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Seismic Performance Analysis of Mud House in the Context of Bangladesh

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Abstract— Earthquake is a sudden natural disaster that happens unlike other natural disasters without any proven pre-warning system. This phenomenon makes earthquake most devastative and unpredictable natural calamity. In recent years, some earthquakes having their magnitude from 4.0 to 6.9 Richter scale (light – strong) jolted Bangladesh and its neighboring countries, which substantiate the prediction that Bangladesh is in high risk of major earthquake in near future. It is necessary to take preventive measures for covering the risks associated with earthquake hazards. In Bangladesh most of the people lives in village and mud houses are very common in the rural areas. In quantity, fatalities in earthquake are mostly due to structural collapse of weak masonry building i.e. adobe, rammed earth construction etc. In the current paper, computer modeling and seismic analysis of two models of mud houses with reinforcement have been performed using the finite element software STAAD.Pro-2006 and compared with seismic test performed in the laboratory. From the comparison it was observed that finite element analysis can be an alternative of laboratory based seismic tests. Shaking table test is very costly and rarely available. Computer modeling to simulate seismic test involve less budget, labor and time and can be considered as influence from practical consideration. This paper also includes parametric study (height and thickness of wall, opening size, shape and location) and identification of critical location of failure using finite element analysis. The study is expected to give guidelines for design, construction and strengthening of mud houses to mitigate the earthquake hazards in the rural area.

Index Terms— mud house, computer modeling, solid element, seismic analysis, parametric study

1 Introduction

Bangladesh is a developing country. It is located in a tectonically active region close to the junction of the north moving Indian plate and the Eurasian plate resulting in several seismic sources (fault zones) in and around the country. The Great Indian Earthquake (Magnitude 8.7) in 1897 had its epicenter only 230 kilometer away from the capital city of Bangladesh (Ansary, 2006). Every year, about 25-30 small to medium tremors occurs in Bangladesh. The possibility of a stronger earthquake is imminent and corresponding devastation is just destabilization of our hard earned development and huge life loss.

The history of earthquake in Bangladesh is sufficient enough to require their careful consideration in the design of structures and facilities. The objective of earthquake resistant design is to install a structure or facility that can withstand a certain level of ground shaking without excessive damage (Ansary, 2000). Casualties in earthquake arise mostly from structural collapse. The greatest proportion of fatalities results from the collapse of weak masonry buildings i.e. adobe, rubble stone or rammed earth construction (Aikaterini, 2004). About 80% people of Bangladesh live in rural areas and a significant portion of them resides in mud houses. Therefore it has become very much essential to analyze the effect of earthquake on these mud houses. Earthquake analysis with comprehensive coverage of parametric study incorporating openings (shape, size and location) in wall, wall thickness etc. is important.

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2.1 Software and Basic Element

Shaking table test is very costly and not available in our country. Parametric study on the basis of experiment is again laborious, time consuming and expensive. Computer modeling is very suitable for this purpose using software. For the present study STAAD.Pro-2006 was used.

The structure was discretized by 8-noded solid elements (Fig.1). The solid elements used in STAAD have three translational degree-of-freedoms per node. Solid elements enable the solution of structural problems involving general three dimensional stresses in dam and embankment. Solid element has been considered as a tool for the finite element discretization and analysis for mud house.

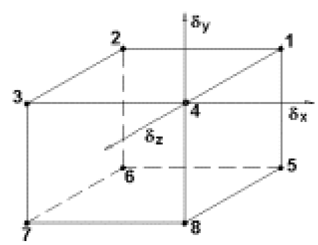

Figure 1: Eight noded solid element

Solid element stresses may be obtained at the center and at the joints of the solid element. The stress items are:

Normal Stresses: SXX, SYY and SZZ Normal
Shear Stresses: SXY, SYZ and SZX
Principal stresses: S1, S2 and S3.

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2.2 Material Property and Seismic Constants

Two types of materials were used for simulation of mud house model, a) Mud and b) Timber (used as reinforcement).

