EXPERIMENTAL ASSESSMENT ON PERFORMANCE OF GEO-GRID MESH IN SEISMIC LOADING CONDITION ON ADOBE STRUCTURES

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ABSTRACT

Adobe structures are one of the oldest and most adapted structures known to humanity. Basically, these structures are constructed without any prior engineering principles. The in-plane and out-of-plane loading failure caused by the earthquake leads to extensive damage and in some cases, the collapse of the structures. The main objective of this study is to assess the effect of geo-grid mesh as a strengthening solution when earthquake-force condition prevails on adobe structures. To attain these objectives two series of tests were performed: A material testing program and a dynamic testing program on 3 reduced-scale adobe masonry house models. A reduced scale of 1:5 was adopted for model structures. The material testing program consists of physical and mechanical tests on the adobe and the dynamic testing program is performed to study the elastic and post-elastic behaviour of adobe structures through the shake table test. The strengthening technique investigated were 1. The model with geo-grid as a wall surface strengthening and 2. The model with geo-grid as a bed-joint strengthening. A shake table test was performed on unreinforced and reinforced adobe-reduced scale models. The models were tested on a shake table with a frequency range of 0-25 Hz. After testing it on the shake table, it is concluded that the model structure with geogrid as a wall surface strengthening and bed joint strengthening shows delayed failure occurrence and more ductile behaviour which avoids the life-threatening collapse of the structure.

Keywords: - *Adobe, earthen structures, vernacular architecture, geo-grid, shake table, seismic strengthening, retrofitting.*

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1. INTRODUCTION

Earthen materials have been present in the construction of civilizations as early as 8000 BCE. Around 30% of the world's population lives in earth-made construction. Approximately 50% of the population in developing countries, including the majority of the rural population and at least 20% of the urban and suburban population, live in earthen dwellings. In India, according to the 2001 Census, 30% of all buildings are made out of earth. Unfortunately, the collapse of this type of structure during seismic events has caused significant loss of life and damage. Seismic deficiencies are caused by poor mechanical characteristics, such as heavy weight, low strength, and brittleness. As an earthquake occurs, structures are hit by in-plane and out-of-plane forces. The wall geometry and stiffness of the roof and floor that carry loads into the wall are critical factors for the number of in-plane forces. Out-of-plane forces tend to push the face of the wall inward or outward.

In adobe structures, conventionally many materials have been used as wall surface strengthening. Examples are steel wire mesh, GRPF strips, Bamboo mesh, Aluminium Sheets, etc are conventionally used materials for wall surface strengthening. Amongst them, steel wire mesh or steel reinforcement is the most used material all around the world in this type of structure. Though due to two main reasons, questions can be raised about the application of steel wire mesh as a solution. The first one is the economy. Compare to geogrid, steel wire mesh is a costly material, and as these structures are mainly built by low-income generating families, the economy becomes the main issue. Second, is the environmental impact of steel wire mesh. As we know, corrosion is one of the big disadvantages of using steel, it also becomes one of the main issues. After a certain time, wall surface strengthening is exposed to the weather and so due to that corrosion of steel wire mesh would generate problems in the structures while the geogrid is environment-friendly material.

2. BASICS OF MATERIAL AND MODELS

The overall study can be divided into two parts. The first part carried out is a material testing program of the Adobe material. Various properties and characteristics of Adobe material are found in the first part and differences in behavior between the prototype and reduced scaled material are found. The Second part consists of static and dynamic testing of 3 reduced-scaled single-story, Single room Adobe masonry house models.
Three cubes of size 70.6×70.6×70.6 mm of different proportions of clay and sand were casted to finalize material proportion.

- Cube 1 of Clay: Sand = 60:40
- Cube 2 of Clay: Sand = 50:50
- Cube 3 of Clay: Sand = 40:60

After Sun drying the cubes for 14 days, it has been observed that there were no cracks on any of the 3 Cubes. Therefore, it has been decided to use Material Proportion of Clay: Sand as 60:40. A mechanical Mixer was used to mix the clay and sand uniformly. Straw was also added to the mix. Straw is generally added as it is useful in binding the bricks together and then allowing it to dry evenly, so as to prevent cracking of bricks due to uneven shrinkage rates through the brick.

