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EXPERIMENTAL STUDY ON TRADITIONAL ASSAM-TYPE WOODEN HOUSE FOR SEISMIC ASSESSMENT

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Abstract

Assam-type wooden houses are one of the very few housing systems in India that have performed exceptionally well during past earthquake shakings. Due to the historical high seismicity of the north-eastern region of India, 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 houses. These houses are easy to construct, maintain, and economical. The walls of Assam-type house are the most highlighting feature of this typology, as they are made of light-weight Ikra or bamboo mesh due to which such houses do not require extensive foundations, and therefore, can be used in varied geological conditions. The housing is known to have a number of features that contribute to the safety of the house during an earthquake. These houses have regular and symmetric configuration in plan, smaller openings, and small projections and overhangs. The structural features include very light mass of walls and roof, good wall-to-wall connection (in case of formal construction), and good quality and strength of materials used. Another unique feature of these houses is flexible connections (nut-bolts, nails, grooves, etc.) used for different wooden elements at different levels. In spite of all these exceptionally good features these houses have not received due attention and their performance under seismic action has not been studied so far.

The uniqueness of this type of house from other traditional wooden houses lies in its construction methodology, framing members, special type of connection between framing members, light-weight walls, and foundation. A description of the material used, typical construction methodology adopted, and the lateral load performance of the Assam-type house are discussed in this paper. In the current study, individual full-scale frames of a typical single-story Assam-type house were tested under monotonic and slow cyclic lateral loads to gain an insight into the lateral load behaviour of such houses. The experimental results showed excellent behaviour in terms of drift and ductility. Both wooden frames, without ikra walls and with ikra walls, exhibited very high lateral displacements without significant drop in lateral load carrying capacity. Failure of the frames was primarily due to separation of various secondary members at connections and flexural failure of vertical posts at high lateral drift levels. Interestingly, the connections between the main posts and the foundation and between the main posts and the top beam remained intact during the tests. Hysteretic behaviour of the frames showed stable and more or less symmetric loops with low energy dissipation due to pinching. The excellent performance observed can be attributed to the unique type of construction with flexible connections and light-weight material used in construction. Experimental data thus obtained can be used to develop an analytical model for seismic assessment of such houses.

Keywords: Assam-type house; traditional wooden house; seismic evaluation; Ikra wall; cyclic test

1. Introduction

Traditional wooden type of houses are found in most parts of the world. These timber frame buildings are characterized by a timber frame infilled with variety of materials (masonry, wood products, etc.), and are also known as half-timbered buildings. Half-timbered constructions are commonly found in Portugal (Edificios Pombalinos), Italy (Casa Baraccata) ,Germany (Fachwerk), Greece (Ksilopikti Tichopiia), France (Colombage), Scandinavia (Bindingsverk), United Kingdom (Half-Timber), Spain (Entramados), India (Dhajji-Dewari) and

Turkey (Himis) [1, 2, 3, 4]. In Turkey, Baghdadi, Himis and Dizeme are the traditional timber-frame systems, differentiated mainly in the choice of infill [2, 5, 6, 7]. The seismic performance of these traditional timber-braced frame systems has been found to be exceptionally resilient to earthquake shaking [2, 3, 8]. The excellent performance of these system can be attributed to the closely spaced vertical posts, horizontal and diagonal bracing, and the inherent flexible property of wood. One of the reasons for Baghdadi and Himis traditional timber houses to have performed well during the earthquakes is due to their light weight infill. Assam-type house is one of such traditional houses, found in North-Eastern region of India, which has light weight infill besides other good properties [9].

Assam-type houses are one of the very few housing systems in India that have performed exceptionally well during past earthquakes compared to other popular structural systems, such as, reinforced concrete frame buildings and masonry buildings. Due to the historical high seismicity of the North-Eastern region of India, the local people have developed a unique housing system in terms of both its construction technique and the material used in the structural components. This type of construction has been in practice for many decades, and is mostly seen in the North-Eastern part of India, where the local people mostly use the local resources in construction of such houses. This makes Assam-type houses easy to construct, maintain, and an economical housing construction typology. The walls of Assam-type houses are made of Ikra (locally available reed found in river beds) or bamboo mesh material that makes it light weight due to which it does not require extensive foundations, and therefore, can be constructed in varied geotechnical conditions. It has excellent ability to withstand seismic events which has been proven in past earthquakes [9, 10, 11]. Also, these walls have good thermal and acoustic qualities. This type of construction does not require commercially processed materials or a skilled labour force; rather unskilled local labour can conveniently construct an Assam-type house. A typical Assam-type house is shown in Fig.1 [10].

In spite of all these exceptionally good features, these houses have not received due attention and their performance under seismic action has not been studied so far. The uniqueness of this type of house from other traditional wooden houses lies in its construction methodology, framing members, special type of connection between framing members, light-weight walls, and foundation. So, in this study, a description of the material used, typical construction methodology adopted, and the lateral load performance of the Assam-type houses are discussed. For evaluation of lateral load performance of a typical single-story Assam-type house, individual full-scale frame walls were tested under slow cyclic and monotonic loads to gain an insight into the lateral load behavior of such houses. Experimental data thus obtained can be used to develop an analytical model for seismic assessment of such houses.

