You Can Keep Your Family Safe From Earthquakes and Typhoons

Residential Design and Construction Guidelines

Based on the 2010 National Structural Code of the Philippines

BUILD CHANGE

Cordaid

Published April 1, 2016

USA Headquarters
535 16th St., Suite 605
Denver, CO 80202 USA
Telephone: +1 303-953-2563

Philippines Office
3 Gabutan Compound, Buena Hills Subdivision
Guadalupe, Cebu City, Cebu, 6000 PHILIPPINES

Haiti Office
Rue Casseus no. 16, Pacot
Port-au-Prince, HAITI

Indonesia Office
Jl. Raya Sengeda - Mampak, Desa Bukit, Kec. Kebayakan
Takengon, Aceh Tengah, INDONESIA

Colombia Office
Calle 31 No.13a 51
Bogota, COLOMBIA

Nepal Office
Chaudhary Group Lane
Sanepa-2, Lalitpur, NEPAL

info@buildchange.org
www.buildchange.org

ISBN: in process

BUILD CHANGE

Foreword

Build Change is a non-profit social enterprise whose mission is to save lives in earthquakes and typhoons. Build Change designs safe buildings, trains homeowners, builders, engineers and government officials to build them, works with governments to develop and implement building standards, partners with the private sector to improve building materials quality and create jobs, and facilitates access to incentive-based capital for reconstruction and retrofitting by partnering with financing institutions and government subsidy programs.

Build Change started its work in Aceh, Indonesia, after the 2004 earthquake and tsunami, and since has expanded to include programs in China, Haiti, Colombia, the Philippines, and Nepal. Build Change has trained more than 23,000 people in disaster-resistant design and construction techniques, and has provided technical assistance for more than 47,000 safer homes, impacting an estimated 236,000 people. This handbook is dedicated to homeowners and builders in the Philippines so that they can use it to keep their families and communities safe during earthquakes and typhoons.

Cebu, Philippines, September 2015

Elizabeth Hausler Strand, Ph.D.
Founder and CEO, Build Change

Acknowledgements

Build Change would like to acknowledge the partners who have provided support for production and endorsement of the Residential Design and Construction Guidelines, including the Department of Public Works and Highways (DPWH), Housing and Urban Development Coordinating Council (HUDCC), National Housing Authority (NHA), Department of Social Welfare and Development (DSWD) and Cordaid. Build Change would also like to thank the individuals that participated in the design, production, and revision of the Residential Design and Construction Guidelines; their contributions have been invaluable.

DPWH

HUDCC

NHA

DSWD

Republic of the Philippines
DEPARTMENT OF PUBLIC WORKS AND HIGHWAYS
OFFICE OF THE SECRETARY
Manila

26 May 2016

Message

Geographic vulnerability of the Philippines against natural and man-made disasters demands for sustainable measures and actions.

The Department of Public Works and Highways commends Build Change for coming up with the Residential Design and Construction Guidelines for building low-rise disaster-resistant houses.

It is worth to underscore the appropriateness of your endeavor to enable people to build and live in disaster-resilient houses especially now that we are sourcing all possible means to reduce the destructive impact of climate change.

We appreciate the brilliant minds of the people behind this project, as well as the contributions of your partners both in private and public sector, for collectively sharing your expertise in order to produce useful guidelines on disaster-resiliency, thus filling in the gap in technical engineering support for local infrastructure nationwide.

Congratulations and *Mabuhay!*

ROGELIO L. SINGSON
Secretary

Awards

Build Change's house design for Aceh, Indonesia won a 2006 Excellence in Structural Engineering Award from the Structural Engineers Association of Northern California.

Build Change's homeowner-driven housing reconstruction program in West Sumatra, Indonesia was named a 2008 Tech Laureate in the Equality category for the San Jose Tech Museum Awards for Technology Benefiting Humanity.

Build Change's Seismic Evaluation and Retrofit Guidelines for Haitian Masonry Housing, created with Degenkolb Engineers, received an Award for Excellence from the Structural Engineer's Association of Northern California and the Structural Engineer's Association of California in 2013.

Build Change is a founding member of the Confined Masonry Network, www.confinedmasonry.org

Chapter List

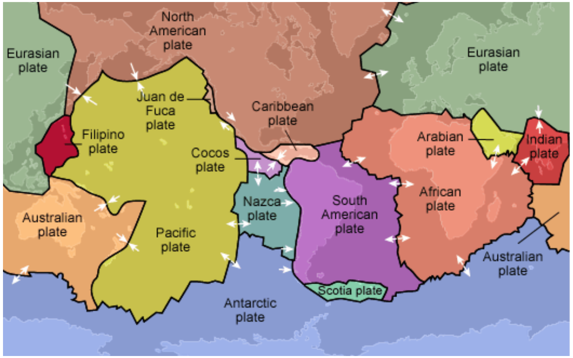
BUILD CHANGE

CHAPTER 1

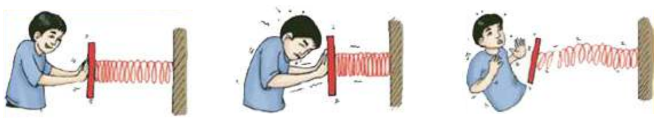
EARTHQUAKE AND TYPHOON HAZARDS IN THE PHILIPPINES

WHAT IS AN EARTHQUAKE?

An earthquake is shaking and vibration at the surface of the Earth.



US Geological Survey

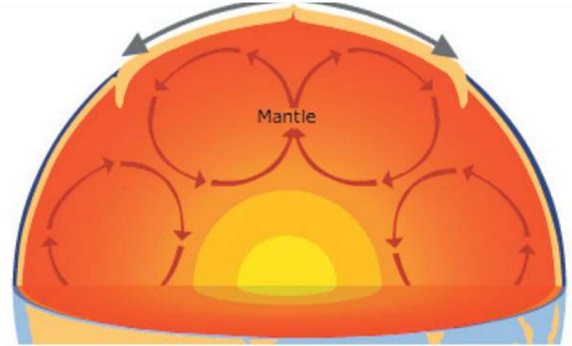


build up energy
pressure getting bigger
release of energy

Geology Text Book of Indonesia University (UPI), Nanin Triana Sugito

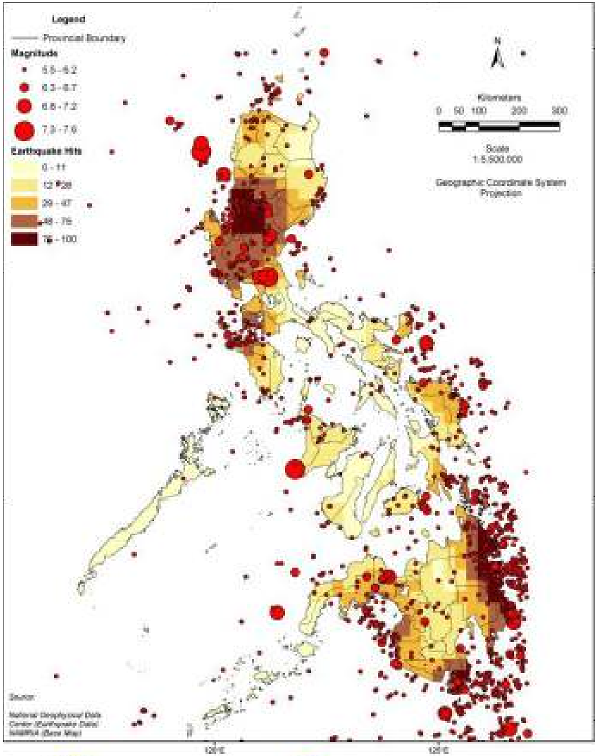
HOW DO EARTHQUAKES HAPPEN?

Earth's outer layer is broken into pieces called tectonic plates which are about 100km thick and are constantly moving towards, away from or past each other. These plates are moving due to the movement of magma in the layer below.



British Broadcasting Corporation (BBC)

Where two plates meet each other, they can become temporarily stuck, causing energy to build up slowly in the plates. Occasionally, the plates become "unstuck" and a very sudden movement occurs. This sudden movement at the boundary of the plates causes the shaking and vibration that we call an earthquake. This slow build up and quick release of energy can be thought of like slowly compressing and quickly releasing a spring.



MANILA OBSERVATORY

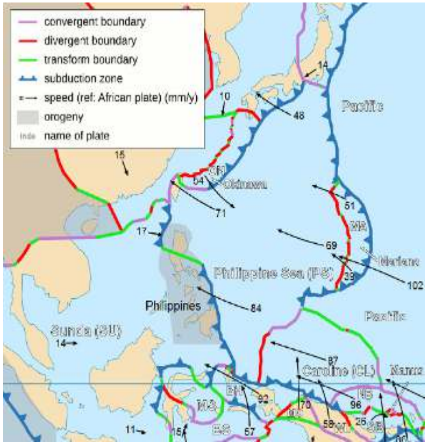
DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES

WHY DO EARTHQUAKES HAPPEN OFTEN IN THE PHILIPPINES?

EARTHQUAKE HISTORY

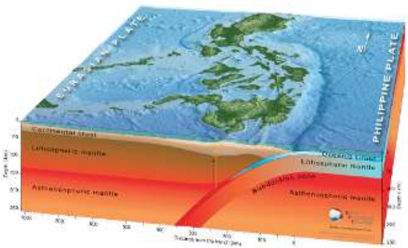
From historical record, the Philippines are exposed to periodic earthquakes. Almost every year the Philippines are visited by two or more earthquakes of various scale. The Philippines Institute of Volcanology and Seismology recorded 14 destructive earthquakes in the Philippines between 1968 and 2013.

PHILIPPINES SETTING



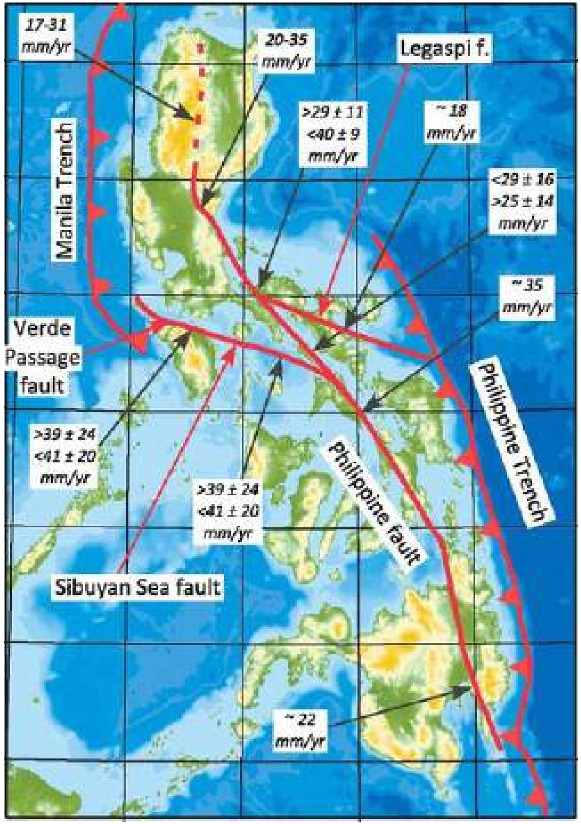
US Geological Survey

The Philippines is located in a very complex tectonic setting, sitting on two tectonic micro plates, The Philippine Sea Plate and the Sunda Plate, which are surrounded by two much larger plates, the Eurasian Plate and the Pacific Plate. The movement of converging plates creates a subduction zone at the boundaries. These subduction systems establish the trenches at the margin plate and faults that spread all over the Philippines.



Earth Observatory of Singapore

The west part of the Philippine Sea Plate is subducting beneath the Eurasia Plate, while from the east the Philippine Sea Plate is being subducted by the Pacific Plate. Subduction of the Philippine Sea Plate occurs at the eastern margin of the archipelago along the Philippine Trench and its northern extension, the East Luzon Trough. On the western margin of the Philippines, the Sunda Plate subducts eastward along a series of trenches, including the Manila Trench in the north, the smaller and less well-developed Negros Trench in the central Philippines, and the Sulu and Cotabato Trenches in the south. These highly active subduction zones explain why so many earthquakes happen in the Philippines.



Geosphere Journal (August 2010)

THE PHILIPPINE FAULT

Other than the subduction systems on its east and west sides, the unusual tectonic setting of Philippines is also characterized by a major transform fault that cuts the archipelago, the Philippine Fault.

The Philippine Fault Zone decouples the northwestward motion of the Pacific with the southeastward motion of the Eurasian Plate. It extends over 1,200 km within the Philippine arc and transects the whole archipelago from northwestern Luzon to southeastern Mindanao. This fault has been very active in the past 200 years with destructive earthquakes accompanied by surface rupture. More than half of large historical crustal earthquake in the Philippines are related to the Philippine Fault.

EARTHQUAKE PREPAREDNESS GUIDE

BEFORE

- Know the earthquake hazards in your area.
- Follow good structural design and engineering practice when constructing a house.
- Evaluate the structural soundness of your house; strengthen or retrofit if necessary.
- Strap or bolt heavy furniture and cabinets to the walls.
- Check the stability of hanging objects like ceiling fans or chandeliers.
- Breakable items, harmful chemicals, and flammable materials should be stored properly in the lowermost secured shelves.
- Get familiar with the evacuation routes.
- Prepare a handy emergency supply kit that contains a first aid kit, canned food and can opener, water, clothing, a blanket, a battery-operated radio, flashlights, and extra batteries.
- Participate in regular earthquake drills.

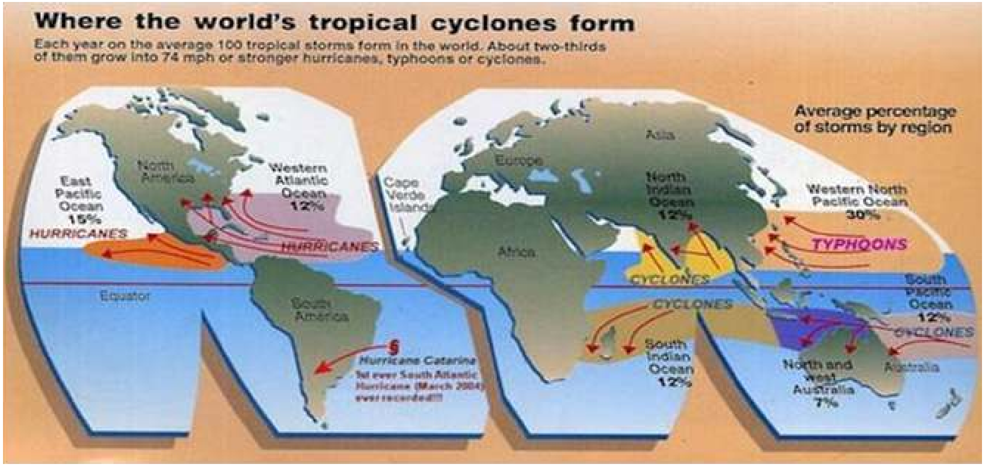
DURING

- Stay calm.
- When you are inside a structurally sound building or home:
  - If possible, quickly exit to the street.
  - Duck under a sturdy desk or table, or protect your head with your arms.
  - Stay away from glass windows, shelves, cabinets, and other heavy objects.
  - Beware of falling objects.
- If you are outside, move to open area.
  - Stay away from trees, power lines, posts, and concrete structures.
  - Move away from steep slopes which may be affected by landslides.
- If you are near the shore, move quickly to higher ground. Tsunamis might follow.
- If you are in a moving vehicle, stop and get out!

AFTER

- Be prepared for after-shocks. Once the shaking stops, take the fastest and safest way out of the building.
- Do not enter damaged buildings.
- Do not panic.
- Check water and electrical lines for damages.
- Check for spills or chemical, and toxic or flammable materials.
- Control fires which may spread.
- Keep updated on disaster instructions from a battery-operated radio.

