Effect of Using Timber Reinforcements in Mud Houses on Response to Earthquake

M. R. AWALL[1], M. S. AZAD[2], M. O. RAHMAN[2], N. SAMADDER[2], M. HASAN[3]

[1]Department of Civil Engineering, RUET, Bangladesh (robi95@gmail.com)
[2]Department of Civil Engineering, RUET, Bangladesh (samdani.civil.ruet@gmail.com)
[2]Department of Civil Engineering, RUET, Bangladesh (oli110064@gmail.com)
[2]Department of Civil Engineering, RUET, Bangladesh (niloy.samadder.ns@gmail.com)
[3]Department of Water Resource Engineering, BUET, Bangladesh (mahmudulce10@gmail.com)

Abstract

Earthquake effect in conventional mud houses is a great concern. Mud house construction is a very typical context in the rural areas of Bangladesh ascribable to its ease of construction, low cost, availability of materials. These houses are susceptible to earthquake damage due to some attributes of materials consisting of less stiffness, brittleness and poor bonding between the units. In recent years, a number of earthquakes have been faced in Bangladesh with magnitude of more than 7. Present study deals with the strengthening of such houses using timber reinforcement with definite proportion contemplating the mud wall sizes. Arrangements of reinforcement has been followed such a way which would not require skilled labor and much cost. A finite element application Staad.pro-V8i has been adopted to execute the required analysis of unreinforced and reinforced models. For conventional distinction, the analysis performed for both one story and two story models by considering a reinforced and unreinforced one for each case. Two methods of analyses incorporating equivalent static force and response spectrum analysis have been conducted to comprehend the actual response of models. Investigations from analyses delineate that timber reinforcements impart greater stiffness and strength against overturning which increases the frequency of structure and diminish the lateral displacements to a good extent. Such arrangement of reinforcement can be a good choice to subside the detrimental effect of earthquake.

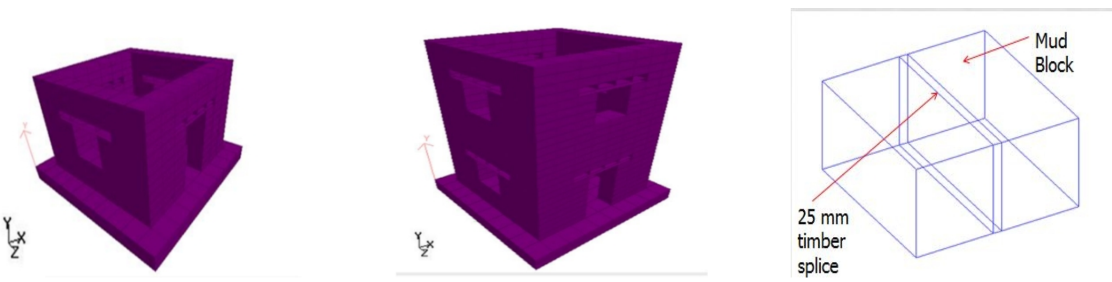
Keywords: *Mud House, Timber Reinforcements, Finite Element, Equivalent Static Force, Response Spectrum Analysis.*

