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Reinforcement-dependent long-term deflection response of baked clay beams

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Sustained load;
Low-cost material.

Abstract. Reinforced Baked Clay (RBC) may serve as low-cost materials of building construction to substitute Reinforced Cement Concrete (RCC). Deflection of a beam under a sustained load is considered an important parameter. Based on reports obtained from the literature, no study has been carried out on the effect of reinforcement on long-term deflection response of RBC beams and relative comparison to that of RCC beams. For this purpose, RBC beams were manufactured, baked, and post-reinforced in the tension zone only with three ratios of reinforcement (i.e., 0.003, 0.006, and 0.009). All the beams were subjected to a sustained load of 50 kN for one year. The results indicate that long-term deflection of RBC beams was reduced to 20% and 50% when the reinforcement ratio increased to 2 and 3 times the initial reinforcement ratio of 0.003, respectively. The ultimate load-carrying capacity of the RBC beams was similar to that of RCC beams. The deflection of RBC beams was thrice the deflection of RCC beams. This paper shows that RBC beams can be utilized instead of RCC ones while the element of strength is considered.

1. Introduction

To provide shelter for low-income people is one of the major problems with which Pakistan is entangled. The population of Pakistan in 2017 was about 210 million people. Due to an increase in population, there is scarcity of houses which is about 9 million units. As a result, low-income people live in slums, which are located everywhere in cities and rural areas [1,2]. These people are dwelling in huts of straw unsheltered from rain, heat, and cold weather (see Figure 1).

In plains of the country, soil consists of mainly clay, silt, and sand. To construct Reinforced Cement Concrete (RCC) houses in such regions, conventional building materials (i.e., aggregates and cement) are transported from hilly areas located far away. Thus, the overall cost of these materials is high. With continuous and increasing use of these raw materials, their cost may raise at an alarming rate in the future. Besides, cement and steel are industrially produced materials that may create environmental problems due to emission of hazardous gases. Therefore, it is crucial to utilize indigenous and low-cost materials of construction instead of RCC. In plains of Pakistan, huge deposits of clay are available. Panels of beams could be cast from clay. These panels could be dried, fired, and reinforced. These reinforced panels of baked clay beams are called Reinforced Baked Clay (RBC) beams. Thus, precast RBC panels of beams, columns, slabs, and footings can be used to provide affordable houses for slum dwellers. For this purpose, a long-term research program is planned and carried out to find structural performance of RBC as a replacement of RCC.

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Figure 1. Slum houses located in Ghulam Hyder Shah colony, Nawabshah, Pakistan.

In Pakistan, the temperature is usually high in summer. Average temperature during summer in Sindh, Pakistan is approximately higher than 45°C. Houses made of RBC remain cool in summer as compared to the ones made of RCC. In addition, baked clay is 20% lighter than normal concrete. Baked clay is a sustainable and durable material of construction. Baked clay is capable of remaining intact without disintegration for a very long period. For about 5000 years, sun dried and fired clay bricks have been utilized to construct houses and ziggurats in Mesopotamia [3,4]. The Egyptian houses in the Nile valley were constructed out of mud bricks [5]. In Babylonia, fired clay bricks were utilized to construct Nebuchadnezzar palace [6]. Five thousand years ago, in Indus valley, fired clay bricks were used for construction of houses at Moen-Jo-Daro, Sindh, Pakistan [7].

Previous conducted studies reported that baked clay exhibited 1.5 to 2 times higher crushing strength than that of normal concrete [7-15]. RBC beams with tensile reinforcement, without shear and compressive reinforcement, only failed at the ultimate load of 80 kN applied at mid span [15]. These beams showed a flexural mode of failure by yielding and necking of reinforcing bars. Since the loading increased, a single crack opened at the bottom and propagated vertically to the compression zone. At the ultimate failure, neither flexural nor shear cracks were observed. This implies that these RBC beams do not require both shear and compressive reinforcement.