2.1. DETAIL PLAN AND GEOMETRY OF STRUCTURE

For the casting of the Reduced scale bricks and Reduced scaled Adobe masonry model, a Reduced scale of 1:5 is used. Detailed Plan, Elevation, and Side view are given in figure shown below.

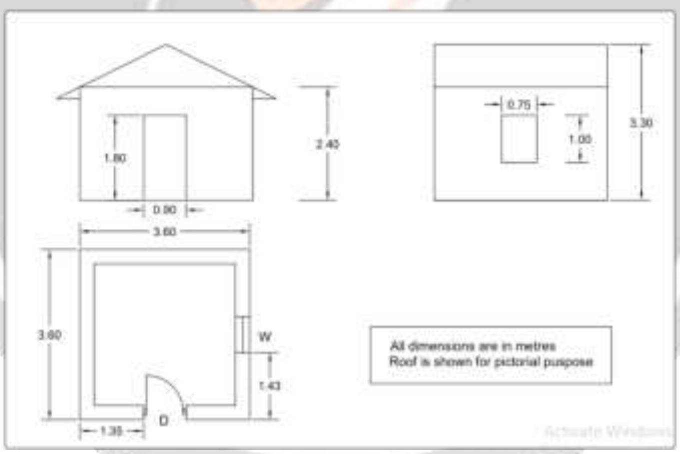

Fig 1: - Deatiled Plan, Elevation and Side View of the Structure

2.2. MODEL SIMILITUDE

There should be a resemblance between the prototype and model through the rules which can relate geometry, material properties, initial conditions, and boundary conditions between them. To satisfy the modeling requirements for dynamic testing, models without the simulation of gravity forces are considered. For lower-storey houses (In this case Single storey), the stresses induced by gravitational forces are small compared to the stresses induced by seismic forces. So due to the negligible effect of gravity forces, there is no need to simulate gravitational forces. For the reduced scale of 1:5, the following are the transformations from the model domain to the prototyping domain.

For, Frequency, f(Prototype) = f(Model)/5
Time, t(Prototype) = t(Model)/5
Force, F(Prototype) = F(Model)×25
Displacement, δ(Prototype) = δ(Model)×5
Acceleration, a(Prototype) = a(Model)/5

3. MATERIAL SPECIFICATION AND ITS PROPERTIES

This part describes the various material used for making the reduced scaled models including the strengthening technique and its classification and properties. Given below is the table of the properties of adobe soil.

Table 1: - Properties of Adobe Soil

Colour of Soil	Type of Soil	Bulk Density of Soil (g/cm^3)	Clay Content in %	Sand Content in %
Brown Soil	Clayey, Highly Compressible Soil (CH Soil)	1.89	60	40

3.1. Brick

Before finalizing the size of the brick of the prototype structure, various references regarding the size of Adobe brick used worldwide were studied and then the brick size was finally adopted which is given in the table shown below.

Table 2: - Specification of brick

Brick Size	Full Scaled (in Cm)			Reduced Scale (1:5) (in Cm)		
	L	B	H	L	B	H
Adobe Bricks	25	30	8	5	6	1.8

3.2. Geo-grid

Geogrid is a type of geo-synthetics that is a synthetic product, usually made from or including polymeric materials, that are used to solve civil and geotechnical engineering problems. Geogrid has been used for enhanced performance against seismic loading in Embankments, Earth retaining structures, etc. Geogrids work by interlocking with the granular or fine material placed over them. The apertures allow for strike-through of the cover soil material which then interlocks with the ribs (flat straps/bars) providing confinement of the overlaying granular/soil material due to the stiffness and strength of the ribs. The advantages of geogrid are that they result in more economical construction, are environmentally friendly, and ensure ease of construction as the placement techniques are simple.

Geogrid used in the project is the CTM-GGU geogrid manufactured by CTM technical textiles. CTM- GGU Geogrid is a uniaxial geogrid composed of high-tenacity polyester (PET) multifilament yarn with high molecular weight and a low carboxyl end group. This Geogrid is woven and coated with PVC which is inert to biological and chemical degradation. The technical product data sheet is given below.

