World Housing Encyclopedia

an Encyclopedia of Housing Construction in
Seismically Active Areas of the World

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Earthquake Engineering Research Institute (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
Mud House of Bangladesh

Report #	143
Report Date	18-09-2007
Country	BANGLADESH
Housing Type	Adobe / Earthen House
Housing Sub-Type	Adobe / Earthen House : Mud walls
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Summary

In Bangladesh, a mud house is one of the traditional housing types that are used by poor families mainly in rural areas as well as in the outskirts of small cities. This building type is typically one or two stories and preferably used for single-family housing. It is more predominant in less flood-prone areas, i.e. in the highlands or in mountainous regions. The masses of these buildings are generally high and their walls are characterized by insignificant

strength, particularly against forces that act out-of-plane. This type of building is highly vulnerable to both seismic forces and high pressures due to flood flow. The main load bearing system consists of mud walls of 1.5 to 3.0 ft thickness, which carry the roof load. Clay tiles, thatch or CI sheets are used as roofing materials. The application of these materials depends on their local availability and the ability of the house owners. There is no monolithic joint between the wall and the roof. For this reason, these buildings behave poorly under any type of lateral load (e.g. earthquake, wind).

1. General Information

Buildings of this construction type can be found in villages and suburban areas of the country. Generally, areas of less rainfall dry dimate, lateritic soil (rich in minerals, typically red in color) and where the lands are normally above the flood level, are more suitable for the construction of mud houses. This type of housing construction is commonly found in both rural and urban areas.

Nowadays in rural and suburban areas, economically stable people try to build semipacca (more permanent) houses. Despite of this, the percentage of mud houses is higher in these areas.

This construction type has been in practice for more than 200 years.

Currently, this type of construction is being built. Locally this type of housing is called a Kutcha. About 74% of the total houses of Bangladesh are Kutcha houses, most of which might be considered as Mud houses. The percentage of Kutcha houses is 46% and 83% for urban and rural areas, respectively. Among mud houses, those of rammed earth type are most common but also mud block wall systems are being used. This type of construction is still being practiced in developing countries like Bangladesh.

Figure 1. Typical building with tin roof in Muktagacha, Mymensingh (Asraful Alam, 2006)

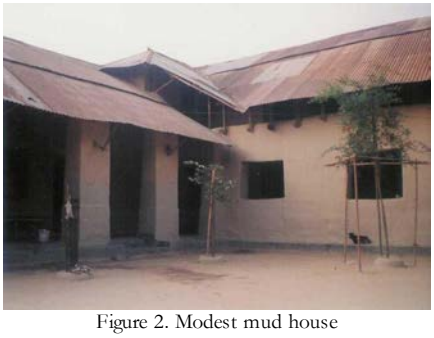

Figure 2. Modest mud house

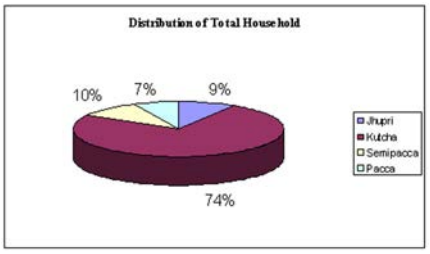

Figure 3. Total household distribution in Bangladesh

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They share common walls with adjacent buildings. Though people in the hilly areas have been building this type of mud house for many centuries, it repeatedly suffers serious damage during earthquake shaking due to its heavy roof construction When separated from adjacent buildings, the typical distance from a neighboring building is 2-4 meters.

2.2 Building Configuration

The plan shape of this type of construction is generally rectangular with lengths between 20-30 ft and widths between 10-15 ft. The main structural elements are mud walls which carry the load of the roofing. Many houses have open verandas at the front with roof supported by posts. The opening area is about 30 percent of the total wall area. The construction of doors can be done in two ways. Either by providing doors with heights equal to the wall height, or by

a discontinuous construction of the wall at the location of the opening according to their dimension. The door frames are provided afterwards. In case that doors are provided with height less than the wall height, a wooden plank is provided over the opening with support of 6" on both sides. Afterwards the construction of the wall is continued leaving the opening. In case of the construction of windows, the walls are raised up to window sill level and then the walls are discontinued at the location of the opening. When the walls are raised up to the top level of the window, wooden planks are again placed over the openings with support of 6" on both sides. The remaining wall is constructed as described before.

