	CARITAS	

Selected Technical Advice
Tsunami House Reconstruction
Aceh ~ Indonesia

By
Sjoerd Nienhuys, Architectural Engineer
Shelter Advisor, Trócaire (Ireland)

Indonesia
April 2007

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 of the 123,000 destroyed houses. Site visits were conducted to various Caritas and non-Caritas permanent housing reconstruction projects along the northern and western coasts of Aceh. Although many houses have already been completed, technical details could be observed in a large number of houses still under construction. The earthquake- and tsunami-resistant properties of the houses are assessed and recommendations provided to increase occupant safety and improve structural strength according to the national code for earthquake-resistant reinforced concrete design. Rebuilding safer houses, including in safer locations, should have been the basic criterion for the government and the NGOs. Observations and recommendations are made with regard to the use of materials, climatic design, rainwater harvesting and WatSan solutions.

Photo Front Page:
One of the project sites with completed houses, ready for occupation. Most houses in the tsunami rehabilitation programme have similar physical characteristics.

Photographs and drawings: Sjoerd Nienhuys (unless otherwise mentioned)
Document editing: Doreen J. Nienhuys
Email contact: Sjoerd@nienhuys.info
Website Trócaire, Ireland: http://www.trocaire.org

Table of Contents

Note: Indonesian Rupiah (Rp) 10,000 = Euro 1

1. INTRODUCTION

The observations presented in this paper are based on a series of site visits undertaken during February and March 2007, discussions with several Caritas reconstruction programme managers and management staff, BRR government staff[1], contractors and personal observations. The site visits included both Caritas and non-Caritas housing reconstruction projects and discussions with house occupants.

The principal issues covered in this report are not exclusive to the Caritas permanent housing projects, but have been observed in other NGO tsunami housing projects as well. General advice is given on how shortcomings can be adjusted or avoided in the future. It is hoped that the information provided will be used as part of a learning process and appropriate measurements are taken when executing future projects.

The overall need for house reconstruction following the 26 December 2004 tsunami and the 28 March 2005 earthquake exceeded 130,000 in Aceh alone. About 20% will be realised by the collected Caritas projects by the end of 2008. From this, it is roughly estimated that less than 4% (or 1000 units) of the Caritas-financed houses could have been technically better constructed (less than 1% of the overall reconstruction). It has been assumed that the already completed houses (plastered and painted) in a project would have similar characteristics as the houses under construction, especially when the same contractors are involved.

In comparing the construction techniques of the Caritas projects with other projects in the area, it was evident that the Caritas rehabilitation houses were of good standards and in many cases substantially better than those neighbouring projects, even when some observations could be made about particular details. Houses being built by local contractors with insufficient on-site supervision were often of inadequate structural quality to withstand earthquakes. Unfortunately, when these constructions are plastered over, the differences between good and bad construction will not be visible and only become evident during an earthquake.

The houses being constructed by Caritas are often better than what the people lost in the tsunami. The more durable material choice, including reinforced 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 will be adequately earthquake resistant, considering their small size and weight.

Unfortunately, if a tsunami similar in magnitude 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 fate for some of the newly built Caritas houses, but for many other NGO- and government-built houses in the same zones as well. That is because many houses have been rebuilt on the same high-risk location as the destroyed houses and, so far, no other measurements have been taken to protect these houses from large tsunamis. Nevertheless, most of the Caritas-built houses and others may survive a smaller tsunami.

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

[1] BRR = Badan Rehabilitasi dan Rekonstruksi (Reconstruction and Rehabilitation Agency of Indonesia).

2. TSUNAMI AND EARTHQUAKE 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 tsunami disaster, but all agreed that earthquakes would be a regular phenomenon.

Most houses in Aceh are ground level only and reconstructed in the same location as the destroyed house. 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. This decision often came after long waiting periods and the inability of the local government to provide safer land on higher ground.
- 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. The former houses often consisted of timber frames with panelling.
- Most new houses are built of more durable materials than the houses lost. Only the first houses constructed shortly after the tsunami had concrete and brick foundations with a timber structure above the windowsill level (see photo page 28).
- People are aware that earthquakes will occur in the region.
- Most of the new house designs 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).
- 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.
- When given a choice of type of housing of equal size – on columns or on the ground – the beneficiaries said to prefer ground-level houses, even if the cost difference was absorbed by the NGO or aid organisation.
- The BRR has produced some guidelines on reconstruction and settlement planning, considering a recurrence of a tsunami, but these are not always followed.

NEW GROUND-FLOOR-ONLY HOUSES ARE BEING BUILT ON OLD FOUNDATIONS

3. SPEED OF IMPLEMENTATION

Speed of implementation is a general requirement in a disaster rehabilitation programme, especially for the people living in barracks where the housing conditions are poor. The local pressure on the labour and building material markets, combined with partly destroyed infrastructure, made it very difficult to speed up the process. Moreover, a number of verification conditions had to be complied with, and approval of the design and site layout needed to be obtained from the BRR.

Notwithstanding the above, the NGOs were constantly pressed to start building even without having received site access, beneficiary lists or BRR-approved plans. When not starting immediately, they were threatened with losing their village reconstruction assignments. As a result:

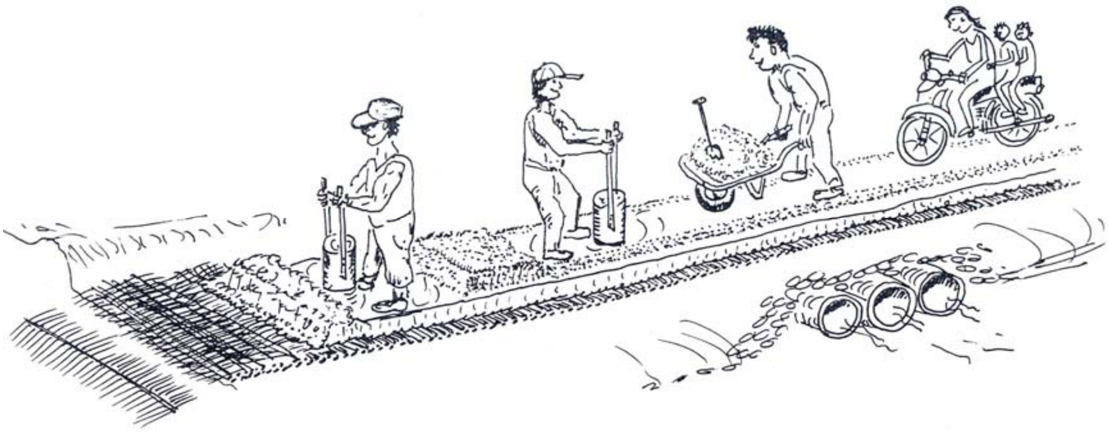
- Some NGOs mobilised construction staff and building materials before approval of designs and sites were obtained.
- Some NGOs started to build the access roads to the sites themselves (in 2007). Otherwise, they could not start with the large-scale reconstruction projects in the relocation areas.

LAYING OF A ROAD FOUNDATION CLOTH ON SWAMPY SOIL BY THE NGO

- Some NGOs were given sites that were completely unsuitable to build on or sites that were refused by the beneficiaries.
- In 2007, two years after the disaster, some NGOs started to consider buying land for renters and squatters in order to enable them to build for these categories[2]. The BRR is only in 2007 developing regulations for these people.
- Some NGOs needed to demolish the newly constructed houses because these were found to be in the way of a new major road construction project.

The larger the disaster, the larger is the political pressure to see fast results[3].

[2] In Sri Lanka, the purchase of land for people who lost their house, but could not be relocated in the buffer zone, was taken up in an early phase of the programme.
[3] The political pressure was actually from two sides, the original donor and the local government. In this context, the original donor supplying the funds must be informed and create awareness of the possibilities or impossibilities of fast implementation.



NARROW ACCESS ROAD – A 10 CM C-C PALM LEAF BED, 6" COMPACTED CLAY, 6" COMPACTED GRAVEL

After a large disaster, a review needs to be made why the disaster was so large and plan measurements to avoid a similar disaster in the future. Taking fast action without following adequate planning procedures can easily lead to wrong decisions on site location or road planning. Developing new sites without due consent of the beneficiaries may lead to non-occupation of the houses.

Although the political pressure is understandable, humanitarian NGOs should have the safer location of the beneficiaries as first priority and be able to insist on proper planning and coordination.

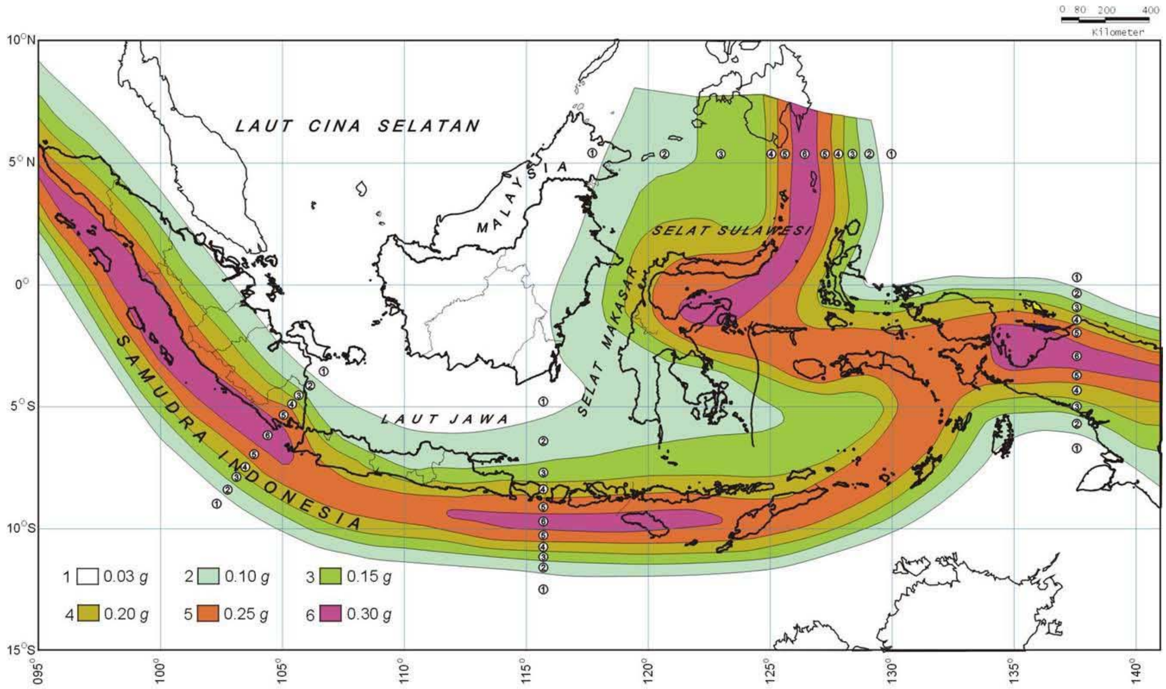
Recommendation

In order to allow proper planning of reconstruction after a large disaster, it is necessary to accommodate the victims in such a way that they can start to rebuild their lives from their transitional shelter accommodation. Good quality transitional shelters with WatSan, which can easily last 3-4 years, are necessary, especially if planning of new housing estates is required. Pressing hard on fast reconstruction will lead to excessive price increases in the construction market and after the boom lead to deflation of the same market.

