EARTHQUAKE RESISTANCE OF FIBER REINFORCED ADOBE

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1. Introduction

Most losses of lives and wealth in the developing countries during earthquakes are due to the collapse of adobe houses. In spite of this, after considering different socio-economic reasons and availability of other alternate solutions, it is expected that adobe structures will continue for the decades to come, especially in the developing countries. Seismic deficiencies of adobe structures are caused by their heavy weight, brittle behavior, and low strength of the mortar. Reinforcement for adobe structures should be cheap, easily available, and easy to construct. Islam (2002) showed that straw is effective to improve the ductile behavior of the adobe material at the cost of compressive strength. However, many deep cracks were also found in the adobe material reinforced with straw. To this context, jute and hemp had been selected to improve the seismic resistance of adobe. Cement had been selected to improve the strength of mortar. This paper describes the effectiveness of selected natural fibers and stabilizer to improve the earthquake resistance of adobe structures.

2. Soils Selection and Specimen Preparation

Locally available Japanese soils Acadama clay, Toyoura sand and Bentonite has been mixed with a ratio of 2.5:1.0:0.6 by weight to make adobe. This mixture had been named as 'soil-sand mixture' in this study. More details about the soil selection are available in Islam (2002). Specimens were prepared from soil-sand mixture, fiber and cement. At first, water and soils were mixed vigorously so that a homogeneous mix was formed. The mix was then poured into a steel mould of the size of 5 cm in diameter and 10 cm in height in three layers. Each layer was compacted to remove the entrapped air. After that the mould with sample had been kept in an oven at 60°C for 3 days. Finally, specimens were taken out from the mould and kept again in the oven at the same temperature for more 3 days. Figure 1 shows the details of specimen preparation.

Fig. 1. Preparation of adobe specimens

3. Characteristics of Fiber Reinforced Adobe

Effect of three different fibers-hemp; jute and straw on seismic resistance of adobe material have been investigated. In all cases, specimens were prepared by mixing soil-sand mixture with 1.0% fiber (by weight) of 1.0 cm length. Final water content and dry density of the specimens ranged from 3.5 to 5.8% and 1.05 to 1.18 g/cm^3, respectively. Figure 2 shows typical stress-strain relationships of reinforced and unreinforced adobe. It is observed that failure of unreinforced and hemp reinforced adobe is brittle. But the failure of jute and straw reinforced adobe shows ductile behavior. However, straw reinforced adobe has significantly lower strength than that of jute reinforced adobe. To compare, toughness has been calculated using the area under the stress-strain curve under uniaxial test up to failure. Failure point was defined as the point corresponding to $2/3q_u$ (where, q_u is compressive strength). Table 1 presents the mean q_u and toughness of the unreinforced and reinforced adobe. It is seen that jute reinforced adobe has the maximum toughness. It indicates that the jute fiber is the best option among these three fibers for improving the seismic resistance of adobe material. In Figure 3, the first two photographs show unreinforced and jute reinforced specimens at failure. The third photograph shows the close view of the failure plane of the jute reinforced specimens. From this photograph, the action of fiber can be seen clearly. Fiber resists the brittle failure of the adobe material.

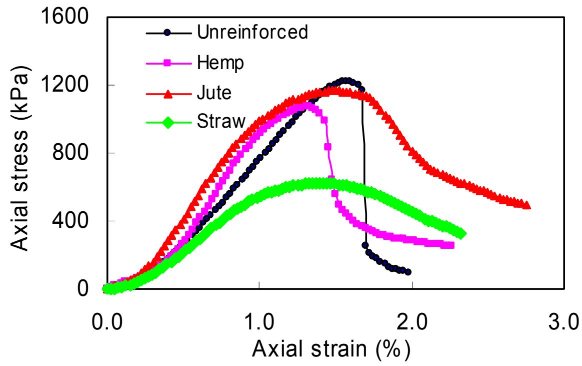

Fig. 2. Stress-strain relationship of adobe

Table 1. Characteristics of adobe

Reinforcement	q_u (kPa)	Toughness (kPa)
Unreinforced	1177.8	10.09
Hemp	1058.3	8.26
Straw	585.6	8.48
Jute	996.3	15.93

Fig. 3. Failure pattern of reinforced and unreinforced adobe

4. Effect of Fiber Content

Specimens were prepared using 1.0 cm long jute fiber by varying the jute content from 0.5 to 4.0% by weight.

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Final water content and the dry density of the specimens varied between 3.2 to 4.6% and 0.93 to 1.15 g/cm^3, respectively. Variation of toughness with jute content has been presented in Figure 4. It is observed that adobe reinforced with 2% jute has the maximum toughness. It indicates that 2% fiber is the optimum for improving the seismic resistance of adobe material.

