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Analysis of stress dispersion in bamboo reinforced wall panels under earthquake loading using finite element analysis

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Abstract. Present study is mainly concerned about the idea of innovative utilization of bamboo in modern construction. Owing to its compatible mechanical properties, a beneficial effect of its use in reinforced concrete (RC) frame infills has been observed. In this investigation, finite element analyses have been performed to examine the failure pattern and stress distribution pattern through the infills of a moment resisting RC frame. To validate the pragmatic use of bamboo reinforced components as infills, earthquake loading corresponding to Nepal earthquake had been considered. The analysis have revealed that introduction of bamboo in RC frames imparts more flexibility to the structure and hence may causes a ductile failure during high magnitude earthquakes like in Nepal. A more uniform stress distribution throughout the bamboo reinforced wall panels validates the practical feasibility of using bamboo reinforced concrete wall panels as a replacement of conventional brick masonry wall panels. A more detailed analysis of the results have shown the fact that stress concentration was more on the frame components in case of frame with brick masonry, contrary to the frame with bamboo reinforced concrete wall panels, in which, major stress dispersion was through wall panels leaving frame components subjected to smaller stresses. Thus an effective contribution of bamboo in dissipation of stresses generated during devastating seismic activity have been shown by these results which can be used to concrete the feasibility of using bamboo in modern construction.

Keywords: reinforced concrete frame; bamboo reinforced concrete; finite element method; Nepal; earthquake; sustainable construction; bamboo reinforcement; finite element method

1. Introduction

Concrete is construction material which is strong in compression and weak in tension. Due to which steel bars are used as reinforcement to increase tensile strength. However, usage of steel makes it costly to use moreover it is a non-renewable material, so attempts are being made to find an alternative of steel by using available materials. Many researches have shown bamboo good for reinforcement due to its properties like high tensile strength, low cost, high strength to weight ratio, environment friendly and easy availability. Usage of bamboo was studied as a reinforcement in lightweight concrete beams (Ghavami 1995) and bamboo as a reinforcement in concrete slabs (Kankam *et al*. 1986a, Kankam *et al*. 1986b). Venkateshwarlu and Raj (1989) developed bamboo based ferrocement roofing elements for low cost housing. Moreover, large span bamboo ferrocement elements were developed for flooring and roofing purposes (Raj 1990). Kodur *et al*. (1998) investigated bamboo as reinforcement in arch. Applications of bamboo were studied in reinforced concrete masonry shear walls (Moroz *et al*. 2014). It was investigated for flexural and shear reinforcement in concrete beam (Nathan *et al*. 2014). Glued laminated bamboo in beams was studied (Sinha *et al*. 2013) with chemically treated bamboo in concrete beams and columns (Agrawal *et al*. 2014). Bamboo was analyzed for reinforcement in concrete beams, permanent shutter concrete slabs and columns (Ghavami 2005).

With the increase in the population and degradation in our natural resources, the construction industry has opted RC frame construction as preferable choice for almost any construction project regardless of the utilization purpose of structures (Cosgun and Sayin 2014). Frame construction provides a moment resisting skeletal structure which has proved to be an efficient and effective approach as far as seismic safety of structures is concerned (Ashish *et al*. 2018). Between the column and beam member of alternate storey and bay of a building a space is left, which is infilled with other building materials. Generally, only dead load of these infill materials is accounted during designing of the structures. But past researches have shown that different building materials impart some structural properties to the overall characteristics of the structure. Properties such as flexibility, stiffness, energy dissipation during earthquake, natural period of buildings can be altered using suitable building materials as infills (Kumar and Ashish 2015).

The importance of the infill frames was analyzed with its utilization in pragmatic design (Annamalai 1981). The influences of infills on various frames were observed in

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terms of ultimate strength and stiffness (Govindan and Santhakumar 1985). The behavior was examined of brick infilled square panels under diagonal static loading (Santhakumar and Govindan 1989) and reinforced concrete frames with brick masonry infills subjected to both horizontal and vertical loads were analyzed (Rahaman and Ra 1992). The analytical study was performed using ANSYS. The importance of lateral stiffness of a building on its seismic design was discussed (Jain *et al.* 1997). In a nut shell all these, and several others, researches on frame with brick masonry infill have shown the importance of considering infills during designing of structures (Santhi *et al.* 2005).

A brick masonry infill wall panel imparts stiffness to the frame structure and hence reduces the deflection of the whole structure under seismic activity. Clay brick is the most common building material used as infill. Brick masonry, undoubtedly, provides beneficial effects to a structure by making it more stable and durable. Despite of its beneficent effects, brick masonry also comes up with some problems during earthquake. The most common concern with brick masonry is its incapability to resist out of plane failure when subjected to lateral loadings. Almost 60% of damage during any earthquake can be accounted for out of plane failure of brick wall panels. Investigations with reinforced brick masonry have shown good and satisfactory results but proved to be a burden on pocket. Another solution to the out of plane failure can be monolithic construction which can be accomplished by using slab panels in place of brick wall panels (Kumar and Ashish 2015). Keeping in view the characteristics and properties of steel reinforced concrete, lightly reinforced slab panels seems to be a viable option as monolithic infill wall panel. But, again, considering the sky touching costs of steel which has to be used as reinforcing material, one can only think about using reinforced concrete slab panels as wall panels. However, this concept has been used in large constructions such as nuclear power plants etc. (Kumar and Ashish 2018).

Extensive researches in quest of a sustainable building material have revealed the potential of bamboo as construction material. At present day, bamboo has almost 1500 listed uses including its uses in construction industry. Investigations have revealed that bamboo has a potential to replace steel as reinforcement in concrete and can produce a sustainable composite with concrete. Considering the short harvesting time, easy adaptability to any environment condition, comparable tensile and compressive strength and most importantly, natural occurrence of bamboo, it can be attributed as perfect sustainable, eco-friendly building material (Elizabeth and Datta 2013).

The research and investigations reported in INBAR had unveiled bamboo's advantages and disadvantages as a construction material. Till date is the largest organization indulged in the research works related to bamboo (Kutty and Narayanan 2003). A review on bamboo feasibility by R. Tjerk seems to suggest the viability of bamboo to replace certain traditional construction material. Survey of failure pattern of buildings during Bhuj earthquake and proposal of using bamboo reinforcement in brick masonry lays the ground of this paper (Iyer 2002).