Fig. 1 – A typical Assam-type house [10]

2. Assam-type house and its construction methodology

Due to high seismicity in the north-eastern region of India, the local people have developed a unique construction typology using locally available materials to construct their dwellings that are highly earthquake resistant and commonly known as Assam-type houses or Ikra houses. The name Ikra given to such housing typology is derived from a 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. The housing is known to have a number of features that influence earthquake safety of the house. These include: (a) Architectural aspects: regular plan, small openings, central 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 (using bolts, nails, grooves, etc.) between various wooden elements at different levels [10].

Several modifications in the construction methodology and materials used in Assam-type housing have been observed at various places to suit the local requirements. The frames and panels of the windows and doors are made of locally available wood material. The door and windows are small in size and are generally placed in the center of the walls. The sizes of main post are about 100 to 125 mm for square sections and 125 to 150 mm for round logs. The wall plate beams are generally 75×100 mm. The intermediate stud frame sections are about 65 to 75 mm square. The rafter sections are about 75×65 mm and purlins are about 75×50 mm. The simplest version of the house is geometrically regular and rectangular in plan of size 3x6 m. In rural areas, such houses are not constructed on formal foundations. But in construction of formal houses, the main wooden posts of the house are supported on plain concrete pillars constructed over the ground up to plinth and the connections between wooden posts with foundation are achieved through steel clamp. An important aspect of this housing type is its connection between various elements: posts, intermediate studs, wall plate, wall panels, roof trusses, and roofing elements. Typical Assam-type houses have false ceilings made of timber and bamboo mats, while in modern construction, ply wood or AC sheets are used. Pitched CGI (Corrugated Galvanized Iron) sheet roofing over timber trusses is the most common form of roofing used in these houses.

3. Description of specimens and material properties

In the present study, a 3 m × 3 m full scale Assam-type house is considered. Before construction of full scale specimen, a wall (2-D frame) of the full scale specimen was constructed. The wall specimen was fully infilled 2-D frame with masonry wall below sill and ikra wall without opening above sill (Frame 2). Besides this specimen, one 2-D frame specimen was also constructed which has masonry wall below sill and no ikra wall above sill (Frame 1). This frame was constructed to understand the influence presence of Ikra wall in overall lateral load response. The details of the tested 2D frames are shown in Table 1. The details of the frame dimensions, section sizes and location of different types of joints in both specimens are shown in Fig.2.

The connections between each vertical post and the concrete pillars are achieved using two L-clamps and steel bolts as shown in Fig. 3(a). These connections resist load in the direction of the clamps and allow rotation in the other direction. The orientation of L-clamps changes at various post locations (Fig. 2). At the top of main post, wall plate is inserted through the open mortise and tenon joint as shown in Fig. 3(b). The connection is also known as tongue and fork joints or Bridle joint. The tongue part is bolted with the main post using one bolt at the center of the joint, and in order to reduce the sway due to flexible joints, this connection is extended with the help of a steel plate and another bolt connecting the main post with the steel plate as shown in Fig. 3(b). The intermediate vertical and horizontal studs are placed at a spacing of about 800-900 mm. At one end, the connection is mortise and tenon joint (Fig. 3c) and at the other end the horizontal stud rests on the shear key type of arrangement as shown in Fig. 3(d). For inserting the vertical bamboo meshing and vertical intermediate studs, grooves of size 5 mm width and depth 15 mm are made along the length of the horizontal studs (Fig. 3e). The vertical studs are toothed on both sides so that they can fit into the groove of the horizontal stud (Fig. 3e). Single nail is driven in all the connections between vertical and horizontal stud members of the wooden frame. Brick masonry of thickness of about 75 mm is used as infill up to sill level, and above sill level locally available bamboo mesh of thickness of about 45 mm is used as infill. For out of plane stability of masonry walls, two long nails are provided in the mortar joint which are driven in each main post so that the masonry wall should not fall out of the plane.

For construction of the specimens, locally available materials were used. The main framing members of the specimens were of Sal (*Shorea Robusta*) timber and bamboo mesh was used for infill panels. The infill panels of bamboo mesh and the clay brick infill (below sill) were plastered with cement mortar. Material properties of timber used in the study are shown in Table 2.

Table 1 – Details of the specimens tested in the present study

Specimen no.	Type of frame	Notation
1	Frame with no Ikra wall (masonry wall provided till sill level)	Frame 1
2	Frame with Ikra wall without opening (masonry wall provided till sill level)	Frame 2

Table 2 – Material properties of Sal Timber used in tests

Material property	Range
Specific gravity	0.9-1.1
Moisture content (%)	25-35
Static bending strength (MPa)	5-8
Compressive strength parallel to grain (MPa)	40-45
Compressive strength perpendicular to grain (MPa)	35-40
Tensile strength parallel to grain (MPa)	80-85