From a structural point of view, a building is designed to function safely during its service life. For this purpose, deflection under sustained loads during service life of a building plays a key role. Long-term flexural behaviour of RBC beams, using constant ratio of reinforcement, subjected to varying loading intensities was investigated [15]. However, the specific subject of how the deflection of RBC beams could be controlled by increasing reinforcement has not been covered in the literature. In this study, long-term deflection of RBC beams is examined for three reinforcement ratios of 0.003, 0.006, and 0.009 at a constant load of 50 kN applied for 360 days.

Figure 2. A view of locally quarried pit sand.

2. Materials and methods

2.1. Quarrying of clay-sand

Clay was acquired from an agricultural field near Hala, District Matiari, Sindh, Pakistan. The clay was obtained at a depth of 1.5 m, which was free from organic matter and vegetation. Pit sand (Figure 2) was excavated from neighboring Indus River near Nawabshah, Sindh, Pakistan. To reduce shrinkage and obtain more density, pit sand was mixed with clay in proportion to 30:70 [16]. For convenience, the word clay-sand will be used to represent clay-sand mixture in this paper.

2.2. Preparation of mixture

The clay was obtained from the site containing lumps (Figure 3). The clay was inserted in the Pulverizer (Figure 4) and mechanically ground into a powdered form (Figure 5). Twenty percentage of water was poured into the mixture, and mixing was carried out in a pan mixer for 15 minutes. The mixture was put in plastic bags for one day. This mixture practically required 20% of water to achieve proper workability, whereas its Optimum Moisture Content (OMC) was

Figure 3. Excavated clay in the form of lumps.

Figure 4. A view of Pulverizer.

Figure 5. Lumps present in clay are mechanically ground into powdered form.

found to be 12.5%. The additional quantity of water above OMC was required for easy molding of beams.

2.3. Casting of beams

The clay-sand beams were manufactured in a mold characterized by dimensions of 165 (width) × 400 (depth) × 1980 mm (length), as shown in Figure 6. A porous sheet of propylene fabric was provided on the internal surface of the mold to make an exit point for extra water, added beyond OMC. The moist mixture spread to five layers in the mold. Water slightly spread before putting the successive layers. Each layer was compressed with a tamping rod.

Figure 6. Steel mold for manufacturing of clay-sand beams.

The top surface of the beams was also properly covered with the same fabric sheet. This sealed arrangement did not allow the soil to be oozed out from the openings in the mold, yet allowed water to be drained. The mold was then pushed in the pressing compartment of the mechanized system [17], as depicted in Figure 7. The function of this compartment is to apply compressive force to the top of the moist clay beams by means of a wooden plunger (Figure 7) of size 165 mm × 150 mm × 1980 mm. The plunger was powered by four strong hydraulic jacks which were connected to hydraulic pump through hose pipes (Figure 7). The compressive pressure was gradually increased to 6 MPa, and the same was maintained for

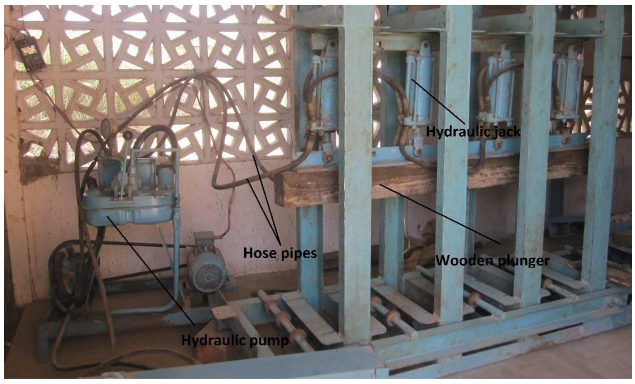

Figure 7. Compacting chamber of the mechanized system.

Figure 8. Clay-sand beam is being compressed in compacting chamber with a wooden plunger for 24 hours at 6 MPa.

24 hours (Figure 8). A study shows that when the clay beams are compacted at 6 MPa using this mechanized system, more fired compressive strength than that of normal concrete is shown.

