*Research article*

# Engineering Properties of Adobe Brick for Earth Structures

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Received 16 January 2014 Accepted 1 April 2014 (*Corresponding Author)

**Abstract** The aim of this research is to investigate basic engineering properties of soil mixture materials and adobe bricks for earth structures. The soil mixture materials consist of soil, sand and rice husks. Samples of soil mixture materials and adobe bricks were collected from three villages (i.e. sources) in northeastern Thailand with adobe brick earth structures. The raw materials obtained from the three sources are: (1) soil, sand and rice husks from Baan Sikha Thai village of Nakhon Ratchasima province, (2) soil and rice husks from Baan Sai Rung village of Chaiyaphum province, and (3) soil and rice husks from Baan Thep Pana village of the province of Chaiyaphum. The physical properties of soil mixture materials and the mechanical characteristics in terms of adobe bricks and wall bearing strength (prism strength) were carried out. According to ASTM D-2487 of the Unified Soil Classification System, the soils from the three sources are of sand-poorly graded (SP) type. PI of soils and the horizontal compressive strength ($\sigma_c$) of adobe bricks from the first, second and third sources were 7.93, 6.02 and 2.88%; and 21.76, 15.76 and 13.48 kg/cm$^2$ (ksc), respectively. The findings indicate a positive relationship between plasticity index (PI) from Atterberg's limits test and horizontal $\sigma_c$. A comparison was made between the horizontal $\sigma_c$ of adobe bricks of three sources and those specified in the Uniform Building Code (UBC) Standard 21-1. The horizontal $\sigma_c$ of the first, second and third sources relative to the UBC standard (17.6 ksc) were 21.76, 15.76 and 13.48 ksc, equivalent to 123.65%, 89.57% and 76.57% of the standard, respectively. The horizontal flexural strengths ($f_b$) of adobe bricks from the three sources were 5.86, 3.24 and 4.27 ksc. Thus, no indefinite relationship exists between $f_b$ and PI as well as horizontal $\sigma_c$. In addition, a comparison between the horizontal $\sigma_c$ of adobe bricks from three sources and the wall bearing strength (prism strength) of walls made from the identical three sources was performed. The wall bearing strength values of the first, second and third sources were 9.44, 6.39 and 3.63 ksc, respectively. The results show a positive relationship of prism strength to PI and to horizontal $\sigma_c$. The performance of adobe bricks in terms of greater strength and lower shrinkage could be enhanced by inclusion of appropriate quantities of sand and rice husks in the mixture.

**Keywords** earth structure, adobe brick, engineering properties

## INTRODUCTION

A form of architectural work, earth structures harmoniously coexist with the environment and are perfectly suitable for the tropics. In addition, most earth structures have been designed and constructed in line with the livelihoods of local inhabitants. Raw materials of adobe bricks which are subsequently used to construct earth structures are mostly natural materials, e.g. clay, sand and plant fibers, and can be acquired locally and inexpensively. Besides, several reused items, e.g. glass bottles, wooden windows and frames, are used in the construction of earth structures. Thus, earth structures are a viable alternative to meet the housing demand of low-income earners and in line with the concept of self-sufficiency economy, which in turn promotes the community sustainability.

The current practices of adobe brick-making are nevertheless varied by which local residents make adobe bricks relying on their past experience and rough estimation. This leads to substandard adobe bricks in terms of horizontal compressive strength, horizontal flexural strength and wall bearing strength.

Although previous research studies on improvement of adobe brick-making exist, the local villagers prefer the traditional local brick-making methods to the improved ones. Therefore, this research paper attempts to examine the engineering properties of raw materials and adobe bricks. The findings could be adopted as a guideline in building of earth structures to guarantee the stability and safety of the final constructions.

## METHODOLOGY

**Determination of variables:** Types of raw materials and mixing ratios are factors that affect the strength of adobe bricks. To obtain the results that adequately represent actual outcomes, the raw materials and their respective quantity in this research work are: 10 kg each of soil and sand from three sources (30 kg of soil and 30 kg of sand in total); and 35 finished adobe bricks each from three sources (105 ready-to-use bricks in total). The dimensions of adobe brick are 20x40x10cm (WxLxH). Figure 1 illustrates a photograph image of an adobe brick and a drawing of its dimensions.

