		1				1		1		
8	Nezel Capentes	Brgy 37, Reclamation Area	37		1			1		1			1			1			1			1			1			1				1		1				1		1			1		
9	Judy Ann Miranda	Brgy 37, Reclamation Area		1			1			1			1			1			1			1			1			1			1				1			1			1		1		
10	Jocel Gacura	Brgy 37, Reclamation Area				1	1			1			1					1	1			1			1			1					1	1					1				1		
11	Maria Mellano	Brgy 37, Reclamation Area	70		1		1			1			1				1			1		1				1			1		1				1			1		1					1
12	Anna Rose Omlang	Brgy 37, Block 10 Lot 10	47		1			1		1			1			1				1		1				1		1				1		1			1				1			1	
13	Zeny Bucatcat	Brgy 37, Block 10 Lot 11	29		1			1		1			1				1			1		1			1			1				1			1		1			1			1		
14	Mark Anthony Mirall	Brgy 37, Reclamation Area			1		1			1			1				1				1	1					1	1				1			1				1	1			1		
15	Jocelyn Faigera	Brgy 37, Reclamation Area	42	1					1	1			1			1			1				1		1			1				1			1		1				1		1		
16	Jonrey A. Miranda	Brgy 37, Reclamation Area	24		1		1			1			1			1			1			1			1			1				1		1	1		1	1		1			1		
17	Florencia De Lira	Brgy 37, Reclamation Area	66		1			1		1			1				1		1				1				1			1	1			1					1	1				1	
18	Jejie T. Padoc	Brgy 37, Reclamation Area	25			1	1			1			1			1			1				1			1			1		1			1			1				1			1	
19	Alma S. Camora	Brgy 37, Reclamation Area	27		1		1			1				1			1		1			1				1		1				1		1			1			1				1	
20	Randy V. Colas	Brgy 37, Reclamation Area	34		1		1			1			1				1			1			1		1			1				1		1			1			1			1		
21	Elena Ecisa	Brgy 37, Reclamation Area			1		1			1			1			1				1			1		1			1				1			1		1			1				1	
22	Mcflowin H. Elago	Brgy. 66 Paseo	17		1				1	1			1			1				1				1		1				1			1	1					1		1				1
23	Myrna Maragrag	Brgy 37, Reclamation Area	35		1		1			1			1					1	1				1				1			1	1			1					1		1			1	
24	Teresita Gueza	Brgy 37, Reclamation Area	29		1			1		1			1			1				1			1			1				1	1			1					1		1			1	
25	Esyong Solayao	Brgy 37, Reclamation Area	32		1			1		1					1	1					1	1				1				1	1			1					1		1			1	
26	Mark M. Joseph	Brgy 66, Paseo	20		1			1		1			1			1				1			1			1			1		1			1					1		1			1	
27	Randy Tesones	Brgy 66, Paseo			1			1		1			1			1				1			1			1				1	1			1					1		1			1	
28	Eduardo Prasa	Brgy 66, Paseo	24		1			1		1			1			1				1			1				1			1	1			1					1		1			1	
29	Jovelyn Palad	Brgy 37, Reclamation Area	24		1			1		1			1			1				1			1			1			1				1	1					1		1			1	
30	Loveta Cinco	Brgy 37, Reclamation Area	36		1		1				1		1				1			1			1				1			1	1			1					1		1			1	
31	Kimberly Dacoycoy	Brgy 66, Paseo	16		1			1		1			1			1				1			1			1				1	1			1					1		1			1	
32	Beinvarido Molinto	Brgy 37, Reclamation Area	35		1			1		1			1				1			1			1			1				1	1			1					1		1			1	
33	Nonie M. Herida	Brgy 66, Paseo	18		1		1			1			1			1				1			1			1				1	1			1					1		1				1
34	Lea Tabadon	Brgy 66, Paseo	25		1			1		1			1			1				1		1				1		1				1		1				1			1			1	
35	Lea Bituin	Brgy 66, Paseo	27		1			1		1			1			1							1			1				1				1					1		1			1	
36	Diosdado Cinco	Brgy 66, Paseo	29		1			1		1			1			1				1			1			1				1			1	1			1				1				1
37	Christine Mae Siose	Brgy 66, Paseo	18		1				1	1			1			1					1		1			1				1			1	1					1		1				1
38	Nelsi Nuevo	Brgy 37, Reclamation Area	29		1			1		1			1			1				1			1			1		1			1			1					1		1			1	
39	Erlinda Mercado	Brgy 37, Reclamation Area	44		1			1		1			1			1				1			1			1				1	1			1					1		1			1	
40	Noel S. Macase	Brgy 66, Paseo	37		1				1	1			1			1					1	1				1				1	1			1					1		1				1
41	Teresita P. Husa	Brgy 37, Reclamation Area	51		1			1		1			1			1				1			1			1				1			1	1					1		1			1	
42	Rowena A. Sanchez	Brgy 66, Paseo	24		1			1		1			1			1				1				1		1				1	1					1			1		1			1	
43	Marian Diaz	Brgy 66, Paseo	24		1		1			1			1					1		1			1			1			1		1			1					1		1			1	
44	Mary Jane Centillas	Brgy 66, Paseo	28		1		1			1			1			1				1			1		1			1			1			1					1		1				1
45	Princess Charity Ung	Brgy 37, Reclamation Area	28		1			1			1		1				1		1				1		1			1				1		1			1			1			1		
46	Kemberlly L. Palad	Brgy 37, Reclamation Area	15			1	1			1					1		1				1	1			1			1				1		1					1			1		1	
47	Arjay Ballos	Brgy 37, Reclamation Area	46		1		1			1				1				1			1		1			1				1	1			1				1			1			1	
48	Cesar P. Edaniol	Brgy 37, Reclamation Area	58		1			1		1			1				1		1				1		1			1				1			1			1		1			1		
49	Roseta Cuyo	Brgy 37, Reclamation Area	48		1			1		1				1				1		1				1		1				1	1			1					1		1			1	
50	Ronnie Alberto	Brgy 37, Reclamation Area	23		1			1		1					1	1				1			1			1				1	1			1					1		1			1	

50	Ronnie Alberto	Brgy 37, Reclamation Area	23		1			1		1					1	1				1			1			1				1	1			1					1		1			1	
51	Celso Canones	Brgy 37, Reclamation Area	33		1		1			1			1					1	1			1				1				1	1			1					1		1			1	
52	Ma. Leonora M. Mar	Brgy 66, Paseo	52			1	1			1			1			1				1		1				1		1				1		1	1		1				1				1
53	Gregonia Ginigo	Brgy 37, Reclamation Area	69		1			1		1			1			1				1			1			1				1			1	1					1		1			1	
54	Harvey Montederam	Brgy 37, Reclamation Area	18	1				1		1			1			1			1			1			1			1				1		1			1			1			1		
55	Erry Gagarin	Brgy 37, Reclamation Area			1			1		1			1					1		1		1				1		1			1				1		1				1		1		
56	James Patrick E. Gir	Brgy 37, Reclamation Area	14	1				1			1		1			1			1			1			1			1				1			1			1		1			1		
57	Jesus Balderama	Brgy 37, Reclamation Area	29			1		1		1			1					1	1			1					1	1					1	1	1				1			1	1		
58	Marvin L. Espino	Brgy 37, Reclamation Area	18		1		1			1			1			1				1			1		1					1	1				1			1		1				1	
59	Philip B. Paclibare	Brgy 37, Reclamation Area	20		1		1			1				1			1		1			1			1			1			1				1			1			1		1		
60	Judith Sabuco	Brgy 37, Reclamation Area	45		1			1		1			1			1				1			1			1				1	1			1					1		1			1	
61	Sylvia Sulayao	Brgy 37, Reclamation Area	61		1			1		1			1			1				1			1			1				1	1			1					1	1				1	
62	Felix Laurente	Brgy 37, Reclamation Area			1			1		1			1			1				1			1			1		1			1			1					1	1				1	
63	Rogelio Sabuco	Brgy 37, Reclamation Area	65		1			1		1			1			1				1				1			1		1		1			1					1		1			1	
64	Francis Dave Canos	Brgy 66, Paseo	17			1		1			1			1			1			1			1		1			1			1			1			1			1			1		
65	Lorenz C. Comendad	Brgy 37, Reclamation Area	18			1	1			1			1			1				1			1			1				1	1				1				1	1				1	
66	Maria Tanola	Brgy 37, Reclamation Area	77		1			1		1			1			1				1		1				1			1		1			1							1			1	
67	Merlita Fabillar	Brgy 37, Reclamation Area	43		1			1		1			1			1				1				1		1				1	1			1					1		1			1	
68	Ricardo Guyo	Brgy 37, Reclamation Area	27		1			1		1			1				1			1			1			1				1	1			1				1			1			1	
69	Jomarie Padernal	Brgy. 67, Anibong	38	1					1		1			1			1		1			1			1			1				1		1				1			1		1		
70	Christopher Begnal	Brgy 37, Reclamation Area	57		1			1		1			1			1			1			1			1			1				1			1			1			1			1	
71	Segundina Ayon	Brgy 37, Reclamation Area	74		1			1		1			1			1			1				1			1		1			1			1			1				1			1	
72	Ailyn Baron	Brgy. 83-B San Jose	44			1		1			1			1			1			1			1			1		1				1				1			1		1				1
73	Evelyn Juntilla	Brgy. 83-B San Jose	34		1				1	1			1				1			1			1				1	1			1				1			1		1					1
74	Neressa Ponce	Brgy. Gulod, San Jose	62			1		1		1			1			1				1				1		1			1		1			1	1		1			1					1
75	Estela Linde	Brgy. 83-B San Jose	54		1				1		1		1				1				1		1			1				1			1	1			1				1			1	
76	Joson Villamor	Cogon, San Jose	21			1	1				1				1			1	1				1				1	1				1		1					1			1			1
77	Mario S. Perida	Brgy. 84 Cogon, San Jose	52			1		1		1			1					1			1	1				1				1	1				1				1			1			1
78	James C. Tusilero	Brgy. 83-A, Burayan, San Jose	19		1			1				1	1				1		1			1				1		1			1			1					1		1			1	
79	Juvius Sabusar	Brgy. 84 Cogon, San Jose	24			1		1			1		1				1			1			1		1					1			1	1				1			1			1	
80	Terry Misias	Brgy. 83-A, Burayan, San Jose	50		1				1		1		1				1		1				1				1		1		1				1				1	1				1	
81	Sylvia Daban	Brgy. 83-A, Burayan, San Jose	54		1		1			1				1		1				1		1				1			1		1			1			1			1			1		
82	Mateo Ronda	Brgy. 87, San Jose	49			1		1		1			1			1				1			1			1				1	1			1					1		1			1	
83	Samuel Vervoso	Brgy. 87, San Jose	60			1			1	1				1			1				1		1			1				1	1					1			1		1			1	
84	Donne Entereso	Brgy. 87, San Jose	61		1				1	1			1			1				1			1			1		1			1					1	1				1			1	
85	Jocelyn Vertudaso	Brgy. 83-B, Cogon, San Jose	86		1			1			1		1				1				1			1		1				1	1			1					1	1				1	
86	Marifel Rogero	Brgy. 83-B, Cogon, San Jose	29			1			1	1			1				1			1			1			1		1			1			1				1			1			1	
87	Regina Ronda	Brgy. 83-B, Cogon, San Jose	38			1			1		1		1				1		1					1			1			1		1		1				1		1				1	
88	Elsa Ortega	Brgy. 83-B, Cogon, San Jose	51			1		1			1			1			1				1			1		1				1			1			1	1				1			1	
89	Susan Rona Almade	Brgy. 87, San Jose	23			1		1				1	1				1			1		1					1	1				1				1		1			1			1	
90	Aurora Gerado	Brgy. 83-B, Cogon, San Jose				1		1			1				1		1			1			1			1				1	1			1			1			1				1	
91	Anthony Joy Bongca	Brgy. 84 Cogon, San Jose	29		1				1	1				1				1			1		1			1		1			1					1	1			1				1	
92	Pure Jabinal	Brgy. 84 Cogon, San Jose	27		1				1			1		1			1			1			1				1	1			1				1			1			1			1	
93	Roseanne Gapang	Brgy. 87, San Jose	47		1		1					1		1		1					1	1			1			1				1				1		1				1		1	
94	Raides Barrante	Brgy. 87, San Jose	27		1			1		1					1		1			1			1			1		1			1			1					1		1			1	
95	Aubric Palana	Brgy. 87, San Jose	26	1				1				1		1			1				1	1			1			1				1				1		1			1			1	
96	Alden B. Agapito	Brgy. 83-B, Cogon, San Jose	16			1		1		1				1			1			1				1		1			1			1		1			1				1			1	
97	Rapar Omir	Brgy. 83-B, Cogon, San Jose	59		1				1		1			1				1			1		1			1		1				1				1	1				1			1	
98	Faith P. Abdon	Purok 2, Brgy. 95, San Jose	21		1				1	1			1					1		1			1			1				1		1				1	1				1			1	
99	Gil Noybas	Brgy. 83-C, Taguiktik, San Jose	25		1			1		1				1				1			1		1				1			1	1					1		1				1		1	
100	Macky Candelario	Brgy. 83-C, Taguiktik, San Jose	19		1				1	1				1			1			1			1			1				1			1		1				1		1			1	

