How to Build Earthquake and Typhoon Resistant Buildings?

Guidelines for the low-income housing

Louise Mattsson

1 Introduction

The Philippines is one of most natural disaster prone area in the world. With its location in the ring of fire earthquakes occur at least five times a day and with the Pacific Ocean to the east typhoons hit in average 20 times a year (Samson, 2008, p. 8).

In the end of 2013 the Philippines suffered both from a harmful earthquake and the strongest typhoon recorded in the Philippine's history (Build Change, 2014:01, p. 2). The earthquake occurred in the Bohol Island and killed 222 people, 976 were injured and in total 3 221 248 people were affected, according to the National Disaster Risk Reduction and Management Council. They also report that 14 512 buildings were completely destroyed and 58 490 were partially damaged. (NDRRMC, 2013:03). Even worse were the effects of the typhoon named Yolanda (also Haiyan) that struck several islands in the Visayas area. There were 6 318 killed, around 1 000 people still missing, 550 928 buildings were completely destroyed and the same amount of buildings were partly damaged. (NDRRMC, 2014:03)

A big cause of deaths during earthquakes and typhoons is due to poorly built buildings which collapse or get ripped apart, forming hazards rather than shelters. Most of the damaged buildings are so called non-engineered building, which are built with traditional methods and materials without any involvement of an architect or an engineer. They are often constructed informally, outside the building code and with lack of concern, skills or finance to achieve earthquake and typhoon resistant buildings. (Arya, et al., 2013, pp. 18-19)

An example is the house of a man who I interviewed during my study trip to the Philippines in the spring of 2015. His house was a traditional Nipa hut, constructed with a light frame of bamboo, covered with amakan (woven bamboo mat). He was working in bar in Boracay when I met him, while his house and his family were in Iloilo. When typhoon Yolanda came to Iloilo the house flew away and was destroyed. Luckily the family survived. Now he is building a new house with exactly the same technique, because he cannot afford to build it with a stronger material.

So what will happen during the next typhoon? Will the house collapse once more and will he become even poorer? Or even worse - his family could come to harm. This reflection led to the question of this paper: How can you build constructions resistant to typhoons and earthquakes using traditional and affordable materials, such as wood and masonry?

2 Literature Review and Discussion

The following section will answer the previous question based on several publications of recommendations on how to build resistant, and discuss this in a Philippine context. The reviewed literature consists of:

- UNESCO's publication; "*Guidelines for Earthquake resistant non-engineered construction*" written by Anand S. Araya, Tebby Boen and Yuji Ishiyama (2013).
- A booklet entitled "*Guidelines for Building Reconstruction in Cyclone affected Areas in Orissa" written by* Anand S. Araya (2000
- The book "*Technical principles of Building for safety*" written by Andrew Coburn (1995)
- TAO-Pilipinas's (technical assistance organization) publication; "*Integrating Disaster Risk Management*", written by Geraldine Matabang, Roselyn Frances Marcelo and Berly Baybay (2009),
- Build Change's report (2014) of the house damages assessment from typhoon Yolanda and earthquake Bohol in 2013.

Common for all these publications is that the recommendations are only for small, one or two storey houses, often built by low-income people with traditional techniques (Arya, et al., 2013, p. 20) (Matabang, et al., 2009, p. 27) (Coburn, et al., 1995, p. 2). According to TAO many of these recommendations are not new in the Philippines, but actually a part of their building tradition. Yet, they have been rejected to lower the building cost, even though the review literature confirms that these recommendations do not generate any additional cost, or very little compared to what it will cost to rebuild a completely destroyed house (Arya, et al., 2013, p. 20) (Samson, 2008, p. 8). The challenge is to overcome this misunderstanding and spread the knowledge of how to build resistant.

