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Design and fabrication of a mechanized system for casting and compacting laboratory-size clay beams

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Compressive strength.

Abstract. To provide low cost residential buildings as the shelters of the growing population is a challenge in Pakistan. In its plains, it is economical to use clay as the material of construction instead of reinforced cement concrete due to its higher cost and transportation charges. The structural properties of clay can be modified by compacting and baking. This paper presents a mechanized system to cast, compact, and consolidate laboratory-size clay beams. The object of this study was to develop a mechanized system which could expel mixed water from moist clay beams up to optimum moisture content in order to obtain maximum density. This mechanized system is mainly composed of steel mould, truss supported railing, overhead mono-rail system, hydraulic pump, and a bulk head unit. Using this mechanized system, moist clay was compacted up to the density of 2000 kg/m^3 at the moisture content of about 13%, whereas the optimum moisture content of the clay was 12%. It is concluded that this mechanized system can be used for quick production of compressed clay beams, which can be baked and reinforced. Those reinforced baked clay beams can be used as pre-cast panels for construction of low cost houses.

1. Introduction

Shelter is one of the basic requirements of human being in this civilized world. People have tried to build their shelter using the indigenous materials of construction since the prehistoric age. In the modern construction industry, pre-cast panels of beams, columns, and slabs are cast and cured in the factory and are transported to a site to erect buildings [1-4].

Alluvial soils (sand, silt, and clay) occur in the plain areas of Pakistan. In these regions, there is scarcity of fine and coarse aggregates. To construct buildings in such regions, the fine and coarse aggregates, cement, and steel bars are transported from distant places [1-2]. The transportation charges of these materials become significant [1-2]. Thus, the total cost of constructing a house can increase substantially. Hence, the majority of population in plain areas cannot afford to construct houses using reinforced cement concrete [1-2]. Therefore, it is important to investigate the potential use of clay as a material of construction in order to reduce the cost of building.

Clay, besides stone and timber, is one of the oldest naturally occurring geological materials of construction building. Clay, in the form of sun-dried and baked bricks, has been used for construction of houses since the dawn of civilization in various parts of the world [5-6]. The structural properties of clay can be enhanced by using more compaction [7]. Density of clay bricks can vary between 1700-2200 kg/m^3 [8].

In a previous study [9], the compressive strength of baked clay cubes of 100 mm of size was found to be 27.61 N/mm^2 (3950 psi) when compacted to a compressive force of 6 N/mm^2 (870 psi). The

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acceptable cube crushing strength of normal cement concrete is 20 N/mm^2 (3000 psi) [10]. This indicates that clay has a potential for replacing concrete to produce pre-cast, post-reinforced structural panels for construction of low-cost buildings. The results of earlier studies [9,11-19] conducted suggest that if the structural panels of beams, columns, and slab cast with clay are compacted, baked, and reinforced, can be used effectively as pre-cast panels for the construction of buildings. The use of these reinforced baked clay panels can lead to cheap and durable construction of buildings [9].

Studies were conducted in past to examine the structural behaviour of indigenous baked clay bricks, blocks, and laboratory-size clay beams [9,11-19]. For compaction of those clay beams, the manual process of compaction was adopted. The mould used in previous study [9,11-19] was not stiff enough and posed the following problems during casting of clay beams: (i) It could not sustain high intensity of compaction, (ii) It started to bulge out when the compacting force was increased; and (iii) The moist clay oozed out from the crevices and openings of mould. Thus, with the previous manual compacting system, [9,11-19] higher intensity of compaction could not be achieved.

If these laboratory-size clay beams can be compacted at a higher intensity of compaction, there will be the possibility to achieve more density and low moisture content in its green state. Thus, more compressive strength can be achieved when these compacted beams are baked.

This paper presents a mechanized system that was designed and fabricated to cast, compact, and consolidate laboratory-size clay beams. These beams were compacted at higher degrees of compaction. The beams were dried and baked. These pre-perforated beams were reinforced and grouted properly. We tested the reinforced baked clay beams in laboratory to examine their structural properties in order to check whether these baked clay beams are strong enough to be used as pre-cast panels for the construction of low cost houses.

