Sustainable bamboo housing for the earthquake prone areas

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Abstract. Bamboo-based housing systems are prevalent as a vernacular type of construction in many parts of the world where bamboo is available locally. Even in India, bamboo-based houses are not so uncommon, especially in the north-eastern part, which is seismically the most vulnerable zone. Structural evaluation, chiefly seismic evaluation, significantly requires a lot of infrastructures. Prohibitively expensive infrastructure cannot be used to evaluate housing systems which themselves are extremely low-cost in nature. There is a need to evaluate the components of a bamboo-based housing system in addition to the full-scale models under seismic loads by using simple and cost-effective facilities. A seismic evaluation of a full-scale bamboo housing system was carried out on two models using a shock table test facility. This helped in identifying the extreme limits of seismic vulnerability of the bamboo-based housing system. From this study, it was observed that the model did not collapse nor did it show any signs of collapse. Also, there were no indications of any tendency of any local collapse of the roofing elements. Hence, it can be concluded that the model had fulfilled the requirement of resisting major levels of lateral forces without losing its stability.

1. Introduction

Bamboo has been traditionally used for a variety of purposes and has gained renewed importance in the present day context of shortage of wood due to its fastest growing capability. Bamboo is widely used for construction of houses/structures, foot-bridges, scaffolding walls etc. in bamboo rich countries.

Apart from being structurally efficient, because of its applications and varied uses in construction bamboo is established as cost-effective and an energy-efficient construction material. Bamboo is an important resource found in the forest as well as non-forest areas in the country. In India, 11 exotic and 125 indigenous species of bamboo belonging to 23 genera have been reported. As per FAO report on world forest resources, India is in the second place in the world after China in terms of bamboo genetic resources (FSI report, 2011 [1,2]). Out of 78.29 million hectares (Mha) of forest area, the bamboo bearing area of the country is estimated to be 13.96 Mha (17.83%). Some of the major states in India like Arunachal Pradesh have the maximum bamboo bearing area (1.6Mha) when compared with other states like Orissa (1.05 Mha), Maharashtra (1.1 Mha) and Madhya Pradesh (1.3 Mha)[1,2]. Although lot of information is already available on bamboo and a standard on preservative treatment of bamboo (IS 9096:1979[4]) is already in existence in India since a long time, though not widely practiced. Most of the rural houses built in India use untreated bamboo. This may be due to the fact that facilities and chemical required for treatment are neither available nor the user is aware of the advantages of preservative treatment.

For development of bamboo building technology particularly if bamboo has to be used in load bearing structures requiring high reliability needs information on authentic data (physical / mechanical properties) for various species of bamboo available to engineers and designers. It has been felt that
suitability of bamboo for various uses depends upon its strength and dimension especially when bamboo is used for structural purposes. Generation of required data on various physical/mechanical properties of bamboo require large scale of systematic testing of bamboo specimen in a laboratory. In order to design different structural components, economically and for handcraft, it is necessity to classify bamboos and grade different species of bamboos growing in India.

1.1 Grading & Preservation:
Commercial grading of bamboos was attempted irrespective of species with the classification based on purely the dimension and general appearance, qualitative evaluation of defects and evaluation of units of defects and fixing permissible defects based on volume/area of the material in each grade as per National Building Code of India (NBCI, 2005[3]). Preservation treatment is an important component in the overall development of Bamboo Building Technology. Information is already available on bamboo preservation and a standard on the preservative treatment of bamboo (IS 9096:1979 [4]) is already in existence in India since a long time, however it is not widely practiced. There is no doubt that the success of bamboo building technology depends upon the availability of simple manuals on preservative treatment to create awareness among users and specifiers.

2. Bamboo housing for earthquake-prone areas

Bamboo-based housing systems are prevalent as a vernacular type of construction in many parts of the world where bamboo is available locally. Even in India, bamboo-based houses are not so uncommon, especially in the northeastern part, which is seismically the most vulnerable zone. There are many buildings where bamboo has even been used extensively as structural components. Even in tropical India wall panels made of bamboo grids are quite common.

In the northeastern part of India, the bamboo-based housing systems are known to perform better than the conventional economically equivalent structures like masonry, but the general perception of this benefit seems to be lacking, perhaps due to two reasons, viz.,

a) Lack of awareness of utilization of available species with even marginal treatments.

b) Lack of published data on the seismic evaluation of bamboo buildings and quantification of the structural performance of bamboo components.

While the former is currently being addressed through many organizations such as FRI, Dehradun; IPIRTI, Bangalore; IWST Bangalore; KFRI, Kerala, there appears to be scanty attempt to address the latter issue.

Structural evaluation, chiefly seismic evaluation, significantly requires a lot of infrastructures. Prohibitively expensive infrastructure cannot be used to evaluate housing systems which themselves are extremely low-cost in nature. There is a need to evaluate the components of a bamboo-based housing system in addition to the full-scale models under seismic loads by using simple and cost-effective facilities. It is against this backdrop that the present research finds its focus. The bamboo houses built using IPIRTI-TRADA technology are able to withstand the moderate to highest levels of earthquake loading likely to be experienced in India.

2.1 Features of the IPIRTI-TRADA technology:

The wall infill of IPIRTI-TRADA technology is non-load bearing, and comprises a grid of split bamboo (19 mm x 9 mm), tied together with Mild Steel binding wire at 150mm spacing as shown in Figure 1. The grid is tied to steel dowels passing through the columns. Welded wire mesh is fixed to the outer face of the grid. By virtue of the wire ties, bolts and straps, the entire framework is positively connected and fully integrated. In effect, once assembled it becomes a single composite unit. A
cement-sand mortar (1:3) is applied over the grid to a finished thickness of 50mm. The roof is constructed from bamboo trusses and purlins with simple bolted connections, fixed to the wall plate above the columns using steel straps. Bamboo Mat Corrugate Sheet is used as a roofing sheet.