1 Introduction

Practicing of construction of mud houses has been continuing since last few centuries. These houses are mainly of one, two or three story buildings. Selection of story levels depend on some factors associated with the family members and economic point of view. These houses are vulnerable to earthquake. Traditional mud houses suffer serious structural damages or collapse. In spite of this, these structures are expected to continue to use for decades to come, especially developing countries like us. The reasons of rapid failures of such structures are not far to seek. A number of reasons are behind this problem. These problems include brittleness, weak joints, lack of structural integrity. Brittleness is a very common property of mud. Once yielding occurs, cracks development occurs in the mud wall and results a complete loss of tensile strength which may cause severe damage to the structure. On the contrary, unreinforced mortar is much weak and the connections between mud blocks become very sensitive against lateral loads induced from earthquake. With a few shaking of earthquake vibration, this result partial or full disintegration of materials. Furthermore, for safety purpose, larger thickness mud walls are used which increase the seismic weight of structure. A number of researches have already been conducted in this issue. Illustrations from the previous researches defines that using reinforcements, different materials can improve the performances of traditional mud houses. Islam and Iwashita (2010) discuss about mud materials which are reinforced with low cost materials. A series of lab experiments have been carried out in the research. Straw, jute, cement has been added to mud block to improve the performance of such houses. In case of straw, a number of facts have been taken into consideration like as straw content, length of straw, crushed straw and scale effect test of straw. In case of jute, jute content, length was the features of reflection. Furthermore, effects of gypsum and clay content have also been considered. Finally, effect of cement has also been inspected. The outcome of the research deliberates that straw and jute increase the ductility while gypsum and cement improve the bonding. Meli et al. (1980) represents strengthening of adobe houses for seismic actions. An experimental shaking table test has been regulated in this study. Only a part of structure was considered in the test due to the table size requirements. Three strengthening methods have been adopted in the research consisting of using concrete bond beam, using steel ties and using wire mesh and mortar. The output of the study delivers that the strengthening methods cover the essential aspects of using reinforcements. Ottazzi et al. (1988) discussed on the shaking table tests to improved adobe masonry houses. A full-scale model has been tested using a shaking table for assessing the performance of improved adobe masonry house. Reinforcement technique comprising of interior cane mesh and a crowning tie beam have been adopted in the research. Research outcome shows that using such reinforcements improves the quality of structures against earthquake. Further study on earthquake resistant non-engineered building construction for rural area in Bangladesh has been narrated by Alam et al. (2014). A vast study on damage analysis has been carried out in this research. New techniques for strengthening mud, masonry and non-engineered house have been adopted in this paper. Conversely the economic consideration has also been given priority. Techniques for existing structure and new structures have been explored broadly. For mud house consideration, bamboo bracing in cross orientation is considered. The results of the research give a better idea for present practice of non-engineered houses. Arya (2000) studied on non–engineered construction in developing countries. Earthquake risks, its management, damages due to previous earthquakes, damage risks for non-engineered houses and some techniques for strengthening such houses have been deliberated in this investigation. Various types of retrofitting schemes in earthen houses have been studied. In addition to saving existing and future building, the schemes in this might be some good options. Nasir (2008) reviewed on traditional housing technology in Bangladesh. This paper highlights the mud made house technology in Bangladesh. This paper explores the traditional housing technology, local's interpretation against disasters. Vargas et al. (1984) explored seismic strength of adobe masonry. They discussed about the factors controlling the strength of adobe masonry, effect of additives, improvements of adobe masonries by adding sands, straws. A number of practical recommendations have been delivered from this study. Bariola et al. (1990) inspected seismic tests of adobe walls. A comprehensive research consisting of nine specimens and two type ground motion have been conducted. Performing shaking table tests, the base motion at failure have been investigated. Besides, the failure types have also been noted. The response from shaking table test has also been taken into consideration. Hossain et al. (2013) illustrates seismic effects of mud house. They delineated the seismic effect in mud house by numerical analysis. They analyzed the crack pattern and made a comparison before using and after using reinforcement. Reduction of earthquake effect is a challenging matter. From the literature review, a number of processes stated. Most methods have been evaluated by means of lab experiment. In the present research, a numerical evaluation has been carried out by means of software analysis of model. For mitigating purpose of earthquake forces, timber splices have been used as reinforcement thoroughly in the mud house. The objectives of this study include a great value as the topic is related to life and property loss. Traditional mud houses are susceptible to earthquake and the objective includes a series of analysis. The main objectives of this research include analysis of unreinforced and reinforced mud house, comparison of lateral displacements, frequency and mode shapes.

2 Modeling

To model the single story mud house, firstly a solid node has been generated. Then the node is translated along x-direction. After performing this, the total line translated again along z-direction. A floor plane can be observed after this operation. After that, the mud wall has generated by maintaining clearance. In case of modeling of double story, the ground floor generation is the same. But, a floor system is needed to be added. Here, a timber floor system has been considered. Timber splices have been used as reinforcement through the mud wall to gain sufficient stiffness.