100	Macky Candelario	Brgy. 83-C, Taguiktik, San Jose	19		1					1	1				1			1			1			1			1				1			1		1					1		1			1	
101	Francis T. Capada	Brgy. 83-C, Taguiktik, San Jose	15		1			1		1			1			1						1		1			1				1					1					1		1			1	
102	Floriza Arguilles	Brgy. 83-C, Taguiktik, San Jose	47			1		1			1			1			1				1			1		1				1			1		1		1				1		1			1	
103	Sergio Abequibel	Brgy. 83-C, Taguiktik, San Jose	46			1		1			1			1			1				1	1			1			1					1			1		1			1			1	
104	Samuel Alera	Brgy. 84 Cogon, San Jose	69			1		1		1				1				1				1				1			1		1				1				1		1			1	
105	Carlos De La Cruz	Brgy. 83-A, Burayan, San Jose	43			1		1			1				1			1			1	1				1		1					1			1	1				1			1	
106	Maria T. Arpon	Brgy. 83-C, Taguiktik, San Jose	30			1			1		1			1			1			1				1			1	1					1	1					1		1			1	
107	Melane Auila	Brgy. 83-C, Taguiktik, San Jose	17			1		1			1			1			1				1			1			1	1					1		1				1			1		1	
108	Cecilia Batas	Brgy. 83-C, Taguiktik, San Jose	58		1			1				1		1				1		1				1		1		1					1			1		1				1		1	
109	Mayel F. Lorendo	Brgy. 83-C, Taguiktik, San Jose	32	1				1		1			1				1			1		1				1		1			1			1					1			1		1	
110	Anastacio B. Nombr	Brgy. 83-A, Burayan, San Jose	83		1			1			1			1			1		1				1		1			1				1			1			1			1			1	
111	Edralyn C. De Los R	Brgy. 83-A, Burayan, San Jose	49		1		1			1			1				1			1		1				1			1		1			1				1		1				1	
112	Denny Garcia	Brgy. 84 Cogon, San Jose	45		1			1		1			1			1				1		1				1				1			1	1			1				1				1
113	Augusto B. Pulma	Brgy. 84 Cogon, San Jose			1			1			1			1			1			1			1		1			1				1				1	1				1		1		
114	Cornelia C. Oracion	Brgy. 83-C, Taguiktik, San Jose	19		1		1			1			1			1					1	1				1				1	1				1				1	1				1	
115	Liza Rohel	Brgy. 83-A, Burayan, San Jose	40	1				1			1		1			1			1			1			1			1				1			1		1	1			1			1	
116	Jerome N. Separa	Brgy. 83-A, Burayan, San Jose	34		1		1			1				1			1		1			1					1			1	1			1				1		1			1		
117	Renato Ay	Brgy. 84 Cogon, San Jose	55			1		1			1		1				1		1			1			1				1			1		1				1			1				1
118	Ronne Bida	Brgy. 87, San Jose	57		1			1			1			1				1		1			1		1			1				1				1			1		1				1
119	Rolando Torlo	Brgy. 87, San Jose	44		1				1		1			1		1				1			1				1		1				1			1			1	1				1	
120	Gladys Coppera	Brgy. 87, San Jose	21		1				1	1				1				1			1		1			1		1				1				1			1		1				1
121	Mylene Rose Gaspa	Brgy. 87, San Jose	49	1				1			1			1			1				1	1			1			1				1				1		1				1	1		
122	Jericho Nino Homer	Brgy. 87, San Jose	29		1				1	1			1			1					1		1			1		1			1			1					1		1				1
123	Melvin Mangnita	Brgy. 90, Paya-paya, San Jose	27		1		1			1			1			1				1			1			1				1	1			1					1		1			1	
124	Ronald Batica	Brgy. 90, Paya-paya, San Jose	34		1		1			1			1				1			1			1			1				1	1			1					1		1			1	
125	Edgar Cabibihan	Brgy. 77, San Jose	51			1		1		1			1					1		1			1		1			1				1		1			1			1				1	
126	Maria Luisa M. Mun	Brgy. 83-A, Burayan, San Jose	14		1		1			1			1				1			1			1			1		1			1			1			1			1			1		
127	Nenita Rosito	Brgy. 83-A, Burayan, San Jose	60		1		1			1			1				1			1			1			1				1	1			1					1		1			1	
128	Maria Christine C. R	Brgy. 83-A, Burayan, San Jose	26		1		1			1			1			1			1				1			1			1		1			1					1		1			1	
129	Vincent Barona	Brgy. 83-B, Cogon, San Jose	37		1				1	1			1				1		1				1			1			1		1			1					1		1			1	
130	Jaspher Guy	Brgy. 83-B, Cogon, San Jose	25		1		1			1			1				1			1			1			1			1		1			1					1		1			1	
131	Jovita Gumbre	Brgy. 83-B, Cogon, San Jose	59		1		1			1			1				1			1			1			1			1		1			1					1		1			1	
132	Juana Vanadora	Brgy. 83-A, Burayan, San Jose	77		1		1			1			1				1			1			1			1				1			1	1						1		1			1	
133	Erma Daban	Brgy. 83-A, Burayan, San Jose	40		1		1			1			1				1			1			1		1			1				1		1						1			1			1
134	Elizabeth Capno	Brgy. 83-A, Burayan, San Jose	42		1		1			1			1				1			1			1			1				1	1			1			1			1				1	
135	Diosdado Dabor	Brgy. 83-A, Burayan, San Jose	42			1	1			1			1				1			1			1			1				1	1			1					1		1			1	
136	Jepoy Jabinal	Brgy. 83-B, Cogon, San Jose	35		1		1			1			1				1		1				1			1			1		1			1					1		1			1	
137	Christine Go	Brgy. 83-B, Cogon, San Jose	81		1		1			1			1				1			1			1		1			1				1		1						1		1		1		
138	Maria Adona	Brgy. 83-B, Cogon, San Jose			1		1			1			1				1		1				1			1			1		1			1					1		1			1	
139	Jun Jun Bagari	Brgy. 83-B, Cogon, San Jose	52		1		1			1			1				1		1				1			1			1		1			1					1		1			1	
140	Rogelio A. Barcimor	Brgy. 83-A, Burayan, San Jose	61		1		1			1			1				1			1			1			1				1	1			1					1		1			1	
141	Christian Arman O. F	Brgy. 83-A, Burayan, San Jose	21		1		1			1			1				1			1			1			1				1	1			1					1		1			1	
142	Ramon Dizon	Brgy. 83-A, Burayan, San Jose	64		1		1			1			1				1			1			1			1				1	1			1					1		1			1	
143	Angie Villanueva	Brgy. 83-A, Burayan, San Jose	23		1		1			1			1				1			1			1			1				1	1			1					1		1			1	
144	Panlo C. Otic	Brgy. 83-A, Burayan, San Jose	44		1		1			1			1			1			1				1			1			1		1			1					1		1			1	
145	Ebeles Papito	Brgy. 83-A, Burayan, San Jose	52		1		1			1			1				1		1				1		1			1			1				1		1			1				1	
146	Jecer Carl B. Rebus	Brgy. 83-C, Taguiktik, San Jose	23		1		1			1			1				1			1			1			1				1			1	1						1			1		1	
147	Rhojan C. Dadula	Brgy. 83-C, Taguiktik, San Jose	15		1			1			1		1				1						1		1			1			1				1		1			1			1		
148	Ashley Joy Candelar	Brgy. 83-C, Taguiktik, San Jose	16		1		1			1			1				1		1				1			1				1	1			1					1		1			1	
149	Ma. Merlita H. Alem	Brgy. 83-C, Taguiktik, San Jose	47		1			1		1			1				1			1			1		1				1			1		1				1			1			1	
150	Julius Ralf B. Macan	Brgy. 85, Sogod, San Jose	18		1		1			1			1			1				1		1				1			1			1			1			1		1			1		

151	Kenny S. Adorza	Brgy. 83-A, Burayan, San Jose	18		1		1				1		1				1			1		1				1			1		1		1			1					1		1			1	
152	Ariel Lacaba	Brgy. 83-A, Burayan, San Jose	31		1		1			1			1				1			1			1				1	1			1			1					1	1				1	
153	Mark Lawrence L. Or	Brgy. 83-A, Burayan, San Jose	17		1		1				1		1				1		1							1				1	1			1					1		1		1		
154	Larry Gil D. Grantos	Brgy. 83-A, Burayan, San Jose	22		1		1			1			1				1			1			1			1				1	1			1					1		1		1		
155	Raizo Athecoso	Brgy. 83-B, Cogon, San Jose	25		1		1			1			1			1				1			1			1			1		1			1					1		1			1	
156	James Mia	Brgy. 83-B, Cogon, San Jose	40		1		1				1			1		1				1			1		1				1		1				1				1		1			1	
157	Eloenor Abajair	Brgy. 83-B, Cogon, San Jose	46		1		1			1			1				1			1			1			1			1		1			1					1		1			1	
158	Nelson Sanchez	Brgy. 83-B, Cogon, San Jose	43		1			1		1				1			1		1				1			1			1		1			1				1			1		1		
159	Angeline Go	Brgy. 83-B, Cogon, San Jose	34		1		1			1			1				1		1				1			1			1		1			1					1		1			1	
160	Enrique Soledo	Brgy. 83-A, Burayan, San Jose	40		1		1			1			1				1			1			1			1				1	1					1			1		1			1	
161	Boy Salcedo	Brgy. 83-B, Cogon, San Jose	48		1		1				1			1		1			1			1			1				1			1			1		1				1			1	
162	Juanita Vasaves	Brgy. 83-B, Cogon, San Jose	64		1		1			1			1				1			1			1			1				1	1			1					1		1			1	
163	Bobby Alapag	Brgy. 83-B, Cogon, San Jose	38		1		1			1				1		1			1				1			1			1		1			1					1		1		1		
164	Ian Barona	Brgy. 83-B, Cogon, San Jose	28		1		1			1			1				1		1				1			1				1	1			1					1		1			1	
165	Virgie Reposan	Brgy. 83-B, Cogon, San Jose	52		1		1			1			1				1			1			1			1				1			1	1					1		1		1		
166	Mark Reyes	Brgy. 83-B, Cogon, San Jose			1			1			1					1			1			1			1			1				1				1	1				1	1	1		
167	Ignacio Mendoza	Brgy. 83-B, Cogon, San Jose	52		1			1		1				1		1				1			1		1					1	1					1			1		1			1	
168	Joryl Piabad	Brgy. 83-B, Cogon, San Jose	19	1			1			1			1			1				1		1				1			1		1			1				1			1			1	
169	Homer Alonte	Brgy. 83-B, Cogon, San Jose	22		1		1			1			1				1			1			1			1				1	1			1				1			1			1	
170	Joel Carbita	Brgy. 83-B, Cogon, San Jose	26		1		1			1			1				1			1		1			1			1				1			1		1				1		1		
171	Angela Naputo	Brgy. 83-B, Cogon, San Jose	17		1		1			1			1				1		1			1			1			1				1			1		1				1		1		
172	Joseph Sarmento	Brgy. 83-B, Cogon, San Jose	27		1		1			1			1				1			1			1			1				1	1			1					1		1			1	
173	Cardo Cobilla	Brgy. 83-B, Cogon, San Jose	33		1		1			1				1			1			1			1			1			1		1			1					1		1			1	
174	Carlos Guarido	Brgy. 83-B, Cogon, San Jose	17		1		1			1			1				1			1			1			1				1	1			1					1		1			1	
175	Tienda Santiago	Brgy. 85, Sogod, San Jose	48		1		1			1			1			1			1				1			1			1		1			1					1		1			1	
176	Edgardo Balais	Brgy. 83-B, Cogon, San Jose	34		1		1			1			1				1		1				1			1			1		1			1					1		1			1	
177	Andrew Permejo	Brgy. 87, San Jose			1			1			1			1		1				1			1		1			1			1			1			1			1			1		
178	Calvin Pretencio	Brgy. 85, Sogod, San Jose	23	1				1		1			1			1			1			1			1			1				1		1			1				1		1		
179	Jerome Alcantara	Brgy. 87, San Jose	18		1		1			1			1			1				1			1			1				1	1			1					1		1			1	
180	Ryan Delantar	Brgy. 85, Sogod, San Jose	20	1				1		1			1			1				1		1			1			1				1		1			1				1		1		
181	Jay-Ar Atar	Brgy, Manlurip, San Jose	28	1				1			1			1			1		1			1			1			1				1		1	1		1				1			1	
182	Aljon Agita	Brgy. 85, Sogod, San Jose	33		1				1		1			1			1			1		1				1			1		1	1				1			1		1			1	
183	Noel Irzon Jr.	Brgy. 85, Sogod, San Jose			1		1			1			1			1			1				1			1			1		1			1					1		1			1	
184	Miguel Balos	Brgy. 85, Sogod, San Jose	17		1		1			1			1			1				1			1			1			1		1			1				1			1			1	
185	Angel Cabis	Brgy. 85, Sogod, San Jose			1		1			1			1			1				1			1			1			1		1			1					1		1			1	
186	Daniel Bartolome	Brgy. 85, Sogod, San Jose	29	1				1		1			1			1				1			1			1				1	1			1					1		1			1	
187	Friz Tayiela Monteza	Brgy. 85, Sogod, San Jose	22		1		1				1		1			1			1				1			1			1		1			1					1		1			1	
188	Flaire Chavez	Brgy. 85, Sogod, San Jose	27		1		1			1			1			1				1			1			1				1	1			1					1		1		1		
189	Sandrek Dantos	Brgy. 85, Sogod, San Jose	16		1		1			1			1			1			1			1				1			1			1		1					1		1			1	
190	Franz Bastero	Brgy. 85, Sogod, San Jose	32		1		1			1			1			1				1			1			1			1		1			1					1		1			1	
191	Cyrus Luterio	Brgy. 85, Sogod, San Jose	25		1		1			1			1			1				1			1			1			1		1			1					1		1			1	
192	Francis Sajara	Brgy. 85, Sogod, San Jose	18		1		1			1			1			1			1				1			1			1		1			1					1		1			1	
193	Roberto Ilago	Brgy. 85, Sogod, San Jose	23		1		1			1			1			1			1				1			1			1		1			1					1		1			1	
194	Gelo Victor	Brgy. 85, Sogod, San Jose	17		1		1			1			1			1			1				1			1			1		1			1					1		1			1	
195	Rachel Reledor	Brgy. 85, Sogod, San Jose	19		1		1			1			1			1			1			1				1			1		1			1					1		1			1	
196	Leo Gabon	Brgy. 85, Sogod, San Jose	45		1			1			1			1			1			1		1			1			1				1			1			1			1			1	
197	Nicole Bolena	Brgy. 85, Sogod, San Jose	23		1		1			1			1			1			1				1			1			1		1			1					1		1			1	
198	Elloisa Uy	Brgy. 85, Sogod, San Jose			1			1				1	1				1			1			1				1	1				1		1					1			1	1		
199	Kate Anne Perrejo	Brgy. 85, Sogod, San Jose	19		1			1		1				1				1	1				1						1				1	1	1			1		1					1
200	Basty Verosa	Brgy. 85, Sogod, San Jose	27	1					1		1			1			1		1							1					1		1				1		1				1			1