Providing good quality transitional shelter with WatSan is essential.
This allows sufficient time to properly plan and build new settlements in safer locations.

4. 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.



4.1 Materials Increase or Reduce 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[4]) 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 if there exists the potential for liquefaction. If construction is to be realised in such areas, then only very lightweight houses should be considered.

Recommendations

- *Considering the frequency and size of the earthquakes in the coastal area of Sumatra, all housing should be built according to the earthquake codes[5]. The own mass or weight of the construction should be kept low.*

- *Housing areas and houses being built in high-risk tsunami areas should have additional precautionary features to avoid the tsunami forces or fatal damage by these forces.*

[4] 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.

[5] On average, six major earthquakes occur yearly in Sumatra alone, several of these may cause tsunamis.

4.2 Space-Frame and Box-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). The code prescribes horizontal and vertical reinforcement and anchorage at every 60-90 cm.

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 were realizing anchorage between columns and walls.

SUPPORTING COLUMN CONSTRUCTION (SPACE-FRAME STRUCTURE)

In a 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 the columns through anchorage. A common shortcoming in many new houses is that no provisions are made to anchor the walls to the columns.

In a box-frame structure, the walls form part of the supporting structure together with the surrounding columns. Horizontal and vertical wall reinforcement is also required.

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-risk tsunami 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, avoiding the tsunami load.

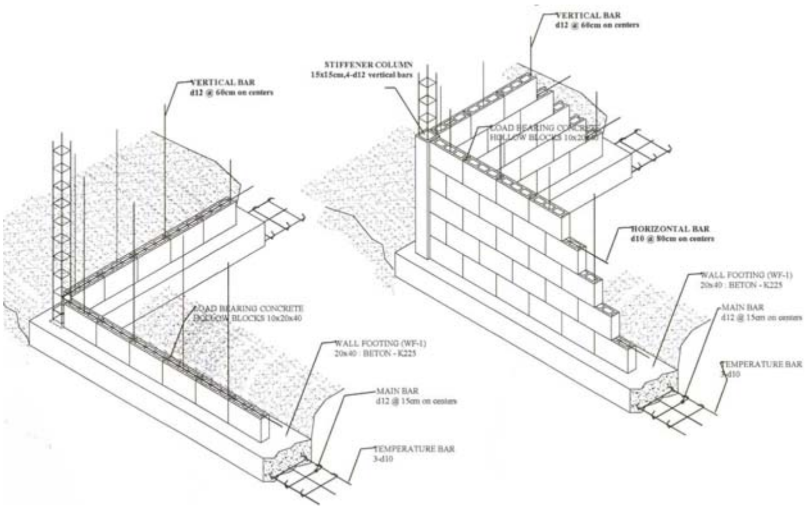
As it is impossible to predict the actual earthquake force, earthquake reinforcement must consider the possibility of the forces exceeding the design force. In such a case, the construction must still hang together without total failure or collapse.

4.3 Construction Guidelines

The government has formal guidelines and technical construction standards for earthquake resistant designs. These government guidelines, however, are usually not easily understood by self-help builders or small local contractors and, if they are understood, they are usually not followed by the local contractor in order to lower construction costs.

The sketch to the right is a good example of detailed drawings providing technical information to the contractor or self-help builder. Detailing the entire house using 3D drawings can assist in creating a good understanding of the designs.

(DIAGRAM SOURCE: CRS MEULABOH)



Although the government is formally the entity to control the correct application of the standards and building codes, after a large disaster they will often only be able to realise such control on the basis of spot inspections, usually after the construction has been realised. Large contractors may have the professional staff to supervise the site works, but it is not in their immediate interest to do so, as it will increase their construction costs.

Recommendations

- *The local government and NGOs should be able to supply detailed practical and technical information on how to build an earthquake-resistant house. This information needs to be tailored to the users, written in the local language and presented in a comprehensible modality (illustrated, step-by-step manuals, videos) so that they can build and exercise quality control at the construction site.*

- *NGOs should focus their quality control activities on capacity building of the beneficiary population and organise practical training sessions in the early stages of the rehabilitation programme. Senior inspectors from the NGOs need to undertake spot inspections and provide backstopping to the community inspectors on problems identified.*

From random field inspection of a variety of housing projects, it was clear that many newly built houses would not survive a large earthquake. Although reinforcement and concrete was used, the anchoring of the different members was insufficient.

In the photo left, the anchoring between the stiffener column and wall plate beam is totally inadequate. Once this is cast with concrete, one will be unable to discern this faulty construction from a good construction.

4.4 Anchorage between Columns and Walls

Most 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 new 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.*

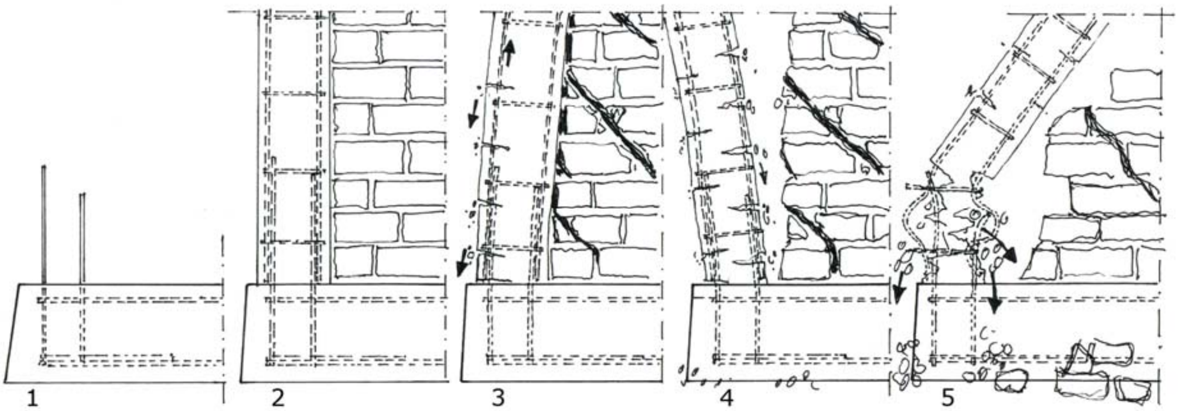
➢ *Space-frame structures should have an autonomous support structure (not needing the walls for strength). In an earthquake-only area, all walls should be well connected to the columns, and the floors to the beams.*

In the picture above a good positioning of the stiffener columns and ring beams has been realised – a foundation beam, a ring beam under the windows, one lintel ring beam between the window and the higher ventilation openings, and one (to be made) above the wall.

4.5 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 free-standing columns is not being applied.

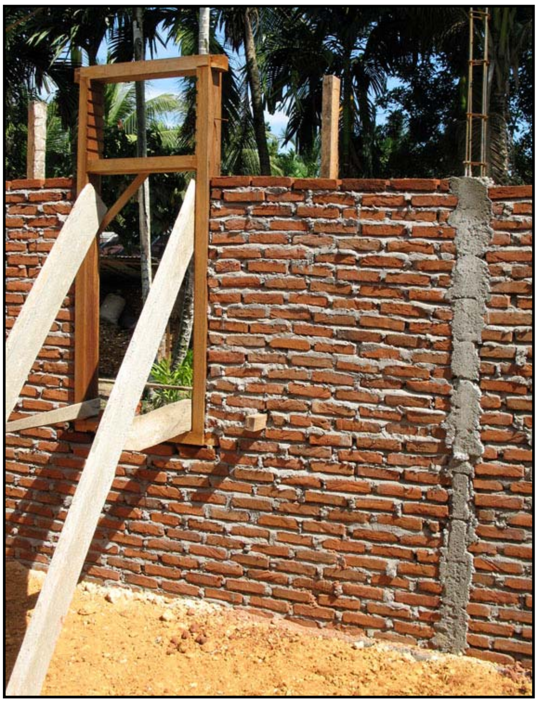
The photo right shows a detail of the smooth bar reinforcement protruding from the foundation. The column reinforcement will be placed alongside these bars. The overlap length of the smooth bars is less than 50 times its diameter. With a side force to the column, this connection will not hold and the column will be pulled off from the smooth bars, allowing it 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 these shortcomings, 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.

STIFFENER COLUMN CAST BETWEEN TWO DOORS



STIFFENER COLUMN CAST IN LONG WALL

<u>Recommendation</u>

For ground-floor-only houses, the wall reinforcement design with stiffener columns at all wall junctions (all properly linked to all-wall ring beams at floor and lintel level) is adequately strong enough to withstand large earthquakes. The stiffener columns should have horizontal anchorage into the masoned walls.

4.6 Stiffener Columns

Stiffener columns are an important component for strengthening box-frame houses in an earthquake region. Even a double storey earthquake-resistant building can be made, provided there are sufficient stiffener columns and it is in a non-tsunami risk zone. However, proper supervision of the reinforcement design and casting of the stiffener columns by the self-help builders or contractors is required because once the tie-beams are cast, the reinforcement bars inside are hidden.

The same holds true for the brick walls and stiffener columns; once they are plastered over, one cannot see whether they are well constructed or not. For that reason permanent site inspection is necessary.

A stiffener column in burned brick walls is made by masoning the wall, leaving a gap for the column, and after that casting the positioned reinforcement bars in concrete. These stiffener columns are placed in long walls, at wall junctions and at wall ends.

Most house designs observed in the newly reconstructed villages are ground-floor-only houses. For these low houses, the possible earthquake impact is rather limited and does not require heavy wall reinforcements, such as 20 cm x 20 cm reinforced concrete columns. The 10 cm x 12 cm stiffener columns, properly linked with foundation ring beams, upper lintel ring beams and fitted with a lightweight roof (red painted 0.3 mm sheet metal), are more than adequate to withstand a large earthquake, provided the stiffener columns are anchored into the brick walls.

A benefit of using stiffener columns is that it is easier and cheaper to extend the house than when pre-cast reinforced concrete columns are used. Stiffener columns are cast against and in between the masoned brick walls, whereas the 20 cm x 20 cm square reinforced concrete columns require large amounts of formwork and concrete, both expensive elements. The adherence between the wall and the stiffener column is automatically achieved, while for square concrete columns additional anchorage is needed to avoid cracks.