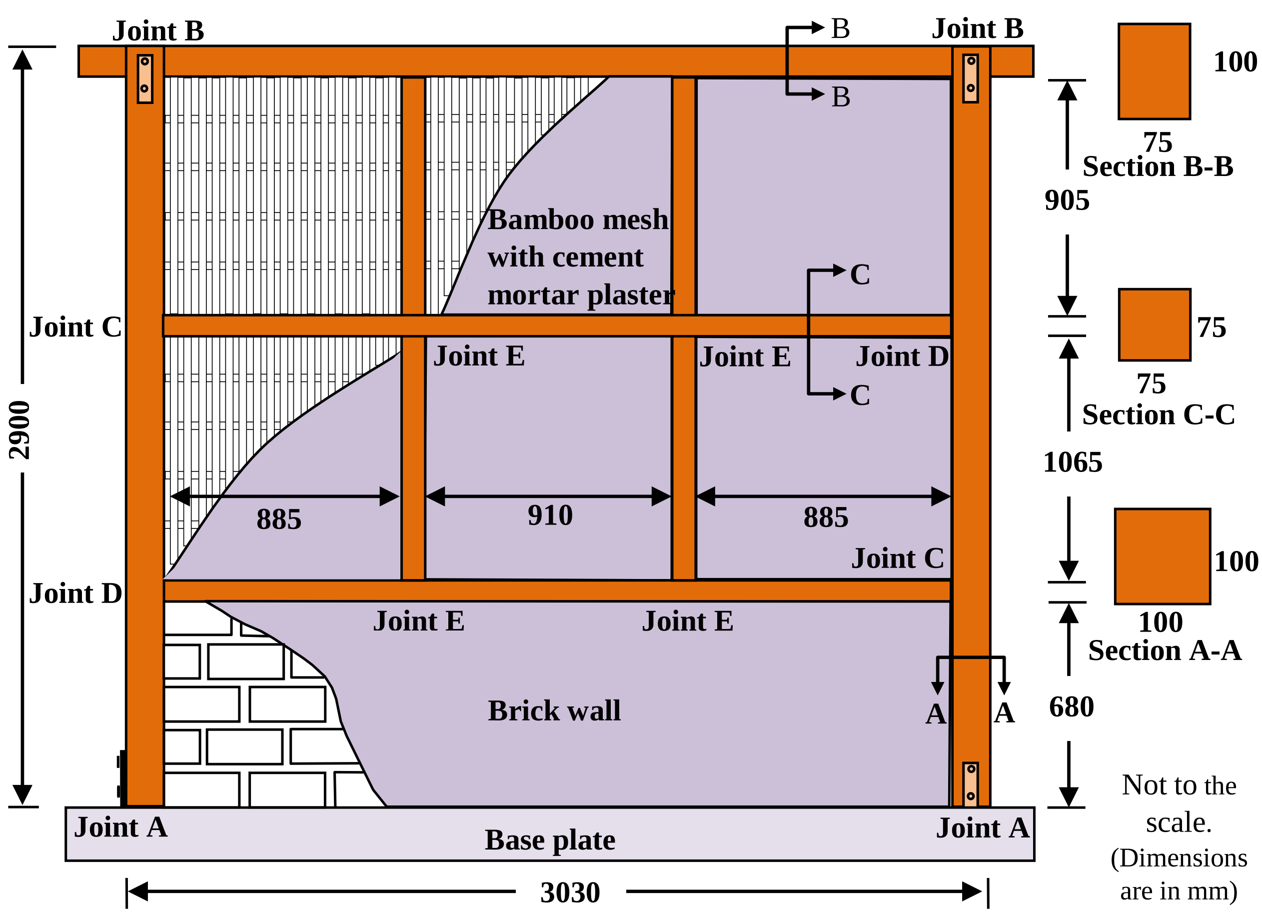


Fig. 2 – Details of member sizes and types of connections used in Assam-type frame specimens