201	Jumari Dente	Brgy. 85, Sogod, San Jose	17		1		1				1		1					1		1		1					1	1				1			1						1				1	
202	Jeshka Hermosa	Brgy. 85, Sogod, San Jose	18	1				1			1		1				1							1		1			1		1			1					1		1			1	
203	Bon Bon Egracial	Brgy. 48-B	24		1			1		1			1			1			1			1				1			1	1			1			1				1		1		
204	Henry Ragat	Brgy. 48-B	37		1			1		1			1			1			1			1			1			1				1		1	1			1		1			1		
205	Yan Yan Esmero Ba	Brgy. 48-B			1		1			1			1			1				1		1				1			1		1			1					1	1			1		
206	Allam Agbalen	Brgy. 48-B			1			1		1			1			1				1			1			1				1	1			1					1		1		1		
207	Sernio Albino Jr.	Brgy. 48-B			1		1			1			1			1				1		1				1				1	1			1					1	1			1		
208	Alysa M. Sernio	Brgy. 48-B			1		1			1			1			1				1		1			1			1			1			1					1	1			1		
209	Diana Tubaobao	Brgy. 48-B	33		1			1		1			1			1			1				1			1				1	1			1			1			1			1		
210	Aloha M. Sernio	Brgy. 48-B	28		1		1			1			1			1				1		1			1				1		1			1					1	1			1		
211	Justine Beltran	Brgy. 48-B	22		1			1			1		1				1			1			1		1			1				1		1				1		1			1		
212	Khyra Mae B. Magdi	Brgy. 48-B			1		1			1			1			1				1			1			1					1	1		1					1	1			1		
213	Leaneth A. Batula	Brgy. 48-B	23		1			1		1			1			1				1			1			1				1	1			1					1	1			1		
214	John Pau Ayuson	Brgy. 48-B	22	1				1			1		1				1			1		1			1			1				1		1				1		1			1		
215	Arkien A. Batula	Brgy. 48-B			1			1		1			1			1				1			1			1				1	1			1					1	1			1		
216	Elmer Castillio Mag	Brgy. 48-B	22		1			1		1			1			1				1			1				1	1			1			1					1	1			1		
217	Christian G. Lajara	Brgy. 48-B	24		1			1		1			1			1			1			1				1				1	1			1					1	1			1		
218	John Hector A. Batu	Brgy. 48-B	19		1			1		1			1			1				1			1			1				1	1			1					1	1			1		
219	Lyka Loraine A. Batu	Brgy. 48-B			1			1		1			1			1				1			1			1		1			1			1					1	1			1		
220	Kyle B. Hidalgo	Brgy. 48-B	18		1		1						1			1				1			1			1				1	1			1					1	1			1		
221	Illena Baduna	Brgy. 48-B	51		1		1			1			1			1			1				1			1				1	1			1					1	1			1		
222	Kyle G. Lajara	Brgy. 48-B	18		1			1		1			1			1						1				1				1	1			1					1	1			1		
223	James Ryan Assi	Brgy. 48-B	29		1			1		1			1			1			1			1				1				1	1			1					1	1			1		
224	Laiza Loraine A. batu	Brgy. 48-B			1			1		1			1			1				1			1			1				1	1			1					1	1			1		
225	Alexandra Gauile	Brgy. 48-B	63		1			1		1			1			1			1			1				1				1	1			1					1	1			1		
226	Rubilya Magdiwa	Brgy. 48-B	25		1			1		1			1			1			1			1				1				1	1			1	1				1	1			1		
227	Hannah Jade Magdi	Brgy. 48-B	24		1			1		1			1			1				1			1			1				1	1			1					1	1			1		
228	Maricris G. Lajara	Brgy. 48-B			1			1		1			1			1			1			1					1	1			1			1					1	1			1		
229	Cacay G. Magdiwa	Brgy. 48-B	22		1			1			1		1			1				1			1			1				1	1			1					1	1			1		
230	Jesica G. Magdiwa	Brgy. 48-B	27		1			1		1			1			1				1			1			1				1	1			1					1	1			1		
231	Rosalia B. Daito	Brgy. 48-B	73		1			1			1			1				1	1			1			1			1				1		1				1		1			1		
232	Richie G. Magdiwa	Brgy. 48-B	18		1			1		1			1				1			1			1		1					1		1			1			1		1			1		
233	Glenda Misa	Brgy. 48-B	45		1			1		1			1			1			1				1			1				1	1			1					1	1			1		
234	Ferlie Mae Kae Mag	Brgy. 48-B	23		1			1		1			1				1			1		1			1				1		1			1		1			1			1		
235	Carmen Abraham M	Brgy. 48-B	74		1			1		1			1			1			1				1			1				1	1			1	1				1	1			1		
236	Serome Lazada	Brgy. 48-B	22		1		1			1			1				1		1				1			1			1		1			1	1				1	1				1	
237	Fernando A. Magdu	Brgy. 48-B	52		1			1		1			1				1			1		1			1					1		1			1		1			1			1		
238	Henry D. Ragot	Brgy. 48-B	37		1			1		1			1			1				1		1			1			1				1		1	1			1		1			1		
239	Jessica Lazada	Brgy. 48-B	24		1			1		1			1				1		1				1			1			1		1			1	1				1					1	
240	Rogelio Dario	Brgy. 48-B	78		1			1			1			1				1	1			1			1			1				1		1				1		1			1		
241	Herman Ragot	Brgy. 48-B	34		1			1		1			1			1				1		1			1			1				1		1	1			1		1			1		
242	Domingo Estoya	Brgy. 48-B			1		1			1			1					1			1		1				1		1		1			1				1			1			1	
243	Kathlia L. Abella	Brgy. 48-B	23		1			1		1			1			1			1				1		1			1				1		1				1		1			1		
244	Carlito Ragot	Brgy. 48-B	31		1		1			1			1					1			1		1			1		1				1		1					1	1			1		
245	Rogelio Estoya	Brgy. 48-B	62		1		1			1			1					1			1		1			1				1	1			1					1			1			1
246	Kimberly Ragot	Brgy. 48-B	17		1		1			1			1			1					1		1			1			1		1				1				1	1					1
247	Me Ann Canduli	Brgy. 48-B			1		1			1			1					1			1		1				1			1	1				1				1			1			1
248	Dominic Estoya	Brgy. 48-B	17		1		1			1			1					1			1		1				1			1	1			1					1			1			1
249	Nimfa Raganot	Brgy. 48-B	48		1		1			1			1			1				1			1			1			1		1				1				1	1					1
250	Harold Ragat	Brgy. 48-B	19		1			1						1		1				1		1			1			1				1		1				1		1			1		

251	Angelica Quisagan	Brgy. 48-B	31	1			1			1			1			1				1		1				1			1		1				1		1			1			1		
252	John Kenneth Abellia	Brgy. 48-B	18		1			1		1			1			1			1				1			1			1		1			1				1	1			1		
253	Harold Ragat	Brgy. 48-B	19		1			1		1			1			1			1			1			1			1				1		1	1		1			1			1		
254	Roberto Magdua	Brgy. 48-B	50		1		1			1					1	1				1			1			1					1		1			1		1			1			1		
255	Junevic M. Cabardo	Brgy. 48-B	26	1				1		1			1			1			1			1					1		1		1			1			1						1	
256	Ruth Magdua	Brgy. 48-B	23			1	1			1			1			1			1				1				1		1		1			1			1			1			1		
257	Evelyn Magdua	Brgy. 48-B	48		1		1			1					1	1				1			1			1					1		1			1		1			1			1	
258	Chie Ang	Brgy. 48-B	23		1			1		1			1			1			1				1			1					1	1			1			1			1			1		
259	Joseph M. Dano	Brgy. 48-B	22		1		1			1			1			1			1			1				1					1	1								1		1		1		
260	James Bilton A. Mag	Brgy. 48-B			1		1			1					1	1				1			1								1	1				1		1			1					1	
261	Jonah B. Dano	Brgy. 48-B	44		1		1			1			1			1			1			1				1					1	1			1			1					1		1		
262	Alona M. Sernio	Brgy. 48-B					1	1			1			1					1		1				1			1			1	1			1					1	1							1
263	Nicanor Magdua	Brgy. 48-B	45				1	1			1			1			1			1				1			1					1	1			1	1					1		1			1	
264	Nora M. Dano	Brgy. 48-B	44		1		1			1			1			1			1			1				1					1	1			1					1		1		1		
265	Jericho M. Dano	Brgy. 48-B	24		1		1			1			1			1			1			1				1					1	1			1	1					1		1			1	
266	Riza S. de Paz	Brgy. 48-B	39	1			1			1				1		1			1				1			1		1			1			1			1					1	1		
267	Jessiel M. Dano	Brgy. 48-B	27		1		1			1			1			1			1			1				1					1	1			1	1					1		1		1		
268	Carmelia A. Magdua	Brgy. 48-B	39	1			1			1				1		1			1				1		1			1			1			1					1	1			1		
269	Mylene Magdua	Brgy. 48-B	39			1	1			1			1			1			1			1				1					1	1			1	1					1		1			1	
270	Jomora M. Dano	Brgy. 48-B	20		1		1			1			1			1			1			1				1					1	1			1	1					1		1		1		
271	Raquel D. Nacurawat	Brgy. 48-B	39		1			1		1			1			1			1			1						1				1		1	1			1		1			1		
272	Rogus Magdua	Brgy. 48-B	24	1			1			1				1		1						1		1			1			1			1	1		1			1					1	
273	Racky Marcial Magd	Brgy. 48-B	21		1			1		1			1			1			1			1			1			1				1				1			1		1			1		
274	jade Patrick Misa	Brgy. 48-B	24		1			1		1			1			1			1			1			1			1				1		1			1			1			1		
275	Jefferson Abellia	Brgy. 48-B	17		1			1		1			1			1			1				1			1		1			1			1			1			1			1		
276	Harvey Magat	Brgy. 48-B	22		1			1		1			1			1			1			1			1			1				1		1	1			1		1			1		
277	Rinalyn Alimongo	Brgy. 62-A			1			1			1			1					1		1		1					1		1					1	1			1			1		
278	Clyde Cedric Comm	Brgy. 48-B	18		1			1			1			1			1		1			1			1			1				1					1		1		1			1		
279	Bona Marie Misa	Brgy. 48-B	20		1			1		1			1			1			1				1					1	1			1			1			1						
280	Ann Alimongo	Brgy. 48-B			1			1			1			1					1		1		1					1	1			1					1	1			1			1		
281	Garry Estoya	Brgy. 48-B	45		1			1		1			1			1			1				1			1					1	1			1					1	1			1		
282	Charlotte D. Ragot	Brgy. 48-B	18		1			1		1				1		1				1		1			1			1				1		1				1		1			1		
283	John Kenneth Abella	Brgy. 48-B	18		1			1		1			1			1			1				1		1			1				1		1				1		1			1		
284	Jinky Sampan	Brgy. 60-A	31		1		1			1			1			1					1		1				1	1			1			1					1	1			1		
285	Romelivan Cordavo	Brgy. 60-A	18			1	1			1			1			1					1		1				1			1	1			1			1					1				1
286	Remart Ayaso	Brgy. 60-A	24		1		1			1			1			1				1			1			1		1				1		1				1			1		1		
287	Lando Obera	Brgy. 60-A	61		1			1		1			1			1			1				1			1					1	1			1			1				1			1	
288	Jomel G. Baloro	Brgy. 60-A	21		1		1			1				1			1			1			1					1		1		1			1			1				1			1	
289	Marlon Ragbag	Brgy. 60-A	21		1		1			1			1			1			1				1			1			1		1			1				1				1			1	
290	Garcia Residence	Brgy. 60-A	68		1		1			1			1			1					1		1			1			1		1			1					1			1		1	
291	Rodriguez Residence	Brgy. 60-A	28	1				1			1		1			1			1			1			1			1				1				1	1				1		1		
292	Gayons Residence	Brgy. 60-A	48		1		1			1			1			1				1			1			1			1		1			1					1		1			1	
293	Belle Store	Brgy. 60-A	59		1		1			1			1			1			1				1			1			1			1		1				1			1					1
294	Michael Antino Shop	Brgy. 60-A	45		1		1			1			1			1			1				1			1		1				1		1			1				1					1
295	Erzen Store	Brgy. 60-A	69		1		1			1			1			1			1			1			1			1				1				1		1				1		1		
296	Bonifacio C. Digdiga	Brgy. 60-A	72		1		1			1			1			1			1				1			1			1		1			1				1				1	1		
297	Picardal Eduardo	Brgy. 60-A	56		1		1			1			1			1					1		1			1						1			1				1			1			1	
298	Jerhard Dahonan	Brgy. 60-A	21			1	1			1			1			1					1		1				1			1	1			1			1				1					1
299	Duran Carlo Stefano	Brgy. 60-A	25		1		1			1			1			1				1			1			1			1			1		1				1			1			1	
300	Gilmark Baltazar	Brgy. 60-A	37		1		1			1			1			1					1		1			1					1	1			1				1		1					1

