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Environment-friendly Sustainable Rural House Designs for Different Geographic Regions of Bangladesh

Mohammad Shariful Islam¹, Tahsin Reza Hossain², Ratan Kumar Podder³ and Olivier Moles⁴

¹Professor, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET) Dhaka-1000, Bangladesh (e-mail: msharifulbd@gmail.com)

²Professor, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET) Dhaka-1000, Bangladesh (e-mail: tahsin.hossain@gmail.com)

³Caritas Bangladesh, Dhaka, Bangladesh (e-mail: ratan@caritasbd.org)

⁴CRAterre-ENSAG, 2 Rue de la Buthière, 38090 Villefontaine, France (e-mail: oriamole@club-internet.fr)

Abstract

Natural disasters- flood, cyclonic tidal/storm surge, land slide, river bank erosion, drought and earthquakes are the main hindrance to the sustainable development of Bangladesh. In recent years, these have caused extra burden for the marginal people of the country jeopardising country's economic growth as a whole. Although it is a small country, its culture, disaster types, availability of building materials are diverse and the housing practices in different regions vary widely too. A large number of rural houses are damaged due to disaster on a regular basis and cause economic losses and sufferings to the people. Repetitive constructions of such houses also impart deterioration of the environment as much of the construction materials are obtained locally from surrounding nature and thus sustainable development is also hampered significantly. The past experiences on post-disaster shelter response have emphasised the need for more contextual approaches to develop disaster resilient low-cost rural houses. Based on lessons learnt from shelter response after Sidr 2007 and Aila 2009 cyclones, Caritas Bangladesh took an initiative jointly with BUET, Bangladesh and CRAterre-ENSAG of France to develop design of disaster resilient low-cost houses involving local communities. Also, attention was given to develop design of houses that can be built quickly after a disaster. To this context, a seven year project is being carried out in eight different geographic regions of Bangladesh. To develop the design, at first the local practices and availability of local materials were studied. Besides, it was considered essential to understand and accommodate the need and culture of the community. At the same time it is important to consider environmental issues. Three-stage community level meetings attended by people, leaders and local masons were held to gather their views, demand and experience. Properties of the local construction materials were ascertained from laboratory tests. Respecting local affordability and considering the service and environmental loads, designs were finalized based on FEM analyses. Model houses were constructed at the selected locations to demonstrate them to the local community with an aim that new design or at least some features would be replicated. Different treatment schemes for increasing the durability of materials were employed to study their effectiveness. Thirty five designs have been developed in this research for eight different geographic regions of Bangladesh which will be useful for any individual, the Government and NGOs for constructing disaster resilient sustainable rural houses. Performances of these model houses are being monitored. The designs have been found to be accepted by the local community and some features are already replicated.

Keywords: Building culture, community participation, disaster resilient, local material, rural housing, sustainable development

1. Introduction

Bangladesh is considered to be one of the most disaster prone countries in the world due to its geographic location and socio-economic condition of people. Common disasters of Bangladesh are flood, cyclonic tidal

surge, land slide, river bank erosion, drought and earthquakes. About 50% of the land is within 6-7m above Mean Sea Level, MSL (DMB, 2008) and thus the country remains very vulnerable to flood and cyclone.

House is one of the basic needs of human beings. It is a pity that majority people of Bangladesh live in non-engineered (83%, BBS, 2011) and unhygienic housing. The main cause of substandard housing is poverty. Majority of these houses are damaged due to disasters on a regular basis and cause the most economic losses during disasters (DMB, 2008). In recent years, frequent disasters have caused extra burden for the marginal people of the country and jeopardizing its economic growth as a whole. At the same time, the environment is also under threat as people are compelled to live in disaster-prone areas and damaging the surrounding natural resources. For example, in Kuakata and in Bandarban, people are using timber and bamboo from nearby forest and damaging the eco-system. In Kuakata, local people are procuring timber and thatch from nearby mangrove forest and thereby damaging the natural protection belt against cyclone.

Although it is a small country, its culture, disaster, availability of building materials are diverse and the housing practices are also widely varied. After a disaster event, Government and NGOs provide housing to the disaster affected people. Some are very costly and strong enough and some are very nominal and temporary. However, constructions of these houses often do not respect local culture and sometimes constructed in highly vulnerable locations. After the construction of external agency led houses, it is rare that the community replicates the same design. In 2007, a super cyclone Sidr (velocity= 242 km/hr and storm surge height= approx. 5m) passed through Bangladesh coast and damaged lots of houses. In response to that cyclone many houses also were constructed by the Government and NGOs. However, as can be seen from the photograph of the Figure 1 that many houses were constructed in paddy field which lacks both local practice and technical knowledge. This also imparts damages to the agricultural land and causes threat to the food security of the country.

