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APPLICATION OF LOAD BEARING BRICK WALL FOR LOW RISE CONDOMINIUM PROJECTS IN ETHIOPIA AND ASSESSMENT OF LOCALLY PRODUCED BRICKS

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A Thesis submitted to The Department of Civil Engineering Presented in partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Construction Technology and Management)

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The undersigned have examined the thesis entitled '**Application of Load Bearing Brick Wall for Condominium Projects in Ethiopia and Assessment of Locally Produced Bricks**' presented by **BETELHEM BAYOU**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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Abstract

Bricks are one of the oldest building materials in construction. Application of bricks in construction of Ethiopia is not new. They are used for construction of internal and external walls in all over the country. Once more brick is commonly used building material; however, there is a tendency to use brick masonry more as cladding and in-fill material rather than as a structural material.

In order to solve the housing problem in Ethiopia, saving-house condominium projects, real-estates, and private residential buildings have been constructed in many regions of Ethiopia for the past decades, there is also a bigger plan set by the government for the next GTP. From the past experience of building projects, wastage of materials, unsafe construction process, poor quality of output, high time and cost overrun, and risk of failure due to structural errors and mistakes made during construction process have been observed.

The objective of this study is to assess locally produced bricks quality and availability to recommend a load bearing brick wall construction for low rise residential building and compare the cost with concrete frame structure building of the same plan, form and story.

Over centuries, the utilization of bricks in construction has evolved significantly. In developed nations, bricks have emerged as the primary load-bearing system for various types of buildings, spanning from modest single-story residences to relatively tall commercial and industrial structures. Extensive analysis conducted on developed countries showcases the cost-related benefits of employing bricks. Additionally, brick walls exhibit excellent thermal insulating properties, leading to reduced fuel consumption and manufacturing energy expenditure.

The analysis establishes that a three-story load bearing building can be built from locally produced fired clay bricks. There is also overall saving in both materials and cost when using load bearing structure instead of reinforced concrete of the same selected apartment building. The encouragement of the load bearing structure will result in the establishing number of modern factories for brick and clay product in Ethiopia.

Key Words: Brick, Load Bearing structure, RC framed Structure, Compressive Strength, Cost Estimate, Housing and Condominium

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CHAPTER ONE: Introduction

Brick is commonly used building material; however, here in Ethiopia there is a tendency to use brick masonry more as cladding and in-fill material rather than as a structural material.The application of bricks in construction has been advanced for centuries and in developed countries it has been used as the principal load bearing system for buildings, ranging from small single-story housing to fairly tall commercial and industrial buildings. A load-bearing wall is a wall that bears a load resting upon it and transfer the load to a foundation structure. The materials most often used to construct load-bearing walls in large buildings are concrete, block, stone, and brick [1].

Load bearing wall structure is used for many reasons including cost and availability [2]. The economic success of brickwork construction has been achieved not only by the rationalization of structural design, but also because it is possible for the walls which comprise a brick building structure to perform several functions, such as thermal and acoustic insulation, fire and weather protection, as well as sub-division of space. As a building material, it is relatively cheap and durable, can provide virtually infinite flexibility in plan form and offer an attractive external appearance.

Europe, USA and Australia contain many examples of load-bearing brick structures built in the early and mid-nineteenth century that are still in daily use despite more than a century and a half of exposure to damp and aggressive industrial atmospheres. The brick arch bridges, viaducts, tunnel linings and retaining walls of the early railway system provide examples of the excellent durability of load-bearing brick structures under the most adverse service conditions. Clay brick is one of the oldest building materials in construction. It is produced from the readily available clay soil and water on earth. At high firing temperature, the mixed and shaped clay material is irreversibly converted into a solid, hard and durable material which makes it a timeless and classic prefabricated building element [3].

Bricks are produced in numerous classes, types, materials, and sizes which vary with region and time period, and are produced in bulk quantities. For over 6000 years' brick has been used as main construction material all over the world.

However, there is no past study made about load bearing brick wall housing construction in Ethiopia. Therefore, before proposing such technology to our country, assessing its applicability with regarding to availability and quality of locally produced bricks and its cost is of prime necessity. Studies showed that it has been repetitively stated by practitioners that the quality of bricks produced these days is much inferior to those produced about 30-40 years ago [4]. Also, studies made show that brick, being one of the oldest building materials has untapped potential in Ethiopia construction industry.

Thus, in this research the application of load bearing brick wall is proposed as a solution for housing problems in Ethiopia by providing an alternative structural material for low rise buildings located in earthquake free zones or areas. But most importantly, it is aimed to examine and prove if it is cost effective as compared to the current reinforced concrete building construction methodology. The research will also benefit the application of brick material as a more versatile technology which will also initiate better production and also business plans.

1.2 Statement of the Problem

Housing is one of the prime necessities of human life. Saving-house condominium projects, real-estates, and private residential buildings have been constructed in many regions of Ethiopia for the past decades. In the next phase of the GTP (2015/16- 2020/21), the Ethiopian government is planning to build 2.45 million residential houses in both urban and rural areas to solve housing shortage problem [5]. From the past experience of building projects, wastage of materials, unsafe construction process, poor quality of output, high time and cost overrun, and risk of failure due to structural errors and mistakes made during construction process has been observed. For the planned major projects ahead of us there is no way we could achieve the goal without the use of any alternative building material and technology.

1.3 Objective of the Study

- Review the overall brick production process and studying the material property of locally produced bricks for the required construction purposes.
- Propose a load bearing brick wall construction for low rise condominium building and compare the cost with concrete frame structure building of the same plan, form and story.

1.4 Scope of the Work

The scope of the work includes:

A) To study and establish the load bearing capacity of bricks produces at brick selected factories.

B) Prepare a preliminary design for a suitable loadbearing apartment building similar to a concrete frame structure-based apartment building of the same story height, area and function. Specific project for this study is a G+2 10/90 saving house building, and assumptions made during design are discussed under Chapter Four of this thesis.

C) Compare the cost of the two types of construction method in relation to the overall cost of the buildings and their component. Estimating method selected, and carryout cost analysis and comparison are discussed under Chapter Five of this thesis.

CHAPTER 2: Literature Review

2.1. The History and Development of Load Bearing Masonry Buildings

Load bearing masonry construction was the most widely used form of construction for large buildings from the 1700s to the mid-1900s. It is very rarely used today for large buildings, but smaller residential-scale structures are still being built. It essentially consists of thick, heavy masonry walls of brick or stone that support the entire structure, including the horizontal floor slabs, which could be made of reinforced concrete, wood, or steel members [11].

In contrast, most construction today is not load-bearing masonry but frame structures of light but strong materials that support floor slabs and have very thin and light internal and external walls.

In traditional European load bearing masonry structures, the floor slabs were made of horizontal wooden beams, joists, and planks. A joist is a smaller wooden beam that rests on two larger beams [6].