301	Mario Residence	Brgy. 60-A	54		1		1			1			1			1				1			1			1		1			1			1				1			1			1	
302	Jeilyn Montilla	Brgy. 60-A	69		1		1			1			1			1					1		1			1			1		1			1				1			1			1	
303	Carlos Fish Dealer	Brgy. 60-A			1		1			1			1			1				1			1			1			1		1			1				1			1			1	
304	Isoy Residences	Brgy. 60-A	36		1			1			1			1		1			1			1			1			1				1			1		1				1				1
305	Jeremy Abarico	Brgy. 60-A	26	1				1			1			1		1				1		1			1			1					1		1			1		1			1		
306	Mac-mac Carlos	Brgy. 60-A	29		1			1		1			1			1				1			1		1					1			1		1			1		1			1		
307	Boyet Cerdano	Brgy. 60-A	52		1			1			1			1		1					1		1			1				1	1			1					1			1		1	
308	Indic Casas	Brgy. 60-A	39		1		1			1			1			1				1			1			1				1	1			1					1		1			1	
309	Kim Dexter Dado	Brgy. 60-A	43		1		1			1			1			1				1			1			1			1		1			1			1				1				1
310	Arniedel canete	Brgy. 60-A	56		1		1				1			1				1			1			1			1		1				1			1		1					1		1	
311	Ida Tan	Brgy. 60-A	36		1			1		1			1			1				1			1			1			1		1			1				1			1			1	
312	Maricel Sagusad	Brgy. 60-A	47		1		1			1			1			1			1				1			1				1	1			1				1			1			1	
313	Alcober Norman	Brgy. 60-A	41		1		1			1			1			1			1				1			1		1				1		1				1		1				1	
314	Kim-kim Go	Brgy. 60-A	24		1		1			1			1			1					1		1			1				1	1			1	1			1			1			1	
315	Gabriel Go	Brgy. 60-A	24		1		1			1			1			1			1				1			1			1		1			1				1				1		1	
316	Marigil Ramos	Brgy. 60-A	42		1		1			1			1			1			1			1				1			1		1			1				1			1				1
317	Marco Bacani	Brgy. 60-A	41	1				1		1			1			1			1			1			1			1					1		1			1				1			1
318	Man De Los Reyes	Brgy. 60-A	47		1		1			1			1			1			1			1				1		1			1			1				1			1			1	
319	Jubert Daiz	Brgy. 60-A	67		1		1				1		1			1					1		1			1			1			1		1				1			1			1	
320	Rosita Del Pillar	Brgy. 60-A	46		1		1			1			1			1			1				1			1			1		1			1				1				1		1	
321	Pablo Agustin	Brgy. 60-A	59		1		1			1			1			1			1				1			1			1		1			1				1			1			1	
322	Mark Antoni Reyes	Brgy. 60-A	36		1		1			1			1				1				1		1			1			1				1	1				1			1				1
323	Judah Villamor	Brgy. 60-A	19		1		1			1			1			1					1		1			1				1	1			1					1			1			1
324	Biboy Fernandez	Brgy. 60-A	67		1		1			1			1			1				1			1			1			1		1			1				1			1			1	
325	Joban Badrina	Brgy. 60-A	57		1		1					1	1				1			1			1				1		1		1					1		1			1				1
326	Bryan Salado	Brgy. 60-A	27		1		1			1			1			1			1			1				1			1		1			1				1		1					1
327	Mark Esperas	Brgy. 60-A	33		1		1			1			1			1			1				1			1			1		1			1					1		1			1	
328	Coring Dacatimbang	Brgy. 60-A	52		1		1			1			1			1			1			1				1				1	1			1				1				1		1	
329	Rogelio Go	Brgy. 60-A	48		1		1			1			1			1			1			1				1			1		1			1				1			1			1	
330	Dan-dan Reid	Brgy. 60-A	18		1			1		1			1			1					1		1				1			1	1			1				1				1			1
331	Jose Baldo	Brgy. 60-A	51		1		1			1			1			1			1			1				1		1			1			1				1				1			1
332	Daniel Gil	Brgy. 60-A	64		1		1			1			1			1			1			1				1		1			1			1				1		1				1	
333	Rubu Garson	Brgy. 60-A	34		1		1			1			1			1					1		1			1			1		1			1					1		1			1	
334	Andy Asis	Brgy. 58, Aslum Sagkanan	33		1		1			1			1			1			1				1			1			1		1			1					1		1				1
335	Kim Asis	Brgy. 58, Aslum Sagkanan	33		1		1			1			1			1			1				1			1			1		1			1					1		1				1
336	Lastrillas Residences	Brgy. 58, Aslum Sagkanan	34		1		1				1			1			1			1		1			1			1				1		1			1			1			1		
337	Ken Mark Sabalberin	Brgy. 58, Aslum Sagkanan	27		1		1			1			1			1			1				1			1			1		1			1					1		1				1
338	Roel Rambacod	Brgy. 58, Aslum Sagkanan	36		1		1			1			1			1			1				1			1			1		1			1					1		1				1
339	Renan Equipage	Brgy. 58, Aslum Sagkanan	25		1		1			1			1			1			1				1			1			1		1			1					1		1				1
340	Felicisimo Rosillo	Brgy. 58, Aslum Sagkanan	48		1		1			1			1			1			1				1			1		1			1			1					1		1				1
341	Ricardo Asuncion	Brgy. 58, Aslum Sagkanan	52		1		1			1			1			1			1				1			1			1		1			1					1		1				1
342	Jimbo Lavadia	Brgy. 58, Aslum Sagkanan	25		1		1			1			1			1			1				1			1			1		1			1					1		1				1
343	Marlon Basas	Brgy. 58, Aslum Sagkanan	26		1		1			1			1			1			1				1			1			1		1			1					1		1				1
344	Paeng Beringa	Brgy. 58, Aslum Sagkanan	37		1		1			1			1			1			1				1			1			1		1			1					1		1				1
345	Parenos Residence	Brgy. 58, Aslum Sagkanan	26		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
346	Ivor Almaden	Brgy. 58, Aslum Sagkanan	36		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
347	Ludwig Almaden	Brgy. 58, Aslum Sagkanan	37		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
348	Bodjie Navarro	Brgy. 58, Aslum Sagkanan	36		1		1			1			1			1			1				1			1			1		1			1					1		1				1
349	Claud Lagunzad	Brgy. 58, Aslum Sagkanan	28		1		1			1			1			1			1				1			1			1		1			1					1		1				1
350	Jasper Deguito	Brgy. 58, Aslum Sagkanan	30		1		1			1			1			1			1				1			1			1		1			1					1		1				1

350	Jasper Deguito	Brgy. 58, Aslum Sagkanan	30		1		1			1			1			1			1				1			1			1		1			1					1		1				1
351	Marlon Awar	Brgy. 58, Aslum Sagkanan	33		1		1			1			1			1			1				1			1			1		1			1					1		1				1
352	Art Legnin	Brgy. 58, Aslum Sagkanan	28		1		1			1			1			1			1				1			1			1		1			1					1		1				1
353	John Rey Lequin	Brgy. 58, Aslum Sagkanan	27		1		1			1			1			1			1				1			1			1		1			1					1		1				1
354	Edgar Corpin	Brgy. 58, Aslum Sagkanan	36		1		1			1			1			1			1				1			1			1		1			1					1		1				1
355	At-at Caridad	Brgy. 58, Aslum Sagkanan	26		1		1			1			1			1			1				1			1			1		1			1					1		1				1
356	Anthony Basas	Brgy. 58, Aslum Sagkanan	30		1		1			1			1			1			1				1			1			1		1			1					1		1				1
357	Melvin Awaaw	Brgy. 58, Aslum Sagkanan	35		1		1			1			1			1			1				1			1			1		1			1					1		1				1
358	Yoe Navarro	Brgy. 58, Aslum Sagkanan	26		1		1			1			1			1			1				1			1			1		1			1					1		1				1
359	Claudette Lavadia	Brgy. 58, Aslum Sagkanan	26		1		1			1			1			1			1				1			1			1		1			1					1		1				1
360	John Lagunzad	Brgy. 58, Aslum Sagkanan	28		1		1			1			1			1			1				1			1			1		1			1					1		1				1
361	Vanessa Novio	Brgy. 58, Aslum Sagkanan	26		1		1			1			1			1			1				1			1			1		1			1					1		1				1
362	Rodel Rambarod	Brgy. 58, Aslum Sagkanan	31		1		1			1			1			1			1				1			1			1		1			1					1		1				1
363	Pablo Rambarod	Brgy. 58, Aslum Sagkanan	61		1		1			1			1			1			1				1			1			1		1			1					1		1				1
364	George Corpin	Brgy. 58, Aslum Sagkanan	58		1		1			1			1			1			1				1			1			1		1			1					1		1				1
365	Palconete's Residen	Brgy. 58, Aslum Sagkanan	56		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
366	Cordero's Residenc	Brgy. 58, Aslum Sagkanan	28		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
367	Navarro's Residence	Brgy. 58, Aslum Sagkanan	42		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
368	Lagunzad's Residenc	Brgy. 58, Aslum Sagkanan	52		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
369	Jovero's Residence	Brgy. 58, Aslum Sagkanan	32		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
370	Basa's Residence	Brgy. 58, Aslum Sagkanan	27		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
371	Jimenez's Residence	Brgy. 58, Aslum Sagkanan	21		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
372	Rick Mortega	Brgy. 58, Aslum Sagkanan	32		1		1			1			1			1			1				1			1			1		1			1					1		1				1
373	Twinkle Navarro	Brgy. 58, Aslum Sagkanan	30		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
374	Jun Lampaya	Brgy. 58, Aslum Sagkanan	50		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
375	Garcia's Residence	Brgy. 58, Aslum Sagkanan	54		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
376	Montiel's Residenec	Brgy. 58, Aslum Sagkanan	35		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
377	Ligta's Residence	Brgy. 58, Aslum Sagkanan	45		1			1			1			1			1			1		1			1			1				1		1			1			1			1		
378	Tupas Residence	Brgy. 58, Aslum Sagkanan	59		1			1			1			1			1			1		1			1			1				1		1			1			1			1		

APPENDIX D
Yield line method for 3x3m wall (load bearing wall)

			Wall Design Specifications						Effective Compression Width per Bar				Steel			Concrete				Nominal Moment Capacity			
			Spacing of Reinforcement		CHB Dimensions			Size of Rebar	a	b	c	Min	As	fy	Asfy	Ø	f'm	b	a	Asfy	d	a/2	Mn
			Horizontal	Vertical	Length (mm)	Height (mm)	Thickness (mm)	Diameter (mmØ)	(meters)	(meters)	(meters)	(meters)	(sq. mm)	(Mpa)	(N)		(Mpa)	(mm)	(mm)	(N)	(mm)	(mm)	(N.mm)
S1	C1	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	8	0.8	0.6	1.829	0.6	50.27	275	13823.01	0.80	6.89	600	4.18	13823	100	2.09	1353413.02
S1	C1	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	10	0.8	0.6	1.829	0.6	78.54	275	21598.45	0.80	6.89	600	6.53	21598	100	3.27	2089318.16
S1	C1	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	12	0.8	0.6	1.829	0.6	113.10	275	31101.77	0.80	6.89	600	9.40	31102	100	4.70	2963932.31
S1	C2	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	8	0.8	0.9	1.829	0.8	50.27	275	13823.01	0.80	6.89	800	3.13	13823	150	1.57	2051785.39
S1	C2	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	10	0.8	0.9	1.829	0.8	78.54	275	21598.45	0.80	6.89	800	4.90	21598	150	2.45	3186872.41
S1	C2	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	12	0.8	0.9	1.829	0.8	113.10	275	31101.77	0.80	6.89	800	7.05	31102	150	3.53	4555581.89
S1	C3	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	8	0.8	1.2	1.829	0.8	50.27	275	13823.01	0.80	6.89	800	3.13	13823	200	1.57	2742935.80
S1	C3	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	10	0.8	1.2	1.829	0.8	78.54	275	21598.45	0.80	6.89	800	4.90	21598	200	2.45	4266794.93
S1	C3	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	12	0.8	1.2	1.829	0.8	113.10	275	31101.77	0.80	6.89	800	7.05	31102	200	3.53	6110670.32
S2	C1	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	8	0.6	0.6	1.829	0.6	50.27	275	13823.01	0.80	6.89	600	4.18	13823	100	2.09	1353413.02
S2	C1	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	10	0.6	0.6	1.829	0.6	78.54	275	21598.45	0.80	6.89	600	6.53	21598	100	3.27	2089318.16
S2	C1	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	12	0.6	0.6	1.829	0.6	113.10	275	31101.77	0.80	6.89	600	9.40	31102	100	4.70	2963932.31
S2	C2	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	8	0.6	0.9	1.829	0.6	50.27	275	13823.01	0.80	6.89	600	4.18	13823	150	2.09	2044563.43
S2	C2	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	10	0.6	0.9	1.829	0.6	78.54	275	21598.45	0.80	6.89	600	6.53	21598	150	3.27	3169240.68
S2	C2	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	12	0.6	0.9	1.829	0.6	113.10	275	31101.77	0.80	6.89	600	9.40	31102	150	4.70	4519020.75
S2	C3	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	8	0.6	1.2	1.829	0.6	50.27	275	13823.01	0.80	6.89	600	4.18	13823	200	2.09	2735713.85
S2	C3	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	10	0.6	1.2	1.829	0.6	78.54	275	21598.45	0.80	6.89	600	6.53	21598	200	3.27	4249163.21
S2	C3	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	12	0.6	1.2	1.829	0.6	113.10	275	31101.77	0.80	6.89	600	9.40	31102	200	4.70	6074109.18
S3	C1	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	8	0.4	0.6	1.829	0.4	50.27	275	13823.01	0.80	6.89	400	6.27	13823	100	3.13	1338969.11
S3	C1	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	10	0.4	0.6	1.829	0.4	78.54	275	21598.45	0.80	6.89	400	9.80	21598	100	4.90	2054054.71
S3	C1	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	12	0.4	0.6	1.829	0.4	113.10	275	31101.77	0.80	6.89	400	14.11	31102	100	7.05	2890810.03
S3	C2	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	8	0.4	0.9	1.829	0.4	50.27	275	13823.01	0.80	6.89	400	6.27	13823	150	3.13	2030119.53
S3	C2	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	10	0.4	0.9	1.829	0.4	78.54	275	21598.45	0.80	6.89	400	9.80	21598	150	4.90	3133977.24
S3	C2	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	12	0.4	0.9	1.829	0.4	113.10	275	31101.77	0.80	6.89	400	14.11	31102	150	7.05	4445898.47
S3	C3	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	8	0.4	1.2	1.829	0.4	50.27	275	13823.01	0.80	6.89	400	6.27	13823	200	3.13	2721269.94
S3	C3	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	10	0.4	1.2	1.829	0.4	78.54	275	21598.45	0.80	6.89	400	9.80	21598	200	4.90	4213899.76
S3	C3	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	12	0.4	1.2	1.829	0.4	113.10	275	31101.77	0.80	6.89	400	14.11	31102	200	7.05	6000986.90