Different international guidelines are available for a number of years (Seraj and Ahmed, 2004; Ahmed, 2005; Sadeq et al., 2008). At the same time there is a lot to learn from existing vernacular houses even they lack technical adequacy. A question may naturally be asked: why are these not being followed in practice? The answer is that R&D does not focus enough on local practice and that the fruits of existing R&D are not being transferred into the field as these houses are mostly designed and built by owners or masons who do not have access to these booklets. Current codes (BNBC, 2006) also do not have provisions for disaster resistant rural house design. There is a gap among the responding agencies for not having an effective design and technology for the construction of low-cost housing (LCH). At the same time, each of the community has their own construction techniques and materials for LCH. Some of them are very effective and scientific. These are sometimes overlooked during the construction of LCH. There is also a gap in understanding the local knowledge for having effective design and technology for the construction of LCH. Obviously, there is a necessity for bridging these gaps by learning from the people and then, transferring backs the improvement to them. Input of local people, local masons, local building culture and environment should be considered for sustainability. To this context, a seven year project has been completed in two phases.

2. Background and Objectives of the Project

Caritas Bangladesh (CB), as a human development organization has been constructing shelters i.e. Low Cost Houses (LCH) for disaster-affected families since 1970. As on June 2015, CB provided shelter support for 444,644 families all over the country. However, types of hazards are different and the people have cultural distinctions in different regions. Even in the same region, the culture may vary in different groups of people.



Figure 1. Constructed houses by NGOs in paddy field after the cyclone Sidr 2007

Moreover, the natural resources are specific from one site to other; therefore, the coping strategies for shelter should not be same. Previously one particular model house design was prepared by CB for all areas of Bangladesh. Some modifications were done from time to time. Disaster, geographical area, cultural aspects were also considered in some cases. Community people's opinions were sometimes taken into considerations for design of houses. But these were not adequate. Similarly Caritas Bangladesh constructed LCHs in Sidr 2007 affected areas having financial support from Secours Catholique/Caritas France. An evaluation was carried out in 2008 by International Centre for Earth Construction (CRAterre)-ENSAG for Caritas France supported houses. In the evaluation report, it was recommended that both the social and technical features of such houses should be improved. To this context, CB approached BUET to provide technical assistance towards their LCH Project in disaster-prone areas. CRAterre-ENSAG, France as a consultant to Caritas France also joined to provide technical support.

Upon successful completion of the CB implemented first phase of pilot LCH project in 2009-2010 Fiscal Year in Kuakata of Patuakhali and Sirajdikhan of Munshiganj district with financial support from Caritas France, CB took up its second phase (October 2011- April 2015) for other six regions of Bangladesh with funding support of Caritas France and Caritas Luxembourg wherein CRAterre-ENSAG and BUET are the technical partners for the project. Findings of the evaluation for first phase Pilot LCH Project done in collaboration with BUET and CRAterre-ENSAG have been considered for the second phase project. The main objective of the project is to minimize the impact of recurrent disasters on LCH by developing more disaster resilient design. In total, 35 types of LCH have been designed for 8 regions; at the same time 60 pilot LCHs have been constructed and 48 existing houses were repaired. The developed designs are given in the report (Islam and Hossain, 2015). Finally, the learnings are being disseminated to the rural people, engineers, other NGOs and educators (Islam et al., 2013; Moles et al., 2013; Moles et al., 2014). This current paper presents the findings of the project.

Based on the lessons learnt in the first two phases, guidelines are being developed for different stakeholders in the third Phase of the Project (May 2016-December 2016).

3. Project Locations

The project has been completed in two phases. At the first and second phases of the project, two and six regions were selected, respectively. Project locations are marked on Bangladesh map as presented in Figure 2. Name, disaster vulnerability and brief description of the locations are presented in Table 1. In the first phase, designs were developed for Kuakata and Sirajdikhan. In the second phase, designs were developed for Gaibandha, Mymensingh, Sylhet, Naogaon, Satkhira and Bandarban.