The major impede to its utilization as reinforcement is its durability and bond strength with concrete. These problems had been debated by investigators and remedies to enhance these two properties have been suggested. The durability aspect of bamboo to be used as reinforcement in concrete was observed (Lima *et al*. 2008). Experiments to obtain the results of bond strength between bamboo and surrounding concrete and compared it with bond stress of steel with concrete (Masakazu and Koichi 2012). Similar studies have been carried out by Ghavami (1995). The bond strength of untreated bamboo and bamboo in concrete with low cost treatments for dropping water absorption was analyzed (Kute and Wakchaure 2013). Sustainable concrete using bamboo as infill in the wall panel reduced lateral and vertical deflection, thus reducing the probability of collapse (Karthika *et al.* 2015). Parametric study was conducted to investigate the seismic performance of the bamboo structures which revealed it as better performer in earthquake than reinforced concrete residential building (Elizabeth and Datta 2013). Different types of connections between bamboo members and dowel connection capacity was studied (Correal 2016). Bamboo and it's conceivable used in Nigeria demonstrated its accessibility and impacts on the environment (Atanda 2015). Bamboo as reinforcing material in concrete members was studied with its fracture behavior (Masakazu and Koichi 2011). Species of Indian bamboo was observed for structural members by verifying its cleavage and compressive strengths (Mukhopadhyay and Dutta 2014). A complete review on utilization of bamboo as reinforcement and its beneficial and economical effects have been provided (Kumar and Ashish 2015, Ashish and Kumar 2018) which were based on the previous researches done on this subject. The investigations were made to introduce new natural fibers used as fillers (Rao and Rao 2007). The deformation behavior and damage resistance of bamboo composites were investigated (Zhang *et al*. 2000).

2. Research significance

In spite of the fact that it has potential to be utilized as reinforcement after giving species specified treatment, it has been used for lab testing only. Keeping in view the satisfactory performance in lab testing, this study considers the viability of using bamboo reinforced wall panels in place of brick wall panels in RC frames. An attempt has been made through this research work to investigate and compare the failure pattern of bamboo reinforced wall panels and brick masonry wall panels subjected to effects of recent devastating earthquake triggered in Nepal by simulating through commercial finite element software ANSYS Workbench 13.0. The results of this study strengthen the idea of using bamboo reinforced wall panels in frame structures as infill.

3. Finite element modal and analysis setup

Two frame models (2-bay and 3-bay) were modeled in ANSYS workbench using solid body for concrete and line body for steel and bamboo reinforcements. Each of two

Table 1 Specification of table

Parameter	Dimension
Number of storey	4
Size of column	200×300 mm
Size of beam	200×300 mm
Height of each storey	2700 mm
Width of bay	2700 mm

Table 2 Specification of 3-bay frame modal

Parameter	Dimension
Number of Storey	4
Size of Column	200×300 mm
Size of Beam	200×300 mm
Height of Storey	2700 mm
Width of First 2 Bays	2700 mm
Width of Last Bay	3600 mm

frame model was attributed by brick masonry infill (BMF) and bamboo reinforced wall panel (BRWF). These four frames were analyzed for deflection in orthogonal direction and stress induced under a high magnitude earthquake loading which corresponds to major shock of earthquake triggered in Nepal. Modal Analysis followed by Response Spectra Analysis has been used to accomplish the objective of this study. Details of model specification and loading are presented in the Tables 1-2.

Models were created for above mentioned specification with solid body and line body features available in ANSYS. After modeling, these models were meshed into smaller elements and particular elements were assigned to particular component according to the requirements of that component. For example, Solid65 element was assigned to the concrete components of the structure whereas Solid185 was used for the brick infills. As far as reinforcements are concerned, Link180 element was utilized for steel as well as bamboo reinforcement. Fixed support conditions were applied on the base of the frame models to simulate the pragmatic conditions as much as possible. In order to achieve the simulation, frictionless supports were introduced at the beam column joint levels. These models were then subjected to a response acceleration spectra corresponding to the recent severe earthquake of magnitude around 7.2 on Richter scale, triggered in Nepal in 2015. The response spectra is shown in Fig. 1.

3.1 Model analysis

Modal analysis were carried out on four types of frame, viz. 2-Bay and 3-Bay Brick Masonry Frame (BMF) and 2-Bay and 3-Bay Bamboo Reinforced Wall Frame (BRWF) in order to find out the natural frequencies, which were to be used for further analysis of these frame. Number of modes required to carry on the analyses were decided on the basis of the fact that ratio of effective mass to total mass should be equal to or greater than 0.90 i.e., 90% of total mass is participating in any mode. Thus mode shapes were determined until the participation factor in X direction have fulfilled the criteria.

3.2 Response spectra analysis

Acceleration response spectra curve shown above have been used as loading on the fixed supports of the frames. Response of the structure in terms of deflection in three orthogonal directions and stresses induced in the structure (Normal Stress, Equivalent Stress and Shear Stress) have been observed and analyzed. Summary of results from response spectra analysis of each frame type is given in the next section.

4. Response of frames

4.1 Modal analysis results

Results from the modal analysis ascertained the possible mode shapes at different possible frequencies which further can be used to determine the natural frequency of any structure. The criteria for minimum number of required mode shapes was fulfilled at different frequencies for each frame due to the difference in geometry and material. For 2-bay BMF criteria was met at 28 mode shapes whereas for 3-bay BMF it raised till 40. In case of 2-bay BRWF the requirement was met at 20 mode shapes which in case of 3-bay BRWF was met at 93 mode shapes. Details of major mode shapes for each frame are Table 3-6.