2. Materials and method

2.1. Strong and stiff mould

This mould consists mainly of one base plate, a pair of each of side plates, hinge units, and end plates (Figure 1). Each side plate was welded with a 12.7 mm thick plate at its base and a 127 mm angle section at the top in order to increase its stiffness. In order to further increase the stiffness of side plates, they were welded with eighteen angular stiffening plates as shown in Figure 2. An 18 mm steel plate was welded to both of the ends of each side plate to serve as a cleat for both the end plates (Figure 1). The side plates were drilled with three equally spaced 31 mm diameter holes for bolting the side plates (Figure 1). Each side plate was connected with the base plate by a hinge unit (Figure 1). In order to control the movement of mould box, a pair of 15 mm square bars were welded to the sole of base plate as guides.

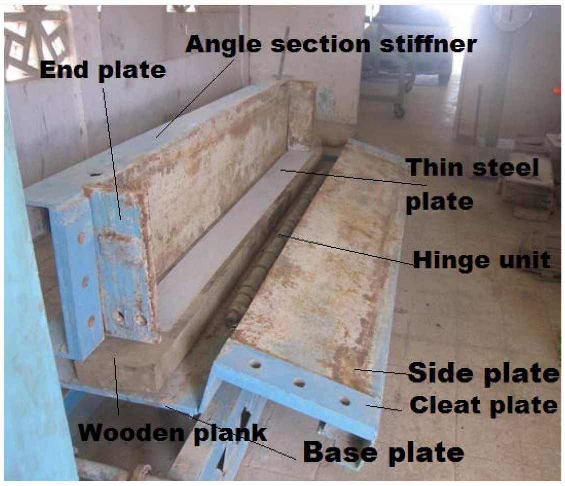

Figure 1. Mould box in open condition.

Figure 2. Mould box in working state.

2.2. Railing frame

The railing frame, on which the mould box moves, consists of two parts. The first part is a truss type frame of 2700 mm length (Figure 3). Six steel shafts, each attached with three ball bearings, were welded on the top of this frame (Figure 3). This unit was bolted to the main frame by steel plates on both sides. Due to the bolt connection, this railing frame is fixed against any horizontal movement and is allowed a small movement in vertical direction.

The second part is channel type railing frame which is 2100 mm long and consists of a pair of 125 mm channel sections (Figure 4). Four steel shafts, each attached to three ball bearings, were welded on the top of this frame.

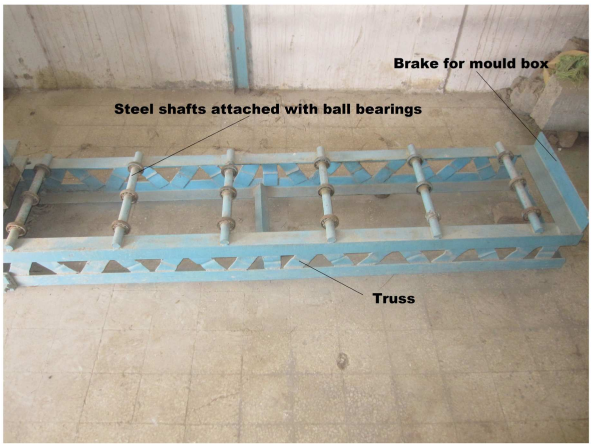

Figure 3. Truss type railing frame.

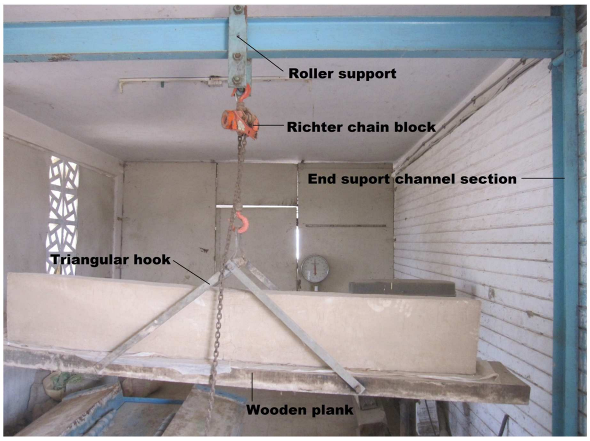

Figure 5. Over-head mono rail system.

Figure 4. Channel type railing frame.

Figure 6. Compacting bulk head unit.