Maximum Pressure Capacity								
Nominal Moment, Mn	Wall Width, a	Wall Height, b	$\frac{a^2}{b^2}$	Yield Line Pattern	$\frac{w_u}{ø} = 12(\frac{M_{nx}}{a^2} + \frac{M_{nxy}}{b^2})$			Wu
(KN.m/m)	(meters)	(meters)			$\frac{M_{nx}}{a^2}$	$\frac{M_{nxy}}{b^2}$	$\frac{w_u}{ø}$	kPa
2.26	3	3	1.00	Pattern 1	0.25	0.25	6.02	6.68
3.48	3	3	1.00	Pattern 1	0.39	0.39	9.29	10.32
4.94	3	3	1.00	Pattern 1	0.55	0.55	13.17	14.64
2.56	3	3	1.00	Pattern 1	0.28	0.28	6.84	7.60
3.98	3	3	1.00	Pattern 1	0.44	0.44	10.62	11.80
5.69	3	3	1.00	Pattern 1	0.63	0.63	15.19	16.87
3.43	3	3	1.00	Pattern 1	0.38	0.38	9.14	10.16
5.33	3	3	1.00	Pattern 1	0.59	0.59	14.22	15.80
7.64	3	3	1.00	Pattern 1	0.85	0.85	20.37	22.63
2.26	3	3	1.00	Pattern 1	0.25	0.25	6.02	6.68
3.48	3	3	1.00	Pattern 1	0.39	0.39	9.29	10.32
4.94	3	3	1.00	Pattern 1	0.55	0.55	13.17	14.64
3.41	3	3	1.00	Pattern 1	0.38	0.38	9.09	10.10
5.28	3	3	1.00	Pattern 1	0.59	0.59	14.09	15.65
7.53	3	3	1.00	Pattern 1	0.84	0.84	20.08	22.32
4.56	3	3	1.00	Pattern 1	0.51	0.51	12.16	13.51
7.08	3	3	1.00	Pattern 1	0.79	0.79	18.89	20.98
10.12	3	3	1.00	Pattern 1	1.12	1.12	27.00	30.00
3.35	3	3	1.00	Pattern 1	0.37	0.37	8.93	9.92
5.14	3	3	1.00	Pattern 1	0.57	0.57	13.69	15.22
7.23	3	3	1.00	Pattern 1	0.80	0.80	19.27	21.41
5.08	3	3	1.00	Pattern 1	0.56	0.56	13.53	15.04
7.83	3	3	1.00	Pattern 1	0.87	0.87	20.89	23.21
11.11	3	3	1.00	Pattern 1	1.23	1.23	29.64	32.93
6.80	3	3	1.00	Pattern 1	0.76	0.76	18.14	20.16
10.53	3	3	1.00	Pattern 1	1.17	1.17	28.09	31.21
15.00	3	3	1.00	Pattern 1	1.67	1.67	40.01	44.45

APPENDIX E
Yield line method for 4x3m wall (load bearing wall)

			Wall Design Specifications						Effective Compression Width per Ba				Steel			Concrete				Nominal Moment Capacity			
			Spacing of Reinforcement		CHB Dimensions			Size of Rebar	a	b	c	Min	As	fy	Asfy	Ø	f'm	b	a	Asfy	d	a/2	Mn
			Horizontal	Vertical	Length (mm)	Height (mm)	Thickness (mm)	Diameter (mmØ)	(meters)	(meters)	(meters)	(meters)	(sq. mm)	(Mpa)	(N)		(Mpa)	(mm)	(mm)	(N)	(mm)	(mm)	(N.mm)
S1	C1	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	8	0.8	0.6	1.829	0.6	50.27	275	13823.01	0.80	6.89	600	4.18	13823.01	100	2.09	1353413.02
S1	C1	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	10	0.8	0.6	1.829	0.6	78.54	275	21598.45	0.80	6.89	600	6.53	21598.45	100	3.27	2089318.16
S1	C1	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	12	0.8	0.6	1.829	0.6	113.10	275	31101.77	0.80	6.89	600	9.40	31101.77	100	4.70	2963932.31
S1	C2	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	8	0.8	0.9	1.829	0.8	50.27	275	13823.01	0.80	6.89	800	3.13	13823.01	150	1.57	2051785.39
S1	C2	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	10	0.8	0.9	1.829	0.8	78.54	275	21598.45	0.80	6.89	800	4.90	21598.45	150	2.45	3186872.41
S1	C2	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	12	0.8	0.9	1.829	0.8	113.10	275	31101.77	0.80	6.89	800	7.05	31101.77	150	3.53	4555581.89
S1	C3	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	8	0.8	1.2	1.829	0.8	50.27	275	13823.01	0.80	6.89	800	3.13	13823.01	200	1.57	2742935.80
S1	C3	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	10	0.8	1.2	1.829	0.8	78.54	275	21598.45	0.80	6.89	800	4.90	21598.45	200	2.45	4266794.93
S1	C3	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	12	0.8	1.2	1.829	0.8	113.10	275	31101.77	0.80	6.89	800	7.05	31101.77	200	3.53	6110670.32
S2	C1	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	8	0.6	0.6	1.829	0.6	50.27	275	13823.01	0.80	6.89	600	4.18	13823.01	100	2.09	1353413.02
S2	C1	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	10	0.6	0.6	1.829	0.6	78.54	275	21598.45	0.80	6.89	600	6.53	21598.45	100	3.27	2089318.16
S2	C1	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	12	0.6	0.6	1.829	0.6	113.10	275	31101.77	0.80	6.89	600	9.40	31101.77	100	4.70	2963932.31
S2	C2	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	8	0.6	0.9	1.829	0.6	50.27	275	13823.01	0.80	6.89	600	4.18	13823.01	150	2.09	2044563.43
S2	C2	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	10	0.6	0.9	1.829	0.6	78.54	275	21598.45	0.80	6.89	600	6.53	21598.45	150	3.27	3169240.68
S2	C2	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	12	0.6	0.9	1.829	0.6	113.10	275	31101.77	0.80	6.89	600	9.40	31101.77	150	4.70	4519020.75
S2	C3	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	8	0.6	1.2	1.829	0.6	50.27	275	13823.01	0.80	6.89	600	4.18	13823.01	200	2.09	2735713.85
S2	C3	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	10	0.6	1.2	1.829	0.6	78.54	275	21598.45	0.80	6.89	600	6.53	21598.45	200	3.27	4249163.21
S2	C3	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	12	0.6	1.2	1.829	0.6	113.10	275	31101.77	0.80	6.89	600	9.40	31101.77	200	4.70	6074109.18
S3	C1	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	8	0.4	0.6	1.829	0.4	50.27	275	13823.01	0.80	6.89	400	6.27	13823.01	100	3.13	1338969.11
S3	C1	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	10	0.4	0.6	1.829	0.4	78.54	275	21598.45	0.80	6.89	400	9.80	21598.45	100	4.90	2054054.71
S3	C1	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	12	0.4	0.6	1.829	0.4	113.10	275	31101.77	0.80	6.89	400	14.11	31101.77	100	7.05	2890810.03
S3	C2	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	8	0.4	0.9	1.829	0.4	50.27	275	13823.01	0.80	6.89	400	6.27	13823.01	150	3.13	2030119.53
S3	C2	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	10	0.4	0.9	1.829	0.4	78.54	275	21598.45	0.80	6.89	400	9.80	21598.45	150	4.90	3133977.24
S3	C2	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	12	0.4	0.9	1.829	0.4	113.10	275	31101.77	0.80	6.89	400	14.11	31101.77	150	7.05	4445898.47
S3	C3	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	8	0.4	1.2	1.829	0.4	50.27	275	13823.01	0.80	6.89	400	6.27	13823.01	200	3.13	2721269.94
S3	C3	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	10	0.4	1.2	1.829	0.4	78.54	275	21598.45	0.80	6.89	400	9.80	21598.45	200	4.90	4213899.76
S3	C3	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	12	0.4	1.2	1.829	0.4	113.10	275	31101.77	0.80	6.89	400	14.11	31101.77	200	7.05	6000986.90

Maximum Pressure Capacity													
Nominal Moment, Mn	Wall Width, a	Wall Height, b	$\frac{a^2}{b^2}$	Yield Line Pattern	$4a(M_{ny})x^2 + 4b^2(M_{nx})x - 3ab^2(M_{nx})=0$				$\frac{w_u}{Ø} = \frac{12[b^2(M_{nx}) + 2ax(M_{ny})]}{b^2(3ax - 2x^2)}$				Wu
(KN.m/m)	(meters)	(meters)			$4a(M_{ny})$	$4b^2(M_{nx})$	$3ab^2(M_{nx})$	x	$b^2(M_{nx})$	$2ax(M_{ny})$	$b^2(3ax-2x^2)$	$\frac{w_u}{Ø}$	kPa
2.26	4	3	1.78	Pattern 2	36.09	81.20	-243.61	1.71	20.30	30.79	131.87	4.65	5.17
3.48	4	3	1.78	Pattern 2	55.72	125.36	-376.08	1.71	31.34	47.53	131.87	7.18	7.97
4.94	4	3	1.78	Pattern 2	79.04	177.84	-533.51	1.71	44.46	67.43	131.87	10.18	11.31
2.56	4	3	1.78	Pattern 2	41.04	92.33	-276.99	1.71	23.08	35.01	131.87	5.29	5.87
3.98	4	3	1.78	Pattern 2	63.74	143.41	-430.23	1.71	35.85	54.37	131.87	8.21	9.12
5.69	4	3	1.78	Pattern 2	91.11	205.00	-615.00	1.71	51.25	77.73	131.87	11.74	13.04
3.43	4	3	1.78	Pattern 2	54.86	123.43	-370.30	1.71	30.86	46.80	131.87	7.07	7.85
5.33	4	3	1.78	Pattern 2	85.34	192.01	-576.02	1.71	48.00	72.80	131.87	10.99	12.21
7.64	4	3	1.78	Pattern 2	122.21	274.98	-824.94	1.71	68.75	104.26	131.87	15.74	17.49
2.26	4	3	1.78	Pattern 2	36.09	81.20	-243.61	1.71	20.30	30.79	131.87	4.65	5.17
3.48	4	3	1.78	Pattern 2	55.72	125.36	-376.08	1.71	31.34	47.53	131.87	7.18	7.97
4.94	4	3	1.78	Pattern 2	79.04	177.84	-533.51	1.71	44.46	67.43	131.87	10.18	11.31
3.41	4	3	1.78	Pattern 2	54.52	122.67	-368.02	1.71	30.67	46.51	131.87	7.02	7.80
5.28	4	3	1.78	Pattern 2	84.51	190.15	-570.46	1.71	47.54	72.10	131.87	10.89	12.10
7.53	4	3	1.78	Pattern 2	120.51	271.14	-813.42	1.71	67.79	102.80	131.87	15.52	17.25
4.56	4	3	1.78	Pattern 2	72.95	164.14	-492.43	1.71	41.04	62.24	131.87	9.40	10.44
7.08	4	3	1.78	Pattern 2	113.31	254.95	-764.85	1.71	63.74	96.66	131.87	14.60	16.22
10.12	4	3	1.78	Pattern 2	161.98	364.45	-1093.34	1.71	91.11	138.18	131.87	20.87	23.18
3.35	4	3	1.78	Pattern 2	53.56	120.51	-361.52	1.71	30.13	45.69	131.87	6.90	7.67
5.14	4	3	1.78	Pattern 2	82.16	184.86	-554.59	1.71	46.22	70.09	131.87	10.58	11.76
7.23	4	3	1.78	Pattern 2	115.63	260.17	-780.52	1.71	65.04	98.65	131.87	14.90	16.55
5.08	4	3	1.78	Pattern 2	81.20	182.71	-548.13	1.71	45.68	69.28	131.87	10.46	11.62
7.83	4	3	1.78	Pattern 2	125.36	282.06	-846.17	1.71	70.51	106.94	131.87	16.15	17.94
11.11	4	3	1.78	Pattern 2	177.84	400.13	-1200.39	1.71	100.03	151.71	131.87	22.91	25.45
6.80	4	3	1.78	Pattern 2	108.85	244.91	-734.74	1.71	61.23	92.86	131.87	14.02	15.58
10.53	4	3	1.78	Pattern 2	168.56	379.25	-1137.75	1.71	94.81	143.79	131.87	21.71	24.13
15.00	4	3	1.78	Pattern 2	240.04	540.09	-1620.27	1.71	135.02	204.78	131.87	30.92	34.36