A comparison of mode shape requirement gives a hint of effect of bamboo reinforced concrete on the structural characteristics of frame. In case of brick masonry the natural frequency of frame was found to be much lower than that of the frame with bamboo reinforced wall panels. It is due to the fact that in case of concrete wall panels,

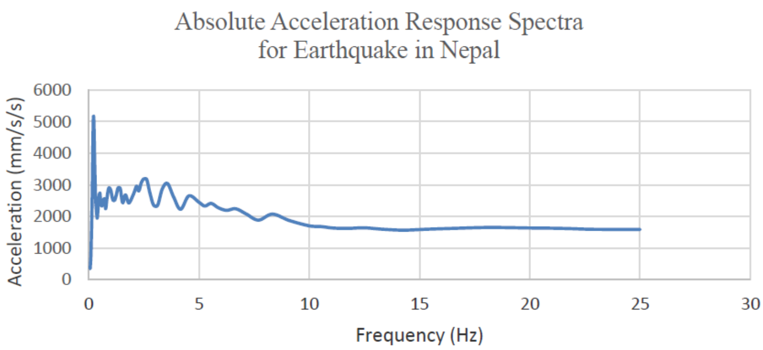


Fig. 1 Absolute acceleration response spectra (load case)

Table 3 Major mode shape results for 2-bay BRF

Mode	Frequency (Hz)	Time period (sec)	Participation factor	Effective mass	Eff. mass/ Total mass
1	0.103063	9.7028	427.38	182655	0.727858
10	0.318885	3.1359	-201.78	40716.3	0.162249
28	0.600343	1.6657	85.576	7323.19	0.029181
Total				230697	0.919297

Table 4 Major mode shape results for 2-bay BRWF

Mode	Frequency (Hz)	Time period (sec)	Participation factor	Effective mass	Eff. mass/ Total mass
1	0.190760	5.2422	376.22	141538	0.647519
20	0.700512	1.4185	236.88	56112.7	0.256709
Total				197655	0.904228

Table 5 Major mode shape results for 3-bay BMF

Mode	Frequency (Hz)	Time period (sec)	Participation factor	Effective mass	Eff. mass/ total mass
1	0.114710	8.7176	550.95	303548	0.755679
16	0.330043	3.0299	226.08	51113.8	0.127247
39	0.510623	1.9584	68.151	4644.62	0.115627E -01
Total				361923	0.901003

Table 6 Major mode shape results for 3-bay BRWF

Mode	Frequency (Hz)	Time period (sec)	Participation factor	Effective mass	Eff. mass/ total mass
2	0.276401	3.6179	477.31	227823	0.655123
35	0.796186	1.2560	-271.00	73440.9	0.211185
93	1.81243	0.55175	113.00	12768.5	0.367167E -01
Total				322830	0.928324

maximum mass participate at much lower frequency as it is a monolithic construction in contrast to the layered construction in case of brick masonry. However, a mode shapes were increased when geometry of the frame was expanded. Natural time period of the frame had experienced a reduction upon the expansion of the structure on account for increase in lateral stiffness caused by additional bay.

4.2 Response spectra analysis results

After the required mode shapes were ascertained, responses of each frame subjected to a major earthquake were determined through response spectra analysis. For this purpose, absolute acceleration curve shown in Fig. 1 was used as ground acceleration at fixed supports. Results were observed in terms of deflection in orthogonal direction and various stresses induced in the frame structure. Responses of BMF and BRWF (2-Bay and 3-Bay) when subjected to given load case are tabulated in the Tables 7-8.

As shown by results, it can be observed that the deflection shown by all the frames is incompatible in magnitude. But the major point is that in case of 2-bay frames, BMF experienced a much lesser deflection in the direction of force i.e., X direction, as compared to the deflection experienced by BRWF. This difference can be attributed to the flexibility imparted to the structure due to utilization of bamboo in wall panels. In case of brick masonry the deflection was much lesser due the increased stiffness of the frame. On the other hand, the deflection in X direction is showing a reverse trend as it is much lower in case of BRWF as compared to that of BMF. In this case, the stiffness induced by the concrete in the wall panels can be considered to be dominating the structural characteristics of the frame as concrete is much stiffer than brick components.

Table 7 Response of BMF

Entity		2-Bay	3-Bay
Deflection In Direction	X	2784.7 mm	3074.1 mm
	Y	531.87 mm	653.07 mm
	Z	9.31 mm	15.80 mm
Equivalent Stress		5439.5 MPa	7243.8 MPa
Shear Stress		671.52 MPa	1987 MPa
Normal Stress		1545.8 MPa	885.38 MPa

Table 8 Response of BRWF

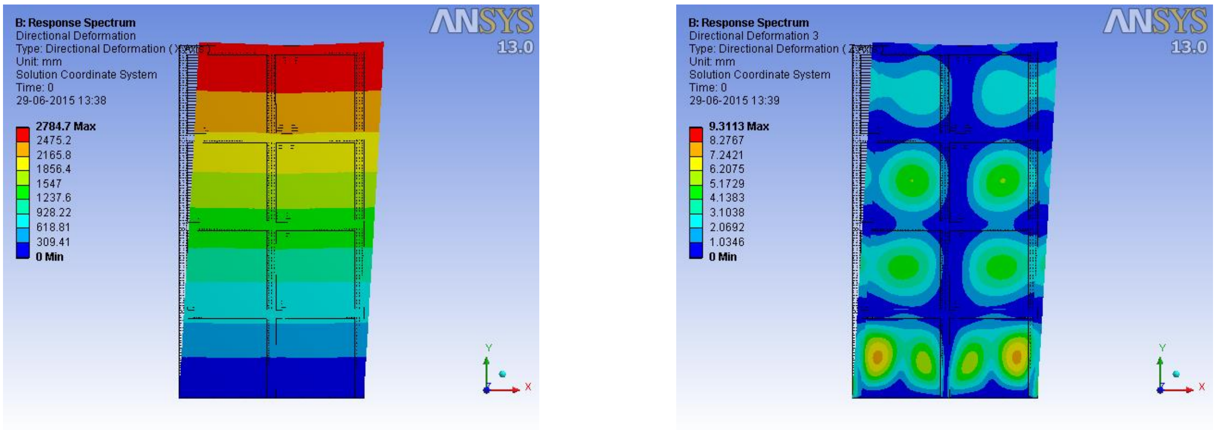
Entity		2-Bay	3-Bay
Deflection In Direction	X	4275 mm	1612.7 mm
	Y	1222.7 mm	607.82 mm
	Z	11.7 mm	4.953 mm
Equivalent Stress		29823 MPa	6082.3 MPa
Shear Stress		12441 MPa	37.726 MPa
Normal Stress		35318 MPa	1153.9 MPa

The major cause of damage during the earthquake is out of plane failure of the wall panels. To consider the resistivity of both panels to the out of plane failure, deflection in Z-direction can be compared. Again it shows an opposite trend in both types of frame similar to that of deflection in X-direction. Albeit, magnitude wise it made a little point but the analysis of the deflection pattern have revealed the importance of using bamboo in wall panels. Thus, deflection pattern for the Z-direction had been compared and the observations have been discussed in the next section.

