EVALUATION OF PROPERTIES OF COMPRESSED EARTH BLOCK

ARIF AHMED

A project report submitted to the Department of Civil Engineering,
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SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ENGINEERING IN CIVIL AND GEOTECHNICAL ENGINEERING

BY
ARIF AHMED

DEPARTMENT OF CIVIL ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
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The thesis titled "Evaluation of Properties of Compressed Earth Block", Submitted by Arif Ahmed, Roll No: 0409042252(P), April/2009; has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Engineering (Civil and Geotechnical) on 17th November, 2014.

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

(Arif Ahmed)

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ABSTRACT

In a reinforced concrete (RC) frame structure building, partition wall has very low compressive stress. To replace traditional fired brick, environment friendly Compressed Earth Block (CEB) may be used as partition wall. This study investigated the feasibility of using CEB as interior and exterior partition wall. Soil samples were collected from 8 traditional brick fields and their index properties and percentage of sand were determined for selecting suitable soil for making CEB. After that, standard proctor test was performed for the selected soil sample to know the optimum moisture content under which maximum compaction can be achieved which will ensure the maximum strength also. A mould with a dimension 241mm x 114mm x 203mm was made for making CEB and 36 bricks were made using compression testing machine. Compressive strength test was performed after 7 days and 28 days maturation of brick whereas absorption capacity was determined for 24 hours submergence under water for different conditions i.e. normal CEB, CEB with slurry coating and CEB with plaster coating. From this study it is concluded that CEB is feasible for using it as interior wall but not as external wall in flood prone areas. Cement slurry and plaster coating could not reduce absorption capacity of CEB. Cement plaster coating has very little use in case of reducing absorption capacity of CEB. Soil composition used for making fired brick in Bangladesh is not suitable for making CEB because of presence of very low percentage of sand. There is always a certain range of moisture content for which CEB gains its maximum strength. Certain moisture content ensures maximum compaction of soil sample inside the mould.

Chapter 1
INTRODUCTION

1.1 General

10,000 years ago, when man learnt to build homes, earth was undoubtedly been one of the most widely used construction materials in the world. Now a day, 50% of the population in developing countries, including majority of the rural population and at least 20% of the urban and suburban population, live in earthen dwellings (Houben and Guillaud, 2005).

Because of being a developing and densely populated country, there is an abundant use of clay fired bricks in house construction of urban, semi urban and even in rural areas. Bangladesh's brick industry has grown approximately 5.3 percent per year during the last decade. It represents one of the largest sources of greenhouse gas emissions in the country. In 2008, total carbon dioxide emissions in Bangladesh reached 50.39 million Metric Tons; within which estimated at 6 million tons of carbon dioxide due to the use of outmoded technologies and substandard fuels such as wood, sulphur coal and burning of tires (Hossain and Abdullah, 2012). Bangladesh is ranked at 172 worldwide, with per capita emissions increasing on 2007 by 0.02 metric tons to 0.33 metric tons. From another source (The Daily Ittefaq, 2009), at present, 6000 traditional brickfields are emitting 8.75 million tons carbon annually. According to the UNDP, Bangladesh uses about 23 tons of coal to produce 100,000 bricks (UPI, 2010). The annual greenhouse gas emissions by the traditional brickfield is equivalent to emissions of more than 230,000 passenger vehicles or carbon sequestered by more than 250,000 acres of pine or fire forests (The News Today, 2011).

The problem inherent with fired bricks can be solved to a great extent by soil block named Compressed Earth Block (CEB) which has been developed and became popular in many parts of the world for its low cost construction, eco friendliness, and efficiency and for being available locally and cheaply.

1.2 Background of the study

The idea of compacting earth to improve the quality and performance of molded earth blocks is, however, far from new, and it was with wooden tamps that the first compressed earth blocks were produced. This process is still used in some parts of the world.

The first machines for compressing earth probably date from the 18th century. In France, Francois Cointeraux, inventor and fervent advocate of "new pies" (rammed earth) designed the "crecise", a device derived from a wine-press. But it was not until the beginning of the 20th century that the first mechanical presses, using heavy lids forced down into moulds, were designed. Some examples of this kind of press were even motor driven.

The fired brick industry went on to use static compression presses in which the earth is compressed between two converging plates. But the turning point in the use of presses and in the way in which compressed earth blocks were used for building and architectural purposes came only with effect from 1952, following the invention of the famous little CINVA-RAM press, designed by engineer Raul Ramirez at the ClNVA centre in Bogota, Columbia. This was to be used throughout the world. With the '70s and'80s there appeared a new generation of manual, mechanical and motor-driven presses, leading to the emergence today of a genuine market for the production and application of the compressed earth block.

Since its emergence in the '50s, Compressed Earth Block (CEB) production technology and its application in building have continued to progress and to prove its scientific as well as its technical worth (Guillaud et al, 1995).

1.3 Objectives of the Study

The main objectives of the present study are:

i. To collect soils for making Compressed Earth Block and perform index tests for selecting suitable soil.
ii. To fabricate a mould for making Compressed Earth Block using compression testing machine of concrete.

iii. To evaluate compressive strength and absorption capacity of Compressed Earth Block.

1.4 Methodology

The methodology used for the analysis involves comparing strength of brick in different stages of curing under different circumstances .With a view to considering the effect of different weathering condition exposed on brick was the main consideration in the way of research. A simplified flow diagram explains methodology of this study.

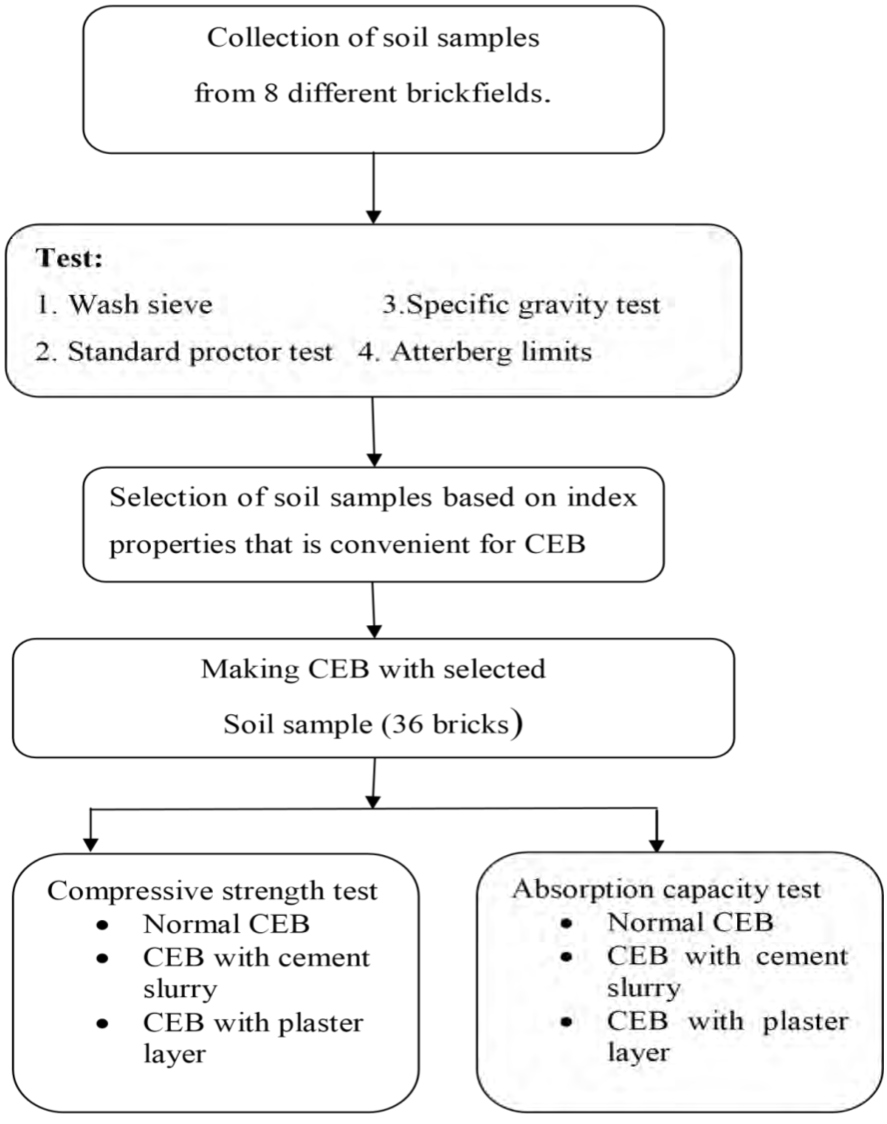

Figure 1.1: Flowchart of research methodology.

1.5 Thesis layout

Chapter one describes the background, objective and methodology of project work. Chapter 2 includes earthen architectural scenario all over the world, past research on compressed earth block. Other relevant past research have been described in this chapter. Earthen house practice in Bangladesh also described in this chapter. Its present status and future prospect are also described. Here earthen and other type of rural houses is compared. A table showing possible solutions to the weakness of earthen houses also been presented.

Chapter 3 deals with experimental program. Here selection of soil and stabilizing material with their physical properties described. Preparation of specimens for test, test methodology and definition of test parameters are also described. Finally, a test plan has been included in this chapter.

In Chapter 4, result of index property and standard proctor tests are discussed. Then results of compressive strength test of CEB under different conditions are presented. The results of test parameters are discussed with the help of figures, graphs and charts. The results have been compared for normal CEB, CEB with cement slurry and plaster layer.

Finally, Chapter 5 is devoted to conclude the research work. At first, effect of soil composition, moisture content on different properties is discussed. Effect of cement slurry layer and plaster layer is also presented. The findings from the research work are then enumerated. Finally, scopes for further research are listed in this chapter.

Chapter 2
LITERATURE REVIEW

2.1 Introduction

Construction with earth or clay has been around for thousands of years. In the 1970's it was estimated that there were more than 80 million earthen dwellings in India without considering significant numbers in Africa and China (Norton, 1997). It may be conservative to suggest that over two billion of the worlds' population live in buildings primarily made from earth or clay.

Additionally, UN-HABITAT estimates that 3 billion people lack decent housing. With a continually growing global population, this figure is likely only to rise. In Uganda, for example, demand exists for 1.6 million new homes each year; this is met by a supply of a mere 100,000. Building new homes on such a scale requires large amounts of construction materials. Traditional building methods such as fired masonry or concrete are environmentally damaging on many fronts – deforestation occurs to provide firewood, concrete involves large amounts of embodied energy etc (The Good Earth Trust, 2008).

In contrast to traditional fired masonry, building with unfired mud or clay bricks reduces the cost of construction and the environmental impact. Importantly it also promotes local business and employment. As a potential construction material it seems to tick all the sustainability boxes and has great potential in the developing world.

The Good Earth Trust aims to promote the use of Interlocking Compressed Stabilized Blocks (ICSB) in the developing world with an eventual aspiration to transform the market so that people will opt for this technology rather than fired bricks. According to them, "To do this we take a multi-pronged approach through awareness raising, advocacy, technical and business training, capacity building, research and development of the technologies, and the provision of information and guidance. In our advocacy work we target the government to ensure they are aware of the technology and include it in building codes, technical specifications, and policy. We also advocate to Agencies, NGOs, and the private sector to adopt these technologies in the projects and work they do. In selected areas, we engage directly with local communities to implement practical projects to understand what is needed to promote the adoption of the technology at community levels"(The Good Earth Trust, 2008)

2.2 Background

2.2.1 Mud and earth construction

Although mud and earth construction has been around for thousands of years it is important to ask whether it is still relevant today. Hadjriet al. (2007) interviewed ten residents of earthen buildings about five key points: durability, affordability, living conditions, aesthetics and their general performance compared to a 'modern' house. Their findings are as follows:

(a) Durability– Half of the residents indicated that their dwelling was durable, with a lifespan of more than 20 years. The other half reported a lifespan of just 10 years with regular maintenance required. The latter category reported the major factors in lack of durability were water and/or termite damage.

(b) Affordability– All residents agreed that earthen dwellings were affordable when compared to modern dwellings.

(c) Living Conditions– 8 out of 10 interviewees stated that their homes offered very comfortable living conditions with excellent thermal properties; cool in summer and warm in winter. The other two were less impressed. However, it should be noted that the two who complained about conditions lived in buildings roofed with corrugated iron resulting in excessive heat transmission.

(d) Aesthetics – Four interviewees appreciated the appearance of earthen architecture, two were indifferent but four found the appearance less pleasing compared to 'modern' dwellings.