2.3 Functional Planning

The main function of this building typology is single-family house. In villages this type of construction can be used as godown or storage house. Though most of the mud houses are used as single-family houses, they can also be used by the extended, combined family depending on the houses available living area. In a typical building of this type, there are no elevators and no fire-protected exit staircases. In a typical building of this type, there are no elevators and no fire-protected exit staircases. Houses generally have two entrance doors. Both can be located either at the front side of the house or one can be at its backside where usually the kitchen is arranged. If buildings are two-storied stairs made of mud are provided to access the upper story.

2.4 Modification to Building

A typical modification of these buildings consists in the lateral extension. Vertical extension is not very common.

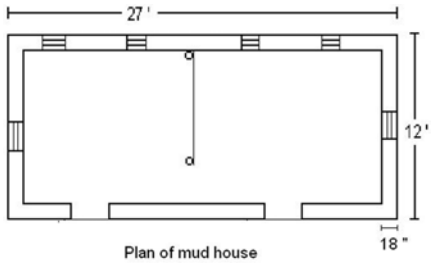

Figure 4. Plan of a typical mud house

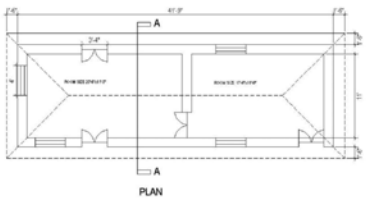

Figure 5. Plan of a typical mud house

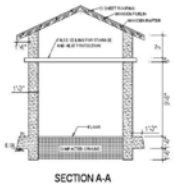

Figure 6: Elevation of the mud house shown in Fig. 5

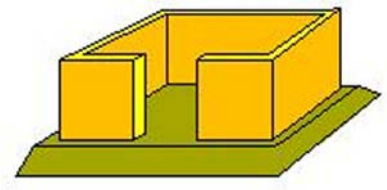
Figure 7. Construction of door with height equal to the wall height

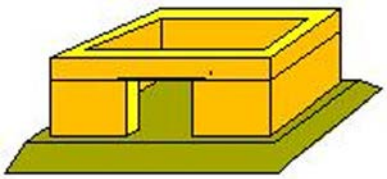
Figure 8. Construction of door with height less than the wall height

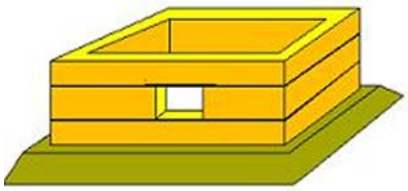
Figure 9. Construction of window

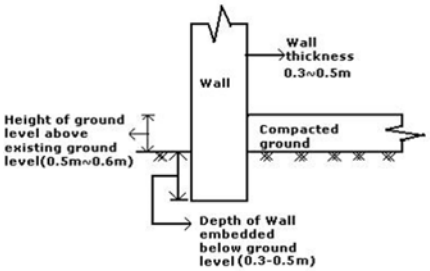

Figure 10. Cross-section of wall and floor connection

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☐
		2	Dressed stone masonry (in lime/cement mortar)	☐
	Adobe/ Earthen Walls	3	Mud walls	☑
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
Structural concrete	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☐
		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐

	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☐
	Hybrid systems	45	other (described below)	☐

