World Housing Encyclopedia

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

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

HOUSING REPORT
Assam-type House

Report #	154
Report Date	20-02-2009
Country	INDIA
Housing Type	Timber Building
Housing Sub-Type	Timber Building : Walls with bamboo/reed mesh and post (Wattle and Daub)
Author(s)	Hemant Kaushik, K. S. Ravindra Babu
Reviewer(s)	Amit Kumar, aan, aan

Summary

Assam-type houses are commonly found in the northeastern states of India. Generally, it is a single storey house; however, two-storey houses are also found at some places. The main function or use of this construction type is multi-family housing. These are generally single dwelling units and do not have common walls with adjacent buildings. The house is made largely using wood-based materials. Performance of Assam-type houses has been extremely good in several past earthquakes in the region. Structural strengths that influence earthquake safety of the house include good

configuration, light-weight materials used for walls and roofs, flexible connections between various wooden elements at different levels, etc. However, the houses are vulnerable to fire because of use of untreated wood-based materials. When built on hill slopes, unequal length of the vertical posts leads to unsymmetrical shaking that may damage the house.

1. General Information

Buildings of this construction type can be found in the northeastern states of India. Ikra-type construction is also used in the Gangetic planes of Bihar, UP, Bengal and Orrisa. This type of construction is also widely constructed in south and southeast Asian countries, largely found in Bangladesh, Myanmar, Thailand, Cambodia etc. The current report covers the typology commonly used in the states of Assam and Sikkim (Figure 1). Based on local requirements, there may be small variation in the typology used in other states. The northeastern part of India is one of the most seismically active regions in the world; three great earthquakes and several big earthquakes have struck this and adjoining regions in last 110 years. The region experiences severe shaking due to subduction of the Indian plate under the Eurasian plate along the north northeastern direction at a rate of about 40 mm per year. Due to historical high seismicity of the region the local people developed a unique construction methodology using locally available materials to construct their dwellings that are highly earthquake resistant. Such houses are commonly known as Assam-type houses or Ikra (Figure 2). The name Ikra given to such housing typology is derived from the reed locally known as Ikra used extensively in walls and roof of such houses. This type of housing construction is commonly found in both rural and urban areas.

Currently, this type of construction is being built mostly in rural areas; in urban areas it is not used anymore. However, many old buildings some of which are decades old, are still in good condition and are inhabited. These houses are generally located on sprawling areas in rural Assam with abundant frontage for flower garden. (Traditionally, this frontage is used to erect temporary sheds for organizing family functions and religious get-togethers. However, in urban areas, the frontage is small, roughly about 5-6 m).

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

Currently, this type of construction is being built. Some century-old buildings are still in use in Guwahati, the capital city of Assam (Banerjee 2004). Generally, it is a single-storey house; however, two-storey houses are also found at some places. The plinth of the house is raised above the normal ground level to avoid marshy ground, run-off during rains and stray animals (especially reptiles). The house is made largely using wood-based materials. The vertical posts, roof trusses and elevated floor are made of Sal wood. A weed, called Ikra, which grows wildly in river plains and adjoining lakes across the state of Assam, is extensively used in the walls and roof of the house. The wall panels are made of bamboo frames infilled with the shoots of the Ikra reed oriented in the vertical direction; the Ikra reed shoots are plastered from either side with mud-dung mixture. The covering on the roof truss is a thick stack of Ikra reed. Those who can afford, choose metal sheet roof instead of reed roof covering on the roof truss. Nowadays construction of such houses is on decline due to variety of reasons including non-availability of cheap wood, fire hazard, and high cost of insurance. It was reported by one of the residents that the insurance cost for Ikra type houses is significantly more than that for corresponding reinforced concrete structure (sometimes even two times more expensive).

Figure 1: Map showing the northeastern states Assam and Sikkim in India


Figure 2: A typical Assam-type house commonly built in northeastern India.

(Source: www.mapsofindia.com).

