CARITAS

Caritas Czech

Project Site Visits ~ Aceh

Villages of Babah Nghom,
Meudang Ghon and Jambo Masi

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Abstract

The Tsunami Relief and Rehabilitation Programme, set up following the devastating tsunami of 26 December 2004, allocated large international financial support to the reconstruction of houses lost in the disaster. The Aceh district of Sumatra in Indonesia was hard hit and many national and international organisations provided assistance in the reconstruction. Site visits were conducted to Caritas Czech permanent housing reconstruction projects along the western coast; 32 completed and ready for handing over in Babah Nghom, 30 houses under construction in Meudang Ghon and 26 houses nearing completion in Jambo Masi. The earthquake- and tsunami-resistant properties of the houses are assessed and recommendations provided to increase occupant safety, improve structural strength and ensure the correct application of the national code for earthquake-resistant reinforced concrete design. Observations are made with regard to the use of material use, rainwater harvesting and WatSan solutions.

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Photograph on page 7 by: Alexander Angermaier (Caritas Austria)
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1. INTRODUCTION

The observations presented in this paper are based on site visits and discussions with Caritas Czech programme manager Martin Vane and the construction management staff. A number of issues covered are not exclusive to the Caritas Czech permanent housing project, but have been observed in other NGO tsunami reconstruction housing projects as well.

Site visits to three villages were realised on 21 and 22 February 2007:

- Babah Nghom – located near the shore – 32 houses.
- Meudang Ghon – situated on low land – 30 houses.
- Jambo Masi – situated on low land, but more inland – 26 houses.

The Meudang Ghom houses were taken over from another NGO, which could not complete the assignment.

The houses being constructed by Caritas Czech are of good quality and in many cases better than what the people lost in the tsunami. The more durable material choice of concrete, bricks and plasterwork makes the houses less vulnerable to flooding. If the reinforcements in the concrete are correctly placed, the ground-floor-only houses would be reasonably earthquake resistant, considering their small size and weight.

On the other hand, if a tsunami similar in scale to the one of 26 December 2004 reoccurs, most of the new houses will again be wiped off their foundations. Such would not only be the case with the Caritas Czech houses, but would also be the plight of many other NGO-built houses in the same areas. This is because they have been rebuilt on the same high-risk location as the destroyed houses. Nevertheless, the houses may survive a smaller tsunami.

The houses are simple, attractive to the villagers, reasonably well built and adequately finished. The recommendations presented aim at improving the overall strength of the house and comfort level for the occupants.

Tsunami Safety

One of the most important findings of the site visits in the Aceh region is that many beneficiaries are not very much concerned about the recurrence of another such disaster. Most houses are ground level and reconstructed in the same location as before the tsunami. Based on discussions with the beneficiaries and observations of the non-affected housing in the same region, the following points can be made:

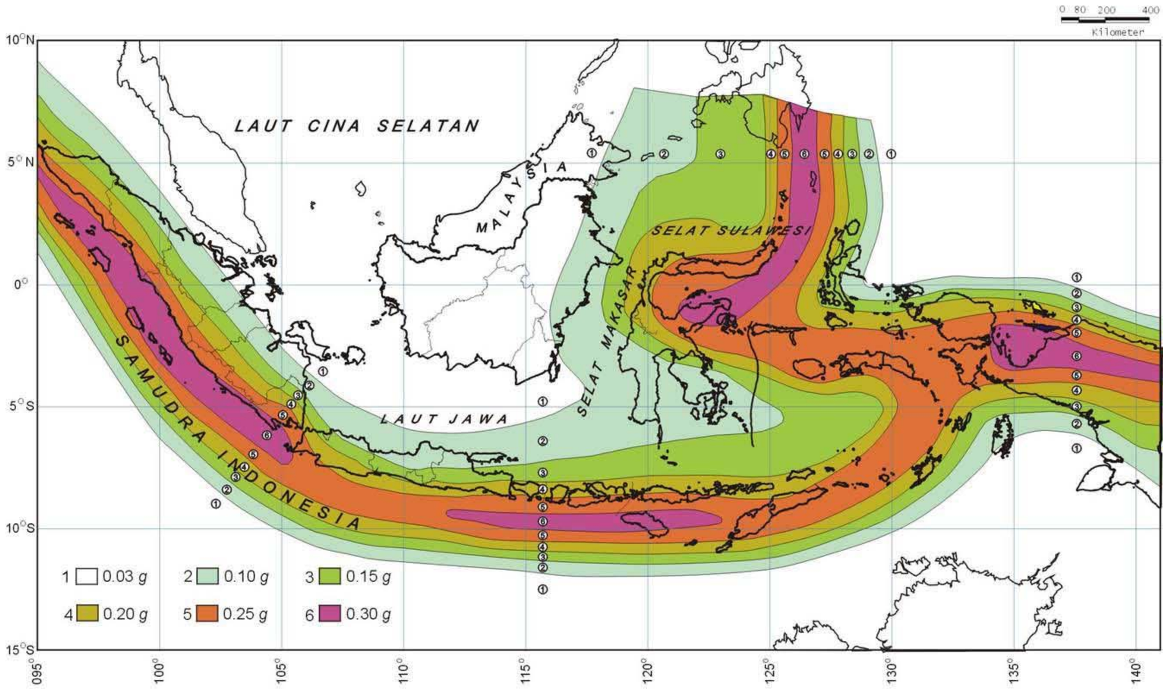
- The beneficiaries want to have their permanent house rebuilt on their own land and not be relocated.
- Almost all people have lost relatives in the tsunami and hope that another such disaster will not occur again during their lifetime. However, if it does, then it is the will of God and so be it.
- Technically, most new houses are stronger than those lost in the tsunami.
- Structurally, most houses are built of more durable materials than the houses lost.
- People are aware that earthquakes will occur in the region.
- The design will withstand moderate to strong earthquakes.
- Permanent house designs expected to last more than 50 years will be regularly subjected to various magnitudes of earthquakes (average 6 per year in Sumatra).

General Observations

a) The availability of new land for housing is very limited. The steep rocky hills rise immediately beyond the low, flat coastal land, providing no elevated area on which housing can be safely built.
b) When given a choice of type of housing of equal size – on columns or on the ground – the beneficiaries prefer ground-level houses, even if the cost difference is absorbed by the NGO or aid organisation.

2. EARTHQUAKE-RESISTANT DESIGN

There are some differences between an earthquake-resistant design and a tsunami-resistant design. The priority of a good construction design in Sumatra is earthquake resistance. Building to withstand an earthquake should conform to the generally accepted building codes. The map below provides an overview of the different earthquake-risk areas. The ground acceleration along the western coast causes a horizontal force on the building of 0.25 g or 0.25 times the total mass of the construction.



Materials Increase or Reduce Potential Earthquake Forces

The force of an earthquake is directly related to the weight or mass of the building. The heavier the building materials, the larger the forces will be between the ground acceleration and the upper construction. Therefore, lightweight constructions and building materials (timber, plywood, bamboo, wattle, and zinc or aluminium roofing sheets[1]) are preferred over heavy materials (reinforced concrete, cement blocks, stabilised soil-cement blocks, plastered burned brick, and clay or cement roofing tiles).