The presence of more moisture in soil mass causes higher degree of shrinkage and cracks on drying. Therefore, it is necessary to reduce the added water content in the moist mixture up to the extent of optimum moisture content. For this purpose, the load was gradually exerted on beams by means of a wooden plunger. When pressure exceeded 2 MPa, water trickled through the porous sheet, which was wrapped around the clay beams. As mentioned earlier, the pressure intensity was slowly raised to 6 MPa and, then, was maintained for 24 hours. During this period of the time, drainage of the clay beams occurred, which resulted in a decrease in water content close to the level of the optimum moisture content.

During the casting process, two steel bars with 25 mm diameter were inserted in bottom portion of the beams to create holes for providing tensile reinforcement. These steel bars were pulled out by means of a puller after the beams were compressed for 24 hours.

The beams were demolded from the mold (Figure 9) and were covered with plastic sheet and placed in shade. The beams were dried in a ventilated hall to avoid cracks during the drying process (Figure 10). On average, the drying process of the beams took 150 days with temperatures varying from 20°C to 40°C. The drying time of clay-sand beams could be reduced by artificial methods by subjecting the beams to hot air in an air tight chamber. However, the reduction of drying time of clay-sand beams is beyond the scope of this paper. These dried beams were carried with platform lift (Figure 11) to a potter type kiln (Figure 12) present in the laboratory. The beams were fired at 1000°C.

Figure 9. A view of clay-sand beams after demolding from mold.

Figure 10. Clay-sand beams dried in shade.

2.4. Reinforcement in baked clay-sand beams

Two steel bars were inserted in the holes at the bottom of beams. Two plates were welded on both sides of these beams to the reinforcing bars as anchor plates.

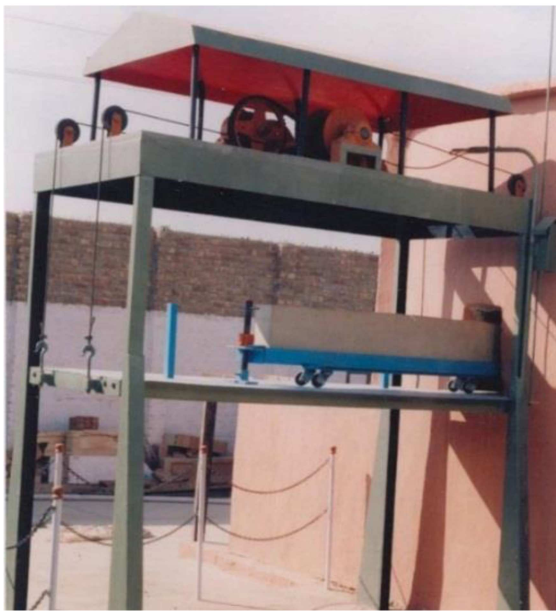

Figure 11. Platform lift for shifting of beams to kiln.

Figure 12. Potter type kiln for firing of clay-sand beams.

The holes were then filled with cement grout and cured in two weeks.

Three groups of reinforced baked clay-sand beams were prepared using three different ratios of reinforcement, i.e., 0.003, 0.006, and 0.009. Each group contains six beams. Groups I, II, and III of baked clay-sand beams were reinforced with a pair of 6.5 mm, 12.7 mm, and 18.5 mm diameter steel bars, respectively. Only tensile reinforcement was provided. Testing of beams was carried out on Universal Beam Testing Machine. Overall length of the beams was 1880 mm with 1720 mm as clear span.

3. Testing program

3.1. Cube crushing strength

Six clay-sand beams were cast without perforations in the tension zone. These beams were utilized for cutting of cubes to determine crushing strength. The sawing process was carried out using a cutter (Figure 13). Five cubes were taken from each beam. The total number of cubes tested was thirty. Crushing strength of cubes was carried out in universal testing machine (Figure 14).

3.2. Modulus of rupture

Plain baked clay-sand beams of length 900 mm [18] were sawed. Universal beam testing machine was utilized for testing (Figure 15). Midpoint loading was applied [19]. The effective length of the beams was taken as 850 mm. The beams were loaded to failure. Modulus of rupture (R) was evaluated via Eq. (1) [19]:

$$R = 1.5PL/bd^2, \tag{1}$$

where P denotes load at failure, L, b, and d are length, width, and depth, respectively.