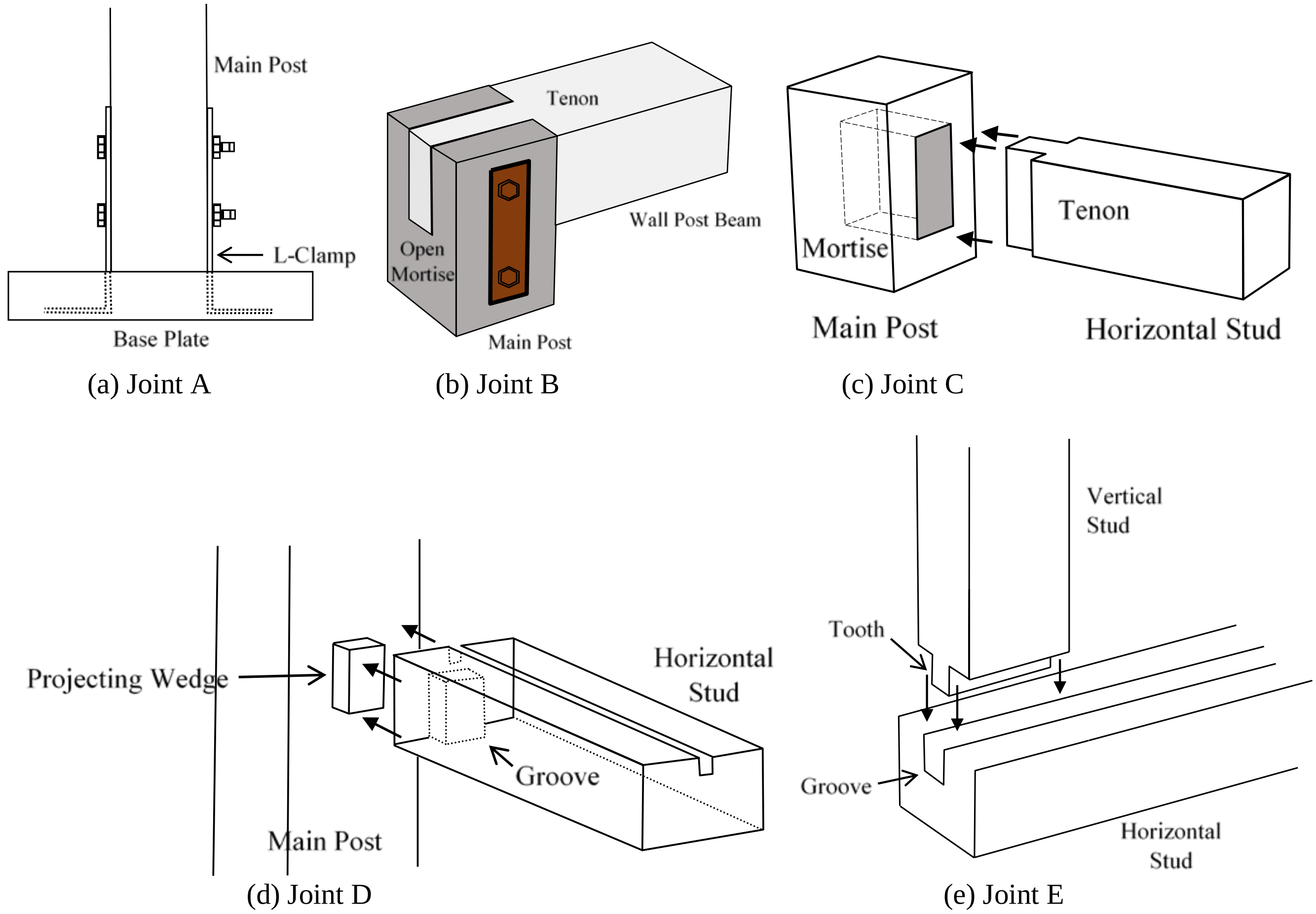


Fig. 3 – Details of various connections between different members of the frame (location shown in Fig. 2)

4. Testing procedure and experimental set up

Servo controlled hydraulic actuators of 250 kN load capacity and a stroke length of ±250 mm was used to apply slow cyclic lateral load followed by monotonic loads over the specimens. The experimental procedure followed in testing was same for all the specimens and the displacement history is shown in Fig. 4. Three cycles of each displacement level were applied and the response was recorded using a data acquisition system. The displacement was increased by 2.5 mm after every displacement cycle up to 25 mm, and by 5 mm thereafter with the frequency of each cycle being 0.015 Hz. Maximum lateral load resistance of the specimens is reported in both push (-) and pull (+) directions.

The experimental test setup for testing of the specimens in the laboratory is shown in Fig. 5.The main posts and masonry wall of the test specimens were supported by concrete slab (Fig. 5) and the concrete slab was fixed with the strong floor with the help of the nut and bolts. To prevent the out of plane movement of the specimens during in plane loading, lateral supports with roller bearing arrangement were provided in both sides of the specimens as shown in Fig. 5(a) and Fig. 5(b). The main lateral response of the specimens were recorded by load cell and displacement transducer in the hydraulic actuator. To record the lateral displacements at different levels of the specimens, LVDTs (linear varying displacement transducers) were used as shown in Fig. 5(c).

