USE OF COLD FORMED STEEL AS REINFORCEMENT FOR EXPERIMENTAL STUDIES ON SEISMIC BEHAVIOUR OF VERNACULAR STRUCTURES

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ABSTRACT

A vernacular structure is a type of local or regional construction that utilises traditional materials and resources from the area in which the building is located. The focus of this study is only on vernacular home structures built from adobe bricks. Because of its cost-effectiveness adobe buildings are likely to continue meeting the housing demands of rural people. Unfortunately, conventional adobe buildings are extremely vulnerable to earthquakes and significantly increase the loss of life and property. Such structure's seismic failures are primarily caused by the brittleness and the absence of structural integrity. This study aimed to understand the effect of cold formed steel as reinforcement for the seismic behaviour of rural adobe houses. The main objective of the study is to observe the seismic behaviour of adobe structure reinforced with cold–formed thin–walled steel and damage or failure pattern of adobe structure under earthquake force. To attain this objective two series of tests were performed: A material testing programme for adobe material and Shake table testing programme for dynamic testing on reduced scale adobe house models. A comparative analysis between three different reduced scaled models were carried out in this study. After testing it is concluded that model A2 and A3 which are reinforced with cold formed steel strips shows better seismic performance than model A1 which is without any strengthening simple adobe model.

Keyword : - *vernacular structures, earthquake resistant, adobe material , and cold formed steel reinforcement….*

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1. INTRODUCTION

Vernacular adobe structures, rooted in local or regional construction practices, have long been a prominent form of architecture in many parts of the world. These structures are characterized by their use of traditional materials and resources obtained from the surrounding environment, making them closely intertwined with the local culture, climate, and geography. Adobe, a mixture of clay, sand, water, and organic materials such as straw, has been a favored material for constructing vernacular homes in rural areas. Its availability, affordability, and thermal properties make it an attractive choice for meeting the housing demands of rural communities. The use of adobe bricks, which are sun-dried rather than kiln-fired, is a hallmark of vernacular adobe construction. However, despite their advantages, conventional adobe buildings face significant challenges, particularly in terms of their vulnerability to seismic events. Earthquakes can cause catastrophic damage to these structures, leading to a loss of life and property. The inherent brittleness and lack of structural integrity of adobe construction contribute to their seismic vulnerability. The seismic failures observed in adobe structures can be attributed to the inability of the material to withstand the dynamic forces exerted during earthquakes. The brittle nature of adobe makes it prone to cracking and collapsing under seismic loads. The absence of reinforcement or structural elements further exacerbates their vulnerability. Recognizing the need to enhance the seismic resilience of vernacular adobe homes, research efforts have been directed towards investigating methods to reinforce and strengthen these structures. One promising approach is the use of cold-formed steel, which offers high strength and ductility, making it suitable for seismic applications.

2. DETAIL PLAN AND GEOMETRY OF STRUCTURE

At a scale of 1:5, total of 3 reduced scaled models of adobe masonry structures were made. All of the models were made out of scaled adobe bricks. Details plan and elevation of structures are shown in figure 1.