Figure 2-1: Han well railway viaduct, a brick arch structure [10]

Source: https://commons.wikimedia.org/wiki/File:The Wharncliffe Railway Viaduct in Hanwell

Americans then comes up the with the super sized Mondadnock Tower, a 16-storey office building built in 1893 in Chicago. It was made of brick walls 6 feet (182.88 cm) thick at the base and about 18" (42.72 cm) thick at the top. It was built to be the world's largest office building[8]. Europe as well contain many examples of load-bearing brick structures built in the early and mid-nineteenth century that are still in daily use despite more than a century and a half of exposure to damp and aggressive industrial atmospheres. The brick arch bridges, viaducts, tunnel linings and retaining walls of the early railway system in Britain provide examples of the excellent durability of load bearing brick structures under the most adverse service conditions [9].

Figure 2-2 Mondadnock Tower

Source: http://www.understandconstruction.com/uploads/

2.2. Various Types of Building Structures

Obviously, shelter is one of the prime necessities of human life. Most constructions today are not made up of load-bearing masonry but frame structures of light but strong materials that support floor slabs and have very thin and light internal and external walls. There are different types of building constructions found in the world today. Table 2-1, describe the most common and widely use ones around the globe.

Table 2-1 Various Types of Building Structures [8]

Item	The Various Types of Building Structures	Futures	Figures
1	Concrete Frame Structures	Concrete frame structures are widely used, and they typically consist of reinforced cement concrete or RC, which incorporates steel bars. This combination proves highly effective due to concrete's exceptional compression strength, ease of on-site production, and affordability, along with steel's remarkable tensile strength.	
2	Steel Frame Structures	Mild steel possesses significant strength and exhibits an impressive degree of flexibility, making it a highly advantageous material for construction. Its exceptional strength allows for durable structures, while its remarkable flexibility enables the ability to bend without suffering from cracks. This unique characteristic grants steel-framed buildings the capacity to withstand external forces like lateral pressure, wind, or seismic activity by flexing and adapting accordingly.	
3	Timber/ Wood Frame Construction	It is light, and allows quick construction with no heavy tools or equipment. Every component can easily be carried by hand a house essentially becomes a large carpentry job.	
4	Load Bearing Masonry Construction	A load-bearing wall, also known as a bearing wall, is responsible for supporting the weight of a structure by transferring the load to the foundation. In the construction of sizable buildings, load-bearing walls are typically constructed using materials such as concrete, blocks, or bricks.	

2.2.1. Load Bearing Masonry Construction

A load-bearing wall (or bearing wall) is a wall that bears a load resting upon it by directing its weight to a foundation structure. The materials most often used to construct load-bearing walls in large buildings are concrete, block, or brick [4].

Depending on the type of building and the number of floors, load-bearing walls are gauged to the appropriate thickness to carry the weight above them. Without doing so, it is possible that an outer wall could become unstable if the load exceeds the strength of the material used, potentially leading to the collapse of the structure.

The key idea with this construction is that every wall acts as a load carrying element. The immense weight of the walls actually helps to hold the building together and stabilize it against external forces such as wind and earthquake. Note the absences of concrete column and beam since the walls are the principal load caring elements [1].

2.3 Advantages and Development of Load Bearing Masonry

The basic advantage of masonry construction is that it is possible to use the same element to perform a variety of functions. Thus, masonry may, simultaneously, provide structure, subdivision of space, thermal and acoustic insulation as well as fire and weather protection. As a material, it is relatively cheap but durable and produces external wall finishes of very acceptable appearance [2].

2.4. Brick as a Load Bearing Wall

The materials most often used to construct load-bearing walls in large buildings are concrete, block, or brick. All systems were highly competitive, but the load-bearing brick solution was chosen because of lists of Advantages discussed below [6].

2.4.1. Advantages

(a) Cost

Obtaining precise and comprehensive costs for building elements is challenging. The costs are influenced by the current condition of the building market and typically encompass only the expenses involved in constructing the building and its long-term costs throughout its lifespan. Based on past experiences and practical observations, it has been demonstrated that brickwork structures tend to be more cost-effective than alternative structural options. This is attributed to the following reasons: -

(i) Brickwork or alternative materials are employed in steel and concrete frame constructions to create the outer shell, partitions, and similar elements. When these partitions and other walls are constructed as load-bearing brickwork, they have the capability to support loads independently, eliminating the need for a framework.

(ii) Experience has shown that generally the less the amount of work put out to subcontractors, the lower are the construction costs. With brickwork structures not only is the number of subcontractor reduced, but there is also reduction in the number of site operations, trades and materials.

(iii) Brickwork buildings tend to be quick to erect, resulting in lower site overhead costs.

(iv) The maintenance costs are reasonable.

(v)A high degree of fire resistance, thermal and sound insulation, exposure protection, is automatically provided within the structural requirements of brickwork buildings making them to be relatively economical.

(b) Speed of Erection

A brickwork wall can easily be built in few days, and can support a floor or roof load after few days. While concrete frame will require more than few weeks to erect shuttering, fix reinforcement, cast concrete, cure, prop and then strike the formwork.

(c) Repair and Maintenance

Properly designed brickwork requires little or no maintenance and is extremely economical in terms of maintenance costs. A well-designed building will contain the majority of damage within the mortar and movement joints, and re-pointing the brickwork will make good most of the defects.

(d) Availability of Materials and Manpower

The normal module size of bricks and the generally readily available of their raw materials mean that they can be mass produced in many locations and stocked in standard sizes. Modern transportation and packing enable speedy delivery of bulk supplies of bricks, and reduce the number damage in transit to the minimum. Similarly, the materials used in mortar are available in many locations and are easily transported. Being a well-established trade, skilled bricklayers are normally available in most areas. Early discussions with the tradesmen on the site regarding the constructional requirements will result is a proper understanding of the job.

(e) Durability

The excellent durability of brickwork is one of its greatest advantages. It varies accordingly to the nature of units, the composition of the mortar and the degree of exposure to the weather, atmospheric pollution and aggressive condition. For example, in severe exposure such as that below damp-proof course particular attention should be paid to the choice of brick and mortar.

(f) Fire Resistance and Accidental Damage

Brick structures suffer less damage than steel or concrete buildings which fact provides evidence of not only the high fire resistance of brickwork structures, but also of their inherent capacity to resist accidental damage.

Brickwork is incombustible and do not start or spread a fire. Brickwork is rarely seriously damaged by fire, it does not buckle like steel or spell like reinforced concrete or burn like timber and only melt under very high temperature.

(g) Thermal Insulation

To provide for acceptable thermal conditions inside buildings, brick wall envelopes can provide insulation against excessive loss or gain in heat and have adequate thermal capacity if properly designed.

The loss or gain in heat through the wall depends on temperature difference between the air on both sides of the wall. The good thermal properties of cavity walls have long been recognized.

(h) Sound Insulation

The major noise intrusion is considered to be caused by airborne sound and the best defense against this is by material insulation. The denser a partition the less is the noise transmitted through it. Brickwork provides the dense partition without too much rigidity.

(i) Aesthetics

The aesthetic appeal of a building is a result of many factors: form, massing, scale, elevation treatment, color, texture, etc. Brickwork is of human scale, available in a vast range of colors and texture, and due to the small module size of bricks is extremely flexible in application. That it can be used to form a great variety of shapes and sizes of walls, piers, arches, domes etc.