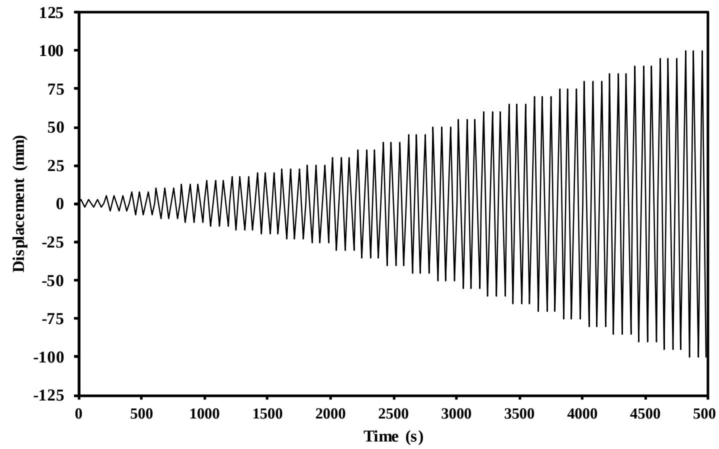
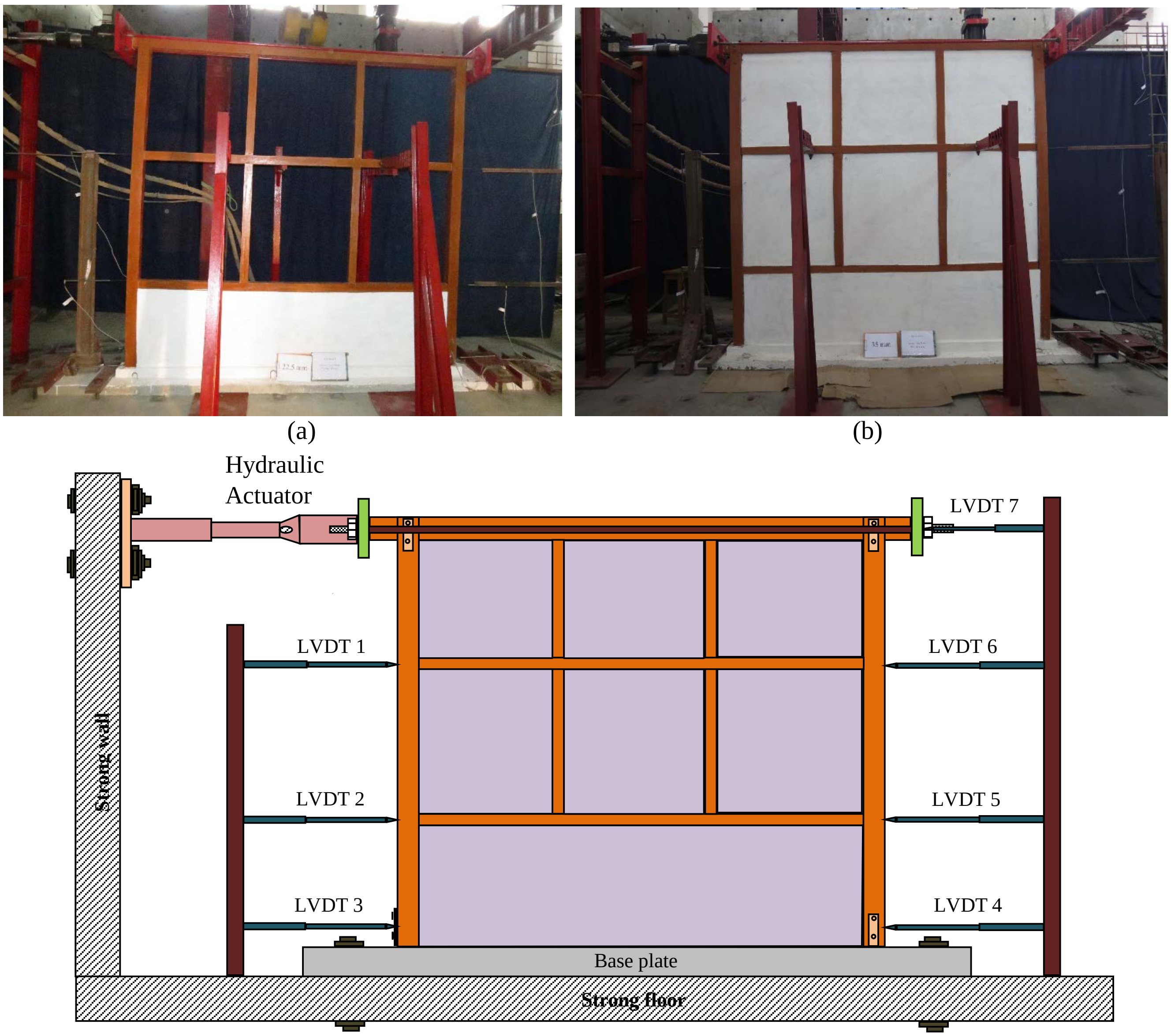


Fig. 4 – Testing program for all specimens



(a) (b)

(c)

Fig. 5 – Details of experimental test set up: (a) Test set up of Frame 1, (b) Test set up of Frame 2, (c) Sensor locations in the set up

5. Behavior of specimens during the testing

The common behavior observed during the testing are summarized here. Both the specimens were first subjected to a cyclic loading up to a lateral displacement of ± 250 mm. Since failure of the specimens was not observed even up to a lateral displacement of 250 mm, the damaged specimens were subjected to a monotonic displacement controlled loading for another 250 mm. Fig. 6 shows behavior of both tested frame specimens during cyclic testing and after monotonic testing. When horizontal displacement was imparted to the frames, the single nail connection between the horizontal and the vertical studs loosened, and at higher drifts, the nails pulled out from the joints. As shown in Fig. 2, the connection of the horizontal studs with the main post is such that if one side is mortise and tenon joint then the other side is open grooved which rests on a small wooden projection in the main post. Thus, such connections in the horizontal studs make the frame more flexible. Similarly, the connections between vertical and horizontal studs are also flexible as the joints are tooth and groove joint, and at higher drift, the vertical members slide in the groove of horizontal stud as shown in Fig. 6. Due to this, differential movement of wall panels was observed above and below the lintel stud level without damage in wall panels (Figs. 6c and 6d).