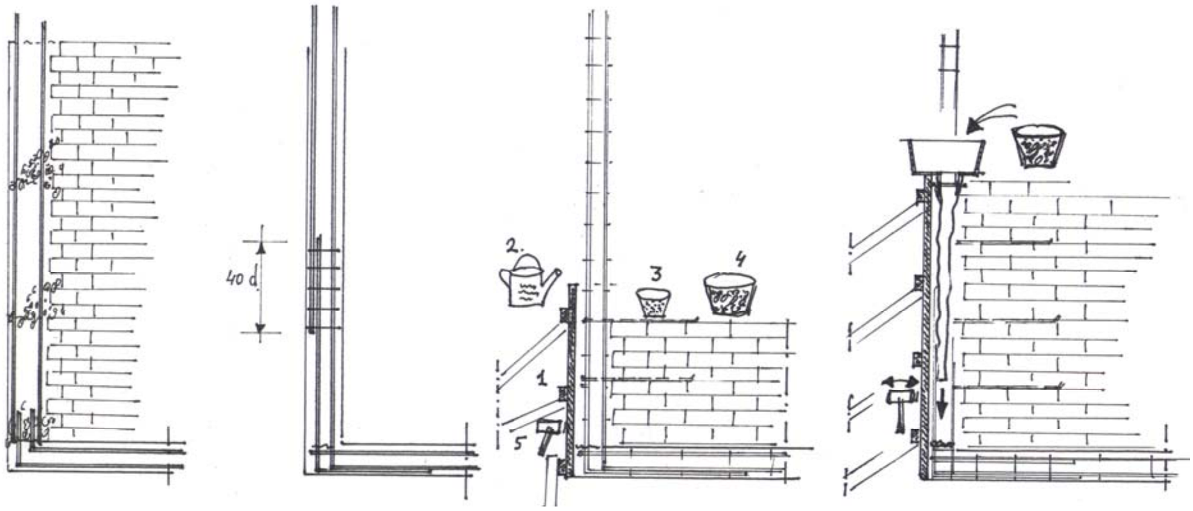
The photo right shows a typical problem related to the casting of stiffener columns in between burned brick walls. The columns are cast in three sections, each about one meter high. Yet the casting is incorrect due to three reasons:

1) The bricks were inadequately watered before casting, thus absorbing large amounts of cement water from the concrete. With cement and water taken out of the concrete, it will leave the concrete porous and weak. The porous concrete will not provide sufficient protection to the reinforcement bars against corrosion, especially not in coastal areas with salty sea air.

2) The casting is not primed with a bucket of strong cement sand slurry (1:3) that coats the reinforcement bars and provides an amount of cement mortar to rise with the concrete when the column is cast.

3) When casting the columns, the concrete itself or the formwork is not adequately vibrated to ensure that the concrete settles in all corners and around all reinforcement bars.

The first sketch below illustrates the aggregate pockets, the same situation as the above photo. The second sketch shows the correct placement of the beam reinforcement, which is brought upward from the ring beam into the column for at least of 1/3 of its height.



The third and fourth sketches illustrate the better way of casting a stiffener column. The fourth sketch indicates that for casting from a height greater than one meter, a funnel is required to avoid dis-aggregation.

Step 1 – Strong form work and horizontal anchorage into the wall.
Step 2 – Watering the bricks.
Step 3 – Priming with cement-sand slurry.
Step 4 – Casting concrete.
Step 5 – Vibrating the formwork or concrete.

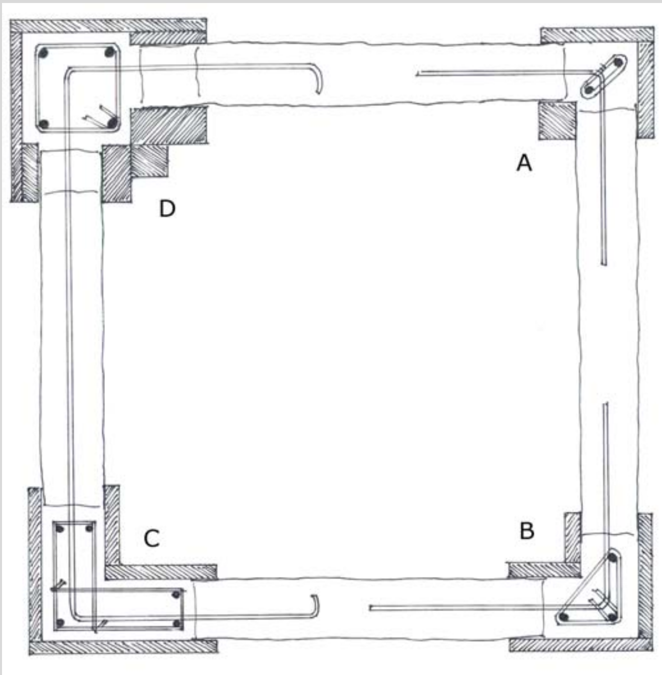
Options for Stiffener Columns Cast Alongside 10 cm Burned Brick Walls

Corner A: Minimum solution with only two bars. When applied along all openings (including door and window frames) and with horizontal tie-beam reinforcements, this is an earthquake-resistant and low-cost option.

Corner B: Wider and heavier stiffener columns. This allows for **L-**, **T-** and **X-** shaped junctions and intersections, and has an increased number of reinforcement bars and stiffness. Horizontal reinforcement is required for good earthquake resistance.

Corner C: For columns that need to be stronger or when the distance between columns becomes greater than 4.00 m. Because of the increased distance between the bars, a 10 mm bar diameter can be used, having the same moment resistance as slimmer columns with thicker bars.

Corner D: For casting wider (20 cm x 20 cm) columns onto existing brick walls of 10 cm. This is an option when heavier reinforcement bars are needed (12 mm) or when the columns are to be part of an autonomous support frame.



5. TSUNAMI-RISK ZONES

Tsunamis are caused by earthquakes. This means that for low-lying coastal zones located in earthquake areas, the risk of tsunamis should also be taken into account. This is an essential issue for any post-disaster reconstruction project. In the Aceh reconstruction zones, many houses are now being rebuilt in high-risk tsunami zones, without these houses being able to withstand a similar tsunami.

A substantial difference can be observed between Sri Lanka and Aceh in their perception of disaster risk reduction (DRR). Although both populations have some fatalism, the Aceh people are more inclined to take the risk and pray for the best. Religious leaders have now started in Indonesia an awareness programme to educate people that some disasters can be avoided or the effect minimised.

With the high political pressure to start building houses, many NGOs began to realise houses in areas with a high tsunami risk, such as rebuilding on the old foundations. It would have been better if the NGOs had first convinced the villagers that new houses should be <u>safer</u> than what they had before.

> *Although the political pressure is understandable, humanitarian NGOs should have the safer location of the beneficiaries as first priority and be able to insist on proper planning and coordination.*

The planning of the new housing sites was the responsibility of the BRR. Due to the lack of available land, most villagers opted, after more than a year, to be housed again on their original plot[6]. Many beneficiaries are not very much concerned about the recurrence of another similar tsunami.

<u>Recommendations</u>
- *Building in tsunami-risk zones or flood areas should be avoided[7].*
- *For each settlement area, the possible environmental risks and natural hazards need to be assessed and measurements taken to reduce these hazards and risks.*
- *A large part of the risk reduction can be achieved by site planning.*
- *The site planning and adjusted construction should be compulsory for the occupants. The occupants should be informed of the cost and maintenance consequences.*

5.1 Options for Constructions in Tsunami-Risk Areas

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

- House in a safer location: (a) building on higher ground and (b) building away from the shore.
- Buffer zones between sea and houses.
- Raised buildings and living floors above the possible tsunami level.
- Collapsible infill walls on the ground level in high-risk tsunami areas.
- Avoid blocking the floodwaters by lines of houses situated close together.
- Reinforcement of houses facing the coast with cross walls.
- Narrow side of the house should be facing the sea.
- Deep corner foundations to avoid under-scouring by retreating water.

[6] This is significantly different with the situation in Sri Lanka where ample land was available behind the buffer zone.
[7] The same applies for flooding of urban sections due to rainwater or rivers that exceed their banks due to deforestation.

A House in a Safer Location

Although the first option is the most effective in avoiding, and thus eliminating, the tsunami hazard and safeguarding lives, it is often the most difficult to implement due to the scarcity of suitable alternative land, resistance of beneficiaries to be relocated, acceptance of the proposed relocation site, purchase cost of the new land, title deeds, size of plots, etc.

A house in a safer location implies houses being built on higher land, further away from the shore, on more solid ground, away from possible flood hazards, etc. Relocation may cause more travel distance from home to the workplace, being a disadvantage. Therefore, a farther (safer) house location might be compensated with transport facilities. When relocating people away from their original habitat (such as may be the case with fishermen), measurements should be developed to compensate the effects of the resettlement.

GOOD EXAMPLE OF A NEW TIMBER HOUSE – BUILT FARTHER AWAY FROM THE SEA, ON A HILL AND ON SHORT STILTS. THE ROOF IS LIGHTWEIGHT METAL AND THE OWNER HAS APPLIED WOOD PRESERVATIVE ON THE STRUCTURAL MEMBERS.

Recommendation

NGOs should ensure that reconstructed houses are built in a safer location or safer. When this is in a location other than where the houses were lost, adequate measurements should be developed to enable the beneficiaries to continue with their former manner of livelihood or to be assisted in developing other employment and income generation. For resettlement projects, a budget needs to be reserved for this re-deployment activity, which also may require an extended project period.

Buffer Zones between Sea and Houses

Buffer zones are important for lessening the impact of a tsunami before it reaches residential areas. As previously stated, many houses are being rebuilt on the same location, even in the same style, as before the tsunami, making them equally vulnerable to another tsunami of similar size. The beneficiaries have insisted on rebuilding using materials that are more durable. Not only does this increase the lifespan of the house, but also the number of times the house will be subjected to disasters.

Recommendation

NGOs should respect the wishes of the beneficiary, but they should also clearly point out the risks involved in remaining and rebuilding on the old location. NGOs should not rebuild on the same location when the overall situation after rebuilding remains equally unsafe as before, but rather seek improved solutions together with the local government and the beneficiaries.

When people are properly housed in transitional shelter, adequate time can be dedicated to finding safer locations or safer housing solutions.

In Meulaboh, where an entire village section was wiped away by the tsunami because it was located on a peninsula, some substantial buffer zone development was ongoing. However, the large concrete crosses were already sinking into the sand. This measurement does provide some protection against erosion by the sea, but not for another tsunami.