2.4.2. Disadvantages

(a) Increase in Obstructed Area Over Steel and Reinforced Concrete

Although brickwork units can be obtained with extremely high crushing strength, the design compressive strength of brickwork walls are generally lower than for steel or reinforced concrete. It follows, therefore that for a particular loading condition, brickwork will require a greater cross-sectional area. In location where large unobstructed areas are required, brickwork may be proved unacceptable.

(b) Large Openings

In situations where large openings are to be formed and a level soffit is required, reinforced concrete or steel beam are generally found to be the most economical means of support. They can be combined with the composite action of any brickwork above and, unless fair faced brickwork is a particular requirement for the soffit of the support, they will usually provide a more economical solution than the brickwork alternative.

2.5. Principles of Design of Load-Bearing Brick Structures

Brickwork is always designed to act in compression and is assumed incapable of carrying tensile stresses. Vertical dead and live loads are transmitted by load-bearing walls down the height of the building to the foundation. Each story-height of wall must carry the load transmitted to it from the above together with any bending moments transmitted from the floor slabs.

Under this combination of load and bending moment, no tensile stresses should develop in the wall. Lateral wind loads are transmitted to the load-bearing walls via the external cladding of the building and the floors. All lateral loads are resisted by the load-bearing walls acting as vertical cantilevers. Here also, no resultant vertical tensile stress can be allowed to develop in the walls [10].

2.6. Load Transfer Mechanism on Load Bearing Walls

For low-rise buildings, bearing brick walls typically possess inherent structural support for other building components without requiring specific modifications. To effectively bear vertical loads, it is necessary for the wall to maintain uninterrupted continuity from the top to the bottom. [11].

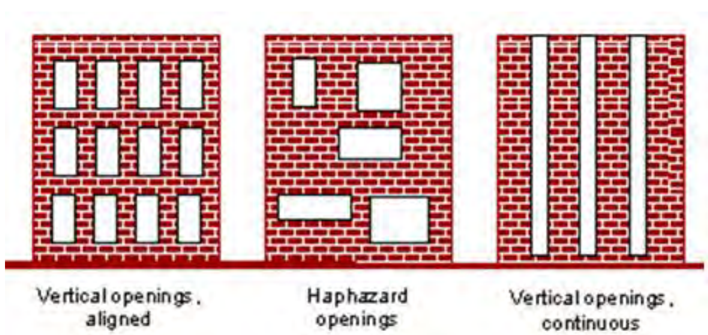

Figure 2-3 load transfer mechanisms in load bearing walls [11]

Since walls bank on crossing with each other to provide some of their stability, continuous vertical openings would turn the wall into a series of isolated piers. [11].

2.6.1. Layout of walls to support floor loads

To utilize load bearing brick walls for supporting floor loads, it is necessary to take into account the appropriate span for the floor structure. Slab systems can be directly supported on walls without interruption, while beam systems typically require thickened piers beneath the beams. As a result, there are multiple systems to choose from when considering this matter.

If the building is narrow enough, the external walls alone can support the entire floor structure. The floor slabs (or slab and beam systems) span right across [11].

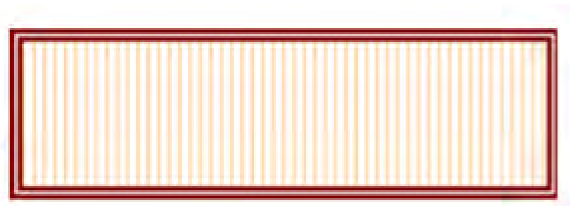

Figure 2-4 Narrow building, floors supported by external walls

If there are an ample number of internal walls, it is possible for the collective strength of both the internal and external walls to bear the weight of the entire floor. Consequently, it is common for the internal walls to have narrow doorways, while the external walls feature sizable windows. As a result, the majority of the load will be directly borne by the internal walls [4].

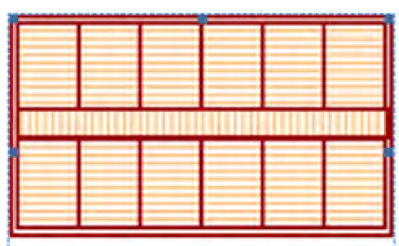

Figure 2-5- Floors supported by external and internal walls

2.6.2. Stability of load bearing walls

Early in the design of a building, decisions will be made about the overall structural system and the character of the facades. These decisions will take into account the characteristics of masonry walling systems, and in turn they will influence the development of masonry detailing.

In order to counteract horizontal forces, walls depend on either their thickness or the support they receive when two walls intersect at right angles. The primary vertical forces acting upon a wall include its own weight, and if it is a load-bearing wall, it must also withstand the loads exerted by the building's floors and roofs. It is imperative for the wall to possess the capacity to withstand and support these loads. [4].

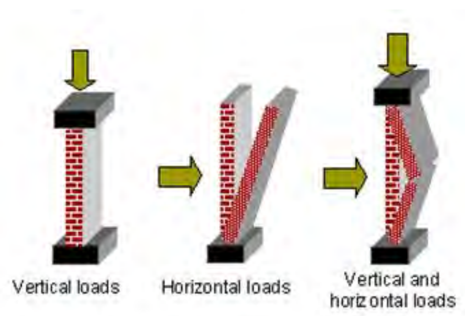

Figure 2-6; Stability of load bearing walls [4]

The external wall will experience horizontal wind forces. It needs to withstand the impact of the wind, which can either cause the entire wall to topple or cause a wall panel to flex inward or outward between its supports. A load-bearing wall is partially stabilized by the vertical load exerted on it, as it is connected to a floor or roof structure at the top. This attachment provides more stability compared to a freestanding wall.

In regions prone to earthquakes, walls will also encounter seismic loads, which typically result in either individual walls or the entire building overturning. In areas with high seismic activity, masonry can be reinforced to enhance its ability to deform without collapsing (ductility).

2.7. General Requirements of a Load-Bearing Brick Structure

2.7.1 Material Requirements

In a properly engineered load-bearing structure, the brickwork should be carefully strained up to its maximum safe capacity. Consequently, the designer needs to have a comprehensive understanding of the properties of the material being used and the permissible stresses that can be applied during the design phase. Furthermore, during the construction process, constant evaluations of the quality and strength of the brickwork must be conducted to ensure compliance with the design specifications. The strength of the brickwork relies on the durability of both the bricks and mortar, and allowable stresses are determined through strength tests on brickwork samples, such as prisms and cubes, using the proposed materials and conditions that closely resemble the expected on-site environment. Additionally, the brickwork is prone to movement caused by both external loads and environmental factors. [10].

2.7.2. Structural Requirements

Load-bearing brick structures are fundamentally stable due to the force of gravity. In other words, they withstand overturning forces because of their own weight. This is a result of the fact that brickwork without reinforcement, similar to unreinforced concrete, possesses strength when compressed but lacks tensile strength. The following criteria need to be fulfilled for these structures to be structurally sound [10].