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They do not share common walls with adjacent buildings. As roads in hilly regions are always on ridge lines, the houses rise from low-lying areas along road until they are accessible from the road When separated from adjacent buildings, the typical distance from a neighboring building is 10-15 meters.

2.2 Building Configuration

When built on flat lands, the common plan shape is rectangular for single/two family house, and L- and C-shaped for multi-family house (Figure 3). Generally the building plan is regular for houses with smaller built-up area. Detailed drawings of a typical single-storey house constructed formally are provided in Annexure A (Figures A1 - A8). When built on slopes, the common plan shape is rectangular with the long side running along the slope, and the access is from the hill slide with a verandah facing the valley side; as a variation, the verandah runs along the full length of the building instead of being located just at the end of the building. The roof is pitched with a high gable to cater to the heavy rainfall in the region over many months. The simplest version of the house is geometrically regular and rectangular in plan of size 3x6 m. The eves height is about 4m and the pitch of the sloped roof about 2 m. The slope of the roof varies from one-third to one-fifth of the span depending upon the permeability of the roofing material. Thatched roofs have steeper slopes than tin sheet roofs. Kitchen is one of the major sources of fire accidents in such houses. Therefore, an open space (verandah) of about 3 m is generally provided between the kitchen and the rest of the house in order to prevent fire accidents. Farming animals, if any, are usually kept outside the house, but with a shelter provided for them within the courtyard. Their shelter has walling on three sides and a roof on top. The door and windows are small in size and are generally placed in the center of the room. Windows are about 900x1200 mm in size and the door about 900x2100 mm; the frames and panels of the windows and doors are made of locally available Hallock or Sal wood, which is quite similar to teak wood with respect to engineering properties except that the texture is not as good as teak wood. Other wood types that are usually available in this region and used in such houses are Gamari, Nahar or Mango.

2.3 Functional Planning

The main function of this building typology is mixed use (both commercial and residential use). Assam-type of construction is not restricted only to dwelling units, it is also adopted for institutional, office and commercial buildings. The configuration of the house also changes with functional requirements. For example, if the requirement is to operate a reasonably big government office, the structure may be a two-storey building with large window openings (Figure 4a). Similarly, the shape and slope of roof, windows, doors, etc, for a Church (Figures 4b and 4c) will be completely different than a school or college building (Figures 4d and 4e). The architecture follows a general norm of having at least one door in the rear of the house that can act as an escape route in case of any emergency. In a typical building of this type, there are no elevators and no fire-protected exit staircases.

2.4 Modification to Building

The same methodology is adopted by the people of the neighboring states also with little modifications to suit availability of local forest products. Timber, bamboos, reed, and some binding materials are the prime construction materials of Assam-type houses. Several modifications in the construction methodology and materials used in Assam-type housing have been observed at various places to suit the local requirements. One such modification, which is rather not suitable for seismically active region is shown in Figure 5. In this two-storey house at Timpyen Basti near Lingdum in South Sikkim, light-weight iron sheet roofing over timber trusses was constructed at the second storey and RC slab was constructed at the first storey. While heavy unreinforced masonry walls were used as infills in the second storey, light-weight Ikra walls were provided in the first storey. Though this may not be treated as a proper modification to the Ikra house system, it is interesting to note the use of Ikra walls and timber framing as infills or partition walls in the first storey. Although damage was not observed in this particular house during the 18 September 2011 earthquake shaking, masonry infill walls constructed in the upper stories of such housing are vulnerable to out-of-plane collapses.

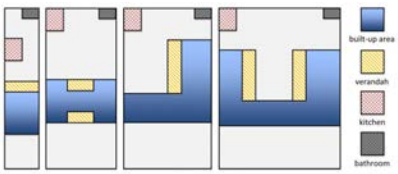

Figure 3: Plan variations of typical Assam-type houses commonly built in NE India.