One should avoid building in areas where the subsoil is sloppy or there exists the potential for liquefaction. If construction is to be realised in such areas, then only very lightweight houses should be considered.

Recommendation

Considering the frequency and size of the earthquakes in the coastal area of Sumatra, all "permanent" housing should be built according to the earthquake codes.

[1] Traditional materials for house building include timber and bamboo. Good analysis of these earthquake-resistant and climatically appropriate designs can assist in making better house designs.

Supporting Frame Structures

For earthquake-resistant buildings with a supporting column (space-frame) construction, the infill walls need to be anchored into the columns and the ring beams (below and above). In a box-frame structure, the walls form part of the supporting structure together with the surrounding columns.

In both cases, reinforcement bars for anchoring the walls have to be cast into the columns and ring beams, and overlap with the horizontal and vertical reinforcement bars in the masonry. From observation, only a few NGOs in the visited housing projects along the western coast were realizing anchorage between columns and walls.

SUPPORTING COLUMN CONSTRUCTION (SPACE-FRAME STRUCTURE)
The column and beam structure supports all floors and walls.
The earthquake load of the floors and walls need to be transferred to these columns through anchorage.
A common shortcoming is that no provisions are made to anchor the walls to the columns.

In a box-frame house construction (walls with stiffener columns), the walls function as the main support structure for the house and are all load bearing. The full wall box-frame structure can withstand large earthquakes when the construction is well designed, but it is not a good design for a high tsunami-risk zone because the walls cannot withstand a tsunami load. The tsunami load on walls is between 1-2 ton/m^2 or about 10 times an earthquake load. Therefore, houses in tsunami-risk areas need to be built on columns, leaving the ground floor free.

As it is impossible to predict the actual earthquake force, earthquake reinforcement must consider the possibility of the forces exceeding the design force. In such a case, the construction must still hang together without total failure.

3. OBSERVATIONS AND RECOMMENDATIONS

3a. General Design

The different communities were presented with a general house design of 42 m^2, having an entrance porch, a main room with a kitchen corner, two bedrooms and a rear platform with an adjoining toilet unit. The entrance porch is considered an important element to the house design. Houses without the porch are not a favourite design among the beneficiaries.

According to the BRR, the standard houses should not include a kitchen, as this is the responsibility of the beneficiaries to realise. Many NGO-built houses (including Caritas Czech), however, are incorporating a small kitchen area inside the house, but with no working surface, storage shelves or sink.

JAMBO MASI VILLAGE ~ YELLOW CARITAS CZECH HOUSE WITH PORCH AND TWO OTHER NGO-BUILT HOUSES.
THE OCCUPANT OF THE PINK HOUSE IS ALREADY ADDING A PORCH.

Most beneficiaries plan to build a bigger kitchen outside. Although some people cook on a kerosene stove, firewood is commonly used. The house will quickly become dirty (blackened ceilings) because there is no kitchen chimney incorporated into the design. The outside kitchen is commonly a timber construction. Several beneficiaries were planning to use their pre-fabricated IFRC temporary shelter as a kitchen or house expansion.

3b. Floor Height

A number of houses are being built with the ground-floor height less than 60 cm above the waterline of the surrounding lakes and ponds, making them vulnerable to flooding during excessive rainy periods. Some houses are being constructed behind the new elevated roads. With seasonal flooding, these roads may act as dikes behind which water will accumulate and flood the houses positioned lower.

Recommendations

- *The floors of new houses should be at least 1 meter higher than the high waterline of the rainy season and minimal 20 cm higher than the top of the road to avoid seasonal (monsoon) flooding.*

- *At the village level, the maximum seasonal flood level of the area and the average maximum flood level of the sea should be clearly marked.*

3c. Anchorage between Columns and Walls

Most NGO house designs are based on a column construction, having pre-constructed reinforced concrete columns (20 cm x 20 cm) with 10 cm brick infill walls and then plastered. When no anchorage exists between the column and the brick wall, these walls will pop out of their framing during strong earthquakes or tsunamis. The columns should support the roof, even if the walls have been destroyed.

The infill walls need to be anchored to the columns and the ring beams (below and above). Reinforcement bars for anchoring the walls must be cast into the columns and ring beams. In earthquake-only areas, these bars should overlap with the horizontal and vertical reinforcement bars in the masonry.

The photo right shows the absence of reinforcement between the column and the masonry. The column is a bit rough in its centre to give some adherence to the masonry mortar. A cemented connection based on adherence of cement mortar is, however, ineffective during an earthquake.

The far left photo shows the effect of a tsunami or an earthquake on a wall that is masoned against a column only having a groove for attachment.

The photo left shows a pre-cast column with reinforcement bars for the wall protruding through the formwork. This house is being built at a considerable distance from the shore.

Recommendations

- *Box-frame houses require ring/tie-beams at the foundation, lintel and roof levels in combination with vertical wall reinforcements on all wall junctions and along all doors or other large openings. In earthquake-only areas, horizontal and vertical wall reinforcements need to be interconnected from the foundation to the roof and through all internal walls.*

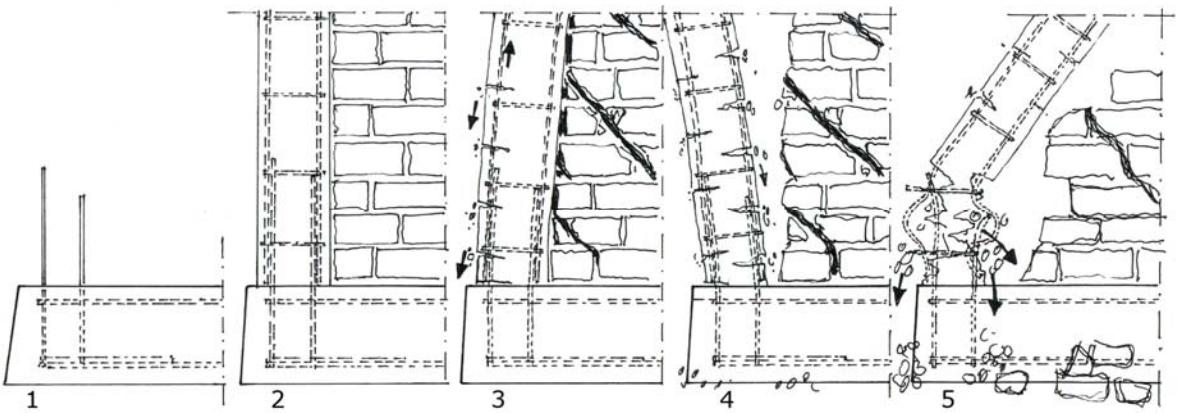
- *Space-frame structures should have an autonomous support structure (not needing the walls for strength). In an earthquake-only area, all walls should be well connected to the columns, and the floors to the beams.*

- *In high tsunami-risk areas, box-frame structures are not recommended. For space-frame structures, the walls should not be fully through-reinforced, allowing substantial parts of the wall to be knocked out in case of a high tsunami load on the wall.*

3d. Anchorage of Columns and Stirrups

The columns should have (1) good anchorage into the foundation ring beam and (2) a high number of stirrups at the maximum moment areas of the column. These two conditions are often lacking in many houses under construction. In particular, the earthquake-resistant column-stirrup design for freestanding columns is not being applied.