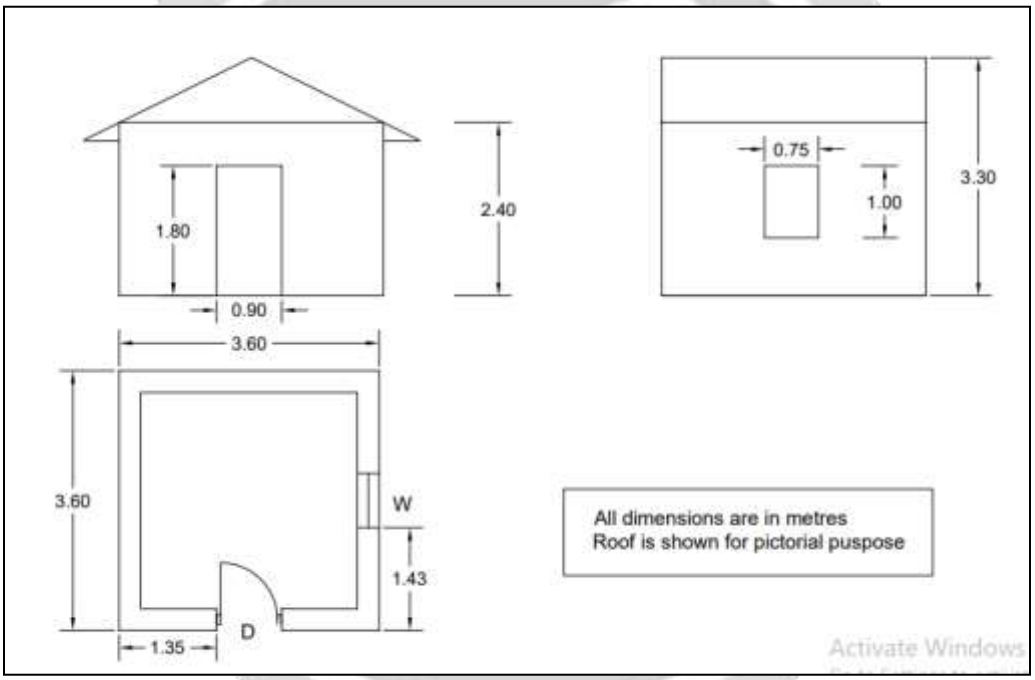

Fig -1: Plan of Structure

2.1 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

The first part of the study focused on a material testing program to evaluate the properties and characteristics of adobe material. This involved conducting tests on both prototype and reduced-scaled adobe samples to analyze any differences in behavior. To determine the appropriate material proportion, three cubes of size 70.6×70.6×70.6 mm were casted using different clay-to-sand ratios. Cube 1 had a clay-to-sand ratio of 60:40, Cube 2 had a ratio of 50:50, and Cube 3 had a ratio of 40:60. After sun drying the cubes for 14 days, it was observed that none of the cubes had developed any cracks. Based on this observation, it was decided to use a clay-to-sand proportion of 60:40 for the adobe material. The clay and sand were mixed uniformly using a mechanical mixer, and straw was also added to the mix. The addition of straw is beneficial in binding the bricks together and facilitating even drying, thereby preventing cracking due to uneven shrinkage rates. This material testing program provided essential insights into the behavior of adobe material and helped determine the optimal clay-to-sand proportion for the subsequent testing phase. By ensuring the homogeneity of the mixture and incorporating straw, the study aimed to improve the overall structural integrity and performance of adobe bricks in the subsequent static and dynamic testing of reduced-scaled adobe house models.

Table -1 : Adobe soil properties

Colour of soil	Type of Soil	Bulk Density of Soil (g/cm3)	Clay Content in %	Sand Content in %
Brown Soil	Clayey,Highly Compressible Soil (CH Soil)	1.89	60	40

Table -2: Brick Specification

Brick Dimensions	Full Scaled (In CM)			Reduced (1:5) scaled (In CM)		
	L	B	H	L	B	**H**
Adobe Bricks	**25**	**30**	**8**	**5**	**6**	**1.6**

3.1 Cold Formed Steel

Cold-formed steel is not typically used as a reinforcement material in adobe masonry structures, it has been proposed as a potential solution to enhance their seismic performance. Cold-formed steel framing involves the use of thin, lightweight steel sections that are fabricated by bending, rolling, or pressing flat sheets of steel. These sections can be prefabricated and easily transported to the construction site, making them a cost-effective and time-efficient solution for low-income housing projects. One of the key advantages of cold-formed steel is its high strength-to-weight ratio, which allows it to resist seismic loads and provide additional stability to adobe masonry structures. Cold-formed steel can be used to create a lightweight and flexible frame that can accommodate the differential movements and settlements that occur during earthquakes. The use of cold-formed steel can also improve the structural integrity of adobe masonry walls and provide better connections between the adobe blocks, which can help prevent the walls from collapsing during seismic events. Research studies have investigated the use of cold-formed steel in conjunction with adobe masonry in seismic-resistant building design. These studies have evaluated the behavior of adobe masonry structures reinforced with cold-formed steel frames under simulated earthquake loading conditions. The results have shown that the use of cold-formed steel can significantly improve the seismic performance of adobe masonry structures, reducing the risk of collapse and improving the safety of the occupants. Overall, while cold-formed steel is not a traditional material used in adobe masonry construction, it has the potential to enhance the seismic performance and structural integrity of these buildings. Its high strength-to-weight ratio, ease of fabrication, and flexibility make it a promising solution for low-cost and sustainable housing projects in seismic-prone areas.