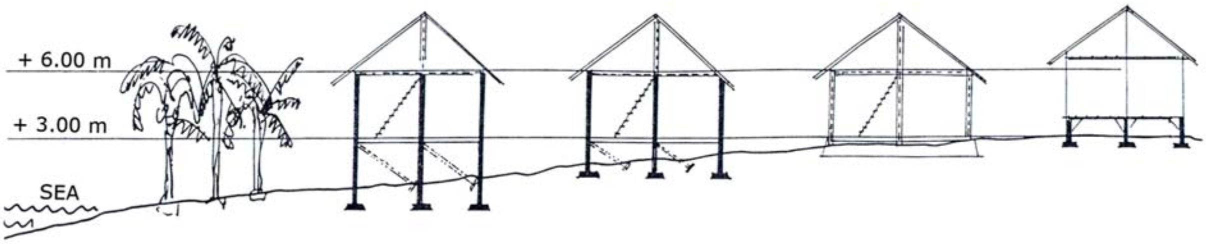
CONCRETE CROSSES CAST ON THE SHORE AND TRANSPORTED TO CREATE AN EROSION CONTROL WALL

<u>*Recommendations*</u>

- *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.*

<u>Raised Buildings and Living Floors</u>

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. For buildings close to the shore (20-50 m), it must be taken into account that the tsunami height above the ground is strongly elevated due to the wave landing on the shore. When building further inland (200-300 m), the required free height under the building can be lower, depending on the elevation of the terrain.



<u>*Recommendation*</u>

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.

<u>Collapsible Infill Walls on the Ground Level</u>

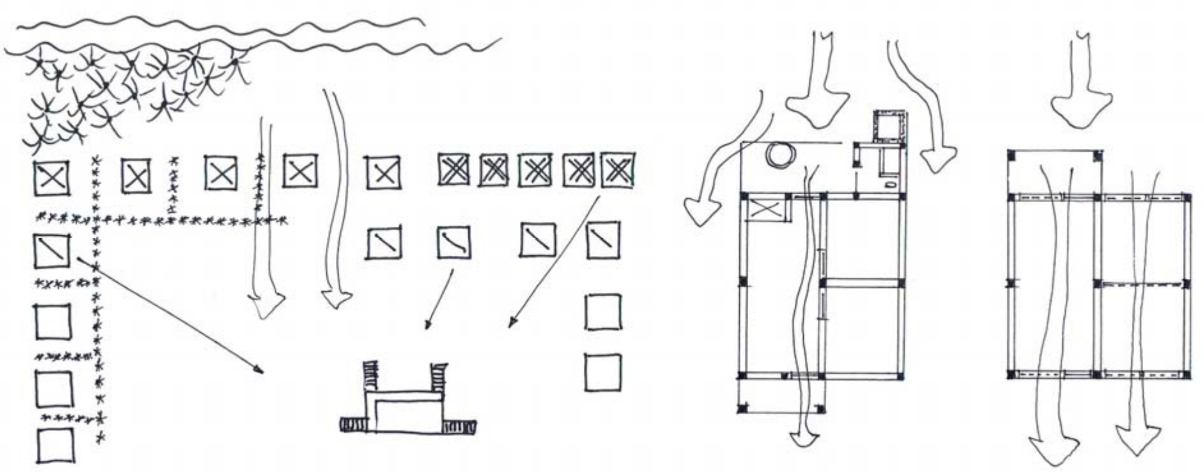
The infill walls between the columns of the main structure should be knocked out by the force of a large tsunami wave. The floodwaters will destroy all that is in its path, but the main building structure and upper floor should survive the impact. Such a design is useful when the occupants can reach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

THE GROUND-FLOOR-ONLY HOUSES WERE DESTROYED BUT THE SECOND STOREY OF THIS HOUSE SURVIVED

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 time before the tsunami wave strikes.



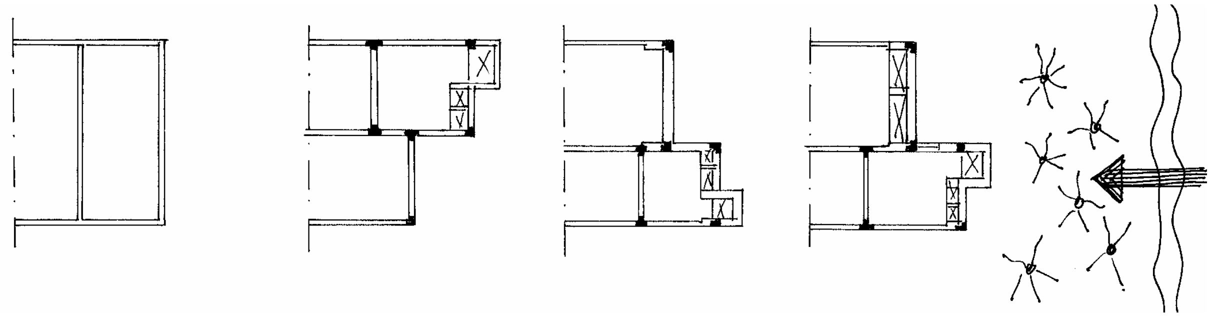
Recommendation

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 on page 16, reinforcing the rear side of the houses facing the coast 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 sea-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 SEA-FACING SIDE UP TO 1.5 METER ABOVE SOIL LEVEL – ADDITIONAL CROSS WALL AND SHELVING IN THE WIDEST ROOM ON THE SEA-FACING SIDE – 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.

Secondly, 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 purposes. Staircases should be built on the outside of the construction and ending in spacious landings.

5.2 Wall Reinforcement in Tsunami-Risk Zones

According to the earthquake code, wall reinforcement is required for all types of houses having a space-frame or box-frame design. While such through-the-wall anchoring will make a house in an earthquake zone safer, that same house will be quite vulnerable if located in tsunami-risk area. When speeding floodwaters hit the house, the anchored wall will pull the columns down. However, if the infill walls are not fully 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. This is beneficial for two-storey houses, where the occupants can seek refuge on the upper floor. For ground-floor-only houses, the walls may fall on the occupants if not vacated soon enough and a higher safe haven reached.

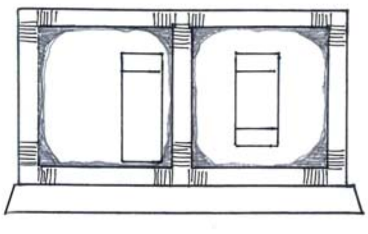
WALLS KNOCKED OUT FROM BETWEEN A SUPPORTING REINFORCED CONCRETE FRAME STRUCTURE

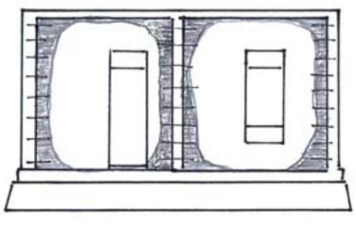
Recommendation
In a high-risk tsunami zone, the ground-floor structure of houses should be self-supporting without applying a full wall box-frame structure. In a house design with supporting columns, the infill walls should be attached to the columns, but they should not be reinforced throughout, allowing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

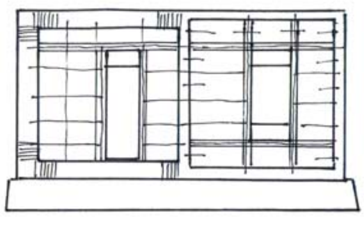
The generally applied BRR building design in most of the reconstruction houses is based on nine 20 cm x 20 cm reinforced columns with infill masonry walls. The columns always need to withstand the horizontal earthquake load, even when most of the ground floor infill walls have been destroyed.

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 60-90 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, the third design is not recommended in a high-risk tsunami zone.

In the photo left, the stiffener column in the left wall has almost collapsed. The combination of three stiffener columns in the centre of the picture have survived the impact of the tsunami and keep the roof up.

Recommendation
In high-risk tsunami areas, box-frame structures with stiffener columns should have wide L, T and X stiffeners or combinations of small stiffeners. For space-frame structures, the walls should not be fully through-reinforced, allowing substantial parts of the wall to be knocked out by the force of the tsunami load on the wall.

6. REINFORCED CONCRETE DETAILS

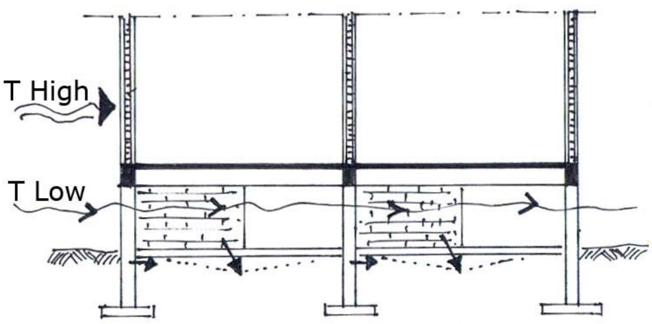
The following are some common errors observed in many housing projects, along with recommendations to rectify the shortcomings. The errors are caused by a combination of factors, such as the involvement of many new organisations in the building of houses, lack of experienced contractors, insufficient site inspection, etc. Once the houses are plastered and painted, one cannot see if the construction is earthquake resistant or not.

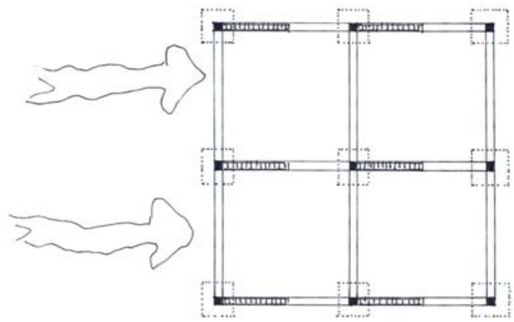
6.1 Foundation Columns (Stilts)

One of the lessons learned from the 2004 tsunami is that houses built on columns (stilts) are safer than houses built directly on the ground. The height of the floor above the average sea level and the distance from the shore determines the safety of a house and its occupants. With a one-meter elevation above the soil level (=1.5m above sea level), this height provides sufficient clearance for common flooding or a small tsunami. However, considering the height of the past tsunami, the height of the first floor should be preferably three meters above the average sea level.

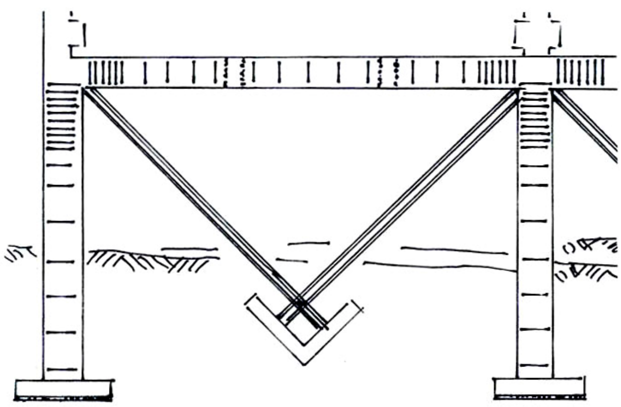
The houses on stilts are constructed as a reinforced box-frame structure. The part above the columns has a closed wall construction and functions like one block. If a tsunami hits higher than the floor level of these houses on stilts, unsupported bottom columns will not be able to withstand the horizontal pressure (load) and break off under the ring-beam. That is because the tsunami load is about 10 times greater than an earthquake force.

<u>*Recommendation*</u>
To resist another high tsunami that reaches above the elevated floor level, bracing walls or supporting diagonals should be placed between the stilt columns.