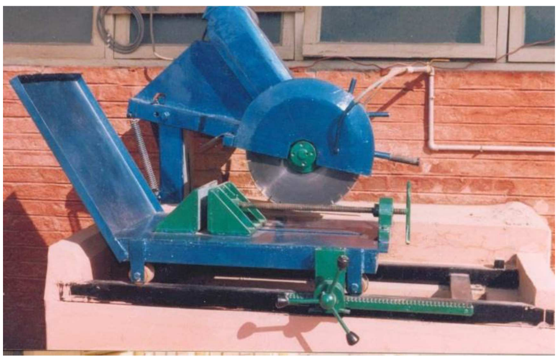

Figure 13. Cutter machine for trimming and sawing of baked clay-sand cubes and beams.

Figure 14. Compressive strength of baked clay-sand cubes tested in universal testing machine.

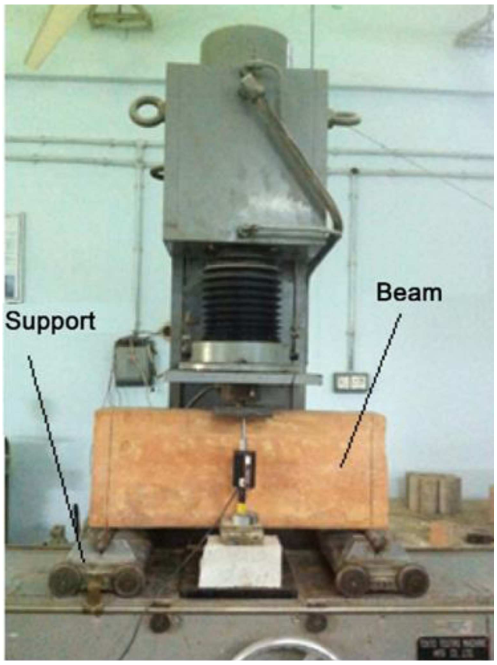

Figure 15. Modulus of rupture of plain baked clay-sand beams tested in universal beam testing machine.

To compare results of baked clay-sand with concrete, modulus of rupture of the latter was determined via Eq. (2) [20]:

$$fr = 7.5\sqrt{f_c}. \tag{2}$$

3.3. Long-term load deflection response of reinforced baked clay-sand beams

Nine long-term laboratory-size beam load testing frames (Figure 16) were designed and fabricated. Clear span between the supports was maintained as 1780 mm. Each frame consists of:

(i) A truss frame with the length of 1880 mm and height of 450 mm, as supporting base;
(ii) Vertical posts formed by welding channel sections of 1600 mm in height;
(iii) Two pairs of stiffening plates;
(iv) Hydraulic jack;
(v) A pair of hose pipes;
(vi) Load cell;
(vii) Hydraulic pump;
(viii) Dial gauge;
(ix) LCD display.

This long-term load testing frame is so strong that it is capable of testing RBC beams at various intensities of loading without self-deformation.

Figure 16. Reinforced baked clay-sand beams tested under long-term sustained loading of 50 kN.

4. Results and discussion

4.1. Cube crushing strength

Mean crushing strength of baked clay-sand is determined to be 30 MPa. The crushing strength of normal concrete is reported to be 20 MPa [21]. The crushing strength of baked clay-sand is 1.5 times higher than normal concrete.

4.2. Modulus of rupture

Table 1 shows the modulus of rupture of baked clay-sand. On average, the modulus of rupture is evaluated to be 5.5 MPa. The modulus of rupture of normal concrete, with 20 MPa compressive strength, can be calculated as 3 MPa (cf., Eq. (2)). The results suggest that baked clay-sand is as strong as normal concrete in resisting tensile stresses.

4.3. Ultimate load at failure of RBC beams

The RBC beams belonging to groups I, II, and III were reinforced with three respective ratios of reinforcement: 0.003, 0.006, and 0.009. The beams were tested in universal beam testing machine. Loading increased until the beams reached failure. The beams of groups I, II, and III showed ultimate loads of 56, 96, and 143 kN, respectively. Ultimate load at failure of RCC beams with the same size and reinforcement as that of RBC beams was also calculated using ACI code [20]. Both the RCC and RBC beams showed similar ultimate load at failure.