(e) General Preference – 70% of residents stated that they would not live in an earthen home if they had the financial resources to do otherwise. This was mainly due to the fact that earthen dwellings were associated with poverty and a lower social class.

These results show that there are still issues with the perceptions of earthen architecture in the developing world (Hadjriet al., 2007) and that any drive to promote earthen architecture as a realistic alternative to 'modern' building materials must be combined with an educational program.

Earthen architecture, however, has changed considerably in recent years with better understanding and increased use. The current trend for sustainable living combined with greater understanding of the thermal benefits, safety and potential durability of earth has led to substantial advances in the quality and appearance of mud and clay based buildings (Burroughs, 2009). Some examples of earthen architecture, old and new, are shown in Figs 2.1 and 2.2 These examples show that with the correct materials, dedication and imagination, earth structures can be as impressive as more modern construction methods.

Figure 2.1: Examples of Earthen Architecture in India
(Source: www.banasura.com).

Figure 2.2: Example of a Modern Earthen Structure in Riyadh, Saudi Arabia (Source: www.rael-sanfratello.com)

Figure 2.3: Rammed Earth Construction Underway in India (Source: www.banasure.com).

2.3 World scenario of earthen house construction

The use of earthen house is very common in some of the world's most hazard-prone regions, such as Latin America, Africa, the Indian subcontinent and other parts of Asia, the Middle East, and southern Europe (Fig. 2.la). It has been observed that in Peru 60% of homes are built of adobe or rammed earth. In Kigali, the capital of Ruwanda, 38% of housing is built in unbaked earth. Earth architecture has also deep roots in the Middle East: In Iran, the heart of ancient Persia; Iraq, cradle of the Sumerian civilization; Afghanistan, North and South Yemen. The techniques of the barrel vault and dome were perfected in Iran, as the ancient centers of bam, Yazd, Seojan and tabriz bear witness.

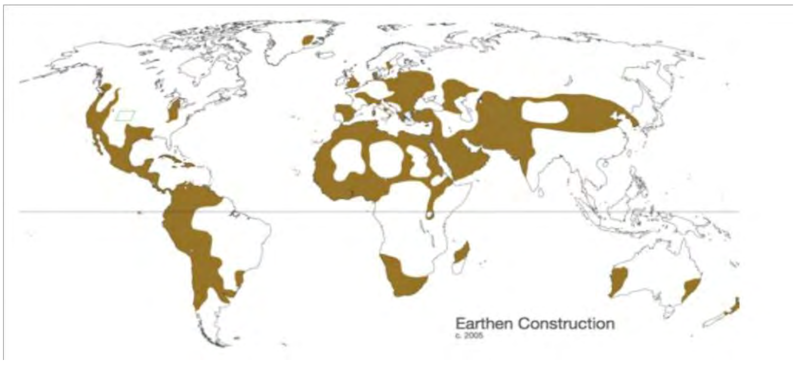

Figure 2.4: Distribution of global earthen architecture (De Sensi, 2003).

Sat Saibam in South Yemen, there are *cob* buildings which are more than ten storied high. In China, in the provinces of Henan, Shanxi and Gansu, more than 10 million people live in homes dug out of the loess layer. Passing on the Inner Mongolia, inHebei and Jilin, at Sichuan and Hunan, rural dwellings are for the most part built in daub, adobe, or rammed earth. In India, the 1971 census shows that 72.2% of all buildings are made in earth (Houben and Guillaud, 2005).

Distribution of global earthen architecture areas are presented in Fig. 2.4. Some of the earth structures from different countries are described in figure 2.5.

(a) Earthen houses in Thailand.

(b) Earthen houses in China.

(c) Earthen houses in India.

Figure 2.5: Earthen house in different places.

2.4 Present scenario of earthen house construction in Bangladesh

Earthen house construction practice is more than 200 years old in Bangladesh. Here about 73% of the population lives in "ketch" (made of bamboo, thatch and earth) Houses (BBS, 2003), and a major portion of ketch houses may be considered as earthen houses. Some greater districts of Bangladesh: Rajshahi, Potuakhali, Khulna, Dinajpur, Bogura and Chittagong (Figure 2.6) are the areas where mud house system is widely practiced (Uddin, 2007). 1981 census record the presence of earthen houses as high as 50-60% in some northern parts of the country (Chowdhury, 1995). Here all of the earthen houses are one storied with some exception of two storied houses in the Northern areas of the country. It is more predominant in less flood prone areas i.e. in highland or hilly and mountainous areas where clay soil base is available to transmit the load.

However, due to social uplift, lack of knowledge about its manifold advantages and lack of environment concern, the trend of earthen house construction starts falling down. At present, 18% of total houses of Bangladesh are made of earth (GOB, 2008).

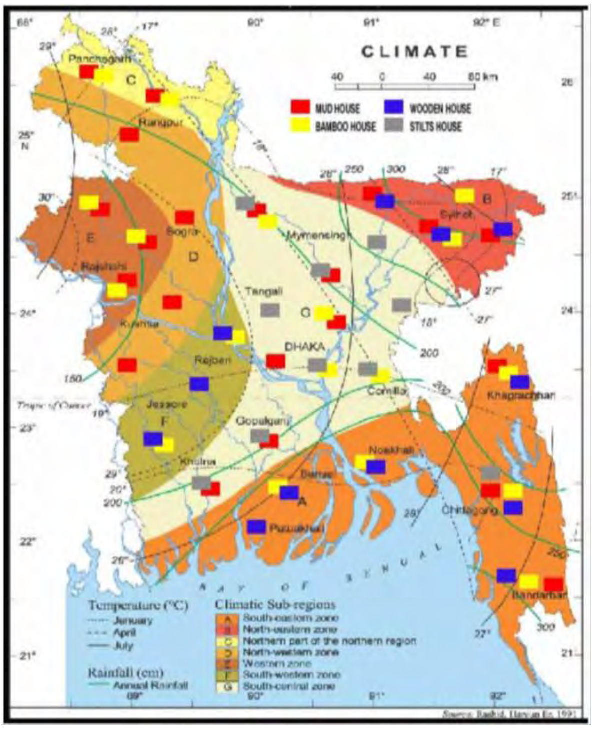

Figure 2.6: Map showing house distribution in Bangladesh.

Table 2.1: List of major earthquakes affecting Bangladesh during 150 years (M_s =>7) (Sabri, 2002).

Date	Name of earthquake	Surface wave magnitude	Maximum intensity	Epicenter distance from Dhaka
10/01/1869	Canchar	7.5	IX	250
14/07/1885	Bengal	7.0	VIII - IX	170
12/06/1897	Great Indian	8.7	X	230
08/07/1918	Srimongal	7.0	VIII-IX	150
02/07/1930	Dhubri	7.1	IX	250
15/01/1934	Bihar-Nepal	8.3	X	510
15/08/1950	Assam	8.5	X	780

2.5 Problems of Earthen Houses

Although earthen house possesses many fold advantages, it has got some inherent weaknesses. The main weaknesses of earthen houses are described briefly below.

2.5.1 Shrinkage Problem

Drying shrinkage cracks are developed on the surface of earthen houses as natural wetting and drying continues. Degree of shrinkage mainly depends on soil composition. The shrinkage cracks, thus formed, weaken the joints between block and mortar (Bui et al, 2009).

2.5.2 Moisture Problem

Earthen walls and foundations absorbs moisture when comes in contact with water. Due to absorption of water the soil particles looses bonding strength and starts washing away (Bui et al, 2009).

2.5.3 Earthquake Problem

Seismic behavior of earthen buildings is commonly characterized by a sudden and drastic failure. From historical earthquake events, it is estimated that the collapse of earthen structures is mainly due to the following reasons:

(a) Earth is a Brittle material and practically possesses no tensile strength.

(b) Poor construction practices often decrease the bond between earthen block and mortar. Mortar becomes totally or partially disintegrated after a few cycle of tremor due to earthquake.

(c) They are massive and heavy. Thus they attract high levels of seismic forces. Besides, the architectural concepts of the past have changed and at present the typical thickness of earthen walls have been greatly reduced to make them externally similar to the brick masonry.

These factors together with lack of maintenance make the earthen house vulnerable to earthquake forces. The following typical modes of damages are identified by the observed earthquake damage pattern.

(a) Cracks between walls and floors.

(b) Cracks at the corners and at wall .intersections.

(c) Out-of-plane collapse of perimeter walls.

(d) Diagonal cracks in structural walls.

(e) Partial disintegration or collapse of structural walls.

(a)

(b)

Figure 2.7: Photographs of: (a) formation of shrinkage crack on earthen walls and (b) damage of wall due to moisture absorption (Rahman, 2010).

Typical seismic action modes of failure are shown schematically in Fig. 2.8. The damage of a earthen house due to July, 2003 Barkal earthquake is also shown in Fig. 2.9. The schematic diagram shows that typical vertical cracks in the upper portion of walls occur due to out of plane bending of the walls and the diagonal cracks in the wall between window and door opening occur due to in plane bending of the walls. Similar failure pattern is pictured in Fig. 2.9.

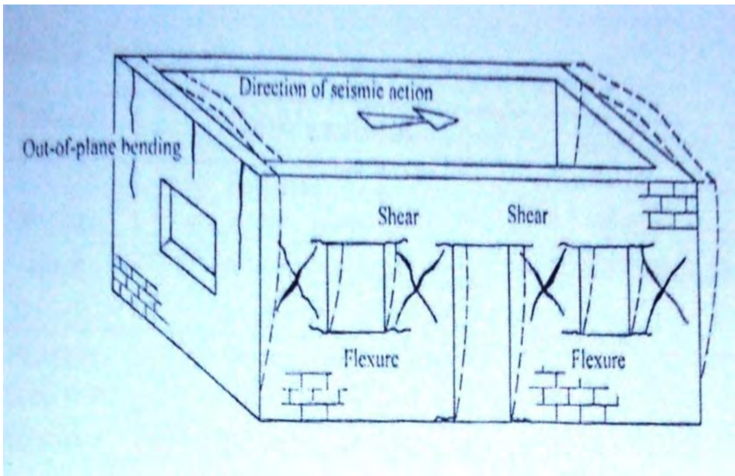

Figure 2.8: Schematic of failure pattern due to seismic action (Tomazevic, 2006).

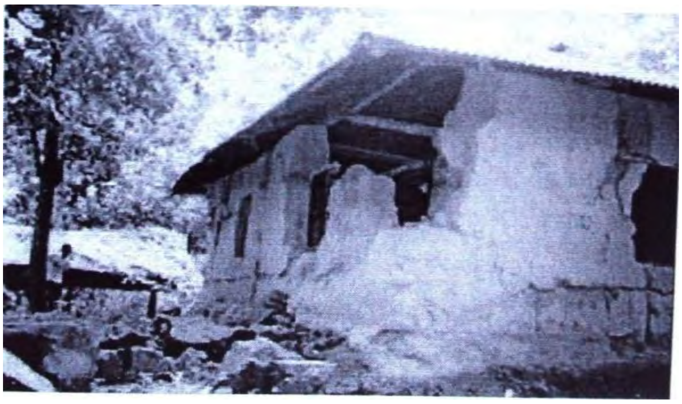

Figure 2.9: Failure of an earthen house due to July, 2003 Barkal Earthquake
(Islam, 2002).

2.6 Solution of the problems

There might have several ways to solve the above mentioned problems. But the challenges lie behind the selection of a suitable solution depending on the type and composition of the soil, availability of reinforcing or stabilizing materials, cost and affordability of the people and overall it's acceptance by the local community. Proposed solutions to the problems are listed in Table 2.2.

Table 2.2: Problems of earthen houses with possible solutions (Rahman, 2010)

Problems	Possible solutions	Proposed solution
Shrinkage crack.	• Selection of soil • Addition of fibre •Addition of stabilization material	• Selection of soil • Addition of fibre
Moisture problem to foundation and plinth	• Provision of drainage • Stabilization of soil • Extension of roof beyond wall	• Provision of drainage • Extension of roof beyond wall
Moisture problem to walls.	• Provision of drainage • Stabilization of soil • Fibre reinforced plaster • Extension of roof beyond wall	• Fibre reinforced plaster • Provision of drainage • Extension of roof beyond wall
Earthquake problem.	• Increasing block and mortar strength by fibre Increasing block and mortar strength by stabilization • Increasing overall stability by reinforced plaster • Improvement of structural integrity.	• Increasing block and mortar strength by fibre • Increasing overall stability by reinforced plaster • Improvement of structural integrity.

