REINFORCEMENT OF ADOBE (SUN-DRIED BRICK) BY STRAW

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1. Introduction

From the energy consideration and economic point of view adobe houses continue to provide the needs for the rural poor people. However, adobe may have large compressive strengths characteristics and low ductility unless reinforced. Unreinforced adobe has low ductility coupled with low strength, which is generally stated as the reason for its poor seismic performance. Straw is generally used as an additive for adobe. Many researchers have reported straw as a crack controlling material for adobe, which contains much clay (McHenry, 1998). The addition of straw was found to be effective in improving the strength of adobe masonry (Vargas et al., 1986). An investigation of the aseismic behaviour of adobe reinforced by straw is critically important. The influence of both the quantity and size in length of straw on adobe regarding compressive strength, E_{50} (elastic modulus at 50% compressive strength), failure strain and ductility has been presented.

2. Soil Selection

Adobe can be made with any soil. However, samples were prepared by mixing locally available Japanese standard clay (Acadama clay: Gs=2.65, LL=145%, PL=67%, PI=78%) and sand (Toyoura sand: G_s=2.64, D_{50}=0.18 mm, U_c=1.3); bentonite (G_s=2.514, LL=232%, PL=31%, PI=201%) and straw at different weight ratios. The grain size distribution of the soil-sand mixture used in this study along with that of old adobe specimens (i.e., MB-1, MB-2, MB-3 and MB-4) which were collected from Iran of the age of 1300BC are presented in Figure 1. From Figure 1 it is seen that the distribution of soil-sand mixture is similar to that of old adobe.

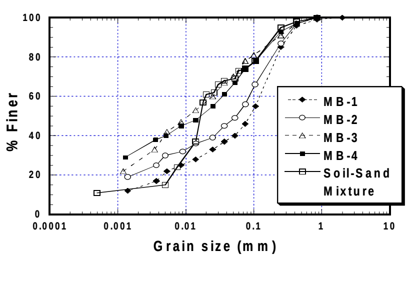

Figure 1. Grain size distributions of old adobe and soil-sand mixture used in this study.

Bentonite is used here instead of smectite and plagioclase which were found in the old adobe from chemical analysis.

3. Sample Preparation

The groups of samples prepared are listed in Table 1 together with the composition (i.e., ratio of clay, sand, bentonite and straw by weight), straw content, s (%) and length of straw, ℓ. After mixing the material by the ratio as described in Table 1, water was added so that the workability was sufficient to pour the mix in the mould by its own weight and then it was mixed vigorously by hand for about 1 hour to make the mix homogeneous. After that, the mix was poured in a steel mould of the size of 5 cm in diameter and 10 cm in height (Figure 2). The moulds were kept for some days so that the water content reduced up to the level that the specimens could stand without any slump. Then the specimens were kept open in a room until they become dry (the specimens having water content of about 8~12% were considered dry in this study due to bad weather; here it is to be noted that dry adobe contains normally 2~3% water content).

Table1: List of sample groups and composition variables

Sample Groups	Mix Ratio (by weight)				Length of straw (cm)
	Clay	Sand	Straw	Bento-nite	
S-1	2.5	1.0	---	0.6	1.0
S-2	2.5	1.0	0.020	0.6	1.0
S-3	2.5	1.0	0.041	0.6	1.0
S-4	2.5	1.0	0.063	0.6	1.0
S-5	2.5	1.0	0.130	0.6	1.0
LS-1	2.5	1.0	0.063	0.6	2.0
LS-2	2.5	1.0	0.063	0.6	3.0

(a)

(b)

Figure 2. Photograph of (a) a typical mould used for sample preparation and (b) pouring of mix in a mould.

Keywords: adobe, ductility, seismic, straw.

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4. Test Results

Uniaxial compression tests were carried out for each group as described in Table 1. For each group, 5 specimens were tested to check the repeatability of the test results. The mean values of initial and final water content of each group were in the range of 95~101% and 8~11% respectively. The mean values of dry density, γ_d of group S-1, S-2, S-3, S-4, S-5, LS-1 and LS-2 (as shown in Table 1) were 10.3, 10.1, 9.8, 9.6, 9.3, 9.5, 8.9 kN/m^3 respectively. It is clear that with the increase of percentage of straw, dry density of the specimens was decreased.