Mud walls are the main structural elements of this type of construction. They carry both lateral and vertical loads.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is earthen walls. Mud walls carry gravity loads due to the roof weight and transmit them to the ground. Rarely, wooden or concrete block lintels assist in resisting the gravity loads at wall openings. Mud walls are mostly susceptible to excessive rainfall, which frequently causes the washing away of mud from the wall.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is earthen walls. The dimensions of the mud walls are typically: height 3.0 m, width 4.0 m, thickness 0.50 m. The walls do not have any additional system (such as crown beam or pilasters) to restrain their out-of-plane movement which is one reason why the buildings are so vulnerable during earthquakes. If the walls fail in out-of-plane direction, the roof generally looses its support and collapses. The wall corners (junctions) are very vulnerable parts of the structure. The typical wall thickness varies from 0.3 to 0.6 m.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 5 and 10 meters, and widths between 3 and 5 meters. The building has 1 to 2 storey(s). The typical span of the roofing/flooring system is 3-4 meters. It is not easy to specify the actual length and width of the house. Generally, this depends on the requirements as well as on the economic situation of the inhabitants. Roughly, the ratio of the length and width of the house can be expressed as 3:2 or 2:1. The span width also depends on the number of members that would occupy a single room. The typical storey height in such buildings is 1.6-2.5 meters. The typical structural wall density is more than 20 %. Generally wall density varies with the thickness of the wall. For the house of the same dimension mentioned above, wall density will be different if the wall thickness is different.

3.5 Floor and Roof System

Material	Description of floor/roof system	Most appropriate floor	Most appropriate roof
Masonry	Vaulted	☐	☐
	Composite system of concrete joists and masonry panels	☐	☐
	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	

			☐
Structural concrete	Flat slabs (cast-in-place)	☐	☐
	Precast joist system	☐	☐
	Hollow core slab (precast)	☐	☐
	Solid slabs (precast)	☐	☐
	Beams and planks (precast) with concrete topping (cast-in-situ)	☐	☐
	Slabs (post-tensioned)	☐	☐
Steel	Composite steel deck with concrete slab (cast-in-situ)	☐	☐
Timber	Rammed earth with ballast and concrete or plaster finishing	☐	☐
	Wood planks or beams with ballast and concrete or plaster finishing	☐	☐
	Thatched roof supported on wood purlins	☐	☑
	Wood shingle roof	☐	☐
	Wood planks or beams that support clay tiles	☐	☐
	Wood planks or beams supporting natural stones slates	☐	☐
	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles	☐	☐
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls	☐	☐
Other	Described below	☑	☑

The floor generally consists of compacted earthen materials. Thatched roofs are very commonly seen, but corrugated sheets or tiles supported by wooden purlins can also be used as roofing materials. The roofs are usually inclined to facilitate the drainage of water. Sometimes flat roofs with wood joists are also used. In Bangladesh, bamboo joists are more common. The roofs (and walls) typically have a 10 cm (4 inch) layer of straw. The compacted ground that is used as floor is generally raised 0.5?0.6 m above the existing ground level.

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	☑
	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☐
	Reinforced-concrete isolated footing	☐
	Reinforced-concrete strip footing	☐
	Mat foundation	☐
	No foundation	☑
Deep foundation	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

In the construction of mud houses no proper foundation is provided. Only the ground is excavated with a width equal to the wall thickness and the wall is then constructed. Generally the wall is embedded to the ground, without footing. The general depth of the embedment is about 0.3-0.5m. As a result no firm connection exists between the building and the ground. Thus the building may fail easily due to severe lateral loading.

Figure 11. A building with thatch roof supported by wooden purlins in Muktagacha, Mymensingh (Asraful Aslam, 2006; Firoza Akter, 2007)

Figure 12: Mud house with straw roof

Figure 13. CI sheet roof supported by wooden purlins (Firoza Akter, 2007)

Figure 14. Two-story mud house (Firoza Akter, 2007)

Figure 15: Mud house with corrugated galvanised iron sheet roof

Figure 16: Two-storied mud house

Figure 17. Too many openings provided in one wall (Firoza Akter, 2007)