2.7 Dynamic behavior of CEB wall

Walls stability was studied based on the comparisons of simulations of the dynamic behavior of some walls built from different combinations of the block-mortar set. These comparisons concern essentially the answer of the walls to the external forces through the determination of their dynamic amplification factor. At the end of the analysis of the simulation results, walls built from the compressed earth blocks and the earth mortar seem to resist better to external forces than walls built from all others block-mortar associations which we used in this work (Ntamacket al, 2012). Details are given in Figure 2.10.

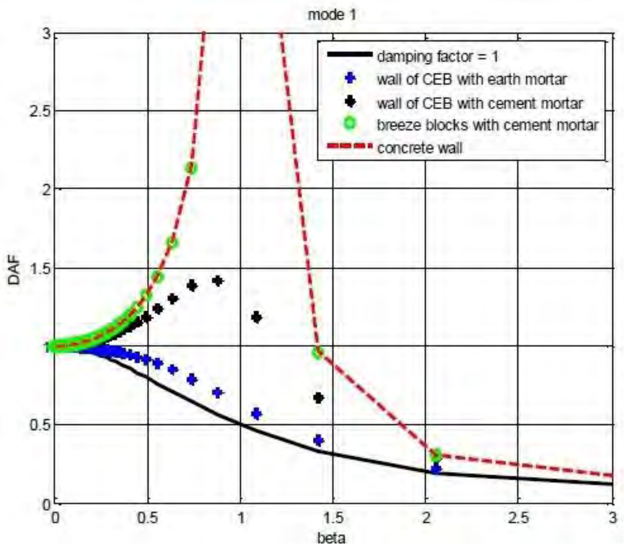

Figure 2.10: Dynamic Amplification Factor (DAF) as a function of beta in vibration mode (Ntamack et al, 2012).

The smallest value of the DAF which is related to the most stability is for the wall made in CEB and the earth mortar. The study also has done many simulations, by taking different values of the damping parameter, the results were the same i.e.: the walls built from CEB and earth mortar have always the smallest values of the DAF (Ntamack et al, 2012). So, walls made with CEB are more stable.

2.8 Key Points from the Literature Review

The following key points have been drawn out from the literature review:

(a) Various forms of earthen construction have been used for thousands of years.

(b) A dishonor is still attached to earthen construction in the developing world where it is associated with poverty and low social standing. Therefore, an educational program will need to run concurrently to any concerted CEB drive promoting it as a viable, modern and sustainable construction material.

(c) Earthen structure has some problem also and suitable solution is also available on different circumstances.

(d) CEB technology has numerous advantages over rival earthen construction

(e) Methods notably in strength, appearance and ease of use.

2.9 Summary

Due to change in social outlook, lack of knowledge about the manifold advantages of earthen houses and unknowing of the consequences of the use of industrial building products, earth construction practice is decreasing day by day. Another big issue is its vulnerability at drought, moisture and earthquake forces. A table has been presented focusing the problems of earthen houses, possible solution to the problems and the solutions proposed at project work.

However, very recently, earth construction witness growing interest both globally and locally. Model houses are being constructed at various part of the country and other parts of the world to motivate low income people towards the use of it. If the problem can be solved at relatively easier and cheaper ways then it will be a suitable low cost solution for both RC frame structure (partition wall) and earthen housing sector for the years to come.

Chapter 3
EXPERIMENTAL PROGRAM

3.1 General

Compressive strength test was conducted on CEB to know the block strength properties. The same test was performed on CEB bricks with a slurry layer and plaster layer on its outer surface to know the strength properties of CEB on different conditions. Again, absorption capacity test was performed to know the absorption capacity of CEB brick in case of critical weather condition like heavy rainfall, flood etc.

Eight types of soil are collected for the experimental program. This sample was collected from different brick fields with a view to finding out the suitability of soil sample in making CEB with the existing soil that is used for making fired clay bricks.

From soil composition and index properties one soil sample was selected for making CEB to know the compressive strength and absorption capacity. Then some of the blocks were provided with a slurry layer and some of them were given a plastering layer for improvement of absorption capacity. Slurry and plaster layer was used to compare the capability to withstand against different weather condition.

A mold was specially prepared for the ease of making brick with compression testing machine as CEB machine is not available in Bangladesh. The mold has enough thickness and provided with 12 bolts with reasonable strength to take the applied load given by the compression testing machine at the time of manufacturing.

This chapter presents the selection of soils and identifying the properties of selected soils. Selection of suitable soil sample is also described. Specimen preparation, experimental set-up and the test parameters are also described.

3.2 Suitable soil for CEB

3.2.1 The Raw Material

A soil is an earth concrete. Soil contains gravel, sand, silt and clay as binder. Clay is the cement of the earth but they are not stable under water. CEBs are made from soil that is 15-40% non-expansive clay, 25-40% silt powder, and 40-70% sharp sand to small gravel content. Soil moisture content ranges from 4-12% by weight. Clay with a plasticity index (PI) of up to 25 or 30 would be acceptable for most applications. The PI of the mixed soil (clay, silt and sand/gravel combined) should not exceed 12 to 15. A good soil for CEB is sandier than clayey or silty. The soil must not contain organic materials and top soil.

As can be seen, the proportions of each type of material can vary considerably depending on the qualities of each, which differ quite widely, particularly for clays. Knowing the proportions of each, as shown on a particle size distribution curve, is an important indicator but is rarely enough for soil selection purposes.

Normally the suitable ranges are:

(a) Clays =15-40%
(b) Silts =25-40%
(c) Sands =40-70%
(d) Gravel =0-40%
(e) Clay plasticity index 25-30 would be acceptable
(f) Mixed soil plasticity index range is 12-15

3.3 Selection of soil

Soil is a stage in a long process of deterioration of the parent rock and its physiochemical evolution. Depending on the parent rock and climatic conditions soil appears in infinity of forms possessing an endless variety of characteristics. It is essential to be aware of the soil properties before using it for construction. These properties fall into major categories of grain size distribution, plasticity, compressibility and cohesion .soil must be classified in order to rationalize and optimize the exploration of knowledge of their properties (Houben and Guillaud, 2005)

3.3.1 Field test on soil sample

The grain particles were examined with a magnifying glass. The porosity and plasticity were checked by pouring water on a soil sample to see the rate at which it drains through the soil particles and by making wet soil ½ inch diameter ball by rolling between palms as well as rolling the ball into 1/8” diameter thread. In order to determine tentative percentages of sand, silt and clay of soil particles, the soil was subjected to the sedimentation test in which each sample was placed in a glass jar and the jar filled with water and stirred properly. The jar was kept in static condition for the settling of the soil particles. Each of the settled soil layer was measured with a scale rule and approximate percentages sand clay, and silt were obtained. (Arumala and Gondal, 2007)

3.3.2 Laboratory test on soil

The soils used for making the blocks were evaluated first by performing some tests for the purpose of classifying and identifying the types of soils. The tests performed were as follows: Soil Particle Size Test, Moisture Content Test, Specific Gravity Tests, the Atterberg Limits Tests and Compaction Test. In the Particle Size (Sieving) Analysis, the soil was first passed through the #200 sieve. The material retained on this sieve was now used for finding out the index properties of soil samples. Again, the material was thoroughly washed on a #200 sieve, oven dried to find out the percentage of sand (fine sieve analysis). All the soil tests were done using a basic Laboratory Manual (McArthur and Roberts, 1996). After classifying the soils, compressed earth blocks were made from the soils and the blocks were subjected to compression and absorption capacity tests after the blocks have “cured” for several days (Arumala and Gondal, 2007).

3.4 Productions

Soil preparation operations will play a crucial part in the ultimate quality of the blocks. These operations can sometimes make it possible to use soils which are unusable in their natural state, because they can include modifying the grain size distribution. Bearing in mind that extraction and transportation costs are generally high, this can allow useful economies to be made.

(a) Pulverization

The object here is to either break up lumps which are held together by clay (crushing) or to fragment stones and gravel (grinding). Applying fairly high pressure is sufficient for crushing, whereas grinding demands a hard impact.

(b) Screening

In general, this is done to remove the particles which are too coarse. In this study the soil was allowed to pass through #4 sieves. After pulverization, the soil which passes the #4 sieve was used to make CEB.

(c) Measuring out water

It is difficult to calculate beforehand the precise volume of water which will be needed to reach the optimum moisture content for compaction, as this will depend on the natural moisture content of the various materials (soil, sand, etc.) which varies greatly. The operator must determine the optimum quantity of water using simple tests and by experience. In our study, standard proctor test was done to find out the optimum moisture content. The difference between the optimum moisture content and moisture content of existing soil sample was added to the soil sample that was screened for making brick. However, this task mainly depends on experience rather than knowing optimum moisture content because of huge variation of water content in same soil sample.

Figure 3.3: Prepared soil sample for making CEB.

(d) Mould preparation

Prepared soil sample was poured into the mould. This mould was specially prepared for this study having a dimension of 241 mm x 114 mm x 203 mm. The bolts of the mould were properly tightened. Now the mould is ready to be compressed mechanically. In real situation, there is no need to prepare any mould because CEB machine itself has a mould on it and the process of making brick is automatic. As CEB machine is not available in Bangladesh, the mould was prepared for this study and the mechanical press was provided by the compression testing machine. However, making CEB using this mould and compression testing machine was very much difficult and painstaking work. It was taken 20 days to make 36 brick for this study.

Figure 3.4: Mould and tightening of bolts.

As the press is fitted with a lid, it must be correctly positioned and soil must not get trapped in the angle between the mould and the lid as this can cause the lid to be displaced or the compression system to jam. It is important to note that, the bottom of the lead and inner surface wall of the mould was provided with grease for the ease of removing the brick from mould after application of compression.

(e) Mechanical press

The mould was set under compression testing machine and it was subjected to compression until the soil was compressed from 8.5inch to 5 inch. Loading rate was 9.28 kN/s.

Figure 3.5: Mechanical press by compression testing machine.

3.5 Specimen preparation

Specimens were prepared for absorption capacity of CEB in three different conditions i.e. normal CEB, CEB with a slurry layer and CEB with plastering. These conditions were also applicable for compressive strength test. The method of specimen preparation, test procedure, test safety and test parameters are described below.

3.5.1 Specimen for compressive strength test

Bricks were prepared by applying mechanical press with certain loading rate. After the lid was forced to down for a certain height, load application was stopped. Then the mould was taken out from compression testing machine and the bolts were removed using necessary tools. After the bolts were disjointed, the brick was removed from the mould.

(a) (b)

Figure 3.6: Photographs of: (a) Brick removed immediately from the mould after mechanical press; (b) Application of load by compression testing machine.

Now the bricks were needed to dry. Carry the wet Compressed Earth Block from the mould and placed carefully in the roof for sun drying. In drying process, water must be allowed to evaporate and the clay fraction to shrink. To prevent shrinkage occurring too quickly, exposure to wind and direct sun must be reduced. Drying out will take approximately 14 days. In our experiment, we conducted compressive strength for 7 days and 28 days.

Figure 3.7: Photograph of drying of CEB.

3.5.2 Specimen for slurry test:

Cement slurry was provided on CEB after completion of 28 days maturation period. Cement slurry ratio was selected as 1:2 and 1:3 and the mixing was done on weight basis.

Required ingredients are listed below:

(a) Water
(b) Bucket
(c) Towel
(d) Cement

The slurry provided brick was kept on drying again and subjected to absorption test and compressive strength test after 7 days and 28 days.

(a)

(b)

Figure 3.9: Photographs of: (a) preparation of slurry; (b) after providing slurry.

3.5.3 Specimen for plaster layer

Remaining CEB was given plastering for making improvement for absorption capacity. Ratio of cement and sand was 1:2 by volume in plastering and the thickness of plastering was 12 mm.

Required ingredients are listed below:

(a) Water
(b) Finishing spatulas
(c) Cement
(d) Sand
(e) Water

(a) (b)

Figure 3.10: Photographs of (a) mixing; (b) after plastering.

For proper curing of plastered CEB, regular watering was provided. Importantly, it is not feasible to provide water in traditional way for CEB because this will make the soil soft underneath the plaster layer. So, spraying was a better option for watering and continued for 3 days after plastering.

The plastered brick was kept on drying again and subjected to absorption test and compressive strength test after 7 days and 28 days.

Figure 3.11: Photograph of Spraying on CEB.

Figure 3.12: Photograph of Plastering on CEB.