In order to answer the question of how to build resistant it is first necessary to define what a resistant building means. According to Arya (2013, p. 19) and TAO-philipinas (Matabang, et al., 2009, p. 27) the building should function as a shelter for its occupants and should therefore not partly or totally collapse. The damage should not be larger than that the usual function of the house can be set to normal soon after an earthquake or typhoon.

First, it is important to understand what forces impact on the building during an earthquake or a typhoon. An earthquake can cause ground shaking, ground failure, fire and tsunamis, whereas the ground shaking is the main cause of damage (Arya, et al., 2013, p. 23). The shaking ground creates forces on the building parts in all directions, both horizontal and vertical, where horizontal forces are often the most damaging since walls, columns and beams are normally only bearing vertical loads. But during an earthquake they suddenly need to withstand horizontal forces as well. (Arya, et al., 2013, pp. 28,29,31)

Horizontal forces are also the primary forces exerted on the building during a typhoon. The wind also creates pressure difference between the inside and the outside of the building which in turn can lead to uplifting forces which can for example dislodge the roof. (Arya, 2000, p. 21)

Site conditions

Regarding floods, landslides, tsunamis and volcano eruptions the most crucial factor to build safe is the choice of site. In comparison to earthquakes and typhoons, the building is the most important factor. (Coburn, et al., 1995, p. 19) In the Philippines the choosing of a site without any of the natural disasters listed above might be extra difficult due to the widespread risk as shown in the risk map, see Figure 1. Furthermore, I believe the possibility to choose location is even further limited for many people for several reasons, for example financial, livelihood, traditions, resources or other factors connecting people to a location or simply due to lack of available space.

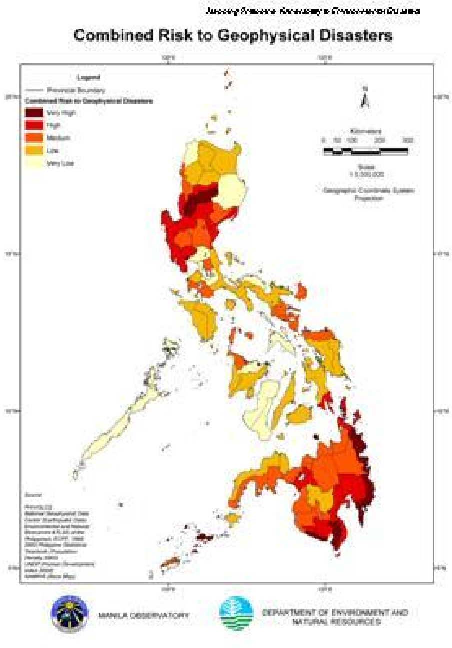

Figure 1; Natural disaster risk areas

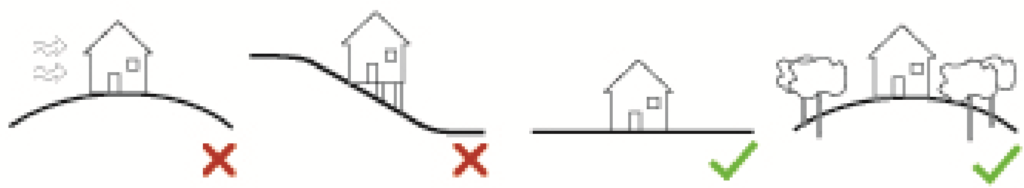

Figure 2; Topography, it is best to build on flat land, not hilltops or slopes. Trees can be planted to protect exposed sites from strong wind.

But if there is a possibility one should, according to the guidelines, choose with topography and soil condition in mind. For typhoons it is recommended to avoid hilltops or clifftops where the wind speed can be up to 15 % stronger. However, the risk of these sites can be reduced by planting trees (in a safe distance) to protect from the wind. (Coburn, et al., 1995, p. 26). It is also known from earlier earthquakes that buildings on a flat site are safer during an earthquake than buildings in steep slopes. See Figure 2. This is because a building is stable when it is well rooted in the ground and the loads are evenly distributed on the foundation. Therefore it is better to have several building blocks on terraces than one large block on footings at different level, as shown in Figure 3. (Arya, et al., 2013, pp. 33, 53) (Matabang, et al., 2009, p. 28)

Figure 3; A big building should have a foundation divided in different levels when built in a slope.