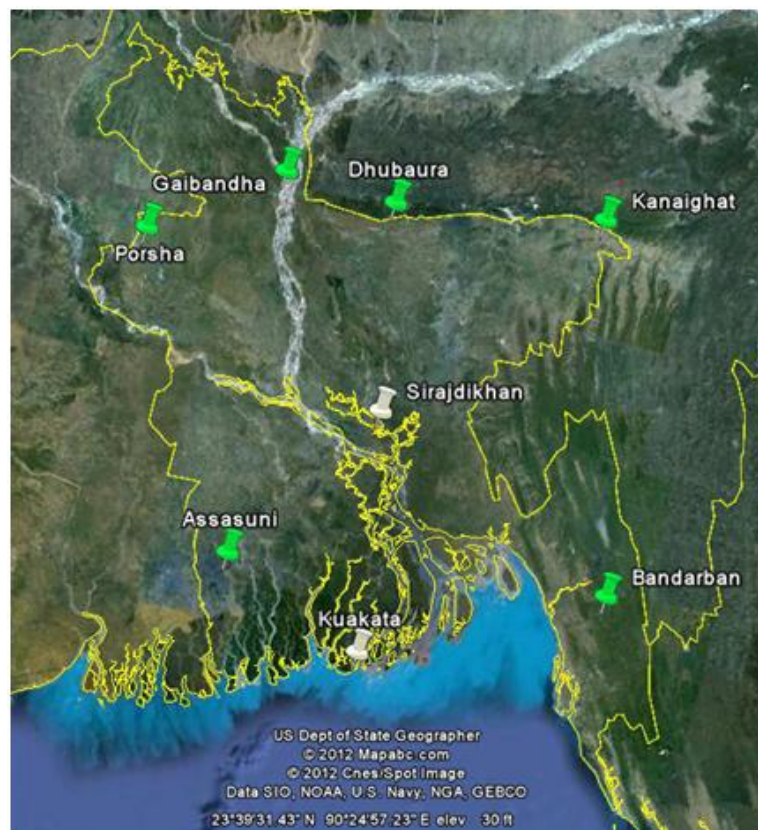


Figure 2. Project locations of the two phases shown on the map of Bangladesh

4. Design Strategies and Project Sequence

Project sequence has been presented in Figure 3. Three-stage community level meetings were held to collect local information and views of the people along with the masons. Properties of the local construction materials of some regions were ascertained from laboratory tests. Considering sustainability and taking into account the service and environmental loads, designs were finalized based on 3-D Finite Element Modeling package ETABS. Model houses were constructed at the selected locations to demonstrate them to the local community with an aim that new design or at least some features would be replicated. Performances of these model houses are being monitored. The main aspects of development of disaster resistant housing consists of (i) surrounding environment and sustainability, ii) survey, iii) design, construction and technical improvement, iv) dissemination of learning and v) follow up and monitoring. Finally to develop design guidelines for different stakeholders for using them for pre-disaster design and post disaster response.

Table 1: Description of Project Regions and House Types Designed in Phase I and Phase II

Phase	Regions	Disaster vulnerability	Geographic description	House type designed
Phase -I	Kuakata, Patuakhali	Cyclone, storm/tidal surge	Flat coastal land	RC and bamboo post, timber roof, bamboo thatch fence and CGI sheet roofing. Wind resistance improved by providing bracings.
	Sirajdikhan, Munshiganj	Flood	Low-lying flood prone area of Ichhamati river	RC and bamboo post, timber roof, bamboo thatch fence and CGI sheet roofing. High plinth, wind resistance, loft for living during flood.
Phase-II	Gaibandha	Flood and river bank erosion	Brahmaputra river bank	RC and bamboo post, timber roof, two part fence-bamboo thatch at top and thin CGI sheet at bottom. CGI sheet roofing. Easy to dismantle and reconstruct.
	Dhubaura, Mymensingh	Flash flood	Flood plain of river Nitai	RC and bamboo post, timber roof, two part fence-bamboo thatch at top and thin CGI sheet at bottom. CGI sheet roofing.
	Kanaighat, Sylhet	Flash flood	Flood plain of river Surma	RC and bamboo post, timber roof, half mud wall at bottom and bamboo thatch fence at top, CGI sheet roofing. Improved plinth, use of local stone.
	Porsha, Naogaon	Drought and earthquake	<i>Barind</i> Tract terraced land	Thick mud wall, bamboo roof, CGI sheet roofing. Stabilized mud, incorporation of bamboo reinforcement for ductility. Another type- <i>tati</i> wall house.
	Assasuni, Satkhira	Cyclone and flood	Coastal saline zone	RC and bamboo post with mud wall, timber roof and clay tiles. High plinth, stabilized mud, wind resistance.
	Bandarban	Land slide	Hilly region	RC <i>katla</i> and timber post, timber roof, bamboo thatch fence and CGI sheet roofing, <i>machan</i> house, house on ground. Optimum use of timber, treatment of timber, lateral stability using bracing.