Coming to the stresses induced in these four types of frames, results shows that bamboo contributes to the stress dispersion mechanism more effectively than brick masonry does. Though the magnitude of stresses induced is higher in case of BRWF (2-Bay), the distribution pattern shows the effectiveness of the bamboo reinforced wall panels. It was analyzed that in case of BMF the stresses were more concentrated on the frame members whereas with introduction of monolithic bamboo reinforced wall panels in frame structures the stress dispersion pattern changes significantly. In that case, wall panels seems to take up maximum of stresses induced, making frame structure much less vulnerable to damage during any seismic activity.

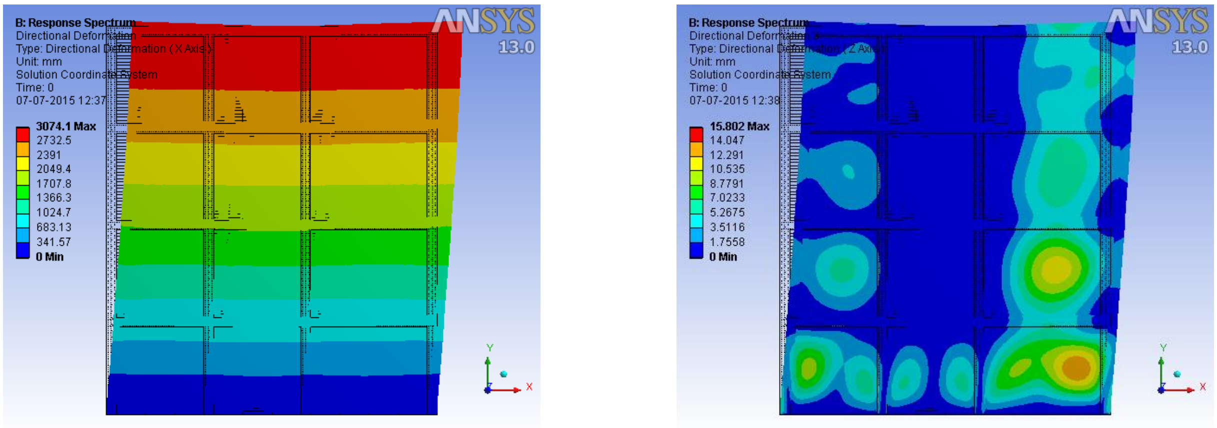
5. Observations and discussion

As mentioned in the results, the magnitude of the results may seem to be incompatible, but the major aim of this study is to analyze the distribution pattern of stresses and



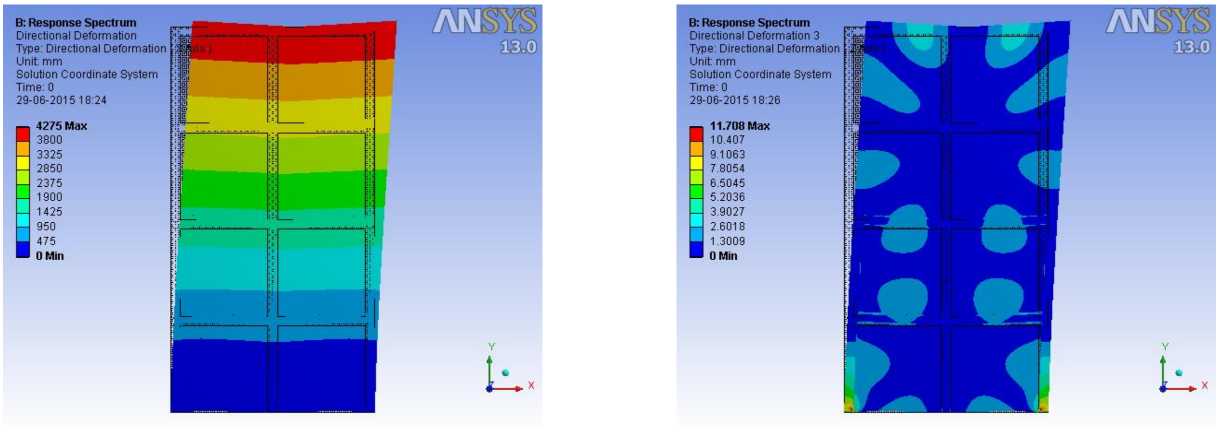
(a) *X*-Direction (b) *Z*-Direction

Fig. 2 Deflection of 2-bay BMF



(a) *X*-Direction (b) *Z*-Direction

Fig. 3 Deflection of 3-bay BMF



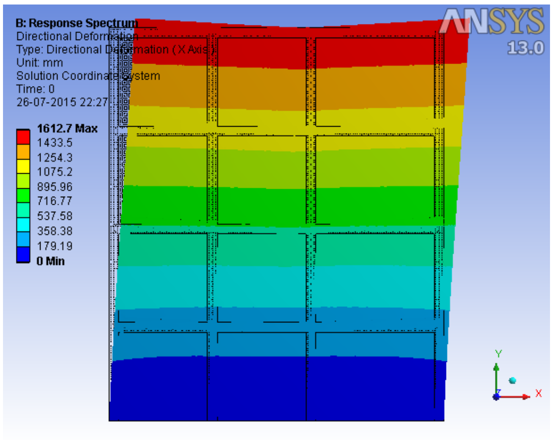
(a) *X*-Direction (b) *Z*-Direction

Fig. 4 Deflection of 2-bay BRWF

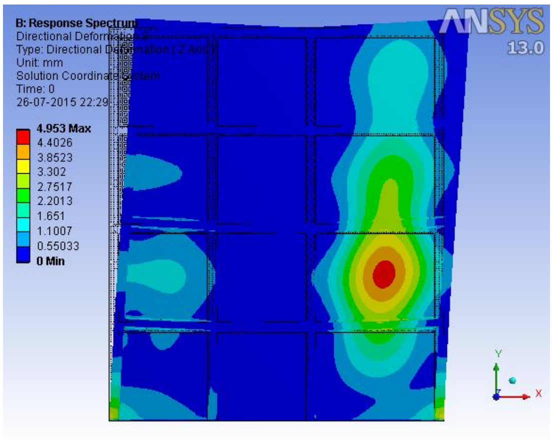
deflection. The deflection concentration and stress distribution pattern for each frame is shown in Figs. 2-5.