3.6 Experimental setup

3.6.1 Compressive strength test

There is no specification on Bangladesh National Building Code (BNBC) for compressed earth block. According to the New Mexico Compressed Earth building code, the compressed earth building code shall be tested on flat position. The length of the test unit must be a minimum of twice the width. The surface must be smooth. The test shall be subjected to a uniform compressive load that is gradually increased at a rate of five hundred psi/minute until failure occurs. A true platen should be used in the testing machine, along with swivel head to accommodate non parallel bearing phase.

However, in our experiment the actual brick wad halved and the length of the test unit was almost equal to the width. The surface was smooth. The compressive strength test was subjected to a uniform compressive load that is gradually increased at a rate of 9.28 kN/s until failure occurs. Two wooden platforms were provided to accommodate non parallel bearing phase.

Figure 3.13: Photograph of specimen setup in compression testing machine.

The compressive strength is defined as P/A, where P=load and A=area of compression surface.

3.6.2 Absorption test

The absorption testing was undertaken over a 24 hour period 28 days after the bricks were constructed**.**

The following equipment was required:

(a) Source of water

(b) Water basin

No additional Risk Assessment was required because of the basic nature of the test.

As stated, the proposed method was adhered to. Additional details are as follows:

(a) The bricks were exposed to water (depth = 12.5 mm) for a period of 24 hours.

(b) The water was topped up once during this period.

(c) The Initial Rate of Water Absorption was calculated using the formulae described below :

$$C_{WS} = \frac{(M_{SO} - M_{dry}) \times 10^3}{A_s t}$$

Where,

M_{so}= mass after absorption

M_{dry}= mass of dry brick

A_s=Area of exposed surface(mm^2)

t = time(s)

C_{ws} = Initial Rate of Water Absorption. ($kg/m^2/min$)

3.7 Test plan

A summary of the proposed test is given in Table 3.4. This table describes the composition of material used in preparing the respective specimens and the intended parameters to investigate from the tests.

Table 3.1: Summary of test conducted.

Type	Test	Condition	Parameters investigated
Index property test	Liquid limit	Soil sample passing #200 sieve	Liquid limit and plasticity index
	Plastic limit	Soil sample passing #200 sieve	Plastic limit and plasticity index
	Wash sieve	Soil sample retain on #200 sieve	% of sand on certain soil sample
Moisture density	Standard Proctor test	Soil sample from SIC brick field	Optimum moisture content
Compressive strength test	Normal CEB	Sun dried brick	Compressive strength test after 7 days and 28 days
	CEB with Cement Slurry layer	Cement slurry ratio 1:2 and 1:3	Compressive strength test after 7 days and 28 days
	CEB with Plaster layer	Plaster ratio 1:2 (cement: sand)	Compressive strength test after 7 days, 21 days and 28 days
Absorption capacity test	Normal CEB	Sun dried brick	Absorption capacity
	CEB with Cement slurry layer	Cement slurry 1:2 and1:3	Absorption capacity
	CEB with Plaster layer	Plaster ratio1:2 (cement: sand)	Absorption capacity

3.8 Summary

This chapter describes experimental program. Sources and types of soil, their physical properties, i.e. optimum moisture content, Atterberg limits have been presented. Preparations of specimens, Safety and required specimens are also described briefly.

Different condition was applied to study strength behavior. Effect of slurry and plaster layer was also studied here. Compression test has been conducted on sun dried brick, brick with slurry layer, brick with plaster layer to study strength behavior.

Finally, absorption capacity test is conducted on these three conditions. Effect of plaster layer and slurry layer is studied to know the weather resistance capability of CEB. At the end of this chapter, test plan is presented in tabular form.

Chapter 4
RESULTS AND DISCUSSION

4.1 General

The physical and mechanical behaviors of compressed earth block (CEB) are compared for different combination (with and without slurry, with cement paste). This Chapter discusses the index property (LL, PL, PI), density of soil sample used in this research. Furthermore, compressive strength of CEB with different combination is also test at different ages. The compressive strength was determined to know the feasibility of partition wall from strength point of view. The absorption capacity test was conducted with a view to understand the capability to withstand against different weather. Based on findings of these tests and field observation, some simple construction guidelines for compressed earth block wall have been proposed.

4.2 Index properties of soil

Eight samples were used for this study. All the samples were collected from the brick fields of different location of Gazipur, Savar and Manikganj. The samples were collected from the soil that is used for making fired brick. The index properties of the selected soil samples are presented in Table 4.1.

Table 4.1: Index properties of collected brick field soil samples.

Source	Liquid limit	Plastic limit	Plasticity index
AUTO Brick field, Nama Genda at Savar	57	28	29
DSS Brick field, Bai maile at Gazipur	33	19	14
AUL Brick field, Bai maile at Gazipur	35	19	16
MAB Brick field, Nama Genda at Savar	39	21	18
RTB Brick field, Nama Genda at Savar	25	24	1
MSB Brick field, Nama Genda at Savar	41	18	23
ABC Brick field, Nama Genda at Savar	37	29	8
SIC Brick field, Manikgonj	43	23	20

4.2.1 Soil composition and soil classification

Soil samples that were collected were mainly clayey soil. So wet sieving was done to find out the percentage of sand. The result of wet sieving is given in Table 4.2 and the name of the soil according to USCS is given in table 4.3.

Table 4.2: Percentage of sand of collected brick field soil samples.

Source	Sand (%)
AUTO Brick field, Nama Genda at Savar	1.4
DSS Brick field, Bai maile at Gazipur	1.5
AUL Brick field, Bai maile at Gazipur	0.2
MAB Brick field, Nama Genda at Savar	4.5
RTB Brick field, Nama Genda at Savar	4.7
MSB Brick field, Nama Genda at Savar	0.4
ABC Brick field, Nama Genda at Savar	0.2
SIC Brick field, at Manikgonj	7.5

Table 4.3: USCS soil classification of collected brick field soil samples.

Source	Soil symbol
AUTO Brick field, Nama Genda at Savar	CH (Fat Clay)
DSS Brick field, Bai maile at Gazipur	CL (Lean Clay)
AUL Brick field, Bai maile at Gazipur	CL (Lean Clay)
MAB Brick field, Nama Genda at Savar	CL (Lean Clay)
RTB Brick field, Nama Genda at Savar	ML (Silt)
MSB Brick field, Nama Genda at Savar	CL (Lean Clay)
ABC Brick field, Nama Genda at Savar	ML (Silt)
SIC Brick field, Manikgonj	CL (Lean Clay)

Comparison with suitable soil composition details are given in table 4.4. The percentage of sand and plasticity index does not meet the standard range of CEB materials. With this respect, the soil composition that is used in this study is not suitable for making CEB. However, within eight soil samples, the closest soil composition compared to the standard one was selected. Details of index property is given in Appendix-A.

Table 4.4: Comparison of soil sample between suitable soil composition and

Type	Suitable soil composition for CEB	Composition of soil used in this study
Sand	25-40%	7.5%
Liquid limit	20-50	43
Plastic limit	5-25	22
Plasticity index	12-15	21

4.3 Optimum moisture content

This optimum moisture content is simple indication of amount of water content needed to mix into the soil. In this experiment, after making of each brick, soil sample was collected to measure the moisture content to know the optimum moisture content for which the brick has gained its maximum density (Figure 4.1). It is important to note that, there is always a certain range of applied load for certain moisture content of a soil sample beyond which the soil inside the mould can't be compressed anymore. This is the maximum possible applied load for certain moisture content for certain soil sample.

Optimum moisture content of the soil is determined by Standard Proctor Compaction test. The relationship between dry density and moisture content is shown in Figure 4.2. The maximum density of soil is found with 20% water content as shown in the Figure 4.2.

(a) (b)

Figure 4.1: Photographs of (a) squeezing out of soil; (b) squeeze out soil sample.

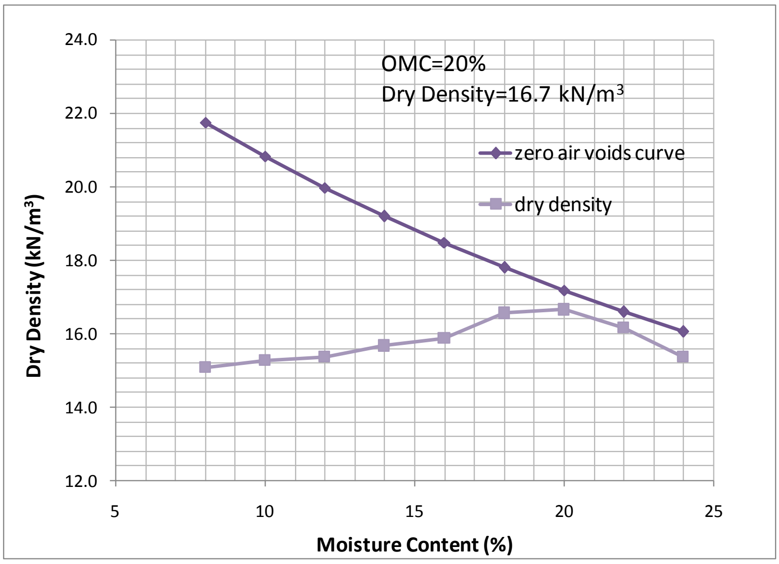

Figure 4.2: Determination of optimum moisture content by standard proctor test.

4.4 Comparison between applied load and moisture content

Moisture content is very important in making CEB. Perfectness in application of optimum moisture content ensures good quality brick. Moisture content smaller or greater than the optimum moisture content will not make the brick a perfect one. Moisture content more than optimum resulted squeeze out of soil as described earlier. Figure 4.3 shows the applied loading during making CEB with moisture content of soil during making CEB. It shows that load requirement during making CEB decreases with increasing moisture content. At low moisture content more force is required to compress the soil during making CEB while less density was achieved. Figure 4.4 shows the compressive strength of CEB and applied load during making CEB with moisture content. At low moisture content load requirement was high but compressive strength of CEB was low. At high moisture content load requirement is low and compressive strength of CEB also low. At moisture content near about 20% both compressive strength of CEB after 28 days and applied load during making CEB was found high. So, for this soil 20% moisture content which a little bit higher than optimum moisture content can be considered as suitable moisture content for making CEB.

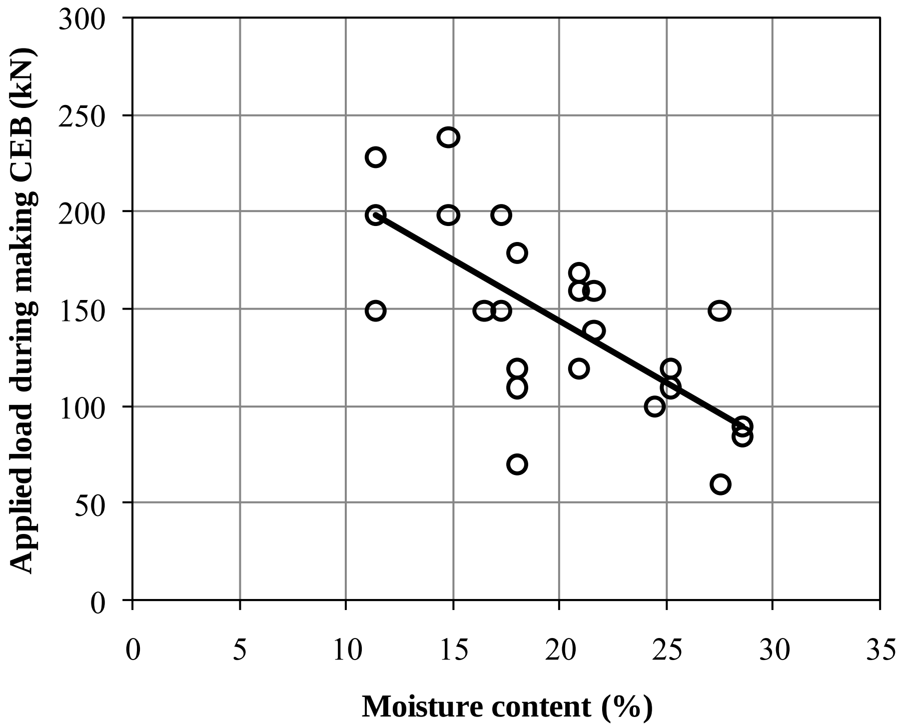

Figure 4.3: Relationship between applied load during block making and moisture content of soil.