Figure 18. A building with tile roof supported by wooden purlins in Pahartoli, Raozan, Chittagong (Rebeka Ahsan, 2006; Firoza Akter, 2007)

Figure 19. Mud house with flat roof supported by bamboo joists

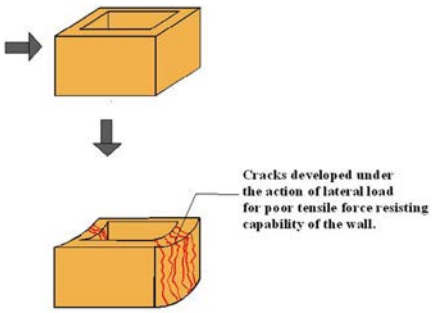

Figure 20. Cracking pattern of mud wall due to lateral load

Figure 21. Effect of roof load on the wall (Rebeka Ahsan, 2007)

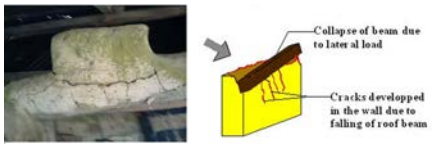

Figure 22. Existing feature of wall and beam connection

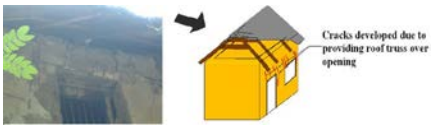

Figure 23. Existing feature of roof truss located above the opening

Figure 24. Earthen wall without reinforcement in Hathazari Chittagong (Iftekhar, 2007)

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). There might be two units if a combined family live in the house. The number of inhabitants in a building during the day or business hours is less than 5. During day/business hours those persons who are working are absent so that less than five persons stay in the house. The number of inhabitants during the evening and night is 5-10. All family members return from their work back home at night. Consequently the number of occupants during night will be more than 5 people.

4.2 Patterns of Occupancy

One family possibly with a married son and his wife typically occupies one house. In rural areas, one family has at least 5--8 members.

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low-income class (very poor)	☑
b) low-income class (poor)	☑
c) middle-income class	☑
d) high-income class (rich)	☐

Most of the middle class families that were originally coming from the villages but that have moved into the cities, still stay in their mud houses when they come to their villages. They even renovate it at least once a year. Generally, the very poor people who live from hand to mouth, cannot engage themselves in any meaningful income generating labor and so they sometimes must live in houses with leaky roofs (even in winter and heavy monsoon). The gross national income of Bangladeshi people is 394 US-$/year. The construction costs of such mud buildings is about 1000--1500 US-$ for a building of 1000 square feet.

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	☐
4:1	☐
3:1	☑
1:1 or better	☐

What is a typical source of financing for buildings of this type?	Most appropriate type
Owner financed	☑
Personal savings	☑
Informal network: friends and relatives	☑
Small lending institutions / micro-finance institutions	☑
Commercial banks/mortgages	☐
Employers	☐
Investment pools	☐
Government-owned housing	☐
Combination (explain below)	☐
other (explain below)	☐

Nowadays, Grameen Bank is the world renowned micro-finance institution, which lends money to the people as per their requirements under some easier terms and conditions. They help the poor people to become independent by loaning money for their development. In each housing unit, there are no bathroom(s) without toilet(s), 1 toilet(s) only and no bathroom(s) including toilet(s).

In the rural areas of Bangladesh, the bathrooms are generally located away from the housing units. When there is a proper surface-water source nearby the houses, middle class people build only a change room rather than a bathroom since they wash in the pond. Poor people generally do not provide any bathroom and construct the toilet in an unhygienic way. Middle class people at least construct one toilet nearby the house. .

4.4 Ownership

The type of ownership or occupancy is outright ownership.

Type of ownership or occupancy?	Most appropriate type
Renting	☐
outright ownership	☑
Ownership with debt (mortgage or other)	☐
Individual ownership	☐
Ownership by a group or pool of persons	☐
Long-term lease	☐
other (explain below)	☐

Generally the occupants are the owner of the house. Renting a house is not very common.