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The material property of mud and timber considered for this study are as follows:

TABLE 1: VARIOUS PROPERTIES OF MUD AND TIMBER

Property	Mud	Timber
Young's modulus (E)	12,500 psi	13,32,800 psi
Poisson's ratio (μ)	0.45	0.15
Density	100 pcf	25 pcf
Shear modulus (G)	4310.35 psi	579478.26 psi

Material properties of mud considered for this study were mainly taken from laboratory tests (Rahman and Bayazid, 2008; Nahid and Mainur, 2008) and those of timber (used as reinforcement) from STAAD material library. In the study, Uniform Building Code (UBC `97) was used to define the seismic loading. The seismic constants used to define seismic load are, (i) Seismic zone factor 'Z'; (ii)Importance factor 'I', (iii) Numerical coefficient 'R' representative of the inherent over strength and global ductility capacity of lateral-force-resisting systems; (iii) Soil Profile type SA, SB-SE; (iv) Near source factor Na, (v) Near source factor Nv ; (vi) Ct value to calculate time period (T).

2.3 Seismic Analysis

Seismic analysis is of two types, i.e. Static analysis and Dynamic analysis. In the current study, static analysis was preferred.

2.3.1 Static Force Procedures for Seismic Analysis

STAAD offers facilities for determining the lateral loads acting on structures due to seismic forces, using the rules available in several national codes and widely accepted publications. The codes and publications allow for equivalent static force method to be used in place of more complex methods like response spectrum and time history analysis. Among the several such codes supported by STAAD are UBC (Uniform Building Code), IBC (International Building Code) etc. UBC code (1997) was used in case of static analysis of mud house due to its availability (STAAD-pro 2006-Technical reference).

STAAD is equipped with built-in algorithms to generate lateral seismic loads (as per the Uniform Building Code) on a structure. Once the lateral loads are generated in STAAD, the program can then analyze the structure for those loads using the applicable rules explained in the code documents (STAAD-pro 2006-Technical reference).

The STAAD seismic load generator follows the procedure of equivalent lateral load analysis explained in the UBC code. It is assumed that the lateral loads will be exerted in X and Z directions (horizontal) and Y will be the direction of the gravity loads. Total lateral seismic force or base shear is automatically calculated by STAAD using the appropriate equation from the code. After the base shear is calculated from the appropriate equation, it is distributed among the various levels of the structure as per UBC specifications. The distributed base shears are subsequently applied as lateral loads on the structure.

2.3.2 Comparison Between UBC97 and BNBC93 Code

According to the Uniform Building Code (UBC 97), design base shear

$$V = \frac{C_v I}{RT} W$$

But the upper and lower limits of the design base shear are respectively

$$V = \frac{2.5 C_g I}{R} W$$

and $V = 0.11 C_g I W$

Where, C_v and C_a are seismic coefficient dependent on soil type, I, R, W has their usual meaning mentioned earlier and elastic fundamental period of vibration, in seconds
Again, according to BNBC 93, the design base shear

$$V = \frac{ZIC}{R}$$

Where, $C = \frac{1.25S}{T^{2/3}}$

Z, I, R, W, T has their usual meaning and S represents the type of soil. Appropriate values of the following parameters were taken from the respective code as showed in Table 2 considering that, the mud house is located in Dhaka and height of mud house is 9.5ft.

TABLE 2: DIFFERENCE OF SEISMIC PARAMETER BETWEEN UBC 97 AND BNBC 93

Seismic Parameter	UBC 97	BNBC 93
Seismic zone factor Z	0.30	0.15
seismic coefficient CV	0.84	-
seismic coefficient Cg	0.36	-
Importance factor I	1.0	1.0
Numerical coefficient R	2.9	4.0
C^{τ}	0.020	0.049
Height of mud house hn	9.5 ft	9.5 ft
Type of soil S	-	1.5

Base shear of the mud house in terms of total seismic weight (W) of the structure as per UBC 97 and Bangladesh National Building Code (BNBC) 93 Code were 0.3103W and 0.3086W respectively. It was observed that the values of base shear obtained from UBC 97 and BNBC 93 code are almost same. Again, the distribution formula of base shear to the structure is same in UBC 97 and BNBC 93 codes. In the current study, Uniform Building Code (UBC) 97 code was used to define the seismic loading.