Another important feature for stability is, as mentioned above, soil condition. Building on a rocky, hard soil is better than building on a sandy, soft soil, as the soft soil shakes more during earthquakes than the hard soil. The site should also have a lot of drainage since soil with high water content can, when exposed to strong vibration, lose its strength and turn into liquid. (Coburn, et al., 1995, p. 27) (Matabang, et al., 2009, p. 27)

Building configuration

The report done by Build Change (2014:01, p. 9) of the structural damage assessment from typhoon Yolanda and the earthquake in Bohol, says that the houses in this region often are of simple design, square or rectangular. This is a good shape for resistance, as a symmetric box is more stable compared to a L-shaped or a U-shaped building. The reason is that a wall exposed to a horizontal force in the direction of the walls length, a so called shear wall, is much more resistant than a wall exposed to a horizontal force in the perpendicular direction of the wall's length. In a box-shaped building the wall perpendicular to the horizontal force does not risk to be turned over as it is supported by two shear walls. In an L-shape the two walls in the inner corner lacks this support. See Figure 4. A rectangular shape is good as long as the perpendicular wall is not more than 3 times longer than the shear walls as it will not receive enough support from the shear wall. (Arya, et al., 2013, pp. 33, 35, 51) (Coburn, et al., 1995, p. 29)

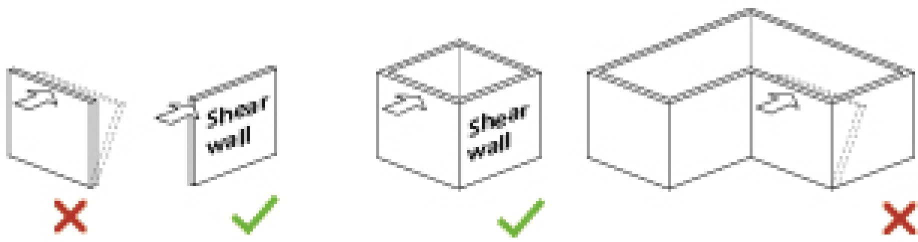

Figure 4; Principle of shear wall. In a box-shape all walls are supported to withstand horizontal forces.

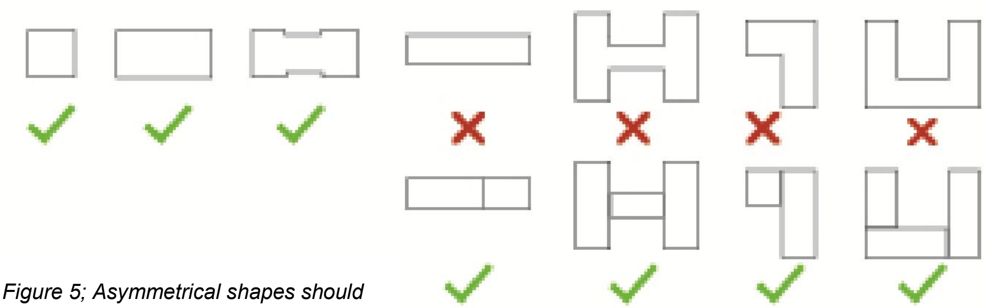

Figure 5; Asymmetrical shapes should be avoided or divided into several rectangular shapes.

However it is possible to get way with an asymmetrical or a long rectangular shape if it is divided into a number of rectangular blocks as show in Figure 5. In a long and narrow shape it is sufficient to add cross walls, but in an asymmetrical shape a physical separation of 40 mm or an expansion joint is required. (Arya, et al., 2013, p. 51)

Openings

But even though most of the buildings in Yolanda and Bohol had the right shape, many structures failed because the shear walls were not constructed to be strong enough to take care of the horizontal forces (Build Change, 2014:01, p. 3). This may be due to openings in the walls.