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		Yes	No	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	☐	☑	☐
Building	The building is regular with regards to both the plan			

Configuration	and the elevation.	☑	☐	☐
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	☐	☑	☐
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☐	☑	☐
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☑	☐	☐
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☐	☐	☑
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☐	☑	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☐	☑	☐
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☐	☐	☑
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☐	☑	☐
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	☐	☑	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☐	☑	☐
Additional Comments				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Walls	1. Very poor lateral resistance. 2. No seismic bands at lintel level provided. 3. The proportions of openings are not favorable. Openings are arranged too close to wall corners. Distances between wall corners and openings are not according to code specifications.	The provisions of bamboo posts at the inner and outer sides of the walls at regular intervals.	Partially or complete collapse of walls.
Beams		Wooden bracings should be	Separation of the

	Improper connection between longitudinal and transversal beams.	provided at each corner where longitudinal and transversal beams are joined together.	transversal beams from the longitudinal beams.
Roof and floors	1. The single roofing elements are not interconnected. 2. The roofing truss is not fully anchored to the walls. 3. Poor maintenance makes the roof truss more vulnerable to damage. 4. Roof does not provide rigid diaphragm action.	Roof rafters should be placed over the solid wall not over openings.	Collapse of roof. Again cracks are formed in the walls above openings.

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is A: HIGH VULNERABILITY (i.e., very poor seismic performance), the lower bound (i.e., the worst possible) is A: HIGH VULNERABILITY (i.e., very poor seismic performance), and the upper bound (i.e., the best possible) is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance).

Vulnerability	high	medium-high	medium	medium-low	low	very low
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☑	☑	☐	☐	☐	☐

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1997	N-E-N of Chittagong	6.1	VIII(MMI)
2003	SW of Daluchari, Rangamati, Chittagong	5.7	VII(MMI)
2003	Barkal	5.6	n.a.
1997	Jaintapur	5.6	n.a.
1997	Bangladesh-Myanmar border	6.0	n.a.

Bangladesh has a long history of devastating earthquakes that have affected earthen buildings. Fortunately, the number of casualties caused by these earthquakes are not so significant. Recently, on July 26, 2003 (local time 5:18 am), a moderate earthquake occurred in the Chittagong hill tracts near the Bangladesh-India border causing minor structural damage, 3 fatalities and 25 injuries. The earthquake had a magnitude of 5.6 and was felt at many places in southeastern Bangladesh. Two women were killed when a mud house collapsed in the town of Rangamati. Five of the injured persons came from Rangamati district where the roof of the Aymyachhara Health complex collapsed in the town of Barkol. The Union Parishad building collapsed in Barkol. Several buildings induding a school were damaged in the town of Rangamati. Five acres of land near the school reportedly caved in. Throughout the region nearly 500 buildings were damaged. In the earthquake in 1997, a five storied building at Hamzarbag was seriously damaged and many people died. Cracks also formed in many weak structures.

Figure 25. Collapse of mud house due to the 2003 Barkal earthquake (EERC, CUET)

Figure 26. Typical earthquake damage: cracking of walls due to the 2003 Barkal earthquake

Figure 27. Typical damage at a mud house in Hathaazari, Chittagong (Iftekhar, 2007)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Mud (i.e. molded soil) is used for the construction of the walls.	In unreinforced mud walls the compressive strength of mud is about 120--140 kPa (Islam and Kanungo, 2006).	The mix proportion of materials is not specific. After mixing with water the mud is kept in place for a few days so that the dispersion of clay particles can take place. Afterwards it is used for construction.The minimum thickness of the walls is 1.5 ft.	Among the lower income class, owners construct their houses themselves. In general, no testing of the material strength is done during construction. This is solely based on experience. Irrespective of this, testing facilities are not available in those areas where these types of constructions are available.
Foundation	Mud (molded soil) is used for the construction of foundation.		The mix proportion of materials is not specific.	
Frames (beams & columns)	Bamboo			
Roof and floor(s)	Straw, C.G.I Sheet, Bamboo, Golpata (a kind of leaf found in Mangrove forest).			