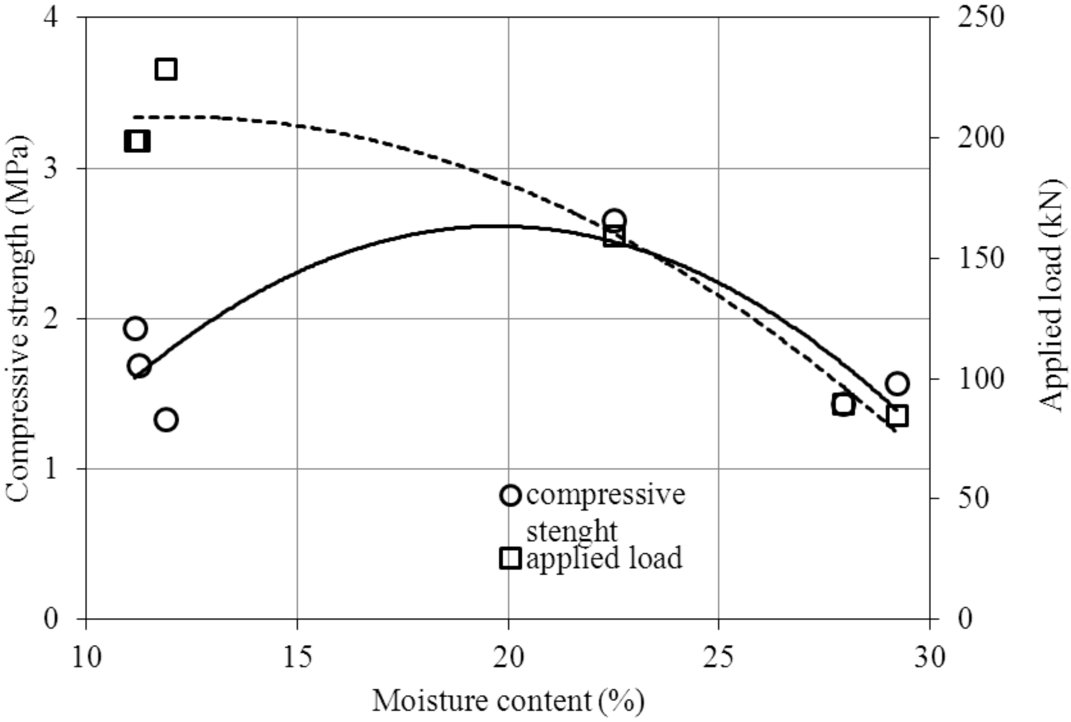

Figure 4.4: Relationship of applied load during making CEB and compressive strength of CEB at 28 days with moisture content during making CEB.

4.5 Compressive strength of CEB

4.5.1 Normal Sun Dried CEB

Compressive strength of normal sundried CEB at different test age is shown in Figure 4.5. From the graph, it can be seen that, 28 days compressive strength of CEB is 29% higher than seven days compressive strength. It is simply because of more drying at 28 days.

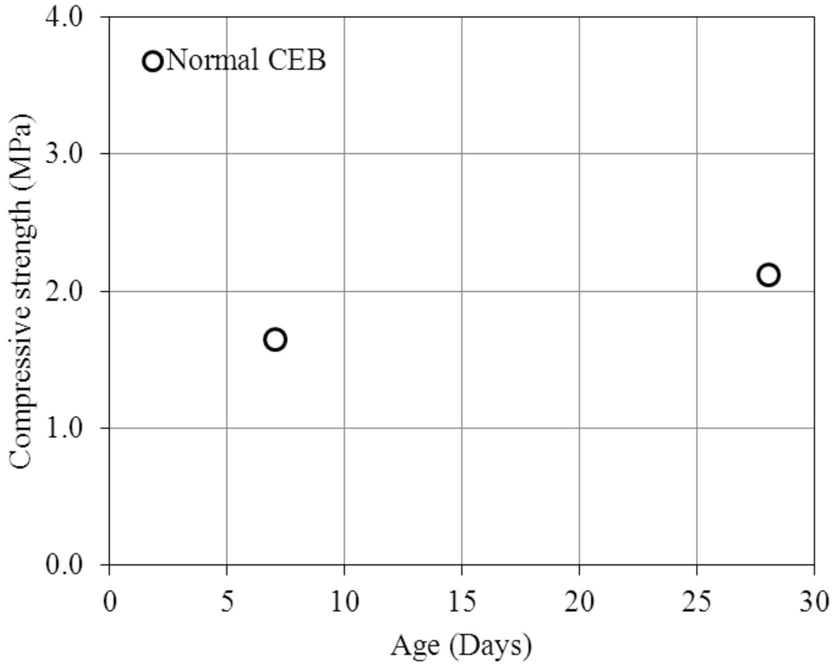

Figure 4.5: Relationship between compressive strength with time for normal CEB.

4.5.2 CEB with cement slurry layer

4.5.2.1 Slurry Ratio 1:3

Compressive strength of CEB with 1:3 (cement : water) slurry ratio at different test age is shown in Figure 4.6. CEB was dried for 28 days after making, and then the CEB was submerged to slurry and cured for 7 days and 28 days. From the graph, it can be seen that, 56 days (28 days curing) compressive strength of CEB is 14% higher than 35 days (7 days curing) compressive strength.

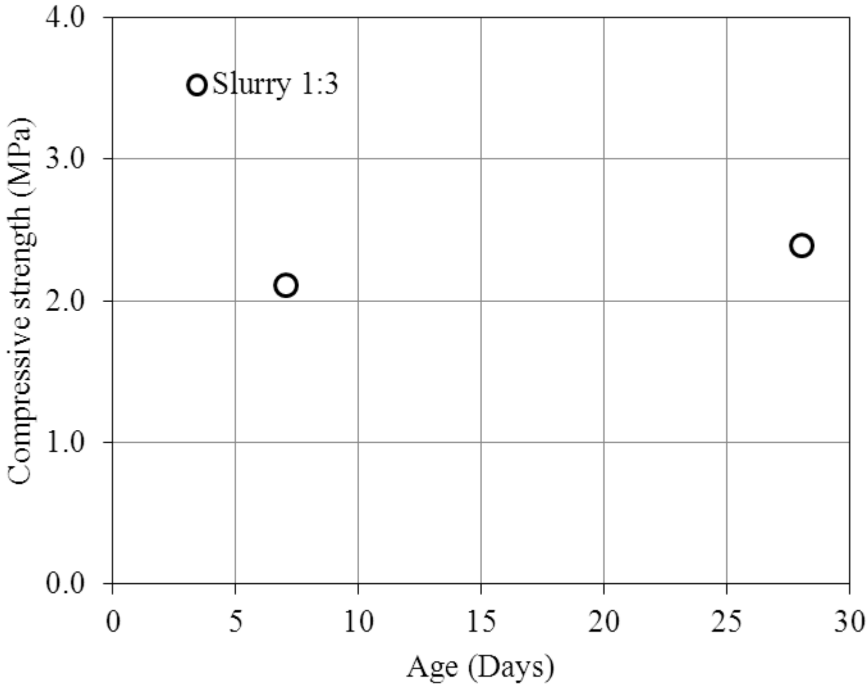

Figure 4.6: Relationship between compressive strength with time for CEB with cement slurry (1:3).

4.5.2.2 Slurry ratio 1:2

Compressive strength of CEB with 1:2 (cement : water) slurry ratio at different test age is shown in Figure 4.7. From the graph, it can be seen that, 56 days (28 days curing) compressive strength of CEB is 64% higher than 35 days (7 days curing) compressive strength.

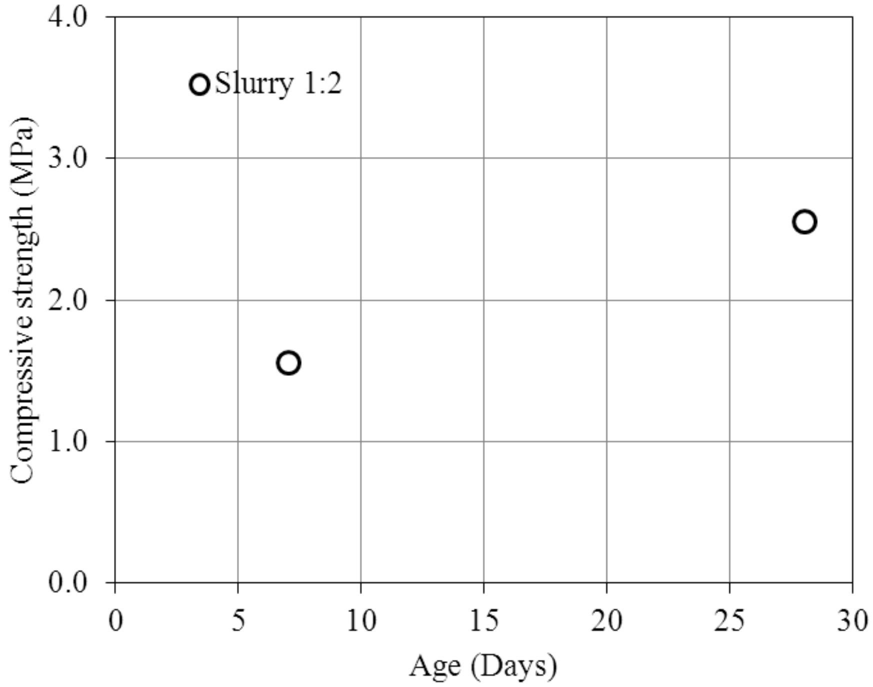

Figure 4.7: Relationship between compressive strength with time for CEB with cement slurry (1:2).

4.5.3 CEB with cement plaster layer

The compressive strength development with time is shown in Figure 4.8 for CEB with cement plaster layer. Cement plaster layer have shown same strength improvement pattern. Interestingly, water that was provided for curing purpose has leached into the soil underneath the plaster layer and made the soil soft. As a result, very much lower value of strength was observed after 7 days strength test.

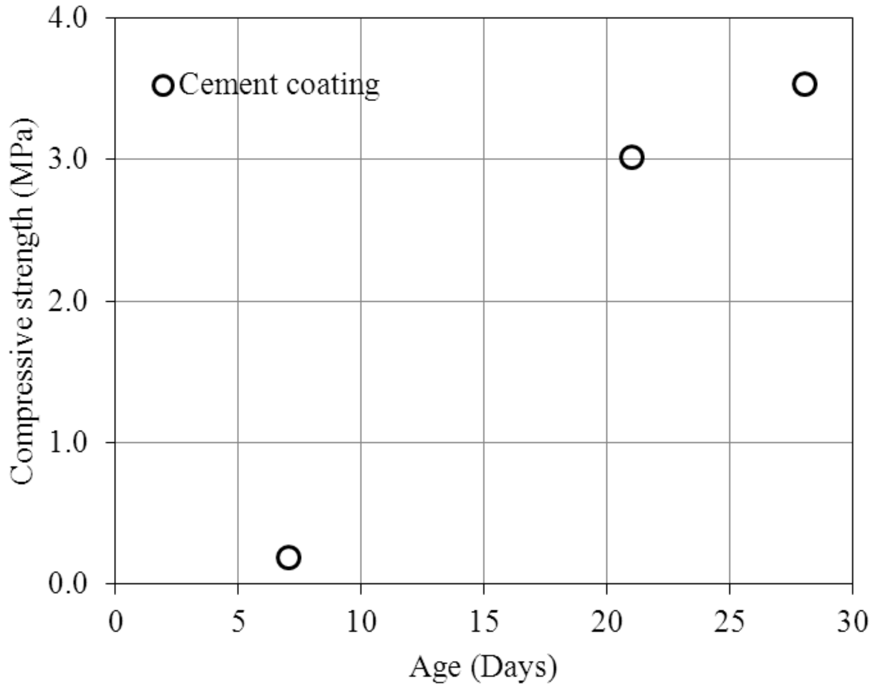

Figure 4.8: Relationship between compressive strength with time for CEB with cement coating.

4.5.4 Effect of CEB type

Normally, an improvement of compressive strength is observed treated CEB as shown in Figure 4.10. The CEB with slurry layer and cement plaster layer showed better performance compared to the normal CEB. This can be another reason of improved strength characteristics. CEB with 1:3 slurry layer, 1:2 slurry layer, and cement plaster layer showed 13%, 21%, and 66% higher compressive strength compared to normal CEB. CEB with cement layer showed best performance among all CEB.