5.1 Deflection

As mentioned earlier, the *Z*-Direction deflection concentration pattern is of utmost important in this study, hence referring to Figs. 2-3 it can be observed that in both these cases (2-Bay and 3-Bay) the maximum deflection is more concentrated in the centre of the wall panels which shows a string cause for out of plane failure and hence validates that brick masonry is quite prone to this type of failure. However, in case of 3-bay BMF, the central bay experienced much less deflection in the normal direction as

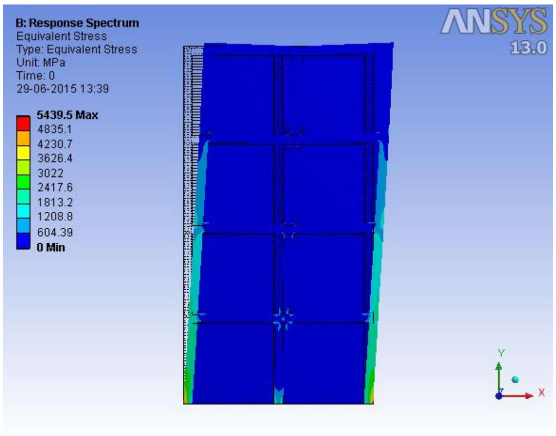


(a) *X*-Direction

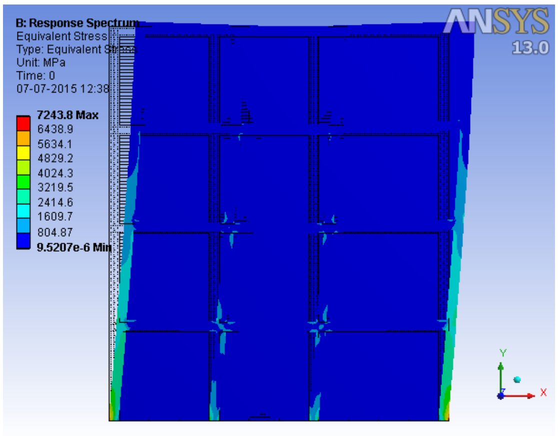


(b) *Z*-Direction

Fig. 5 Deflection of 2-bay BRWF



(a) 2-Bay



(b) 3-Bay

Fig. 6 Equivalent stress distribution pattern in BMF

compared to that of 2-bay BMF.

On the contrary to observations about BMF, the BRWF frames have shown a much safer deflection concentration pattern in Figs. 4-5. In both cases (2-Bay and 3-Bay) the out of plane deflection is distributed over the wall panels, i.e., even though the deflection magnitude is larger for 2-bay frame, but the maximum deflection is not occurring in the wall panels hence showing the effectiveness of bamboo reinforced wall panels in resisting the out of plane failure. Similar to BMF, this pattern changes in BRWF when geometry of the frame changes from 2-bay to 3-bay. For 3-bay frame the normal deflection is high in the centre of the wall panel of larger dimension. Hence before using bamboo reinforced wall panels, a calculation for limiting dimensions is required as it may affect the effectiveness of these panels.

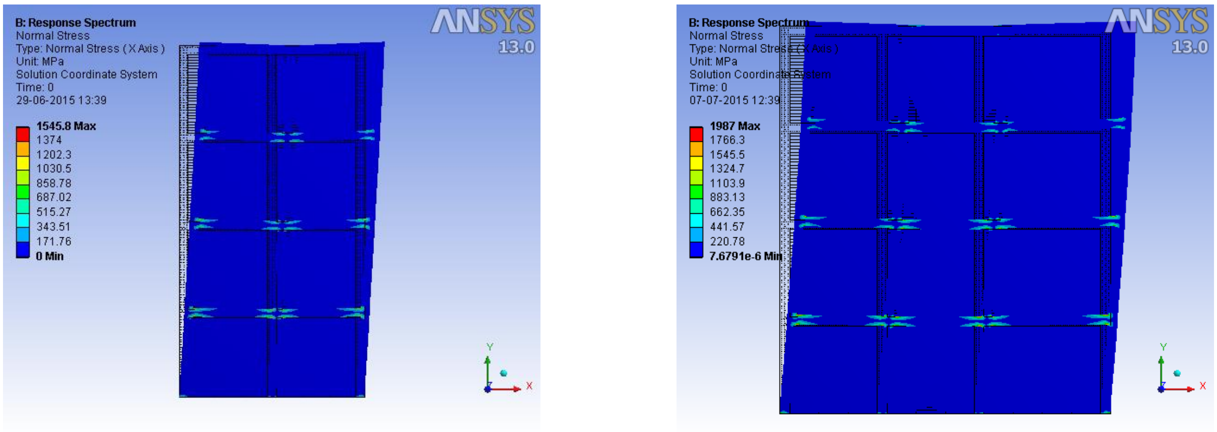
5.2 Induced stress distribution

The stresses are induced in frame structure when subjected to earthquake loading. Distribution pattern of stresses under consideration (Equivalent, Normal and Shear) are shown in following figures followed by a detailed discussion about these patterns.

In case of BMF the Equivalent Stresses (von-Mises Stress) induced in the frame are induced only in frame components, mainly in columns. No contribution from wall panels had been observed.

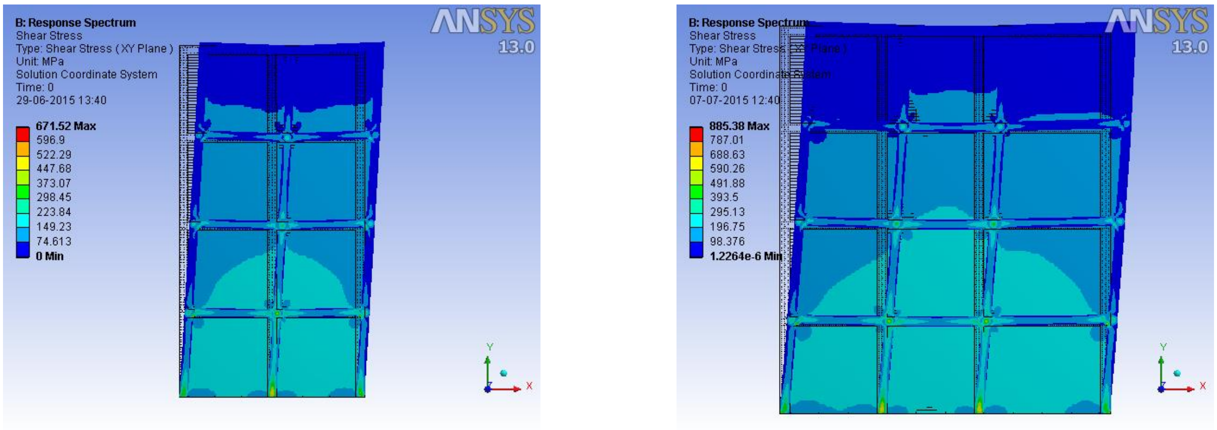
Similar to equivalent stress, the normal stress induced in the frame structure were mainly concentrated at the beam column joints and near the edges of the wall panels. Same pattern exists for 2-bay and 3-bay frames.