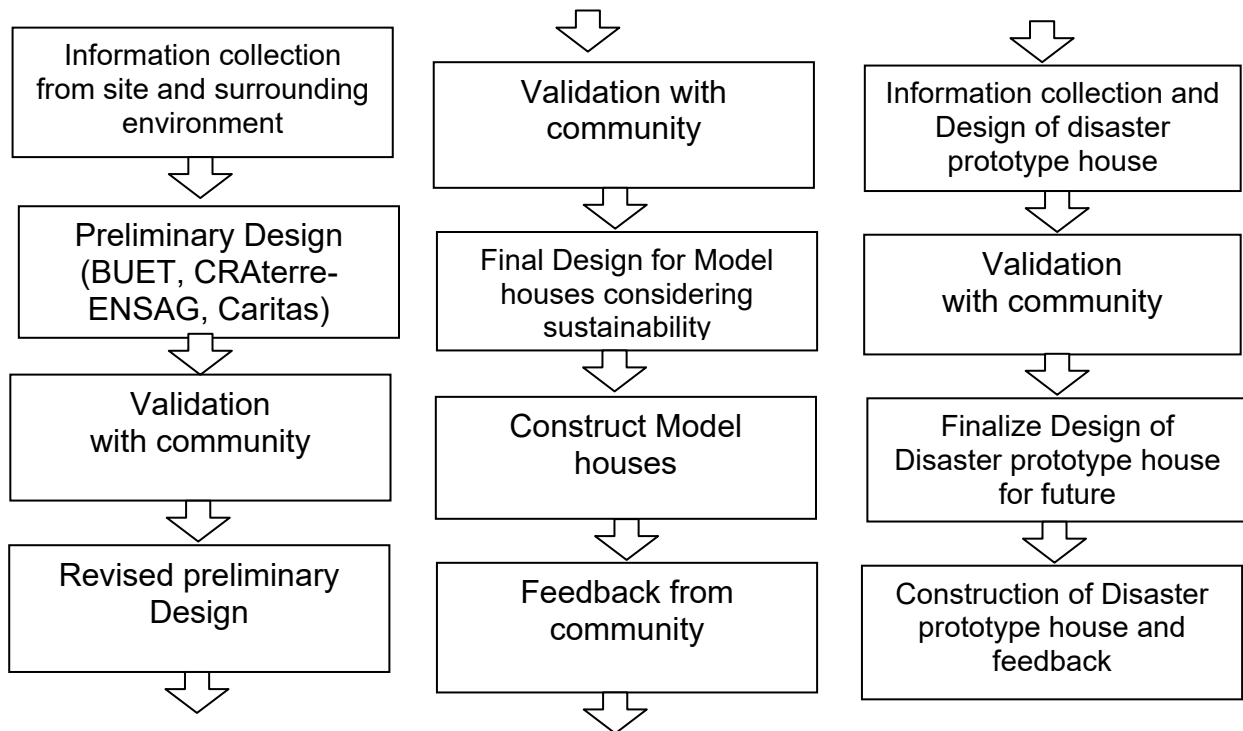


Figure 3. Project sequence followed in the design and construction

4.1 Survey for Collecting Local Information

Survey was jointly conducted by Caritas, BUET and CRAterre-ENSAG to collect local information and intelligent practices and decide about the preliminary design. Following are the key features of the survey conducted:

- Inform the local people about the LCH programme
- Rapport building based on meeting with local authorities, community leaders, etc.
- Development of survey formats for obtaining the social and technical information
- Survey of the types of existing houses, size, material available in consideration to the environment and their costs as well as social map
- Community meeting to understand the overall situation in the village (social and economic conditions including housing)
- Transect walk/observation and selection of houses to be assessed
- Individual house assessment
- Meeting with masons and people involved in the construction to understand types of houses and availability of masons, materials, rates etc.
- Analysis of the survey to determine the design strategy for different types of LCH

4.2. Design Steps

As shown in Figure 3, the design evolution followed an iterative approach to incorporate stakeholders' feedback. Main steps followed in the design are as follows:

- Preparation of preliminary design based on primary survey with particular focus on the environment
- Sharing among CB, BUET and CRAterre for feedbacks
- Preparation of the draft design

- Cost estimation
- Sharing the design with the community for their inputs
- Incorporate feedbacks and validation with community
- Selection of treatment method for different elements of the structure
- Preparation of the final design considering sustainability

5. Design of LCHs

LCH design respected local practice, availability of building materials and culture of the community. Information is collected to identify the client/beneficiary needs. Availability and skill of the local mason, carpenter have been given consideration. The design considerations in different regions are described briefly below.

5.1 Kuakata: Design in Cyclone-prone Area

5.1.1 Design Considerations

A four pitched roof is selected for better wind resistance in the cyclone-prone area. As per BNBC (2006), the house should be designed for 260 kmph fastest mile. However, as these houses are not alternative to cyclone shelter, a realistic compromise on wind speed had been reached. A RC and timber framing system, which is common in the area, is chosen. For the post, 1:2:4 concrete post reinforced with mild steel bars is selected whereas timber from locally available rain tree is used for beams and roof rafters. Timber properties have been ascertained from laboratory testing. A stepped earth plinth is chosen for better protection as the local soil is silty sand. In addition, a clay cover of two inch was provided for better protection and usability. Two parts of bamboo fences were used for better maintenance/repair of the lower part fence and it reduces the repetitive use of the natural resources.