Philippine Institute of Volcanology and Seismology



USA Today, The Weather Book (1992)

WHAT IS A TROPICAL CYCLONE?

A Tropical Cyclone (known as “Bagyo” in the Philippines) is the generic term for an intense circulating weather system over tropical seas and oceans. It is accompanied with very strong winds, heavy rains and large ocean waves.

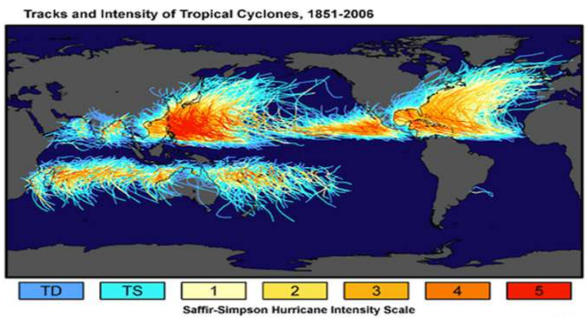
On the average, 100 tropical cyclones form in the world annually; two-thirds become typhoons and hurricanes.

WHAT CAUSES TYPHOONS?

Typhoons are caused by local atmospheric disturbances in the tropics, where ocean surface temperatures and humidity are high.

WHERE DO TYPHOONS OCCUR?

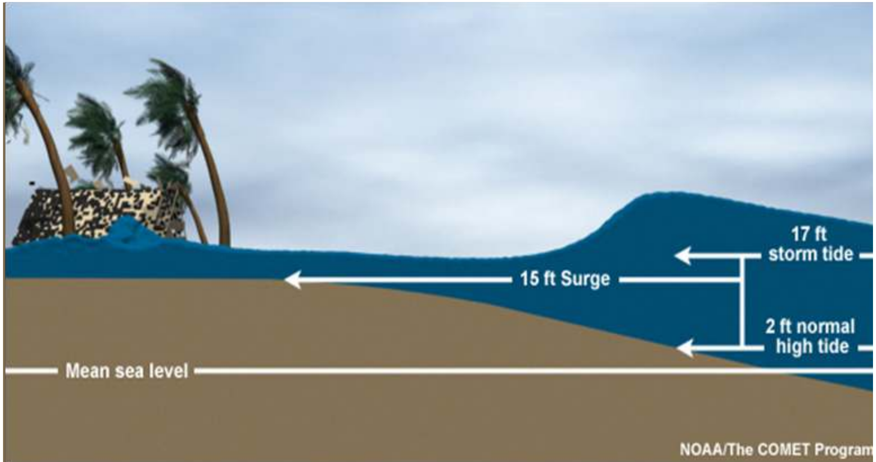
Typhoons occur mainly in the western Pacific Ocean. Typhoons often cause huge damage to coasts and islands that are on their path. They usually start close to the equator and move westward, gathering size and intensity as they move.



National Aeronautics and Space Administration (NASA)

WHAT IS THE DIFFERENCE BETWEEN HURRICANES, CYCLONES AND TYPHOONS?

Hurricanes, cyclones, and typhoons are all the same weather phenomenon; we just use different names for these storms in different places. In the Atlantic and Northeast Pacific, the term "hurricane" is used. The same type of disturbance in the Northwest Pacific is called a "typhoon", or a "cyclone" in the South Pacific and Indian Ocean.



The COMET Program,
US National Oceanic and Atmosphere Administration (NOAA)

TYPHOON HAZARDS

HIGH WINDS

Typhoons are a source of very strong and fast winds. The strong winds can cause a lot of damage, uprooting trees, damaging buildings, and sending dangerous debris flying through the air. The strong winds have the ability to tear apart houses and buildings if they are not built to be strong enough.

STORM SURGE

Along the coast, storm surge is often the greatest threat to life and property from a typhoon. In the past, large death tolls have resulted from the rise of the ocean associated with large storms. Storm surge is the rising of the sea level during a storm. This rise in water level can cause extreme flooding in coastal areas particularly when storm surge coincides with normal high tide, resulting in storm tides reaching up to 9 meters (20 feet) or more in some cases. Surge is produced mostly by water being pushed toward the shore by the force of the winds moving cyclonically around the storm. To a lesser extent, the low pressure associated with large storms also causes an increase in water levels.

TYPHOON PREPAREDNESS GUIDE

BEFORE

- Inspect your house and strengthen if fixing is needed.
- Clean up your house's drainage system so it won't get clogged up.
- Store an adequate supply of food and water that would last for a few days.
- Be aware that if you are living in a lowland, hazard prone area, you may need to evacuate in the event of a typhoon.
- Always keep flashlights, candles, batteries, and first-aid supplies available.
- Keep updated on the progress of the typhoon and whether it is nec-essary to evacuate from barangay officials, local radio, or television.

DURING

- Stay inside the house or evacuation center and keep calm. Postpone any travel.
- Monitor your local radio or television for advisories and information about the progress of the storm.
- In case of flooding, turn off the main sources of electricity.
- Do not operate any electrical equipment during a flood or use electrical or gas appliances that have been flooded.
- Keep an eye on lit (burning) candles or gas lamps.
- Evacuate calmly.
- Close the windows and turn off the main power switch.
- Put important appliances and belongings in a high place.
- Avoid the way leading to or along rivers.

AFTER

- Monitor the progress of the typhoon from a battery-operated radio.
- Check your house for damage and make necessary repairs. Avoid scat-tered debris, especially tin and lumber, as there may be rusty nails protruding.
- Make sure that your house is safe and stable before you enter.
- Have a knowledgeable person inspect electrical connections before using electrical appliances.
- Watch out for live wires or outlets immersed in water.
- Report damaged electrical cables and fallen electric poles to the authorities.
- Beware of dangerous animals, such as snakes, that may have entered your house.

Teleperformace and Weather Philippines website

CHAPTER 2

PLANNING YOUR DISASTER-RESISTANT HOME

WHAT TYPE OF HOUSE SHOULD I BUILD?

The question of which type of house is the safest is a tricky one for those of us living in areas at risk of earthquakes and typhoons. Generally speaking, houses made of lightweight and flexible materials such as timber or bamboo will be safer in earthquakes, but may be more vulnerable in typhoons. On the other hand, concrete and masonry houses are studier in the strong winds of a typhoon, but can be vulnerable in earthquakes if not built correctly. For both housing types, there are good and bad construction practices. No matter what materials are chosen for your house, it is important to build it correctly and use good quality materials.

Wood Framed Contruction
- Safer in earthquakes
- Cheaper
- Faster

Masonry Contruction
- More expensive
- More difficult to build safely
- Better protection from wind-borne (flying) debris during typhoons

Wood Confined Masonry
Don't ever use wood columns in masonry walls! The timber is much more flexible than the masonry. When the wood columns bend, the masonry walls will fall out.

WIND-BORNE DEBRIS AND OCCUPANT PROTECTION CONSIDERATIONS

Even though you can build a house that will be safe in the high winds of a typhoon, parts of a house can be damaged by the debris blown around by the winds. Wind and rain can still damage some elements of your house and make it unsafe to occupy during the typhoon.

EXTERIOR WALL FINISHES

Use solid, hard exterior wall finishes that prevent wind and rain from entering your house.

- Concrete block walls, plywood that is nailed at all edges, or diagonal lumber sheathing are the best wall enclosure finishes to prevent damage from blowing debris.
- Houses with walls using metal strap bracing or diagonal wood bracing may not be safe to occupy during a storm if the wall finishes are not solid. Any light wall finishes over the bracing could be blown off by the high winds or broken by flying debris.
- Amakan or tarp wall coverings can be blown away by wind or broken open by wind-blown debris. Spaces enclosed by these finishes are not safe to occupy during a typhoon.
- Open spaces, like outside kitchens or covered verandas, are not safe from blowing debris.

DOOR AND WINDOW COVERINGS

Use solid doors and window coverings for protection during a typhoon.

- Use solid wood doors that can be securely closed and will not blow open.
- Glass windows and vent slats can be easily broken by blowing debris. Use wood slats and cover glass windows with boards or shutters during a storm.

EVACUATION WARNINGS

Whatever type of house you build, listen to evacuation warnings and prepare to evacuate to a safer area before a typhoon arrives.

- Evacuation may be needed due to the danger of flooding or tsunamis related to the storm.
- It may be better to evacuate your house because water, food, and power may not be available for a long period of time after the storm passes, and roads for transportation may be damaged.
- Use STRONG concrete blocks. Make the effort to find a vendor that sells good quality blocks, even if they are a bit more expensive.

ONE STORY OR TWO-STORY?

The heavier the house is, the more load it must take in an earthquake. The taller the house is, the more load it must take in a typhoon. That is why you should take extra care if you are considering building a two-story house.

One-Story House
A one-story house is always a good option. It is lower and lighter than a two-story building, making it more resistant to typhoons and earthquakes.

Two-Story House
If you are building a two-story house, or are planning on adding another level in the future, consider using masonry for the first story and wood for the second. This will keep the house from being too heavy and will therefore make it safer in an earthquake.

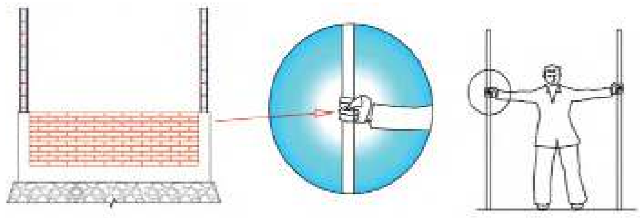
Multiple Story RC Frame
If you want to build a two-story reinforced concrete and masonry building, make sure you consult a qualified structural engineer to do the design. The structure will have to be bigger and stronger than for a simple single-story building.

BUILD CHANGE

CONFINED MASONRY OR CONCRETE FRAME WITH MASONRY INFILL?

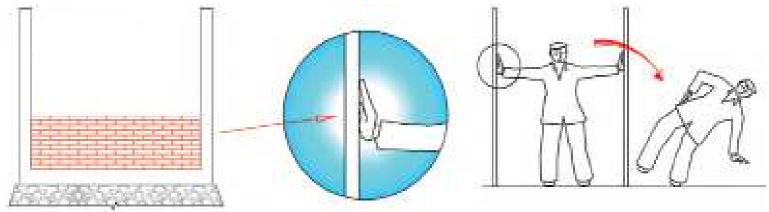
These two systems may look similar, however there are important differences.

CONFINED MASONRY ANALOGY



Confined Masonry
In a confined masonry building, the walls are built before the columns and beams are poured. This helps to make a better connection between the walls and the columns.

REINFORCED CONCRETE FRAME ANALOGY



Reinforced Concrete Frame
In a reinforced concrete frame building, the columns and beams tend to be larger, and are poured before the wall is built. This makes for a weaker connection between the walls and the reinforced concrete members.

The reinforced concrete frame with masonry infill method is more common for taller buildings with multiple stories where the columns and beams must be much larger and stronger, because the beams and columns do all the work to keep the building standing up. However for a simple house with only one story in masonry, we recommend a confined masonry system to improve the connection from the walls to the columns. The walls, columns, and beams can work together to resist wind and earthquake forces.

NATURAL DISASTERS DON'T KILL PEOPLE, POORLY BUILT BUILDINGS DO

Earthquakes and typhoons cannot be prevented, but they don't have to be disasters. We can anticipate and plan for these events by building strong and safe houses. If we do so, we can prevent the house from collapsing. It is not the earthquake or typhoon that kills people, but the building collapsing.

You can keep your family safe in earthquakes and typhoons by following the Three C's.

FIRST C

Use a simple, symmetric **CONFIGURATION**

- Choose a square or rectangular plan.
- Avoid long and narrow structures where the length is more than three times the width.
- Space parallel walls at no more than 3.5 meters apart.
- Don't use masonry in the gable wall. Make a hipped roof or use timber or another lightweight material for the gable.
- Don't put too many openings in the wall, and use columns on either side of door openings.
- Use lightweight material for terrace roofs and make sure the terrace columns are connected together.

SECOND C

Use strong **CONNECTIONS** between the structural elements.

- Follow the bar bending and overlap rules to connect the columns and beams together, especially the top of the column and the ring beam.
- Use rebar dowels to connect the masonry wall to the columns.
- Use metal straps with sufficient nailing to connect wood members together, to connect the roof to the walls, and the timber walls to the foundation.

THIRD C

Use good quality materials and methods for **CONSTRUCTION QUALITY**

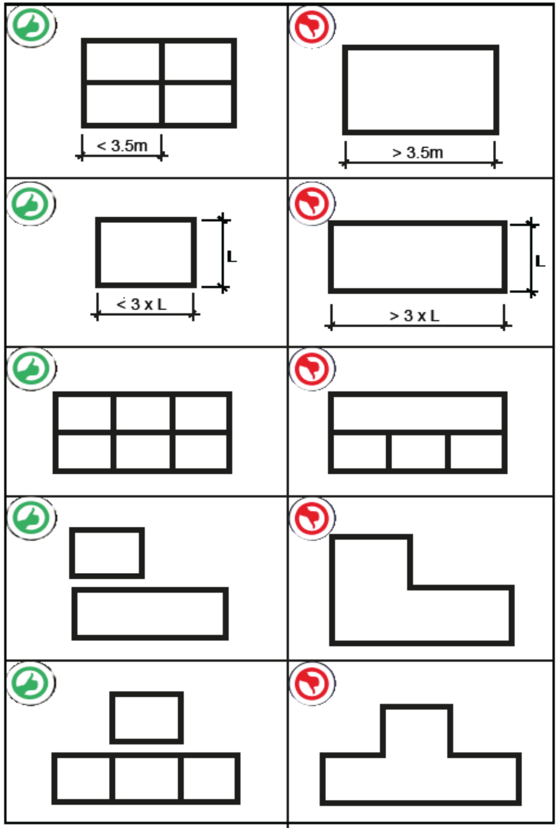
- Use good quality building materials.
- Use the correct mix for concrete and mortar, and not too much water.
- Use STRONG concrete blocks. Make the effort to find a vendor that sells good quality blocks, even if they are a bit more expensive.

FIRST C : CONFIGURATION

Using a simple, square, symmetric layout, building a one story house instead of two, avoiding heavy material in the gable wall, and avoiding or mitigating large openings can make a big difference in disaster resistance. Most of these changes are free or cheap and easy to make.

a. Use Simple, Symmetric Layout

Layout is one of main points in creating disaster-resistant houses, because an irregular shape can result in both increased wind and earthquake forces. It is best to stick with a simple, square, symmetric and redundant form.



Please consider these points in choosing your house layout :

- Choose a uniform and symmetric layout like a square or short rectangle, or circle.
- Avoid long and narrow structures where length of the wall is more than 3 times the width.
- Every length of wall more than 3.5 m should be supported by a crosswall or brace.
- Avoid L-shaped corners, which catch wind and collect earthquake loads.

More information about good wall configuration can be found in chapter 6 (for masonry walls) and chapter 8 (for wood walls).

b. Do Not Use Masonry in the Gable Wall

Gable walls made of masonry can easily collapse or crack during a disaster because they are so tall and often stand alone without any support or bracing. If you build the gable wall from masonry, make sure it is well reinforced with a well-connected ring beam on top. This is difficult and expensive. It is easier, cheaper, and more safe to build the gable wall with timber or use a hipped roof.