A) It is essential to prevent differential settlement. In challenging soil conditions, it is recommended to employ piled or raft foundations to minimize differential movement. Another option is to incorporate movement joints into the structure, either as a standalone solution or in conjunction with other measures, to allow for differential movement without causing any harm to the structure. Furthermore, the design should account for and accommodate moisture, thermal, and creep movements of the brickwork.

(b) In order to prevent uneven stress distribution, it is advisable for the floor layout to be consistent across each level. However, this doesn't mean that reinforced concrete construction cannot be utilized at the ground or ground and first floor levels to create open, column-free spaces such as lobbies and assembly areas.

(c) The walls and wall intersections should be organized in a way that offers resistance to horizontal loading caused by wind and other factors. This can be achieved through either cellular construction or cross-wall construction.

(d) The positioning of windows holds significance, and having "hole in wall" fenestration provides more structural strength to the building compared to having "strips" of windows divided by vertical brick panels. It is crucial to incorporate designed and built-in ducts for various services.

(e) Randomly cutting into walls to install plumbing, electrical conduits, and similar elements should not be permitted as it can compromise the building's integrity.

(f) Adequate precautions must be taken to prevent rain from penetrating through the exterior walls.

2.8. Brick

2.8.1. Manufacturing of Brick and History of brick

Brick is made of clay or shale formed, dried and fired into a durable product [13]. Clay brick is defined as a solid masonry unit, usually made of clay, molded into a rectangular shape while plastic. It is treated in a kiln at an elevated temperature to harden, so as to give it mechanical strength and to provide it with resistance to moisture; after being removed from the kiln, the brick is said to be burnt, hard-burnt, kiln-burnt, fired, or hard-fired [9].

It has been reported in literatures that the first clay brick was probably made in the Middle East, between the Tigris and Euphrates rivers in Iraq. The earliest bricks were dried brick, meaning they were formed from clay-bearing earth or mud and dried usually in the sun until they were strong enough for use [14].

The fundamentals of brick manufacturing have not changed over time. However, technological advancements have made contemporary brick plants substantially more efficient and have improved the overall quality of the products. A more complete knowledge of raw materials and their properties, better control of firing, improved kiln designs and more advanced mechanization have all contributed to advancing the brick industry. Figure 2-7 shows process of manufacturing of brick.

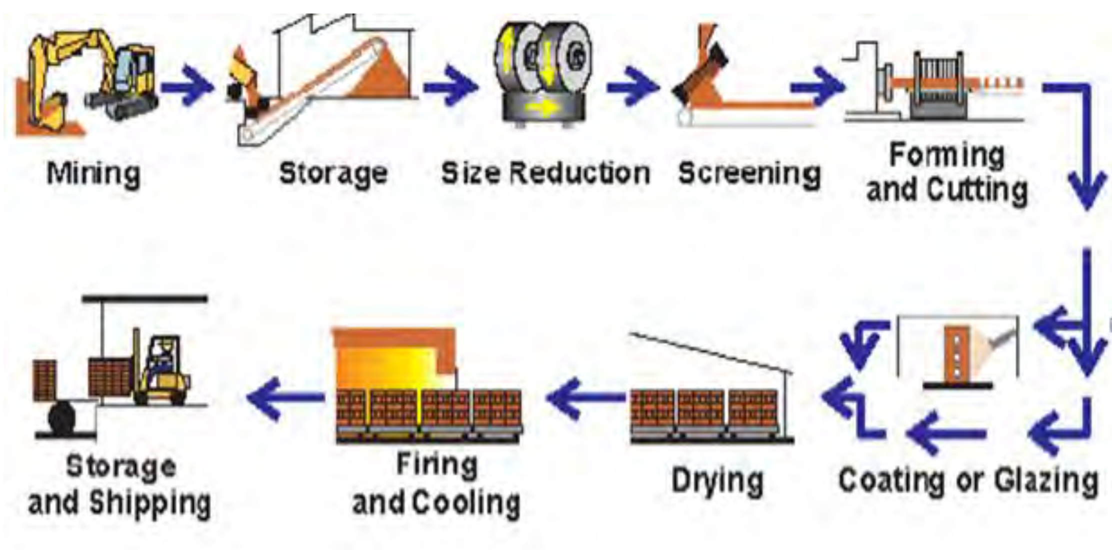

Figure 2-7 Process of Manufacturing of Brick [20]

There are generally four basic stages in brick manufacturing; clay preparation molding, drying and firing.

A. Clay preparation

Clays are usually mined from open pits. The excavated lumps of soli are then broken and are transported to storage areas. It is common practice to store enough raw materials for several days' operation regardless of weather conditions. Normally several storage areas, one for each source, are provide to permit same blending of clays [4].

Blending produce more uniform raw materials and helps to control color and permits some control over raw materials suitable fire manufacturing a given type of unit. The clay is usually crushed to break up large chunks and remove stones. After grinding the raw materials are mixed with the addition of water.

B. Molding

Temperature is the first step in the forming process, which produces a homogeneous and plastic mass ready for molding. It is most commonly achieved by adding water to the clay in a pug mill, which is a mixing chamber that contains one or more revolving shafts with blades. The molding technique is designed to suit the moisture content; semi-dry (dry) process, Stiff mud process, the wire cut process, and soft mud process [4].

¡) semi-dry (dry) process: This process is particularly adaptable for clays of very low plasticity. Clay is mixed with a minimum of water up to ten (10%) percent, then formed in steel molds under pressure using hydraulic or compressed air rams.

¡¡) stiff mud process: Is in which clay is mixed with only sufficient water to produce plasticity, usually from 12 to 15 percent by weight after thorough mixing,

¡¡¡) the wire-cut process: in which the clay is tempered to about twenty (20%) percent moisture content and must be processed to form a homogenous material. This extruded to a size, which allows for drying and firing shrinkage and units are cut to the correct thickness by tensioned wires, perforated bricks are made in this way, the perforation being formed during the extrusion process wire cut bricks are easily recognized by the perforation or 'drug marks 'caused by the dragging of small clay parties under the wire.

¡v) soft mud process: - which is particularly suitable for clays, which contains too much natural water to be extruded by the stiff-mud process. It contains of mixing clays so that they contain twenty to thirty percent (20-30%) water and then molding the units in the molds. Brick may be produced in this manner by a machine or by hand process.

C. Drying

When wet clay units come from molding or cutting machines, they contain from seven to thirty (7- 30%) percent moisture, depending upon the forming method. Before the firing process begins, most of this water must be evaporated. Drying enables such bricks to be staked higher in the kiln without lower bricks becoming destroyed by the weight of the bricks above them. Drying also enables the firing temperature to be increased more rapidly without such problem as bloating, which may result when gasses or vapor are trapped within the brick.

Drying is out in dryer chambers and the drying time varies usually from 24 to 48 hours. Although heat may be generated specifically for dryer chambers, it is more commonly supplied as exhaust heat from firing kilns.

While drying heat and humidity must be carefully regulated to avoid excessive cracking. Bricks can also be dried in the sun. The process normally takes a number of days, higher moisture-content bricks requiring a greater time.