APPENDIX F

Yield line method for 2.5x3m wall (load bearing wall)

	Wall Design Specifications						Effective Compression Width per Bar			
	Spacing of Reinforcement		CHB Dimensions			Size of Rebar	a	b	c	Min
	Horizontal	Vertical	Length (mm)	Height (mm)	Thickness (mm)	Diameter (mmØ)	(meters)	(meters)	(meters)	(meters)
S1 C1 B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	8	0.8	0.6	1.829	0.6
S1 C1 B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	10	0.8	0.6	1.829	0.6
S1 C1 B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	12	0.8	0.6	1.829	0.6
S1 C2 B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	8	0.8	0.9	1.829	0.8
S1 C2 B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	10	0.8	0.9	1.829	0.8
S1 C2 B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	12	0.8	0.9	1.829	0.8
S1 C3 B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	8	0.8	1.2	1.829	0.8
S1 C3 B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	10	0.8	1.2	1.829	0.8
S1 C3 B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	12	0.8	1.2	1.829	0.8
S2 C1 B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	8	0.6	0.6	1.829	0.6
S2 C1 B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	10	0.6	0.6	1.829	0.6
S2 C1 B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	12	0.6	0.6	1.829	0.6
S2 C2 B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	8	0.6	0.9	1.829	0.6
S2 C2 B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	10	0.6	0.9	1.829	0.6
S2 C2 B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	12	0.6	0.9	1.829	0.6
S2 C3 B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	8	0.6	1.2	1.829	0.6
S2 C3 B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	10	0.6	1.2	1.829	0.6
S2 C3 B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	12	0.6	1.2	1.829	0.6
S3 C1 B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	8	0.4	0.6	1.829	0.4
S3 C1 B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	10	0.4	0.6	1.829	0.4
S3 C1 B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	12	0.4	0.6	1.829	0.4
S3 C2 B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	8	0.4	0.9	1.829	0.4
S3 C2 B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	10	0.4	0.9	1.829	0.4
S3 C2 B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	12	0.4	0.9	1.829	0.4
S3 C3 B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	8	0.4	1.2	1.829	0.4
S3 C3 B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	10	0.4	1.2	1.829	0.4
S3 C3 B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	12	0.4	1.2	1.829	0.4

	Steel			Concrete				Nominal Moment Capacity			
	As	fy	Asfy	Ø	f'm	b	a	Asfy	d	a/2	Mn
	(sq. mm)	(Mpa)	(N)		(Mpa)	(mm)	(mm)	(N)	(mm)	(mm)	(N.mm)
S1 C1 B1	50.27	275	13823.01	0.80	6.89	600	4.18	13823.01	100	2.09	1353413.02
S1 C1 B2	78.54	275	21598.45	0.80	6.89	600	6.53	21598.45	100	3.27	2089318.16
S1 C1 B3	113.10	275	31101.77	0.80	6.89	600	9.40	31101.77	100	4.70	2963932.31
S1 C2 B1	50.27	275	13823.01	0.80	6.89	800	3.13	13823.01	150	1.57	2051785.39
S1 C2 B2	78.54	275	21598.45	0.80	6.89	800	4.90	21598.45	150	2.45	3186872.41
S1 C2 B3	113.10	275	31101.77	0.80	6.89	800	7.05	31101.77	150	3.53	4555581.89
S1 C3 B1	50.27	275	13823.01	0.80	6.89	800	3.13	13823.01	200	1.57	2742935.80
S1 C3 B2	78.54	275	21598.45	0.80	6.89	800	4.90	21598.45	200	2.45	4266794.93
S1 C3 B3	113.10	275	31101.77	0.80	6.89	800	7.05	31101.77	200	3.53	6110670.32
S2 C1 B1	50.27	275	13823.01	0.80	6.89	600	4.18	13823.01	100	2.09	1353413
S2 C1 B2	78.54	275	21598.45	0.80	6.89	600	6.53	21598.45	100	3.27	2089318.16
S2 C1 B3	113.10	275	31101.77	0.80	6.89	600	9.40	31101.77	100	4.70	2963932.31
S2 C2 B1	50.27	275	13823.01	0.80	6.89	600	4.18	13823.01	150	2.09	2044563.43
S2 C2 B2	78.54	275	21598.45	0.80	6.89	600	6.53	21598.45	150	3.27	3169240.68
S2 C2 B3	113.10	275	31101.77	0.80	6.89	600	9.40	31101.77	150	4.70	4519020.75
S2 C3 B1	50.27	275	13823.01	0.80	6.89	600	4.18	13823.01	200	2.09	2735713.85
S2 C3 B2	78.54	275	21598.45	0.80	6.89	600	6.53	21598.45	200	3.27	4249163.21
S2 C3 B3	113.10	275	31101.77	0.80	6.89	600	9.40	31101.77	200	4.70	6074109.18
S3 C1 B1	50.27	275	13823.01	0.80	6.89	400	6.27	13823.01	100	3.13	1338969.11
S3 C1 B2	78.54	275	21598.45	0.80	6.89	400	9.80	21598.45	100	4.90	2054054.71
S3 C1 B3	113.10	275	31101.77	0.80	6.89	400	14.11	31101.77	100	7.05	2890810.03
S3 C2 B1	50.27	275	13823.01	0.80	6.89	400	6.27	13823.01	150	3.13	2030119.53
S3 C2 B2	78.54	275	21598.45	0.80	6.89	400	9.80	21598.45	150	4.90	3133977.24
S3 C2 B3	113.10	275	31101.77	0.80	6.89	400	14.11	31101.77	150	7.05	4445898.47
S3 C3 B1	50.27	275	13823.01	0.80	6.89	400	6.27	13823.01	200	3.13	2721269.94
S3 C3 B2	78.54	275	21598.45	0.80	6.89	400	9.80	21598.45	200	4.90	4213899.76
S3 C3 B3	113.10	275	31101.77	0.80	6.89	400	14.11	31101.77	200	7.05	6000986.90

Maximum Pressure Capacity													
Nominal Moment, Mn	Wall Width, a	Wall Height, b	$\frac{a^2}{b^2}$	Yield Line Pattern	$4b(M_{nx})y^2 + 4a^2(M_{ny})y - 3ba^2(M_{ny})=0$				$\frac{w_u}{Ø} = \frac{12[a^2(M_{ny}) + 2by(M_{nx})]}{a^2(3by - 2y^2)}$				Wu
(KN.m/m)	(meters)	(meters)			$4b(M_{nx})$	$4a^2(M_{ny})$	$3ba^2(M_{ny})$	y	$a^2(M_{ny})$	$2by(M_{nx})$	$a^2(3by-2y^2)$	$\frac{w_u}{Ø}$	kPa
2.26	2.5	3	0.69	Pattern 1	27.07	56.39	-126.88	1.36	14.10	18.42	53.40	7.31	8.12
3.48	2.5	3	0.69	Pattern 1	41.79	87.05	-195.87	1.36	21.76	28.43	53.40	11.28	12.53
4.94	2.5	3	0.69	Pattern 1	59.28	123.50	-277.87	1.36	30.87	40.34	53.40	16.00	17.78
2.56	2.5	3	0.69	Pattern 1	30.78	64.12	-144.27	1.36	16.03	20.94	53.40	8.31	9.23
3.98	2.5	3	0.69	Pattern 1	47.80	99.59	-224.08	1.36	24.90	32.53	53.40	12.90	14.34
5.69	2.5	3	0.69	Pattern 1	68.33	142.36	-320.31	1.36	35.59	46.50	53.40	18.45	20.50
3.43	2.5	3	0.69	Pattern 1	41.14	85.72	-192.86	1.36	21.43	28.00	53.40	11.11	12.34
5.33	2.5	3	0.69	Pattern 1	64.00	133.34	-300.01	1.36	33.33	43.55	53.40	17.28	19.20
7.64	2.5	3	0.69	Pattern 1	91.66	190.96	-429.66	1.36	47.74	62.37	53.40	24.74	27.49
2.26	2.5	3	0.69	Pattern 1	27.07	56.39	-126.88	1.36	14.10	18.42	53.40	7.31	8.12
3.48	2.5	3	0.69	Pattern 1	41.79	87.05	-195.87	1.36	21.76	28.43	53.40	11.28	12.53
4.94	2.5	3	0.69	Pattern 1	59.28	123.50	-277.87	1.36	30.87	40.34	53.40	16.00	17.78
3.41	2.5	3	0.69	Pattern 1	40.89	85.19	-191.68	1.36	21.30	27.83	53.40	11.04	12.27
5.28	2.5	3	0.69	Pattern 1	63.38	132.05	-297.12	1.36	33.01	43.13	53.40	17.11	19.01
7.53	2.5	3	0.69	Pattern 1	90.38	188.29	-423.66	1.36	47.07	61.50	53.40	24.40	27.11
4.56	2.5	3	0.69	Pattern 1	54.71	113.99	-256.47	1.36	28.50	37.23	53.40	14.77	16.41
7.08	2.5	3	0.69	Pattern 1	84.98	177.05	-398.36	1.36	44.26	57.83	53.40	22.94	25.49
10.12	2.5	3	0.69	Pattern 1	121.48	253.09	-569.45	1.36	63.27	82.67	53.40	32.79	36.44
3.35	2.5	3	0.69	Pattern 1	40.17	83.69	-188.29	1.36	20.92	27.33	53.40	10.84	12.05
5.14	2.5	3	0.69	Pattern 1	61.62	128.38	-288.85	1.36	32.09	41.93	53.40	16.63	18.48
7.23	2.5	3	0.69	Pattern 1	86.72	180.68	-406.52	1.36	45.17	59.01	53.40	23.41	26.01
5.08	2.5	3	0.69	Pattern 1	60.90	126.88	-285.49	1.36	31.72	41.44	53.40	16.44	18.27
7.83	2.5	3	0.69	Pattern 1	94.02	195.87	-440.72	1.36	48.97	63.98	53.40	25.38	28.20
11.11	2.5	3	0.69	Pattern 1	133.38	277.87	-625.20	1.36	69.47	90.76	53.40	36.01	40.01
6.80	2.5	3	0.69	Pattern 1	81.64	170.08	-382.68	1.36	42.52	55.55	53.40	22.04	24.49
10.53	2.5	3	0.69	Pattern 1	126.42	263.37	-592.58	1.36	65.84	86.02	53.40	34.13	37.92
15.00	2.5	3	0.69	Pattern 1	180.03	375.06	-843.89	1.36	93.77	122.51	53.40	48.60	54.00

De La Salle University

APPENDIX G
Yield line method for 3x3m wall (non-load bearing wall)