PROBLEM
October 15, 2013
Bohol earthquake

SOLUTION

Option 1
Use a hipped roof, which is less expensive than a pitched roof with masonry in the gable wall and better for strong winds

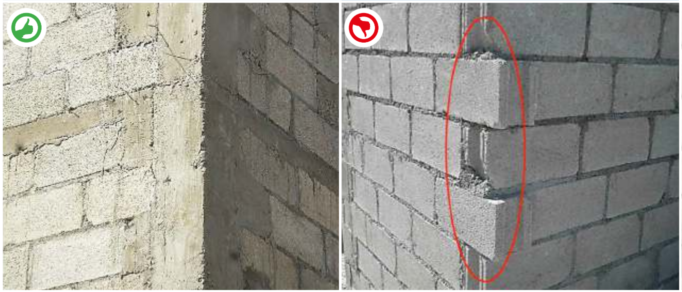
Option 2
Use lighweight material such as timber, amakan or CGI sheeting in the gable to increase safety in an earthquake. Remember to use adequate wind bracing in the roof structure.

c. Use Confining Columns and Beams

Use a plinth beam at the base of walls, a ring beam above walls, and columns at every wall intersection and door opening. These beams and columns provide a connection between walls, so that the house can act as one unit to resist the forces from the earthquake or typhoon.

Use a plinth beam at the base of walls.

Use a ring beam on top of walls.



Use columns at every wall intersection and corner.

Use a column at the edge of door openings.

d. Reduce the Weight and Improve Connections on Covered Veranda

The covering over the front veranda can also be dangerous in an earthquake or high winds if it is not built correctly. A covered veranda that has a heavy mass made of blocks supported by columns which are not connected to the beams and the main house can collapse. Many people run out of their houses when they start to feel an earthquake. If they run out of the front door under the covered veranda and it collapses, they can be injured or killed.

Reasons for failures include :

- Masonry gable is too heavy and it collapses.
- Connection between column and beam is not strong enough.
- Prefabricated columns may be strong but usually do not connect well to the ring beam.
- No diagonal bracing or shear walls.
- Beam separates from the main building.
- Veranda is too tall or extends too far from the main building.

Here are some recommendations for building a safe covered veranda :

- Build the covered part not too far forward from the main building.
- Do not use prefabricated, decorative columns unless there is room for steel to connect to the ring beam.
- Use a lightweight material above the veranda (like timber).
- Reduce the height of the roof.

PROBLEM

SOLUTION

SECOND C : CONNECTIONS

Connecting the elements of a house is essential for earthquake and typhoon resistance. That is why many of the recommendations in this book focus on making good connections. To make a house that is earthquake and typhoon resistant, there must be good quality connections all the way from the roof to the foundation.

Important points of connection include:

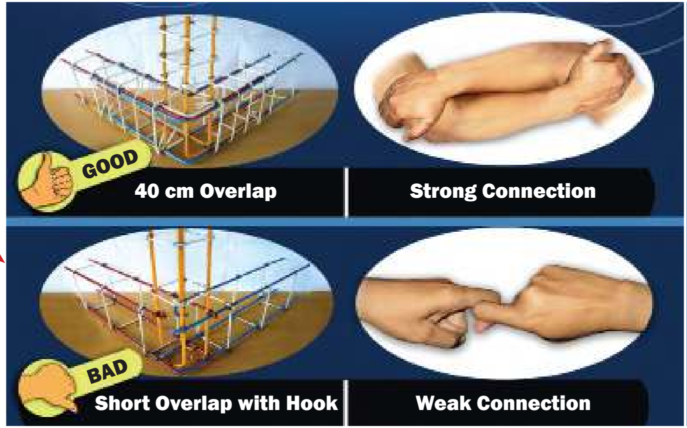
- Connecting the columns to the foundation.
- Connecting walls to the column.
- Connecting beams and columns to one another.
- Connecting the roof to the walls.
- Connecting the purlins to the rafters.
- Using enough nails or steel straps to connect wood members together.

Strong connections are necessary for a house to survive an earthquake or typhoon. If the parts are not connected, the house may collapse and kill or injure your family.

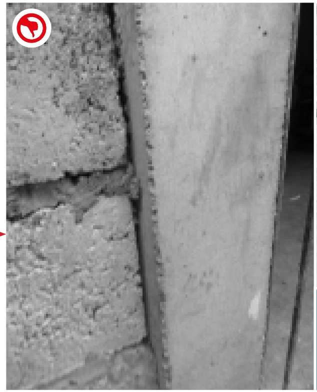
Connect roof members strongly to one another.
More information about wood roof construction can be found in Chapter 9.

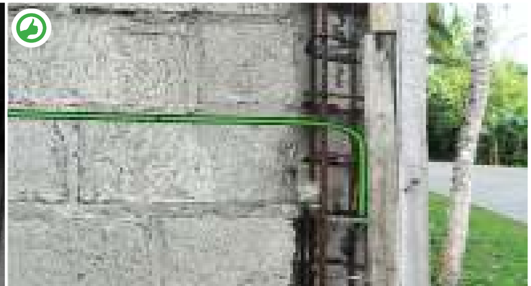
Wooden structures must be well connected to the foundation. More information about foundations can be found in Chapter 5. Information about wood-framed walls can be found in Chapter 8.

Good Connections Save Lives



More information on making strong and well connected reinforced concrete beams and columns is in Chapter 7.





Use rebar dowels to connect the wall to the column. More information on building strong and well connected masonry walls is in Chapter 6.

THIRD C : CONSTRUCTION AND MATERIALS QUALITY

Even the best design will not perform well in an earthquake if it is not built properly. Extra care should be taken in building a confined masonry house because poor quality materials and workmanship can have a devastating effect during an earthquake. Good construction quality is made up of :

- Good quality materials, such as clean sand and strong blocks. More information on good quality materials can be found in Chapter 3.
- Mixing concrete and mortar with enough cement and not too much water.
- Building good quality masonry or wood-framed walls – even in a simple single story house, it is important to build the walls well!
- Skills and will of the builder – it's hard work to build a safe house! Make sure you pay your builder enough money so that he can slow down and make sure he does a good job building your house. But if he does not, fire him and hire a new builder.

Poor construction quality makes for a weak house. Choose a builder that takes pride in doing good quality work, rather than one that cares more about money than safety. Make the builder demolish and rebuild any parts of the house that are not up to standard.

A house is only as strong as the materials that it is made of. For example, using weak blocks will make for a weak house. There is a myth that concrete blocks are "non-structural." This is false! The quality of the blocks and all other materials that make up the structure of the house will affect the overall strength of the house.

BUILD CHANGE

CHAPTER 3

HOW TO CHOOSE GOOD QUALITY MATERIALS

A house will only be as strong as the materials that it is made of. In other words, using weak construction materials will make for a weak house. That is why it is important to make the effort to purchase good quality materials for your house. You may be tempted to buy the cheapest materials without thinking about quality, but doing that would be a mistake. It will end up costing you more if the house collapses in the future and you have to rebuild again!

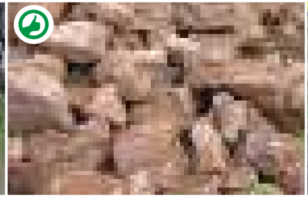
The following pages provide guidance for selecting good quality construction materials.

STONE

MOUNTAIN STONE

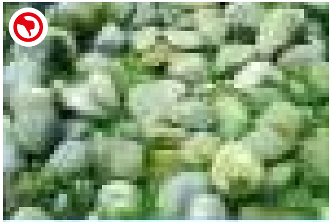
There are 3 main types of large quarried stones for stone foundation:

1. Black mountain stone - BEST
2. Red mountain stone - GOOD
3. Yellow mountain stone - NOT SO GOOD



Black mountain stone is stronger, denser, and has almost no pores or cracks. But it is more expensive and more difficult to find. Red mountain stone is more common and it is stronger than yellow mountain stone. Using yellow mountain stone is not recommended because it is weaker. It is sandstone with clay so its looks more like soil, and can have fibers in the cracks.

The size or the diameter of the stones should be between 15 and 30cm. If you use stones that are too small, you will spend a lot of money on cement, and the mixture may not be able to support a heavy load. If you use stones that are too big, it is more difficult work for the builder. It will be difficult to arrange the stones so that they interlock and allow enough space in between for the mortar. If the stones are touching with no mortar in between, it will reduce the strength of the foundation.



RIVER STONE

It is better to use mountain stone than river stone because the mountain stone is angular and it can lock together. But if mountain stone is not available in your area, you can use river stone. Because of the smooth surface and rounded shape, river stone does not bond as well to conrete or create an interlock between the stones like mountain stone does. The size is same as mountain stone, 15-30 cm. If you use river stone, try to break up the stones so that they have some rough edges.

SAND

Use good quality sand to build a strong house, because sand is used in mortar and concrete for many important parts of the house, including the foundation, concrete for the tie columns and bond beams, and to bond the blocks in the walls.

Good quality sand is:
- **Grey in color**
- **Clean and free from mud**
- **Not mixed with rubbish, wood bits, or roots**
- **Not too fine (particles are not too small)**

Crushed Sand

River Sand

Yellow/Brown Sand

Beach Sand

Avoid using yellow or dirty brown sand. The material is weak and there are too many fine particles to make strong mortar and concrete.

Avoid using beach sand. Beach sand has salt, which corrodes steel. If beach sand is used for reinforced concrete, the steel will rust and expand, causing the concrete to crack and making beams and columns weaker and weaker until they fail.

GOOD

BAD

FIELD TEST

To check that the sand is clean and does not contain mud, put a cup of sand in a plastic bottle, add water, shake it up, and let it settle for 4 hours. If the water is clear, the sand is good and clean. If the water is cloudy, the sand is not so good. It won't bond well with the cement, and the mortar or concrete will not be strong.

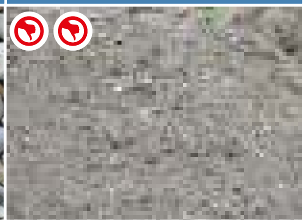
GRAVEL

Gravel is used in the concrete for the plinth beam, tie columns, ring beam and the floor. A smaller gravel, called "pea gravel" is used for grout in grouted masonry walls. Walls, beams, and columns are all important structural elements, and therefore the gravel that is used to make them must be of good quality.

Good quality gravel is:

- **Crushed and angular (not round)**
- **Clean and free from mud**
- **Not mixed with rubbish, wood bits, or roots**
- **Not larger than 2 cm (¾") in diameter for reinforced conrete beams and columns**
- **Not larger than 1 cm (⅜") in diameter for grout**

Large pieces of gravel will cause problems when pouring.

Crushed Gravel	Rounded Gravel	Mixed Sand & Gravel
		

Crushed gravel is angular, which allows the pieces to lock together and make stronger concrete. If you use rounded gravel, try to use more sharp and angular or broken pieces.

GOOD

BAD

FIELD TEST

You can check the quality of gravel the same way you check the quality of the sand (see page 3-3).

CONCRETE BLOCKS

For a simple, single story house built with masonry and reinforced concrete, the strength of the masonry walls is very important. A strong masonry wall is the first line of defense in an earthquake and typhoon. It is therefore important that we use strong blocks to make our walls.

INSPECTION TEST

Check the following about the blocks:

- **No cracks and no chips.**
- **Blocks should not have an overly porous texture.**
- **Blocks should be 15 cm (6") wide minimum.**
- **Blocks should be grey in color.**
- **When two blocks are hit together, the sound is a metallic clunk, not a dull thud.**


Use 6" (15cm) wide blocks


Do not use thin blocks


Do not use chipped blocks

GOOD

BAD

DROP TEST

Before buying all of the blocks you need, test the blocks by dropping them from shoulder height. Test five blocks at a time. If two or more break, find stronger blocks elsewhere.

If possible, check to see how the blocks are being made.
Buy from a block-maker that is using the correct materials and techniques to make strong blocks.

CEMENT CONTENT

In order for a block to be strong enough, we must use enough cement in the mix. There should be at least one part cement to seven parts sand.

CURE THE BLOCKS

The longer blocks are kept moist, the stronger they will be. This is because cement gets strong by reacting with water. The blockmaker should cure the blocks by spraying water over them three times a day and keep them covered or in the shade so that they stay wet. Blocks should be cured for seven days to make sure they will reach the strength we need.

AGGREGATE TYPE

Use clean crushed aggregates or river sand.
Avoid using yellow sand or beach sand to make blocks.

CEMENT

There are different types of cement available. The first type, Type 1, is Portland cement. It hardens fast and cures fast and is better for concrete elements, such as the plinth beam, columns, and ring beam.

The second type is type 1P, which is Portland cement mixed with pozzolan material. This makes it easier to work with, especially for masonry. It hardens slower, so it doesn't have to be used as quickly. If Type 1 Portland cement is used for the masonry, it must be used up very quickly after mixing, which is not always possible for masonry construction.

Type 1 cement becomes strong faster than Type 1P, but this is not as important for a single story house which does not have a heavy mass. Over time, the strength will be the same no matter if you use Type 1 or Type 1P, so both types can be used for concrete elements. Type 1P is better for the mortar used to lay blocks in the wall.

Masonry cement is yet another type of cement. It is Portland cement mixed with lime, which increases workability. Because it is easy to work with, this cement is best used to make the mortar needed to lay blocks. Both type M and type N masonry cement can be used for this purpose. Masonry cement should not be used for reinforced concrete elements.

CONCRETE SPACERS

Concrete spacers are helpful for separating the steel from the formwork so that there is enough space for the concrete to cover the steel and protect it from the environment. If the steel is not covered up by concrete, it will get rusty, lose strength, and cause cracking in the concrete. Using a concrete spacer also helps to straighten out the bars.

Concrete spacers can be made from sand and cement at a minimum ratio of 1:3 (1 part cement to 3 parts sand) with maximum size of 5x5 cm and thickness according to the amount of concrete cover required over steel, but at least 4 cm (see chapter 7 on steel detailing). Concrete spacers are easiest to use if they are cast with a binding wire, so the wires can tie the spacers to the bars. Concrete spac-ers can be square or round.

REBAR

One of the critical components for a disaster-resistant house is the steel reinforcing bars. Bars should be new and ribbed to make a good bond with the concrete. Avoid reusing steel from old buildings, since it is likely to be rusty, bent, and less ductile.

Deformed Reinforcing (Ribbed) Steel

Plain Round Bar (Smooth Steel)

Don’t use recycled steel!

Bar bending is discussed on page 7-2.

TIMBER

In choosing timber for your building construction, the type of timber must be matched to the function of the timber element. Choosing timber elements of the appropriate type and dimension will reduce the cost and improve the safety of the house. Make sure the timber is dry enough before you start to build with it. It is better to use lumber harvested from a certified source, to protect the environment. All timber that is directly exposed or open to weather, like rain, wind, and sun, should be protected by finishing the exposed surfaces with paint or varnish. Do not use coconut lumber for structural members - it may not be strong enough and deteriorates too fast.

Good quality timber is:

- **Straight-grained**
- **Free of excessive knots**
- **Free of warps and moisture**
- **Grade 2 or better**

Mahogany, lawaan, and gmelina can be used for structural members

Coconut lumber can be used for scaffold and shoring

Do not use coconut lumber for structural members - it may not be strong enough and deteriorates too fast

CHAPTER 4
CHOOSING A SAFE SITE

CHOOSE A SAFE AND STABLE LOCATION

Do not build ON TOP of a steep slope

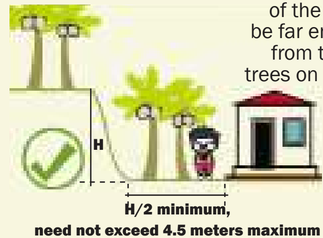
Do not build near a cliff because the building may collapse due to landslides

Building should be far enough away from the cliff and trees on the edge of the cliff

Do not build AT THE BASE OF a steep slope

Do not build near the base of a cliff because the building may be damaged or collapse due to landslides

Building at the base of the cliff should be far enough away from the cliff and trees on the edge of the cliff



Do not build IN A RIVER BED or CLOSE TO A SHORELINE (ocean or lake)

Do not build your house too close to water because the area is probably prone to flooding

Building should be far enough away from the water and above flood level

"Simple Guidelines for Earthquake-Resistant Houses", Red Cross Indonesia (IFRC)

CHECK THAT THE SOIL IS STRONG ENOUGH TO SUPPORT THE HOUSE

Even if you follow all of the rules for good construction in this booklet, your house could have cracks or collapse in earthquake if the soil under it is weak. For a simple, single-story house, there are two types of soil you should avoid:

CLAYEY SOIL OR PEAT THAT IS VERY STICKY

This type of soil is usually found near the coast and sometimes near rice paddies or fish ponds. This type of soil is easy to identify because it usually:

- Sticks to your hands and is difficult to wash off.
- Smells musty and rotten.
- Dries out slowly.
- Shrinks when it dries out.
- Breaks up or crumbles easily when it is dry.
- Contains organic matter such as small fibers or seashells.