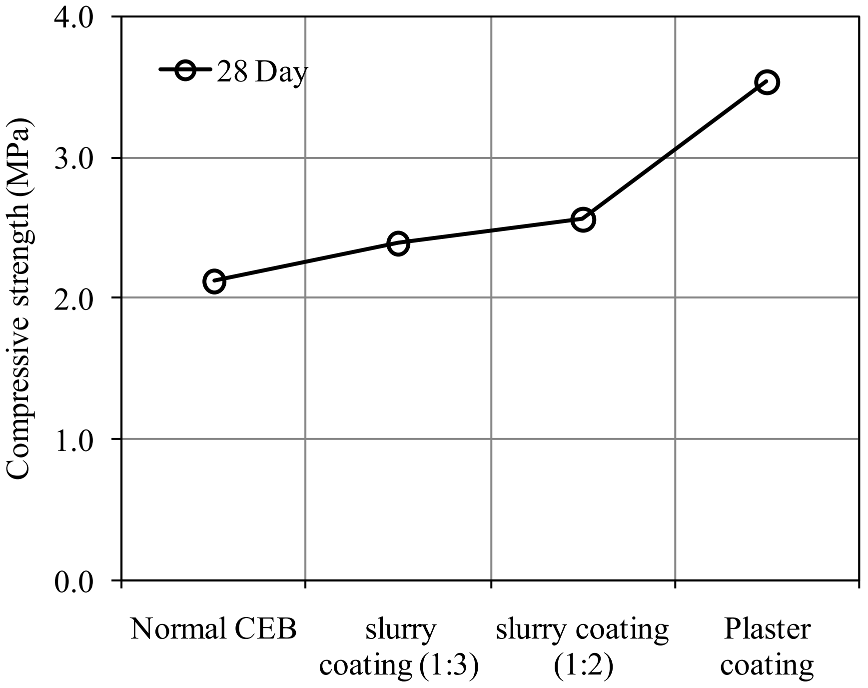

Figure 4.10: Effect of improvement type on compressive strength of CEB at 28 days after application of improvement.

4.5.5 Absorption capacity test

Most important part of the study was to find out the stability of CEB wall when exposed to water. Initially, normal sun dried CEB was kept under water for 24 hours. Figure 4.11 shows the absorption test and the condition of brick after remaining 24 hours under water. From the figure, it is clear that all the bricks washed away after 24 hours submergence beneath the water. So, to improve the absorption capacity cement slurry with 1:2 and 1:3 ratio was provided. Then, these bricks with slurry layer were also kept under water for 24 hours. Figure 4.12 shows the absorption test and the condition of CEB brick with slurry layer after remaining 24 hours under water. No improvement was observed compare to normal CEB in our absorption capacity test. Only a thin slurry layer remains at the top and the remaining soil washed away. So, CEB with slurry layer has no impact in improving weather resistant efficacy. Further effort to improve the absorption capacity was to provide 12.5 mm plaster layer over the brick with a ratio of 1:2(cement: sand). Again, the brick was kept under the water for 24 hours. Figure 4.13 shows the absorption test of CEB with plaster layer. Better performance is observed when cement paste is provided.

Figure 4.11: Photographs of (a) CEB under water; (b) after 24 hours.

Figure 4.12: Photograph of CEB with slurry after 24 hours submergence under water.

Figure 4.13: Photograph of CEB brick with plaster layer is under water.

A good improvement was observed in absorption capacity but ultimate result was same. Through the pores of plaster layer, water entered into the brick and softened the soil underneath the plaster layer. As a result, after 24 hours submergence, these bricks also washed away. But very small amount of soil was washed away comparing to normal CEB and CEB with slurry layer. Figure 4.14 and 4.15 shows the condition of plastered CEB after 24 hour submergence under water. From the figure, it is observed that the plaster layer still existing after 24 hours submergence and that is why amount of soil washed away was very small.

Figure 4.14: Plaster layer existing after 24 hours submergence under water.

Figure 4.15: Photograph of CEB after absorption test.

Chapter 5

CONCLUSION AND RECOMMENDATION

5.1 General

This study aimed to find low-cost solution to partition wall construction in RCC frame structure building. Various traditional brick fields were visited and soil samples were collected from those brick fields to find the suitable soil sample for CEB.

Again, within the soil samples, which have closest soil composition, compared to the suitable soil composition for CEB was chosen for laboratory test. For this purpose index property tests and wet sieving test was conducted.

After choosing soil sample, standard proctor test was performed to know the required amount of water needed to add with the soil sample for maximum densification. Compressive strength test was performed after 7 days and 28 days of drying period. Absorption test was performed after 7 days and 28 days counting from the application of coating by cement slurry or cement plaster.

5.2 Conclusions

Following conclusions were made from this experimental study on Compressed Earth Block.

i. CEB is feasible for using as interior wall but not as external wall in flood prone areas.
ii. Cement slurry coating could not reduce absorption capacity of CEB.
iii. Cement plaster coating has very little use in case of reducing absorption capacity of CEB.
iv. Soil composition used for making fired brick in Bangladesh is not suitable for making CEB because of presence of very low percentage of sand.
v. There is a certain value of moisture content for which CEB has gained its maximum compressive strength.
vi. There is a certain value of moisture content for which maximum compaction of soil block can be achieved.

5.3 Scopes for further study

The following list outlines some recommended topics for further research. This is not an exhaustive list and there are many more variables that could be adjusted or amended. The topics detailed here are those which have become obvious avenues of exploration after the research undertaken during this project; there are countless others involving compressed earth blocks in general and other sustainable construction materials. The research work has given birth to certain research interest for future. Those are listed below.

(a) More Extensive Testing

Due to time constraints the sample size considered in this report was very small. Indeed, it was the smallest possible sample size that allows useful comparison. There is scope to increase the number of bricks tested, the variations in mix composition, the number of stabilizers tested and different curing conditions.

(b) Chemical changes

Detailed research into the chemical reactions that take place during cementation would be useful. There has been some research already undertaken in this area but there is still scope to clarify the chemistry that occurs when using alternative stabilizers. The results may drive a consistent approach to mix compositions that could be implemented in a practical environment.

(c) Testing on bricks made with a Press

Perhaps the most limiting factor in this study is that the bricks tested were hand-made and not made using a Magika press (or similar). This is likely to have an effect on the uniformity of the shape, the chemical structure and, ultimately, on the performance of the bricks.

(d) Alternative methods of stabilization for CEB

There are many other methods for stabilizing the CEB. Stabilizing is needed when the material is going to be exposed: bad design, failing to take account of the fundamental principles of building with earth, or location constraints: a damp site or walls exposed to driving rain, flood prone areas for example. Several option of stabilizing CEB is listed below:

1) Reinforcing
2) Cementation
3) Bonding by forming inert matrix
4) Water proofing by material which is not water-sensitive

(e) Dynamic property

Due to limitation of scope, this research work was confined into investigation of static properties only. But analysis of dynamic properties is also equally important in this field.

(f) Dynamic test

Dynamic test like Shake Table test of full scale model and simultaneous numerical analysis will provide important information in this regard.

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APPENDIX A: ATTERBERG TEST

DATA: A.B.C brick

LIQUID LIMIT

sample no	1	2	3	4	5
can no	131	763	762	202	888
mass of can	7.4	7	7.8	7.6	7.1
can+wet siol	17	27.9	20.9	19.6	21.5
can+dry soil	14.5	22.5	17.6	16.1	17.8
mass of soil solid, Ws	7.1	15.5	9.8	8.5	10.7
mass of pore water,Ww	2.5	5.4	3.3	3.5	3.7
water content, w%	35	35	34	41	35
no of drops	20	25	36	15	40

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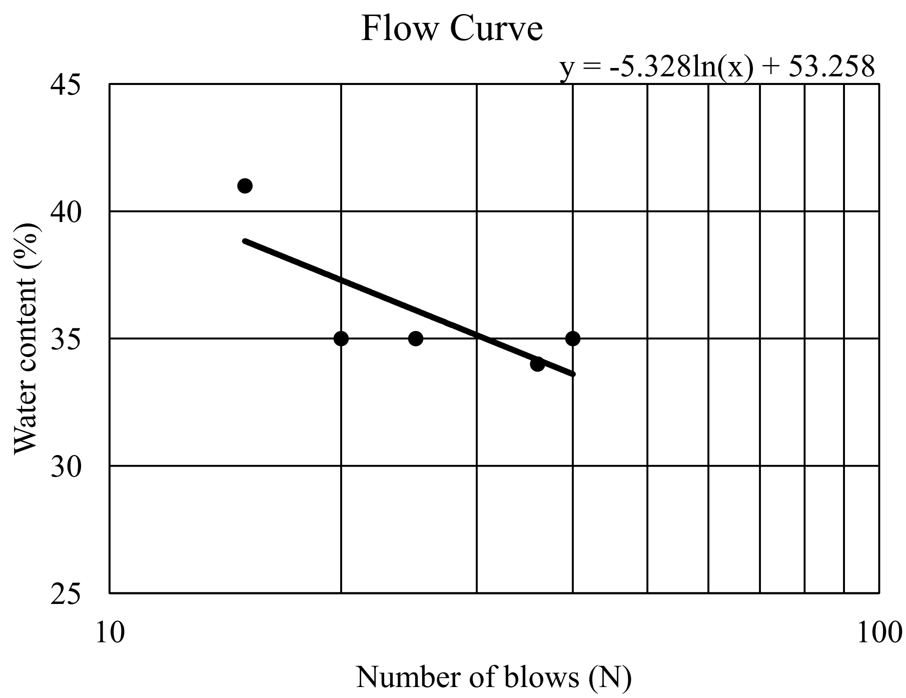
GRAPH:



LIQUID LIMIT=37

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DATA: A.B.C

PLASTIC LIMIT

sample no	1	2	3
can no	200	300	753
mass of can	7.3	7	7.9
can+wet siol	18.7	22.3	23.5
can+dry soil	16.1	19	20
mass of soil solid,Ws	8.8	12	12.1
mass of pore water,Ww	2.6	3.3	3.5
water content,w%	29	27	28
plastic limit	28		

PLASTIC LIMIT=29

PLASTICITY INDEX=8

SOIL NAME= CL

From wash sieve analysis percentage of sand in sample soil= 0.2%

`

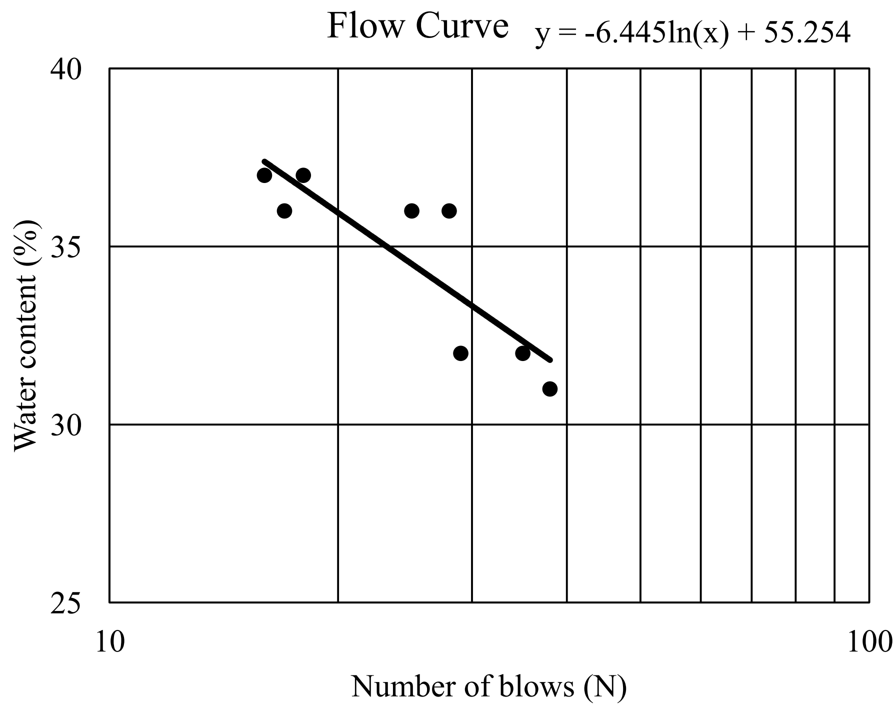
DATA: AUL brick

LIQUID LIMIT

sample no	1	2	3	4	5	6	7	8
can no	17	835	822	34	48	8	753	763
mass of can	7.1	7.1	7.8	7.3	6.8	7.2	7.8	7
can+wet siol	28.2	23.1	22.9	25	20	21.2	21.2	22.8
can+dry soil	23.1	19.3	19.2	20.3	16.5	17.5	17.6	18.5
mass of soil solid,Ws	16	12.2	11.4	13	9.7	10.3	9.8	11.5
mass of pore water,Ww	5.1	3.8	3.7	4.7	3.5	3.7	3.6	4.3
water content,w%	32	31	32	36	36	36	37	37
no of drops	35	38	29	25	28	17	16	18