Here geogrid used is CTMGGU 100/30. Here 100/30 means it has the ultimate tensile strength of 100 kn/m in the machine direction of the geogrid and 30 means it has 30 kn/m of ultimate tensile strength in the perpendicular direction of the geogrid. Other than the ultimate tensile capacity of the geo-grid, other properties are given in the product technical data sheet.

3.3. Physical and Mechanical Properties of Adobe Material

The physical tests performed on the adobe material are the standard proctor test, liquid limit, and plastic limit test. The mechanical tests performed on the adobe material are the compressive strength test and the flexural strength test

In total 6 cube specimens were prepared for determining the Compressive Strength of Adobe Cube. 3 Cube specimens were of size 150×150×150 mm and the other 3 were of size 70.6×70.6×70.6 mm. As the strength of the adobe is very less (approx. 1-4 mpa), the compressive tests were performed on a strain-controlled machine. The strain rate adopted is 1 kn/s. The avg compressive strength of adobe cubes of 150 mm size is 3.14 mpa and of size 70.6 mm is 4.60 mpa. Now as per NZS 4298: - Materials and Workmanship for Earth Buildings [10], Recommendations for Compressive strength are given.

For the Aspect ratio between 0.4 and 5.0, the Least of the individual results in the set > 1.30 Mpa (For Aspect ratio 1). In our case with aspect ratio 1, Each cube has Compressive strength greater than 1.30 Mpa. So, the Adobe material is safe in compression.

A Flexural Strength test was carried out on the brick of original size 250 cm × 300 cm × 80 cm. The Flexural Strength of the brick comes out to be 2.9 Mpa. Now as per NZS 4298: - Materials and Workmanship for Earth Buildings [10], Recommendations for Flexural strength are given. Flexural Strength should be greater than 0.25 Mpa and in our, it is 2.9 Mpa and so it is greater than the recommended strength.

4. THEORY AND CONSTRUCTION OF REDUCED-SCALE ADOBE MODELS

The reduced Scale used is 1:5 for Brick Manufacturing and so the size of the brick is 5×6×1.8 cm. A total No. of 3000 Bricks is manufactured. Three model buildings were constructed and tested. The construction of each of the three Adobe models is discussed briefly in this section. Each of the models is identical in plan and wall layout. The only difference is the strengthening applied to the wall of the models is different in different models.

Each of the models is constructed in a similar manner. The model is prepared on a 90×90 cm plywood base plate. The walls were constructed with reduced-scale adobe bricks and with mortar made up of the same material (mud mortar). The model walls are single brick thick and constructed with a running bond. The thickness of the mortar joint is kept 2 mm for all the model buildings. reduced-scale window and door are used in the model-making. The size of the door was 36×18 cm and the size of the window was 20×18 cm. For internal support, wooden planks were used on the internal side of the adobe wall. The base layer was made with the help of cement mortar and fibre mesh. At the lintel level, the RCC band is made to mitigate the shear cracks developed in the wall.

4.1. Construction of Model A1

Model A1 was the base model without any strengthening technique for the study. The construction procedure of the model is discussed above.

4.2. Construction of Model A2

Model A2 was strengthened with the wall surface strengthening technique with geogrid as a confinement reinforcement. Wall surface strengthening is a technique that is most widely used and easy to apply for any type of structure. Here in Model A2, polypropylene strips are used to tie the geogrid to the wall surface. While making the model buildings, these strips were placed in the bed joint of the successive brick layers, and after the completion of the model, geogrid was tied internally and externally with these strips.

4.3. Construction of Model A3

Model A3 was strengthened with the bed-joint strengthening technique with geogrid as a bed-joint reinforcement. Most strengthening uses wall-surface strengthening, which requires good surface preparation, as irregularities can cause poor bonding and delamination. The other hindrances of this method were vulnerability to environmental impacts like fire, moisture, frost, etc. Bed joint strengthening is an effective solution to overcome such problems. So, due to these reasons, in Model A3 bed-joint strengthening technique is used to resist the seismic forces. Geogrid is placed in alternate layers and accordingly, strips are made and laid down in the bed joint of the masonry layer.