SAND SOIL THAT IS LOOSE OR SATURATED WITH WATER, LIKE QUICKSAND

This type of soil is usually found near the beach or near the river bed. If you think you may have this type of soil, try pushing a 12mm steel bar into the ground. If you can push it in more than 30 cm by hand, the soil may not be strong enough to support your house.

If you find either type of these soils, you should move to a different location. But if that is not possible, you may be able to dig out the soil and replace it with a compacted fill of better soils or gravel and soil combined. You can also consider building a lightweight timber structure instead of a masonry and concrete structure. A timber house will be more flexible, so if the house settles a bit, it will be less of a problem or it will be easier to repair.

TAKE PRECAUTIONS FOR DRAINAGE AND GRADING

Make sure the rainwater can drain away from your house, and the greywater from your bathroom does not drain into the foundation.

INADEQUATE DRAINAGE
Poor grading and site selction

INADEQUATE DRAINAGE
Greywater drains into foundation

Drain pipes should not pass through any reinforced concrete elements like the foundation beam or columns because this will weaken these elements. Put the pipe through the wall above the foundations, or below the foundation.

PLAN FOR STORM SURGES AND TSUNAMIS

Some of the most devastating effects of typhoons and earthquakes come from storm surges and tsunamis. Unfortunately, it is very difficult to make a small home that can survive the strong flow of water and debris that can result from these phenomena. If you live in a low-lying coastal area, you may be at risk for one or both of these hazards. Try to choose a site outside of risk zones. If that is not possible, it is important to be aware that you are at risk and be ready to evacuate in the event of a large storm or earthquake that could trigger a surge or tsunami.

Associated Press

CHAPTER 5

BUILD A STRONG FOUNDATION

The foundation is the main support for carrying the weight of the building. The size and type of foundation depend on the type of building, the weight of the building, the materials available, and the type of soil.

FOUNDATION FOR WOOD HOUSE

FOUNDATION FOR MASONRY HOUSE

What type of foundation is best for my house?

For a wood house, a foundation needs to raise the wood members off of the ground to protect them from moisture, insects, and decay. The foundation also needs to be deep and heavy enough to prevent a lightweight timber house from blowing away in strong winds.

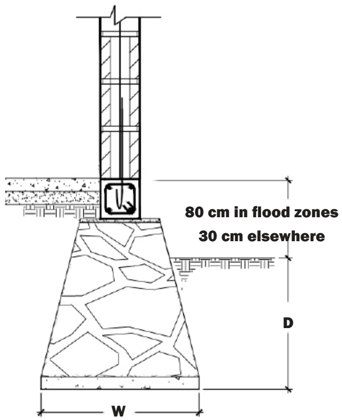
For a masonry house, the foundation must provide support for the heavy walls of the house. Building a strong foundation and connecting the house to it well is not only necessary for earthquake and typhoon resistance, but will also prevent the house from settling unevenly and cracking over time.

If good quality stone is available in your area, it can be used to make a solid foundation. Otherwise, reinforced concrete and block can be used to make the foundation.

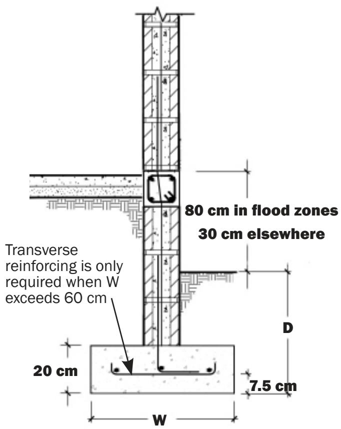
Use the following minimum dimensions to build your foundation for a one or two-story masonry house:

MASONRY HOUSE

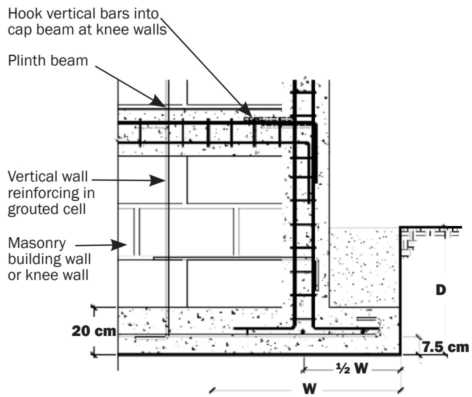
	Weak Soil	Hard Soil
Depth of Excavation (D)	50 cm	40 cm
Width at Base (W)	70 cm	60 cm
Width at Top	30 cm	30 cm
Base Layer	5 cm Concrete Screed	5 cm Small Stones and Gravel



STONE MASONRY FOUNDATION



MASONRY FOUNDATION FOR MASONRY HOUSE

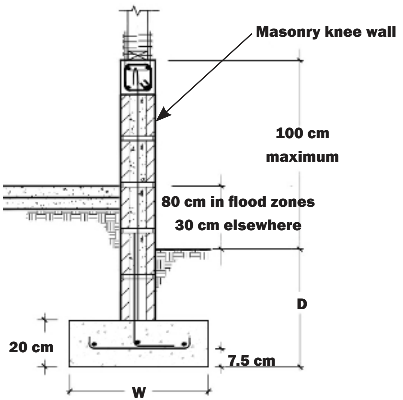


CONCRETE COLUMN FOUNDATION FOR MASONRY HOUSE OR KNEE WALLS

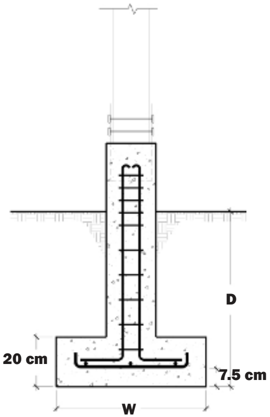
Use the following minimum dimensions to build your foundation for a one or two-story wood house:

WOOD HOUSE

	All Soils
Depth of Excavation (D)	40 cm
Width at Base (W)	50 cm



MASONRY FOUNDATION FOR WOOD HOUSE



WOOD COLUMN PIER FOUNDATION FOR WOOD HOUSE

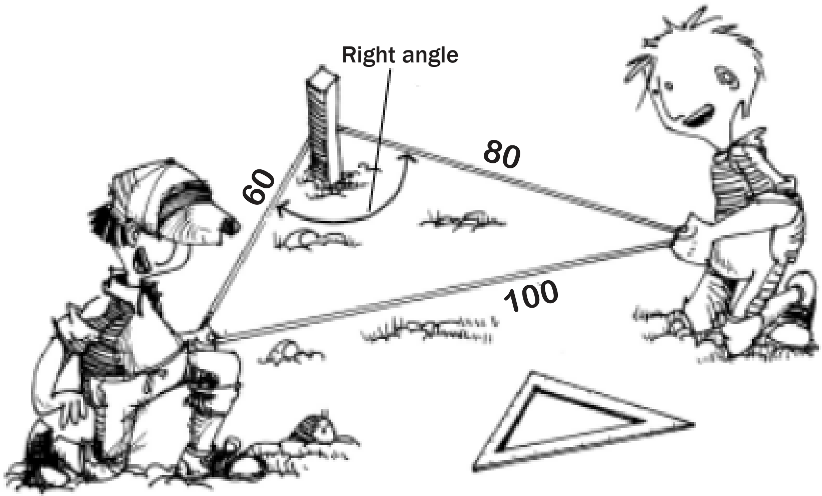
See page 5-2 for foundations and columns at ends and intersections of knee walls.

BUILD CHANGE

LAYOUT AND BATTERBOARDS

Right angles are very important in building a house. Without these the house will not stand straight. A right triangle can be used to find right angles when laying out the building. This simple “3-4-5 Triangle” method can be used to be sure the corners are square. When each string is laid out in a triangle as shown below, and each string is the exact length indicated, the corner is a right angle.

- The 60 cm long string is called the “dead thread,” because it does not move. Both ends of the thread are nailed or held along the line of the wall.
- The 80 cm long thread is called the “living thread.” One end is fixed at the end of the dead thread. The other end is moved inwards or outwards until the diagonal is exactly 100cm long.
- The 100 cm long string is oriented diagonally. One end is fixed to the end of the 60 cm dead thread. The other end is pulled to reach the end of the 80 cm living thread. When the strings are taut and the dimensions 60-80-100 are reached exactly, the corner between the dead and living threads is a right angle. (Note that 60-80-100 = (3x20) - (4x20) - (5x20), so it is a big version of the 3-4-5 Triangle).



“Construction and Maintenance of Confined Masonry Houses For Masons and Technicians,” Marcial Blondet

FOUNDATION EXCAVATION

Remove water, organic matter, and debris from the foundation excavation.

Excavate to the appropriate depth as required by the table on page 5-2. The bottom surface should be flat and level.

On weak soils use a lean concrete mix (1 cement : 3 sand : 6 gravel) to make 5 cm thick screed floor. This will create an even working surface.

Do not build a masonry house on soil that is spongy or extra soft. The building may settle, causing the walls to crack. In these areas it is better to build a more flexible wooden house.

STONE MASONRY FOUNDATION

Place the column steel reinforcing at each column location.

In between columns and along lines of walls, build the stone masonry foundation.

Stone masonry should NOT have:

- Stones laid vertically
- Stones touching each other
- Gaps in the mortar

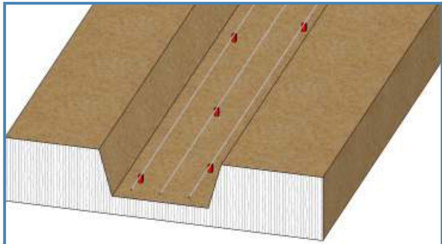
Lay stones horizontally. Fill all gaps with mortar.

Overlap stones from one course to the next to avoid having aligned vertical joints.

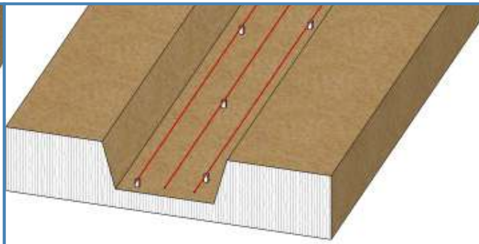
Level the top with mortar and roughen the surface to improve the bond between the foundation and plinth beam.

REINFORCED CONCRETE STRIP FOOTING WITH MASONRY STEM WALL FOUNDATION

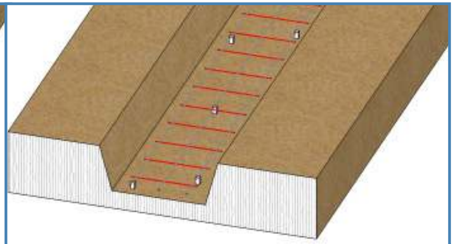
An alternate method is to use a reinforced concrete strip footing with a reinforced masonry stem wall.



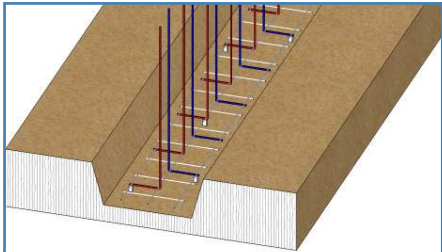
Use large (7.5 cm) spacers and place rebar in the foundation excavation.



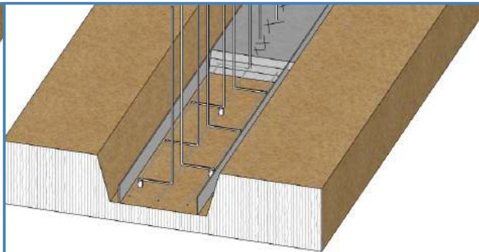
For masonry buildings, use (3) 12mm diameter longitudinal bars. For wood buildings with a short masonry wall, use (2) 12mm diameter bars.



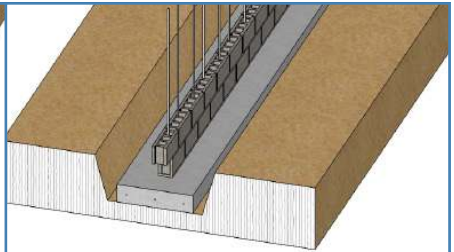
For footing over 60 cm wide, add 12mm diameter transverse bars at 40 cm on center.



Place 10mm diameter vertical starter bars at 40 cm on center. Make sure they are long enough to make a 40 cm overlap with the wall reinforcement.



Pour concrete to a height of 20 cm and roughen the top surface where the blocks will be laid.



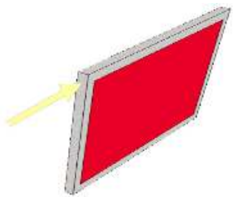
Build the masonry stem wall (follow the guidelines in Chapter 6 to make the block wall).

CHAPTER 6

BUILD A STRONG MASONRY WALL

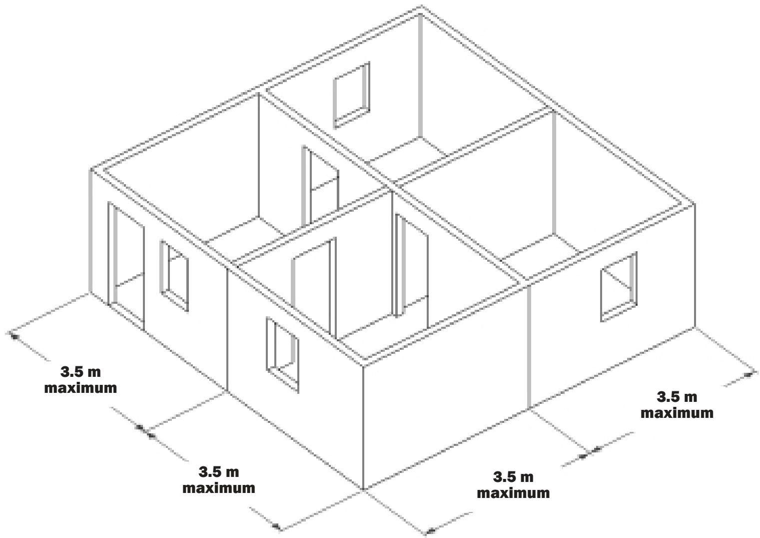
The walls are one of the most important elements required to resist the forces from earthquakes and typhoons. However masonry walls are heavy and can fall easily if not configured and built correctly.

Masonry walls are weak when pushed in the "out-of-plane" direction and strong when pushed "in-plane." To make a strong masonry building, we must therefore make sure we have a good configuration with enough out-of-plane strength.



