EXPERIMENTAL STUDY ON SEISMIC BEHAVIOR OF ADOBE MASONRY WITH HEMP FIBRE ROPES

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ABSTRACT

Vernacular structures are found widely around the world in reflection of the comparatively low cost, material availability, and ease of construction. Earthquakes occurring demonstrate again and again that vernacular structures are highly vulnerable and that millions of residents who live in these houses are at great risk. This emphasizes the need to find simple and economic solutions. This study aimed to improve the seismic strength of the unstabilized adobe houses involving the application of hemp fibre rope nets to the surface of adobe walls. The main objective of the study is to observe the seismic behaviour of adobe masonry wall using hemp fibre ropes and examine failure or damage patterns. The material for adobe housing were tested and adobe models using hemp fibre ropes were casted and tested in shake table and damage due to shaking were observed. To attain this objective two series of tests were performed. A material testing programme for reduced scaling of material and shake table testing programme for dynamic testing on 3 reduced scale Adobe masonry house models were performed. 3 models can distinguish as a simple reduced scale masonry structure with no extra or additional features, a similar masonry structure aided with hemp fibre ropes uniformly spaced grid as the earthquake resistant feature and a similar masonry structure aided with hemp fibre rope at the wall junctions and the openings. After testing it is concluded that masonry structure model A2 and A3 shows more ductile behaviour which avoids life-threatening collapse of structure.

Keyword: - *vulnerable structures, earthquake resistant, adobe masonry, strengthening techniques with hemp fibre ropes.*

1. Introduction

Vernacular architecture is an architectural style that is specifically designed to meet local requirements, utilize available construction materials, and reflect indigenous traditions. It is a unique form of architecture that is rooted in a particular time and place, not replicated from elsewhere. Over time, the design of vernacular architecture naturally evolves adapting and refining itself to suit the specific contexts in which it exists. These contexts include factors such as the availability of resources, a skilled labor force, and other local considerations. Climate also plays a significant role, encompassing factors like sunlight, humidity, rainfall, wind patterns, temperature profiles, and more. The building form of vernacular architecture is greatly influenced by the local culture and the way of life of its occupants. This includes considerations such as family size, building usage, social conditions, local customs, religious values, and more. The surrounding environment, whether it be near water, woodlands, deserts, or mountains, also shapes the architecture. Economic conditions and historical influences further contribute to the development of vernacular architecture. Vernacular architecture incorporates various sustainable construction techniques, including adobe construction, rammed earth construction, timber frame construction, thatch roof construction, wattle and daub construction, and stone masonry. These techniques emphasize the use of locally available materials and environmentally friendly practices, ensuring a harmonious relationship between the built environment and nature.

2. Detail Plan and Geometry of Structure

A reduced scale of 1:5 is employed for the production of smaller bricks and a reduced scale Adobe masonry model. A total of 3 reduced scale models were casted by smaller bricks. The original size of the brick intended for use in the prototype structure as well as the reduced scale bricks is given in the Table 1. Detailed Plan, Elevation, and Side view is given in the Fig. 1.

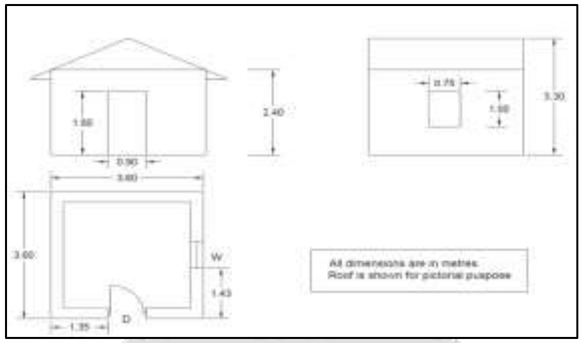


Fig.-1 Detailed Plan, Elevation and Side Elevation of Prototype Structure

2.1 Model Similitude

In order to meet the requirements for dynamic testing, models that do not incorporate the simulation of gravity forces are taken into consideration. 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 Properties

Regarding its physical properties, the standard proctor test, liquid limit test, and plastic limit test were conducted. In terms of its mechanical properties, the compressive strength test and the flexural strength test were performed.

Table-1 Properties of Adobe Soil

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

A total of six cube specimens were used to measure the compressive strength of adobe cubes. Among them, three cubes had dimensions of 150×150×150 mm, while the remaining three had dimensions of 70.6×70.6×70.6 mm. The strain-controlled machine was employed to conduct the compressive tests, with a strain rate of 1 kN/s. The average compressive strength of the 150 mm adobe cubes was found to be 3.14 Mpa, whereas the average compressive strength of the 70.6 mm cubes was measured as 4.60 Mpa.

A Flexural Strength test was conducted on a brick with dimensions of 250 cm × 300 cm × 80 cm. The test determined that the Flexural Strength of the brick was 2.9 Mpa.

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 below Table 2.

Table 2 Adobe Bricks Specification

Brick Size	Full scaled (in cm)			Reduced scaled (in cm)		
	L	B	H	L	B	H
Adobe Bricks	25	30	8	5	6	1.8

3.2 Hemp fibre rope as a strengthening material

Hemp fibre rope is a natural fibre rope made from the stems of the hemp plant. Hemp fibre is known for its strength, durability, and resistance to moisture, making it a popular material for use in various applications, including rope making. Hemp fiber has been studied as a potential material for seismic strengthening in construction. Seismic strengthening refers to the process of retrofitting existing buildings to improve their ability to withstand earthquakes. One of the properties that make hemp fiber a potentially effective material for seismic strengthening is its high tensile strength. Hemp fiber also has good adhesion to cement and other building materials, which allows it to be integrated into concrete or mortar to reinforce structures. The test is usually conducted using a tensile testing machine, which applies an increasing load to the rope until it breaks.
A tensile strength test was carried out on two sample of the 5mm dia. of hemp fibre rope under strain control.