As it is a well-known fact that brick masonry is not pretty much capable of taking shear induced due to the movement experienced by frame during the seismic activity, the analysis results have shown the same. In spite of the lower magnitude of shear stress, the major shear stresses taken up by the columns instead of the wall panels. A much larger area of wall panel is affected even by the smaller shear stresses showing the incapability of brick masonry for resisting the shear stresses and more vulnerability for cracking and ultimately tearing apart. The major cause for this type of stress distribution or say for incapability of brick masonry is the layered construction technique which, though, provides the facility to complete the work in shifts but makes bonding between elements weaker. Hence these weak bonds between two layers makes the brick masonry less effective during the earthquake and causing a shear failure in the form of out of plane failure.



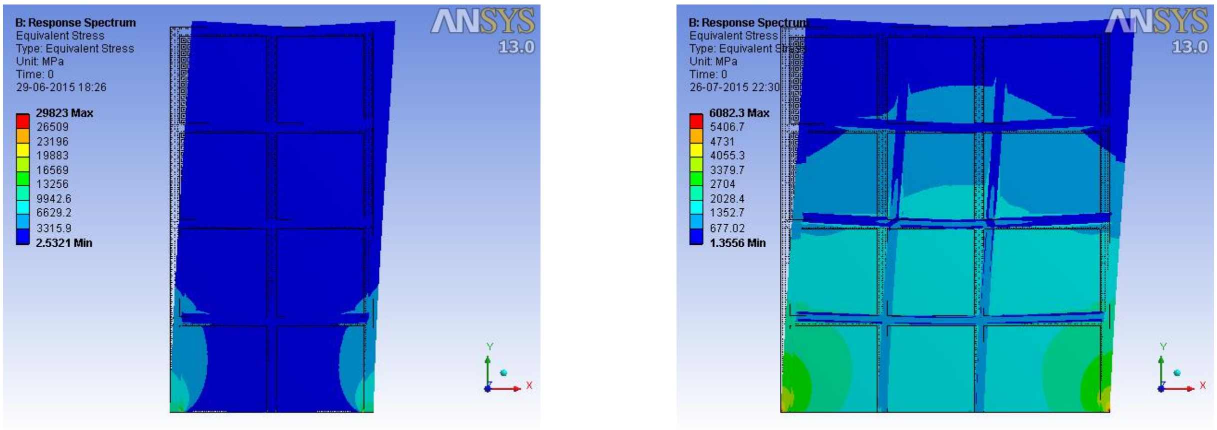
(a) 2-Bay (b) 3-Bay

Fig. 7 Normal stress distribution in BMF



(a) 2-Bay (b) 3-Bay

Fig. 8 Shear stress distribution pattern in BMF

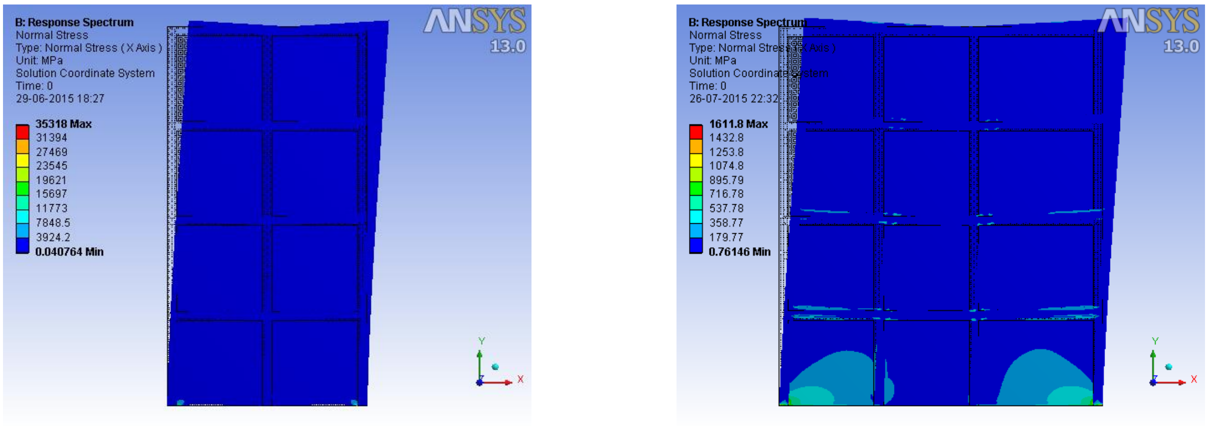


(a) 2-Bay (b) 3-Bay

Fig. 9 Equivalent stress distribution pattern in BRWF

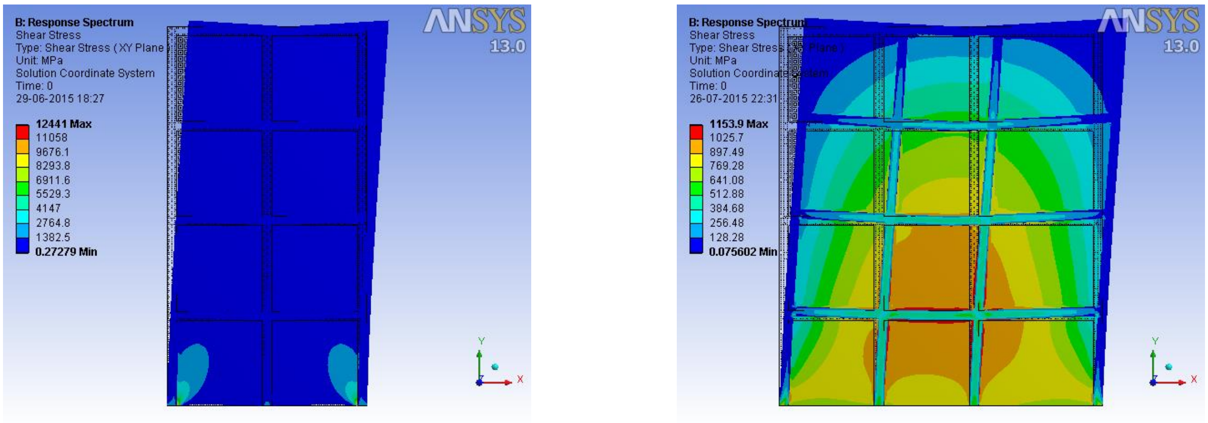
On the contrary to the stress distribution pattern exhibited by the BMF frames (Figs. 6-8), the stress distribution pattern in BRWF frame (Figs. 9-11) is quite uniform in the wall panels and hence showing the effective participation of