Figure 4: Changes in basic configuration of Assam-type houses as per the functional requirements: (a) a century old government Municipal Corporation building at Guwahati, (b) front view of Assam-type Church, (c) side view of Assam-type Church at Guwahati, (d) front view of Century Old single storey Cotton College Building, and (e) side view of Cotton College Building at Guwahati.

Figure 5: A vulnerable modification to the Ikra-type housing in Sikkim: heavy masonry infill walls above and light-weight Ikra walls below.

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)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is timber frame. .

3.3 Lateral Load-Resisting System

The lateral load-resisting system is timber frame. .

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 6 and 12 meters, and widths between 6 and 12 meters. The building has 1 to 2 storey(s). The typical span of the roofing/flooring system is 3 meters. These houses are mostly single-storied (Figures 2); very rarely two-storied houses are built. In some cases when two-storied houses are built they are with second storey as light wood construction and first storey as conventional load-bearing brick construction. The typical storey height in such buildings is 3.5 meters. The typical structural wall density is up to 20 %. .

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	☐	☐
Structural concrete	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	☐
	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	☑	☑

Different types of flooring can be seen in Assam-type houses. Wooden plank flooring is adopted in stilted houses and mud plaster flooring in rural areas. Other common types of flooring include cement flooring over an under layer of sand or brick soling, etc. Pitched/corrugated/galvanized iron sheet roofing over timber trusses is the most common form of roofing system used in these houses.

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	☐

No formal foundation is used in typical Assam-type houses. The main wooden verticals of the house are pierced into the ground by about 600-900 mm. In some cases involving construction of formal houses, the main wooden posts of the house are supported on masonry or plain concrete pillars constructed over the ground up to plinth or sill level. The connections between wooden posts and the pillars are achieved using steel bolts and U-clamps.

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). The number of inhabitants in a building during the day or business hours is less than 5. Residents of the house are mostly the family members. The number of inhabitants during the evening and night is 5-10.

4.2 Patterns of Occupancy

Single or combined families ranging from 4 to 10 people for residential buildings. Varied number in case of office / institutional buildings.

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)	☐

Though mostly very poor people living in rural areas live in this type of housing, few middle class people in urban areas have also constructed such houses. In addition, several government offices also operate from such housing.

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	**Most appropriate type**

financing for buildings of this 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)	☐

In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and no bathroom(s) including toilet(s).

The house consists of a living room, verandah and kitchen. Toilets are constructed away from the main house near the periphery of the plot. .

4.4 Ownership

The type of ownership or occupancy is individual 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)	☐

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 Configuration	The building is regular with regards to both the plan 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	Note: Generally the building plan is regular for houses with smaller built-up area. As discussed in Section 2, L- or C-shaped plan is also used for bigger multi-family houses.			

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Foundations	For houses constructed on slopes susceptible to landslides and run-off, the house can be unsafe. In plane areas, these buildings are observed to perform best.		Settlement and sliding of foundations during landslides triggered by EQ or monsoon. Tilting of foundation posts during liquefaction.
Frames		The wooden frames of the houses are connected to the light-weight walls and roof using flexible connections. Such a system offers good EQ resistance.	Connection failure between posts and beams resulting in tilting, dislodging and out-of-plane failure of timber frames during earthquake shaking.
Walls		The Ikra wall system is very light imparting lightness to the overall structure. Due to less mass, these houses perform well during earthquakes.	Dislodging of Ikra panels during earthquake shaking.
Roofing		Roofing is made of weed, leaves or (in modern buildings) corrugated galvanized iron sheets. Roofing is very light and thus the overall mass of the building is kept low.	Connection failure between various members of the timber frame may result in dislodging of roof purlins and rafters and subsequent failure of truss. This may further result in tilting and subsequent collapse of light roof due to failure

			of roof support system.