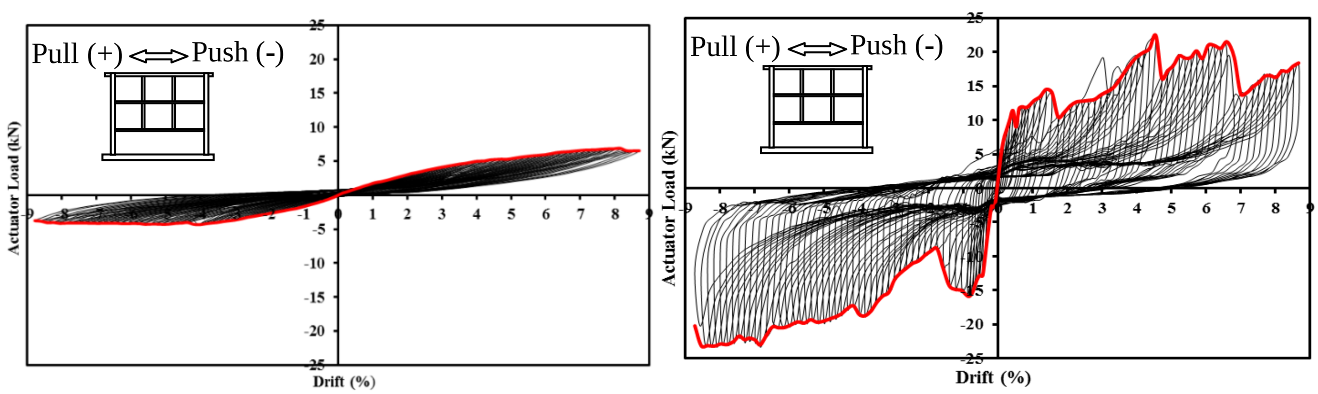
Though internal member joints were loosened during the tests, no major damage occurred in structural members during cyclic testing. Since the wooden posts were neither inserted in the foundation nor fixed on any wooden member, the damage in main joints are unlikely contrary to the damages in the main joints of other traditional frames [1,2,7] which resulted in very high lateral drift and ductility. The main post connections in the frame allow rotation in one direction whereas restrict in the other direction. Due to the difference in support conditions of the main post joints, the deformation profile of both the posts were different under the same lateral load. Joints of the main framing members of all the specimens were fully intact during the entire testing. At a very high lateral drift level (4.74% - 4.9%), minor flexural cracks at sill level and lintel level were observed in the main post of Frame 1 due to excessive bending at those locations as it can be seen in Fig. 6(a). In Frame 2, no major crack was observed in both the masonry wall as well as the Ikra walls during the entire 8.77% drift level in cyclic testing, because the excessive bending that was seen in Frame 1, reduced by the presence of ikra infill panel above the sill level. The major damage occurred in the framing members of Frame 1 and Frame 2 during the monotonic testing only. The damage locations in both the frames at the junction of main post and horizontal stud at sill level during monotonic testing are shown in Figs. 6b and 6d. Interestingly, the infill (ikra) panels were least damaged during the cyclic and monotonic loadings and some corner crushing of the plaster were observed in the specimen (Figs. 6c and 6d). Unlike Frame 1, the Ikra walls helped in maintaining the lateral stability of Frame 2 and reducing the excessive bending of main posts even under large lateral drifts; this resulted in the highly deformable lateral load behavior of Frame 2.

6. Results and discussions

The hysteresis loops of all the test specimens were more or less symmetrical in push and pull directions. The small difference was due to the different support and joint condition at the main post locations causing the force of resistance to be different in both directions. From Fig. 7(a), it can be seen that the lateral load on Frame 1 in both pull and push directions increases and then remains more or less constant till a lateral drift of about 8.7% without significant loss of strength. From Fig.7 (b), it can be seen that the hysteresis loops for Frame 2 are not uniform as compared to Frame 1 and several drops (and further increase) in lateral loading is observed at increasing lateral drift levels signifying the separation of joints between the Ikra walls and the surrounding frame with increasing lateral drift. The increase in strength is comparatively more gradual and uniform in pull direction. This may be due to lesser readjustment of joints in pull direction and better utilization of tensile property of the main framing member. Strain hardening is more prominently observed in the pull direction in Frame 2. There is also a significant stiffness degradation in the hysteresis loops in Frame 2. From the hysteresis curves in Fig. 7a and 7b, it is seen that Frame 1 and Frame 2 have hysteretic response significantly different from each other. This is because of the presence of infill (Ikra) wall in the internal panel in Frame 2 when compared to the bare frame structure of Frame 1.

(a) (b) (c) (d)

Fig. 6 – Assam-type housing frame wall tested specimens: (a) Frame 1 during cyclic loading, (b) Frame 1 at the end of monotonic loading, (c) Frame 2 during cyclic loading, and (d) Frame 2 at the end of monotonic loading



(a) (b)

Fig. 7 – Hysteretic response and envelop curve of the tested specimens: (a) Frame 1, (b) Frame 2

As already discussed, the cyclic tests were followed by the monotonic tests on both frames. Fig. 8(a) shows the comparison of results of monotonic tests on two specimens. The monotonic tests were carried out after the 8.8% drift of cyclic testing and the tests were carried out till a maximum drift level of 17.5%. From the figure, it is clear that Frame 2 has the higher lateral load carrying capacity but it drops suddenly after 12.28% lateral drift due to the failure of the main post at the sill level of the specimen.