Table 3 Results obtained from the testing of Hemp fibre rope

Ropes	Ultimate tensile strength (Mpa)	Elastic Modulus (Mpa)
1	90.88	1430
2	86.05	1318

4. Construction of Reduced Scale Models

All the models are built in a similar way. Models were constructed on a plywood base plate of 90×90 cm. The walls were made of smaller-sized adobe bricks and mud mortar. The mortar joints between the bricks are kept at a thickness of 2 mm for all the model buildings. To provide internal support, wooden planks are placed on the inner side of the adobe walls. The base layer was casted by using cement mortar and fiber mesh. Additionally, at the lintel level, an RCC band was constructed to minimize shear cracks that may occur in the wall.
Model A1: Un-Reinforced model without any reinforcement or seismic strengthening techniques.

Fig.-2 Construction of Model A1

Model A2: It is a adobe masonry model with the use of hemp fibre rope in a grid form as a wall surface seismic strengthening technique which is connected with the horizontally placed shred of ropes.

Fig.-3 Construction of Model A2

Model A3: It is also a similar reduced-scale adobe masonry model with a difference of using hemp fibre rope as a seismic strengthening technique for wall junctions.

Fig.-4 Construction of Model A3

5. Tests and Results

Two sets of tests were performed on each constructed masonry models. Impact hammer test was performed to determine the dynamic characteristic of models like Natural time period & Damping and Shake table test was performed to get the failure and damage pattern. To compute the damping (ξ) following equation was used.

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

Table 4 Results of Impact hammer test

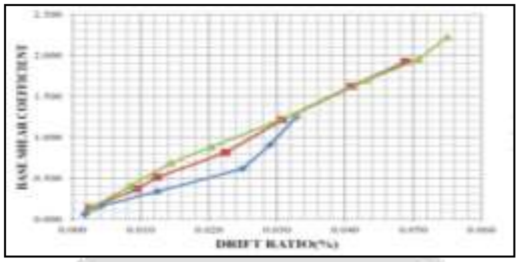
Model	Natural Time Period (Tn in s)	Damping(ξ)
A1	0.008	1.532
A2	0.01	1.572
A3	0.011	1.551

To perform Shake table test the calculated weight of 32 kg on the roof of the structure was applied. All the data for each frequency has to be recorded and saved in digital the 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.

Fig.-5 Model A1, A2 and A3 on shake table

Capacity curve for all 3 models in the form of Base shear coefficient (BSC) vs. Drift ratio is to be plotted. The advantage of comparing capacity in terms of BSC instead of PGA (Peak ground acceleration) is that it provides 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 Model A1, A2 and A3



From the above below following observations are made,

- Both A1 and A2 models reach their ultimate capacity at drift ratio (%) 0.033 and 0.049, however BSC corresponding to model 5 is higher than the BSC corresponding to model A2.
- Capacity curve for model for model A2 and A3 is nearly equal up to the drift ratio of 0.025.
- For Drift ratio of 0.01 to 0.03, less deformation or damage and cracks observed in model A2 for same amount of acceleration than model A3. After that Model A2 fails which shows brittle behavior of the structure.
- Capacity curve of model A1 shows competitively lesser values of BSC for corresponding drift ratio compared to other two models A2 and A3, which shows very low energy absorption for model A1.

6. Conclusion

In conclusion, the research on using hemp fibre rope as seismic strengthening for adobe construction has provided valuable insights and findings. Based on the conducted study, the following conclusions can be drawn:-

- The research confirms that incorporating hemp fibre rope as seismic strengthening in adobe construction can be an effective solution. The use of hemp fibre rope improves the structural performance and enhances the seismic resilience of adobe walls. The rope acts as a flexible element, providing additional tensile strength and improving the overall ductility of the structure.
- The application of hemp fibre rope as seismic strengthening in adobe construction significantly enhances the seismic resistance of the structures. The rope absorbs and dissipates seismic energy, reducing the intensity of forces transmitted to the adobe walls. This results in improved structural integrity, reduced displacement, and increased safety during seismic events.
- The research suggests that using hemp fibre rope as seismic strengthening can be a cost-effective solution compared to conventional reinforcement methods. Hemp fibre ropes are relatively affordable and readily available, making them an attractive option for seismic retrofitting or new construction projects in regions where adobe construction is prevalent.
- Use of Hemp fibre ropes as a uniformly spaced grid contributes to the confinement of the Adobe wall and also it increases the ductility of the Adobe structure.
- In the Model A3, the junction of the perpendicular walls and the adjacent part of the opening is effectively strengthened by use of hemp fibre ropes. When the collapse of the structure occurred, the masonry part of the junction fails as a single unit and so it indicated that the hemp fibre ropes significantly improves the strength of the masonry near the junction as well as at the window and door opening.

In summary, the research supports the utilization of hemp fibre rope as seismic strengthening in adobe construction. The findings highlight the effectiveness of this approach in enhancing the seismic resistance of adobe structures, while also promoting sustainability and compatibility with traditional building practices.

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