The photo right shows a detail of the smooth bar reinforcement protruding from the foundation. The column reinforcement will be placed alongside these bars. The overlap length of the smooth bars is less than 50 times its diameter. With a side force to the column, this connection will not hold and the smooth bars will be pulled out of the column, allowing the column to fall over. On the rear column, the roughening of the column surface to provide adherence to the brickwork can be observed. In addition to this shortcoming, the columns do not have sufficient stirrups in their maximum moment areas.

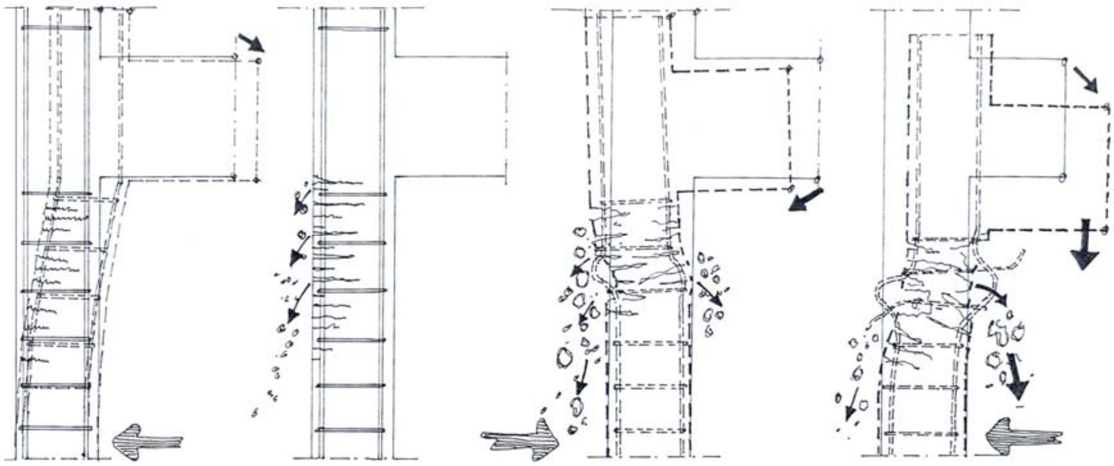


The above sketch illustrates what will happen when:

1) The foundation reinforcement has insufficient length and overlap beyond the maximum moment area in the column above. The column reinforcement pulls up.

2) The brick wall is not anchored into the adjoining column. It will break away at minimal stress because the cement mortar does not take the stress.
3) There are insufficient stirrups in the maximum moment area where the column tends to bend. The broken concrete particles fall out of the column.
4) The earthquake forces crack the non-reinforced brick walls diagonally. The broken bricks fall out of the structure and do not provide a buffer for the column.

The same holds true when a supporting column is attached to a stiffer or stronger upper beam. With the absence of sufficient stirrups, the concrete falls out of the column during excessive earthquake forces, resulting in a rapid failure of the entire support structure.



Excessive and repeated oscillating movements caused by a large earthquake will crumble the concrete. With an insufficient number of stirrups placed close together, the concrete will fall away and lose its compressive capabilities.

<u>*Recommendation*</u>
Each column end should be reinforced with a cage of stirrups at its maximum moment zone to prevent broken concrete from falling out of the construction when earthquake forces exceed the design forces. This is especially the case when connecting beams are stronger than the columns. The column ends should therefore have 6 mm stirrups every 5 cm over a length of minimal 1.5 times the column width under the floor beam, followed by two stirrups 10 cm apart and then continuing with stirrups every 20 cm for the rest of the column.

EXAMPLE OF EXCESSIVE FORCES ON NON-ANCHORED INFILL WALLS, COMBINED WITH LACK OF STIRRUPS IN THE MAXIMUM MOMENT AREAS OF THE SUPPORT COLUMNS

3e. Roofing Material

In Meudang Ghon, the Caritas Czech programme is being realised in coordination with Fauna and Flora International (FFI), both building an equal number of houses. Within the context of this cooperation, micro-concrete roofing (MCR) tiles (single model) are being manufactured in the village under the supervision and quality control of a Swiss expatriate (Patrice Bouchier). The beneficiaries approved using the MCR tiles on their permanent houses mainly because of the production in their village.

The expatriate will be departing upon completion of the production line for the tsunami permanent housing projects. The expatriate expressed his concern that the activity will be unsustainable and most likely the factory will be closed due to the following reasons:

- The current production is subsidised with the purchase of all the equipment from an external project and the presence of expatriate management. With management costs included, the final product will be too costly for the local market (over Rp. 50,000/m^2).
- Training a local factory manager to adequately control the quality of the product has to date not been realised. The process is rather delicate and a small decline in quality will produce an inferior product, resulting in a loss of confidence by the client.
- Based on the expatriate's experience, the only way the MCR tile factory may succeed is for it to be run and managed by women, along with a few men to do the heavy mixing work. This may not be feasible in the local society.
- The product has not yet been commercially sold. For marketing, feedback from the owners of the permanent houses with the MCR tiles is required.
- The product is substantially heavier than metallic roofing sheets and therefore needs more timber for the support structure, increasing the cost per square meter.
- The MCR tile does not radiate heat to the inside of the roof (as metallic sheets do). However, omitting the suspended ceiling as a cost reduction factor is not an option as the villagers consider a suspended ceiling an essential component in their house.
- The product is heavy and rather delicate to transport. Without adequate quality control or insufficiently strong and straight roofing structures, breakage will increase and with that, a rise in the cost per square meter.
- When people are provided with a choice, they will usually choose a product being used by other (wealthier) people. The red-painted metallic imitation roofing tile sheets cost Rp. 50,000/m^2 and are factory guaranteed for 10 years. These roofing sheets are preferred to the corrugated GI sheets that rust within two years due to the sea climate (Rp. 25,000/m^2).

Recommendation
Considering durability and climatic performance, the micro-concrete roofing (MRC) tiles are better than the red-painted metallic roofing sheets. Because the MCR tiles are heavy, they are as a matter of principle not recommended in any severe earthquake area, unless the houses are designed to carry the additional load.

3f. Roof Ventilation

Dark coloured metal roofs (corroded corrugated GI-zinc or red-painted metallic roofing sheets) in the tropics will become very hot in the sun and radiate heat towards the inside. A suspended ceiling is required to reduce heat radiation towards the living quarters. The area above the suspended ceiling must be adequately ventilated. This ventilation detail has been omitted in the basic house design supplied to Caritas Czech and will result in warm, uncomfortable interior living quarters[2].