2.3.3 SEISMIC LOAD AUTO GENERATION IN STAAD.PRO-2006

STAAD is equipped with built-in algorithms to generate lateral seismic loads (as per the Uniform Building Code) on a structure. Once the lateral loads are generated in STAAD, the program can then analyze the structure for those loads using the applicable rules explained in the code documents.

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3 Modelling of Mud House

For modeling of mud house at first the basic finite element unit “8-noded solid element” is generated. Translating the basic unit in global X, Z and Y direction the mud house model can be created. For this purpose, at first the solid element translated in global X direction according to the desired length of plinth; than all the solid elements in the existing window translated in global Z direction according to the desired width of plinth. Next all the solid elements in the existing window translated in global Y direction according to the height of plinth. According to the dimension and location of the walls, the walls are created first up to the height from where opening starts (For the ease of understanding the plinth is not shown in the figure 6) The locations and dimension of openings are selected and then the solids are translated in such a manner that, where there is an opening, a blank space is there in the wall. Finally a complete mud house model of required shape was created (Fig.8).

The step by step procedure of a typical mud house modeling is chronologically illustrated below:

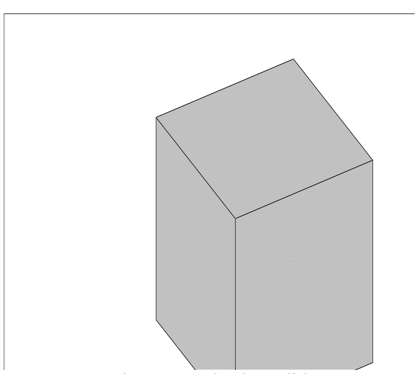

Figure 2: Single solid

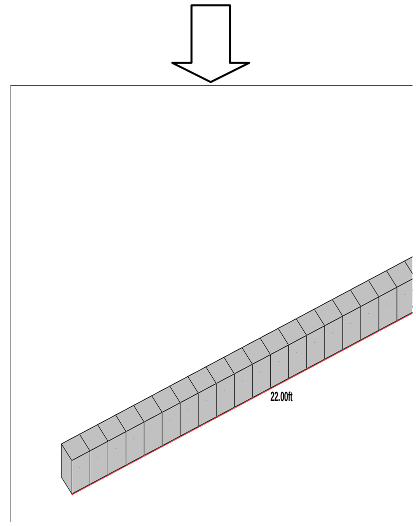

Figure 3: Solid element translation in X

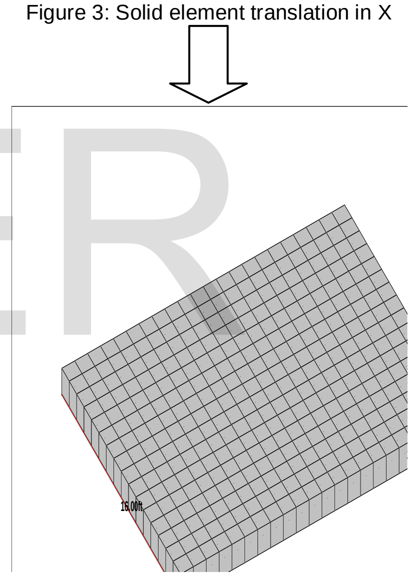