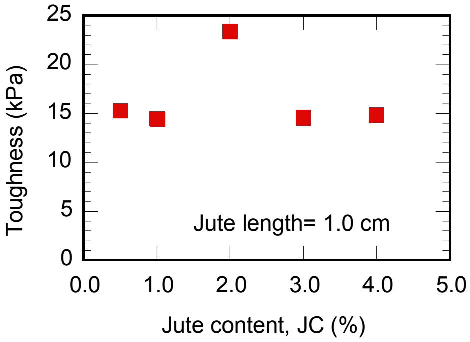

Fig. 4. Variation of toughness with jute content

5. Effect of Fiber Length

Specimens were prepared using 2% jute varying the jute length from 0.5 to 3.0 cm. Variation of toughness with jute length has been presented in Figure 5. In this case, the toughness has been calculated using the area under the stress-strain curve until peak. It is observed that toughness of the material is almost same in all cases except in the case of 3.0 cm long fiber. Toughness of the specimens reinforced with 3.0 cm long fiber is significantly lower than that of other cases. From the Figure 5, it is also clear that jute length should be 1 ~ 2 cm for best seismic performance.

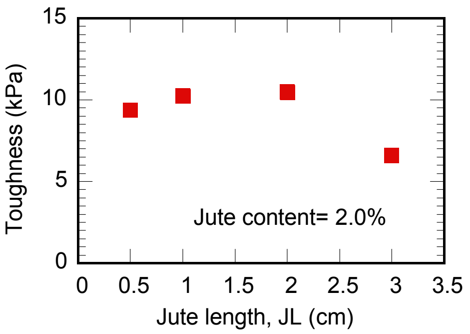

Fig. 5. Variation of toughness with jute length

6. Mortar Strength

Past earthquakes showed that mortar is the weakest part of the adobe structures. Therefore, it is necessary to improve the strength of the mortar to increase the strength of the adobe structures. Sandwich specimens were prepared cutting cylindrical specimen into two pieces at 60° with the horizontal as it was observed from the uniaxial test that the specimen fails at 60 ~ 70° with the horizontal. After that mortar was inserted between two parts. The sandwich specimens were then kept in an oven at 60°C for 3 ~ 4 days for being dry. Figure 6 shows the details of the sandwich specimen preparation. Table 2 presents the mean compressive strength (q_u) and failure strain (ε_f) of the specimens. It is observed that strength of the adobe material with mortar is significantly low. It is also seen that mortar strength using fiber and cement can be increased from 33.2

Fig. 6. Preparation of sandwich specimens

to 196.1 kPa. But in any case the mortar strength is lower than that of block (Table 1 and Table 2). Figure 7 shows the photographs of the failure pattern of the sandwich specimens. It is seen that in all cases separation has been occurred between block and mortar during failure. However, in unreinforced cases, mortar also failed. From the photograph, it is also seen that unreinforced mortar has many cracks. But mortar reinforced with cement and fiber does not have any crack. Cracks in the mortar might be the reason for the low strength.

Table 2. Characteristics of sandwich specimens

Case	Block	Mortar	q_u (kPa)	ε_f (%)
C-1	—	—	33.2	1.10
C-2	Jute	—	68.1	2.13
C-3	Jute	Jute	129.7	2.71
C-4	Jute	Jute, cement	196.1	2.47

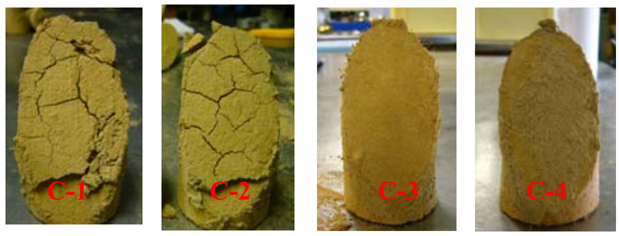

Fig. 7. Photographs of sandwich specimens

7. Cost of Reinforcement

Reinforcement cost of a two room typical adobe house (6.1 m × 9.15 m × 2.90 m) has been estimated. If an adobe house of this dimension is reinforced with 2% jute fiber, the total cost of the fiber will be about 30.0 US dollar. The unit price of jute has been taken from the local market price from Bangladesh (where adobe houses are being used in a large scale and jute is also locally available).

8. Conclusions

Jute is effective for improving the seismic resistance of adobe material. However, there is an optimal jute content (i.e., 2%) for the best performance. Jute length should be in the range of 1.0~2.0 cm to get the best seismic performance of adobe material. Strength of adobe with mortar is very low. Using jute or jute and cement together the strength of the mortar can be increased. Cracks in unreinforced mortar might be the reason for its low strength.

References

Islam, M. S. (2002). Research on Earthquake Resistant Reinforcement for Adobe Structures, PhD Thesis, Dept. of Civil and Envi. Engineering, Saitama University, Japan.