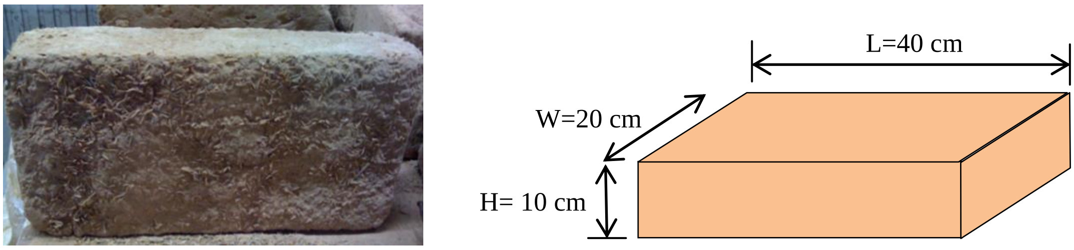


**Fig. 1 Image of an adobe brick and a drawing of its dimensions**

**Selection criteria of sources for collection of raw materials and bricks:** The selection criteria of locations for collection of raw materials and adobe bricks are that: (1) there are a number of adobe brick earth structures in the area; and (2) local residents are economically self-reliant. The areas from which the sample collection were carried out are: (a) Baan Shikha Thai village, Nhong Bua Sala sub-district, Muaeng Nakhon Ratchasima district of Nakhon Ratchasima province; (b) Baan Sai Rung village, Tha Mafai sub-district, Khang Kroa district of Chaiyaphum province; and (c) Baan Thep Pana village, Baan Rai sub-district, Theb Satit district of Chaiyaphum province.

**Test methods:** Tests were carried out on the raw materials and on adobe bricks. The raw materials, i.e. soil, sand and rice husks, were examined according to ASTM standards of the Unified Soil Classification System. The soil grain size was classified by sieving according to the ASTM D422 standard. Atterburg's limits of soils were performed according to ASTM D4318, while Atterburg's limits of soils mixed with sand were conducted according to ASTM D4318. The soils mixed with sand were obtained by crushing adobe bricks from the three sources. Soil specific gravity values were determined according to ASTM D854. In addition, the ASTM C128 standard was used to determine sand specific gravity and absorption values, while the sand grain size was classified by sieving as per ASTM C136. The separation of sand and rice husks from adobe bricks was carried out using the wet sieve method.

**Table 1 Physical requirement of adobe brick**

| Minimum compressive strength (ksc) | | Water absorption (%) | Mowasture content (%) | Minimum modulus of rupture (ksc) | |
|---|---|---|---|---|---|
| 21.13 (Average) | 17.60 (Minimum) | 2.5 | 4.0 | 3.52 (Average) | 2.46 (Minimum) |

*Source: Table 24-B: Uniform Building Code, 1994*

The strength of finished adobe bricks was tested according to the American Standard for Testing Material (ASTM) and referenced to the UBC Standard 21-9 (Table 1). The horizontal $\sigma_c$ and horizontal flexural strengths ($f_b$) of adobe bricks were determined according to ASTM C67-13a. The wall bearing wall strength was tested according to the Standard Test Methods for Compressive Strength of Masonry Prisms (ASTM E447 – 74).

## RESULTS AND DISCUSSION

### Engineering Properties of Soils

Based on the ASTM D2487 standard of the Unified Soil Classification System, soils from the three sources are of coarse grain, poorly-graded soil and sand. Their coefficients of uniformity ($C_U$) and of concavity ($C_C$) are presented in Table 2.

Table 3 summarizes Atterberg's limits of soil and soil mixed with sand according to the ASTM D4318 standard.

The specific gravity of soils from the three sources belongs to the SP group. In addition, the composition of soils from the province of Chaiyaphum (i.e. 2nd and 3rd sources) is 50% sand, a condition that enables adobe brick-making without additional sand required. However, soils from Nakhon Ratchasima province (i.e. first source) contain much less sand, thereby necessitating an addition of sand to the mixture for brick-making. Thus, the specific gravity of sand of the first source (i.e. Nakhon Ratchasima province) was determined.

The findings also show that types and ratios of raw materials contained in adobe bricks influence the brick strength. For example, if the bricks were made of purely or mostly soil, they would easily disintegrate under the horizontal compressive strength and flexural strength. To improve the brick performance, sand and rice husks should be added to the mixture because the additional raw materials (i.e. sand and rice husks) increase the cohesiveness and strength resistance. Table 4 presents the specific gravity values and material proportions by weight of the raw materials.