5.1.2 Material Testing

Soils and local building materials (wood, water) were tested at the BUET laboratory. Typical test results on wood sample (rain tree) are presented in Figure 4. Wood samples were tested with different water content. It can be seen that water content has significant effect on the strength of the wood.

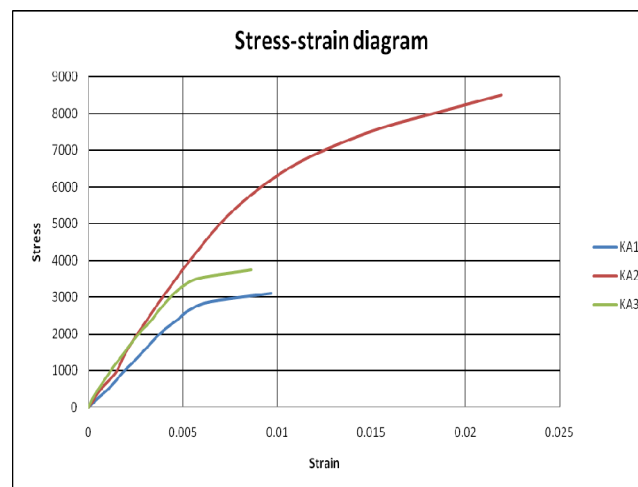


Figure 4. Stress-strain relationships of wood in compression.

5.1.3 Finite Element Analysis

Based on the considerations, a 3-D finite element analysis was conducted (Figure 5a). The photograph of the Figure 5b shows the constructed house. FE analyses using ETABS show that diagonal bracing would be better resistant to wind. However, finally the due to construction difficulty, the diagonal bracings were changed to corner bracing as can be seen from Figure 5(b).

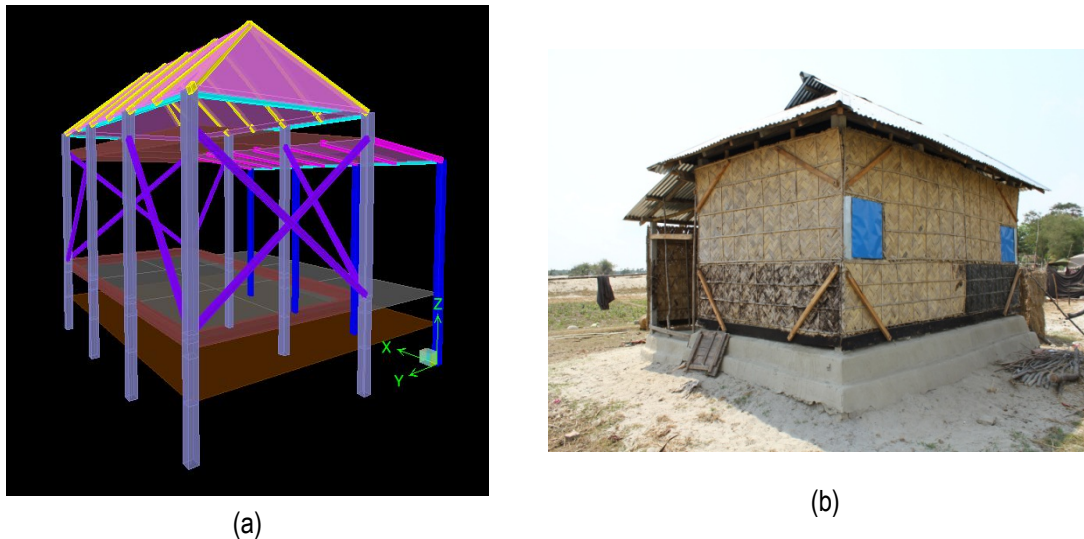


Figure 5. (a) 3-D finite element model of the proposed house in Kuakata; (b) photograph of completed house

5.2 Sirajdikhan: Design in Flood Prone Area

A RC and timber framing system, which is common in the area, is chosen. For the post, 1:2:4 concrete post reinforced with mild steel bars is selected whereas timber from locally available rain tree or *mahogany* is used for beams and roof rafters. Timber properties have been ascertained from laboratory testing. A stepped high earth plinth is chosen for better protection as the area is flood prone. Two parts of the bamboo fences are considered for better maintenance/repair of the lower part fence. A loft/mezzanine is provided to save valuables during flood. Based on the considerations, a 3-D finite element analysis was conducted to finalize the design.