An important aspect of this housing type is the joinery between various elements: posts, wall panels, roof trusses, and roofing elements. In formal constructions, connections are achieved with nailing and bolting. In informal cases, coir ropes are used to connect the various elements. The latter raises concerns on durability of the connection materials, and thereby, on the safety of the house. Connection of Vertical Posts with Roofing: The vertical intermediate posts are connected with the horizontal wooden scants at floor level, sill level, lintel level, and at eaves level using nails, steel clamps, and bolts. Connection between the main vertical posts and other members of the wooden frame and roof truss is achieved through nails, bolts, and steel clamps (Figure 6). The wooden planks used for slabs are supported on intermediate rafters, which in turn are supported on main wooden beams at ends that transfer the load to the main vertical posts as shown in Figure 6c. Attic between the slab and the roof truss is generally used as storage. The truss is made of wooden members that support the tin or asbestos roofing (Figure 7a). Framing Details of Ikra Walls: In the olden days, and even in these days in rural areas, Ikra walling is used as cladding. It consists of providing Ikra reed and/or bamboo matting made of good quality matured bamboos in between the wooden frames and plastering the matting with cow dung and mud/cement mortar (Figure 8). Construction details and sequence of wooden framing and Ikra walling are shown in Figures 7 and 8 and also explained in greater detail in Section 6.1. To prepare cow dung-mud slurry, equal volumes of cow dung and soil are mixed with sufficient water to form a uniform thin paste. This paste is used to fill in the gaps between Ikra reeds and then to plaster the wall. CBRI (1984) guidelines on construction of mud and thatch houses suggest mixing bitumen and kerosene in 5:1 ratio in the cow dung-mud paste in order to arrest formation of fine cracks and voids in the wall plaster. However, such bitumen cutback is seldom used in Ikra panels of Assam-type houses because of additional cost and work involved. Therefore, frequent application of the plaster is required to be applied over the Ikra panels (for example, after every or alternate cycle of summer and rainy season). Sometimes the panels are filled with brick masonry walls up to window sill level. These days, the panels are generally filled with brick walls, and also, the timber framing is replaced by thin reinforced concrete columns. Ikra is a kind of reed that grows wild in marshy land, river beaches, and loamy soils. Ikra shoot is hollow with nodes at an interval of 150 to 300 mm. Skin of Ikra shoot is thin but fairly strong and body of the shoot is covered between internodes by heavy and siliceous sheath. The usual diameter of the Ikra shoot is about 6 to 16 mm. It grows up to 3 to 4.5 m but the serviceable height is about 2.5 to 3.65 m (Figure 9). Matured Ikra shoot (when the plant has flowered; it usually takes about 2 years for full maturity) is best suited for walling or roofing. The main constituents of Ikra reed are starch and cellulose, and it is less susceptible to insect attack unlike bamboo. The air content in the hollow inner core of the reed makes it heat resistant, and therefore, Ikra houses have good thermal insulation. Another important property of Ikra reed is that it does not shrink or flatten during drying process. Seasoning of Ikra shoot is done by sun drying for 12 weeks or by soaking it in water for 3 days and then sun drying. Ikra shoot has excellent bond with mud mortar, lime mortar or cement mortar. Two types of Ikra walls are generally constructed: simple- and fine-type. In simple-type, Ikra reeds are placed in vertical orientation outside horizontal battens of walls and a single Kami lining (Kami is a long strip split out of a bamboo. It is usually 15 to 40 mm wide.) is nailed to the battens at 300 mm intervals to confine the Ikra reeds. In between the battens, Ikra reeds are strengthened by alternate tiers of single and double Kami at 300 mm spacing vertically. A cane rope or binding wire is used to tie the Ikra reed with Kami at a spacing of 300 mm. To impart better bond, Kamis are tied with polished ends towards Ikra reed and the split white portion exposed to receive plaster. Ikra reeds are not compactly placed in the walls but a gap of 6 to 15 mm is maintained between each shoot. In fine-type walls, grooves are made longitudinally at the centre of wooden battens and then Ikra reeds are slipped into these grooves after cutting them to proper uniform size. Kamis are fitted into vertical recess made in the battens. Stiffening and tying with Kami is similar as explained in the simple-type. Ceiling: Typical Assam-type houses have false ceilings made of timber, bamboo mats and in modern construction, ply wood or AC sheet. The false ceiling provides cool environment inside the house and also prevents falling of insects from the roof. The false ceiling work consists of wooden framing of 75x50 mm scants placed at 600 mm spacing and fixed to the frame work by means of nails. In some houses, ceiling made of Ikra reed (similar to Ikra roof) was also observed, especially above the covered verandah (Figures 6c and 10). Flooring: Different types of flooring can be seen in Assam-type houses. Wooden plank flooring is adopted in stilted houses and mud plaster flooring in rural areas. The elevated floor is made of wood runners of size 50×100 mm spaced at about 300 mm spacing spanning between wood beams of size 120×120 mm spaced at about 600 mm spacing. The floors are covered with 25×2500 mm wood planks of thickness about 25 mm. Other common types of flooring include cement flooring over an under layer of sand or brick soling, etc. Roofing: Pitched CGI (Corrugated Galvanized Iron) sheet roofing over timber trusses is the most common form of roofing used in these houses. This roofing is best suited in this area because the region receives high amount of rainfall that may possibly has severe effect on durability of building (Figure 11a). In rural areas, Ikra reed is also used for roofing (Figure 11b).