`

GRAPH:



LIQUID LIMIT=35

`

DATA: AUL

PLASTIC LIMIT

sample no	1	2	3
can no	131	200	886
mass of can	7.3	7.3	7.7
can+wetsiol	26.8	29.4	35.5
can+dry soil	23.7	25.8	30.9
mass of soil solid,Ws	16.4	18.5	23.2
mass of pore water,Ww	3.1	3.6	4.6
water content,w%	18	19	20
plastic limit	19		

PLASTIC LIMIT=19

PLASTICITY INDEX=16

SOIL SYMBOL=CL

SOIL NAME=Lean clay

Percentage of sand in soil sample from wash sieve=0.2%

`

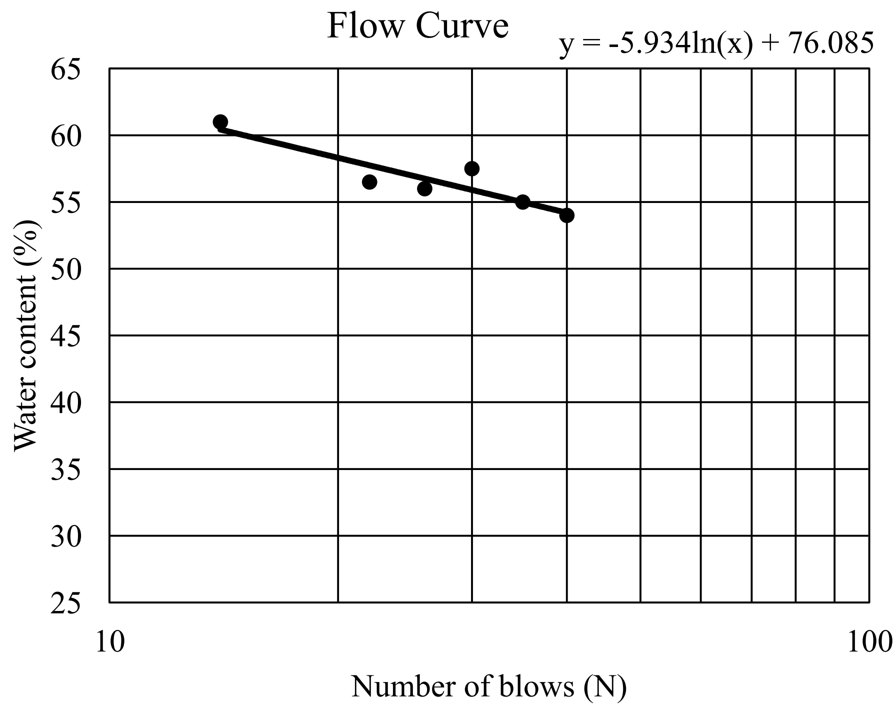
DATA: AUTO brick

LIQUID LIMIT

can no	782	59	901	859	409	857
mass of can	6.9	7.3	7.7	7.1	7.3	7.1
can+wet siol	26	23.2	25.5	25.1	21.5	30.3
can+dry soil	19.1	17.5	19	18.7	16.5	21.5
mass of soil solid,Ws	12.2	10.2	11.3	11.6	9.2	14.4
mass of pore water,Ww	6.9	5.7	6.5	6.4	5	8.8
water content,w %	56.5	56	57.5	55	54	61
no of drops	22	26	30	35	40	14

`

GRAPH:



LIQUID LIMIT=57

`

DATA: AUTO

PLASTIC LIMIT

sample no	1	2	3
can no	7	162	7
mass of can	7.2	7	7
can+wet siol	17.8	19.2	20.5
can+dry soil	15.5	16.5	17.5
mass of soil solid,Ws	8.3	9.5	10.5
mass of pore water,Ww	2.3	2.7	3
water content,w%	28	28	29
plastic limit	28		

PLASTIC LIMIT=28

PLASTICITY INDEX=29

SOIL SYMBOL=Fat clay

Percentage of sand in soil sample from wash sieve=1.4%

`

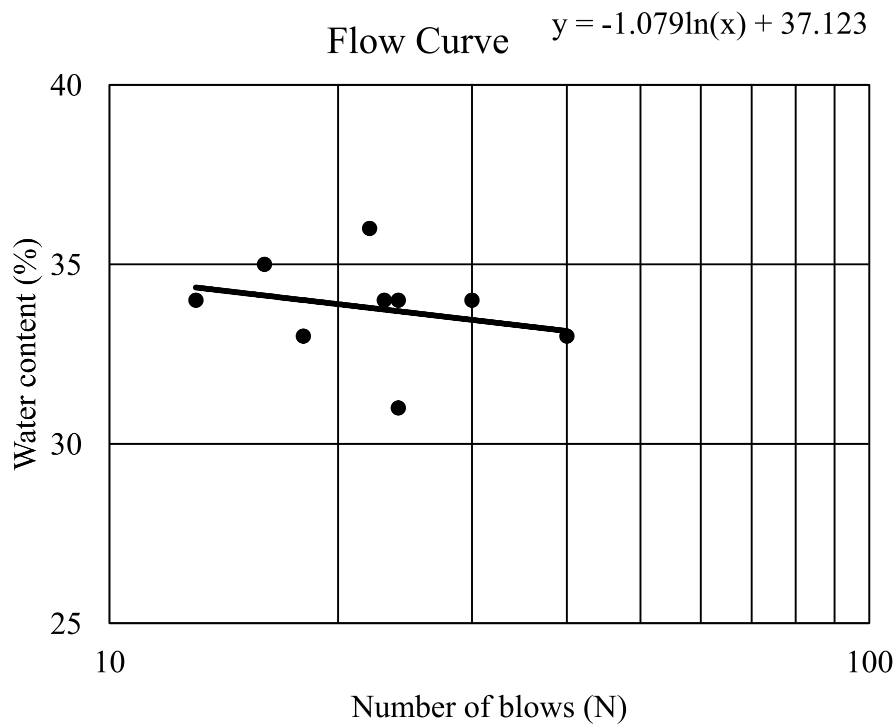
DATA: DSS

LIQUID LIMIT

sample no	1	2	3	4	5	6	7	8	9
can no	14	203	403	853	885	604	847	717	185
mass of can	6.9	6.2	6.7	6.8	7.2	11	11.1	7.2	7.3
can+wet siol	20	18.8	16.9	22.2	22.8	22.4	21.8	20.4	20.2
can+dry soil	16.7	15.7	14.5	18.4	18.8	19.4	19.1	17	16.9
mass of soil solid,Ws	9.8	9.5	7.8	11.6	11.6	8.4	8	9.8	9.6
mass of pore water,Ww	3.3	3.1	2.4	3.8	4	3	2.7	3.4	3.3
water content,w%	34	33	31	33	34	36	34	35	34
no of drops	30	40	24	18	24	22	23	16	13

`

GRAPH:



LIQUID LIMIT=33

`

DATA: DSS

PLASTIC LIMIT

sample no	1	2	3
can no	850	880	175
mass of can	6.9	10.7	7.3
can+wetsiol	25.3	24.4	23.8
can+dry soil	22.4	22.2	21.1
mass of soil solid,Ws	15.5	11.5	13.8
mass of pore water,Ww	2.9	2.2	2.7
water content,w%	19	19	20
plastic limit	19		

PLASTIC LIMIT=19

PLASTICITY INDEX=14

SOIL SYMBOL=CL

SOIL NAME=Lean Clay

From wash sieve analysis percentage of sand in sample soil=1.5%

`

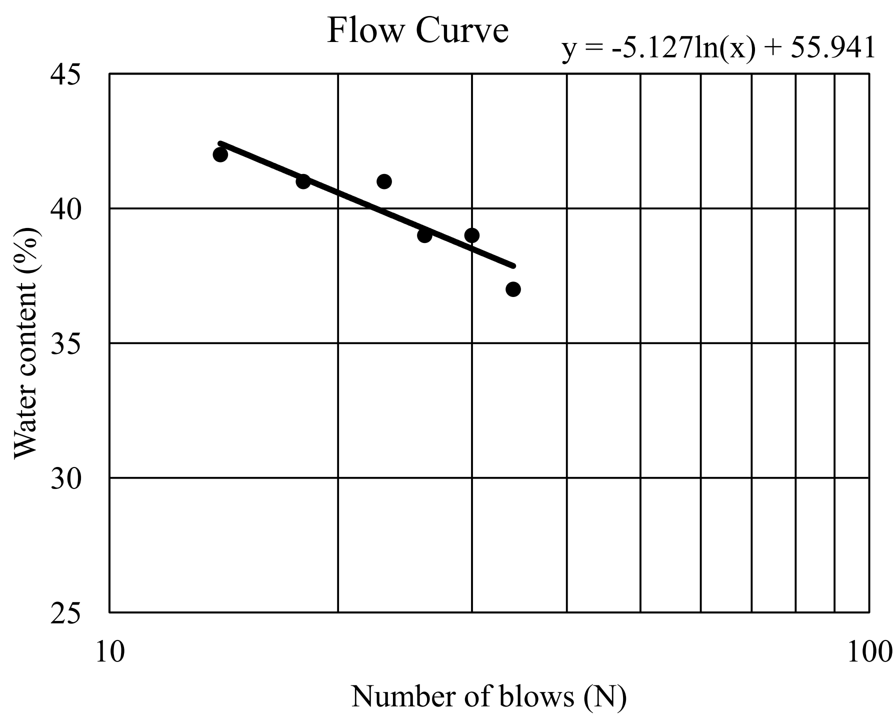
DATA: MAB

LIQUID LIMIT

sample no	1	2	3	4	5	6	7
can no	703	804	805	774	77	14	18
mass of can	7.1	6.9	6.8	7.1	7.6	7.3	7.2
can+wetsiol	23.9	23.2	20	19.7	23.9	28.8	23.6
can+dry soil	19	18.6	16.3	16.3	19.3	22.4	18.8
mass of soil solid,Ws	11.9	11.7	9.5	9.2	11.7	15.1	11.6
mass of pore water,Ww	4.9	4.6	3.7	3.4	4.6	6.4	4.8
water content,w%	41	39	39	37		42	41
no of drops	23	26	30	34		14	18

`

GRAPH:



LIQUID LIMIT=39

`

DATA: MAB

PLASTIC LIMIT

sample no	1	2	3
can no	773	129	837
mass of can	6.8	7.2	6.9
can+wet siol	18.6	22.5	22.2
can+dry soil	16.6	19.7	19.5
mass of soil solid,Ws	9.8	12.5	12.6
mass of pore water,Ww	2	2.8	2.7
water content,w%	20	22	21
plastic limit	21		

PLASTIC LIMIT=21

PLASTICITY INDEX=18

SOIL SYMBOL=CL

SOIL NAME=Lean Clay

Percentage of sand in soil sample from wash sieve=4.5%

`

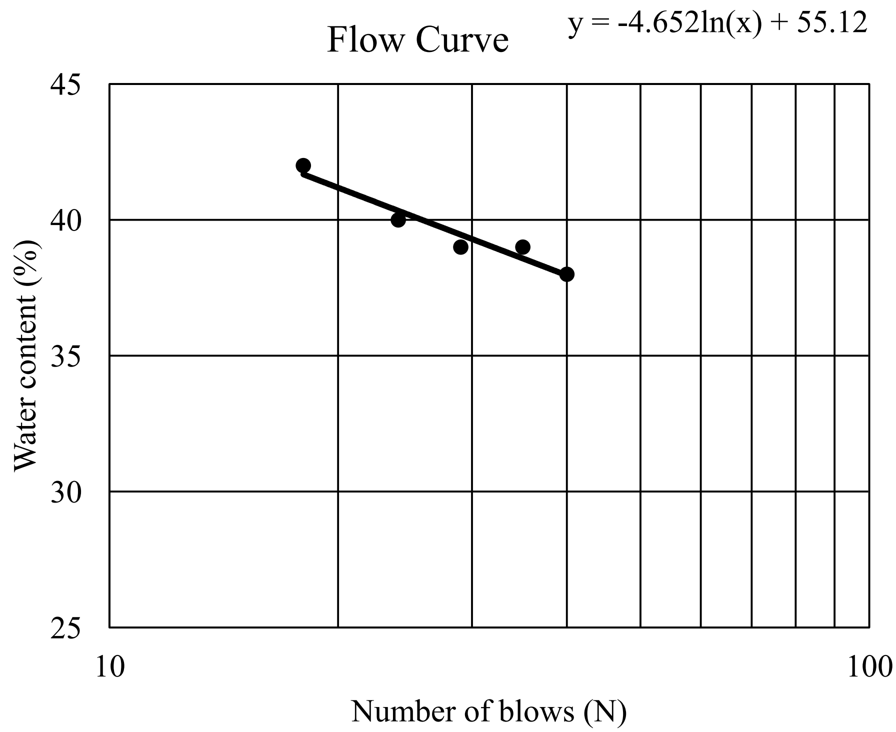
DATA: MSB

LIQUID LIMIT

sample no	1	2	3	4	5
can no	907	152	707	44	11
mass of can	7.5	6.9	7.3	7.9	11
can+wet siol	27.3	25.7	27.1	23.6	30.7
can+dry soil	21.4	20.3	21.5	19.2	25.3
mass of soil solid,Ws	13.9	13.4	14.2	11.3	14.3
mass of pore water,Ww	5.9	5.4	5.6	4.4	5.4
water content,w%	42	40	39	39	38
no of drops	18	24	29	35	40