5.3 Gaibandha: Design in River-bank Erosion Prone Area

The site is flat land and situated on the west bank of Brahmaputra river. Flood, river-bank erosion and strong wind are the main disaster vulnerabilities. It is important to make the house easy to dismantle as river-bank erosion can happen very quickly. In the implemented design, there are joints in the post as well as connection between post and roof system for quick dissemble and reconstruction. To increase the durability of the fence against rain, CGI sheet has been used in the lower part and bamboo fence in the upper part for comfortable dwelling. A number of treatment strategies have also been tried in the location. A photograph of the completed house is shown in Figure 6.

5.4 Dhubaura, Mymensingh: Design in Flash Flood Prone Area

Main design consideration in this region is flash flooding of Nitai river. Stepped plinth has been incorporated and roofing has been extended to increase the life of the fence. Two-part fence- thin CGI sheet in the lower part and bamboo thatch in the upper part- has been introduced. Platform in the center of the house was provided for storing goods.



Figure 6. Photograph of completed house in Gaibandha

5.5 Kanaighat, Sylhet: Design in Flash Flood Prone Area

Main design consideration in this region is sudden flooding of Surma river. Improved plinth has been designed using locally available stones. These stones are not suitable for using as coarse aggregate in civil construction works as the quality is not satisfactory. Half wall made with mud and local stone has also been tried and demonstrated to the local people and masons. It has been observed that dampness in plinth is a problem of local houses and the situation is improved in the new design. Bracings are incorporated to increase lateral wind resistance. A photograph of the completed house is shown in Figure 7.



Figure 7. Photograph of completed half walled house with stone plinth in Kanaighat, Sylhet

5.6 Porsha, Naogaon: Drought Prone Area

Mud wall stabilization has been used in the design employing local natural fibers i.e. jute and vetiver to reduce thickness of wall to decrease earthquake vulnerability. This has been demonstrated to the local community and masons so that stabilized blocks can be prepared even in the dry season when water is scarce. To improve the durability of mud walls against rain-cut erosion, stabilized blocks and fire bricks have been used. Bamboo strips have been incorporated in layers to enhance ductility of the building system. Alternate design has also been developed for disaster response using local plant *ikor* and bamboo post with the provisions of future addition of

mud wall for comfortable living which is a common feature of local houses. Plan and section of the completed house is shown in Figure 8 and Figure 9, respectively. Another type, *tati* wall with RC and bamboo posts has been designed for low income people. In this type, *tati* wall is made with locally available plant covered by mud plaster on both sides.