Wall with in-plane force

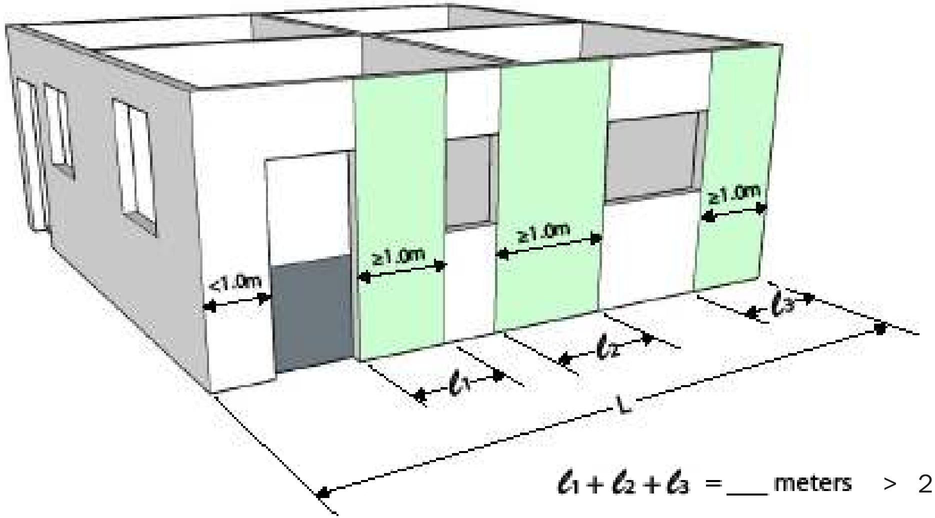
Wall with out-of-plane force



To ensure good configuration, lines of perpendicular supporting walls should be spaced at no more than 3.5 meters.

WALL LENGTH CALCULATION

Each line of walls must have enough length of solid, full-height wall and not too many openings. There is a simple way to determine if you have enough wall. The calculation method is shown below. For this calculation we can only consider the solid walls that are at least 1 meter long.



Each interior and exterior line of walls must have a minimum length of 2 meters of full height wall, or 25% of the length of the building in that direction, whichever is greater. Only count sections of full-height wall that are at least 1 meter long.

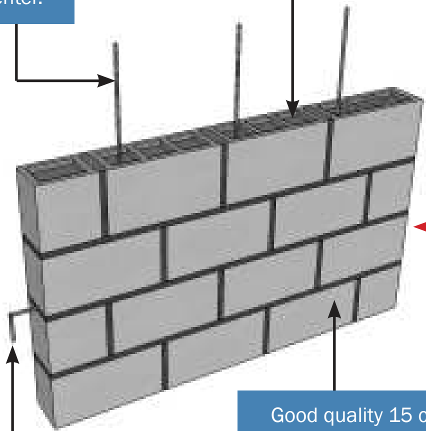
$l_1 + l_2 + l_3$ = ___ meters > 2 meters

$\frac{(l_1 + l_2 + l_3)}{L} \times 100$ = ___% of wall line > 25%

ELEMENTS OF A STRONG MASONRY WALL

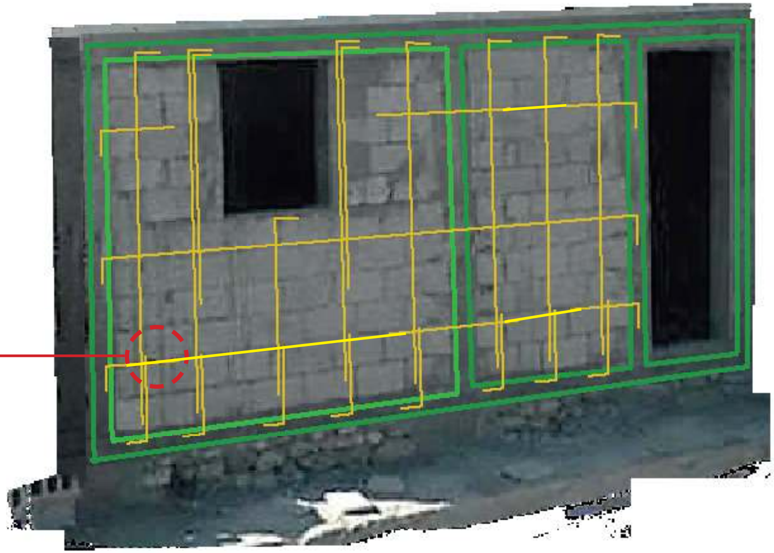
10mm vertical reinforcing bars at 40 cm on center.

All cells grouted with properly mixed grout (see page 6-6 for more information on making grout).



Rebar dowels connecting the wall to the column every 3 layers of horizontal blocks.

Good quality 15 cm (6”) block (see page 3-5 for more information on selecting good quality block). Blocks properly laid and bonded with mortar in horizontal and vertical joints.



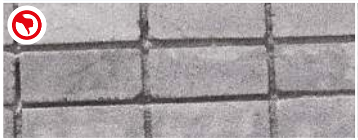
Each masonry wall panel must be confined by a plinth beam at the base, a ring beam above, and columns at corners, wall intersections and door openings. See Chapter 7 for more information on reinforced concrete beams and columns.

LAYING BLOCKS

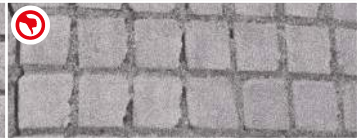
Erect story poles on either side of the wall and use a string as a guide to place the blocks. Story poles must be straight and plumb.

Mix your mortar with 1 part cement to 5 parts sand.

Lay blocks with a ½ block stagger using mortar joints that are 0.6-1.6 cm in thickness. Make sure all joints, horizontal and vertical, are filled with mortar.



Aligned vertical joints create weakness in the wall.



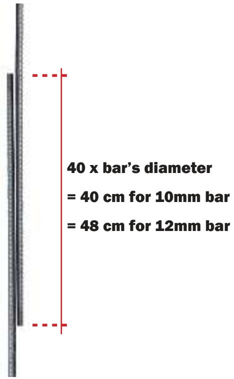
Using broken blocks in the middle of the wall will make it weak.

Blocks are too close so there is no room for the mortar.

Mortar joints are too thick weakening the bonding between the blocks.

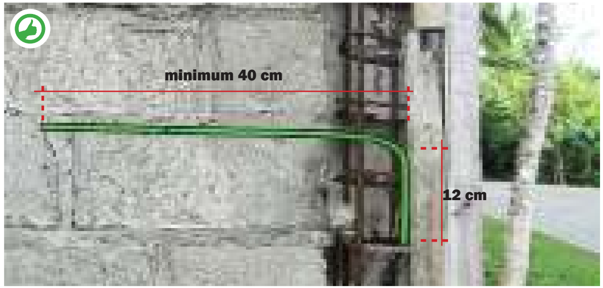
STEEL REINFORCEMENT

The reinforcing steel gives the wall strength and ductility. It must be ribbed (deformed) and properly installed.



Connecting two rebar together with a short overlap simply does not work! Make sure to have an overlap that is long enough for the force to transfer from one bar to the other. Overlap should be 40 cm for 10mm bar. This applies to the starter bars at the base of the wall as well as splices in the middle.

Use 10mm rebar dowels in the column to wall connection every 3 layers to prevent the wall disconnecting from the column.



BUILD CHANGE

GROUTING

Grout Mix

Use 1:2:3 Mix

Mix grout the same as concrete, described on page 7-4.

1 container of cement **2 containers of sand** **3 containers of pea gravel (1cm max)**

Clean any debris and extra mortar out of the cells. Pour grout into the cells. Make sure the grout is well compacted and does not have any voids.

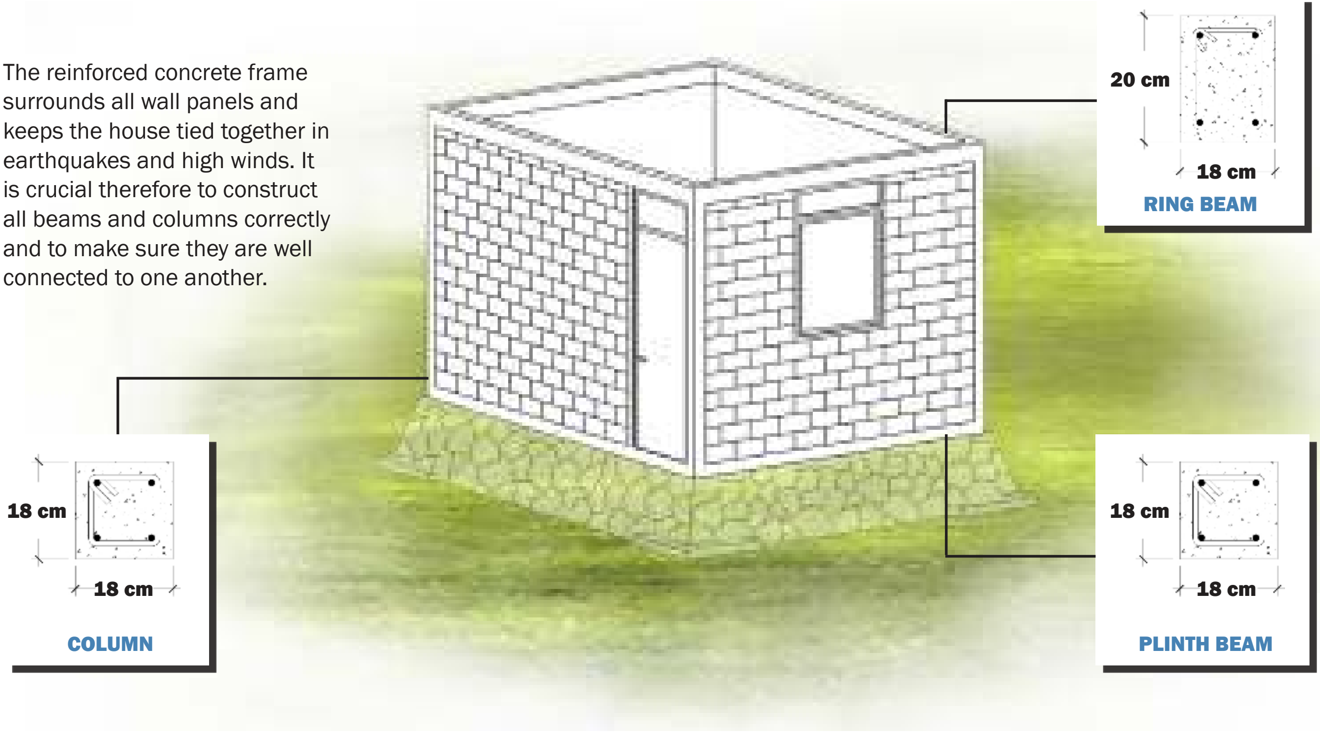
Grout walls 0.6 meters at a time minimum. Stop pouring grout 5 cm below the top of the block so that the next pour will make a better connection with the wall below.

Cure the wall by wetting it 3 times a day for 7 days to make sure that the wall reaches the required strength.

CHAPTER 7

REINFORCED CONCRETE MEMBERS

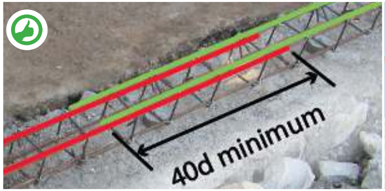
The reinforced concrete frame surrounds all wall panels and keeps the house tied together in earthquakes and high winds. It is crucial therefore to construct all beams and columns correctly and to make sure they are well connected to one another.



CONNECT THE TIE COLUMNS AND BOND BEAMS

Good connections and anchoring of the steel in the reinforced concrete is critical to prevent collapse in earthquakes and high winds. A beam or column that is not well anchored at the joints will be useless once the connections fail.

The method of using a short hook at the end of the bar is not sufficient. The bars should continue through the joint, and there should be an overlap of 40 times the bar diameter (40d) at bar splices. Bars must be ribbed.



40 x bar diameter overlap:
40 cm for 10mm bars or
48 cm for 12mm bars

Overlap too short

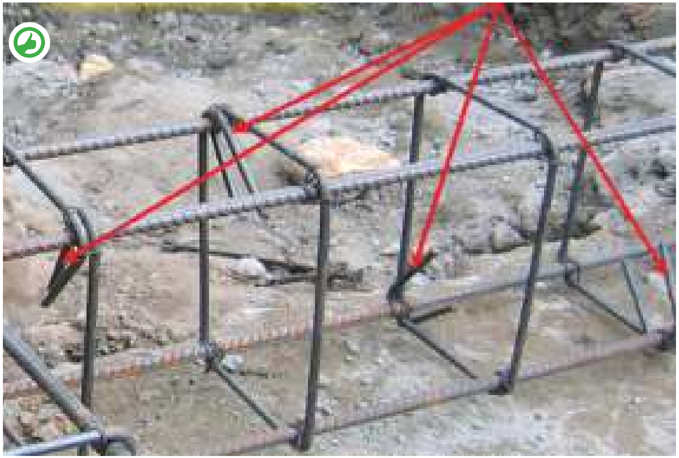
T - CONNECTION

L - CONNECTION

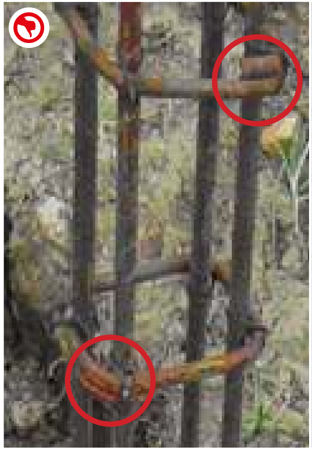
BENDING AND ASSEMBLING STIRRUPS AND TIES

- Use 6mm bars for the stirrups minimum.
- Bend the hooks at 135 degrees.
- 5cm hook length.
- Place the stirrups at a maximum of 10 cm for the first 5 stirrups next to a connection and 20 cm everywhere else.
- Rotate stirrups so that the position of the hooks changes.

STIRRUPS ARE ROTATED



GOOD
Hooks bent at 135 degrees, tied tightly to the longitudinal bars with binding wire



POOR
Hooks not long enough

POOR
Stirrups spaced too far apart

MIX, POURING, AND CURING GOOD QUALITY CONCRETE

Concrete Mix

Use 1:2:3 Mix

1 container of cement **2 containers of sand** **3 containers of gravel**

- You can mix concrete either by hand on a flat surface or by using a mechanical mixer. If you mix by hand, use a paved surface, or a plywood mixing board, or a lean concrete surface that is clean from trash and soil.
- Mix the dry ingredients first (sand + gravel, then cement) and keep mixing until the color is uniform.
- Make a hole in the center of materials, add clean water, and mix it well.
- Use the concrete within 90 minutes of adding water.

MIXING SAND, GRAVEL, AND CEMENT
Thoroughly mix dry ingredients, mixing sand & gravel together first, then adding the cement.

MIXING SAND, GRAVEL, AND CEMENT
It is completely mixed when the color is uniform.

MIXING IN WATER
Mix in water gradually and use up within 90 minutes of mixing the water.

The proper way of mixing using one bagger mixer:

1. Pour in half of the water needed.
2. Add the aggregates first and mix for 2 minutes.
3. Add the cement and mix for 3 minutes.
4. Add the remaining water to correct the slump needed.

BE CAREFUL!
When mixing concrete using a mechanical mixer, it's easy to use too much water. Do not use too much water. If you use too much water, the concrete will be weaker.

TOO MUCH WATER!
This concrete has too much water - it is like soup and will not be strong enough.

SIMPLE TEST

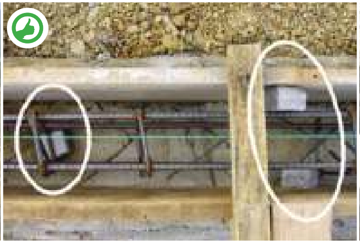
FIELD TEST
You can check the water content in a simple way. Just pick up a handful of mixed concrete and if there is a lot running out between your fingers, the mix is too wet.