Figure 4: 1st layer of plinth

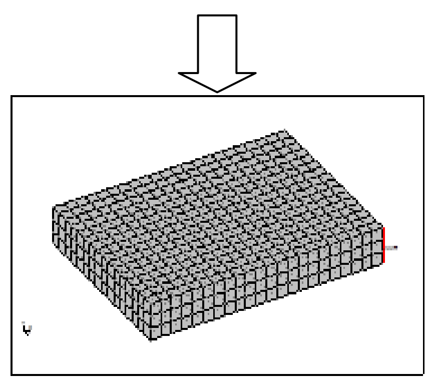

Figure 5: Plinth of mud house

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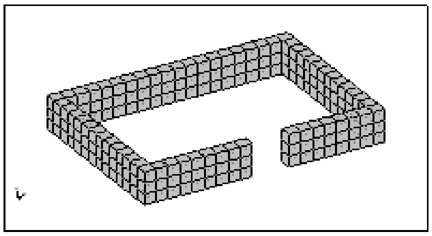

Figure 6: Mud wall (height below window)

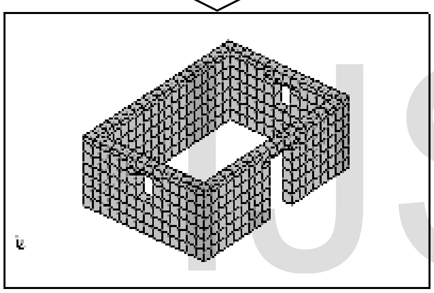

Figure 7: Mud house model without plinth of mud house excluding plinth

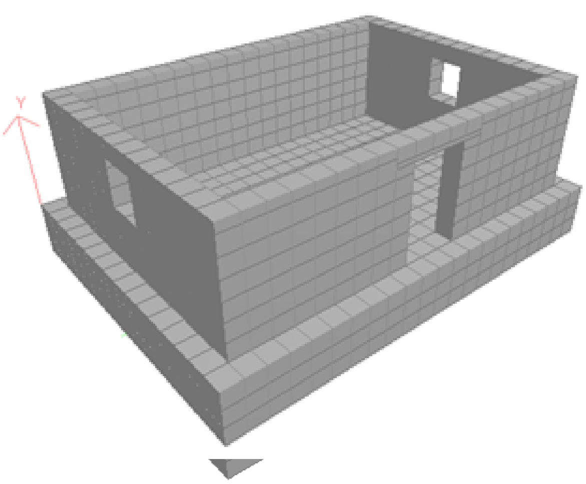

Figure 8: Complete mud house model

4 ANALYSIS AND VERIFICATION

In case of analysis by a model, the analysis result should be verified and material property should be representative. The efficiency of modelling needs to be verified. In most case the verification is done by experimental test.

4.1 Analysis and stress distribution

According to procedure described before a mud house model was created for analysis as shown in figure 8. The user friendly load menu of STAAD.Pro-2006 was used to generate load (density and UBC seismic load) on the structure. The resulting output includes stress distribution, base shear, deflection etc. of which normal stresses are discussed in this paper. For ease of understanding of the result the limiting value as determined by laboratory tests (compressive stress,10 psi ; tensile stress,1.2 psi) was assigned to identified elements. The results having higher stress than allowed are correspondingly represented by color. For example green color shows the safe zones. Red color shows the compressive stress zone and the purple color shows the tensile stress zones. From the analysis result critical locations of failure identified by analysis were found near the base of mud house, at the bottom of door, above the lintel of door, corners of mud house, and the adjacent area of opening (as shown in figure 9,10 and 11)