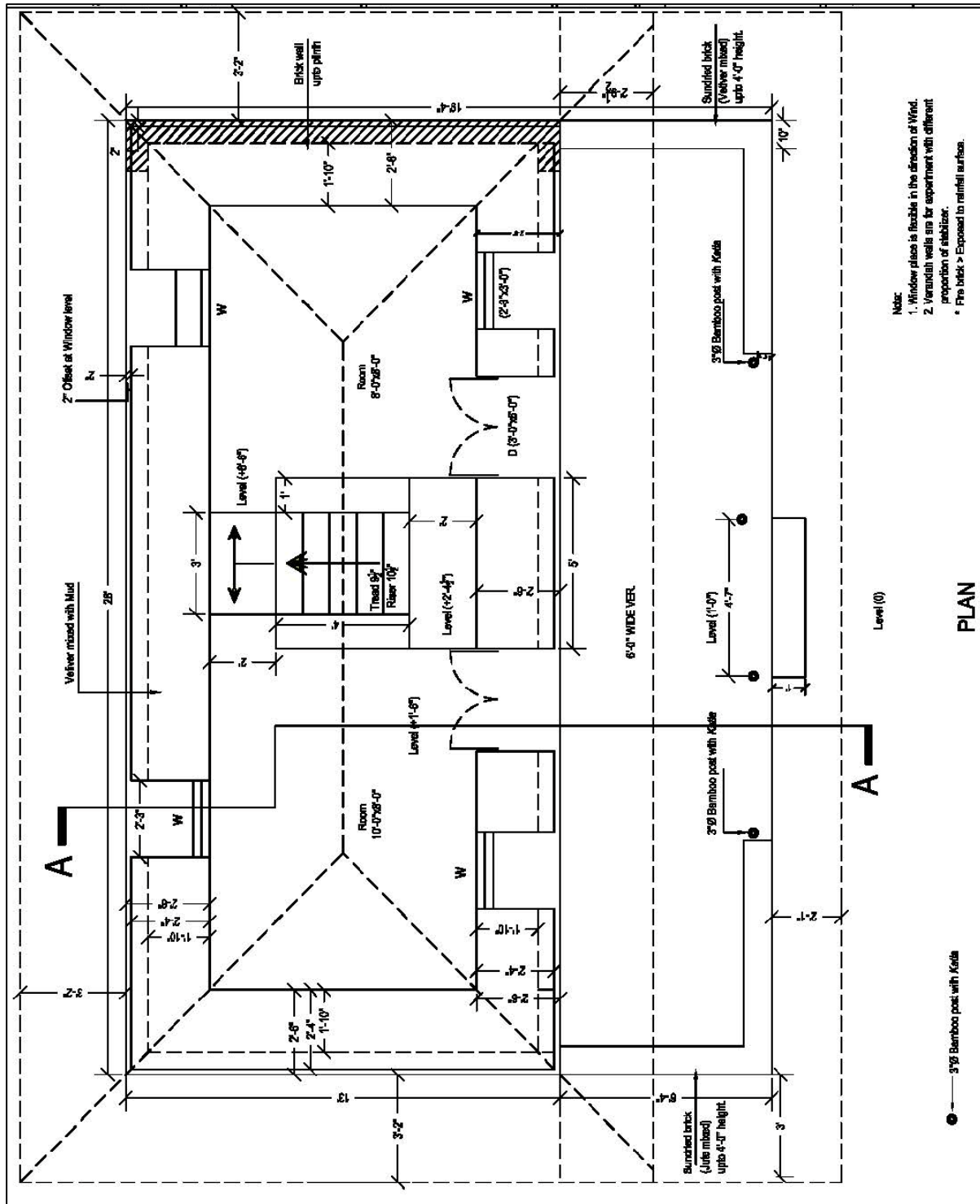


Figure 8. Plan of the constructed improved mud house in Porsha, Noagaon

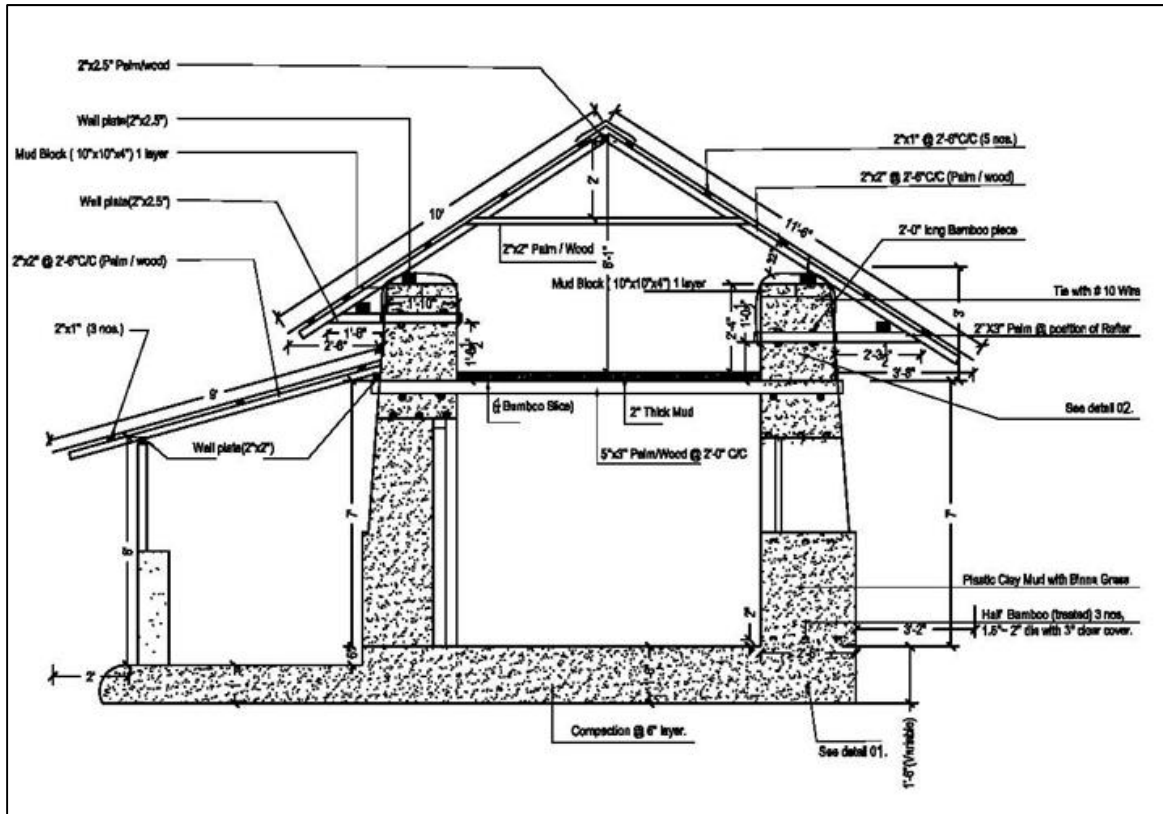


Figure 9. Section of the constructed improved mud house in Porsha, Naogaon

5.7 Assasuni, Satkhira: Cyclone and Flood in Coastal Saline Region

Raised plinth of 4 to 5 feet height is common in the area. Mud wall stabilization has been used in the design employing local natural fibers i.e. jute and rice-husk. Mixing of such natural fibers is effective in improving strength and ductility (Islam and Iwashita, 2010). Bamboo strips have been incorporated in layers to enhance ductility of the building system. Alternate design has also been developed for disaster response using RC and bamboo post with the provisions of future addition of mud wall for comfortable living which is a common feature of local houses. Frame of bamboo and RC post are added outside to the mud wall system so that even if the mud wall is washed away during flood, the building will remain intact on the frame. A photograph of the completed house is shown in Figure 10. Environment-friendly clay tiles have been used as roof materials.



Figure 10. Photograph of completed house in Assasuni, Satkhira

5.8 Bandarban: Hilly Region

In the hilly regions of Bandarban, it is a common practice of the indigenous people to live in an elevated house, commonly known as *machan* house. Timber is available in the region, however, large procurement from the forest is putting extra pressure on the already continuing deforestation process. Less timber has been used in the design with suitable treatment scheme to increase the durability. A joint, locally known as *katla*, has been incorporated in the timber post to improve durability. Bracings are also included to enhance lateral load carrying capacity. Photographs of *machan* house and house on ground are shown in Figure 11a and 11b, respectively. However, another type, house-on-ground has also been designed.



Figure 11. (a) Photograph of machan house and (b) house on ground in Bandarban

6. Construction of Houses

Four houses were constructed in each regions. Construction of the houses were done in the following steps under supervision of Caritas, BUET and CRAterre-ENSAG:

- Formation of Project Committee
- Community-led beneficiaries selection
- Training of masons
- Selection of masons
- Procurement of materials
- Treatment of materials
- Organization of the house, position and space arrangement
- Construction of 2 houses, one for each model
- Validation of 2 houses for improvements
- Providing feedbacks on the constructed houses for design improvements
- Construction of the rest 2 houses
- Improvement/ repair of houses

7. Monitoring/Follow up Phase

After the construction and handing over to the owner, the houses are continuously being monitored by CB and BUET. Feedback and learning from the monitoring are recorded systematically which would be used in future