6.2 Builder

These buildings are typically built by the owners, whereas the owner is directly involved in the construction process and may also contribute his own labor.

6.3 Construction Process, Problems and Phasing

Soil is excavated about 1.5--2 ft all around the building. In a first step, the wall base up to a height of 2--3 ft is erected out of compacted mud before it is left for one day for hardening. The same procedure is repeated several times in order to raise the wall up to the desired height. Roofing: The roof truss consists either of bamboo or wood. For the construction of the roof, first wooden beams are provided on top of the walls. The longitudinal beams are provided with grooves in equidistant intervals. Then the cross beams are placed at the positions of the grooves. Afterwards, the roof trusses are provided onto the longitudinal beams and fixed to them by nails. It has been observed that the roof trusses are not always provided directly over the cross beams. On top of the roof truss a roof frame is applied and

fixed to the trusses by ropes. At the end, cover materials such as CI sheets or straw are provided. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size.

6.4 Design and Construction Expertise

Local unskilled persons and villagers without any technical knowledge construct these buildings. Generally the builders construct their own houses and sometimes they employ skilled labor. Generally, the craftsmanship is poor. There is no special expertise and no formal training of labor. Their seniors trained them.

6.5 Building Codes and Standards

This construction type is not addressed by the codes/standards of the country. This type of construction is an informal construction. There are no guidelines for this type of housing.

No prior approval is required.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and not authorized as per development control rules.

This type of construction is very common in rural areas where no strict development authorities are present to observe the construction process of this type of construction. Building permits are not required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s).

6.8 Construction Economics

BDTK 50 per square feet. It takes about 60 days for 2-3 persons (120-180 person days) to complete the construction.

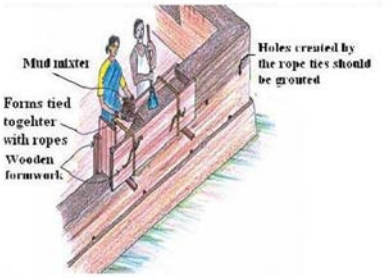

Figure 28. Construction of wall (Ahmed, 2005)

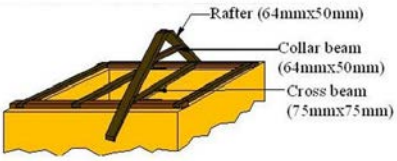

Figure 29. Fixing of roof truss resting on beam

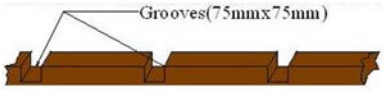

Figure 30. Grooves made into the longitudinal beam

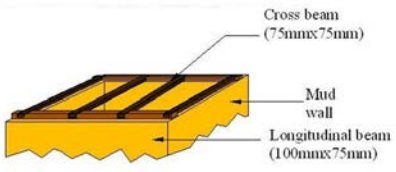

Figure 31. Placing of crossbeam over the longitudinal beam

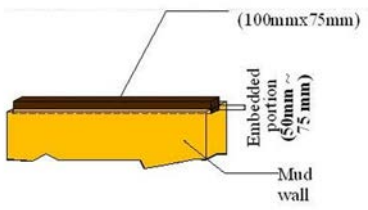

Figure 32. Placing of longitudinal beam over the wall

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable. Even today, people in Bangladesh are not aware about earthquake risk.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Walls are not strong enough because of low compaction and absence of horizontal force resisting element.	1. In order to increase the horizontal load-resisting capacity of the walls, bamboo can be used as a bracing material at the inner and outer sides of the walls. 2. A mesh of bamboo can reinforce the walls. Tying the vertical bamboo splints with the horizontal splints using wire would create a bamboo mesh that would be tied to the collar beam. 3. Jute mat cover with the help of bamboo slices can be used to resist the horizontal load.