Figure 1: Features of IPIRTI-TRADA wall technology [2]

3. Seismic performance studies on bamboo house models

Generally in India and many other Latin American and Asian countries use bamboo for construction of low rise rural houses either on prepared foundation or on bamboo or wooden stilts. Raised bamboo is extensively used as either dry walling either using whole culms or split bamboos or more elaborate walling like ‘Bajareque’ or Wattle type walls [5]. In Bajareque system whole culms placed at short intervals or covered on either side with horizontally place split bamboo very close to each other or flattened bamboo (Esterilla) panels serving as base for plaster (stabilized mud with lime or cement). In Quincha technique, woven sliver mats held between whole culm posts serve as plaster base. In ‘Bajareque’ system, the cavity is generally filled with mud and stone making wall solid and heavy. Both these constructions are known to have stood earthquakes well as the walls act as bracing giving overall stability to the structure.

The test building using IPIRTI-TRADA technology shown in Figure 2 resisted seven repetitions of a typical Zone 5 earthquake, the highest in India and equivalent to 7 on the Richter scale, and showed no damage [6].

Figure 2: Bamboo house under shake table testing at CPRI, Bangalore [6]
An overly simplified version of the shake table is a shock table. The table is excited by an impulsive force due to a base impact by a pendulum, generating a shock. The shock table can be used to simulate the cumulative effects of ground motion by subjecting it to a series of such base impacts. Since the base input is sequential, it is possible to study the failure/crack patterns developing after each shock in the building model.

The shock table was first developed at the Department of Earthquake Engineering, Roorkee by Keightley [7]. It comprises of central model carrying platform on rails along with two loaded wagons on both the ends for striking and rebound. Arya [8] applied this concept in shock table testing of masonry models subjected to moving tractor impacts. More similar studies were carried out by Rajendra Desai and Jagadish [9] at Latur, where a series of four shock-table testing involving eight different models were undertaken.

Rajendra Desai and K S Jagadish [10] conducted a series of experiments on "Earthquake Resistant Design for Stone and Brick masonry Buildings through Shock Table Tests" at National Centre for People's Action in Disaster Preparedness (NCPDP), to quantify the seismic performance of masonry buildings with various seismic performance improvement measures.

Pankaj Agarwal and S.K. Thakkar [11] have reported on the shock table study conducted on stone masonry-building models. Here, a shock table was used to study experimentally the effectiveness of the existing earthquake resistant measures by model testing.

Shock table test is an effective alternative to shake table tests, especially to subject building models to intensive damage levels with minimal sophistication, though with certain de-merits.

4. Seismic evaluation of bamboo housing system using shock table studies

A seismic evaluation of a full-scale bamboo housing system carried out on two models using a shock table test facility. The shock table test facility has been specially designed to house these models and evaluate it for lateral dynamic loads. The shock table has essentially been designed to ensure that the influence of the dynamics of the shock table did not impinge on the seismic performance of the models. This was achieved by fabricating the shock table to be extremely rigid in its own plane. The dynamics of the shock table have been characterized by free-vibration test and validated using finite element analysis. Later studies were conducted to identify a suitable material at the point of impact of the pendulum with the shock table in order to effectively transfer the energy imparted to the models. Later, the models were constructed on the shock table and evaluated [Figure 3].

Figure 3: Bamboo house during testing under shock table
The test program consisted of 15 shocks given to the shock table. A series of three base shocks each varying the angle of release of the pendulum from 20 to 40 degrees in the interval of 5 degrees [20°, 25°, 30°, 35° and 40°] were applied with the help of the 400kg pendulum mass. This amounts to a total cumulative energy of 13236 Nm from the fifteen shocks given to the shock table. After the last set of three shocks with an angle of 40° the cracks portions were observed even in the inside portion of the house model. However the cracks were clearly visible only on the outside portion of the walls. Figure 4 shows the propagation of cracks after the shock table test.

After the test programme, it was observed that the prototype resisted the shocks and showed no signs of falling apart. Thus it can be stated that the model has met the objectives of resisting moderate levels of dynamic forces with minimal damage levels. The amount of cumulative energy imparted was severe enough to cause damages far more extensive than the damages that were reported from various earthquakes. Thus, as opposed to the shaking table test reported out in the TRADA program, the shock table tests were performed up until the model seemingly lost its serviceability criteria. This helped in identifying the extreme limits of seismic vulnerability of the bamboo-based housing system [12].

Figure 4: Propagation of cracks after the shock table test

From this extensive study, it was observed that the model did not collapse nor did it show any signs of collapse. Also, there were no indications of any tendency of any local collapse of the roofing elements. Thus, it can be concluded that the model had satisfied the requirement of resisting major levels of lateral dynamic forces without losing its stability.

5. Future prospects

India, particularly the north-eastern part, is witnessing a paradigm shift in housing construction technology wherein a traditional material such as bamboo is increasingly being replaced with concrete-an inappropriate choice for seismically-active zones. This is partly due to urbanization and, perhaps, the quest to emulate the contemporary urban lifestyle. It is hoped that the results from the work, provide the engineering impetus that can help rekindle the art of constructing beautiful and seismically strong houses using bamboo as a basic material in places where bamboo is available abundantly.
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