The plot between the lateral loads acting on the frame and the corresponding lateral displacement gives the envelope curve. Fig. 8(b) shows the comparison of envelop curves of the tested specimens. The lateral load carrying capacity and stiffness of the Frame 1 was obviously lesser that that of the Frame 2. Frame 2 has more lateral load carrying capacity due to presence of Ikra walls, which have significant influence on the overall lateral load behavior of Assam-type houses, unlike other traditional houses in which infill have little influence on the lateral strength [2, 12].

Energy dissipated is the area enclosed by the load-displacement hysteresis loops. The comparison of cumulative energy dissipation curve of both the tested specimens are shown in Fig. 8(c). From the figure, it is clear that Frame 2 showed very high energy dissipation as compared to Frame 1 which highlights the very high energy dissipation capability of the infill ikra panels in the Assam type houses.

The comparison of cyclic loads and monotonic loads along with the corresponding maximum drift levels and cumulative energy dissipation of tested specimens are shown in Table 3.

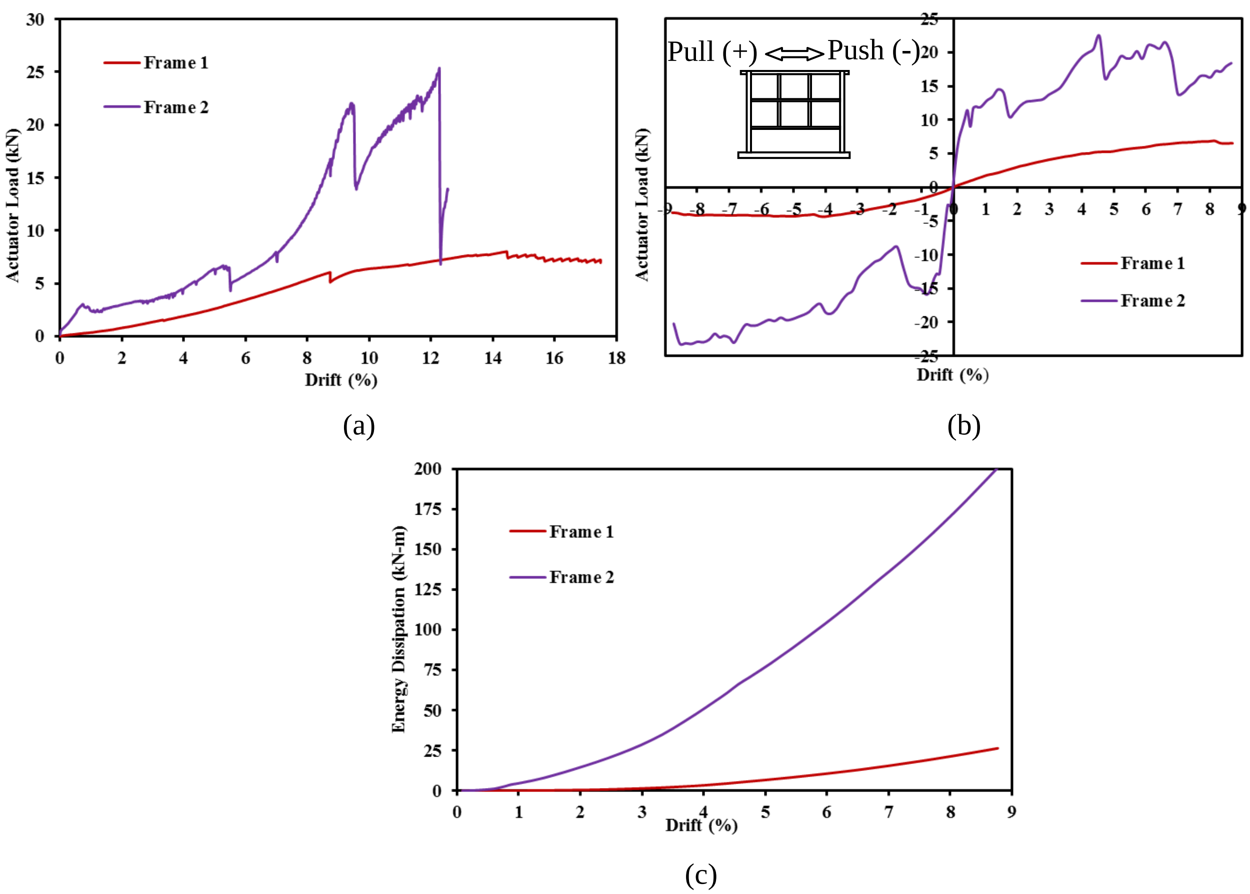


Fig. 8 – Comparisons of test results for both the specimens: (a) monotonic curves, (b) envelop curves, and (c) cumulative energy dissipation curves