One end of this frame was hinged firmly with the main frame and the other was simply supported (Figure 4). A 100 mm angle section was welded at the simply supported end of this frame (Figure 4). This angle section strengthens and stiffens this unit on one hand and works as a brake to mould box on the other hand, and at least it can move out of the main frame.

Then the beam was cast out of the moist clay in the mould. The mould was railed into the main frame to be pressed by the plunger. As the compacting load was increased by the help of hydraulic pump and control unit, this part of the railing frame started moving downward. As a result, the main frame moved up and supported the pressing load on its bottom support. As soon as the load was released from the mould, the bottom support of main frame came down and the railing frame raised up to support the unloaded mould on its ball bearings.

2.3. Over-head mono rail system

This part of the system consisted of a frame having two channel sections, roller support, chain block, and a triangular hook (Figure 5). The channel sections were 2100 mm long and were fixed to the side walls of corridor as end supports of the mono rail system. A 3600 mm steel girder section was simply supported at the top of these channel sections. This mono rail system is capable of lifting a weight more than 600 kg. The triangular hook is so designed and got fabricated that it can lift beam from the mould, and put it on trolley smoothly.

2.4. Compacting and consolidating bulk head unit (main frame)

The main frame consisted of four sub units. Each sub-unit was fabricated by welding two 2100 mm long, 125 mm channel sections with the help of four 100 mm $\times$ 100 mm angle sections at the top and bottom. Each sub-unit was attached to a strong hydraulic jack cylinder (Figure 6). These four sub-units of the main frame were connected by welding to a pair of angle sections both at the top and bottom of frame to form a single unit called main frame (Figure 6).

2.5. Hydraulic pumping and control unit

The hydraulic pumps convert mechanical energy into pressure energy. This unit consisted of swash plate plunger pump, oil reservoir tank, 5 horse power 3-phase electric motor, dial gauge, control valve, and hose pipes.

2.6. Casting of beams

Clay and pit sand were dried properly after being quarried. Clay and pit sand in a ratio of 70:30 by weight were mixed with 22% of potable water in a pan mixer for 15 minutes. This amount of water was experimentally required for proper mixing, easy handling, and workability of the indigenous clay for casting beams. This moist clay paste was covered properly under a plastic sheet and allowed to mature for twenty four hours.

A 75 mm thick wooden plank having a width equal to 250 mm and a length equal to 2200 mm was placed on the base plate of the mould. A thin steel plate with very finished surface was placed on this wooden plank. A double layer of plastic sheets was also placed on this steel plate before casting the beam. The side walls of mould were raised and end plates were vertically fixed inside the cleat plates at both the ends of the mould. The side plates were then bolted firmly before filling the moist clay in mould.

Clay was put in the mould in five equal layers; each layer was moderately tamped. A slight spray of water was applied on top of the previous layer before filling the next one. Mould box was railed in the main frame for compaction. The system is designed effectively such that the beam in mould can be pressed and compacted to the desired degree of compression.

3. Results and discussions

3.1. Calibration of the compacting system

The hydraulic pump and control unit of the system were attached to a dial gauge which showed the intensity of compression applied by the hydraulic pumping unit. There were seven jack cylinders attached to the main frame for compression. The load was distributed on the surface of beam having a size of 150 mm×1950 mm, with a wooden plunger attached to these jack cylinders. Therefore, the system needed calibration and was calibrated, as depicted in Figure 7. Calibration shows the direct relation between dial gauge readings in N/mm^2 and intensity of compaction in N/mm^2 by plunger on the clay in the mould.

3.2. Casting and drying the beam

The clay was quarried below the depth of 1200 mm in order to curtail the possibility of mixing aggregate and organic debris in it. Pit sand was added to eliminate the possibility of drying cracks [17]. For easy working and moulding of the clay, 22% water was added.

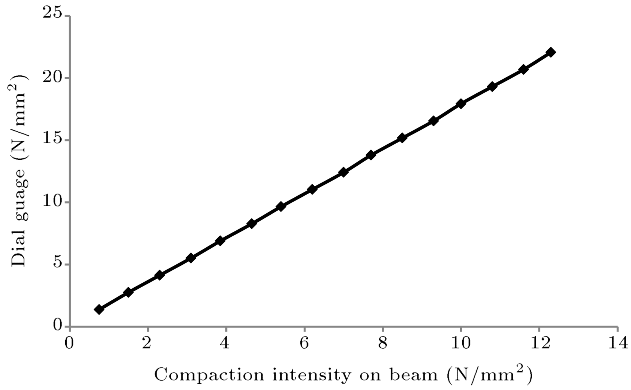

Figure 7. Calibration of the compacting system.