Single Story Mud House Double Story Mud House Timber as Reinforcement

Figure 1. Mud House Model

Table 1. Table of relevant properties of used materials

Property	Mud (In British Unit)	Timber (In British Unit)	Mud (In US Unit)	Timber (In US Unit)
Young's Modulus	12500 psi	1332800 psi	86184.4 kN/m^2	9.18933e6 kN/m^2
Poisson' ratio	0.45	0.15	0.45	0.15
Density	100 pcf	25 pcf	15.69 kN/m^3	3.92 kN/m^3
Shear modulus	4310.35 psi	579478.26 psi	29718.8 kN/m^2	3165521.04 kN/m^2

The single story and double story mud house models and timber splices are shown in Fig. 1 and relevant properties that used in the modeling are taken from Rahman et al. (2013) research data given in Table 1.

3 Methodology

Earthquake analyses of structures are based on the specifications of country codes. Bangladesh National Building Code (BNBC, 2014) has specifications for seismic analysis. Earthquake zone coefficients are prime factors to be considered for proper analysis. As per BNBC2006, the seismic zoning map is needed to be taken. In present research, the zone factor has been considered as Z=0.2. A finite element package staad.pro V8i has been used for performing analysis. In this package, it follows the seismic load generation by maintain the codes comprising of UBC, IBC, IS. For this reason, Uniform Building Code (UBC1997) code has been considered here. The outcome following UBC and BNBC are almost same and is has delineated by Rahman et al. (2013). Earthquake analysis methods considered in this study are of two types like, static analysis and dynamic analysis.

3.1 Static analysis

In case of static analysis, the seismic force is assumed to be acted as static forces. There are provisions in different codes for static analysis. As a rule, regular shaped buildings with height below 75 meters are in the range in which engineers can adopt static method of analysis. On the contrary, irregular buildings with height below 20 meters can be taken in such consideration (BNBC, 2014). Irregularity of structures based on different criteria and assumptions. Static analysis is of two types consisting of Equivalent Static Force method and Pushover method.

In this research, equivalent static force method has been adopted for static analysis. If equivalent static force method is selected for seismic analysis of a building, the design seismic forces, their vertical distribution over the height of the building, and the corresponding internal forces will be calculated and determined as per UBC97 code provisions to which are given in equations (1 - 4).

$$V = \frac{C_v I}{RT} W \quad (1)$$

$$V = \frac{2.5 C_a I}{R} W \quad (2)$$

$$V = 0.11 C_a I W \quad (3)$$

$$T = C_t (h_n)^{3/4} \quad (4)$$

Where,

C_t = 0.020 (0.0488) for all other buildings
W= Total seismic weight of the building
C_v= 0.32 and C_a = 0.24
R=Response modification factor = 2.9
Soil profile = S_c
T = Structural period, which can be calculated from equation (4)

I = Structural importance factor=1
The value of base shear obtained from equation (1) must be less than from the base shear obtained from equation (2) and must be greater than the base shear calculated by using equation (3).

3.2 Dynamic analysis
In case of dynamic analysis, the seismic force is considered as dynamic loads. There are provisions in different codes for dynamic analysis. As per BNBC2014, regular shaped buildings with height greater than 75 meters are must be analyzed by using dynamic analysis method. On the contrary, irregular buildings with height greater than 20 meters can be taken in such consideration. Dynamic analysis is of two types comprising of Response Spectrum Analysis method and Time History Analysis method

For conducting dynamic analysis, response spectrum method has been considered. Dynamic analysis by using the response spectrum method is the method of calculating peak modal responses for sufficient modes to capture at least 90% of the participating modal mass of the building. A particular damping ratio is taken considering the property of structure materials. A normalized response spectra considering the soil profile and relevant co-efficient is to be made for the analysis purpose. Displacements, story forces, story shears, and base reactions for each mode of response can be combined following two methods consisting of SRSS (square root sum of squares) rule or the CQC (complete quadratic combination). In present study SRSS combination method has been used.

4 Results and Discussions

From the static analysis, a number of attributes have been noted. The outcome from this analysis comprehends lateral displacements and developed stresses in mud wall.