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *F: VERY LOW VULNERABILITY (i.e., excellent seismic performance)*, the lower bound (i.e., the worst possible) is E: LOW VULNERABILITY (i.e., very good seismic performance), and the upper bound (i.e., the best possible) is *F: VERY LOW VULNERABILITY (i.e., excellent 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
1897	Assam	8.7	XII
1934	BiharNepal	8.4	X
1950	AssamTibet	8.6	XII
1988	BiharNepal	6.6	IX
2006	Sikkim	5.7	VII
2011	Sikkim	6.9	VIII

Performance of Assam-type houses has been extremely good in several past earthquake shakings in the region (Kaushik et al. 2006). In the recent 18 September 2011 Sikkim earthquake (M6.9), severe damage was observed in reinforced concrete construction. On the other hand, the only damage observed in Ikra houses due to earthquake shaking alone (not due to landslides) was to additional class rooms of Ikra type constructed on third story of Government Secondary School building at Sichey (Murty et al. 2012) (Figure 12). Therefore, such houses may not be suitable for construction on higher stories due to possible amplification of ground motion along of the height. No injury has been reported due to falling light-weight debris of the Ikra walls. On the other hand, damage sustained by the reinforced concrete part of the school building was severe and the building was abandoned. Strengths that Influence Earthquake Safety of the Building Typology: The housing is known to have a number of strengths that influence earthquake safety of the house. These include: (a) Architectural aspects: good plan shape, small openings, good location of openings, and small projections and overhangs. (b) Structural features: light mass of walls and roofs, good wall-to-wall connection (in case of formal construction), good quality and strength of materials used. (c) Flexible connections (bolting, nails, grooves, etc) between various wooden elements at different levels. Weaknesses Associated with the Building Typology: The housing typology has a few deficiencies. These include: (a) The choice of wood as the basic construction material and thatch as roofing material of the house draws high maintenance and is vulnerable to fire. To a large extent the fire hazard to the house is mitigated, when the kitchen is separated from the main house, but placed within the courtyard of the house. But use of electricity in such houses leaves possibilities of fire due to short-circuit during earthquake shaking. In urban areas, the roof has long been converted to metal roofing hence this hazard is non-existent for this type of houses except when Ikra reed thatch is used as roof cover, the fire safety of the house remains a main concern. (b) The mud-dung plaster on walls requires a lot of maintenance and frequent application. During summers, it becomes brittle and then comes out easily during rainy season. (c) When built on hill slopes, unequal length of the vertical posts leads to unsymmetrical shaking. (d) When built on hill slopes susceptible to landslides and run-off, the house can be unsafe. (e) The thatch on the roof is vulnerable to suction under strong winds. (f) When the wooden vertical posts are directly plugged into the ground without any foundation, houses have sunk up to 300 mm. Sometimes, differential sinking of the vertical posts leads to lateral sway of the house and pulling apart of the house. The problem is aggravated in sites with high water table, and mitigated when the vertical posts are formally provided with stone piers or plain cement concrete as a foundation. In light of the above shortcomings, this type of house is expected to perform poorly during strong earthquake shaking when it is built on hill slope with unequal lengths of vertical posts plugged into ground without any foundation with ground having high water table and susceptible to land slide or slope failure.