3.3. Compaction and consolidation of clay beams

The object of development of this compacting and consolidating system was to decrease the moisture content of the moist clay beam in order to increase its dry density. This object can be achieved by compacting and consolidating the clay, in the mould, at higher degrees of compaction. The moist soil started to ooze out of the crevices and small openings of mould as soon as the compacting force reached 1.94 N/mm^2. To solve this problem, the clay beam was enveloped in a porous poly propylene fabric sheet. When the compacting load on clay beam increased above 1.94 N/mm^2, only clean water started to ooze out of the pores of poly propylene fabric sheet. With this effort, the compacting force could be increased above 1.94 N/mm^2 and was tried up to 7.2 N/mm^2. The water content of clay beam, compacted at various degrees of compaction, was recorded as shown in Figure 8. The data shows that the moisture content of beam decreases with increase in loading intensity. The rate of reduction of moisture content after 14% decreases slowly as compared to the compacting force and it becomes asymptotic at the moisture content of 13%. This value is very near to the optimum moisture content of clay utilized in this study (see Figure 9). It can be observed that the maximum dry density of clay is achieved at a moisture content of 11.95%.

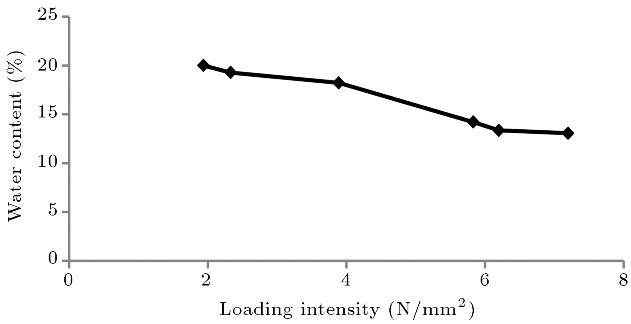

Figure 8. Relation between intensity of loading vs. water content.

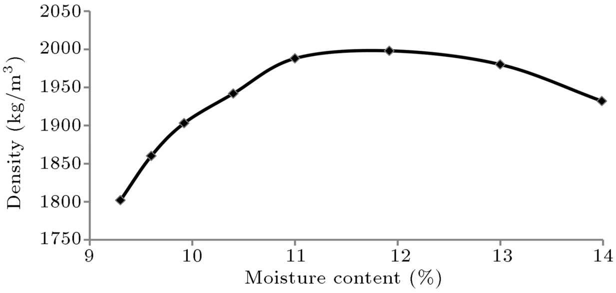

Figure 9. Moisture content vs. maximum dry density.

3.4. Comparison of costs

Reinforced Baked Clay (RBC) beam is a light-weight structural member and can be safely designed without longitudinal compressive steel and without shear reinforcement. Thus, the amount of steel required in a RBC beam is about one third when compared to that needed in a Reinforced Cement Concrete (RCC) beam of the same size and strength. Up to this experimental stage, it was found that the cost of a laboratory size RBC beam is 50% of that of a RCC beam of the same size and strength.

4. Future study

Baked clay is a very brittle material and is fragile during handling; it easily breaks if it falls from a very small height. An attempt was made to pre-stress these baked clay beams in order to solve the problem of fragility. Pre-stressing seemed to strengthen these baked clay beams in the sense of fragility and the beam became strong enough during the process of handling. Thus an optimum amount of partial pre-stressing should be devised and codified.

5. Conclusions

This paper describes a mechanized system to cast, compact, and consolidate the laboratory-size clay beams. Using this system, the laboratory-size clay beams could be compacted and consolidated up to the desired degree of compression. At the intensity of compaction of 1.94 N/mm^2, moist clay oozed out of the crevices and opening of the mould. This problem was solved by enveloping clay beam in a poly propylene fabric sheet and then it became possible to expel out the mixed water through compaction and consolidation at an intensity close to the optimum moisture content of the clay. It is further concluded that this system can be used for rapid and cost-effective production of clay beams for commercial purposes.

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