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Walls are not strong enough because of low compaction and absence of horizontal force-resisting element.	1. In order to increase the horizontal load-resisting capacity of the walls, bamboo can be used as a bracing material at the inner and outer sides of the walls. 2. A mesh of bamboo can reinforce the walls. Tying the vertical bamboo splints with the horizontal splints using wire would create a bamboo mesh that would be tied to the collar beam. 3. Jute mat cover with the help of bamboo slices can be used to resist the horizontal load.
Lack of preventive measures against flood damage at plinths and walls. Consequently, during rain and flood soil particles of the wall can absorb water easily and become weak over time.	In order to increase horizontal load-carrying capacity of the walls bamboo can be used as a bracing materials at the inner and outer sides of the walls.
Large openings	Lintels must be provided above the openings. The length of the windows should not be more than 3 ft and not more than 1/3 of the total length of the wall.
Poor connection between the roofing materials and the walls. The rafters are not tightly connected to the wall tops so that they easily loose support during earthquake action.	To reduce the movements at the longitudinal direction of the walls bracing can be provided between the upper and the lower longitudinal pair. The movement at the cross (transverse) direction can be reduced by providing bracings between two upper longitudinal pairs and the cross pair (see Figure 28).

The suggested retrofit provisions are not complex and can be done by local masons and available laborers.

8.2 Seismic Strengthening Adopted

Has seismic strengthening described in the above table been performed in design and construction practice, and if so, to what extent?

This has not yet started in Bangladesh in real practice. Strengthening is applied in experimental studies at BUET.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?

Even smaller earthquake shaking may damage mud buildings to a greater extent. Dilapidated dwellings are generally replaced by houses made of straw (jhupri) or brick (unreinforced masonry). Consequently, the techniques previously

described may be implemented on undamaged buildings in the near future. However, the application of these techniques in order to repair existing earthquake-damaged buildings will be impractical.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
Not applicable.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
Owner. Neither architects nor engineers were involved in the strengthening process.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
Not applicable.

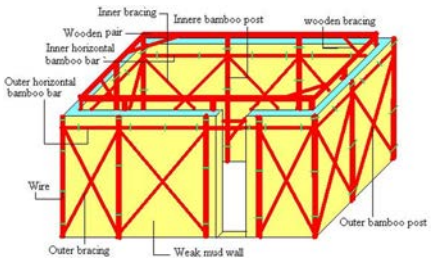

Figure 33. Bracing with bamboo inside and outside the wall

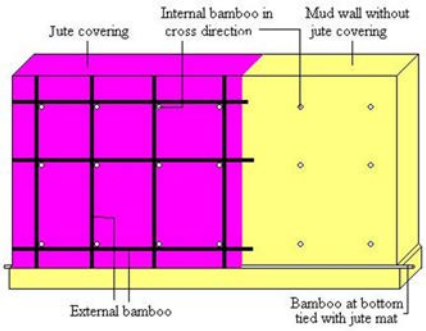

Figure 34. Jute mat covering the mud wall using bamboo slices

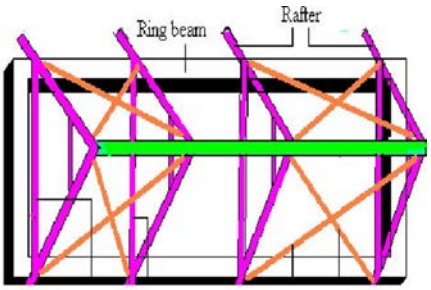

Figure 35. Modification of roof truss

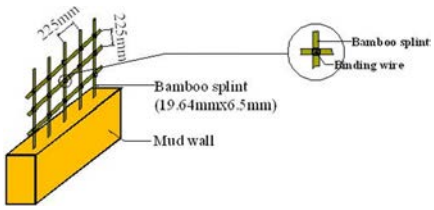

Figure 36. Use of bamboo mesh to reinforce the wall

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