The photo right shows a new house with the beneficiary leaning against the water well. While there are sufficient ventilation slats above the windows, no ventilation vents have been provided under the roof.

The ventilation slats above the windows should be located well back under the roof overhang or designed in such a way that rainwater cannot enter when the wind is onto the gable.

Recommendations
- *The amount of heat transfer (radiation) from metallic roofs to the suspended ceiling is reduced by creating a well-ventilated space under the roof. There should be minimum 1 m^2 openings in the two gable tops. The use of pre-fabricated cement blocks will avoid the use of timber.*

- *To reduce heat radiation from the metal sheets, a layer of thermal insulation should be applied. The thermal insulation layer can be made from agricultural bags filled with coconut husk or empty PET water bottles.*

3g. Internal Climate

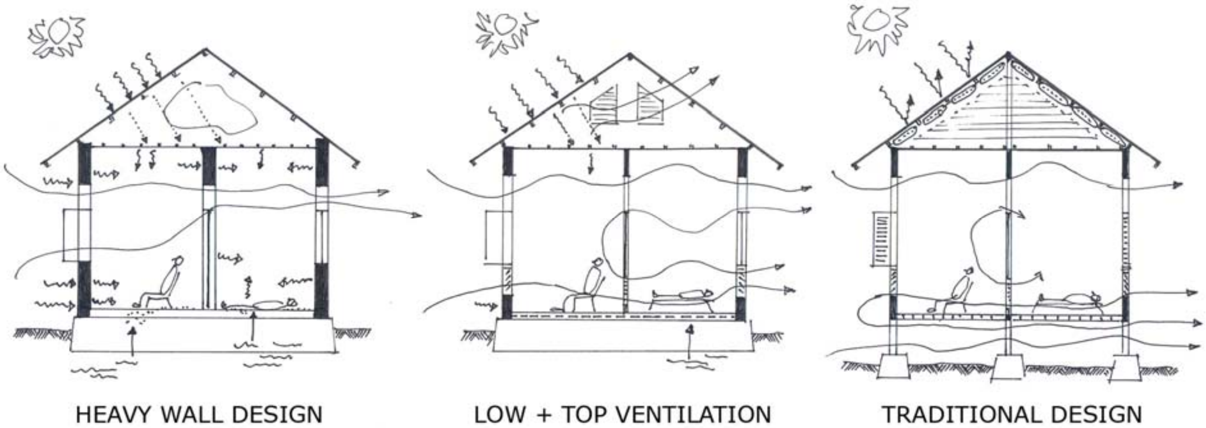
The internal climate of the house plays an important role in determining the comfort level of the occupants. Traditional houses in tropical coastal areas are usually lightweight timber constructions having a small own mass and large windows. The combination of good cross ventilation and low heat storage of the lightweight walls provides for a cooler, drier and more comfortable living environment.

On the other hand, the desired concrete and brick houses have a large mass and heat storage capacity. In addition, they often have small openings with insufficient cross ventilation. Consequently, these “modern” houses take a long time to cool off in the evening, rendering them uncomfortable during the hot, humid periods of the year. Yet, many people favour the brick-type buildings above lightweight constructions because rich people are living in these types of houses.

[2] One villager actually paid the contractor to put in the required ventilation openings.

TRADITIONAL HOUSE ~ LIGHT CONSTRUCTION AND WELL VENTILATED

Low ventilation openings are absent in the living room and bedrooms of the current brick house design. As a result, the rooms will be uncomfortably warm during the night, unless all the doors are kept opened. The sketch below gives the differences between the "modern" heavy house design and the traditional lightweight timber house design.



Heavy Wall Design has large heat accumulation during the day and requires good ventilation to cool off the walls. Because there are no low ventilation openings, warm air is removed only from under the ceiling. With lack of ventilation under the roof, the ceiling gets very warm and heats the rooms. The cement floor does not stop rising moisture from the ground, making the rooms moist.

Low + Top Ventilation is introduced. Plastic foil is placed under the floor before casting, keeping the cement floor dry. The walls are less heavy and the internal walls are lightweight for rapid cooling in the evening.

Traditional Design has all the properties of a comfortable house. Because the lightweight floor is raised, it cools off rapidly in the evening. When metal roofing sheets are used, thermal insulation can be placed under the roofing sheets to stop the heat radiation.

Recommendation

Ventilation vents should be installed under the windows providing a cooling airflow at sitting or sleeping height. Ventilation vents can also be placed in the lower parts of the internal doors. Ventilation openings under the windows should be fitted with mosquito wiring to prevent the entry of snakes and creepers.

4. EARTHQUAKE-RESISTANT DESIGN IN TSUNAMI-RISK ZONE

According to the earthquake code, wall reinforcement is required for houses having a box-frame design. Such through-the-wall anchoring, however, will make the entire building vulnerable in another large tsunami, especially when built in an area prone to floods. When speeding floodwaters hit the wall, the anchored wall will pull the columns down. However, if the infill walls are not firmly attached to the columns (whether pre-cast or post-cast stiffener columns), they will be knocked out of their frame during a large tsunami, leaving the remainder of the building standing. In this case, however, the walls may fall on the occupants.

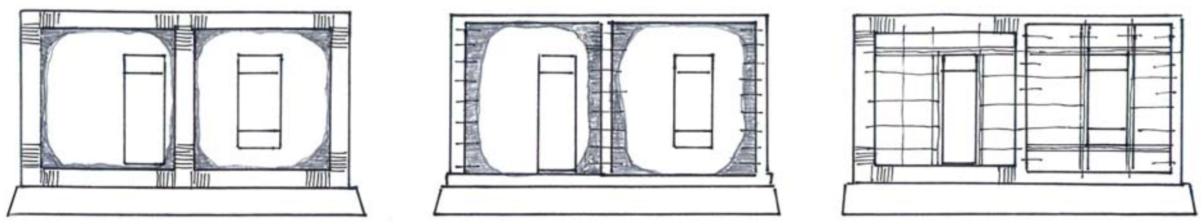
<u>Recommendation</u>
In a high potential tsunami zone, the ground-floor structure of houses should always be self-supporting without applying a box-frame structure. In a house design with supporting columns, the infill walls should be attached to the columns, but not reinforced throughout, allowing these walls to be knocked out of their column framing by the force of a large tsunami.

4a. Wall Reinforcement Construction

The generally applied BRR building design in most of the reconstruction houses is based on nine 20 cm x 20 cm reinforced columns with infill masonry walls. <u>The columns always need to withstand the horizontal earthquake load, even when most of the ground floor infill walls have been destroyed</u>.

> *Houses with supporting columns and infill walls may survive a tsunami impact if the walls are partly knocked out. However, if the occupants of the house have no means to escape the tsunami – either to a higher, safer floor or a two-storey building in the nearby vicinity – they could become trapped between collapsing brick walls and floating debris.*

The left sketch below illustrates the situation in which the space-frame columns remain standing and the walls are knocked out of their framing because of lack of anchorage. In such a case, the collapsing walls can do a lot of damage to the occupants of the house.