Figure 3 shows the typical stress-strain relationships for the uniaxial compression test of different groups. The relationships of compressive strength, q_u and of failure strain, ε_f with the straw content, s (%) and length of straw, ℓ are presented in Figs. 4a and b. The relationships of E_{50} and ductility, μ (the ratio of failure strain to that of yield strain; yield strains were taken as the strain corresponding to the $q_u/2$) with s and ℓ are presented in Figs. 5a and b. From Figure 4a and 5a, it is observed that for straw content up to 0.5%, both q_u and E_{50} did not change significantly. However, for larger amount of straw contents, the mean value of q_u decreased from 587.0 kN/m^2 to 223.0 kN/m^2 and that of E_{50} decreased from 59.7 MPa to 21.5 MPa. The mean of ε_f decreased from 1.9% to 1.4% for 0~1% of straw content and then increased up to 3.08% for a straw content of 1~3%. But for 0~1% of straw contents the mean value of ductility (3.85) did not change significantly and after that for 1~3% of straw content, ductility increased up to 8.4. From Figure 4b and 5b it is clear that with the increase of length of straw both the mean value of q_u and E_{50} were decreased from 333.0 kN/m^2 to 200.0 kN/m^2 and 42.5 MPa to 19.3 MPa respectively while that of both ε_f and μ increased from 2.03% to 4.9% and 4.9 to 11.3 respectively.

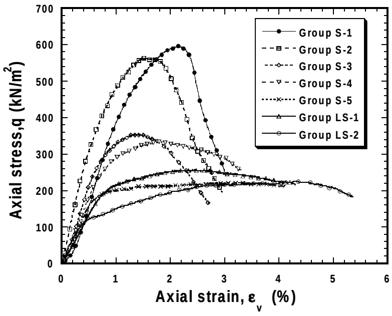

Figure 3. Typical stress-strain relationships of each group.

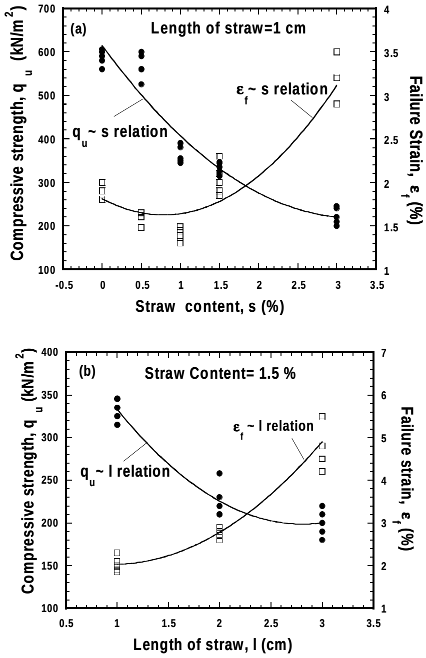

Figure 4. Relationships of (a) $q_u \sim s$ and $\varepsilon_f \sim s$, (b) $q_u \sim \ell$ and $\varepsilon_f \sim \ell$.

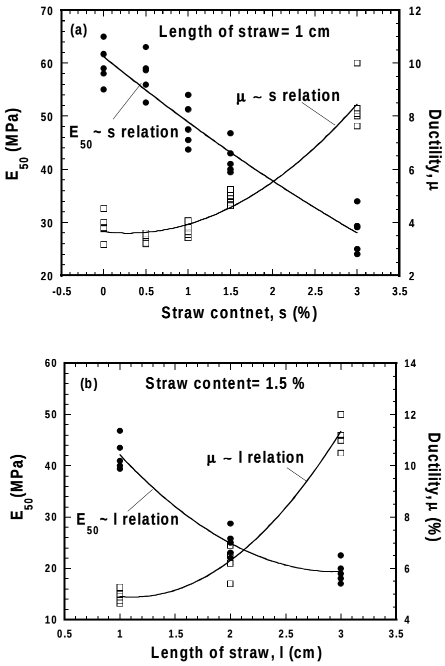

Figure 5. Relationships of (a) $E_{50} \sim s$ and $\mu \sim s$, (b) $E_{50} \sim \ell$ and $\mu \sim \ell$.

5. Conclusion

Compressive strength, E_{50}, failure strain and ductility were dependent upon both the straw content and length of straw for the particular soil composition that was used in this study. Straw content up to 1% was not effective to improve the ductile behaviour of the adobe. Both the failure strain and ductility were found to be increased with high straw content (i.e., from 1.5 to 3.0%) and with the increased length of straw. However, compressive strength and E_{50} were decreased in both cases. The decrease in the strength and E_{50} might be due to the decrease in soil-sand part that was replaced by straw. The composition of the material, which will give maximum ductility with least decrease in the strength and E_{50}, might be the best seismic resistant adobe.

References

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