Table 3 – Comparison of cyclic load and monotonic load of tested specimens

Specimen no.	Type of frame	Cyclic loading			Monotonic loading		Cumulative energy dissipation (kNm)
		Push (kN)	Pull (kN)	Drift (%)	Max. load (kN)	Drift (%)	
1	Frame 1	-4.3	6.9	8.8	8.0	17.5	26
2	Frame 2	-23.2	22.4	8.7	25.4	12.5	200

7. Summary and conclusions

Lateral load behavior of Assam-type house, which was a common housing typology in North-eastern part of India till recent past, has been examined in the current experimental study. The study showed that the ability of Assam-type house to undergo high lateral deformation without failure is primarily due to the flexible joints of the framing members and due to light infill walls (Ikra) of the house. Unlike other similar housing typologies, the main wooden posts in Assam-type houses are not inserted into the foundation and are not fixed on any wooden member, thereby reducing the possibility of the failure of the main joints. Further, the Ikra walls in the house do not damage the surrounding timber frame even at large lateral drifts because of their light weight and their unique connection with the timber frame that allows sliding of the Ikra walls in the frame. The connections between main wooden posts and concrete pillars in the houses are also unique in nature; they allow some rotation in one direction whereas restrict it in the other direction. Further, the flexible connections between the horizontal studs and vertical studs make the frame even more flexible. Such types of connections between different members of the frame and between Ikra walls and the frame are not commonly observed in other traditional housing systems. The absence of rigid joints in the entire wall frame system is one of the reasons for better performance of the Assam-type house during severe earthquake shakings.

From the comparison of results of both the specimens, it can be concluded that there is a significant influence of Ikra walls used as infills on the lateral strength, stiffness, energy dissipation and the overall lateral load behavior of the Assam-type house. Due to the presence of Ikra walls in Frame 2, initial stiffness and lateral load carrying capacity of Frame 2 was found to be significantly higher than that of Frame 1. From the envelope curves, it is clear that in case of Frame 2 the lateral load carrying capacity was maintained and did not drop even at a drift level of 8.7%. Frame 2 also exhibited significantly higher energy dissipation due to presence of Ikra walls. Though Ikra walls themselves did not suffer any damage, they helped keeping the wooden frame in a stable condition at large lateral drifts. Even though the cyclic tests were carried out till 8.7% lateral drift, the tested frames incurred very less damage, and major damage was observed only during monotonic loading at even higher lateral drift levels (about 12%). Overall, both the frames exhibited a very promising performance, especially, quite high deformability under lateral loads without any significant damage. The test results showed a significant influence of presence of Ikra walls on lateral load behavior of Assam-type house. More tests are required to be carried out in Assam-type houses in order to further understand their behavior under dynamic loads and to develop analytical models for their lateral load analyses.

8. Acknowledgements

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9. References

[1] Poletti E (2013): Characterization of the seismic behavior of traditional timber frame walls. *Universidade do Minho Escola de Engenharia*, Gualtar, Portugal.

[2] Ali Q, Schacher T, Ashraf M, Alam B, Naeem A, Ahmad N, Umar M (2012): In-plane behavior of the Dhajji-Dewari structural system (Wooden braced frame with masonry infill). *Earthquake Spectra*, 28(3), 835−858.

[3] Rai DC, Murty CVR (2005): Preliminary report on the 2005 North Kashmir Earthquake of October 8, 2005, *Indian Institute of Technology Kanpur*, India.

[4] Langenbach R (2007): From "Opus Craticium" to the "Chicago Frame": Earthquake-resistant traditional construction. *International Journal of Architectural Heritage*, 1(1):29-59.

[5] Gülkan P, Langenbach R (2004): The earthquake resistance of traditional timber and masonry dwellings in Turkey. *13th World Conference on Earthquake Engineering*, Paper No. 2297, Vancouver, BC, Canada.

[6] Dogangun A, Tuluk O, Livaoglu R, Acar R (2006): Traditional wooden buildings and their damages during earthquakes in Turkey. *Engineering Failure Analysis*, 13, 981−996.

[7] Aktaş YD, Akyüz U, Türer A, Erdil B, Güçhan NS (2014): Seismic resistance evaluation of traditional Ottoman timber-frame himis houses: Frame loadings and material tests. *Earthquake Spectra*, 30(4), 1711-1732.

[8] Cardoso R, Lopes M, Bento R (2004): Earthquake resistant structures of Portuguese old "Pombalino" buildings, *13th World Conference on Earthquake Engineering*, Vancouver, BC, Canada.

[9] Jain SK (2016): Earthquake safety in India: Achievements, challenges and opportunities. *Bull Earthquake Engineering*, 14, 1337–1436.

[10] Kaushik HB, Ravindra Babu KS (2012): Assam-type House. *World Housing Encyclopedia*, Report no. 154.

[11] Kaushik HB, Dasgupta K (2013): Assessment of seismic vulnerability of structures in Sikkim, India, based on damage observation during two recent earthquakes. *Journal of Performance of Constructed Facilities*, 27(6), 697−720.

[12] Vieux-Champagne F, Sieffert Y, Grange S, Polastri A, Ceccotti A, Daudeville L (2014): Experimental analysis of seismic resistance of timber-framed structures with stones and earth infill. *Engineering Structure*, 60, 102−115.