UNESCO's guidelines (Arya, et al., 2013) present a basic rule; the fewer and smaller openings, the stronger the wall, which means less damage. But from the Philippine climate point of view the bigger the openings, the better the indoor climate due to cross ventilation. The guidelines does not mention anything about this, but they mention that it is preferable to spread the openings evenly around the building or at least place them in opposite walls both for stability and for letting the wind blow though the building to decrease the internal suction forces and for cross ventilation, see Figure 6. (Arya, et al., 2013, pp. 33, 50) (Arya, et al., 2013, p. 21)

For multistory building it is important to place the openings in the same place on every level so that the vertical load can go straight down to the ground. The openings should not either vary in size between the levels or at least have the biggest openings in the top. Buildings on columns are therefore not generally good practice during earthquakes, but on the other hand they are good in an event of flooding. See figure 6. (Coburn, et al., 1995, pp. 15, 60-61)

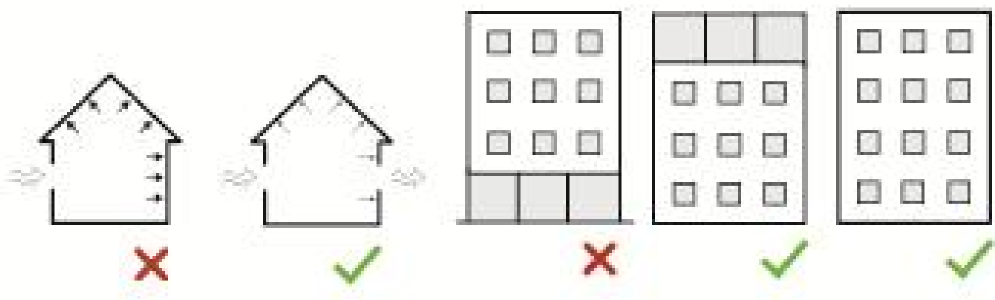

Figure 5; Openings should be in opposite walls. It is preferable to have same size and placement of opening on all floors.

Choose of Material

The choice between wood and concrete hollow blocks is not simple as both have advantages and disadvantages. In order to build a strong building it is a necessity to have materials with good quality. It is fairly easy to find wood with good quality in Bohol, while it is more difficult to produce concrete hollow blocks good enough for constructions. In order to lower the cost, hollow blocks made locally in hand filled aggregates often lacks sufficient amount of cement. Significant for these blocks is that they break as they are dropped to the ground. But at the same time, the disadvantage with wood is that it can be affected by mold, insects or fire. (Build Change, 2014:01, pp. 20-22)

In typhoon Yolanda almost every wooden house was entirely destroyed or carried away in the strong winds, while the masonry houses remained. The situation was the opposite in the earthquake in Bohol. (Build Change, 2014:01, pp. 10-12) This is because the wooden structure is lighter than a masonry construction. The amount of seismic force which acts on a building material during an earthquake is directly dependent on the weight of the material, which means that the wood is more resistant as it is lighter. In addition, the wooden structure is more flexible and ductile than masonry and can be shaken and bent more than concrete before collapsing. But the low density of wood is not an advantage in a typhoon, simply because it is easier for the wind to move or break it. (Arya, et al., 2013, p. 26)

Figure 7a; Lack of heavy foundation

Figure 7b; Lack of bracing caused damage after earthquake

Figure 7c; Good foundation and well braced

However, it is possible to make both these building materials more resistant to earthquakes and typhoons. The reason numerous wooden structures are carried away is because of a lack of a deep and heavy foundation to counteract the uplifting forces of the wind, as shown in case in Figure 7a. Many houses lacked enough diagonal bracing in the walls, which is crucial to make the building withstand horizontal forces. This was the case in the house in Figure 7b. In addition, the connections between wooden members often consisted of a single nail instead of metal straps and gusset plates. Figure 7c shows a well-braced example with an appropriate foundation (Build Change, 2014:01, pp. 10, 16)