3.2 Physical and Mechanical Properties of Adobe

- Standard proctor test, liquid limit, plastic limit tests were performed to classify the soil. It was found that the MDD was 1.71 g/cc and the OMC was 16% through the standard proctor test. From the liquid limit and plastic limit test the liquid limit and plastic limit were 0.53 and 0.1933 respectively. So, the soil was classified as CH type of soil.
- Compressive strength test was performed to determine the compressive strength of adobe specimen. Three adobe specimen were tested for compressive strength. It was comes out to be 3.14Mpa as shown in table below.

Fig -2 : Compression testing of adobe specimen

Table -3 : Compressive strength of adobe specimen

Sr.no.	L(cm)	W(cm)	H(cm)	Peak Load (Kn)	Comp.Strength (Mpa)	Avg.Comp. Strength (Mpa)
1	129.6	134.4	133.1	53.5	3.07	3.14
2	137.7	139.7	140.8	71.5	3.72	
3	136.65	140.8	134.4	50.5	2.62	

- A test was conducted to determine the flexural strength of an adobe brick with dimensions of 250 mm x 300 mm x 80 mm. The test results showed that the flexural strength of the brick was 2.9 Mpa. According to the guidelines set forth in NZS 4298 for materials and workmanship in earth buildings, the recommended minimum flexural strength is 0.25 Mpa. Therefore, the brick's flexural strength is greater than the recommended value.

4. CONSTRUCTION OF REDUCED SCALE MODEL

This section presents the theory behind dynamic testing of reduced-scale models and its application in this project. Three model buildings were constructed and tested, with each model having an identical plan and wall layout. However, the strengthening techniques applied to the walls differed for each model. Model A1 was the base model with no strengthening technique. The construction of each model is briefly discussed in this section. A1, A2, and A3 reduced Adobe masonry models were casted. The parameters that separate the models are listed here.
A1 : First model was a simple reduced scale adobe brick masonry structure with no extra or additional features.
A2 : A2 model has same geometry as first model but to improve dynamic characteristic cold formed steel strips are used near the openings, corners and at lintel level.
A3 : A3 model has also the same geometry as further two models but to strengthen the adobe masonry structure grid pattern is made using cold formed steel strips.

Fig -3: Model A1

Fig -4: Model A2

Fig -5: Model A3

5. TEST AND RESULTS OF MODEL STRUCTURE

After the construction of all 3 models testing of the models can be started. Two tests were conducted on each constructed masonry models. First test was Impact hammer test to determine the dynamic characteristic of models like Natural time period and Damping. Second test was 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.

Following are the figures which shows all the models before the testing on shake table.

Fig -6 : Model A1

Fig -7: Model A2

Fig -8: Model A3

All three models were tested on shake table for dynamic response of structures. The failure pattern was observed through dynamic testing of modeled structure on shake table testing. From the data collected from the shake table testing of all three models the graph is plotted between the base shear coefficient and drift ratio. Capacity curve for all 3 models in the form of Base shear coefficient (BSC) vs. Drift ratio is to be plotted. 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 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 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.

Table -4 : Results of Impact Hammer test

Model	Natural Time period (Tn)	Damping (ξ)%
A1	0.008	1.54
A2	0.009	2.67
A3	0.01	4.61

Following is the graph of base shear coefficient vs drift ratio which is obtained by shake table testing of models.