Table 2 shows the differences of lateral displacements of different models. It is clear that the unreinforced models face greater displacements considering the reinforced models. In single story mud house, the unreinforced one is with a displacement of 6.35 mm and 5.72 mm along x and z directions. On the contrary, the reinforced samples are susceptible to less deflection with 4.14 mm and 3.41mm along the corresponding directions. The percentages of reduction due to using reinforcement are 34.8% and 40.38%.

Contemplating the double story mud houses, substantial differences can also be observed. Unreinforced one is with displacements of 20.26 mm and 19.46 mm while the reinforced one is of 7.09 mm and 6.9 mm along x and z directions. The percentages of reducing displacements are 65% and 64.54% which defies the use of unreinforced models.Also it has been observed from Table 3, that the lateral displacements from response spectrum analysis exhibit a similar behavior like the static analysis. But the numerical values are not alike at all. The displacement values are almost double with respect to the values of static analysis. But there is a reduction of displacements while using timber splices as reinforcements. The percentages of reducing displacements in single story models are 30.91%

Table 2. Displacements from Equivalent Static Force Analysis

	Single story un-reinforced	Single story Reinforced	Percentage decreasing	Double story un-reinforced	Double story Reinforced	Percentage decreasing
Along X(mm)	6.35	4.14	34.8%	20.26	7.09	65%
Along Z(mm)	5.72	3.41	40.38%	19.46	6.9	64.54%

Table 3. Displacements from Response Spectrum Analysis

	Single story Un-reinforced	Single story Reinforced	Percentage decreasing	Double story Un-reinforced	Double story Reinforced	Percentage decreasing
Along X(mm)	9.64	6.66	30.91%	35.40	13.12	62.93%
Along Z(mm)	9.18	5.59	39.10%	33.88	13.01	61.59%

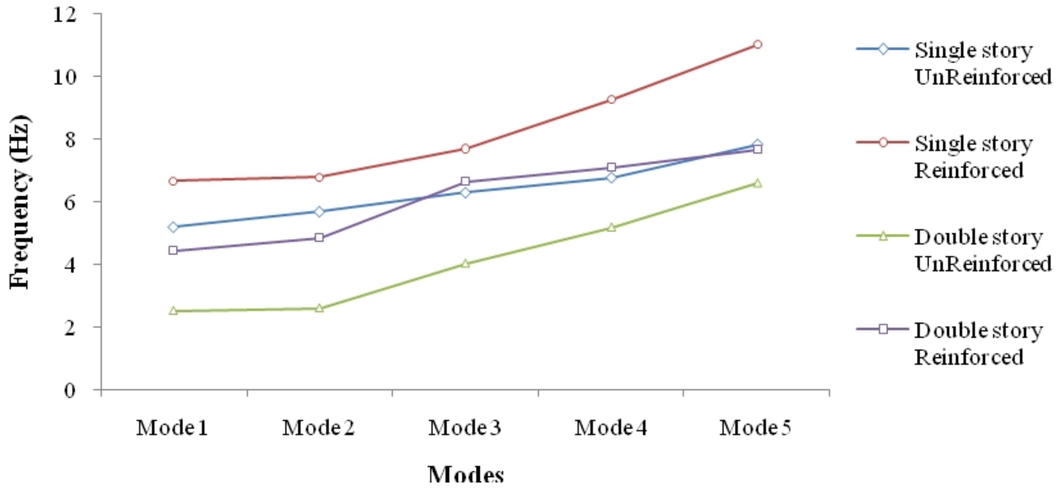
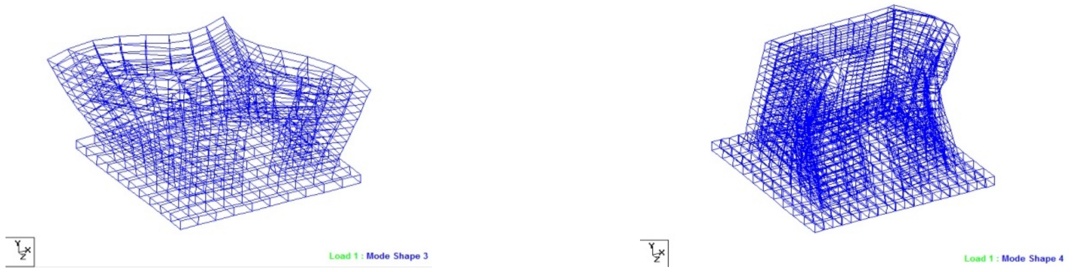


Figure 2. Frequency comparison of different models

and 39.10% to the corresponding directions. On the other hand, the reduction percentages of double story are 62.93% and 61.59%. The percentages of reduction of displacements are nearly same in both static and response spectrum analysis. Figure 2 defines the differences of frequencies of different models due to dynamic loading. It is understandable from the figure that the reinforced samples are with greater values of frequencies considering the unreinforced ones. The greater values of frequencies indicate greater stiffness of the structures.