Reinforcement in masonry

In order to make the concrete hollow block masonry more ductile and stronger it can be reinforced with steel bars or bamboo sticks (Arya, et al., 2013, pp. 57, 135). The bars should be placed both horizontally and vertically around openings and in the corners of the building. All the walls should be tied together by a continuous band of steel in the top of the walls as shown in Figure 8a. (Matabang, et al., 2009, p. 29) If two perpendicular walls are not properly tied together, they will not act as shear walls and one of them will collapse as shown in Figure 9a.

Figure 8a; Reinforcement marked in red

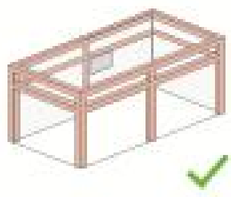

Figure 8b; Reinforced concrete frame with masonry infill

Another even better solution to this is to have posts and beams made out of reinforced concrete above openings, in corners and instead for a steel band See Figure 8b. (Matabang, et al., 2009, p. 29)

Figure 9a

Figure 9b

The house in Figure 9b has a reinforced concrete frame, but one of the walls failed because the distance between the other perpendicular walls was too large and could not support the longer wall. Also note that the hollow blocks were not reinforced with a sufficient amount of vertical steel bars. (Build Change, 2014:01, p. 13)

Connections

Figure 10; Examples of poor connections with only nails found in Bohol

The major cause of damage in Yoland and Bohol was due to poor connections between foundations, wall, roof etc. and is therefore a significant aspect to consider when building. Figure 10 shows examples of inadequate connections with only nails found by Build Change in Bohol (2014:01, pp. 9-18, 27). In order to avoid destruction, all parts should be tied together so the building acts as an integrated unit during earthquake shaking and no parts shall separate so the horizontal loads from the shaking and wind can be transferred to the vertical elements and down to the ground. (Arya, et al., 2013, pp. 34, 47) In the case shown in Figure 10, it had been better if they used straps and brackets instead. (Coburn, et al., 1995, p. 50)

There are two principles to connected building components to withstand an earthquake. The junction can be either stiff or flexible, depending on if the structure should be stiff enough to endure the shaking or if it should be flexible to isolate from the shaking movements. This could be done by using a shake absorber in the foundation to isolate the whole build from the shaking ground. (Arya, et al., 2013, pp. 58-59) But these are too expensive for small houses in the Philippines. A much more affordable solution is presented in an article in National Geographic (Carroll, 2015). By using a tier filled with sand and stones as a plinth under the building isolation can be achieved, even though it is a third as strong as the more high-tech shock absorbers.

Roofs

In typhoon Yolanda many wooden roofs were destroyed or carried away, because of their light construction. In order to solve this it might have been a good idea to use a heavier building material for the roof. But as shown in Build Change (2014:01, p. 11) report from Bohol concrete roofs were performing very poorly under seismic forces. Arya (2013, p. 67) explains that a heavy roof causes a strong horizontal force on the top of the walls, which cause the walls to overturn and the entire structure may give away. Thus, it is better to invest in a well anchored wooden roof.