The above sketch illustrates an additional support wall built under the floor and against the columns, in the direction of the land. The foundations of these bracing walls need to be adequate to receive a vertical load without the risk of settling.



Supporting diagonals can also be made from three-inch heavy-duty GI water pipes anchored into a sub-surface foundation (sketch left). These supporting diagonals will block and resist a diagonal load. The pipes need to be well anchored into the column-floor junctions.

6.2 Building the Columns

The foundation columns should continue structurally into the columns of the first floor. In the left photo, the reinforcement bars stop about one meter above the floor level, while in the right-hand photo the vertical reinforcement is placed as one piece. Although the later requires some temporary support, this design is better as it does not require overlapping of the reinforcement bars in the base of the columns above the floor, thus saving steel reinforcement.

For a smooth concrete reinforcement bar to work properly, the bar needs to be anchored over a length of minimal 50 times its diameter in the concrete before it can develop its planned strength. In the overlap section, additional stirrups need to be placed. For cold deformed bars, the minimal overlap is 40 times the diameter. In addition, both bar types need end-hooks.

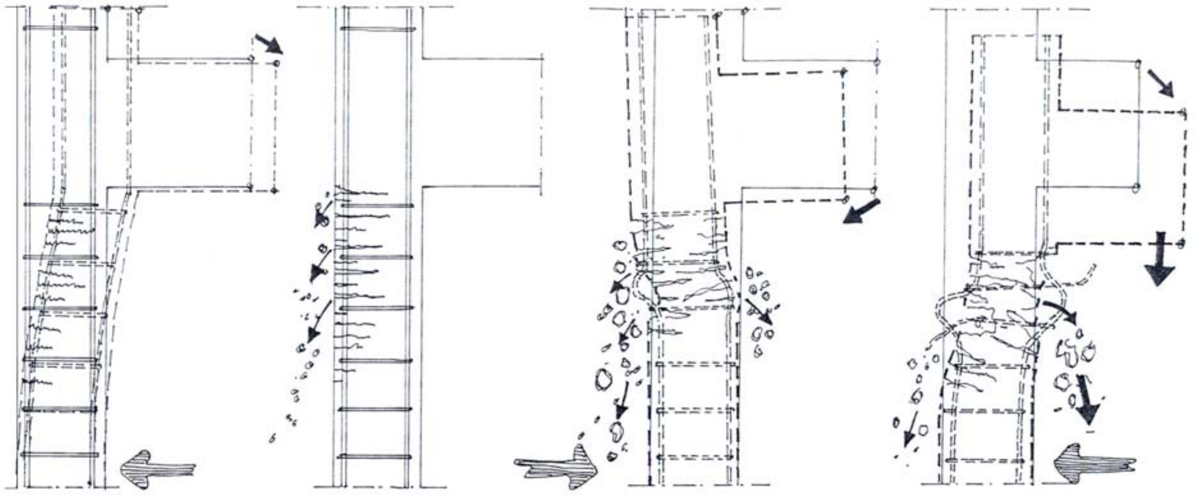
Recommendation
The reinforcement of the columns should be in one piece, where possible, to minimise overlaps.

6.3 Column Reinforcement Design

The ground floor of the house consists of a reinforced concrete floor with 30 cm high concrete ring beams. The walls will be made of brick masonry between the 20 cm x 20 cm columns and plastered. The floor, along with the walls, makes a very stiff box structure standing on the foundation columns. The foundation columns have moment-stiff connections with the floor beams. During an earthquake, the maximum moment will occur at this place and so it is essential to place sufficient stirrups just under the beam. If the maximum design force is exceeded during an earthquake, the concrete will crumble, but not fall out of a cage of stirrups just under the beam. When the columns remain standing, it gives the occupants time to escape from the house during a prolonged earthquake.

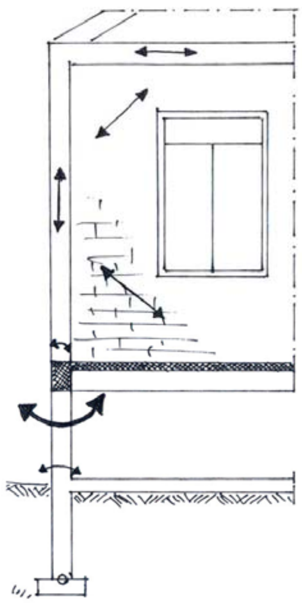
TYPICAL COLUMN FAILURE – NO STIRRUPS

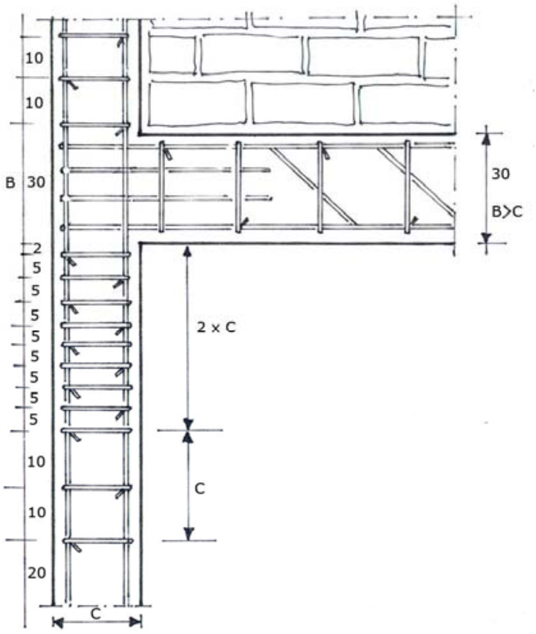
Observation on photo – page 21 (bottom right): At the vital maximum moment zone, there were insufficient stirrups. As a result, the concrete crumbled and fell out during the earthquake. The sketches below explain the process of failure during one shock. In reality, a series of shocks occur during an earthquake, continuing the described process and resulting in the column collapsing and with that bringing the house down.



Recommendation

Each column end should be reinforced with a cage of stirrups at its maximum moment zone to avoid broken concrete from falling out of the construction when earthquake forces exceed the design forces. This is especially the case when the floor 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.





The sketch on the left illustrates the forces that occur in the current structural design. Only the stilt column is subject to a strong bending moment, while the upper stiffener column and tie-beam only receive compression and stress forces when the infill wall remains intact. In such a case, the reinforcement pattern sketched on the right is recommended. Better still is when the floor beam is lighter or thinner than the column, shifting the possible failure area to the beam.

6.4 Design Strength of Columns

The columns were designed with six smooth bars of 12 mm and two bars of 10 mm, with a total section of 8.4 cm^2 or about 2% steel in relation to the concrete section (400 cm^2). Due to the unavailability of smooth bars, the contractor applied six cold deformed ribbed bars of 12 mm and two smooth bars of 10 mm. In combination with cold deformed ribbed steel, the smooth steel becomes useless because they have a lower strength and stiffness. In the above configuration, the smooth bars will only start to work after the cold deformed ribbed steel and the construction have already failed.

Recommendations

- *Never use two different types of steel reinforcement bars in the same force direction, such as low-strength smooth steel with high-strength cold deformed ribbed bars.*

- *The approved technical designs should preferably be accompanied by the relevant calculations. When the specified steel types or diameters are unavailable due to external circumstances, such as may occur in an overstressed market (emergency reconstruction), the implementing organisation, along with the contractor, needs to recalculate the design for the available reinforcement bar type. The recalculation then needs to be re-approved by the design office and local authorities.*

6.5 Ring Beams

The ring beams form one entity with the concrete floor and create a stiff platform for the house above. The reinforcement is often manufactured beam-by-beam and assembled in-situ above the formwork. After assembly, the section is then lowered into the formwork.

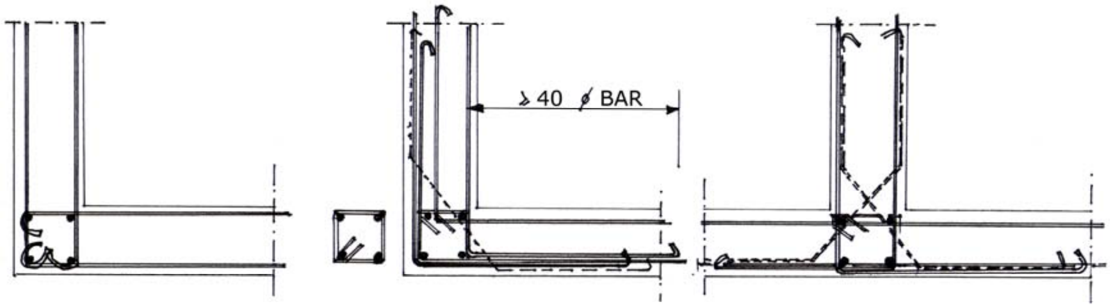
Observation: The eight reinforcement bars in the beam are not going around the 90° corner into the other horizontal beam section, but instead end with hooks inside the column. The eight hooks in the column, coming from two directions, totally congest the space inside the column. When casting the column with concrete, air pockets will be created. Because of the inadequate length of the hooks, the junction will be far below the required structural strength. The situation is aggravated in two other corners because two additional bars were added (photo below).

The standard house design has 13 support columns – nine columns under the main house and four under the front and rear side terraces. The four terrace columns and two other corner columns all had the above-mentioned anchoring failure of the beam-column junction. Only the seven central columns will be able to withstand an earthquake load. If the building has lightweight inside walls, the seven central columns may be strong enough.

The strength of the beam-column junction depends on the continuity of the bars from one beam into the other and their adequate anchoring length in the concrete, not on hooks in the junction. The error in these junctions is based on the following issues:

- The NGO received "approved" drawings and took this approval for granted.
- The design drawings were not specific enough in the reinforcement bar design.
- When the BRR recommended additional bars, the modified design was not reviewed.
- There were no calculations provided with the reinforcement design.
- The design drawings did not have a reinforcement bar cutting-folding schedule.
- The contractor does not have the required experience in reinforcement design.
- The site supervisor does not have the required experience in reinforcement design.

<u>*Recommendation*</u>
The reinforcement design of the ring beams should be detailed showing the reinforcement bars going around the corner, instead of ending with hooks inside the columns.



Left Sketch: Illustrates the applied reinforcement. In reality, four bars were applied in both the upper layer and bottom layer of the beam.

Middle Sketch: Illustrates the correct application of the beam reinforcements. These go through the column, around the corner and end in a hook, providing minimal a 40 bar diameter overlap. The possibility exists to add another diagonal bar (dotted line) depending on the force calculations. In the areas of the maximum moment, in the beam as well as in the column, additional stirrups should be placed with 5-6 cm spacing.

Right Sketch: Illustrates the same principle for a T-junction.

<u>*Recommendation*</u>
Detailed drawings of the ring beam reinforcement bars should be provided and a cutting-folding schedule made available for the ironworkers. The length, shape and quantity of bars need to be detailed for each reinforcement location. Making the reinforcement bar cutting-folding schedule is commonly the task of the architect or engineer providing the drawings.