Figure 6: Connection between: (a) posts and horizontal rafters at verandah, (b) posts and horizontal rafters at eaves level, (c) post and ceiling, (d) post, rafters, and inclined roof member at eaves level from inside, (e) post, rafters, and inclined roof member at eaves level from outside, (f) post, rafters and asbestos sheet used for roofing.

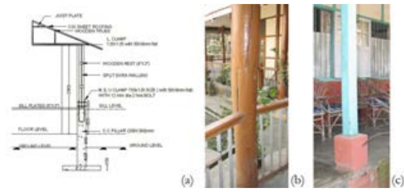

Figure 7: Details of main vertical wooden posts and foundation used in typical Assam-type houses: (a) section showing various components of post and foundation and connection between them in formal housing, (b) splicing of posts at sill level, and (c) brick masonry pedestals for supporting vertical posts.

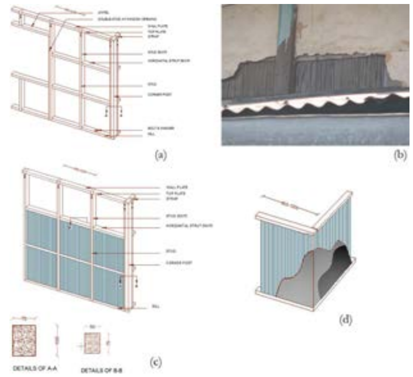

Figure 8: Construction sequence of Ikra walls in wooden frames: (a) details of framing, (b), (c) placement of Ikra reed and bamboo matting in the frames, and (d) filling of empty spaces in the walls and plastering of walls.

Figure 9: (a) Storage of Ikra reed for further use, and (b) making of Ikra roof and boundary wall.

Figure 10: Variants of ceiling observed in typical Assam-type houses: (a), (b) wooden ceiling, and (c) ceiling made using Ikra reed and bamboo similar to roofs.

Figure 11: Commonly used roofing system: (a) CGI sheets, and (b) Ikra reed.

Figure 12: (a) Construction of additional Ikra type class rooms on third floor (on right side) of a reinforced concrete school building, and (b) damage sustained by the walls of the class rooms during 18 September 2011 Sikkim earthquake.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	The walls are made of planar frames of bamboo of different diameters, varying from 25 to 100 mm, infilled with Ikra reed panels as shown in Figures 8 and 13a. These panels can be either mud-plastered or cow dungfine river sand plastered or cement/lime-fine river sand plastered on one/both faces, they are further painted on one or both faces, completely depending on the economic capacity of the house owner. In recent constructions, the Ikra walls do not continue till ground level, instead un-reinforced masonry walls of 120 mm thickness are constructed above ground level till sill level and then Ikra walls are supported on the masonry walls. These masonry walls are supported over 250 mm thick masonry walls below ground level to a depth of about 600 mm. Generally, internal walls do not continue till roof level (except for formal houses); in some cases, plastered walls continue only till lintel level over which walls without plaster continue till roof level or eaves level (Figure 13b). In another variation, walls are not constructed at all over lintel levels; especially in those rooms which do not have any additional door or window openings (Figure 13c).			