wall panels in stress dispersion. The bamboo reinforced wall panels have contributed in the stress dispersion in accordance with the geometry of the frames. In 2-Bay frames, regardless of the type of stress to be anticipated, wall panels have taken up significant stresses in conjunction with the frame members. It can be concluded from the observations of 2-bay frame that bamboo reinforced wall panels had enhanced the stress bearing capacity of the whole frame significantly.

In case of 3-bay BRWF, participation of the wall panels



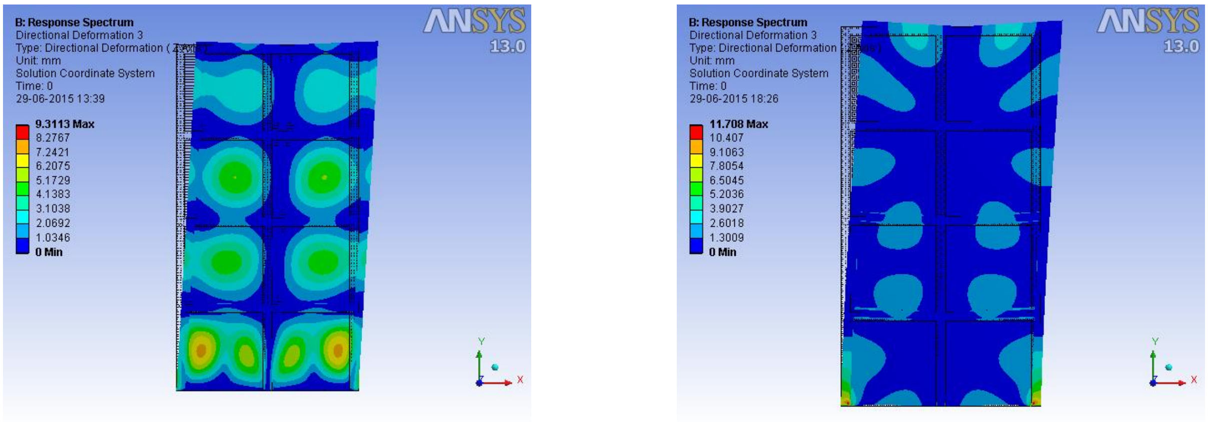
(a) 2-Bay (b) 3-Bay

Fig. 10 Normal stress distribution pattern in BRWF



(a) 2-Bay (b) 3-Bay

Fig. 11 Shear stress distribution pattern in BRWF



(a) BMF (b) BRMF

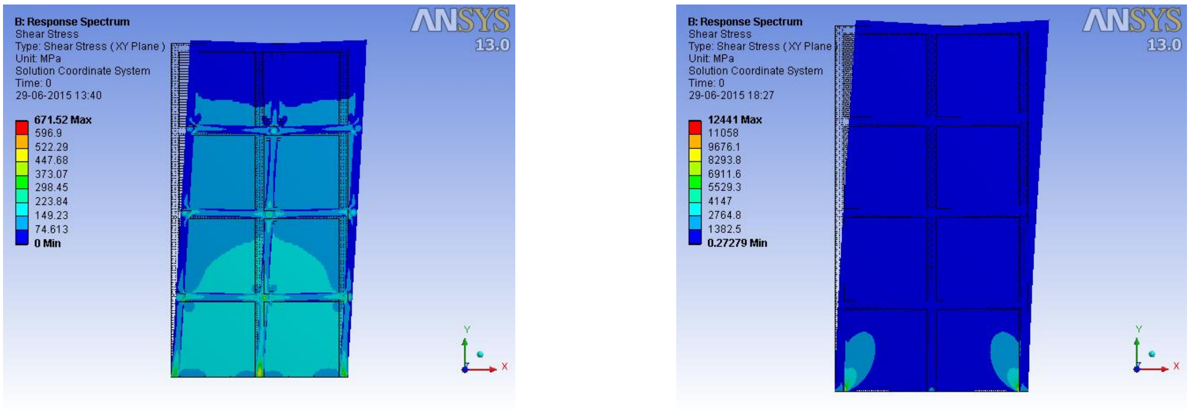
Fig. 12 Z-direction deflection comparison (2-bay)

is more significant, bearing the major stresses and leaving minimal stresses in skeletal members of the frame which may enhance the durability characteristics of the structure in all. More importantly, the maximum shear stress induced in the frames was near the edges of the wall panels.

6. Feasibility comparison

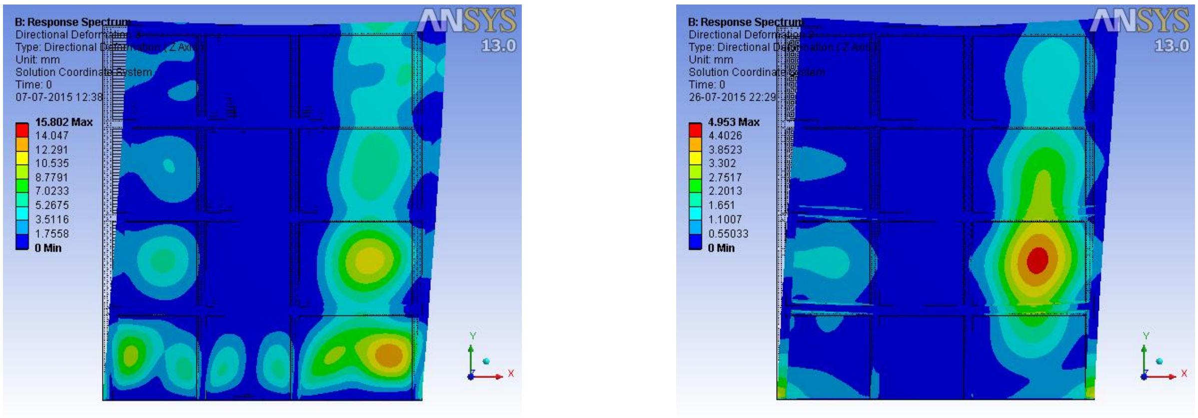
On the basis of the study, brick masonry and bamboo reinforced wall panels can be compared to evaluate the performance of each frame under the same earthquake loading. These four frames were compared for the deflection in *Z*-direction and dispersion pattern of shear stress (Fig. 12) as these are the most critical performance evaluation criteria.