The RBC beams of both groups I and II showed a flexural mode of failure without any sign of compression and shear failure (Figure 17). The beams of group III, generally, showed brittle failure due to over-reinforcement.

4.4. Long-term load versus deflection response

RBC beams of groups I, II, and III with reinforcement ratios of 0.003, 0.006, and 0.009 were respectively subjected to a sustained load of 50 kN applied for 360 days. The long-term deflection response of RBC beams of the above-mentioned groups is presented in Figure 18. As expected, the long-term deflection of RBC beams was controlled by the increasing ratio of reinforcement. The deflection of RBC beams was reduced to 20% and 50%

Table 1. Modulus of rupture of plain baked clay-sand beams.

No.	Load at failure (kN)	Modulus of rupture (MPa)
1	58	5
2	61	5.7
3	65	6
4	57	5
5	59	5.5

Figure 17. Flexural crack near mid span of reinforced baked clay-sand beam tested in short-term loading.

when the reinforcement ratio increased to 2 times and 3 times the initial reinforcement ratio of 0.003.

It is very important to compare long-term deflection of RBC beams with that of RCC beams with compressive strength of 20 MPa. The long-term deflection of RCC beams was computed using ACI code [22]. It can be observed that, for reinforcement ratio of 0.003 and 0.006, the deflection of RBC beams was as high as 2.7 times higher than the corresponding deflection of RCC beams. When the reinforcement ratio increased to 0.009, the deflection of the RBC beams was 1.8 times higher than that of RCC beams. Although deflection of RBC beams was reduced from 3 to 2 times higher than the deflection of RCC beams with the addition of more reinforcement, the mode of failure exhibited by RBC beams was found brittle, which is not desirable.

More deflection of RBC beams may be attributed to bond slip. The bars were stretched throughout full length, whereas, in the case of RCC beams, there was no slip between the bars and concrete. The elongation of bars was only in a very small fraction of length which was equal to the summation of total widths of cracks that occurred in tensile zone. Therefore, the deflection of RBC beams was more than that of RCC beams. The results showed that the slippage of bars reduced by increasing diameter of reinforcing bars. As a result, deflection of RBC beams was reduced from thrice to twice as compared to the computed deflection of RCC beams.

5. Conclusions

This study presented the response of Reinforced Baked Clay (RBC) beams for a constant load of 50 kN continuously applied for one year. Reinforcement ratio varied to examine its effect on deflection and ultimate load. A comparison was made with deflection, and the ultimate load response of RCC beams was computed using ACI code. Important findings of the study are summarized below:

(i) RBC beams carried as much ultimate load as the RCC beams. However, long-term deflection exhibited by RBC beams was about three times more than that of RCC beams;

(ii) This study showed that RBC beams could be used as a substitute for RCC ones without loss of strength for construction of inexpensive houses;

(iii) Future studies are required to investigate the effect of the bond between steel and baked clay on deflection of beams.

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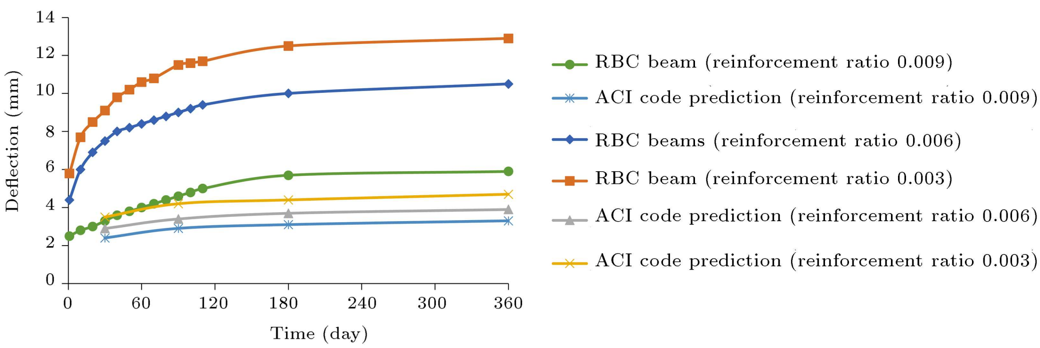

Figure 18. Effect of reinforcement on long-term deflection of RBC beams compared with that of computed values of RCC beams.