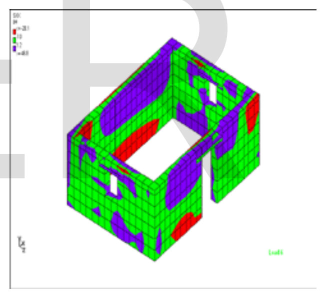

Figure 9: Stress (SXX) distribution contour in mud house

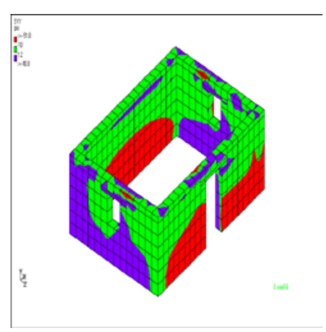

Figure 10: Stress (SYY) distribution contour in mud house

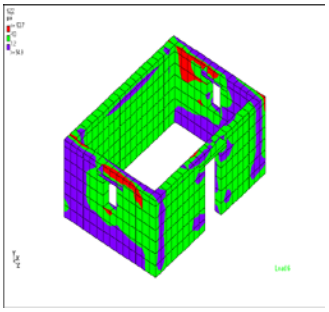

Figure 11: Stress (SZZ) distribution contour in mud house

4.2 Verification with Experimental Result

Two models of mud house (without reinforcement and with reinforcement) were analyzed for seismic loading and compared with experimental result with respect to the usual laggings of modeling procedure.

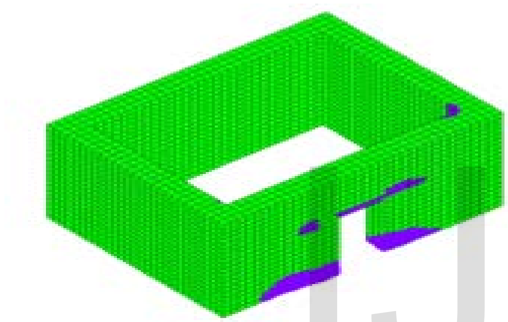

Figure 12: Stress contour in mud house model (without reinforcement) by STAAD analysis

Figure 13: Position of crack formation in unreinforced mud house in experiment.

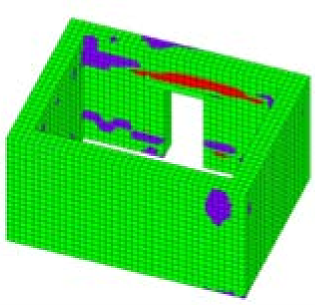

Figure 14: Stress contour in mud house model (with reinforcement) by STAAD analysis

Figure 15: Position of crack formation in reinforced experiment.

It was observed from the analysis result that mud house without reinforcement has greater stress in the bottom (left side wall and back wall), at the bottom of door and near the lintel of door which approximately simulates the crack due to first cycle of horizontal loading in the model tested. In case of reinforced mud house model, analysis result shows that greater stresses were adjacent to the location of reinforcement. In experimental mud house model having reinforcement; the cracks were not localized like unreinforced model, but the cracks were distributed in the whole structure.

The crack distribution predicted by analysis of models show good agreement with that of tested results.

5 Parametric Study

Parametric study on mud house was carried out in the following aspects with respect to seismic loading:

1. Variation of thickness of the mud wall in mud house with respect to a constant height.
2. Variation of the height of mud house with respect to a constant thickness of mud wall.
3. Variation of the size of window (opening) size.
4. Variation of the position of window (opening).

By parametric study following findings were obtained.

1. If the thickness of mud wall in mud house increased with respect to a constant height, the safe zone (green colored area) is also increased.
2. If the height of mud wall in mud house decreased with respect to a constant thickness, the safe zone (green colored area) is also increased.
3. If the size of window (opening) is smaller and square and the window is at mid position of wall, the safe zone (green colored area) is also increased.

6 Conclusion

It can be concluded from analysis result and parametric study that, the mud house will be more safe against earthquake if

1. Thickness of mud wall in mud house is increased.

2. Size of window (opening) is small and square one.
3. Window (opening) is at mid position of the mud wall.
4. Reinforcement is used in mud house.

Mud has a wide range of variation in its property and it differs from place to place, weather condition (i.e. in rainy season the mud walls will have definitely high moisture content than dry season) etc. It is possible to change the property of mud in STAAD analysis. For further study it is recommended that the analysis should be performed with a wide range of variation in property of mud, more parameters should be selected for parametric study i.e. changing the meshing size to know the effect of meshing size variation on result, and dynamic analysis can also be performed for parametric study.

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