design and construction of LCHs. It is interesting to note that some of the design features have already been adopted by the local people.

8. Summary and Recommendations

It is of utmost importance to develop design of disaster resilient LCH to minimize frequent damage and achieve a sustainable development of the country with minimum deterioration of the surrounding environment. At the same time it is imperative to develop design of houses that can be built quickly after a disaster as a rapid response to post-disaster situation. It is the social responsibility of architects, engineers, educational institutions and civil society members to take positive initiatives in this regard.

The main aspects and achievements of the research project are as follows:

- 1) In designing houses the type and level of hazard were first ascertained. It was decided to use locally available materials and technology and show respect for local culture and practice. The skill of local mason and carpenters were also kept in mind. Importance was also given to affordability, safety and replicability of the community.
- 2) Thirty five designs have been developed in this research for eight different geographic regions of Bangladesh which will be useful for any individual, the Government and NGOs for constructing disaster resilient rural houses.
- 3) Model houses were constructed in all eight geographic regions of the country based on community participation. Necessary adjustments were incorporated based on people's and masons' feedback.
- 4) The completed houses are continuously being monitored and have been found to perform well so far.
- 5) The designs have been found to be accepted by the local community and some features are already replicated.
- 6) Disaster prototype designs have also developed for some regions so that houses can be constructed rapidly by NGOs and Government agencies after a disaster.
- 7) Caritas staff members have incorporated their acquired knowledge and skills in disaster preparedness and emergency response activities. CB also aims to disseminate the acquired learning to national and international NGOs, government sectors and Caritas International partners.
- 8) Educational institute like BUET is incorporating the learning from the project into their class lectures. Expansion of research regarding LCH and related topics will have to be included in the curriculum of the technical institutes and universities without delay.
- 9) In designing and construction of houses, in every region, special attention is given to surrounding environment and sustainable issues by using less material, enhancing durability using effective treatment schemes.

Based on the experience, learning and designs developed, third phase of the project is being executed to prepare manuals for LCH design and construction. Different manuals/brochures for different stake-holders- policy makers, NGOs, educators, local masons- will be developed.

Acknowledgements

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