			Wall Design Specifications						Effective Compression Width per Bar				Steel			Concrete				Nominal Moment Capacity			
			Spacing of Reinforcement		CHB Dimensions			Reinforcement	a	b	c	Minimum	As	fy	Asfy	Ø	f'm	b	a	Asfy	d	a/2	Mn
			Horizontal	Vertical	Length (mm)	Height (mm)	Thickness (mm)	Diameter (mmØ)	(meters)	(meters)	(meters)	(meters)	(sq. mm)	(Mpa)	(N)		(Mpa)	(mm)	(mm)	(N)	(mm)	(mm)	(N.mm)
S1	C1	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	8	0.8	0.6	1.829	0.6	50.27	275.00	13823.01	0.80	2.10	600.00	13.71	13823.01	100.00	6.86	1287521.29
S1	C1	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	10	0.8	0.6	1.829	0.6	78.54	275.00	21598.45	0.80	2.10	600.00	21.43	21598.45	100.00	10.71	1928449.68
S1	C1	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	12	0.8	0.6	1.829	0.6	113.10	275.00	31101.77	0.80	2.10	600.00	30.85	31101.77	100.00	15.43	2630355.43
S1	C2	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	8	0.8	0.9	1.829	0.8	50.27	275.00	13823.01	0.80	2.10	800.00	10.28	13823.01	150.00	5.14	2002366.59
S1	C2	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	10	0.8	0.9	1.829	0.8	78.54	275.00	21598.45	0.80	2.10	800.00	16.07	21598.45	150.00	8.04	3066221.05
S1	C2	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	12	0.8	0.9	1.829	0.8	113.10	275.00	31101.77	0.80	2.10	800.00	23.14	31101.77	150.00	11.57	4305399.23
S1	C3	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	8	0.8	1.2	1.829	0.8	50.27	275.00	13823.01	0.80	2.10	800.00	10.28	13823.01	200.00	5.14	2693517.01
S1	C3	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	10	0.8	1.2	1.829	0.8	78.54	275.00	21598.45	0.80	2.10	800.00	16.07	21598.45	200.00	8.04	4146143.57
S1	C3	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	12	0.8	1.2	1.829	0.8	113.10	275.00	31101.77	0.80	2.10	800.00	23.14	31101.77	200.00	11.57	5860487.67
S2	C1	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	8	0.6	0.6	1.829	0.6	50.27	275.00	13823.01	0.80	2.10	600.00	13.71	13823.01	100.00	6.86	1287521.29
S2	C1	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	10	0.6	0.6	1.829	0.6	78.54	275.00	21598.45	0.80	2.10	600.00	21.43	21598.45	100.00	10.71	1928449.68
S2	C1	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	12	0.6	0.6	1.829	0.6	113.10	275.00	31101.77	0.80	2.10	600.00	30.85	31101.77	100.00	15.43	2630355.43
S2	C2	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	8	0.6	0.9	1.829	0.6	50.27	275.00	13823.01	0.80	2.10	600.00	13.71	13823.01	150.00	6.86	1978671.70
S2	C2	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	10	0.6	0.9	1.829	0.6	78.54	275.00	21598.45	0.80	2.10	600.00	21.43	21598.45	150.00	10.71	3008372.21
S2	C2	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	12	0.6	0.9	1.829	0.6	113.10	275.00	31101.77	0.80	2.10	600.00	30.85	31101.77	150.00	15.43	4185443.87
S2	C3	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	8	0.6	1.2	1.829	0.6	50.27	275.00	13823.01	0.80	2.10	600.00	13.71	13823.01	200.00	6.86	2669822.12
S2	C3	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	10	0.6	1.2	1.829	0.6	78.54	275.00	21598.45	0.80	2.10	600.00	21.43	21598.45	200.00	10.71	4088294.73
S2	C3	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	12	0.6	1.2	1.829	0.6	113.10	275.00	31101.77	0.80	2.10	600.00	30.85	31101.77	200.00	15.43	5740532.31
S3	C1	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	8	0.4	0.6	1.829	0.4	50.27	275.00	13823.01	0.80	2.10	400.00	20.57	13823.01	100.00	10.28	1240131.52
S3	C1	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	10	0.4	0.6	1.829	0.4	78.54	275.00	21598.45	0.80	2.10	400.00	32.14	21598.45	100.00	16.07	1812752.00
S3	C1	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	12	0.4	0.6	1.829	0.4	113.10	275.00	31101.77	0.80	2.10	400.00	46.28	31101.77	100.00	23.14	2390444.72
S3	C2	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	8	0.4	0.9	1.829	0.4	50.27	275.00	13823.01	0.80	2.10	400.00	20.57	13823.01	150.00	10.28	1931281.93
S3	C2	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	10	0.4	0.9	1.829	0.4	78.54	275.00	21598.45	0.80	2.10	400.00	32.14	21598.45	150.00	16.07	2892674.52
S3	C2	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	12	0.4	0.9	1.829	0.4	113.10	275.00	31101.77	0.80	2.10	400.00	46.28	31101.77	150.00	23.14	3945533.15
S3	C3	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	8	0.4	1.2	1.829	0.4	50.27	275.00	13823.01	0.80	2.10	400.00	20.57	13823.01	200.00	10.28	2622432.35
S3	C3	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	10	0.4	1.2	1.829	0.4	78.54	275.00	21598.45	0.80	2.10	400.00	32.14	21598.45	200.00	16.07	3972597.05
S3	C3	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	12	0.4	1.2	1.829	0.4	113.10	275.00	31101.77	0.80	2.10	400.00	46.28	31101.77	200.00	23.14	5500621.59

Nominal Moment, Mn	Wall Width, a	Wall Height, b	$\frac{a^2}{b^2}$	Yield Line Pattern	$\frac{w_u}{Ø} = 12(\frac{M_{nx}}{a^2}+\frac{M_{nxy}}{b^2})$			Wu
(KN.m/m)	(meters)	(meters)			$\frac{M_{nx}}{a^2}$	$\frac{M_{nxy}}{b^2}$	$\frac{w_u}{Ø}$	kPa
2.15	3.00	3.00	1.00	Pattern 1	0.24	0.24	5.72	6.36
3.21	3.00	3.00	1.00	Pattern 1	0.36	0.36	8.57	9.52
4.38	3.00	3.00	1.00	Pattern 1	0.49	0.49	11.69	12.99
2.50	3.00	3.00	1.00	Pattern 1	0.28	0.28	6.67	7.42
3.83	3.00	3.00	1.00	Pattern 1	0.43	0.43	10.22	11.36
5.38	3.00	3.00	1.00	Pattern 1	0.60	0.60	14.35	15.95
3.37	3.00	3.00	1.00	Pattern 1	0.37	0.37	8.98	9.98
5.18	3.00	3.00	1.00	Pattern 1	0.58	0.58	13.82	15.36
7.33	3.00	3.00	1.00	Pattern 1	0.81	0.81	19.53	21.71
2.15	3.00	3.00	1.00	Pattern 1	0.24	0.24	5.72	6.36
3.21	3.00	3.00	1.00	Pattern 1	0.36	0.36	8.57	9.52
4.38	3.00	3.00	1.00	Pattern 1	0.49	0.49	11.69	12.99
3.30	3.00	3.00	1.00	Pattern 1	0.37	0.37	8.79	9.77
5.01	3.00	3.00	1.00	Pattern 1	0.56	0.56	13.37	14.86
6.98	3.00	3.00	1.00	Pattern 1	0.78	0.78	18.60	20.67
4.45	3.00	3.00	1.00	Pattern 1	0.49	0.49	11.87	13.18
6.81	3.00	3.00	1.00	Pattern 1	0.76	0.76	18.17	20.19
9.57	3.00	3.00	1.00	Pattern 1	1.06	1.06	25.51	28.35
3.10	3.00	3.00	1.00	Pattern 1	0.34	0.34	8.27	9.19
4.53	3.00	3.00	1.00	Pattern 1	0.50	0.50	12.09	13.43
5.98	3.00	3.00	1.00	Pattern 1	0.66	0.66	15.94	17.71
4.83	3.00	3.00	1.00	Pattern 1	0.54	0.54	12.88	14.31
7.23	3.00	3.00	1.00	Pattern 1	0.80	0.80	19.28	21.43
9.86	3.00	3.00	1.00	Pattern 1	1.10	1.10	26.30	29.23
6.56	3.00	3.00	1.00	Pattern 1	0.73	0.73	17.48	19.43
9.93	3.00	3.00	1.00	Pattern 1	1.10	1.10	26.48	29.43
13.75	3.00	3.00	1.00	Pattern 1	1.53	1.53	36.67	40.75

APPENDIX H
Yield line method for 4x3m wa ll (non-load bearing wall)

	Wall Design Specifications						Effective Compression Width per Bar				Steel			Concrete				Nominal Moment Capacity			
	Spacing of Reinforcement		CHB Dimensions			Reinforcement	a	b	c	Minimum	As	fy	Asfy	Ø	f'm	b	a	Asfy	d	a/2	Mn
	Horizontal	Vertical	Length (mm)	Height (mm)	Thickness (mm)	Diameter (mmØ)	(meters)	(meters)	(meters)	(meters)	(sq. mm)	(Mpa)	(N)		(Mpa)	(mm)	(mm)	(N)	(mm)	(mm)	(N.mm)
S1 C1 B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	8	0.8	0.6	1.829	0.6	50.27	275.00	13823.01	0.80	2.10	600.00	13.71	13823.01	100.00	6.86	1287521.29
S1 C1 B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	10	0.8	0.6	1.829	0.6	78.54	275.00	21598.45	0.80	2.10	600.00	21.43	21598.45	100.00	10.71	1928449.68
S1 C1 B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	12	0.8	0.6	1.829	0.6	113.10	275.00	31101.77	0.80	2.10	600.00	30.85	31101.77	100.00	15.43	2630355.43
S1 C2 B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	8	0.8	0.9	1.829	0.8	50.27	275.00	13823.01	0.80	2.10	800.00	10.28	13823.01	150.00	5.14	2002366.59
S1 C2 B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	10	0.8	0.9	1.829	0.8	78.54	275.00	21598.45	0.80	2.10	800.00	16.07	21598.45	150.00	8.04	3066221.05
S1 C2 B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	12	0.8	0.9	1.829	0.8	113.10	275.00	31101.77	0.80	2.10	800.00	23.14	31101.77	150.00	11.57	4305399.23
S1 C3 B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	8	0.8	1.2	1.829	0.8	50.27	275.00	13823.01	0.80	2.10	800.00	10.28	13823.01	200.00	5.14	2693517.01
S1 C3 B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	10	0.8	1.2	1.829	0.8	78.54	275.00	21598.45	0.80	2.10	800.00	16.07	21598.45	200.00	8.04	4146143.57
S1 C3 B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	12	0.8	1.2	1.829	0.8	113.10	275.00	31101.77	0.80	2.10	800.00	23.14	31101.77	200.00	11.57	5860487.67
S2 C1 B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	8	0.6	0.6	1.829	0.6	50.27	275.00	13823.01	0.80	2.10	600.00	13.71	13823.01	100.00	6.86	1287521.29
S2 C1 B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	10	0.6	0.6	1.829	0.6	78.54	275.00	21598.45	0.80	2.10	600.00	21.43	21598.45	100.00	10.71	1928449.68
S2 C1 B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	12	0.6	0.6	1.829	0.6	113.10	275.00	31101.77	0.80	2.10	600.00	30.85	31101.77	100.00	15.43	2630355.43
S2 C2 B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	8	0.6	0.9	1.829	0.6	50.27	275.00	13823.01	0.80	2.10	600.00	13.71	13823.01	150.00	6.86	1978671.70
S2 C2 B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	10	0.6	0.9	1.829	0.6	78.54	275.00	21598.45	0.80	2.10	600.00	21.43	21598.45	150.00	10.71	3008372.21
S2 C2 B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	12	0.6	0.9	1.829	0.6	113.10	275.00	31101.77	0.80	2.10	600.00	30.85	31101.77	150.00	15.43	4185443.87
S2 C3 B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	8	0.6	1.2	1.829	0.6	50.27	275.00	13823.01	0.80	2.10	600.00	13.71	13823.01	200.00	6.86	2669822.12
S2 C3 B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	10	0.6	1.2	1.829	0.6	78.54	275.00	21598.45	0.80	2.10	600.00	21.43	21598.45	200.00	10.71	4088294.73
S2 C3 B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	12	0.6	1.2	1.829	0.6	113.10	275.00	31101.77	0.80	2.10	600.00	30.85	31101.77	200.00	15.43	5740532.31
S3 C1 B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	8	0.4	0.6	1.829	0.4	50.27	275.00	13823.01	0.80	2.10	400.00	20.57	13823.01	100.00	10.28	1240131.52
S3 C1 B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	10	0.4	0.6	1.829	0.4	78.54	275.00	21598.45	0.80	2.10	400.00	32.14	21598.45	100.00	16.07	1812752.00
S3 C1 B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	12	0.4	0.6	1.829	0.4	113.10	275.00	31101.77	0.80	2.10	400.00	46.28	31101.77	100.00	23.14	2390444.72
S3 C2 B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	8	0.4	0.9	1.829	0.4	50.27	275.00	13823.01	0.80	2.10	400.00	20.57	13823.01	150.00	10.28	1931281.93
S3 C2 B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	10	0.4	0.9	1.829	0.4	78.54	275.00	21598.45	0.80	2.10	400.00	32.14	21598.45	150.00	16.07	2892674.52
S3 C2 B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	12	0.4	0.9	1.829	0.4	113.10	275.00	31101.77	0.80	2.10	400.00	46.28	31101.77	150.00	23.14	3945533.15
S3 C3 B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	8	0.4	1.2	1.829	0.4	50.27	275.00	13823.01	0.80	2.10	400.00	20.57	13823.01	200.00	10.28	2622432.35
S3 C3 B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	10	0.4	1.2	1.829	0.4	78.54	275.00	21598.45	0.80	2.10	400.00	32.14	21598.45	200.00	16.07	3972597.05
S3 C3 B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	12	0.4	1.2	1.829	0.4	113.10	275.00	31101.77	0.80	2.10	400.00	46.28	31101.77	200.00	23.14	5500621.59