The middle sketch illustrates a box-frame building with stiffener columns anchored into the masonry wall, but the wall is not reinforced throughout. The stiffener columns with the attached masonry will keep the house up, while large sections of the walls will be knocked out by the tsunami.

The right sketch illustrates an earthquake-reinforced wall according to the building code. Horizontal tie-beams and vertical stiffener columns are placed around all openings, while horizontal and vertical reinforcement bars are placed at 60 cm intervals throughout the walls, duly anchored into the support structure.

If a large tsunami hits this third building, it is highly likely that the attached walls will transfer the load of the tsunami wave to the columns and the entire building collapses. Hence, <u>the third design is not recommended in a high-risk tsunami zone</u>.

4b. Options for Tsunami Designs

Withstanding a tsunami is based on a number of options. The main issues are:

- Building on higher ground
- Building away from the shore
- Buffer zones between sea and houses
- Raised buildings and living floors
- Collapsible infill walls on the ground level
- Avoid blocking floodwaters
- Reinforcement of the houses facing the coast
- Deep corner foundations to avoid under-scouring
- Round support columns of structures

Although the first two options are the most effective in eliminating the tsunami hazard and safeguarding lives, they are difficult to implement due to scarcity of suitable alternative land, resistance of beneficiaries to be relocated, acceptance of the proposed relocation site, purchase of land, title deeds, size of plots, etc.

Buffer Zones between Sea and Houses

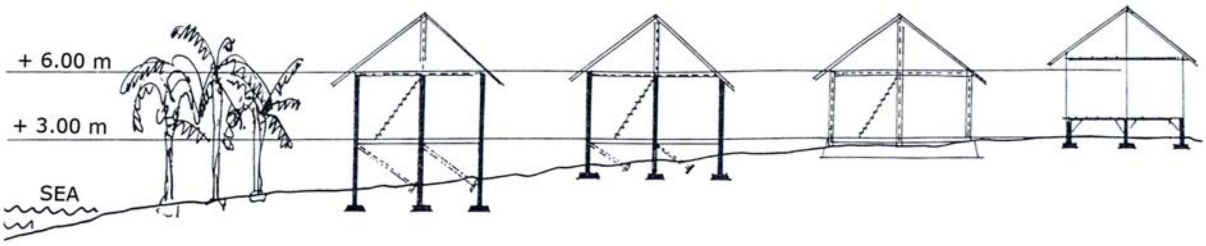
Buffer zones are important for lessening the impact of a tsunami before it reaches residential areas.

Recommendations

- ➢ *Within 100 m from the high waterline, no permanent constructions should be erected.*
- ➢ *Between 100 m and 300 m from the high waterline, only houses with floors elevated 3 meters above that high waterline should be realised. Filling in the lower floor area should be restricted. Foundations should be deep, avoiding the risk of scouring.*
- ➢ *Houses 300-500 m from the high waterline and the ground being lower than 3 meters above the high flood line should be adequately spaced to allow the floodwaters to pass in between them. Infill walls on the ground floor should allow being knocked out by a large tsunami wave.*
- ➢ *Houses constructed beyond 500 m from the high waterline, but lower than 3 meters above the main high waterline, need to be reinforced on the ground floor with supporting cross walls at maximum 1-meter intervals.*

Raised Buildings and Living Floors

Raised buildings allow the tsunami waves to flow through the open space under the building. The problem is to determine the probable height of the tsunami flood above the average seawater level. When building close to the shore (20-50 m), it must be taken into consideration that the tsunami height above the ground is strongly elevated due to the wave landing on the shore. When building farther inland from the shore (200-300 m), the required free height under the building can be lower, depending on the elevation of the terrain.



Recommendation

Building to withstand a tsunami should consider a buffer zone and provisions to reduce the impact of a flood within that buffer zone. Immediately behind the buffer zone, elevated buildings having easy access to the upper floors are preferred. Round columns reduce the pressure of the waves. Wide buildings should have deep corner foundations to avoid under-scouring.

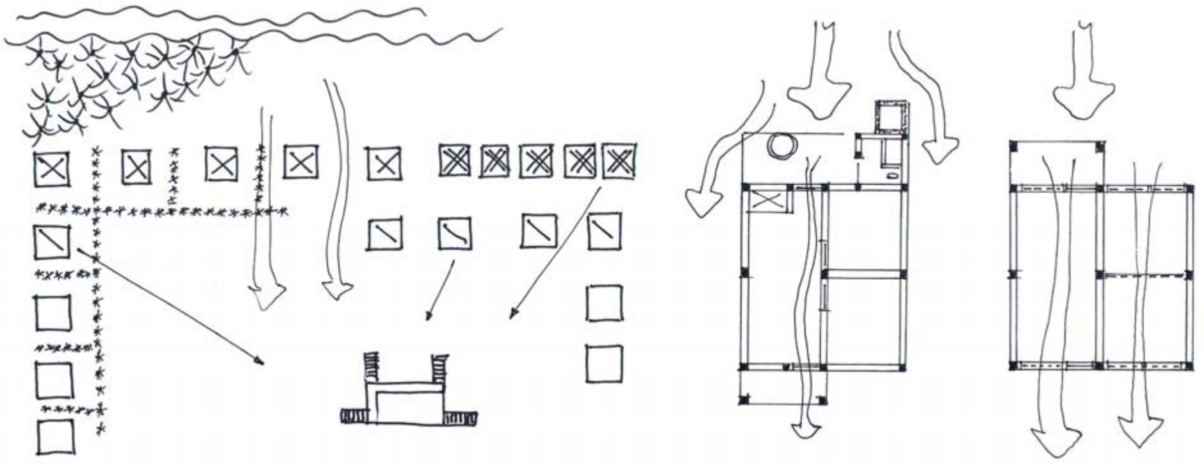
Collapsible Infill Walls on the Ground Level

The infill walls between the columns of the main structure should be knocked out by the force of a large tsunami wave. The floodwaters will destroy all that is in its path, but the main building structure and upper floor should survive the impact. Such a design is useful when the occupants can reach the upper floor easily and rapidly by means of staircases, accessible balconies and terraces.

Avoid Blocking Floodwaters

When the flow of a tsunami wave is blocked by a line of houses, the water will accumulate against these houses and increase the load on the walls. Therefore, houses should not be built close together, but have ample space between them to allow floodwaters to freely flow around them instead of blocking the wave.

In settlements with many ground-floor-only buildings, several higher community buildings should be constructed on safe ground, providing a safe haven where the villagers can escape to in the event there is sufficient warning before the tsunami wave strikes.