**Table 2 Characteristics of soil and sand of three sources under study**

| Source | Avg. passing No.4# (%) | Avg. passing No.200# (%) | Avg. $C_u$ | Avg. $C_c$ | Group symbol |
|---|---|---|---|---|---|
| Baan Sikha Thai | 93.784 | 2.06<5 | 2.852 | 0.772 | S |
| Baan Sai Rung | 90.715 | 5<6.396<12 | 6.621 | 0.641 | S |
| Baan Thep Pana | 99.327 | 5<7.435<12 | 3.333 | 1.071 | S |

**Table 3 Atterberg's limits of soil and soil mixed sand as per ASTM D4318**

| Properties | Baan Sikha Thai | Baan Sikha Thai (Soil+Sand) | Baan Sai Rung | Baan Thep Pana |
|---|---|---|---|---|
| Liquid Limit, LL (%) | 21.17 | 30.84 | 28.47 | 20.68 |
| Plastic Limit, PL (%) | 18.84 | 22.91 | 22.45 | 17.80 |
| Plasticity Index, PI (%) | 2.32 | 7.93 | 6.02 | 2.88 |
| Shrinkage Limit, SL (%) | 9.93 | 9.37 | 9.39 | 7.77 |
| Unified Soil Classification, U.S.C. | SP | SP | SP | SP |

**Table 4 Specific gravity and material proportions by weight of the raw materials**

| Source | Specific gravity | | Material proportion by weight (%) | | |
|---|---|---|---|---|---|
| | Soil | Sand | Soil | Sand | Rice husk |
| Baan Sikha Thai | 2.681 | 2.53 | 74.754 | 18.800 | 6.346 |
| Baan Sai Rung | 2.513 | - | 90.405 | - | 9.595 |
| Baan Thep Pana | 2.542 | - | 88.947 | - | 11.053 |

## Engineering Properties of Adobe Bricks

With respect to the effects of rice husks and sand proportions on the horizontal $\sigma_c$, the horizontal compressive strength values of adobe bricks for different proportions of sand and rice husks are illustrated in Table 5 and Fig. 2.

Based on Fig. 2, the relationship between the proportion of rice husks and the adobe brick horizontal $\sigma_c$; and that between the proportion sand retained with No.4 sieve and the horizontal $\sigma_c$ of adobe bricks can be expressed by equations (1) and (2), respectively.

$$\text{Horizontal compressive strength}_{\text{rice husks}} = -1.7737(\%\text{ of rice husks}) + 32.96 \quad (1)$$

$$\text{Horizontal compressive strength}_{\text{sand}} = 0.2154(\%\text{ of sand}) + 7.3919 \quad (2)$$

The relationship of PI and the horizontal $\sigma_c$ is depicted in Figure 3. The figure indicates a positive correlation between PI and the horizontal $\sigma_c$.

**Table 5 Effects of rice husks and sand proportions on the horizontal compressive strength**

| Propertion of mixeture materials by weight (%) | Baan Sikhathai | Baan Sairung | Baan Theppana |
|---|---|---|---|
| Percent of sand retained sieve No.4# | 56.09 | 51.44 | 26.30 |
| Percent of Rice husk | 6.35 | 9.60 | 11.05 |
| Horizontal $\sigma_c$ (ksc) | 21.76 | 15.76 | 13.48 |

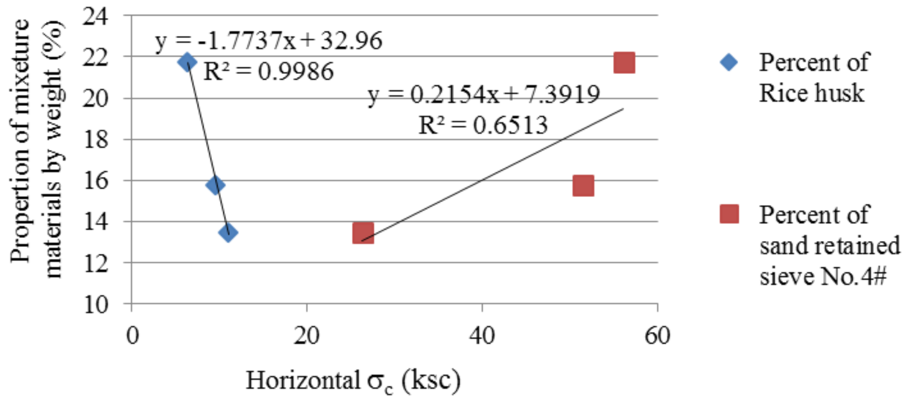


**Fig. 2 Horizontal compressive strength of bricks for different sand and rice husk proportions**

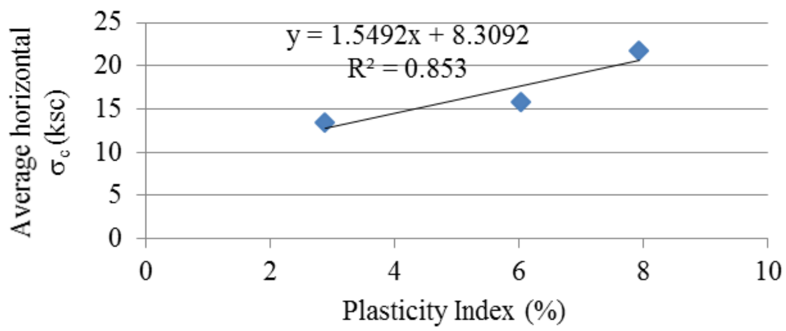


**Fig. 3 Plasticity Index (PI) and horizontal $\sigma_c$ of samples from the three sources**

The relationships of PI of soils to the horizontal $\sigma_c$ of adobe bricks from the three sources can be determined by equations 3, respectively.

$$\text{Horizontal } \sigma_c = 1.5492\text{PI} + 8.3092 \quad (3)$$

where PI denotes plasticity index.