D. Firing

Firing, which is one of the most specialized steps in the manufacture of brick requires from 40 to 150 hours depending upon kiln type and other variables. According to ASTM C 43-98a, fired bond in brick production is abound developed between particulate constituents of brick solely as the result of the firing process. The bond may result from fusion or melting of one or more constituents of the composition or the surface of the particles. Other thermal mechanisms such as sintering and inter particle reaction may be responsible for the bond.

Several kilns are in use: chambers, continuous kiln and tunnel kilns are some, which are widely used in practice. The firing fuel may be natural gas, propane, oil, sawdust, coal, or, combination of these fuels.

Table 2-2 Effect of Firing Temperature on green Brick [4]

Item	Firing Temperature (°C)	Effect on Green Brick
1	0 up to 150	Free water in clay (10%) by weight of after drying will be lost rapidly.
2	150 up to 200	Water within lattice structures of clay minerals will be lost.
3	200 up to 400	Further water which is evolved the clay mineral themselves decompose.
4	400 up to 700	Further water is evolved when clay minerals decompose leaving a residue of major non-crystalline material, mainly silica and alumina oxidization starts.
5	700 up to 900	Oxidization is completed, at this stage several chemical reactions takes place in the presence of oxygen.
6	900 up to 1000	Minerals continue reacting together to form solution which can flow over the less fusible grains, sticking the together and filling the pores.
7	Up to 1200	This marks the onset of crystallizations, which promotes sintering of individual clay particles

Table 2-2 illustrates the effect of kiln firing temperature on green brick. Firing transfers, the raw clay brick in to rigid and continuous materials by way of a complicated succession of physical and chemical changes. The exact temperature depends on the composition of raw material. Figure: - 2-8 summarizes the basic stages of brick production process.

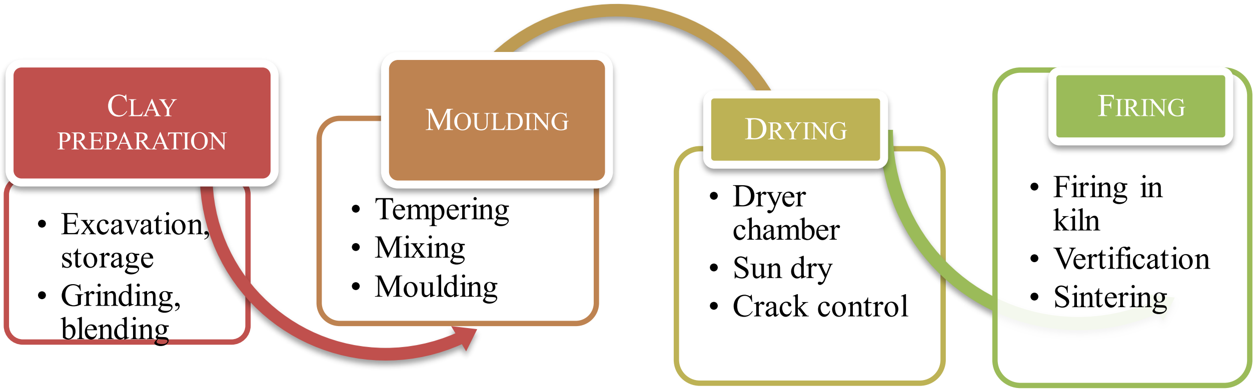

Figure 2-8 Stages of brick manufacturing [20]

2.8.1.1 Raw Materials for Brick manufacturing

Clay, an abundant mineral material found on Earth, needs to possess certain properties and characteristics for its use in brick manufacturing. The clay used in brick production should have specific qualities: it must exhibit plasticity, allowing it to be shaped or molded when mixed with water, and it must possess enough tensile strength when wet and air-dried to retain its shape after forming. Furthermore, the clay particles must have the ability to fuse together when exposed to increasing temperatures [10].

Generally, clays occur in three principal forms, all of which have similar chemical compositions but different physical characteristics.

I. Surface Clays: - are the up thrusts of older deposits or of more recent sedimentary formations. As the name implies, they are found near the surface of the earth.
II. Shale's: - are clays that have been subjected to high pressures until they have nearly hardened into slate.
III. Fire Clays: - Fire clays are usually mined at deeper levels than other clays and have refractory qualities.

Surface and fire clays have a different physical structure from shale's but are similar in chemical composition. All three types of clay are composed of silica and alumina with varying amounts of metallic oxides. Metallic oxides act as fluxes promoting fusion of the particles at lower temperatures [11].

The manufacturer minimizes variations in chemical composition and physical properties by mixing clays from different sources and different locations in the pit. Chemical composition varies within the pit, and the differences are compensated for by varying manufacturing processes. As a result, brick from the same manufacturer will have slightly different properties in subsequent production runs. Further, brick from different manufacturers that have the same appearance may differ in other properties.

Fire clays and have refractory qualities as a rule, they contain fewer impurities than shale or surface clays and have more uniform chemical and physical properties [10]. Chemically, all three are compounds of silica and alumina with varying amount of metallic oxides and metallic oxides other impurities. Although technically metallic oxides are impurities they act as fluxes, promoting fusion at lower temperature. Metallic oxides (particularly those of iron, magnesium, and calcium) influence the color of the finishing – fired product as well while the presence of the silicates contributes for strength and durability [10]. The mineralogical compositions of a good brick raw material or clay are summarized Table 2-3 [15]:

Table 2-3 Ingredients/oxides of a good clay brick

No	**Ingredients/oxides**	**Proportions (%)**	**Remark**
1	Silica (SiO)	50–60%	
2	Alumina(Al_2o_3)	20–30%	
3	Lime(CaO)	10%	
4	Magnesia (MgO)	< 1%	The sum of these ingredients is less than 20%
5	Ferric oxide (Fe_2o_3)	< 10%	
6	Alkalis (NaOH, KOH, …)	< 7%	
7	Carbon dioxide (CO_2)		Very small percentage
8	Sulphur trioxide (SO_2)		
9	Water (H_2o)		

Different types of clay bricks can be produced depending on the types of clay, the molding and the firing process. The three basic subdivisions are;

I) Common bricks: which are ordinary bricks and are not designed to provide good finished appearance or high strength. They are there for in general the cheapest bricks available. Common burnt clay bricks, which are accepted for use in general brick work with no special claim for attractive appearances. Walls built with common bricks require rendering or plastering.

II) Facing bricks: which are designed to give attractive appearance, and they are free from imperfections such as cracks and size variations. Quality burnt clay bricks, which give attractive appearance in their color and texture. It is used without rendering, plastering, or other surface treatments.

III) Load Bearing: Load bearing bricks, which can be either common or facing bricks, conform to specified average compressive strength limits depending on their classes. The table below shows the average compressive strength of load bearing bricks based on British standard 3921:1965.