BETTER TEST

FIELD TEST
A better way of testing the concrete mix is to use a slump test.
Fill the cone, turn it over, remove the cone, and measure the settling of the concrete. The slump should be between 8 and 10 cm.

Formwork and Concrete Spacers






Make the formwork using good quality timber that will not bulge or bow. You can use straight coco lumber and plywood.

Wet the formwork and foundation before pouring concrete so the water in the concrete won't be absorbed by the formwork.

Place concrete spacers on the bottom and both sides of the steel to separate the steel from the formwork.

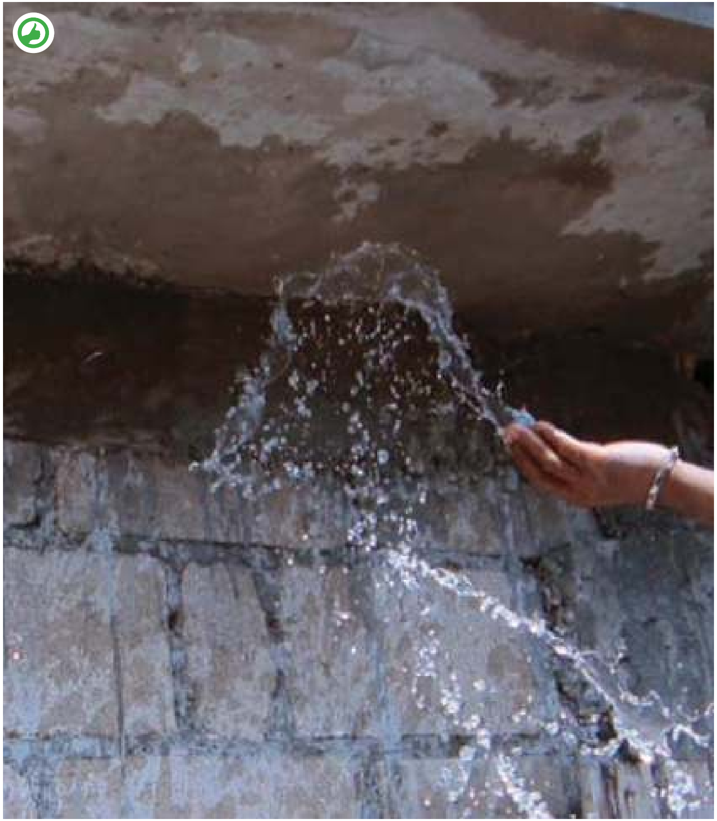
Pouring Concrete

Ram the concrete with a rod and tap the formwork with a hammer to make sure the concrete is compacted and all voids are filled.

To make the concrete compacted and ensure all voids are filled, ram the concrete with a rod and tap the formwork with a hammer.


CAUTION!
If using a vibrator, do not vibrate it for too long because it will separate the mix (gravel will go down to the bottom).

Formworks for columns can be removed after 48 hours. Formworks for hanging beams and slabs can be removed after 14 days. Check for defects such as voids and honeycombing. Such defects cause points of weakness in the concrete and are not acceptable. If defects are widespread or if steel is exposed, the concrete must be demolished and re-poured.



Concrete Curing

Concrete gains strength through a chemical reaction between water and cement called "hydration" or "curing." It is therefore important to keep the concrete moist for several days after it has been poured. Wet the concrete 3 times a day for 7 days so that it can reach the strength needed.

CHAPTER 8

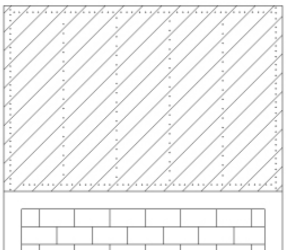
WOOD-FRAMED WALL CONSTRUCTION

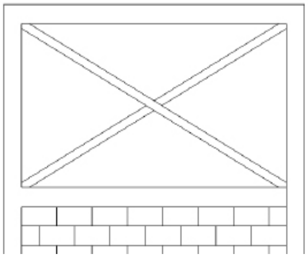
In earthquakes and high winds, the walls must resist strong forces being applied to the house. It is important that the walls are built well, with special attention to the connections between the wall elements.

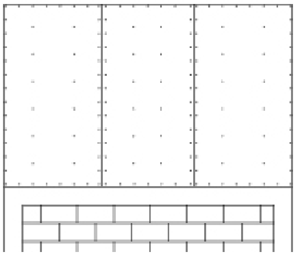
Each line of walls should have a sufficient length of shearwall or diagonal bracing to make sure that the wall can withstand the sideways forces applied to it.

There are different methods to build a wood-framed wall that has adequate strength. Shown below are three recommended methods that can be used anywhere in the Philippines:

DIAGONAL LUMBER SHEATHING	METAL X-BRACING	PLYWOOD SHEATHING



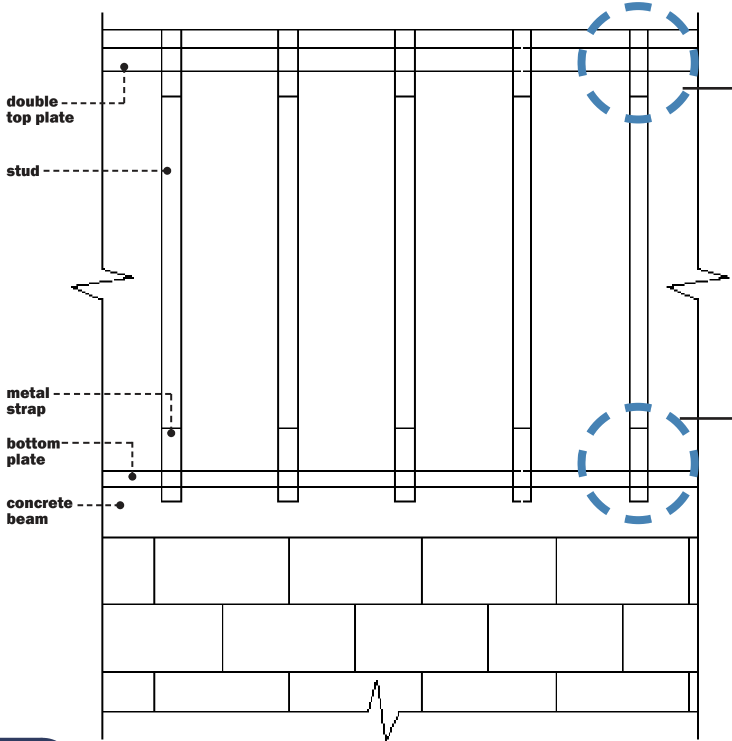


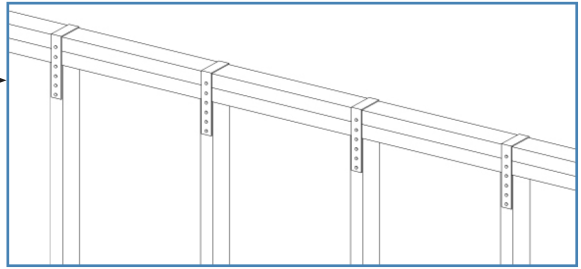


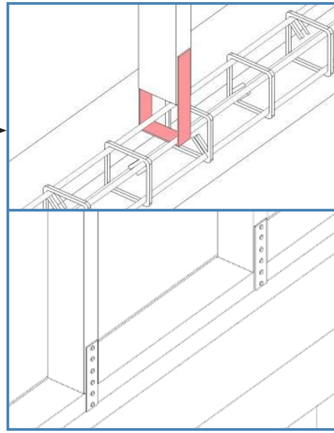
KNEE BRACING IN CORNERS
This method adds some strength to walls, but it would probably not be enough to resist a strong typhoon.

NO BRACING
What must be avoided at all cost is neglecting to use any bracing in your walls.

The frame of each wall should be built of vertical wood studs spaced at about 60 cm. For typhoon wind-resistance, each stud must be fastened at the base to the concrete beam with metal strapping and also at the top plate. High winds will try to lift the roof up, which is why it is important to have strong connections from the roof, through the walls, and down to the foundation.



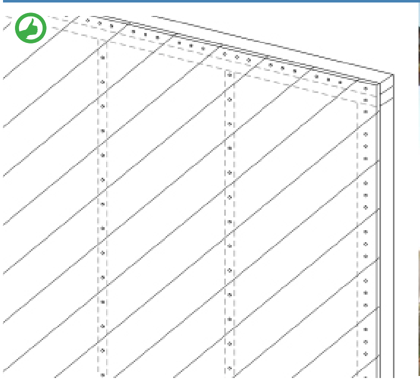


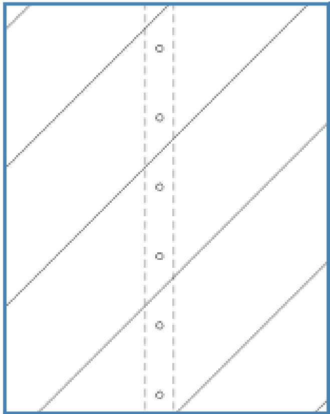


Cut straps to 55 cm long and 4 cm wide. Bend the strap into a U shape and hook it under the top bars of the reinforced concrete beam at every stud location. Tie the strap in place with binding wire. Use 6 nails on each side. 2 nails should go into the plate and 4 into the stud.

Option 1
DIAGONAL LUMBER SHEATHING

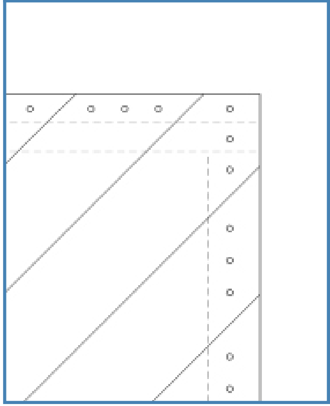
One method is to build a shear wall from lumber. Instead of placing the boards horizontally, orient them diagonally. Simply doing this will make the wall 6 times stronger! Make sure each line of walls has at least 2.75 meters of full-height shear wall to give the wall the strength needed.

DIAGONAL LUMBER SHEATHING	HORIZONTAL LUMBER SHEATHING
	



NAILING AT STUDS

Make sure there are two nails in each board at each stud location.

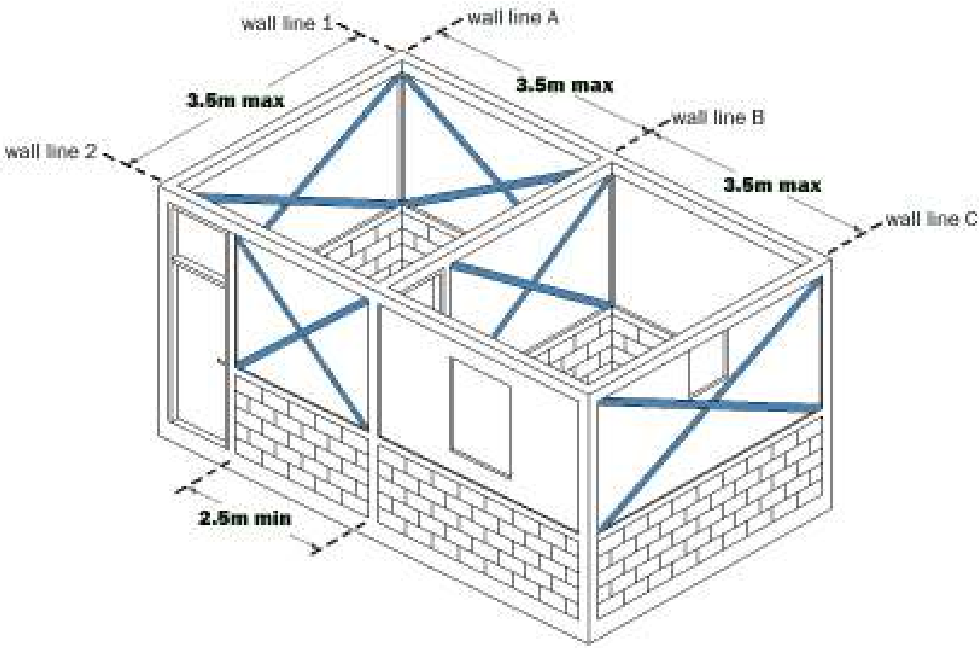


NAILING AROUND EDGES

Around the edges, use 3 nails per board.

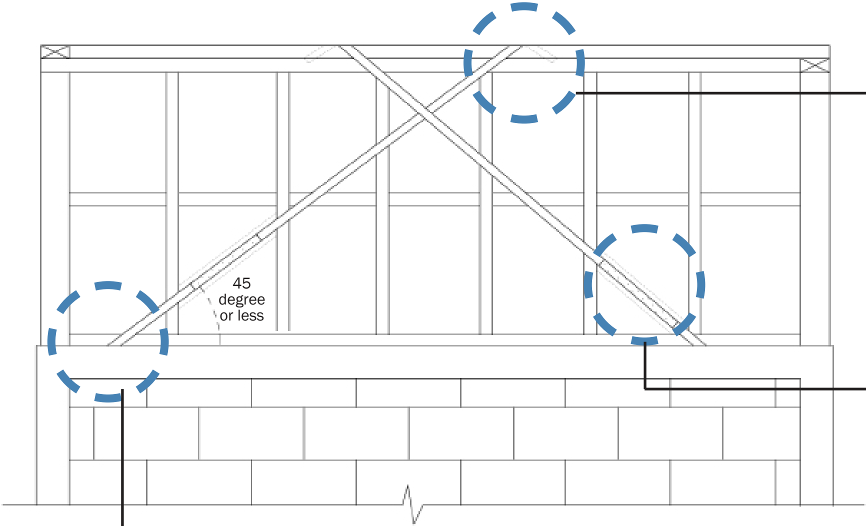
Option 2
METAL X-BRACING

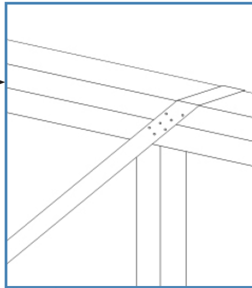
When a non-structural material such as amakan is used to create the walls, it is necessary to provide some form of bracing to give the wall strength. Metal strapping is excellent for this application. Provide metal strapping in an X-pattern. Each line of walls should have at least one pair of metal X-straps



SIZE OF STRAPS

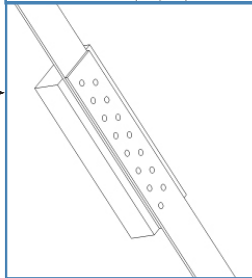
Use 18 gauge (thickness of 1.2 millimeters) strapping or cut sheet metal into strips. The straps should be 4 cm (1.5 inches) wide, and should be used on both sides of the wall.





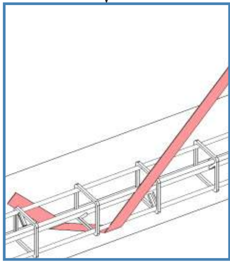
CONNECTION TO TOP PLATE

Cut straps long enough so that there is at least 40 cm of overlap with the top plate. In each strap, use 58 nails of 3 inch length to secure the strap to the top plate. Arrange the nails in 4 staggered rows with a spacing of 5 cm between nails in a row. This is a lot of nails, but they are necessary to make the connection work!



SPLICE

If the straps are being made of cut sheet metal, it will be necessary to make a splice so that the strap can reach the top of the wall. This can be done by overlapping the two straps by 30 cm and adding 34 nails of 2½" length to make the splice. Use a 2x4 as a backing board. Arrange the nails in 2 staggered rows with a spacing of 3 cm between nails in a row.