It is not a solid idea to have a roof gable made in a heavy material, since the gable lacks a perpendicular support to resist the horizontal seismic forces. (Arya, et al., 2013, p. 41) (Build Change, 2014:01, p. 12)

This goes well along with a typhoon resistant roof design, whereas a roof with a gable causes much more uplifting forces than a hipped roof. The ideal shape for wind resistance is pyramidal with a pitch of 30-40 degrees. See Figure 11. (Arya, 2000, p. 24)

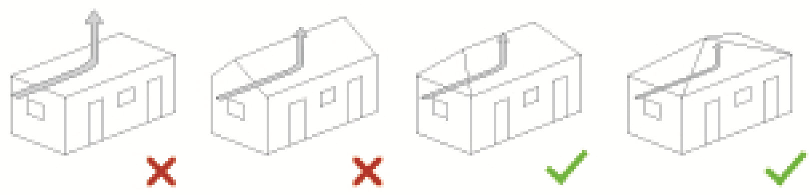

Figure 11; A flat roof and a gabled roof creates a stronger uplifting force than a hipped or pyramidal roof

In the Philippines both heavy rainfall and blazing sun are common. In order to protect the facade from water and sun a 500 mm roof overhang is required. The roof overhang should be well anchored in the wall so that it doesn't risk to be lifted up by strong winds. See Figure 12. (Arya, 2000, pp. 24-25)

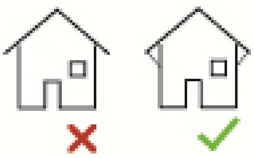

Figure 12; Anchor roof overhang to the wall

3 Shelter Design

Here follows a check list of the recommendations brought up in this paper on how to build safer. Note that these are just simple principles within a small scope lacking any details.

- ✓ Avoid building in a disaster prone area, if possible
- ✓ Build on hard soil
- ✓ Build on flat land
- ✓ Provide for good drainage in the site
- ✓ Plant trees to protect from wind
- ✓ Choose a square or rectangular shape, or divide asymmetric shapes into several separated rectangles
- ✓ Have small and few opening
- ✓ Place openings on the opposite sides of the building
- ✓ Have the same size and placement of opening in all floors
- ✓ Anchor wooden house in a heavy and deep foundation
- ✓ Connect all wooden members with straps, brackets and gusset plats
- ✓ Use diagonal trusses or plywood to brace the wooden frame work
- ✓ Reinforce masonry both vertically and horizontally around openings and in corners
- ✓ Tie all masonry walls together with a continuous steel band or concrete beams placed in the top of the walls
- ✓ Make sure that all connection are strong, especially the connection between walls and roof
- ✓ Shape the roof pyramidal with a pitch of 30-40 degrees
- ✓ Use light materials for the roof, such as wood and corrugated iron
- ✓ Anchor the roof overhang to the walls.

4 The Role of Architects

Generally it is the engineer-profession who is the expert in implementing earthquake and typhoon resistant designs and constructions, while the architect profession has not yet taken up the challenge (Lagorio, 1990, p. 260). But the knowledge of the relation between shapes, choice of material and resistance is, as I believe, fundamental for both collaboration between the professions and to avoid unnecessary building costs. Moreover, it is a part of the building codes to make the building resistant to natural hazards, which of course the architects should follow.

The problem in the Philippines is however that their building code is geared toward larger buildings and not towards the smaller freestanding houses in which the majority lives. For many Philippines it is too expensive to apply the building code on their small scale structures or to hire an architect or engineer. (Build Change, 2014:01, p. 26)

On way of solving this could be to give the low-income people safe shelters, designed and built by professionals, cheaper by financing them by foreign aid and government subsidies. But in my opinion this is not the way to teach Philippines how to build more resistant. Instead we should counter misunderstandings and create awareness of that it is not more expensive to build safer - it is a good investments. In order to create a deeper understanding of how to improve the traditional way of building, I believe this is best accomplished with organized self-help programs with technical assistance from an architect or an engineer, as the people are more involved in the building. The architect's task could be to guide communities and home-owners in their building projects and spread the knowledge of disaster-resistant-principles through workshops, on-the-job guidance, training builders programs and public awareness campaigns. I suggest that the architect can take advantage of their ability to communicate by pictures and create a folder illustrating the recommendations to make them more easily accessible. It could be something like the checklist and the figures I presented in this paper, which could be handed out to home-owners and builders to make a difference before the next disaster have arrived.

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