Table 2-4 BS class and average compressive strength of Load bearing Bricks

Class	**Average Compressive Strength** N/mm^2
1	7.0
2	14.0
3	20.5
4	27.5
5	34.5
7	48.5
10	69.0
15	103.5

IV) Engineering bricks: are designed primary for strength and durability. They are usually of high density and well fired. Engineering bricks are bricks burnt at exceedingly high temperatures. They possess a dense and strong semi-vitreous body and conform to the defined limits for strength and water absorption. They are primarily used in civil engineering works that require high load bearing capacity, good damp-proof, and chemical resisting characteristics. The table below shows the average compressive strength of load bearing bricks based on British standard 3921:1965.

Table 2-5 BS class and average compressive strength of Engineering Bricks

Engineering	**Average Compressive Strength, (No less than) N/mm^2**	**Average Water Absorption, % (No greater than)**
A	69.0	4.5
B	48.5	7.0

2.8.2 Tests for Fired Clay-Bricks as per Ethiopian standard

Before selecting bricks for use in construction it is necessary to carry out complete evaluation of the physical and mechanical properties. The former Ethiopian standard specification for solid clay bricks (ES 86:1990) was formally replaced by another designation ES- 86:2001 [14]and again replaced by CSE 26:201.As per CES 26-2013,various tests that are required to be conducted for evaluation of bricks are [15],

i. Test For Compressive Strength
ii. Test For water Absorption
iii. Test for Efflorescence
iv. Test for Dimensions Tolerance
v. Test for Saturation coefficient

2.8.2.1 Tests for compressive strength

Bricks often had to withstand great compressive stresses; the durability of a masonry structure largely depends on the strength of bricks. Compressive strength is the resistant to compression of bricks and is measured in the laboratory by applying perpendicular load to the largest face [16].Based on the laboratory test result of mean compressive strength, according to Ethiopian standard (CES 26:2013), bricks are classified as shown in Table 2-6.

Table 2-6 Minimum compressive strength of solid clay brick (CES26-2013)

Class	Minimum compressive Strength			
	Average of 5 Bricks		Individual brick	
	N/mm^2	Kg/cm^2	N/mm^2	Kg/cm^2
A	20	200	17.5	175
B	15	150	12.5	125
C	10	100	7.5	75
D	7.5	75	5	50

2.8.2.2 Tests for water absorption

The water absorption of a brick is the weight of water taken up by the brick under given laboratory test conditions or specification, and is expressed as a percentage of the dry weight of the unit. Absorption of water depends on clay properties, manufacturing process and burning [17]. Water absorption of bricks also depends up on their porosity which is due to presence of voids of difference sizes. But the idea of water absorption or porosity is indication of that the brick work will be able to keep away the rain water and protect the interior from the dampness traveling from outside.

Absorption determines the durability of clay bricks. High absorption capacity causes mortar to be dry & results in incomplete hydration of cement in the mortar. So, the bond strength between the mortar and the brick reduced [17].

According to Ethiopian Standard, based on their water absorption, bricks are classified as shown in Table 2-7.

Table 2-7 Maximum water absorption of solid clay-bricks (%), [15]

Class	After 24 hour immersion		After 5 hour boiling	
	Average of 5 Bricks (%)	Individual Brick (%)	Average of 5 Bricks (%)	Individual Brick (%)
A	21	23	22	24
B	22	24	23	24
C	No limit	No limit	No limit	No limit
D	No limit	No limit	No limit	No limit

2.8.2.3 Test for Efflorescence

Bricks are one of the most extensively used building materials. Soils used in manufacturing of bricks should be free from harmful salts such us salts, sodium and potassium. If such salts are present in bricks then they will get dissolved when bricks come in contact with moisture or water. When bricks containing such harmful salts used for exposed surface then serious disfigurement will occur. This phenomenon is known us efflorescence.

According to Ethiopian Standard classes A, B, C and D bricks at least satisfy the requirements for their respective class, accordingly the efflorescence rating for different classes of bricks is indicated in Table 2-8.

Table 2-8 Efflorescence Rating [15]

Class	Efflorescence rating
A,B	Nil to slight
C,D	Effloresced

2.8.2.4. Dimensional Tolerance

Bricks, which have been used for construction for centuries, are among the earliest building materials. As a locally sourced material, bricks come in a wide range of variations depending on the quality of the raw materials and the manufacturing process, thus affecting the overall quality of the final product. Ensuring the appropriate dimensions of bricks is crucial for achieving a strong bond arrangement.

In order to bring uniformity in the quality and dimension of material Ethiopian standard agency has laid down for bricks specification accordingly, the nominal dimensions of solid bricks shall be 60mm x 120mm x 250mm and the deviations from these dimensions shall not exceed the tolerances indicated in Table 2-9.

Table 2-9 Maximum allowable dimensional tolerances mm [15]

Dimensions	Tolerance (mm)
Height	± 2.5
Breadth	± 5.0
Length	± 8.0

2.8.2.5. Test for Saturation Coefficient

The saturation coefficient of brick is the ratio of water absorption after 24-hour immersion in cold water to absorption after 5hr immersion in hot water. According to Ethiopian standard, based on their Saturation coefficients, bricks are classified as shown in Table 2-10.

Table 2-10 Maximum Saturation Coefficients [15]

Class	Average of 5 Bricks	Individual Brick
A,B	0.96	0.99
C,D	No limit	No limit

2.8.3 British Standard Specification for Clay bricks (BS 3921:1985)

According to BS 3921, bricks are classified based on their compressive strength and water absorption as shown in Table 2-11.

Table 2-11 Classification of clay bricks by compressive strength and Water absorption [18]

No.	Classes of clay bricks	Compressive strength (N/mm2)	Water absorption (% by mass)
1	**Engineering – A**	>70	<4.5
2	**Engineering – B**	>50	<7.0
3	Damp-proof course 1	>5	<4.5
4	Damp-proof course 2	>5	<7.0
5	**All Others**	>5	No limit

According to this standard specification,

- Damp-proof course 1 bricks are recommended for use in buildings construction whilst
- Damp-proof course 2 bricks are recommended for other external construction works like for masonry construction which fulfils the requirements of BS 5628: Part 3: 1985.

2.8.4 The American Society for Testing and Materials; Standard Specification for Building Bricks (ASTM C 62-97a)

According to ASTM, standard specification for building bricks (C62- 97a), clay bricks are classified based on their compressive strength, water absorption and saturation coefficient as discussed in Table 2-12 [19].

Table 2-12 Classification of clay bricks based on their physical requirements (ASTM C62-97a)

Designation	Minimum compressive strength, gross area (MPa)		Maximum water absorption by 5 hr boiling, (%)		Maximum saturation coefficient	
	Average of 5 bricks	Individual bricks	Average of 5 bricks	Individual bricks	Average of 5 bricks	Individual bricks
Grade SW	20.7	17.2	17	22	0.78	0.8
Grade MW	17.2	15.2	22	25	0.88	0.9
Grade NW	10.3	8.6	no limit	no limit	no limit	no limit

On this specification grades classify bricks according to their resistance to damage by freezing when wet. Three grades are covered and the grade requirements are listed in Table 2-11.

i. Grade SW (Sever weathering) - bricks intended for use where high and uniform resistance to damage caused by cyclic freezing desired and where the brick may be frozen when saturated with water.

ii. Grade MW (Moderate weathering) - bricks intended for use where moderate resistance to cyclic freezing damage is permissible or where the brick may be damp but not saturated with water when freezing occurs.

iii. Grade NW (Negligible weathering) - bricks with little resistance to cyclic freezing but which are acceptable for applications protected from water absorption and freezing.