Fig 2: - Model A1

Fig 3: - Model A2

Fig 4: - Model A3

5. TESTS ON MODEL STRUCTURES

Two tests were conducted on each constructed masonry model. The first test was the impact hammer test to determine the dynamic characteristic of models like natural time period and damping. The second test was the shake table test to get the failure and damage pattern of models.

5.1. Impact Hammer Test

An impact hammer test was conducted to determine the natural time period and damping of models. Different instruments which were used in the experiment are Impact Hammer, Accelerometer, sixteen channel vibration analyzer instruments, Data cable & Computer with NV gate software.

Fix the model structure on the shake table and put the required calculated weight of 32 kg on the roof of the structure. Attach sensors to their positions on the model and make sure all the sensors and impact hammer are connected to sixteen-channel vibration analyzers. After all connections are made properly, run NV gate software and strike the impact hammer horizontally to the wall of the modeled structure at the hammering place. Record the free vibrations of the structure produced due to hammering and obtain acceleration vs. time plot. Measure the time period required to complete one cycle of vibration to obtain the time period T. Measure the peak acceleration A_1 at time t_1 and acceleration another any particular acceleration A_2 at time t_2 and compute the damping (ξ) from the following Equation.

$$\xi = \frac{1}{n \times 2\pi} \ln \frac{A1}{A2}$$

However, the above equation is for the vibrations related to uniform accelerated motion while the model masonry structure does not perform uniform motion. But to find the Approx. value of damping above decay in motion related to model masonry structure can fairly be assumed to be uniform by selecting peak acceleration and low acceleration data. Repeat the process to get finer data and analyze collected data for final results.

5.2. Shake Table Test

Shake table testing was done for all modeled masonry structures to observe the effect of seismic strengthening techniques (geogrid as wall-surface strengthening and bed-joint strengthening) on the failure mode of the structure. Different instruments which were used in the experiment are Shake Table, Accelerometer, sixteen channel vibration analyzer instruments, Data cable & Computer with NV gate software.

Specifications of low-frequency shake table:

- Design Payload of Approximately 200 kg
- Peak Acceleration 5g
- Operational Frequency Range 0–25 Hz
- Sliding Table Dimensions 3 ft x 5 ft
- Motor capacity 1 HP

Fix the model structure on the shake table and put the required calculated weight of 32 kg on the roof of the structure. Attach sensors to their positions on the model and make sure all the sensors are connected to Sixteen channel vibration analyzer. After all connections are made properly, run NV gate software and start the shaking of the shake table from an initial frequency of 1 Hz with an initial displacement of 15 mm and 5 No. of cycles. Record the collected data from the sensors and save the file, after that frequency has to be increased subsequently until the model fails. All the data for each frequency has to be recorded and saved in digital format.

Data collected from sixteen channel analyzer based on the base acceleration, applied frequency, acceleration at the roof level of the model structure, and displacement at the top of the structure were found out for each shaking. There are three different inputs frequency, displacement, and No. of cycles to be provided to the shake table. However, the input frequency is the frequency of the servo motor which empower the shake table unit may differ from the actual frequency applied at the base of the shake table where the prepared models are to be rested.


Fig 5: - Model A1 on Shake Table


Fig 6: - Model A2 on Shake Table


Fig 7: - Model A3 on Shake Table

5.3. Results of the study

The damping of each model the and natural time period of each model are found in the results of the impact hammer test given in the table given below. As one can observe from Table 3 the damping of Model A2 and A3 increases with respect to Model A1.

Table 3: - Dynamic characteristics of all Modeled masonry structures

Model	Natural Time Period (Tn in s)	Damping(ξ)
A1	0.008	1.532
A2	0.006	2.24
A3	0.01	2.67

The capacity curve for all 3 models in the form of Base shear coefficient (BSC) vs. Drift ratio is to be plotted. The drift ratio is the ratio of the top lateral displacement to the height of the structure and is expressed in percentage drift. Base shear is calculated by multiplying the maximum response acceleration at the top of the structure with the storey mass, while storey mass can be taken as the sum of the mass of the roof and half of the mass of the walls. The advantage of comparing capacity in terms of BSC instead of PGA (Peak ground acceleration) is that it provides a uniform standard for comparing performances of structures subjected to varied testing regimes, and thus similar structures tested anywhere in the world can be conventionally compared without giving specific importance to input excitation and PGA.