Recommendation

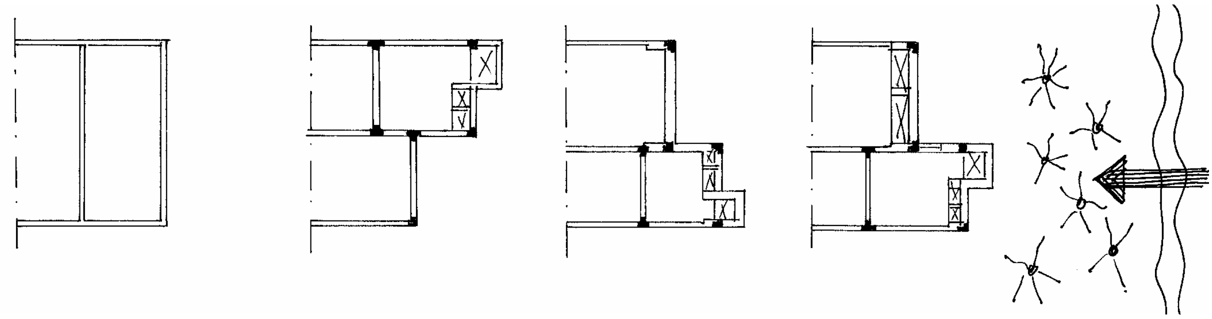
Four principal measurements are required to improve disaster preparedness for housing sites located close to the shore with risk of a tsunami.

1) *Dense plantations should be realised between the shoreline and the houses.*
2) *No extensions (such as kitchens) should be built between the houses, obstructing the flow of onrushing seawater.*
3) *No fences (barbed wire or any other material) should be erected in between the houses, blocking escape routes towards land or safer locations.*
4) *An elevated construction or communal building on columns should be erected in a central location with easy access from all sides. The ground-floor columns should be self-supporting and have no infill walls.*

Reinforcement of Houses Facing the Coast

The sea-facing side of houses built close to the shore should be reinforced with cross walls to deflect the force of the tsunami wave.

In the sketch above, reinforcing the back side of the houses facing the sea is an option that may save the building during a small tsunami. The toilet extension with the water basin is actually a very strong construction because of the cross walls supporting the front-facing wall. This may deflect the water flow. To enhance the strength of the wall, a cross wall can be made in the existing houses or in the new kitchen extension, reinforced with a concrete tabletop.



Sketches from left to right:
Weak wall construction – Strengthened house with shelving in kitchen – Strengthened house with heavier walls on the side facing the sea up to 1.5 meter above soil level – Additional cross wall and shelving in the widest room on the side facing the sea – Buffer zone – Sea.

Deep Corner Foundations to Avoid Under-Scouring

When buildings are wide, the water flow will scour out the soil around the extremes. At these locations, the foundations should be made deeper and, if possible, the soil surface strengthened to limit the effect of the fast flowing water around the corners. The wider the building and the narrower the gap between buildings, the deeper the foundation will be affected.

Resume

Firstly, and most ideally, the houses should be well elevated so that the force of a tsumani passes under it and the upper living area provides a safehaven for the occupants.

Secondarily, houses built close to the sea with high tsunami risk should have the walls anchored to the general support structure of the house, but not fully through-reinforced. This applies to both reinforced columns with infill walls (space frame) and post-cast stiffener columns between the walls (box frame).

Thirdly, centrally located buildings with easily accessible second stories should be realised in each village for refuge purpose. Staircases should be built on the outside of the construction and ending in spacious landings.

WALLS KNOCKED OUT FROM BETWEEN A SUPPORTING REINFORCED CONCRETE FRAME STRUCTURE

5. MATERIAL USE AND CONSTRUCTION METHODS

In the situation after the tsunami, many NGOs and contractors started to build houses using a variety of technologies and construction methods. These methods changed in time depending on the availability of material and exigencies of the client population.

Although Caritas Czech designed a very appropriate demonstration building using local materials, this design was not accepted by the local population who wanted ground-floor-only houses from durable materials (concrete, burned brick and cement plaster).

TWO-STOREY DEMONSTRATION HOUSE WITH WOODEN FRAMEWORK,
INFILLED WITH COCONUT-FIBRE PLASTERED WALLS AND A MCR TILE ROOF.
THE BUILDING IS USED BY CARITAS CZECH AS A FIELD OFFICE AND ACCOMMODATION.

5a. Use of Renewable Resources

The use of timber and other lightweight materials (like bamboo) is advised for earthquake-resistant designs, but these materials may not be readily available in large quantities. Especially the supply of good quality (legally) sawn timber, being termite resistant, is becoming increasingly difficult and costly. In terms of energy consumption, both reinforced concrete (cement, steel and transport) and burned clay bricks (firewood, cement mortar and transport) constructions have high-energy demands and therefore considered environmentally unfavourable. On the other hand, good quality reinforced concrete and reinforced burned brick constructions are longlasting (+50 years). The energy balance will tilt further negative if, due to the overall design of the house, air-conditioning and ventilators are required to keep the occupants comfortable.

With the use of permanent materials lasting 50 years or more, the chances of being affected by heavy earthquakes or another tsunami become increasingly greater. When the reinforced concrete construction is poorly executed by the contractors, it may fall apart by itself within 10 years due to corrosion of the steel.

5b. Lightweight Internal Walls

Lightweight construction components are not only suitable in regard to earthquake areas but also for the hot, humid climate. Internal walls can be made from (asbestos-free) fibre-cement board or plywood, both low in weight. This translates into a weight reduction of 7-8 tons for a ground-floor-only house or 25%, equally reducing the earthquake forces by 25%.

The photo left shows a room with the internal wall made of plywood (right wall). As can be seen, the finishing can be very good, thus reducing the lower image of plywood. In this case, the owner has applied a decorative stencil to the wall.

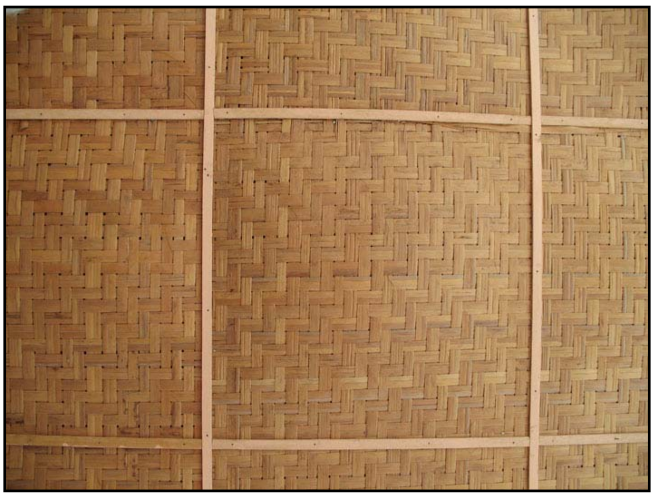
In the photo right, all the internal walls of the house are made from light-gauge galvanised steel profiles onto which the fibre-cement wall panels are fixed. Using (asbestos-free) fibre-cement boards for internal walls has several advantages:

- Fast construction due to less transport needs and easy on-site assembling.
- Lighter own weight and therefore less need for reinforcement.
- Lighter material and therefore cooling off faster in the evening.
- Lower construction cost than heavy brick and cement-plastered walls.