PLACE AND TIE STRAP

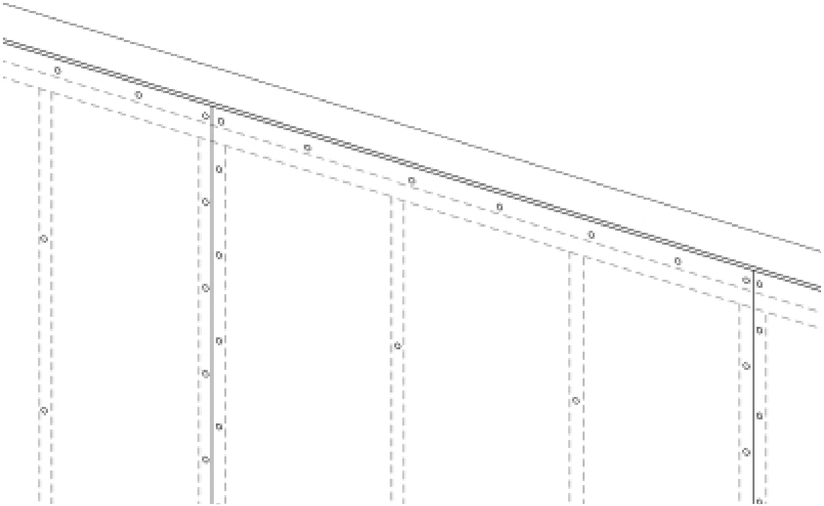
Cut and bend the strapping into a U-pattern that passes underneath the bottom bars of the beam. Tie the strap to the bar such that it forms a 45 degree angle with the beam.

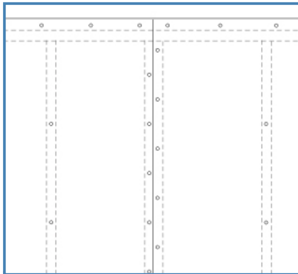
COMPLETED

Once concrete is poured, the strap should look like this.

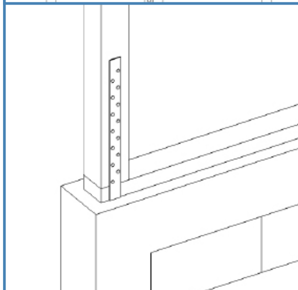
Option 3
PLYWOOD SHEATHING

Plywood can also be used to give strength to a wall. Use a minimum thickness of ⅜" (9.5 mm) plywood. Make sure there is a stud at each edge of the plywood panel. Each line of exterior walls must have at least 2.75 meters of full-height shear wall and each line of interior walls must have at least 4.5 meters of plywood on one side or 2.25 meters of double-sided plywood full-height shear wall.





◀ Around the edges, nail each panel to the wood frame. Use 2.5 inch nails spaced at 10 cm (4 inches). On intermediate studs, space nails at 30 cm (12 inches).



▲ At the edges of the shearwall panel, embed a longer strap at the location of the last post or stud. Make sure the strap hooks underneath the bottom rebar in the beam so that it won't pull out. This strap should overlap the stud or post for a long enough distance to fit 20 nails on each side of the post for a total of 40 nails of 3 inch length.

Option 4
POST, BEAM, AND DIAGONAL BRACING

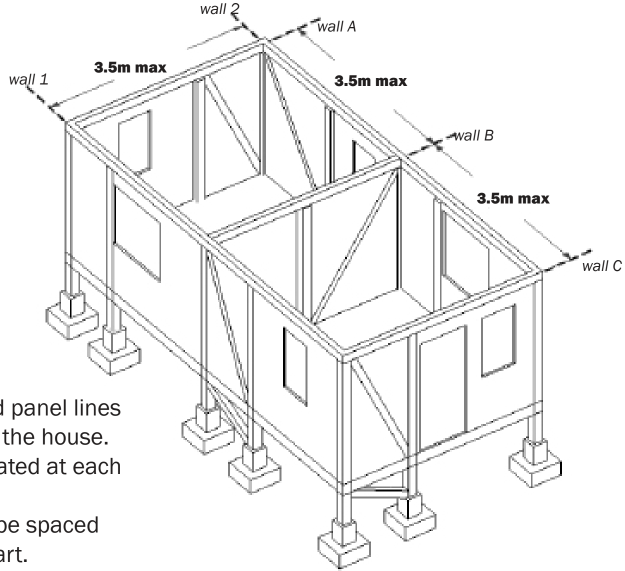
This option should only be used where the maximum wind speed is 150 kph, or in Wind Zone III, as defined by the National Structural Code of the Philippines. Wind Zone III includes these provinces: Basilan, Bukidnon, Davao del Norte, Davao del Sur, Lanao del Norte, Lanao del Sur, Maguindanao, Misamis Occidental, North Cotabato, Palawan, Sarangani, South Cotabato, Sultan Kudarat, Sulu, Tawi-tawi, Zamboanga del Norte, Zamboanga del Sur, and Zamboanga Sibugay.

The posts, beams, and diagonal bracing must resist the forces being applied to the house. It is important that post and beam frames are strongly built and contain diagonal bracing elements. Particular attention should be given to the connections between structural elements. Weak connections will not properly transfer the forces and the structure will be weak.

FLOOR OPTIONS

Raised Floor Framing

Floor on Grade



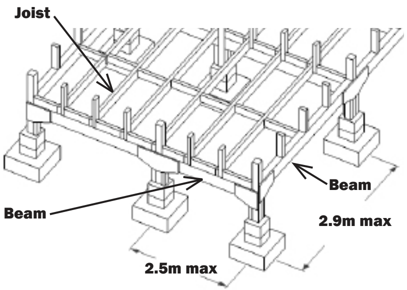
POST, BEAM AND BRACING

- There are at least two braced panel lines in each principal direction of the house.
- Braced panels should be located at each exterior line of the house.
- Parallel braced panels shall be spaced no more than 3.5 meters apart.

FLOOR

RAISED FLOOR FRAMING

- Joists are 2”x6” members, refer to table at right for the spacing.
- Joists shall be blocked at the ends, at each intermediate support, and at joist midspan with 2” thick and full depth blocking element.
- Blocking can be staggered to be easily nailed to the joists.
- Notches at the ends of joists should not exceed 4 cm (1.5”).

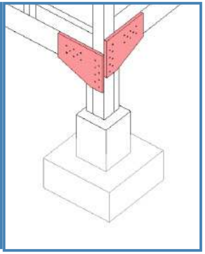


Wood joists should be located at least 45 cm above exposed ground to prevent decay unless the joists are treated wood.

The perimeter beam should be a 4”x8” member and its span should not exceed 2.5 m when supporting joists or 2.9 m when parallel to joists.

The perimeter beam should bear on a 2”x4” shim plate nailed to the post. The beam should be connected to the gravity post using a ½”plywood gusset plate on one side with (8) 3.5” nails on the post and on the beam.

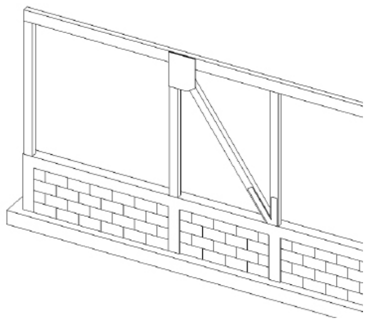
When the post is part of a braced panel, the connection should be a two-sided ½” gusset plate with (19) nails on each side of the beam (see Post, Beam, and Bracing Nailing Table).



Maximum Spacing between Joists, center to center (m)	Maximum Span Length of Joists (m)
1	2
0.5	2.5
0.3	3
0.2	3.5

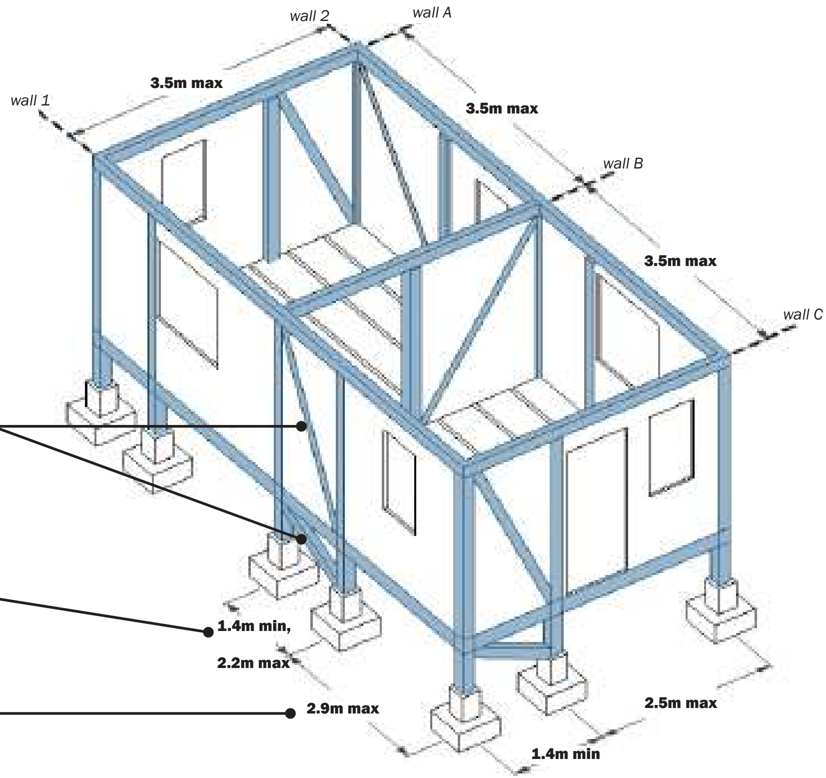
SLAB ON GRADE

When the slab is on grade, the bracing should be well connected to the pier foundation on one side and to the top beam and post on the other side. A cap beam should be placed on top of a knee wall to connect the piers and resist earthquake and high wind loads.



POSTS, BEAMS, AND DIAGONAL BRACING

- For Post and Beam construction, posts and bracing should be at least 4”x4” members.
- The top beam should be at least a 4”x6” member with a span less than 2.9 m.
- The bracing is a single diagonal 4”x4” attached to the post and beam at each end.



Braced panel should be braced all the way from the top beam to the foundation. In case of raised floor, panels should be braced above and below the floor framing with diagonal wood bracing, cripple walls, or knee walls.

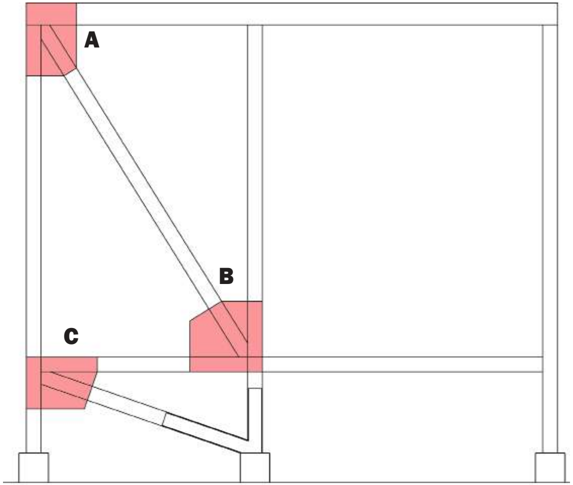
The length of the braced panel must be more than 1.4 m long and less than 2.2 m long.

The maximum span between posts is 2.5 m when the floor beam is supporting joists and 2.9 m when parallel to joists.

BUILD CHANGE Cordaid

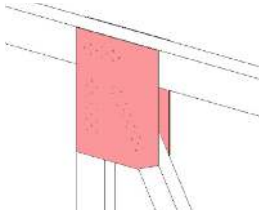
DIAGONAL CONNECTIONS

All the structural elements need to be well connected to transfer earthquake and wind loads.



For **interior walls**, ½"plywood gusset plates on two sides should be used.

For **exterior walls**, a ½"plywood gusset plate on one side should be used.

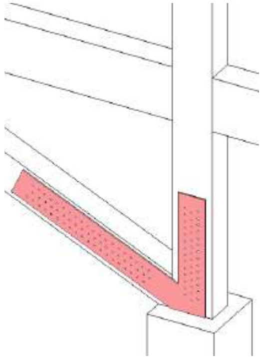


Number of 3.5" nails per gusset plate on each element for each type of connection.

Post, Beam, and Bracing Nailing	Post	Bracing	Beam
A - Top Post/Bracing/Top Beam	15	18	10
B - Bottom Post/Bracing/Bottom Beam	18	18	19
C - Bottom Bracing/Post	18	23	19

An isolated gravity post should be connected to the foundation with a 4 cm wide x 10 Ga. metal strap and (6) 2.5" nails on each side of the post.

When a post is part of a braced panel, a 10 cm wide x 10 Ga. metal strap should be nailed with (42) 3.5" nails to the post and (60) 3.5" nails to the bracing on each side.



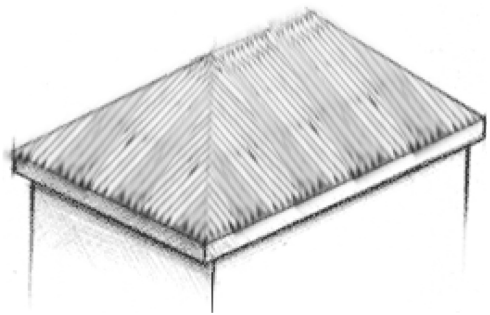
CHAPTER 9

WOOD ROOF CONSTRUCTION

The roof is one of the most vulnerable parts of a building in a typhoon. The strong winds create a strong upward suction force on the roof, which can easily tear apart a poorly constructed roof. This chapter will recommend some ways to improve roof construction so the roof can resist these strong uplift forces in the next typhoon.

ROOF CONFIGURATIONS

The shape of the roof will affect its wind resistance. In general, gable and hipped roofs are more wind-resistant than flat roofs.



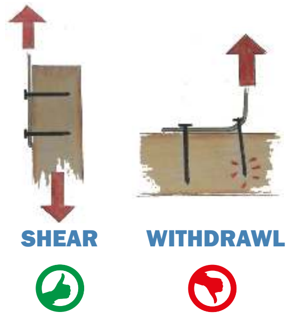
A hipped roof is a good option for a typhoon resistant building

A gable roof can also be build to be typhoon resistant, however this configuration requires diagonal bracing for it to be stable

USING STRAPS AND METAL FASTENERS

The strong upwards pull that the wind puts on the roof can be counteracted with properly installed straps. Strapping can come in a long coil or can be cut from sheet metal. Straps should be a minimum of 18 gage, or 1.2mm, thick.

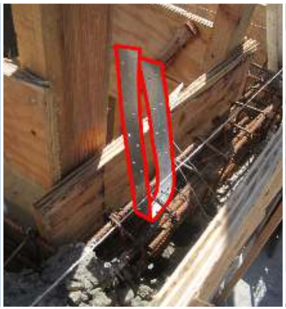
Nails are stronger when counteracting a force from the side than when a force is trying to pull them out. Therefore, it is important to orient the straps so that the nails take the load in shear instead of withdrawal. The number of nails used will also affect the strength of the connection. Nails are a cheap way to add strength, so use the recommended number of nails for the roof system you are using.




Strap nails in shear.


Strap nails in withdrawal.

Straps can be embedded into the concrete ring beam.

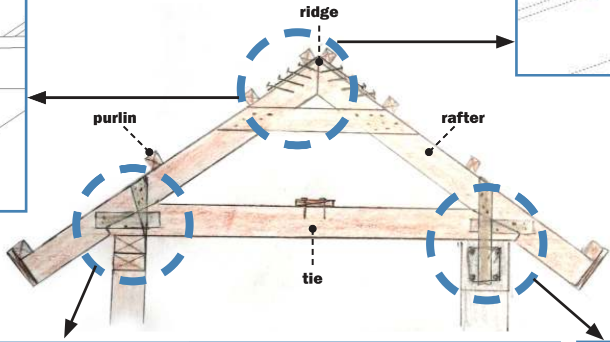


Straps can be cut and bent like this to connect perpendicular wooden members together.