The horizontal $\sigma_c$, $f_b$ and minimum strength according to the UBC 21-9 standard of adobe bricks are depicted in Figure 4. The horizontal $\sigma_c$ of adobe bricks from the first, second and third sources and the minimum standard strength are 21.76, 15.76, 13.48 and 17.6ksc, respectively. This validates the positive relationship between the horizontal $\sigma_c$ and PI.

Although adobe bricks from the three sources outperform the minimum standard strength with regard to $f_b$, the bricks performed less satisfactorily relative to the horizontal $\sigma_c$. $f_b$ of the first, second and third sources and the minimum standard strength are 7.40, 3.36, 4.27 and 2.46ksc, respectively. The low $f_b$ are normal since no additives, e.g. cement or rubber milk, were included in the mixture.

The relationship between the horizontal $\sigma_c$ and the wall bearing strength (prism strength) is illustrated in Figure 5. The figure shows a strong correlation between the prism strength and the horizontal $\sigma_c$, which is similar to that of PI and the horizontal $\sigma_c$. The prism strength of adobe bricks of the first source is highest. The relationship between the horizontal the horizontal $\sigma_c$ and the prism strength can be written as:

$$\text{Prirm strength} = 1.4346\sigma_c + 7.6943 \tag{4}$$

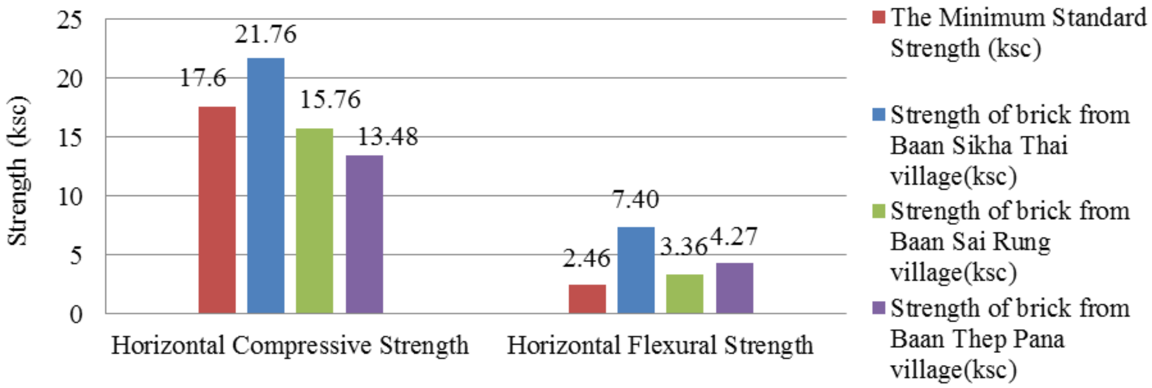


**Fig. 4 Horizontal compressive and flexural strengths of adobe bricks from three sources and the minimum standard strengths**

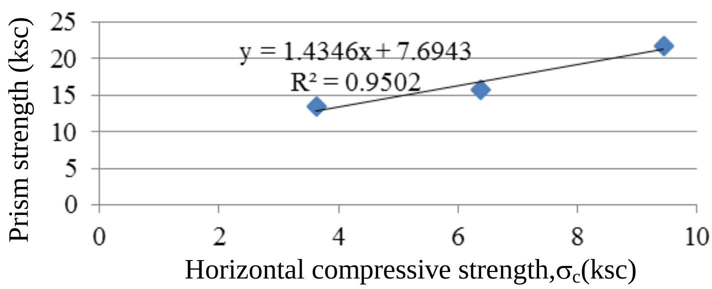


**Fig. 5 Relationship between horizontal compressive strength and Prism strength of adobe bricks from three sources**

## CONCLUSION

The experimental results show that prism strength is subject to PI of soil and the horizontal $\sigma_c$ of adobe bricks. The proportion of sand in the brick mixture affects the horizontal $\sigma_c$, while an addition of rice husks into the mixture reduces the brick shrinkage.

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