Burlap Reinforcement for Improved Toughness Of Low-Cost Adobe Residential Structures

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ABSTRACT
Adobe brick wall construction is commonly used for low-cost dwellings in developing nations. This system, being extremely brittle, performs poorly during earthquakes. The use of burlap layers as a low-tech, low-cost solution to the problem of brittle fracture in adobe brick-wall systems will be investigated. Improvement in both strength and toughness will be shown by comparison with a similar un-reinforced specimen. The diagonal compression test will simulate the stresses induced under earthquake conditions.

INTRODUCTION

The failure of unbaked adobe brick-wall systems under seismic forces is a well-documented problem in house construction. Recent tragedies in earthquake-prone regions where adobe dwellings are built, including parts of South America and the Indian subcontinent, call attention to the need for improving the safety of these structures. The intention of this study is to contribute to the field of adobe construction in poorer regions of the world through research and experimentation with inexpensive, locally available products.

The project builds upon a similar experiment performed by Hana Mori, a UC Berkeley Master’s Recipient.(1) She worked to make adobe brick-wall systems deform in a less brittle manner, giving building inhabitants increased warning of impending failure during an earthquake. She introduced sheets of felt and plastic mesh in the middle of the mortar to determine whether these materials could deter cracks from propagating through the wall. Mori found that the felt significantly improved the toughness of the walls, whereas the mesh greatly enhanced their yield strength. This experiment carries Mori’s findings a step further by trying to identify a material that will substantially improve both toughness and strength and which are abundantly available in developing countries.

The project proposes burlap as a material that is readily available in the targeted regions and will exhibit the combined behaviour of the felt and the mesh. Burlap is a commonly used fabric woven of slender cactus fibres. The relatively simple yet effective method of applying this material as reinforcement in an adobe masonry system will be described.

MATERIALS & METHODS

The materials used to build the specimens adhered as much as possible to those traditionally used in adobe construction: Soil, straw, and water were the main components; clay and sand were added in order to manipulate strength. To a great extent, the concepts from "Nuevas Casas Resistentes de Adobe" (2) were utilized. An initial rule-of-thumb test for demonstrating adequate strength became the basis for composing a mix. This test requires that balls with diameters of two centimetres dried for 24-36 hours at room temperature be unbreakable when held in one’s hand and crushed with the thumb against

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the fingers. The soil used for the mortar and the bricks was found to have a high clay content and would consequently provide high strength. Therefore, there was concern that the mortar, which would be identical in strength to the brick, might not define the failure path as was expected. A weaker mortar mixture would limit cracking to the mortar rather than the bricks to ensure effective testing of the burlap reinforcement. The weakening of the mortar was achieved by adding 8.5% sand to the mortar mix and adding 4.2% clay to the brick mix.

**RELIMINARY PROCEDURES**

**Composing the Mix**

The dry ingredients for the mix were mixed together thoroughly before water was added. The soil was sifted for large rocks and clumps and then measured out in the desired volumes. Drawing on information from "Nuevas Casas," straw was cut into pieces no longer than two inches, and then mixed with the soil. Next, the clay was measured and mixed in. According to the proportions set out by the studies of Hana Mori, water was blended in incrementally. Each batch was kneaded for roughly ten minutes or until high cohesiveness and fair workability was achieved. In most cases, bricks were formed immediately following preparation of the mix.

**Forming the Bricks**

The bricks were produced in batches of eight using 2" x 4" x 8" plywood bottomless molds that were continuously oiled to facilitate removal of the bricks. The molds were placed on a wooden surface that was covered with a thin layer of sand to prevent sticking. The molds were filled in segments, and the mix was compacted by hand as much as possible to prevent air voids. Excess mud was scraped off with a trowel (Fig. 1). Tools were kept moist for maintaining workability of the mix. The sample bricks were then placed in a constant-temperature room of 100 degrees Fahrenheit for seven days. The mortar was made by adding sand and removing all of the extra clay (4.2%) from the brick mixture. Sand would weaken the mix for two reasons: 1) increased porosity in the mix due to large size of sand particles as compared to clay particles and 2) microcracks formed from small restraints on the mix caused by sand particles (Table 1).

**Table 1. Materials used in this study**

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>SOURCE/TYPE</th>
<th>% IN BRICK (weight-lbs)</th>
<th>% IN MORTAR (weight-lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>Residential Lot</td>
<td>85.7</td>
<td>81.8</td>
</tr>
<tr>
<td>Clay</td>
<td>Kentucky Ball</td>
<td>4.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Straw</td>
<td>G. G. Fields</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Water</td>
<td>Tap</td>
<td>9.8</td>
<td>9.4</td>
</tr>
<tr>
<td>Sand</td>
<td>Kaiser Radium</td>
<td>0.0</td>
<td>8.5</td>
</tr>
<tr>
<td>Burlap</td>
<td>Coffee Bean Bags</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
MAIN PROCEDURE

Constructing the Walls

While considering the method of layering burlap that would be the most effective in deterring crack propagation, it was suggested that the target population in the regions of interest would have difficulty finding entire sheets of burlap sufficient for the scale of constructing houses. Thus, two methods of layering burlap in the mortar were tested: 1) a continuous, uncut horizontal layer and 2) a layer of overlapping pieces cut to 4"- to 5" lengths and having the same depth as the wall of 4" (Fig 2). The third wall was a control specimen containing no burlap.