					Pattern 2									
Nominal Moment, Mn	Wall Width, a	Wall Height, b	$\frac{a^2}{b^2}$	Yield Line Pattern	$4a(M_{ny})x^2 + 4b^2(M_{nx})x - 3ab^2(M_{nx})=0$				$\frac{w_u}{Ø} = \frac{12[b^2(M_{nx}) + 2ax(M_{ny})]}{b^2(3ax - 2x^2)}$				Wu
(KN.m/m)	(meters)	(meters)			$4a(M_{ny})$	$4b^2(M_{nx})$	$3ab^2(M_{nx})$	x	$b^2(M_{nx})$	$2ax(M_{ny})$	$b^2(3ax - 2x^2)$	$\frac{w_u}{Ø}$	kPa
2.15	4.00	3.00	1.78	Pattern 2	34.33	77.25	-231.75	1.71	19.31	29.29	131.87	4.42	4.91
3.21	4.00	3.00	1.78	Pattern 2	51.43	115.71	-347.12	1.71	28.93	43.87	131.87	6.62	7.36
4.38	4.00	3.00	1.78	Pattern 2	70.14	157.82	-473.46	1.71	39.46	59.84	131.87	9.04	10.04
2.50	4.00	3.00	1.78	Pattern 2	40.05	90.11	-270.32	1.71	22.53	34.16	131.87	5.16	5.73
3.83	4.00	3.00	1.78	Pattern 2	61.32	137.98	-413.94	1.71	34.49	52.32	131.87	7.90	8.78
5.38	4.00	3.00	1.78	Pattern 2	86.11	193.74	-581.23	1.71	48.44	73.46	131.87	11.09	12.32
3.37	4.00	3.00	1.78	Pattern 2	53.87	121.21	-363.62	1.71	30.30	45.96	131.87	6.94	7.71
5.18	4.00	3.00	1.78	Pattern 2	82.92	186.58	-559.73	1.71	46.64	70.74	131.87	10.68	11.87
7.33	4.00	3.00	1.78	Pattern 2	117.21	263.72	-791.17	1.71	65.93	99.99	131.87	15.10	16.78
2.15	4.00	3.00	1.78	Pattern 2	34.33	77.25	-231.75	1.71	19.31	29.29	131.87	4.42	4.91
3.21	4.00	3.00	1.78	Pattern 2	51.43	115.71	-347.12	1.71	28.93	43.87	131.87	6.62	7.36
4.38	4.00	3.00	1.78	Pattern 2	70.14	157.82	-473.46	1.71	39.46	59.84	131.87	9.04	10.04
3.30	4.00	3.00	1.78	Pattern 2	52.76	118.72	-356.16	1.71	29.68	45.01	131.87	6.80	7.55
5.01	4.00	3.00	1.78	Pattern 2	80.22	180.50	-541.51	1.71	45.13	68.44	131.87	10.33	11.48
6.98	4.00	3.00	1.78	Pattern 2	111.61	251.13	-753.38	1.71	62.78	95.22	131.87	14.38	15.98
4.45	4.00	3.00	1.78	Pattern 2	71.20	160.19	-480.57	1.71	40.05	60.74	131.87	9.17	10.19
6.81	4.00	3.00	1.78	Pattern 2	109.02	245.30	-735.89	1.71	61.32	93.01	131.87	14.04	15.60
9.57	4.00	3.00	1.78	Pattern 2	153.08	344.43	-1033.30	1.71	86.11	130.59	131.87	19.72	21.91
3.10	4.00	3.00	1.78	Pattern 2	49.61	111.61	-334.84	1.71	27.90	42.32	131.87	6.39	7.10
4.53	4.00	3.00	1.78	Pattern 2	72.51	163.15	-489.44	1.71	40.79	61.86	131.87	9.34	10.38
5.98	4.00	3.00	1.78	Pattern 2	95.62	215.14	-645.42	1.71	53.79	81.57	131.87	12.32	13.69
4.83	4.00	3.00	1.78	Pattern 2	77.25	173.82	-521.45	1.71	43.45	65.90	131.87	9.95	11.06
7.23	4.00	3.00	1.78	Pattern 2	115.71	260.34	-781.02	1.71	65.09	98.71	131.87	14.91	16.56
9.86	4.00	3.00	1.78	Pattern 2	157.82	355.10	-1065.29	1.71	88.77	134.64	131.87	20.33	22.59
6.56	4.00	3.00	1.78	Pattern 2	104.90	236.02	-708.06	1.71	59.00	89.49	131.87	13.51	15.01
9.93	4.00	3.00	1.78	Pattern 2	158.90	357.53	-1072.60	1.71	89.38	135.56	131.87	20.47	22.74
13.75	4.00	3.00	1.78	Pattern 2	220.02	495.06	-1485.17	1.71	123.76	187.70	131.87	28.34	31.49

APPENDIX I
Yield line method for 2.5x3m wall (non-load bearing wall)

			Wall Design Specifications						Effective Compression Width per Bar				Steel			Concrete				Nominal Moment Capacity			
			Spacing of Reinforcement		CHB Dimensions			Reinforcement	a	b	c	Minimum	As	fy	Asfy	Ø	f'm	b	a	Asfy	d	a/2	Mn
			Horizontal	Vertical	Length (mm)	Height (mm)	Thickness (mm)	Diameter (mmØ)	(meters)	(meters)	(meters)	(meters)	(sq. mm)	(Mpa)	(N)		(Mpa)	(mm)	(mm)	(N)	(mm)	(mm)	(N.mm)
S1	C1	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	8	0.8	0.6	1.829	0.6	50.27	275.00	13823.01	0.80	2.10	600.00	13.71	13823.01	100.00	6.86	1287521.29
S1	C1	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	10	0.8	0.6	1.829	0.6	78.54	275.00	21598.45	0.80	2.10	600.00	21.43	21598.45	100.00	10.71	1928449.68
S1	C1	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	100	12	0.8	0.6	1.829	0.6	113.10	275.00	31101.77	0.80	2.10	600.00	30.85	31101.77	100.00	15.43	2630355.43
S1	C2	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	8	0.8	0.9	1.829	0.8	50.27	275.00	13823.01	0.80	2.10	800.00	10.28	13823.01	150.00	5.14	2002366.59
S1	C2	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	10	0.8	0.9	1.829	0.8	78.54	275.00	21598.45	0.80	2.10	800.00	16.07	21598.45	150.00	8.04	3066221.05
S1	C2	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	150	12	0.8	0.9	1.829	0.8	113.10	275.00	31101.77	0.80	2.10	800.00	23.14	31101.77	150.00	11.57	4305399.23
S1	C3	B1	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	8	0.8	1.2	1.829	0.8	50.27	275.00	13823.01	0.80	2.10	800.00	10.28	13823.01	200.00	5.14	2693517.01
S1	C3	B2	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	10	0.8	1.2	1.829	0.8	78.54	275.00	21598.45	0.80	2.10	800.00	16.07	21598.45	200.00	8.04	4146143.57
S1	C3	B3	Every 4th CHB Layer	Every 80cm O.C.	400	200	200	12	0.8	1.2	1.829	0.8	113.10	275.00	31101.77	0.80	2.10	800.00	23.14	31101.77	200.00	11.57	5860487.67
S2	C1	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	8	0.6	0.6	1.829	0.6	50.27	275.00	13823.01	0.80	2.10	600.00	13.71	13823.01	100.00	6.86	1287521.29
S2	C1	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	10	0.6	0.6	1.829	0.6	78.54	275.00	21598.45	0.80	2.10	600.00	21.43	21598.45	100.00	10.71	1928449.68
S2	C1	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	100	12	0.6	0.6	1.829	0.6	113.10	275.00	31101.77	0.80	2.10	600.00	30.85	31101.77	100.00	15.43	2630355.43
S2	C2	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	8	0.6	0.9	1.829	0.6	50.27	275.00	13823.01	0.80	2.10	600.00	13.71	13823.01	150.00	6.86	1978671.70
S2	C2	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	10	0.6	0.9	1.829	0.6	78.54	275.00	21598.45	0.80	2.10	600.00	21.43	21598.45	150.00	10.71	3008372.21
S2	C2	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	150	12	0.6	0.9	1.829	0.6	113.10	275.00	31101.77	0.80	2.10	600.00	30.85	31101.77	150.00	15.43	4185443.87
S2	C3	B1	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	8	0.6	1.2	1.829	0.6	50.27	275.00	13823.01	0.80	2.10	600.00	13.71	13823.01	200.00	6.86	2669822.12
S2	C3	B2	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	10	0.6	1.2	1.829	0.6	78.54	275.00	21598.45	0.80	2.10	600.00	21.43	21598.45	200.00	10.71	4088294.73
S2	C3	B3	Every 3rd CHB Layer	Every 60cm O.C.	400	200	200	12	0.6	1.2	1.829	0.6	113.10	275.00	31101.77	0.80	2.10	600.00	30.85	31101.77	200.00	15.43	5740532.31
S3	C1	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	8	0.4	0.6	1.829	0.4	50.27	275.00	13823.01	0.80	2.10	400.00	20.57	13823.01	100.00	10.28	1240131.52
S3	C1	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	10	0.4	0.6	1.829	0.4	78.54	275.00	21598.45	0.80	2.10	400.00	32.14	21598.45	100.00	16.07	1812752.00
S3	C1	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	100	12	0.4	0.6	1.829	0.4	113.10	275.00	31101.77	0.80	2.10	400.00	46.28	31101.77	100.00	23.14	2390444.72
S3	C2	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	8	0.4	0.9	1.829	0.4	50.27	275.00	13823.01	0.80	2.10	400.00	20.57	13823.01	150.00	10.28	1931281.93
S3	C2	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	10	0.4	0.9	1.829	0.4	78.54	275.00	21598.45	0.80	2.10	400.00	32.14	21598.45	150.00	16.07	2892674.52
S3	C2	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	150	12	0.4	0.9	1.829	0.4	113.10	275.00	31101.77	0.80	2.10	400.00	46.28	31101.77	150.00	23.14	3945533.15
S3	C3	B1	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	8	0.4	1.2	1.829	0.4	50.27	275.00	13823.01	0.80	2.10	400.00	20.57	13823.01	200.00	10.28	2622432.35
S3	C3	B2	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	10	0.4	1.2	1.829	0.4	78.54	275.00	21598.45	0.80	2.10	400.00	32.14	21598.45	200.00	16.07	3972597.05
S3	C3	B3	Every 2nd CHB Layer	Every 40cm O.C.	400	200	200	12	0.4	1.2	1.829	0.4	113.10	275.00	31101.77	0.80	2.10	400.00	46.28	31101.77	200.00	23.14	5500621.59

					Pattern 3								
Nominal Moment, Mn	Wall Width, a	Wall Height, b	$\frac{a^2}{b^2}$	Yield Line Pattern	$4b(M_{nx})y^2 + 4a^2(M_{ny})y - 3ba^2(M_{ny})=0$				$\frac{w_u}{Ø} = \frac{12[a^2(M_{ny}) + 2by(M_{nx})]}{a^2(3by - 2y^2)}$				Wu
(KN.m/m)	(meters)	(meters)			$4b(M_{nx})$	$4a^2(M_{ny})$	$3ba^2(M_{ny})$	y	$a^2(M_{ny})$	$2by(M_{nx})$	$a^2(3by - 2y^2)$	$\frac{w_u}{Ø}$	kPa
2.15	2.50	3.00	0.69	Pattern 1	25.75	53.65	-120.71	1.36	13.41	17.52	53.40	6.95	7.72
3.21	2.50	3.00	0.69	Pattern 1	38.57	80.35	-180.79	1.36	20.09	26.25	53.40	10.41	11.57
4.38	2.50	3.00	0.69	Pattern 1	52.61	109.60	-246.60	1.36	27.40	35.80	53.40	14.20	15.78
2.50	2.50	3.00	0.69	Pattern 1	30.04	62.57	-140.79	1.36	15.64	20.44	53.40	8.11	9.01
3.83	2.50	3.00	0.69	Pattern 1	45.99	95.82	-215.59	1.36	23.95	31.30	53.40	12.42	13.80
5.38	2.50	3.00	0.69	Pattern 1	64.58	134.54	-302.72	1.36	33.64	43.95	53.40	17.43	19.37
3.37	2.50	3.00	0.69	Pattern 1	40.40	84.17	-189.39	1.36	21.04	27.49	53.40	10.91	12.12
5.18	2.50	3.00	0.69	Pattern 1	62.19	129.57	-291.53	1.36	32.39	42.32	53.40	16.79	18.65
7.33	2.50	3.00	0.69	Pattern 1	87.91	183.14	-412.07	1.36	45.79	59.82	53.40	23.73	26.37
2.15	2.50	3.00	0.69	Pattern 1	25.75	53.65	-120.71	1.36	13.41	17.52	53.40	6.95	7.72
3.21	2.50	3.00	0.69	Pattern 1	38.57	80.35	-180.79	1.36	20.09	26.25	53.40	10.41	11.57
4.38	2.50	3.00	0.69	Pattern 1	52.61	109.60	-246.60	1.36	27.40	35.80	53.40	14.20	15.78
3.30	2.50	3.00	0.69	Pattern 1	39.57	82.44	-185.50	1.36	20.61	26.93	53.40	10.68	11.87
5.01	2.50	3.00	0.69	Pattern 1	60.17	125.35	-282.03	1.36	31.34	40.94	53.40	16.24	18.05
6.98	2.50	3.00	0.69	Pattern 1	83.71	174.39	-392.39	1.36	43.60	56.96	53.40	22.60	25.11
4.45	2.50	3.00	0.69	Pattern 1	53.40	111.24	-250.30	1.36	27.81	36.33	53.40	14.41	16.02
6.81	2.50	3.00	0.69	Pattern 1	81.77	170.35	-383.28	1.36	42.59	55.64	53.40	22.07	24.53
9.57	2.50	3.00	0.69	Pattern 1	114.81	239.19	-538.17	1.36	59.80	78.13	53.40	30.99	34.44
3.10	2.50	3.00	0.69	Pattern 1	37.20	77.51	-174.39	1.36	19.38	25.32	53.40	10.04	11.16
4.53	2.50	3.00	0.69	Pattern 1	54.38	113.30	-254.92	1.36	28.32	37.01	53.40	14.68	16.31
5.98	2.50	3.00	0.69	Pattern 1	71.71	149.40	-336.16	1.36	37.35	48.80	53.40	19.36	21.51
4.83	2.50	3.00	0.69	Pattern 1	57.94	120.71	-271.59	1.36	30.18	39.43	53.40	15.64	17.38
7.23	2.50	3.00	0.69	Pattern 1	86.78	180.79	-406.78	1.36	45.20	59.05	53.40	23.43	26.03
9.86	2.50	3.00	0.69	Pattern 1	118.37	246.60	-554.84	1.36	61.65	80.55	53.40	31.95	35.50
6.56	2.50	3.00	0.69	Pattern 1	78.67	163.90	-368.78	1.36	40.98	53.54	53.40	21.24	23.60
9.93	2.50	3.00	0.69	Pattern 1	119.18	248.29	-558.65	1.36	62.07	81.10	53.40	32.17	35.75
13.75	2.50	3.00	0.69	Pattern 1	165.02	343.79	-773.52	1.36	85.95	112.29	53.40	44.55	49.50