BAR	NO.	DRAWING FLOOR CONSTRUCTION BEAM "A"	BAR	M'	KG
51	4	40 360 40 ø12 TOR	440	17.60	15.52
52	1	40 80 42 20 160 42 20 80 40 ø12 TOR	48	4.84	4.27
53	1	40 60 42 20 200 42 20 60 40 ø12 TOR	484	4.84	4.27
54	12	30 20 30 10 20 ø8 Stirrup Smooth	80	9.60	3.76
55	2	110 360 110 10 10 ø12 TOR	600	12.00	10.58

SAMPLE REINFORCEMENT BAR CUTTING-FOLDING SCHEDULE

6.6 Ring Beam – Column Stiffness

When excessive earthquake forces occur, the beams should fail first, allowing the columns to continue supporting the house. However, in the design described above, the ring beams with the attached floor are stiffer than the stilt columns under the floor. The upper part of the building will behave as one stiff block, resulting in the columns failing first and thereby causing the building to collapse. If in the given design the column-beam construction had been well implemented (with reinforcement bars going around the corner), there would be no strength issue at all.

Recommendation
In an earthquake-resistant reinforced concrete design, the ring beams should be less stiff (and therefore less thick) than the width of the columns. In other words, the columns need to be relatively stronger than the connecting beams. The maximum moment of the ring beam is at the junction with the column; therefore, the beams should also have stirrups narrowly spaced at these maximum moment areas.

6.7 Reinforced Concrete Quality

The actual quality of reinforced concrete, and therefore the strength of the house, largely depends on good site supervision and workmanship by the building contractor. Even when the design is correct, but poorly executed, the construction will not stand up adequately in a large earthquake. This applies to the following aspects of reinforced concrete:

- Too many concentrated reinforcement bars; thereby not allowing the concrete to be cast properly in between and around the reinforcements.
- Nailing the formwork into fresh concrete of the columns and with that damaging the columns and allowing corrosion.
- Formwork that allows leakage of cement water; thereby causing aggregate pockets.
- Weak formwork (support) that may sag during casting; thereby deforming the design.
- Formwork with un-cast passages or ducts at maximum moment locations, thereby weakening the construction.
- Leaving binding wire inside the formwork, causing corrosion.
- Not having enough bar-to-formwork separators on the reinforcement.
- Using a corrosive mixture – sand, stone aggregate or water with salt content.
- Inadequate density of the concrete due to non-scaled grading of sand and aggregate, presence of clay or dirt in the sand, or excess of water in the mix.
- No qualified inspection of the reinforcement and formwork prior to the casting.
- No qualified supervision during the casting of the concrete.
- Casting concrete without first wetting the adjoining brickwork.
- Casting columns without priming the columns with cement-sand slurry.
- Casting fresh concrete from higher than one meter without a funnel.
- Insufficient densification (vibration or compaction of the concrete during casting).
- Insufficient curing of the concrete after casting, especially the columns.

If the above items are not well supervised and implemented, corrosion of the reinforcement bars will self-destroy the concrete.

SAND BEING COLLECTED FROM THE SEASHORE – THIS SHOULD NEVER BE USED FOR REINFORCED CONCRETE

6.8 Steel Reinforcement

The photo below shows how reinforcement bars can just pull out of the concrete, demonstrating insufficient adherence to the concrete. This is often due to poor concrete quality, but sometimes can be caused by inappropriate steel design.

Recommendation

The reinforcement for reinforced concrete constructions should preferably:

- *Be no more than 1% of the concrete section, with maximum 2% for columns.*
- *Use cold deformed ribbed bars rather than smooth bars.*
- *Use the same strength type of bars in the same force direction.*
- *Use many small diameter bars rather than a few large diameter bars.*
- *Use plenty of stirrups in all maximum moment areas and overlaps.*
- *Use minimum overlap requirement (50 bar diameter for smooth and 40 bar diameter for cold deformed steel). Both types of bars having end hooks.*
- *Have detailed drawings with precise cutting-folding tables for all reinforcement bars.*
- *Have minimum amount of splices or overlaps.*
- *Be well separated from the outside of the concrete through bar-to-formwork separators.*
- *Be inspected before casting the concrete to verify compliance to drawings.*

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

7. HOUSE DESIGN

7.1 General Design

The different communities were presented with a general house design of 42-45 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, however, do incorporate a small kitchen area inside the house, but with no working surface, storage shelves or sink.

THE OCCUPANT OF THIS 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.

Use of Renewable Resources

The use of timber and other lightweight materials is advised for earthquake-resistant designs, but these materials may not be readily available. Especially the supply of good quality (legally) sawn timber is becoming increasingly limited 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 long lasting (+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 to 100 years or more, the chance of the buildings being affected by strong earthquakes or another tsunami increases. When the reinforced concrete construction is poorly executed by the contractors, it may fall apart by itself in 10 years due to corrosion of the steel.

The reinforcement of the foundations in the above photos (houses very near to the Aceh east coast) is not adequately covered with good quality concrete. The plastering will not provide sufficient protection against the salty sea air. Such construction quality will self-destroy due to corrosion.

From a technical point of view, both the IFRC transitional shelters (photo page 4) made with a light-gauge galvanised frame and timber planking and the first houses built (photo below) were technically and climatologically highly appropriate.

The photo shows a few houses with brick or cement block foundation up to the windowsill level (dark grey) and above this a timber construction with a lightweight corrugated metal roof. These houses were highly appropriate – having good earthquake and climate properties and similar to what the people lost in the tsunami. These early constructed houses were later called “semi-permanent”.

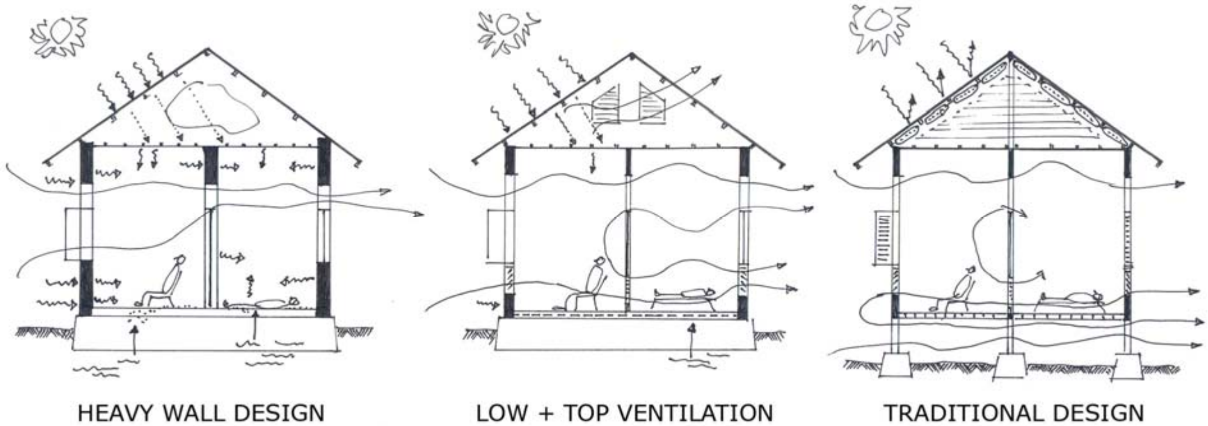
7.2 Internal Climate

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.

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.

LOW-PLACED VENTILATION WINDOWS CAN BE OPENED WHEN DOOR IS CLOSED

7.3 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 should not be omitted in the basic house design, as it will result in warm and uncomfortable living quarters[8].

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 m² 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.*

NEW HOUSE WITH NO VENTILATION VENTS UNDER THE ROOF

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

7.4 Lightweight Internal Walls

Lightweight construction components are not only suitable with 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 left photo 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.

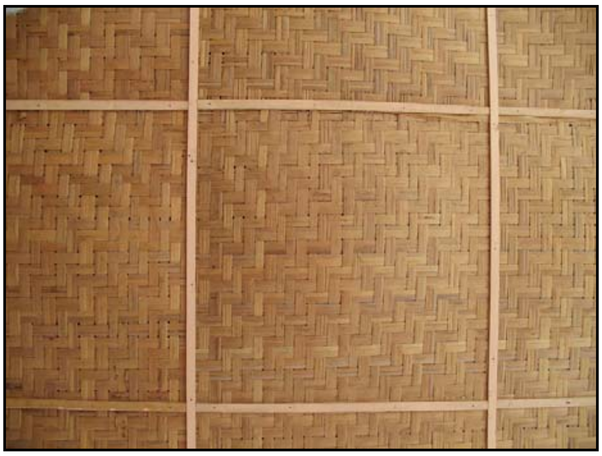
In the right photo, all the internal walls of the house are made from light-gauge galvanised steel profiles onto which the fibre-cement wall panels are fixed. Using (asbestos-free) fibre-cement boards for internal walls has several advantages:

- 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.

7.5 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.

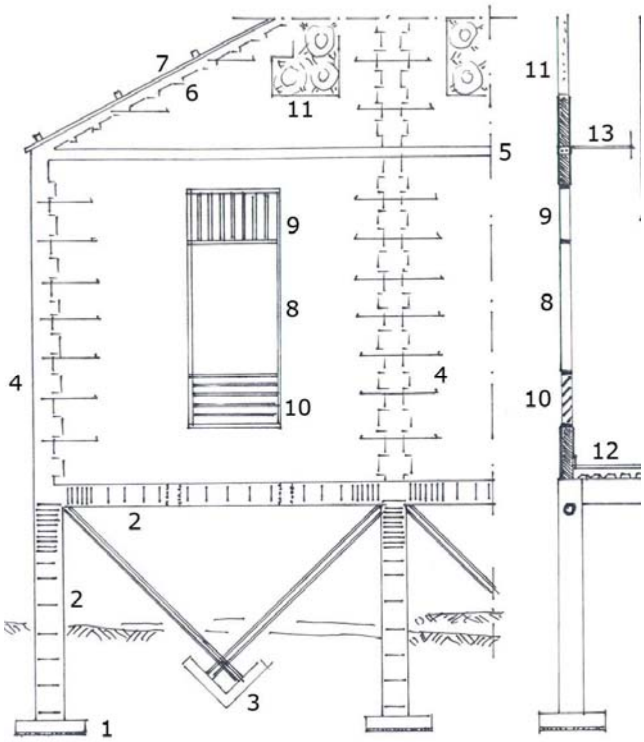
When plywood panels are used, they need to be whitewashed on both sides before fixing to the ceiling, otherwise they will start to deform after some time due to the humid sea climate.



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

7.6 Resume – House Design

The diagram illustrates some elements of a box-frame house on short stilts, in which the walls are not anchored throughout. The stiffener columns have short anchors into the masonry. In the event of a major tsunami, the walls around the windows and doors may be knocked out, keeping the mainframe of the structure up. The maximum moment in the stilt columns is just under the floor beam.