Fig. 1 Forming each brick

![Fig. 1 Forming each brick](image1)

Fig. 2 Burlap pieces cut from coffee bags

![Fig. 2 Burlap pieces cut from coffee bags](image2)

Fig. 3 Laying bricks

![Fig. 3 Laying bricks](image3)
In order to correlate the experimental methods with Mori’s, her standards for individual brick and wall dimensions were followed as closely as possible. However, there were two main divergences in this study. Due to drying shrinkage, the dimension of each brick was somewhat less than 2", producing slightly thinner bricks. In addition, the thickness of the mortar both between the layers of bricks and the joints between the bricks was reduced from 1" to less than 0.5" in order to adhere more closely to actual masonry practices. These two factors caused a decrease in wall specimen size from that of Mori’s project, although more bricks were used. Each wall consisted of 30 bricks. Dimensions were as follows: 23" in length, 23" in height, with a depth equivalent to that of one brick, 4" (Fig. 4).

Walls were constructed vertically and required the use of a wooden guiding form for straightness (Fig. 3). Bricks and burlap alike were gently soaked in cold water prior to use for optimal cohesion with the mortar. Walls were built ten bricks high and then taken to a 100 degree Fahrenheit room where they were left to dry for at least ten days.

**Loading**

In preparation for loading, the dry walls were sawed to an even edge along their vertical sides, and they were fitted with wooden shoes at their corners as shown in Figure 5. The shoe length along the edges of the wall was markedly less than the length of those used by Mori. The premise for the use of smaller shoes was to allow interlayer friction to play a role in the loading, unlike the setup with larger shoes, where most of the load is taken by the compression of the layer that is locked between the shoes. In theory, a smaller shoe should reduce the ultimate strength because only the interlayer friction would resist the entire load. The soil used in this experiment and that used in Mori’s were not the same; thus, the value of the ultimate strengths cannot be directly compared with accuracy.

Special supports were used while the wall specimens were positioned diagonally for testing; these supports were subsequently removed.

*Fig. 3 Control specimen in process of drying*
Fig. 5 Burlap piece reinforced specimen positioned for testing
RESULTS & DISCUSSION

Toughness Comparison Chart (load [kip] vs. displacement [in])

The Diagonal Compression Tests yielded even more pronounced results than anticipated. With all specimens being loaded at 100 lbs./minute, the control specimen was capable of withstanding a force of 2,700-lbs. and equivalent shear stress of 21psi (Fig. 6). It cracked along a single catastrophic crack in a brittle manner, showing little toughness (Fig. 7). Figure 8 shows a detail of a broken specimen. Both burlap-fortified specimens, on the other hand, showed extreme improvement in terms of toughness and ductility. Because all specimens in this study were hand-made, some variation in quality was expected. Despite this, the author feels that the trends in performance can be discussed with relative accuracy and significance.

Fig. 7 Control specimen at the end of testing
Discontinuous Burlap Reinforced Specimen

The specimen with the burlap pieces had an ultimate load capacity of 6,000 lbs and the maximum shear strength was 46psi. Multiple small cracks were observed, demonstrating that the burlap layers served to deter crack propagation in a single area, thus dissipating energy within the entire specimen (Fig. 9). The specimen initially failed through the mortar, but later failed through bricks as well as it began to shear. This was an indication that the burlap layers had higher strength than the bricks. Upon further examination, the cracks seemed to find the overlaps in the burlap pieces. This confirms that the source of strength in the burlap is in the weave itself. It should be mentioned that this specimen was 1.5" taller than the other two because of larger bricks, which may have caused a slight increase in strength and toughness due to increased surface area of the interface.

Burlap Strip- Reinforced Specimen

The specimen made with continuous burlap strips showed an ultimate load capacity of 6,800 lbs. and maximum shear strength of 52psi, which is a 250% increase from the unreinforced specimen. Although the main deformation occurred in one layer of mortar (Fig. 9), this specimen exhibited a far more distributed crack pattern once the first signs of failure appeared. The toughening effect of the interlayer friction from the continuous burlap strip was observed during this testing.

The burlap chosen was perhaps stronger than necessary. Because the burlap came from coffee bean bags, it was thick and tightly woven, adding a great degree of friction and fiber
tension to the specimens. Such tightly woven burlap hindered the gain of additional toughness from fiber pullout within the mesh. A thinner weave may be used to further increase the toughness with a negligible loss in strength.

APPLICATIONS

Both methods of reinforcement showed more than 225% increase in ultimate strength and much greater toughness over the control specimen. The toughness of a system is its potential of dissipating energy without fully loosing its load bearing capacity. This energy dissipating capacity has to be present in any system that has to successfully withstand seismic loads (earthquakes). The outstanding performance of both burlap specimens suggests that the use of burlap reinforcement or similar fibrous material is a construction method worthy of application in the field. Due to the simplicity and minimal expense of this proposed implementation, the dissemination of these results among earthquake prone regions in developing countries is urged.

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REFERENCES


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