As explained earlier, the deflection in the BMF is more



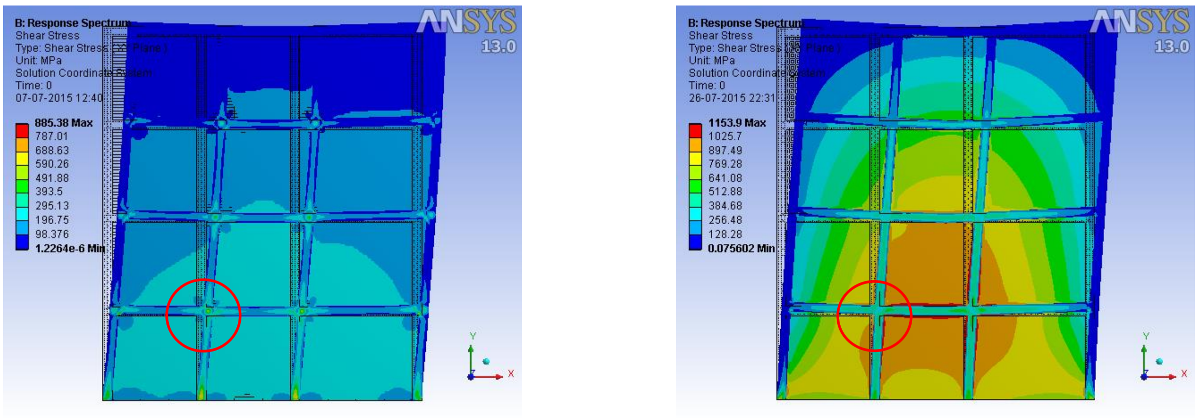
(a) BMF (b) BRMF

Fig. 13 Shear stress distribution pattern (2-bay)



(a) BMF (b) BRMF

Fig. 14 *Z*-direction deflection comparison (3-bay)



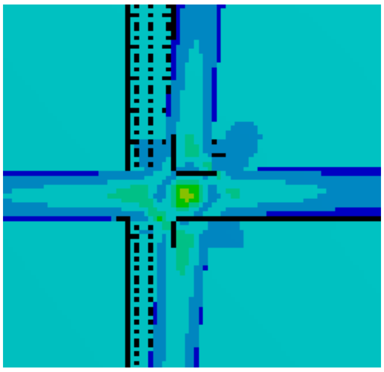
(a) BMF (b) BRMF

Fig. 15 Shear stress distribution pattern (3-bay)

concentrated in the centre of the wall panel showing the more vulnerability to the out of plane failure whereas in case of BRWF the displacement distribution patterns is showing in Fig. 13 the capability of BRWF to resist the failure.

Although, the shear stresses induced in the BMF are much lower than those induced in the BRWF, more area of wall panels is exposed to the shear stress showing in Fig. 14 the incapability of brick masonry in bearing the shear stresses. On the other hand, wall panels were unaffected by the shear stress except the lower wall panels in case of BRWF. It is because of the fact that bamboo reinforced concrete wall panels tend to bear higher shear stresses and resist the out of plane failure.

In case of 3-Bay frames, central bay is the least affected bay. It can be observed that the lower panels of the BMF experienced a larger deflection near the centre of the wall panels in Fig. 15 whereas in case of BRWF the this centre



(a) BMF

(b) BRMF

Fig. 16 Close up of beam-column joints

has been shifted towards the middle wall panel in the last bay with a uniform distribution towards the edges.

The shear stress distribution patterns shows that in case of BMF the higher stresses are taken care of by the skeletal frame components as the region of higher stresses is near the beam column joints. On the other hand, in case of BRWF, the larger shear stresses are taken up by the wall panels, sharing the stresses effectively with skeletal structure. A close up of the beam column joint marked in the Fig. 15 is shown in Fig. 16.

7. Conclusions

This research work included the various aspects regarding the earthquake vulnerability of RC frames and their remedies, sustainable construction material like bamboo and innovative designs using bamboo. Starting from the conclusions about bamboo, drawn on the basis of the studies of the author,

Through the conclusions about feasibility of bamboo reinforced concrete wall panels, drawn on the basis of this study, are listed below.

- Bamboo belongs to the family of grass and has this capability to replace some of the conventional building materials in order to accomplish the requirement of sustainable building material. Though it possess some problems such as durability and bond strength with concrete (When it has to be used as reinforcement in concrete), these impedes can be acknowledged by the specific treatments.
- Masonry infills have great beneficial effects on the frame structures as they can improve the durability, strength, flexibility and other structural characteristics significantly if designed properly in accordance with the requirements of the structure under consideration.
- As brick is the most common building material for the masonry, its production may increase the land degradation which poses a threat to the environment. To call upon this problem bamboo reinforced concrete wall panels seems to be a solution as bamboo plantation will not only increase the production of bamboo but also will lend a helping hand in the local economy.
- Considering the technical aspects, bamboo reinforced wall panels have shown a compatible performance even under the severe earthquake like one in Nepal, as compared to the brick masonry.
- Brick masonry have shown an incompatibility in terms of bearing shear stress and hence vulnerable to out of plane failure. On the other hand, bamboo reinforced wall panels not only resisted the normal displacement but also participated in the stress dispersion mechanisms effectively hence proving their feasibility of replacing brick masonry system.
- Brick masonry contributes to the energy dissipation up to a certain limit while bamboo being more flexible will impart more flexibility which enhances the energy dissipation characteristics of the overall structure.
- Due to the stiffness characteristics of brick masonry, the structure will experience a brittle failure which turns out to be a ductile kind of failure in case of bamboo reinforced wall panels. The deflection in X direction explains this.

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