Foundation	No formal foundation is used in typical Assam-type houses. The main wooden verticals of the house are pierced into the ground by about 600-900 mm. In some cases involving construction of formal houses, the main wooden posts of the house are supported on masonry or plain concrete pillars constructed over the ground up to plinth or sill level. The connections between wooden posts and the pillars are achieved using steel bolts and U-clamps as shown in Figure 7a. Splicing of wooden posts is also commonly observed in these wooden posts (Figure 7b). One variation of the house below the floor level is addition of stone masonry plinths directly resting the house on ground. The plinths are made of stone in mud/lime mortar; the plinth walls are about 400 mm wide and 500 mm deep below ground. The plinth walls rest directly on the soil without any leveling course and without bond stones. In olden days, the wooden posts were embedded in brick masonry pedestals (Figure 7c). The mortar used in the brick masonry was made of lime, rice flour of a particular variety of rice, fine clay particles, etc. Later, the foundations are made of plain cement concrete (CC) mats (generally using 1 part cement : 3 parts sand : 6 parts aggregates) over which pedestals of same grade are raised up to plinth level of buildings. Wooden posts are fixed to these concrete pedestals with the help of iron clamps (Figure 14). Over the period, with the easy availability of cement and steel, reinforced concrete footings and smaller size reinforced concrete columns (for example, 200 mm square) are also being used.			
Frames (beams & columns)	Vertical Posts: The main timber posts are made of 150-250 mm diameter, and intermediate wooden posts are made of variety of sizes, for example, 125×125 mm, 125×75 mm, 100×100 mm, 100×75 mm, using locally available Sal wood or Nahar wood (also known as Iron wood). The intermediate wooden verticals are generally placed at a centre-to-centre spacing of about 1.0-1.2 m. The spacing between main vertical members is kept higher, for example, 2.0-3.0 m, and in addition, intermediate vertical posts are provided between sill band and band at eaves level. These additional vertical posts do not continue below sill level. In any case, the spacing between vertical posts at sill level is not more than 1.0-1.2 m. Actual spacing of these posts is governed by location of door/window openings and other functional requirements. A typical layout of vertical posts in modern Assam-type housing is shown in Figure 15. Connection details between various timber members are shown in Figures 6 and 7.			
Roof and floor(s)	Roof Truss: Ikra houses have sloped roof (doubly pitched gables) made of thatch infill and roofing resting on wood posts, rafters and purlins. The rafters are made of about 150 mm diameter wood logs from locally available Sal wood, placed at about 600-700 mm spacing. The purlins are made of bamboo of size up to 100 mm, placed at about 300 mm spacing. The thatch roofing is made of Ikra reed. As a variation, machine-cut wood runners are used with metal sheeting roof. Wooden bands of size varying from 100×75 mm to 150×75 mm are provided at sill level, lintel level, floor level and eaves level.			

6.2 Builder

Yes. These buildings are mostly built by the owners for self stay.

6.3 Construction Process, Problems and Phasing

The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

No special design is carried out. The local skilled artisans construct this type of houses.

6.5 Building Codes and Standards

This construction type is not addressed by the codes/standards of the country.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and authorized as per development control rules.

Building permits are not required to build this housing type in rural areas. Building permits are required to build this housing type in urban areas. Building permits are 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

The unit construction cost accounts to approximately 5000 Rs/m2 (100 US-$/m2). Labor requirement costs add up to 1250 Rs/m2 (25 US-$/m2).

Figure 13: (a) Details of mud-dung plastering on walls, (b) and (c) arrangement of internal walls.

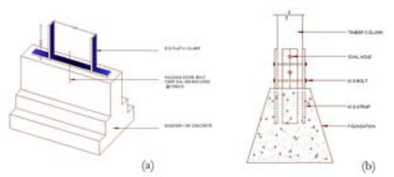

Figure 14: Foundation detail of typical Assam-type house.