2.8.5 Field Tests for Fired Clay-Bricks

Generally different types of bricks can be produced depending on the types of clay, the molding and firing process. Bricks used in construction should be free from cracks, flaw and notice of free line. A good quality brick should have smooth rectangular faces and sharp edges and they should give a clear ringing sound when struck against each other.

It is necessary to check the quality of brick before using it in any construction activities. There are some field tests that we can conduct in the field in order to check the quality of bricks. These tests are as follows [16].

2.8.5.1 Visual Inspection

In this test bricks are closely inspected for its shape. The bricks of good quality should be uniform in shape and should have truly rectangular shape with sharp edges. Also plainness and color checksare done.

2.8.5.2 Hardness

In this test, a scratch is made on brick surface with the help of a finger nail. If no impression is left on the surface, brick is treated as to be sufficiently hard.

2.8.5.3 Soundness

Two bricks are taken, one in each hand, and they are struck with each other lightly. A brick of good quality should not break and a clear ringing sound should be produced properly burnt and free from cracks brick emits a metallic ring sound.

2.8.5.4 Structure

A brick is broken and its structure is examined. It should be homogeneous, compact and free from any defects such as holes, lumps, etc.

2.9 Brick Production Process at Ethio-brick and Burayue Factories

The main processing stages for the production of clay bricks are the following, getting clay from the ground and transporting it to factory, preparation of the clay and forming the shape of the brick, drying the green clay and finally firing or burning the clay. There are generally four basic stages in brick manufacturing; clay preparation molding, drying and firing.

2.9.1. Preparation of the clay

The red clay soil and the white clay soil from Chefe and Burayu quarry sites, respectively, are transported to the production site. The quarry site is about 5km away from the production site. After the selected soils are transported from the quarry they are left to be dried with air, they were sieved with a wire mesh.

2.9.2. Primary Mixer (Dry Mixer)

75% and 25% white and red clay soil blended with the proportions respectively. Blending produce more uniform raw materials suitable for manufacturing a given type of unit. The proportioning is maintained by the rotation of external blades fixed at the end of feeder boxes located opposite to each other. One of the feeder boxes rotate with triple speed to the other feeder, that way the blending will have 1:3 ratio of the raw materials which are white and red clay.

The blended material will be lifted to jaw crusher. The clay is usually crushed to break up large chunks and remove stones, in the meantime large or boulder materials which cannot be crushed will be selected by hand, experienced workers will identify the boulders by observation select the material and remove from the mix before crushing began.

2.9.3. Forming the Shape of the Brick (Molding)

Secondary mixer (Pug mill mixer) or Wet mixer, which is a mixing chamber that contains one or more revolving shafts with blades, is used. For the production of clay bricks from the four blended soil samples, these samples are mixed with water and the amount of water used for mixing each blended soil samples is done manually based on the experience of the operator.

After the wet mixed raw material is crushed again vacuum pump fixed will suck air from the mix removing air holes and bubbles, giving the clay increased workability and plasticity, thus resulting in greater strength.

Next, the clay passes through the extruder which will produce a green brick column, which is plastic sticky clay mix in which the final two dimensions of the unit is determined. The brick column then passes through an automatic cutter to make the final dimension of the brick unit.

2.9.4 Drying the Green Clay

Prior to commencing the firing procedure, it is necessary to evaporate a significant portion of the moisture present in the green brick. This drying phase allows the stacking of these bricks at greater heights in the kiln, preventing the lower bricks from being damaged by the weight of those above. Additionally, drying facilitates a quicker increase in firing temperature, minimizing issues like bloating that may arise from the entrapment of gases or vapor within the bricks. Typically, the drying process spans several days, as bricks with higher moisture content necessitate more time for drying.

And time of drying is dependent on the moisture content of the green bricks and the humidity of the production area. In the case of high humidity and rainy season artificial drying process which is carried out in dryer chambers and the drying time varies usually from 24 to 48 hours. If it is sunny the green bricks are left in a room for four up to seven days and then they are left in a shed to be dried with air and natural sun.

2.9.5. Firing the clay brick

Firing, which is one of the most specialized steps in the manufacture of brick requires from 40 to 150 hours depending upon kiln type and other variables [10]. Several kilns are in use: chambers, continuous kiln and tunnel kilns are some which are widely used in practice. The firing fuel may be natural gas, propane, oil, sawdust, coal, or, combination of these fuels.

In the case of Ethio Brick Company the firing of the brick is done by burning of wood. The firing temperature and also firing hour is not pre-determined. It generally depends on the experience of the worker.

2.10 Brick Production Process at Great wall construction

The major steps carried out in production of bricks at great wall construction is the same but there is a major in the type of raw materials being used. Clay soil excavated from different sites is collected and transported to project site. And after acceptance and purchase of soil it will be mixed with coal or black ash which is a byproduct of Textile Company near the factory (around 3 Km). There is no predetermined mix proportion set to mix the ash with the soil. But the loader operator uses the loader bucket as a means of measuring (proportioning). One loader bucket of black ash is mixed with 3 (Three) loader bucket of soil. After blending the raw materials crushed, mixed, dried and fired in to an end product. Almost all of the procedures are the same as Ethio brick and Burayu brick factory. Table 2-13 summarizes the major procedures taken in production of bricks in Ethio Brick, Burayu and Great Wall Construction Company. It also discusses the main differences among the different brick factories.

Table 2-13 Differences in production of bricks

ITEM	Brick Production Process (Stages)	Brick Production Factories	
		Ethio Brick and Burayu Brick Factory	Great Construction Company
01	Raw material	Red clay soil and white clay soil	Excavated any red /ordinary soil and coal
02	Proportioning	1:3 (red: white) clay soil Ratio	1:3 (soil:coal) Ratio

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Over view

This study mainly was conducted in order to to propose a load bearing brick wall building construction for housing project and study its impact on cost and its applicability as an alternative solution in solving housing problems in Ethiopia. Accordingly, first the review of the overall brick production process was carried out and then an assessment of the quality and availability of locally produced bricks for the required construction purposes were investigated as discussed in Sections 2.9 and 2.10.

03.2. Research design

In order to conduct the research in an efficient manner and make the best of opportunities and resources available, it is organized and conducted systematically using appropriate methods to collect and analyze the data. A survey for assessment is designed first by identifying the topic and setting some objectives. Subsequently, the areas of information needed to address the issue are listed and the objective is refined. Based on that and literatures the interview questionnaire is prepared. In line with the research proposal, the initial assessment is covered at the end of this chapter and the load bearing building design and analysis is covered in Chapter Four of this thesis.

3. 3. Selecting factories and area of study

Great wall construction materials Manufacture, Ethio Brick Factory and Burayu Brick factory were the three companies selected. These companies are among the few brick factories in and around Addis Ababa relate significantly to the study in a way they are the principal companies with a large amount of production capacity supplying bricks for more than 90% of the supply.