5c. Lightweight Ceilings

The use of local materials can reduce costs as well as weight. Bamboo ceiling panels are decorative and lightweight. For durability, they can be varnished and their natural beauty maintained.

When plywood panels are used, they need to be whitewashed on both sides before fixing to the ceiling, otherwise they will start to deform after some time due to the humid sea climate.



Recommendation
Internal walls and ceilings can be made from lightweight materials, such as plywood, asbestos-free fibre-cement boards (Kalsiplank, Eternit) or bamboo mats. This reduces not only the force of an earthquake, but the room cools off faster in the evening.

5d. Comparison of Construction Methods

A comparison is made below between different construction methods, explaining the main advantages and disadvantages. In presenting these concepts to the communities, the decision-making of the villagers is strongly influenced by the following aspects:

- Level of understanding the presented design. This may be very low for new technologies, as they have no practical reference. The realisation of real-size demonstration houses is essential.
- The type of houses the people lost. In general, the people want back what they lost or what they think is better. In the current period, the concept of better is a house from concrete, burned clay brick and cement plaster, completed with tiles and paint.
- The decision-making by the headman of the village. This means that a project needs to seek out the formal and informal decision-makers in the village in order to convince these people of the best building method.
- Limitations in the market on availability of selected building materials.
- Cost of the particular design. It was assumed by many beneficiaries that cost was not a determining factor in the tsunami reconstruction.
- Local standards and building regulations. These appeared to be flexible.

In the following chart, earthquake resistance, internal climate and self-construction options have been considered.

COMPARISON OF CONSTRUCTION METHODS

Design Description	Advantages	Disadvantages
1. Traditional timber house on short pillars. Short pillars on short concrete footings. Palm-leaf roofing.	• Local material and low cost. • Able to self-construct the house. • Lightweight and therefore light earthquake forces. • Well ventilated and cooling off fast during night. • Roofing of palm leaves is low cost and ventilating.	• Durability limited to 20 years without any maintenance (humidity, termites). • Connectors with support system not very strong. • Government restricts the use of timber. • Roofing needs to be repaired annually and stays moist after rain.
2. Improved traditional timber house on short pillars. Use of GI metal bracing straps. Fibre-cement siding, internal panelling or ceiling. Light metal roofing.	• Able to self-construct the house following demonstration example. • Lightweight and therefore light earthquake forces. • Improved earthquake resistance through diagonal bracing. • Connections with support system good. • Well ventilated and cooling off fast during night. • Metal roofing low weight, less timber and allows clean rainwater harvesting.	• Increased material cost of fibre-cement panelling. • Durability main frame needs to be increased to 40 years with treatment of wood preservative on structural members and maintenance. • Galvanised iron straps and connectors need to be locally marketed. • Government restricts the use of timber. • Fibre-cement boards may crack during earthquake.
3. Prefabricated hollow cement blocks B- and U- shape, with stiffener columns and all-wall and ring tie-beam reinforcements. Light metal roofing.	• Durable materials and plastered, being liked by the population. • Simple design, can be easily replicated by masons when following model. • Simple reinforcement method through hollow blocks and U-shaped tie-beams. • No timber use for support structure. • Possibility to use light-gauge roof frame.	• Heavy materials requiring additional reinforcement in stiffener columns and ring or tie-beams throughout the building. • High materials cost in cement, sand, cement blocks and transport of blocks. • Good quality B- and U-blocks are required, needing clean (river) sand. • Requires additional openings for ample ventilation because the heavy house will heat up during the day.

4. Stabilised soil blocks with reinforced concrete ring and tie-beams over all walls. Light metal roofing.	• Same as above, but reduced cement use as compared to the above. • Blocks do not have to be plastered. • Use of local labour to make the blocks. • Cooler interior climate.	• Requires good moisture protection below window level or use of common solid-cement blocks. • Requires special machinery to compact blocks. • Labour intensive manufacturing. • Requires sorted sand-soil quality. • Increased weight requires additional reinforcement.
5. Light-gauge GI main fame structure on short legs with timber panelling. Light metal roof with water harvesting. IFRC transitional shelter design.	• Simple and fast to erect due to numbered parts. • Can be built in many locations, also on wetland because of lightweight. • Durable construction because of timber treatment. • Timber can be replaced with fibre-cement board or plastered bamboo. • Highly earthquake resistant.	• Requires importation of GI frame structure or local sales outlet. • Not replicable without purchase of elements. • Villagers are now expecting brick, cement and concrete houses. • The social standard has been changed by external financing.
6. Ground-floor-only houses.	• Easy access from the land without stairs. • Socially desired due to changed perception of the population. • Small amount of transport and scaffolding.	• Flooding risk. Possibility of rising moisture when no plastic membrane under the floor. • Timber should not be in contact with floor. • Possible splash of rainwater onto the walls.
7. Houses on stilts.	• Improved ventilation of the house. • Safer in the case of floods and tsunami. • Increased durability of the house.	• Increased building costs. • Attention required in column-floor connection. • Stairs are required to reach floor.
8. Plastered burned brick houses with stiffener columns.	• Traditionally known design. • Easy and fast to construct using limited amount of timber and concrete. • Socially well accepted design. • High durability of lower wall sections.	• Increased weight and therefore increased earthquake forces, especially when internal walls are made from plastered bricks. • Requires large windows for cooling off through ventilation during the evening.
9. Reinforced concrete pillar construction with infill masonry or cement block walls and plastered.	• Socially well accepted design. • High durability of lower wall sections. • Design introduced in 2005/2006 after the tsunami by BRR and NGOs. • Possible to make it earthquake resistant.	• More expensive construction as compared with stiffener column construction. • Faulty application of concrete reinforcement possible without good site supervision. • Anchorage between columns and walls seldom applied. • Increased weight and therefore increased earthquake forces, especially when internal walls are made from plastered bricks. • Requires large windows for cooling off through ventilation during the evening.
10. Light-gauge zinc-aluminium or painted roof-tile profiled metal roofing.	• Lightweight and therefore low earthquake impact and fast construction. • Low requirement for roofing timber. • Durable material, guaranteed for 10 years or more.	• High cost as compared to common corrugated GI roofing sheets. • Requires local sales outlet. • Metal has high heat accumulation under the sun; zinc-aluminium less.

6. Rainwater Harvesting

The lightweight metal roof is ideal for rainwater harvesting. Alongside well water, the collected rainwater can be used for drinking, cooking and washing.

Water from shallow wells, can easily become contaminated when the sewerage system is not designed to process all effluents in a safe way, being the situation in many villages. In addition, many housing sites are subject to regular flooding (which is also the case here) and the sanitation or sewerage system is not designed to continue functioning during the floods.

An elevated rainwater-harvesting tank will provide safe drinking water during and after flood periods.

The rainwater is goes through a filter and collected in primary and secondary sedimentation buckets. As these buckets need to be cleaned after every rain, they must have easy access. The main tank also needs to be cleaned periodically. The tanks should be covered to avoid breeding of mosquitoes.