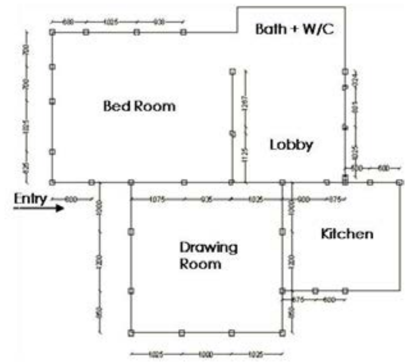

Figure 15: Plan showing arrangement of timber posts in a formally constructed typical Assam-type house.

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.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Cost of strengthening of this type of building may be higher than reconstruction costs. In addition, vulnerability factors associated with this building typology are too low with very low chances of suffering collapse resulting in human fatalities. Therefore, less priority is given to developing retrofitting strategies for this typology and strengthening is generally not conducted. However, repair and routine maintenance of the houses are carried out frequently. Nevertheless, IAEE guidelines for earthquake resistant non-engineered construction (IAEE 1986) suggest the provision of wooden diagonal bracing members in the plane of Ikra walls as well as horizontally at the top of the wooden frame in order to achieve adequate seismic resistance of houses constructed in higher seismic zones. The wooden bracing members (cane or bamboo) may be nailed to the wooden framing members at both the ends as well as at intermediate points of intersection as shown in Figure 16.

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?

Generally seismic strengthening scheme is not adopted.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?

No data available.

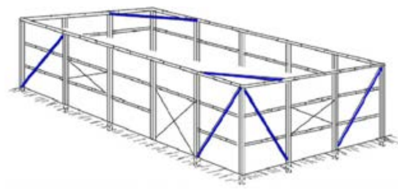

Figure 16: Diagonal bracing in the plane of Ikra walls and horizontally at the top level of the wooden frame for improved seismic performance (IAEE 1986).

Reference(s)

1. Heritage Guwahati
   Banerjee, D.
   published by Kamrup (Metropolitan) District Administration, Guwahati 2004 ed. Monideepa Choudhuri

2. Performance of structures during the Sikkim earthquake of 14 February 2006
   Kaushik, H.B., Dasgupta, K., Sahoo, D.R., and Kharel, G.
   Current Science 2006 91(4): 449-455

3. Guidelines for Earthquake Resistant Non-Engineered Construction
   IAEE
   The International Association for Earthquake Engineering, Japan 1986

4. Live Better with Mud and Thatch Improved Rural Houses
   CBRI
   Published by Central Building Research Institute, Roorkee 1984

5. The Mw 6.9 Sikkim-Nepal Border Earthquake of September 18, 2011
   Murty, C.V.R., Raghukanth, S.T.G., Menon, A., Goswami, R., Vijayanarayanan, A.R., Gandhi, S.R., Satyanarayana, K.N., Sheth, A., Rai, D.C., Mondal, G., Singhal, V., Parool, N., Pradhan, T., Jaiswal, A., Kaushik, H.B., Dasgupta, K., Chaurasia, A., Bhus
   Earthquake Engineering Research Institute 2012 Special Earthquake Report - Fe

Author(s)

1. Hemant Kaushik
   Assistant Professor, Dept. of Civil Engineering, Indian Institute of Technology, Guwahati, Guwahati 781039, INDIA
   Email:hemantbk@iitg.ernet.in

2. K. S. Ravindra Babu, Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati 781039 , INDIA

Reviewer(s)

1. Amit Kumar
   Assistant Director
   , Disaster Management Institute
   Bhopal 462016, INDIA
   Email:Amitverma7@hotmail.com FAX: (91-755) 46 7981

2. aan
   marandius
   ,
   palembang 30149, INDONESIA
   Email:marandius_umb4@yahoo.com FAX: 07117440493

3. aan
   marandius
   ,
   palembang 30149, INDONESIA

Email:marandius_umb4@yahoo.com FAX: 07117440493