BUILD CHANGE

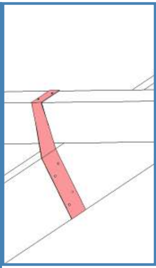
RAFTER AND TIE SYSTEM

For small and narrow floor plans with a width of 3.5 meters or less, we recommend this system for its simplicity and typhoon wind-resistance. Space 2”x4” rafters 1 meter apart and 2”x2” purlins no more than 70 cm apart.



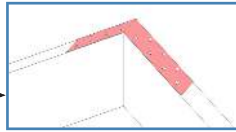
Purlin to rafter connection

Use a bent strap to connect the rafter to the purlin. On the strap connections, make sure there are a total of 4 nails in the purlin and 4 nails in the rafter. Use a single toe nail to keep the purlin in position during normal conditions.



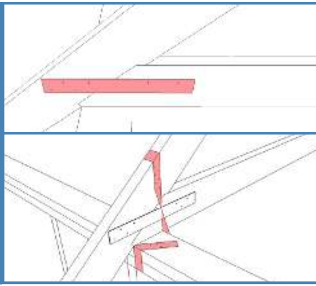
Rafter to Rafter connection at ridge

The wind force will try to pull rafters apart at the ridge. Use a long strap over the top of the ridge to connect the rafters together. Use 7 nails in each rafter.



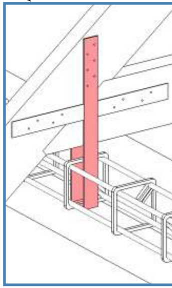
Rafter to wall connection at timber wall

Use a strap on either side to connect the rafter to the top plate. There should be a total of 11 nails in the rafter and 11 in the top plate.



Rafter to tie connection

Use a notched connection from the tie to the rafter so that the tie can take a compressive force in strong winds. Under normal conditions, the rafters will want to spread apart, so use a strap on either side to connect the rafter to the tie. Make sure there are a total of 4 nails in the rafter and 4 in the tie.



Wall to rafter connection at reinforced concrete ring beam

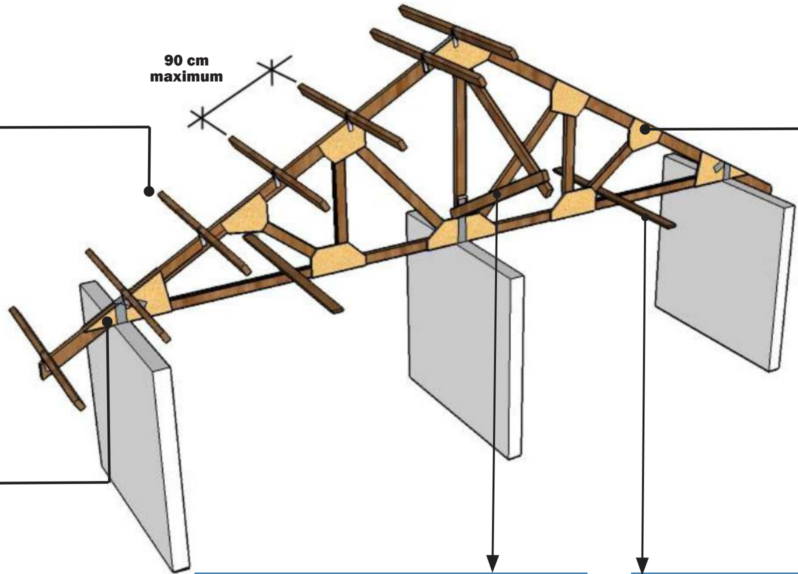
Embed a strap into the reinforced concrete ring beam. Use a total of 11 nails to connect the strap to the rafter.

TRUSS ROOFING SYSTEM

For larger roofs, a truss system is a good option. Trusses can be built with 2”x4”s and plywood gusset plates. Space trusses at no greater than 1.75 meters. The purlin should also be 2”x4”s and should be spaced at a maximum of 90 cm. Make sure the truss has the following elements:

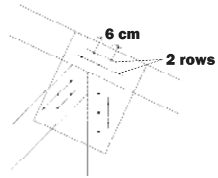
Purlins must be strongly connected to the truss with straps. Make sure there are 7 nails in the purlin and 7 in the truss.

Trusses must be strongly connected to the walls with long straps. Make sure there are 20 nails in the truss and 20 nails in the wall for timber walls, or 20 nails in the truss with the strap under the ring beam reinforcement for masonry walls.



Use ¾ inch thick plywood gusset plates on each side of the members with (5) - 2” nails on each side of the gusset plate to each member (10 total per members). Alternatively, use (5) long nails that pass through both gusset plates and can be crimped secure on the far side to each member.

Gusset Plate Connection



Use diagonal bracing from truss to truss to stabilize trusses in strong winds.

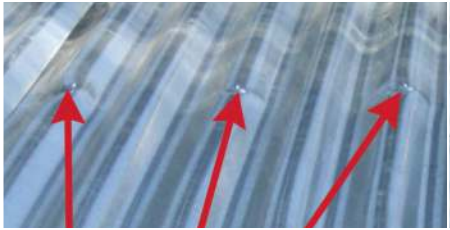
Brace the bottom chord from truss to truss in between supports to prevent buckling in strong winds.

ROOFING SHEETS

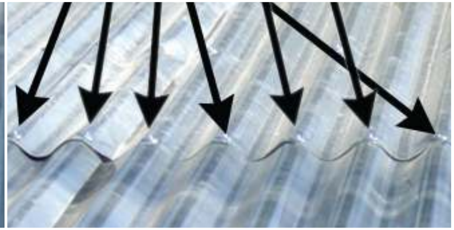
Roofing sheets must be installed correctly to be wind resistant and waterproof. Use minimum 26 gauge (0.48mm) thick metal sheets.

Only use proper roofing nails to secure CGI sheets to purlins

Place sheets straight and in line with one another. Overlap sheets by 15 cm.



Typically sheets should be nailed to the purlin at every two waves.



At roof edges, overhangs, and ridges, use a nail at every wave.

CHAPTER 10

MINIMUM STANDARDS

SITE REQUIREMENTS

- At least 6 meters or h/2 from steep slopes or cliffs, whichever is greater, where "h" is the height of the slope/cliff.
- At least 10 meters from and raised above rivers and bodies of water.
- Not on clayey, peaty, or liquefiable soil.
- Preferably not in an area at risk for storm surge. If in such an area, residents should be aware of the risk and ready to evacuate in the event of a typhoon or tsunami.

MASONRY CONSTRUCTION

FOUNDATION

- Excavation 40 cm deep by 60 cm wide for hard soils and 50 cm deep by 70 cm wide for soft soils.
- Column footings placed at every corner, wall intersection, and on either side of door openings. Column footings are at the same depth as the base of the foundation.
- Foundation made of:
    - OPTION 1 - Stone Masonry:
        - Stones laid horizontally.
        - Stones overlap each other from layer to layer to avoid aligned vertical joints.
        - All spaces are filled with stone and mortar (no voids).
    - OPTION 2 - Reinforced concrete strip footing with masonry stem wall:
        - 7.5 cm minimum concrete cover over steel in the reinforced concrete strip.
        - Concrete strip footing 20 cm minimum height, 60 cm minimum width, with two of longitudinal 12mm bars.
        - 10mm vertical starter bars cast into the concrete strip.
        - Stem wall made of reinforced 15 cm (6") block.
- Use a plinth beam on top of the foundation at the base of walls.
- Top of plinth beam is level with the top of the floor slab and is 80 cm above grade in flood prone zones and 30 cm above grade elsewhere.

PLINTH BEAM

- Planning:
    - 18 cm x 18 cm plinth beam at the base of all walls.
    - 18 cm x 18 cm columns at all corners, wall intersections, and on either side of door openings.
    - 18 cm x 20 cm ring beam on top of all walls.
    - Confined masonry construction is used. Walls are built before columns are poured, and ring beam is cast directly on top of the completed wall.
- Reinforcing Steel:
    - Four 12mm ribbed bars used as longitudinal steel in columns and beams.
    - 6mm stirrups with 5 cm hooks, rotated 135 degrees.
    - Reinforcement is new (not recycled) and is not rusty.

- Stirrups spaced at 10 cm within 50 cm of beam-column joints, and 20 cm elsewhere.
- Lap splices are 40 cm for 10mm steel and 48 cm for 12mm steel.

- Concrete:
  - Concrete mix is 1 part cement : 2 parts sand : 3 parts gravel.
  - Cement is Type 1 or Type 1P.
  - Sand is clean river sand or crusher fines.
  - Gravel is crushed and angular, 2cm diameter (max).
  - Slump is 8 cm to 10 cm.
  - Concrete is well compacted such that there are no voids, exposed steel, or honeycombing.

MASONRY WALL

- Blocks:
  - Select good quality 15 cm (6") wide blocks that do not break when dropped.
- Block Laying:
  - Mortar is 1 part sand : 5 parts cement.
  - Mortar joints between 0.6 cm and 1.6 cm thick.
  - A line and story pole are used to build the wall plumb and level.
  - First half of columns are cast after 1.5 meters of wall height.
- Reinforcement and grouting:
  - 10mm vertical reinforcement used every 40 cm.
  - 10mm horizontal rebar dowels every 3 courses at wall-column connection. Alternatively, toothing may be used at the wall-column connection.
  - Rebar is overlapped 40 cm at splices.
  - Wall reinforcing bars terminate with a 12 cm standard hook into the ring beam or column.
  - All block cells solidly grouted in one meter lifts.
  - One continuous horizontal bar is used below sill level in wall panels with window openings.

WOOD FRAME CONSTRUCTION

FOUNDATION AND KNEE WALL

- Exavation 40 cm deep by 50 cm wide.
- Concrete pier columns placed at every corner, wall intersection, and on either side of door openings. Column footing is at the same depth as the base of the foundation.
- Foundation made of:
  - 7.5 cm minimum concrete cover over steel in the reinforced concrete strip footing.
  - Concrete strip footing: 20 cm minimum height, 50 cm minimum width, with two of longitudinal 12mm bars.
  - 10mm vertical starter bars cast into the concrete strip.
  - Knee wall made of reinforced block, all cells grouted.
- Top of floor slab is 80 cm above grade in flood-prone zones and 30 cm above grade elsewhere.
- Foundation knee wall extends no more than 1.0 meter above grade.

- 15 cm x 15 cm reinforced concrete beam cast on top of knee wall, with four 10mm bars.
- Straps embedded into the plinth beam and hooked underneath longitudinal steel.

WOOD FRAMED WALL

- Gmelina, mahogany, or lawaan used for all structural members. 18 gauge (1.2mm) minimum thickness for straps.
- Preservative used on all wooden members placed on concrete or exposed to the elements.
- 4”x4” (10x10 cm) posts or two 2”x4” (5x10 cm) nailed together every 3” (7.5 cm) used at all corners. Posts are connected to the reinforced concrete foundation piers with metal brackets or long straps.
- 2”x4” (5x10 cm) studs at 60 cm on center. Studs are connected at the top and bottom with metal straps.
- Doubled 2”x4” (5x10cm) or single 4”x4” (10x10cm) top plate.
- Wall options as follow:
  - OPTION 1 - Diagonal lumber sheathing:
    - Boards oriented diagonally.
    - A minimum of 2.75 meters of shear wall length per wall line. Sheath both sides of interior walls only.
    - 2 nails per stud per board typically and 3 nails per stud per board at edges.
    - Long vertical strap embedded under bars in the plinth beam at the edge of the shearwall panel and nailed to post with 20 - 3” long nails each side at exterior walls and 31 - 3” long nails at interior walls.
  - OPTION 2 - Metal X-bracing with non-structural cladding such as amakan:
    - Strapping is in a full-height X-pattern on every wall line.
    - 1.5” 18ga strapping is on both sides of the wall.
    - Starter strap is embedded into the reinforced concrete beam at a 45 degree angle and hooked around longitudinal bars.
    - Splice is made with a 2”x4” backing board and 34 - 2½” long nails through spliced straps.
    - Strap is nailed to the top plate with 58 - 3” long nails in each strap.
    - Long vertical strap embedded under bars in the plinth beam at the edge of the shearwall panel and nailed to 4”x4” post with 34 - 3” long nails each side.
  - OPTION 3 - Plywood sheathing:
    - There is a minimum length of 2.75 meters of full-height plywood shear wall on each exterior wall line and 4.5 meters or double sided 2.25 meters of full-height plywood shear wall on each interior wall line.
    - Use plywood that is a minimum of ⅜” (9.5 mm) thick.
    - Make sure there is a 4”x4” (10x10 cm) post or two 2”x4” nailed together every 8 cm (3”) at the edge of each plywood sheet.
    - Plywood fastened to studs/posts with 2½” long nails at 10 cm (4”) spacings around the edges of plywood sheets and at 30 cm (12”) spacing on intermediate studs.
    - Long vertical strap embedded under bars in the plinth beam at the edge of the shearwall panel and nailed to post with 20 nails each side, using 3 inch long nails.
  - OPTION 4 - Post, Beam, and Diagonal Bracing:
    - **Limited areas where this option applies. Maximum wind speed is 150 kph, or Wind Zone III only.**
    - See pages 8-7 through 8-9 for minimum requirements.
    - A minimum of 2 meters of shear wall length per wall line.

WOOD ROOF CONSTRUCTION

- Gmelina or mahogany used for all structural members.
- Use 18 gauge (1.2mm) minimum thickness metal for straps.
- Preservative used on all wooden members placed on concrete or exposed to the elements.
- Roof options as follow:
  - OPTION 1 - Rafter and tie system:
    - Maximum rafter span between supports is 3.5 meters.
    - 2”x4” (5x10 cm) horizontal tie at the top plate level con necting each rafter pair (1.0 meter, maximum).
    - Horizontal ties fastened at each end to the rafter base with a notched joint, and straps each side with a total of 4 nails in the rafter and 4 in the tie.
    - 2”x4” (5x10cm) rafters spaced at 1.0 meter, maximum.
    - 2”x2” (5x5 cm) purlins spaced at 70 cm, maximum.
    - Rafters strapped to top plate/ring beam with 11 nails total in each wood member.
    - Purlins strapped to rafter with a total of 4 nails in the purlin and 4 in the rafter.
    - Use a strap at the ridge with 7 nails in each rafter.
  - OPTION 2 - Truss and purlin system:
    - Maximum truss span between supports is 3.5 meters.
    - Maximum spacing between trusses is 1.75 meters.
    - 2”x4” (5x10 cm) members used in the truss.
    - 2”x4” (5x10 cm) purlins spaced at 90 cm maximum.
    - Connect purlins to trusses with metal straps and a total of 7 nails in each wood member.
    - Truss members connected with ¾” (20 mm) plywood gusset plates.
    - For the gusset plate connection, use ten 3” (75 mm) nails in double shear per member (each nail goes all the way through both gusset plates, 5 from each side).
    - For the truss to wall connection, use straps anchored under the ring beam reinforcement or nailed to the top plate of timber walls on either side with a total of 20 nails into truss (and 20 into the top plate).
- Roofing sheets:
  - 26 gauge (0.48 mm) minimum thickness of metal sheet.
  - Use roofing nails to secure sheets to purlins.
  - Use a nail every two waves typically.
  - At roof edges, overhangs and ridges, use a nail every wave.

Build Change is an international non-profit social enterprise
whose mission is to reduce the deaths, injuries, and economic losses resulting from housing and school collapses in developing countries.

www.buildchange.org

BUILD CHANGE

BUILD CHANGE

BUILD disaster-resistant buildings
CHANGE construction practice permanently