1) Wide support columns and footings reduce the possibility of settlement. The columns have a larger section than the adjoining floor beams.
2) Increased number of stirrups in columns and beams where maximum moments will occur. The floor beam is not thicker/heavier than the column. The columns are stiffer than the floor construction.
3) Diagonal bracing of the stilts, using either pre-cast reinforced concrete poles or heavy-duty galvanised pipes well anchored into the ground.
4) Stiffener columns, cast after masoning the brick walls, with short anchoring into the brick walls. These are placed in all wall junctions of the building.
5) Thin upper tie-beams at the ceiling level through and over all the walls (2 x 10 mm bars).
6) Thin upper tie-beams over gable ends. The timber wall plate is anchored into the fresh concrete.
7) Wooden wall plate on the gable ends anchored into the concrete upper tie-beam. A lightweight metal roof over the wall plate, trusses and reepers (gording).
8) Large windows and doors, allowing ample cross ventilation.
9) Upper ventilation vents located well under the roof overhang to avoid rain from entering.
10) Lower ventilation vents located under windows; rain should not be allowed to enter.
11) Gable top ventilation openings of pre-cast decorative cement blocks that allow cross ventilation under the roof and above the suspended ceiling.
12) Lightweight floor construction that can absorb a little settlement.
13) Suspended ceiling of fibre-cement boards (asbestos-free).
14) Fibre-cement board internal walls instead of masoned walls, reducing the weight of the building as compared to cement block or brick masoned walls.

A 12 cm reinforced concrete floor with a plaster finish is a heavy construction, responsible for minimal 12 ton of the building's weight above the columns (= 30% of the mass of the building). These thin reinforced concrete floors are easily affected by the sea climate and the reinforcement iron will corrode if the concrete covering at the underside of the floor is not adequate. Such may be the case when concrete is hand mixed, water or sand with salt content is used, insufficient spacers are placed, insufficiently vibrated, etc.

8. WATER and SANITATION

WatSan includes safe drinking water, rainwater harvesting, recycling or processing of sewerage, biogas and solid waste management. These points need to be planned as an integral part of the housing projects right from the beginning.

However, during the project planning, the responsibility of these components was divided between NGOs and local authorities. Yet, they involve considerable investments and time to achieve[9].

Making new deep wells is not an individual activity and care should be taken to avoid drawing in seawater.

The community members must be aware of the implications of the WatSan decisions for the operational and management cost to the settlement. Sewerage and solid waste management are particularly critical areas on which the quality of life within the settlement will depend.

A WELL SPOILED BY THE TSUNAMI AND NOW USED ONLY FOR WASHING – VILLAGERS NEED TO EITHER BUY FILTERED WATER OR TRAVEL LONG DISTANCES TO FIND DRINKING WATER

8.1 Rainwater Harvesting

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

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

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

[9] In northeast Sri Lanka, the aid organisations were supposed to realise the settlement infrastructure, whereas in Aceh the settlement access and infrastructure were to be realised by the local government.

The photo shows the simple design of the rainwater harvesting system provided with the IFRC temporary shelters. By connecting the gutters from both sides of the house, large amounts of good quality drinking water can be regularly collected.

Recommendations

- *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 should drain into the well.*

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

- *During the planning phase of settlements, the WatSan options need to be always planned together with the housing project to allow hygienic, safe and cost-effective operation or low-cost maintenance.*

- *Separation of responsibilities for WatSan implementation should not be done unless it is absolutely guaranteed that good, sustainable solutions will be completed by the time the houses are ready for occupation.*

In urban environments, the installation of grey water collectors (for toilet flushing or gardening) can be considered, to reduce the general need for water[10]. In higher density urban areas, household waste can be used for biogas, providing cooking energy and reduce parasites from the effluent.

None of the projects visited considered garbage management. This obviously will lead to the usual situation where garbage is visible everywhere and clogging the open drains. Poorly managed garbage and public drains is one of the main sources of insects, rats and diseases, such as TB, dysentery, typhoid, dengue and malaria.

RAINWATER HARVESTING COMPLEMENTED WITH A SHALLOW WELL FOR WASHING WATER

[10] Obviously, safer WatSan solutions will cost money for installation, but in the long-term will save money and the environment. The cheapest solution is not a good option when it does not provide a safe and sustainable solution. To get a consensus on safer solutions, extensive education and community awareness is required.

8.2 Sanitation Systems

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

- From interviews with 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. In rural areas, the sanitation should not be attached.
- Where the sanitation is located next to the house, the space in-between is often closed and the WC 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 other side 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 or concrete.

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 CONCRETE 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.*

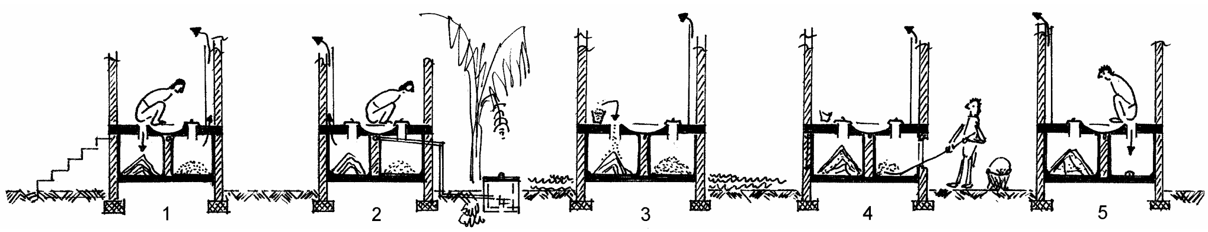
PHOTO LEFT: AN OPEN SEPTIC TANK MADE FROM CONCRETE RINGS. THE FOOTING OF THE RINGS IS ANCHORED TO A WIDER BASE PLATE TO AVOID FLOATING IN HIGH GROUNDWATER AFTER THE TANK IS EMPTIED.

PHOTO RIGHT: A 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 also 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.

8.3 Case Situation

In one project, the NGO had supplied and connected septic tanks (digesters) while the local municipality needed to resolve the further processing before discharging the effluent from the septic tanks into the open channels (photo below). On the left side of the current canal, sufficient land exists to realise a secondary treatment by means of a biological filter bed. However, the shopkeepers living on the right hand side want to rent out the land strip for commercial purposes.

- The first problem is that the overall WatSan solution was not concluded in all its details before the project started.
- The second problem is that there is a phase disruption in the project realisation; the NGO is much faster than the municipality.
- Land use and property issues were not resolved. The villagers did not want to supply land for the sanitation system, while the municipality has no alternative treatment solutions available.

A compounding problem is that in this area the canal was not properly draining due to a recent earthquake. A new canal with lining needs to be constructed. The shops and houses however, are almost ready for occupation.

SEMI-DIGESTED EFFLUENT FROM MANY SEPTIC TANKS WILL BE DISCHARGED INTO THE OPEN DITCH WHEN THE HOUSING (RIGHT, JUST VISIBLE) IS OCCUPIED.

CURRENTLY THE DITCH DOES NOT DRAIN PROPERLY DUE TO THE PAST EARTHQUAKE.

WHEN THESE ISSUES ARE NOT RESOLVED,
DISEASES WILL BE THE RESULT.

A possible solution to the above problem is to collect the sewerage into a communal drainpipe and pomp this to a general treatment site. The high-density housing could also generate biogas; in such a case, the individual fibreglass digesters would not be needed.

9. COMPARISON 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 small 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 small 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 strong 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 hydraulic 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 substantial 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. Use of spur stones. • 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 and constant 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.

10. CONSTRUCTION COST

One of the findings of the site visits was that one LNGO (local NGO) realised houses for almost half the cost as compared to houses from other NGOs or aid organisations. Although many NGO realised houses through contractors for Rp. 90 million (≈ 2 million/m^2), this LNGO realised houses for only Rp. 48 million (≈ 1.15 million/m^2). Both houses have an entrance porch and are from brick. The following main factors are accredited to this situation (the estimated savings costs are indicated at the end of each point):

- The LNGO design has stiffener columns – reinforced concrete and post-cast in between masonry walls (10 cm x 12 cm). Many other houses have pre-constructed reinforced concrete columns of 20 cm x 20 cm, in between which the walls are later masoned (≈ Rp. 10 million).
- For each house, a small building team consisting of five people (2 craftsmen and 3 labourers) is mobilised and trained by the local contractor. The local contractor only delivers the building materials to these teams (≈ Rp. 8 million).
- LNGO is building exclusively with one local contractor, having no sub-contractors. A main contractor often sub-contracts the houses out to local contractors and usually requires 10-12% of the building cost (≈ Rp. 7 million).
- Contractor and LNGO are both non-profit organisations, having lower overhead expenses than commercially operating contractors (≈ Rp. 4 million).
- The overall building speed with many small construction teams is rather slow, avoiding excessive pressure on the local building material market (≈ Rp. 2 million).
- The LNGO design has cemented floors, not tiled such as with the BRR houses (≈ Rp. 4 million).
- There is no sanitation unit incorporated in the design (≈ Rp. 5 million).
- There is no reserve budget in the planned budget for variations or adaptations (≈ Rp. 4 million).
- The LNGO uses university engineer students (new graduates) as construction trainer-inspectors (≈ Rp. 2 million).

It can be observed from the above list that, although the technical building design has an important influence on keeping the building cost low (≈ Rp. 10 million = 15%), the institutional organisation plays even a greater role (≈ Rp. 20 million = 30%).

10.1 Contracting

The decision whether or not to employ contractors or local building teams for the construction depends on the local situation, availability of skilled labour and the overall situation of the building market.

The LNGO was able to keep the construction costs low by working with only one local contractor, being a non-governmental organisation with relatively low overhead costs.

The LNGO explained that open/public tendering often resulted in big contractors being awarded contracts for a large number of houses, but then sub-contract the work in smaller portions to local contractors. The local contractors then need to realise the same construction for about 10% less. These local contractors sometimes further sub-contract the construction to local masons, taking a 10% profit. The result of this sub-contracting process is often that the initial main contractor does not exercise sufficient quality control over its sub-contractor and disappears with its advance finance. To avoid such and to improve quality control, the following is recommended.