References

1. Ghaus, A. and Pasha, H.A. "Magnitude of the housing shortage in Pakistan", *Pak Dev Rev*, **29**, pp. 137-153 (1990).
2. Kiani, M.F. and Siyal, H.B. "Dimensions of urban growth in Pakistan", *Pak Dev Rev*, **30**, pp. 681-691 (1991).
3. Faiella, G., *The Technology of Mesopotamia*, The Rosen Publishing Group, Inc., New York (2006).
4. Bertman, S., *Handbook to Life in Ancient Mesopotamia*, Oxford University Press (2003).
5. Arnold, D., Gardiner, S.H., Strudwick, H., and Strudwick, N., *The Encyclopedia of Ancient Egyptian Architecture*, Princeton University Press (2003).
6. Pearson, D., *The New Natural House Book: Creating a Healthy, Harmonious, and Ecologically Sound Home*, Simon and Schuster (1998).
7. McIntosh, J., *The Ancient Indus Valley: New Perspectives*, ABC-CLIO (2008).
8. Ansari, A.A. and Memon, M. "Performance of postreinforced baked clay panel of beams", *Proceedings of the 3rd CUTSE International Conference Miri*, Sarawak, Malaysia, pp. 334-342 (2011).
9. Ansari, A.A. "Suitability of pre-perforated post-reinforced baked clay beam panels for low cost housing", *Am. J. Civ. Eng.*, **1**(1), pp. 6-15 (2013).
10. Lakho, N.A. and Zardari, M.A. "Relation between compressive strength of baked clay cubes and cylinders", *Engineering*, **8**(8), pp. 509-514 (2016).
11. Lakho, N.A. and Zardari, M.A. "Effect of reinforcement on deflection and cracks in baked clay beams", *Engineering*, **8**(10), pp. 684-690 (2016).
12. Lakho, N.A. and Zardari, M.A. "Suitability of large sized compacted baked clay blocks as a walling material", *Engineering*, **8**(10), pp. 669-675 (2016).
13. Lakho, N.A. and Zardari, M.A. "Experimental study of flexural behaviour of reinforced baked clay beams under impact loading", *Engineering*, **8**(6), pp. 347-352 (2016).
14. Lakho, N.A. and Zardari, M.A. "Comparison of compressive and tensile strength of baked clay with those of normal concrete", *Engineering*, **8**(6), pp. 301-307 (2016).
15. Lakho, N.A. and Zardari, M.A. "Long-term flexural behaviour of reinforced baked clay beams", *Sci. Iran*, **24(3)**, pp. 877-883 (2017).
16. Ansari, A.A. "Experimental study of the behavior of pre-perforated post-reinforced baked clay panels of beams", PhD Thesis, Department of Civil Engineering, QUEST, Nawabshah, Pakistan (2008).
17. Lakho, N.A., Zardari, M.A., Memon, M., and Saand, A. "Design and fabrication of a mechanized system for casting and compacting laboratory-size clay beams", *Sci Iran*, **22**(6), pp. 2046-2051 (2015).
18. ASTM C42/C42M-16 "Standard test method for obtaining and testing drilled cores and sawed beams of concrete", A*STM International*, West Conshohocken, PA (2016).
19. ASTM C293/C293M-10. "Standard test method for flexural strength of concrete (using simple beam with center-point loading)", *ASTM International*, West Conshohocken, PA (2010).
20. ACI 318-14, *Building Code Requirements for Structural Concrete*, American Concrete Institute (2014).
21. Neville, A.M., *Properties of Concrete*, Pearson (2012).
22. ACI 435R-95 "Control of deflection in concrete structures", ACI Committee Report (1995).

Biographies

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