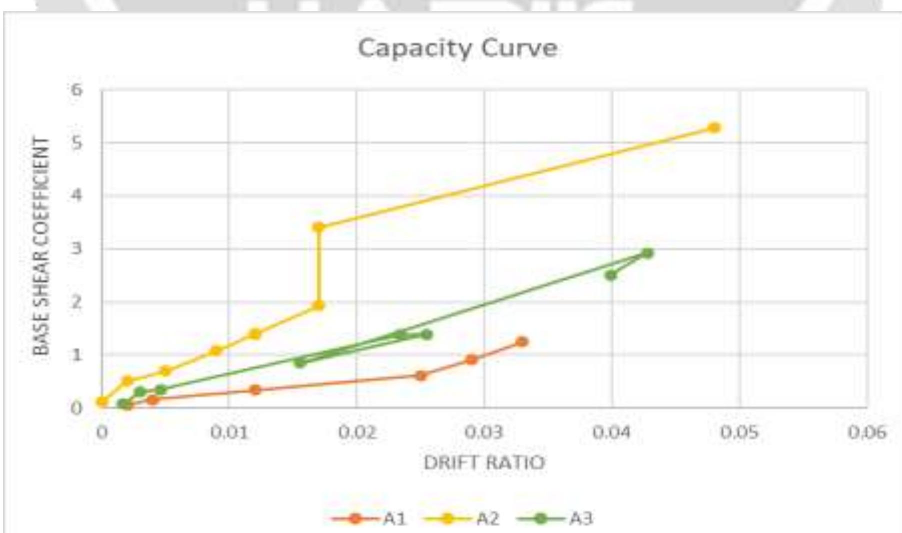

Chart: - 1: BSC vs. Drift ratio (%) curves for Adobe Model structures A1, A2 and A3

From the above graph following observations are made

- The capacity curve of model A1 shows competitively lesser values of BSC for the corresponding drift ratio compared to the other two models A2 and A3. Which shows very low energy absorption for model A1.
- Model A2 has the highest seismic resistance than Model A1 and Model A3 as it has the highest base shear coefficient among all the three models.
- Model A1 reaches its ultimate capacity at drift ratio (%) around 0.033, and Model A3 reaches its ultimate capacity at drift ratio (%) around 0.0428 however BSC corresponding to Model A2 is slightly higher than the BSC corresponding to Model A3 which reaches its ultimate capacity at drift ratio (%) around 0.048.
- In the case of Model A3, the capacity curve shows the reverse behavior at certain points where there is a decrease in BSC with an increase in Drift Ratio.
- For the Drift ratio of 0.01 to 0.03, less deformation or damage and cracks were observed in model A2 for the same amount of acceleration as in model A3.

6. CONCLUSION

- The conventional technique of using strengthening material as wall-surface strengthening provides the best output results which can be seen in the capacity curve of all the models.
- The unconventional technique of bed-joint strengthening also appears to be significantly more resistant than the structure without any strengthening aid but the amount of the maximum base shear carried by it was lesser than the wall-surface strengthening. Lesser environmental impact and economic savings of Bed-Joint strengthening also favor the use of geogrid as a bed-joint strengthening technique. So, in the areas where the influence of the earthquake is not much higher as compared to seismic-prone areas, the use of geogrid as a bed-joint strengthening can be emphasized. Damping of the adobe masonry models with the strengthening techniques varies with the one with no strengthening techniques and the damping of the Model A2 and A3 was almost the same.
- To study the crack pattern of the adobe masonry wall, there was no provision for mud plaster but in the prototype structure where wall surface strengthening is also a retrofitting technique, the use of mud plaster is recommended for the prevention of the de-lamination of the geogrid from the wall surface.

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