Recommendations

- ➢ *Stipulate in contracting agreements that the contractor self-implements the house construction and cannot fully sub-contract the work to third parties. Sub-contracting certain components of the supplies or construction may be permissible provided the contractor remains fully responsible for the execution of the work.*

- *Advances paid to the contractor must be under true bank guarantees and be recoverable in case of non-compliance or failure by the contractor. A financial reservation of 5-10% should be kept on the progress payments as a quality guarantee.*

- *Inspection teams from the Principal (financer) should be able to make independent observations on the quality of the work, and not be influenced by the contractor. These inspectors should team up with the beneficiaries and capacitate them in quality inspection because they are permanently on site. The Principal and the inspecting beneficiary should have a reporting procedure for each construction phase and guidelines to follow when incompliance of construction standards by the contractor is identified.*

- *Well-defined quality-control lists in the local language should be available for the building inspectors and the beneficiaries to serve as reference for the quality inspection. The Principal's building inspector should review the quality-control lists with the local site inspectors and beneficiaries at a prototype house to ensure a good understanding of the criteria.*

10.2 Size and Finishing Quality

Houses built entirely from locally available timber are much cheaper than brick houses, but such houses are considered "semi-permanent" by the villagers. The wooden houses, if unpainted, can be realised for Rp. 10 million. This is 15-25% of the cost of a house built in durable materials. Durable wood with an authentic logging certificate is becoming a scarce commodity. Often timber having a "logging certificate" is not from sustainable forests. In addition, due to the high demand of wood, it is often fresh wood and the quality is reducing.

In the early days after the tsunami, several NGOs built houses similar to those the villagers lost. However, after this initial period, NGOs and the BRR started to build complete houses with reinforced concrete columns and brick walls fully plastered. From then onwards, houses having the upper part from timber were called "semi-permanent" and the brick and reinforced concrete houses were called "permanent houses". The villagers henceforth strongly expressed to the NGOs their desire for a "permanent house".

THE FIRST WOODEN HOUSES WERE OFTEN BETTER THAN WHAT THE PEOPLE LOST

Discussion about house size became complicated for NGOs building the standard 42–45 m^2 houses when in the same region another NGO began building 60 m^2 houses. Beneficiaries often went shopping for the best NGO.

Recommendation
A firm and clear agreement should exist among the NGOs with regard to minimum-maximum house sizes, indicating the total floor and wall area (including the porch, kitchen and sanitation). In addition, the precise finishing details and quality of the walls, floors, ceiling, doors, windows and fittings[11] must be specified in order to reduce competition.

> *"The locals know that a lot of money has come to Aceh, so they want their share and do not accept temporary shelters or semi-permanent houses anymore."*

10.3 Supervision

The building method influences the overall delivery speed of the houses. In the case of the LNGO, the non-profit contractor not only delivered all the building materials, but also mobilised teams of five persons (2 craftsmen and 3 labourers) for each of the 100+ houses being constructed. In addition, they hired engineering students from the university to act as construction supervisors cum trainers. LNGO monitors the work, while occasional site inspection is provided by the local government through the BRR inspectors.

Regular inspection by BRR qualified building inspectors is the ideal situation. Inspection of reinforced concrete constructions should be realised before casting the concrete. However, the vast number of houses being built in the many locations made it impossible for the BRR inspectors to be always there in time. The quality of the contractor and inspection from the Principal therefore are essential elements in ensuring proper reinforcement and concrete quality.

Recommendation
In a disaster reconstruction programme and with a shortage of qualified site inspectors, it is a good idea to make agreements with technical universities to have graduating students get involved in the building site inspection. It is not only economical, but provides the project with knowledgeable young professionals able to grasp technical instructions quickly. For the students, the practical experience gained will be beneficial to their future career.

10.4 Building Teams

According to the information obtained, the LNGO housing project was based on the idea that each house would be realised by its own construction team, involving the future house owner as much as possible.

In a large disaster-relief reconstruction programme, the need for quick delivery of the houses is an important criterion for the victim, the government and the donor. However, the need for every villager to build his/her own house or to become skilled in construction is not a criterion as this requires additional training needs and will bring too many semi-skilled people into the building market. A good option is for a few villagers from each community to be trained so they can use the acquired skills after the housing project has ended. The organisation of one building team per house may include many unskilled workers, which certainly makes the project rather slow and requires a lot of supervision.

An advantage of self-help construction is that the house owner can later extend the house using the acquired skills, rather than hiring an external contractor (high cost). As usual, a balance is required between the need for fast construction and empowering the population in resolving their own housing needs. If there is a constant external pressure to produce the houses quickly, the inclination will be to hire external contractors. If funds are limited, the choice will lean towards self-building.

[11] There is a wide variety of door/window fittings and paints available in the market. It is therefore essential to specify brand names to ensure reasonable quality. For paint finishing, the Bill of Quantity should specify the painting procedure for timber and cement walls.

Recommendation
To increase the speed of construction, a select number of building teams should build the houses in series, rather than trying to build all the houses at once and having one team per house. First, a series of foundations (one after the other) should be realised, then walls, roofs, floors, etc. In this way, as the craftsmen obtain more routine skills, the overall delivery speed will increase and the need for close supervision will reduce over time.

10.5 Material Delivery

The local contractor is supplying the building materials to each building site. The efficiency, and therefore the cost of this delivery service, depends on the organisation of transport, security of the materials after delivery, and the collaboration of the villagers in keeping track of the supplies.

Recommendation
Bulk delivery of building materials should be organised to clusters of houses to improve on the efficiency of transport. It is recommended to deliver some materials to community-managed central storage facilities, which provides safety (doors, windows, fittings, paint, sanitation) and dry storage for cement. The building teams can then collect the materials from these local depots depending on their advancement in construction and certification of progress.

10.6 Budget

The budget of the 100+ houses is committed to the particular sites, but apparently has no flexibility for changes or adjustments in the design. The overall construction cost of the self-help houses or working through a non-profit contracting organisation is so much lower than contractor-built houses that having some reserve funds would go a long way to making eventual adjustments or additions.

For example, when many of the new LNGO houses were flooded during a rainy period, the first consideration for the remaining houses would be to build them 40 cm higher. This obviously would cost money. However, without any budgetary flexibility, the decision cannot be taken without first going back to the donor.

Although it was the responsibly of the local authorities to supply water and sanitation, it is not always realised in time. Either the people occupy the permanent houses with provisional solutions or remain living in the temporary shelters. Because of budget constraints, these facilities cannot be supplied as part of the housing package.

Recommendations
- *In future budgeting of houses, some reserve should be included to allow for eventualities, such as raising the floor, adding steps or changing the sanitation option.*

- *Water and Sanitation (WatSan) should always be included as part of the overall house design, whether part of the main building or separate. In new settlements, consideration must be given to the population and housing density to ensure safe collection of good-quality drinking water and safe disposal of sewerage.*

11. PROTOTYPES CONSTRUCTION

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.

One NGO designed a very appropriate demonstration building using local materials, such as palmtree posts and infill panels with coco nut husk and plastered (photo right). The roof was covered with micro-concrete roofing (MCR) tiles.

This design was not accepted by the local population who wanted ground-floor-only houses made from durable materials (concrete, burned brick and cement plaster).

Understanding Options

Initially, the villagers mainly wanted to get some basic assistance – **"Give us roofing sheets and nails."** However, with the large funds available, this quickly changed to wanting a permanent house, being even more than what was lost in the tsunami or earthquake.

Most villagers do not understand floor plans, so they tend to agree with the proposals from the NGO, assuming that the NGO knows better. In many instances, the community members are unfamiliar with new building techniques and material uses, such as may be the case with pre-fabrication. A meaningful discussion on the design can only be achieved after the villagers have seen a real-size model house. The realisation of demonstration houses on the new settlement site will provide first-hand information on the construction method and will result in qualitative feedback from the community.

NEW BUILDING METHOD USING UNFAMILIAR TECHNIQUES

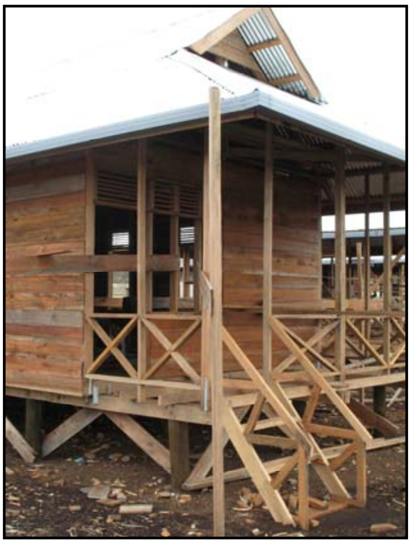
DEMONSTRATION UNIT ON CONSTRUCTION

The right-hand photo above is an example of a demonstration model whereby the masons can see the details of the reinforcement, casting of columns and foundation. This way the Principal (financing NGO), the contractor and the skilled craftsmen have a reference.

Although the principle of the model house was followed in several projects, in one project the villagers had stopped the construction of some hollow cement-block houses because they were not satisfied with the design and the quality of the work. The work could only be continued after the NGO agreed to fill all the holes with concrete. Apart from technically not being necessary, it substantially increased the cost of the house.

Recommendation
When new construction methods are suggested, real-size demonstration houses should be realised on easily accessible sites and in coordination with the target community. Site visits should be organised by the NGO for a large number of community members, including the women, to allow the community to discuss the design as well as the building process.

Evolution of Design
The standard house design has been realised differently by each NGO, depending on the materials available, the architects involved and people's preferences. As time went on, an evolution in these house designs began to take place to adapt to the market situation. Modifications were made to reduce the amount of timber, for example. The two houses below are the same basic design, but the right-hand house is built with 20% less timber, and it is structurally better. The amount of timber can be further reduced by using fibre cement outside boards and similar ceiling panels.



In the photo on the left, the steel roof structure is visible. Due to the lack of legal timber, the roof structures are now being made from light-gauge galvanised profiles. Only the door and window frames are still made from timber.

Page 31 shows a photo of lightweight internal walls, using light-gauge galvanised profiles with fibre-cement boards, thus minimising weight and timber use.

12. SUMMARY

While the Caritas rehabilitation houses are of good standards, in many cases substantially better than neighbouring projects, and often of better quality than what the people lost in the tsunami, there is always room for improvement and lessons learned.

Many of the recommendations in this paper focus on improving the reinforced concrete construction, such as detailing of the reinforcement drawings and site inspection. Most of the recommendations will not only improve the overall performance of the construction during a large earthquake, and thereby increase the safety of the beneficiaries, but some may also lead to cost savings in terms of labour and material (steel, concrete and timber).

Some general recommendations (when applied) may have a large impact on the future safety of the beneficiaries when disaster strikes again. The principal ones are:

- Pay sufficient attention to settlement planning and assure that high-risk tsunami zones are well defined and housing in these zones is adapted to those tsunami risks.
- Ensure that all houses comply fully with the earthquake construction code.
- Decision-making of NGOs on house design and construction should be primarily based on the safety of the future occupants of the houses and not on political pressure to build fast.
- Adapt the design for houses to be built in a tsunami-risk zone. These houses should preferably be elevated and have easy access to the first floor.
- Ensure constant site inspection during the construction phase by qualified and knowledgeable inspectors, especially when dealing with reinforced concrete.
- If the population tends to approve of technically inadequate solutions, additional education is required, i.e. on house design, WatSan, settlement management, etc.
- In order to allow adequate time for planning, education and wise decision-making, the quality of the transitional shelters should be good to last several years.

****