SEISMIC PERFORMANCE OF JUTE AND BAMBOO REINFORCED ADOBE STRUCTURES

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1. Introduction

Damage of adobe structures due to earthquakes causes significant loss of lives and property. In spite of this, after considering different socio-economic reasons and availability of other alternate solutions, it is expected that adobe structures will continue to exist for the decades to come, especially in the developing countries.

Seismic deficiencies of adobe structures are mainly due to low ductility and low tensile strength of the block; poor bonding and low strength of the mortar; and lack of structural integrity. From the consideration of affordability, availability and environmental friendliness, natural fibers (straw, jute and hemp) and bamboo has been selected as reinforcing materials for adobe.

Short discontinuous fibers have the advantage to mix with the matrix homogeneously. Fibers may increase the tensile strength and elasticity of the matrix which will help to prevent the shrinkage cracks of block and mortar. Sewing action of fibers may provide a better coherence between the block and mortar. Fibers in the matrix will provide a means to prevent the crack growth in the shear band due to imposed loads. Thus fiber can improve the ductility, toughness, or both, and cohesion/bonding depending on the fiber properties. Islam et al. (2006) evaluated the effectiveness of the selected fibers for the adobe block through laboratory tests. Jute was found to be the most effective to improve the ductility and toughness of adobe block. High friction of jute to soil and binding capacity of the jute are the facts behind its effectiveness. However, the effectiveness of fiber on the mortar characteristics is yet to clarify. Jute has been selected for mortar improvement.

Bamboo grid might be effective to share tensile stress and hold the structure after the separation of the blocks at the mortar. Bamboo in the grid form might be useful for retrofitting the existing structures also.

This paper describes the effectiveness of jute and bamboo grid to improve the earthquake resistance of adobe structures evaluated by shaking table tests.

2. Experimental program

2.1 Materials used

Locally available Japanese soils—Acadama clay (LL= 145%, PI= 78%), Toyoura sand (D_{50}= 0.16 mm, U_c= 1.4) and Bentonite (LL= 232%, PI= 200%) has been mixed with a ratio of 2.5:1.0:0.6 by weight to make adobe block and mortar. Jute is a natural fiber which is collected from jute plant. More details about the soils and jute are available in Islam et al. (2006). Bamboo of the size of 2.0 cm and 1.5 cm in diameter were used for vertical and horizontal reinforcement, respectively. Portland cement had been used.

2.2 Model description, construction and instrumentation

Four models were tested to evaluate the effectiveness of the proposed reinforcing materials. Description of the models is presented in Table 1. At first, model L-1 and L-2 were constructed on the shake table. Commercially available burnt bricks were used for these two models. It is seen that the difference between model L-1 and L-2 is in the mortar composition only. Therefore, effect of jute on mortar can be understood from these models. Model L-3 and L-4 were constructed on the shake table in the same way. Adobe blocks prepared from the soil-sand mixture and 2.0% jute (by weight) used for these models. The only difference between model L-3 and L-4 is that L-4 is reinforced with bamboo grid also. Comparison of performances of the models L-3 and L-4 will give the effectiveness of the bamboo grid. Five accelerometers of the piezoelectric type have been used for recording acceleration data. Figure 1 and 2 presents the schematic diagram (showing dimensions, accelerometer positions, reinforcement details) and photographs of the models, respectively.

Table 1. Description of the models

Model name	Block type	Reinforcement		
		Block	Mortar	Structural
L-1	Burnt	—	Cement	—
L-2	Burnt	—	Jute & cement	—
L-3	Adobe	Jute	Jute	—
L-4	Adobe	Jute	Jute	Bamboo

Note: Jute content= 2%; Cement content= 10% (by weight)

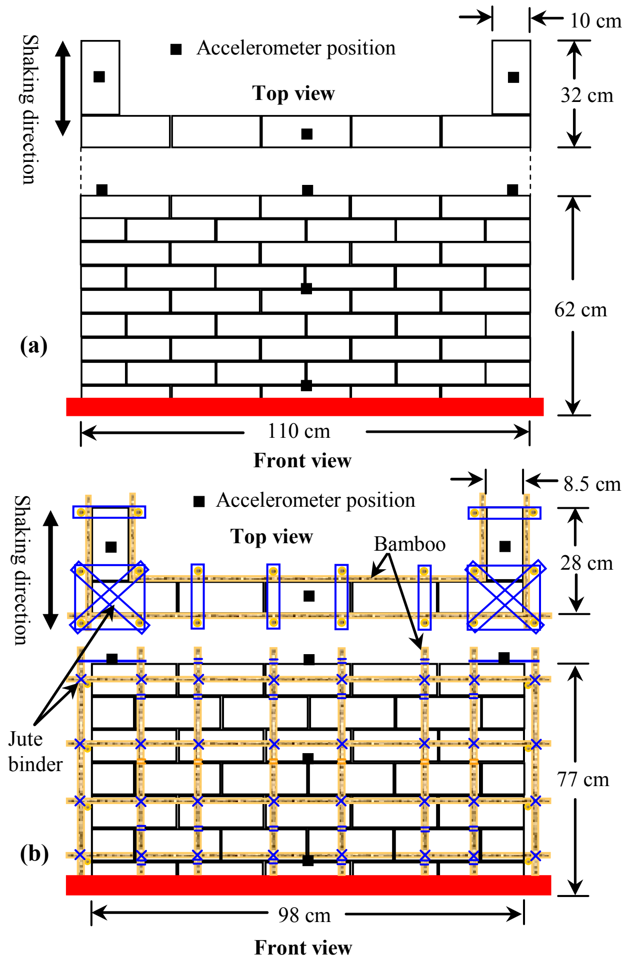

Fig. 1. Schematic diagram of model (a) L1/L-2 and (b) L-4

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Fig. 2. Photographs of models before test