`

GRAPH:



LIQUID LIMIT=41

`

DATA: MSB

PLASTIC LIMIT

sample no	1	2
can no	100	785
mass of can	7.5	7.4
can+wet siol	23.5	26
can+dry soil	21	23.1
mass of soil solid,Ws	13.5	15.7
mass of pore water,Ww	2.5	2.9
water content,w%	19	18
plastic limit	18	

PLASTIC LIMIT=18

PLASTICITY INDEX=23

SOIL SYMBOL=CL

SOIL NAME= Lean Clay

Percentage of sand in soil sample from wash sieve=0.4%

`

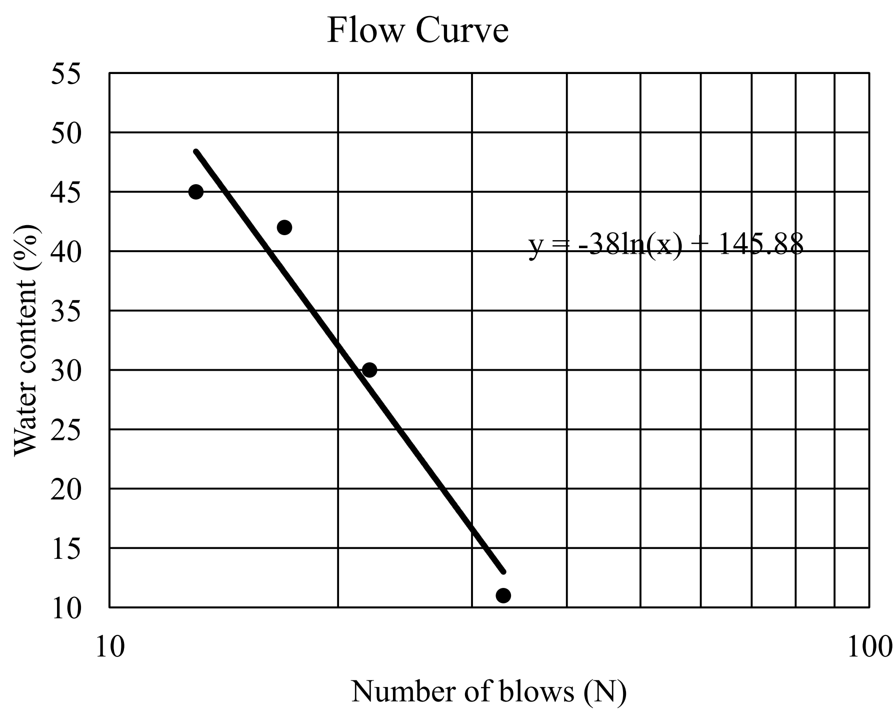
DATA: RTB

LIQUID LIMIT

sample no	1	2	3	4
can no	9019	603	122	50
mass of can	7.4	7.3	7.5	6.9
can+wet siol	19.9	19.3	22	20.8
can+dry soil	18.7	16.5	17.7	16.5
mass of soil solid,Ws	11.3	9.2	10.2	9.6
mass of pore water,Ww	1.2	2.8	4.3	4.3
water content,w%	11	30	42	45
no of drops	33	22	17	13

`

GRAPH:



LIQUID LIMIT=25

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DATA: RTB

PLASTIC LIMIT

sample no	1	2	3
can no	879	14	9
mass of can	7.2	7.2	7.7
can+wet siol	19.9	22.5	19.8
can+dry soil	17.4	19.5	17.4
mass of soil solid,Ws	10.2	12.3	9.7
mass of pore water,Ww	2.5	3	2.4
water content,w%	24.5	24	25
plastic limit	25		

PLASTIC LIMIT=24

PLASTICITY INDEX=1

SOIL SYMBLE=CL

SOIL NAME= Lean Clay

From wash sieve analysis percentage of sand in sample soil= 4.7%

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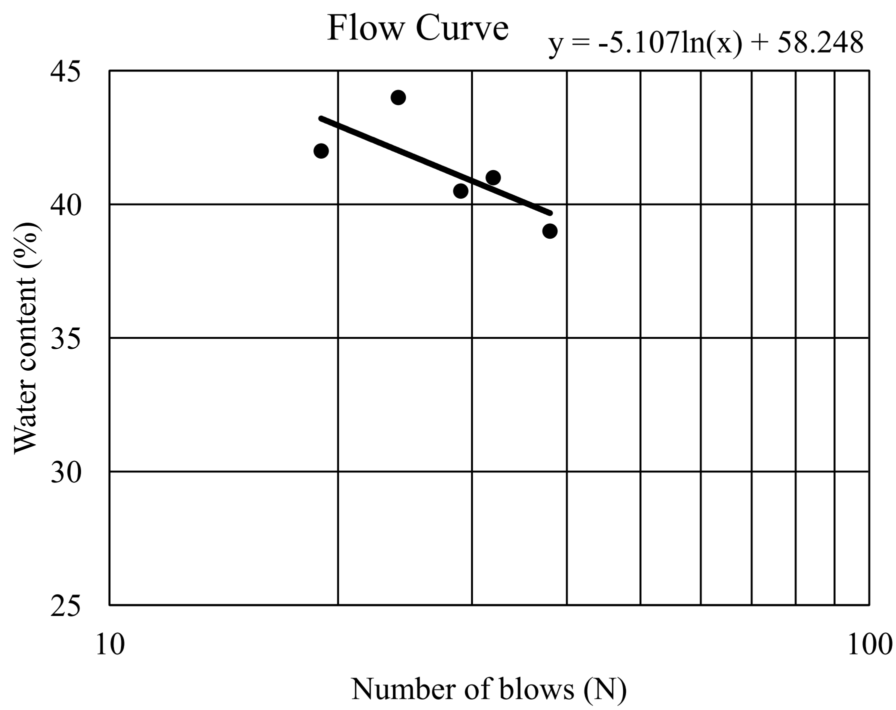
DATA: SIC

LIQUID LIMIT

sample no	1	2	3	4	5
can no	206	206	886	9014	888
mass of can	7.1	6.4	7.6	7.3	7.1
can+wetsiol	24.4	21.9	25.3	23.4	22
can+dry soil	19.1	17.4	20.3	18.6	17.7
mass of soil solid,Ws	12	11	12.7	11.3	10.6
mass of pore Water,Ww	5.3	4.5	5	4.8	4.3
water content,w%	44	41	39	42	40.5
no of drops	24	32	38	19	29

`

GRAPH:



LIQUID LIMIT=43

`

DATA: SIC

PLASTIC LIMIT

sample no	1	2
can no	14	162
mass of can	7	7.5
can+wet siol	22.4	19.4
can+dry soil	19.4	17.3
mass of soil solid,Ws	12.4	9.8
mass of pore water,Ww	3	2.1
water content,w%	24	21
plastic limit	22.8	

PLASTIC LIMIT=23

PLASTICITY INDEX=20

SOIL SYMBOL=CL

SOIL NAME=Lean clay

Percentage of sand in soil sample from wash sieve=7.5%

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compacted-soil sample	8% top	8%bottom	10 % top	10% bottom	12 % top	12% bottom	14 % top	14% bottom	16 %top	16% bottom	18 % top	18% bottom	20 % top	20% bottom	22 % top	22% bottom	24 % top	24% bottom
water content-sample no	601	717	77	745	14	847	28	714	168	211	168	54	8	23	50	776	131	800
wt. of can (gm)	7.7	7.2	7.7	7.4	7.1	11.1	7.5	6.9	7	7.2	7	7	7.2	6.9	11	7.7	7.3	6.4
wt. of can+wet soil(gm)	11.5	14.1	12.1	12.1	15.2	17.2	22.6	18.4	21.6	20.5	17.1	21.6	21.1	23.5	28	31.3	34.9	28.9
wt. of can+dr soil(gm)	11.2	13.8	11.7	11.9	14.5	16.6	21.1	17.1	19.9	19	15.9	19.9	19.1	20.8	24.9	27.4	29.9	24.2
wt. of water(gm)	0.3	0.3	0.4	0.2	0.7	0.6	1.5	1.3	1.7	1.5	1.2	1.7	2	2.7	3.1	3.9	5	4.7
mass of dry soil(gm)	3.5	6.6	4	4.5	7.4	5.5	13.6	10.2	12.9	11.8	8.9	12.9	11.9	13.9	13.9	19.7	22.6	17.8
moisture content%	8.57	4.55	10.00	4.44	9.46	10.91	11.03	12.75	13.18	12.71	13.48	13.18	16.81	19.42	22.30	19.80	22.12	26.40

Mold volume=944 cm^3

G_s=2.7(assumed)

P_w=1 gm/cm^3l

Assumed water content, w%	8	10	12	14	16	18	20	22	24
Actual average water content, w%	6.56	7.22	10.18	11.89	12.945079	13.33	18.12	21.05	24.26
Mass of compacted soil and mold(gm)	5730	5760	5810	5870	5910	5990	6070	6070	6020
Mass of mold (gm)	4180	4180	4180	4180	4180	4180	4180	4180	4180
Wet mass of soil in mold (gm)	1550	1580	1630	1690	1730	1810	1890	1890	1840
Wet density, p , (g/cm^3)	1.64	1.67	1.73	1.79	1.83	1.92	2.00	2.00	1.95
Dry density, pd, (g/cm^3)	1.54	1.56	1.57	1.60	1.62	1.69	1.70	1.65	1.57
calculated , pd (g/cm^3)	2.22	2.126	2.039	1.96	1.885	1.817	1.753	1.694	1.638

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No	date	Load(ton)	Avg. Moisture content (%)
1	23-12-13	15	27.53
2	8-1-14	6	27.54
3	11-1-14	12	25.67
4	11-1-14	12	25.67
5	12-1-14	11	22.23
6	12-1-14	11	22.23
7	15-1-14	15	16.5
8	15-1-14	15	16.5
9	18-1-14	8.5	28.58
10	18-1-14	9	28.58
11	19-1-14	9	15.5
12	19-1-14	10	15.5
13	20-1-14	16	21.64
14	20-1-14	14	21.64
15	21-1-14	20	17.31
16	21-1-14	15	17.31
17	22-1-14	11	25.22
18	22-1-14	11	25.22
19	22-1-14	11	25.22
20	22-1-14	12	25.22
21	25-1-14	17	20.96
22	25-1-14	12	20.96
23	25-1-14	12	20.96

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No	date	Load(ton)	Avg. Moisture content (%)
24	25-1-14	16	20.96
25	26-1-14	7	18.05
26	26-1-14	11	18.05
27	26-1-14	12	18.05
28	26-1-14	18	18.05
29	27-1-14	15	11.42
30	27-1-14	23	11.42
31	27-1-14	20	11.42
32	29-1-14	20	14.80
33	29-1-14	32	14.80
34	29-1-14	20	14.80
35	29-1-14	24	14.80

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APPENDIX D: COMPRESSIVE STRENGTH OF BRICK

Compressive stress of sun dried CEB	7 days(psi)	28 days(psi)
	192.85	343.33
	281.80	320.71
	244.69	258.10

Compressive stress of CEB with slurry layer(1:2)	7 days(psi)	28 days(psi)
	227.69	335.87
	207.60	520.47
	244.69	258.10

Compressive stress of CEB with slurry layer(1:3)	7 days(psi)	28 days(psi)
	252.76	298.09
	321.88	218.91
	343.33	

Compressive stress of CEB with plaster layer	7 days(psi)	21 days(psi)	28 days(psi)
	39.90	385.13	483.02
	20.34	509.18	492.31
	23.2	644.58	337.88