The photo right shows the simple design of rainwater collection provided with the IFRC temporary shelters. A number of villagers are using this facility for the collection of rainwater. For long-term operation, self-cleaning systems are recommended.

By connecting the gutters from both sides of the house, large amounts of clean (drinking) water can be regularly collected during rains.

<u>Recommendations</u>

- *One new house in each village should be fitted with a well functioning rainwater harvesting system as demonstration model. Rainwater harvesting will provide safe drinking water in case of recurrent flooding. Overflow of the collection tank should drain into the water well.*

- *Water and sanitation systems should be designed and realised as an integrated part of each housing project, especially when population density increases.*

7. Sanitation Systems

The agreement with the local authorities and the design of the house assumes that the NGO will realise the sanitation systems with the houses. The following points can be mentioned:

- From an interview with a few female villagers, the sanitation needs to be attached or inside the house because they consider it inappropriate for other people to see one entering or exiting the toilet.
- Where the sanitation is located next to the house, the space in between is often closed and incorporated into the house.
- There is insufficient knowledge within the NGOs and the communities to realise safe sanitation systems that can withstand seasonal flooding and remain operational.
- Increased population densities require improved sanitation systems, other than those commonly used in the former lower density villages.
- Many sanitation systems incur recurrent expenses for operation and maintenance, such as the emptying of septic tanks, while the former systems in the low-density settlements had none.
- The local municipalities require septic tank emptying equipment, safe disposal and processing areas for the sewerage sludge, issues that have not been worked out.

Most houses have the sewerage discharge located at the rear of the houses with a PVC pipe connection running alongside the houses. PVC will become brittle when exposed to the sun, besides the exposed pipes can easily be damaged by villagers. Hence, it is important that these pipes be well covered with cement blocks.

UNCOMPLETED SEWERAGE SYSTEM WITH EXPOSED PVC PIPE FROM TOILET TO SEPTIC TANK AND SOAK AWAY

PVC PIPES MASONED IN WITH STONES ALONG THE HOUSE AND CAST INTO CEMENT FOR PROTECTION

Recommendations

- *Use long, single pieces of HDPE (High Density Polypropylene) pipes because these are UV resistant and will not easily break when the soil shifts due to settlement or earthquakes.*

- *For the rehabilitation housing contracts, WatSan should always be included and not left up to the local population to solve in the traditional way. The designs need to be negotiated with the local government planning and health authorities, as well as with the settlement communities, to find safe and sustainable solutions.*

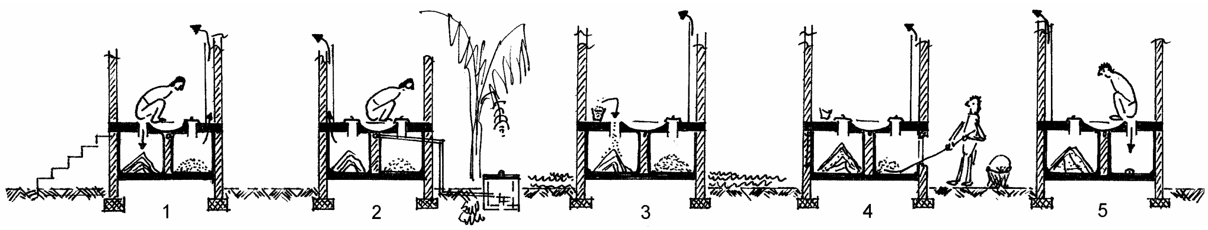
Photo Left: An open septic tank made from concrete rings. The footing of the rings is anchored to a wider base plate to avoid floating in high groundwater after the tank is emptied.

Photo Right: The complete system with the effluent flow bed. The effluent bed should be planted with sugarcane, banana, or other plants that thrive on nutrient-rich overflow water. When the groundwater level is subject to regular flooding, the system should be built higher above ground. This implies that the toilet inside the house also needs to be built higher.

Recommendations (continued)

- *Systems that require regular emptying of sealed septic tanks should only be installed when it can be assured that the septic tank slurry will be safely processed and disposed of without health hazards or groundwater pollution.*

- *In areas flooding annually, for either short or extended periods, the WatSan solutions need to be adequate to withstand these floods without overflowing or allowing effluents to escape into the surface water. Systems such as elevated closed septic tanks and Ecosan toilets should be promoted for flood-prone areas. Systems with biological filtration ponds for post-septic tank effluent can handle high groundwater levels.*



TWO-PIT ECOSAN TOILET SYSTEM

Sketch 1: Two ventilated water-sealed chambers above the ground – one in use and one closed for composting.
Sketch 2: After defecation, anal washing is done over the central pan (urine drain).
Sketch 3: Add wood ash or dry clay to fresh faeces and close squatting hole with lid.
Sketch 4: After ½ year, remove compost from the closed chamber.
Sketch 5: Close the full chamber (for ½ year) and start using the empty chamber.

8. Summary

The house design conforms to the BRR standards but actual quality depends on the site supervision of the contractors. This is especially the case with the internal column and wall reinforcements. In houses having a high tsunami risk, the walls should be anchored to the columns, but not through-reinforced, allowing them to be partially knocked out of their framing. The columns should remain standing.

The location of the houses in the nearly completed Babah Nghom project site is rather vulnerable to a recurring tsunami. Like in other locations, the villagers are aware of the issue but do not believe there will be another tsunami. Houses on stilts or houses reinforced on the coastal side were not considered by the villagers.

A number of the newly built houses may be subject to seasonal rain flooding, which also may adversely affect the on-site septic sewerage system. According to the new occupants, the water supply from most wells was good. The houses most probably do not have sufficient cross ventilation; some do not have ventilation under the roof, a problem that applies to many other NGO houses as well.

Meudang Ghon village was in the process of constructing the columns and brick walls with a local contractor. The low-lying foundations (just above the swamp) were noticed, as well as the lack of anchorage between the foundation and columns, and between the columns and the brick walls. There was no evidence of proper column reinforcements. Similar problems were identified in many other housing projects.

Near the Meudang Ghon village site, a micro-concrete roofing (MCR) tile factory had been set up and managed by a Swiss expatriate. The impression of the expert was that the local villagers would not be able to continue running the factory due to lack of systematic quality control skills and lack of market. Some of the problems were the continuous need for supervision, continued project subsidy, high cost of the MCR tiles in comparison to lightweight metallic roofing sheets, fragility of the product and so far not being introduced commercially into the local market.

The Jambo Masi site, the difference in housing designs between the NGOs was rather obvious. The villagers preferred a house with a porch to a house without, even if the second house was larger. In addition, the villagers preferred a plastered brick construction to a house with the upper part of timber. In general, the villagers preferred a fully painted house and floor tiles. In some cases, the villagers with an income had already started extending their houses and linking the transitional shelter to the NGO-provided permanent house.

The houses and sewerage systems were in their final stage of completion. Sewerage pipes need to be protected against sun radiation and mechanical damage.

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