3. Test results and discussions

3.1 Performance of jute reinforced mortar

Models L-1 and L-2 were subjected to unidirectional sinusoidal excitations (15.0 Hz) parallel to short dimension (Fig. 1a). Centre block of the top layer of the model L-1 was separated when the base acceleration was 252 gal. Vibration was continued increasing the base acceleration, block kept peeling off from the top gradually (Fig. 3a). Then model L-1 was removed from the shake table for safety. After that model L-2 was vibrated alone increasing the input acceleration. Separation occurred between the block and mortar of the bottom layer of the model L-2 when the input base acceleration was 848 gal (Fig. 3b). The model L-2 did not collapse completely. Base acceleration at failure indicates that model L-2 is much stronger than L-1. While the model L-1 was damaged by block peeling off, L-2 failed at the bottom of the model due to bending. It means that failure type is different for jute fiber reinforced and unreinforced one. However, jute is not effective to resist the flexural failure. Comparison of the response acceleration along the height (centre line) and length (top) of the models L-1 and L-2 is presented in Fig. 4. It is seen that response is higher for model L-1 than that of L-2 (Fig. 4a). It means that L-2 is stiffer than L-1. From Fig. 4b, it is seen that the response along the length of the model is maximum at the centre of the model L-1. That is the reason for the separation of central block first. Significant cracks were observed in the mortar of the model L-1 while there was no crack in the model L-2. It indicates that jute fiber prevent the cracks in the mortar due to drying shrinkage. Thus jute fiber improves mortar strength and the bonding.

Fig. 3. Photographs of model (a) L-1 and (b) L-2 after test

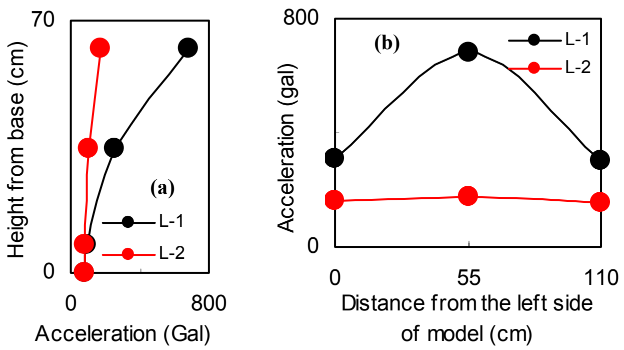

Fig. 4. Mode shapes of model L-1 and L-2

3.2 Performance of bamboo grid

Model L-3 and L-4 were also subjected to unidirectional sinusoidal wave (15.0 Hz) parallel to the short dimension (Fig. 1b). Separation occurred between the block and mortar of model L-3 when the input base motion was 450 gal as shown in Fig. 5a. After that model L-3 was removed from the table, and vibration continued increasing the base acceleration. Separation occurred between the block and mortar between first and second layer of the model L-4 when vibrated with 850 gal. Vibration was continued up to 1200 gal, but model L-4 did not collapse. However, test was stopped because of the limitation of shaking table capacity. It is seen that bamboo grid is effective to improve the strength of the structure. Again bamboo grid can hold the structure after separation has occurred as shown in Fig. 5b. Figure 6 presents the variation of response acceleration along the height (centre line) and the length (top) of the models. Response acceleration of the model L-4 is higher than that of L-3 for the same base motion. It means that bamboo grid could not reduce the displacement of the adobe structure. However, bamboo grid was effective to improve the strength of the model and structural ductility.

Fig. 5. Photographs of model (a) L-3 and (b) L-4 after test

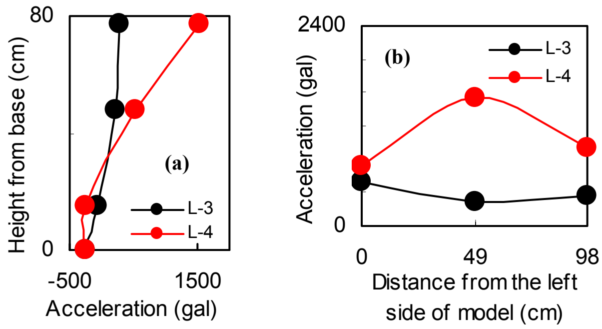

Fig. 6. Mode shapes of model L-3 and L-4

4. Conclusions

Jute is effective to improve the ductility and toughness of adobe block. Jute is also effective to prevent the shrinkage cracks in the mortar and thus to improve the strength and coherence of mortar. However, jute is not effective to resist the bending failure. Bamboo grid increases the strength and the ductility of the structure. Because bamboo grid is able to hold the structure after separation of the blocks and can prevent the collapse of the structure. Bamboo grid or grid of similar natural or industrial material might be effective to retrofit existing earthen structures against earthquakes.

References

Islam, M. S., Honda, K. and Iwashita, K. (2006). Improvement of seismic resistance of adobe structures, *First European Conference on Earthquake Engineering and Seismology*, Geneva, Switzerland, Paper No. 146.