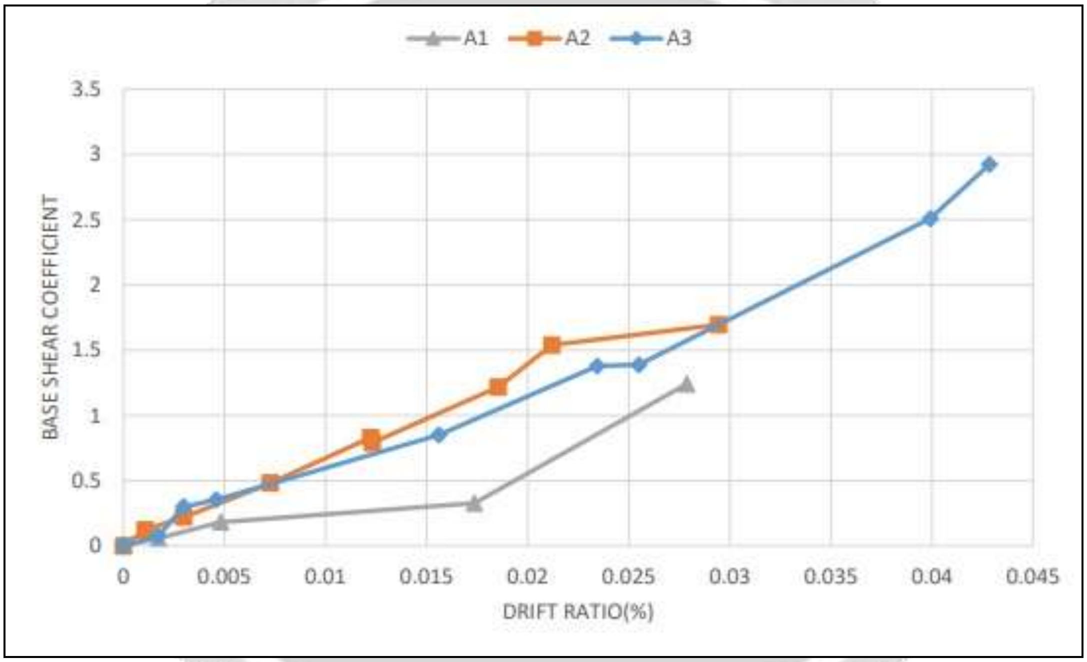

Fig -8: BSC vs. Drift ratio (%) curves for Model masonry structures

From the above below following observations are made

- Seismic resistance of model A3 is significantly larger than the other models A1 and A2.
- Both A1 and A2 models reach their ultimate capacity at drift ratio (%) around 0.028, however BSC corresponding to model A2 is slightly higher than the BSC corresponding to model A3.
- Capacity curve for model for model A2 and A3 is nearly equal up to the drift ratio of 0.015.
- Model A2 shows higher values of BSC than Model A3 for corresponding drift ratio up to 0.028 after that Model A2 Fails.
- 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 behaviour 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

- Model A2 and A3 sustain higher frequency, large displacement and more number of cycles as compared to model A1 so the failure of model A2 and A3 shows more ductility and energy consumption as compared to model A1. Which we can also see in the graph of drift ratio vs BSC.
- The model A2 shows better performance in out of plain wall with opening due to confinement of steel strips near the opening of wall as compared to model A1 and A3.
- The model A3 shows better performance in in-plane wall with opening of door.
- The research demonstrates that the use of cold-formed steel effectively controls and mitigates cracks in adobe structures subjected to seismic loading. The steel elements distribute stress and provide reinforcement, reducing the formation and propagation of cracks. This mechanism significantly improves the durability and longevity of adobe walls.
- The damping of reinforced model is more as compared to the unreinforced model.
- One of the notable findings is that incorporating cold-formed steel as seismic strengthening in adobe construction is compatible with traditional building practices. The integration of steel elements does not disrupt the traditional aesthetic and construction methods associated with adobe buildings, allowing for a harmonious blend of modern strengthening techniques with traditional architectural styles.
- But we talk about compatibility in the form of utilizing the tensile capacity of cold form steel it does not utilise up to the full capacity. The adobe fails before the cold formed steel breaks. The failure in the steel is just like it yields and it breaks from connection between adobe and cold formed steel strips.

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