1st Torsion mode shape in Model 1 (Mode 3, 6.293 Hz)   1st Torsion mode shape in Model 2 (Mode 4, 9.166 Hz)

Figure 3. Mode shapes of Model 1 and Model 2

1st Torsion mode shape in Model 3 (Mode 3, 4.021 Hz)   1st Torsion mode shape in Model 4 (Mode 4, 7.11 Hz)

Figure 4. Mode shapes of Model 3 and Model 4

It is observed from Figures 3 and 4 of mode shape analysis that for both single and double story house, the first torsion mode is found in mode 3 for unreinforced and for reinforced one, the first torsion mode is found at mode

4. This phenomenon can be observed for both single story and double story houses. The vulnerability of unreinforced models can be predicted from this mode shape observation. So, timber reinforcement can be reduces the damage of mud house.

5 Conclusions and Recommendation

From the investigation and results obtained from numerical analysis, it is evident that using timber splices can be a good choice in mud houses. Considering the outcomes, a number of conclusions can be made

1. Reinforced samples are susceptible to less lateral displacements compared to the unreinforced one which is a parameter of safety for the use of reinforcement. So, it has no doubt that using of timber reinforcement can be chosen as proposed in present research.

2. The stiffness of models is increased to a great extent through using reinforcement which indicates that it can resist from being collapse rapidly against earthquake load.

3. Mode shape analysis has also been proved that the proposed timber reinforcement can be used to resist seismic effects. The torsional modes are shifted by using reinforcements.

Present research deals with the linear analysis of structures. It is recommended that non-linear static and dynamic analysis can also be performed for further study.

References

Alam, D.M.J., Ahsan R., Akhter F. and Paul A. (2014). Earthquake resistant non-engineered building construction for rural area in Bangladesh. http://www.iitk.ac.in/nicee/wcee/article/14_09-02-0006.PDF.

Arya, A. (2000). Non-engineered Constructions in Developing Countries-An Approach Towards Earthquake Risk Prediction. 12th World Conference on Earthquake Engineering, 187-208.

Bangladesh National Building Code (BNBC), 2014.

Bariola J. and Sozen M.A. (1990). Seismic Tests of Adobe Walls. Earthquake Spectra. 6, 37-56.

Islam, M. S. and Iwashita, K. (2010). Earthquake resistance of adobe reinforced by low cost traditional materials. Journal of Natural Disaster Science. 32, 1-21.

Meli, R., Hernandez, O. and Padilla, M. (1980). Strengthening of Adobe Houses for Seismic Actions. In Proceedings, 7th World Conference on Earthquake Engineering (Istanbul, Turkey), Turkish National Committee on Earthquake Engineering, Ankara, 465-472.

Ottazi, G., Yep, J. and Blondet, M. (1988). Shaking Table Tests of Improved Adobe Masonry Houses. Proceedings of the 9th World Conference on Earthquake Engineering. Toky-Kyoto, Japan, 8, 1123-1128.

Rahman M., Hassan M.R. and Hossain M.T. (2013). Seismic Performance Analysis of Mud House in the Context of Bangladesh. International Journal of Scientific & Engineering Research. 4(10), 1612-1617.

STAAD-pro 2006-Technical references.

Uddin, N. (2008). A study on traditional housing technology of Bangladesh. Indian Journal of Traditional Knowledge. 7, 494-500.

Uniform Building Code, 1997.

Vargas, J., Bariola, J. and Blondet, M. (1984). Seismic strength of adobe masonry. U.S. Agency for International Development (AID) Research Project DI-84-01.