3.4. Data collection

Data for this study is collected using observation at selected brick factory and review of the entire brick manufacturing procedure, conducting structured and formal interview with brick manufacturers and standard agency offices. Additionally, laboratory tests are conducted for fired clay brick and results are used. In addition to these relevant literatures are reviewed, as described in Chapter Two of this thesis.

3.5 Design of Interview Questionnaires

Interview questionnaires were designed and used for this study to interviewing concerned individuals at selected brick factories in and around Addis Ababa. The interview questionnaires for brick manufacturing company include: company profile, raw materials sources, material preparation and blending, production processes, firing during production and general questions.

And questions for standard agency include issues related to standardisation of clay bricks in Ethiopia.

3.6 Laboratory Tests of the Fired Clay Bricks

Fired clay bricks samples were collected from three different brick manufacturing companies, and tests were carried out for compressive strength, water absorption, efflorescence, dimensions tolerance, and test for saturation coefficient. Tests were conducted at Ethiopian Conformity Assessment Enterprise (ECAE) materials testing laboratory. The tests results are analyzed based on the Ethiopian standard specification of solid clay bricks (CES 26-2013) and are classified accordingly. The results are described in Chapter Four of this research.

3.7 Field Tests of the Fired Clay Bricks

Field tests were carried out at each factory and the results are summarized in Chapter 4, Table 4.6.

3.8. Data Analysis of Interviews Responses

For the analysis of the research, both quantitative and qualitative data was collected through the conducting of personal interviews and conducting test on the selected brick factory for the research.

The data analysis for this study is based on the interview questionnaires and the laboratory test results. The experimental results are numerical data which are shown on Appendix C and summary of the results is shown Chapter Four using tables.

3.9. Proposed Load Bearing Structure Methodological Assumption

3.9.1 Preliminary design of load bearing wall

After the analysis has been made on the material actual preliminary design of load bearing wall structure is carried out. The preliminary design is presented in Chapter Five of this research. Table 3-1 shows the load bearing building structure proposal methodological assumption in summary.

Table 3-1- Load bearing structure proposal summary

Proposed Load Bearing Structure Methodological Assumption

Load bearing structure proposal is done by first studying the brick material property and preparing a preliminary design for a suitable loadbearing apartment building similar to a concrete frame structure-based apartment building of the same story height, area and function. Specific project for this study is a G+2 10/90 saving house building,

Proposal	Load Bearing wall replacing RC framed Structure
Load bearing material type	Brick
Proposal	low rise building (G+2) Residential buildings - 10/90 cost saving design
site location	Earthquake Hazard Free cities (in Ethiopia) both urban & rural cities
Selection criteria	Less Earthquake Hazard and high housing problem
Reason for selection of site	New technology for our country therefore to minimize risk and to minimize design and construction complication.
Reason for selection of material	All the advantages related to cost, speed of erection, availability of their raw materials (sustainability) and manpower, excellent durability of brick, fire resistance brickwork is incombustible and do not start or spread a fire, to provide for acceptable thermal conditions inside buildings, sound insulation, natural and aesthetically appealing of brick.

3.9.2. Method of data analysis of the proposed design

Following preparation of preliminary design of load bearing brick wall structure, estimates are prepared. And, the result of estimates of load bearing brick wall structure is compared with the result of reinforced concrete framed structure. The comparison method followed the estimation of both optional structures and the components of the structures for cost estimating are discussed in Chapter Five of this thesis. At the end savings in total project cost for the load bearing structure and savings in quantities of the main materials are determined.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1. Introduction

This Chapter presents the evidence and results of primary research which are undertaken. It also discusses the survey findings including the interpretation of results obtained from interview response, observations during the interview and visit of the brick factories, experimental results, and the design analysis.

4.2. Findings from Observation and Interview Response

Three (3) brick factories in Addis Ababa were visited to help in answering the research questions. During this study, up to two to three interviewees from each of the three studied brick factories and also from Ethiopian standard agency were interviewed and all of them volunteered to answer the interview questionnaires.

The relevant respondents which have long experience in the factories and technical eligibility about the subject matter were selected by managers of each factory. And for standard agency, interview question was held with both management and technical staff of the agency. The quantitative research findings are discussed in the following section.

4.2.1 Company Profile

Three Brick manufacturing companies selected for this research are located in and around Addis Ababa. Table 4-1; summarize company profile of brick manufacturing companies surveyed.

Table 4-1- Company profile of brick factories surveyed during this study

No	Name of Brick factory	Years of Establishment	Type of ownership	Annual production capacity (Pcs)	No. of employees Male	Female
1	Great wall construction materials Manufacture	1997 EC	Started as JV between Chinese and Ethiopian Investor currently Private company	14,600,000	43	57
2	Brick Production processing Share Company - Ethio Brick Factory	1942 EC	Started as a private Owned then confiscated by government currently the company Private company (Sold to Afro-Tsion Construction Company)	6,700,000	317	519
3	Brick Production processing Share Company- Burayu Brick factory					

Both Ethio brick factory and Burayu brick factory are managed under one factory named Brick Production Processing Share Company. Each factory is located around Burayu area on Ambo road producing bricks independently. Having the largest annual production capacity Great wall construction materials Manufacture has lower employees as compared with corresponding factories.

In factory two and three green brick produced it is transported to the shades for drying by hand which affects the speed of production. On the other hand, at company one green column brick out from the extruder cut in shape (20) twenty piece at a time and transported with a wheel without hand contact to the bricks. This and a better labor management helped Company one to increase their productivity.

4.2.2. Raw materials

Table 4-2 is presented to show the raw materials used by selected clay brick production companies.

Table 4-2 Brick factories raw material

No	Name of Brick factory	Raw materials for production of bricks	Source of Raw materials	Test for raw materials
1	Great wall construction materials Manufacture	Red soil and coal (black ash)	different supplies of soil from bulk excavation below 1m from NGL	by observation/ experience
2	Ethio Brick Factory	Red clay soil and white clay soil	mining from Burayu area 5km from factory	by observation/ experience
3	Burayu Brick factory	Red clay soil and white clay soil	mining from Burayu area 5km from factory	by observation/ experience

From the table 4-2 is can clearly be seen that there is no test conducted on raw materials before use. After raw materials are delivered to production factory responsible individual will decide only visual observation of the soil delivered.

For company one Coal is a major raw material of the production of brick, Coal or fly ash which is a byproduct from Textile Company just 100 m away from the brick production company.

4.2.3. Brick Production

All factories produce the same type of bricks, and there is no test conducted on produced bricks before supply. Table 4-3 shows the different types of bricks produced on selected factories.

Table 4-3 Brick Production

No	Name of Brick factory	Type of brick produced	Size of brick produced	Tests conducted for fired clay on site	Additional raw material or technology to improve the quality of brick
1	Great wall construction materials Manufacture	Common brick and Facing	25cmx12cmx6cm	None	Use coal (black ash) to strengthen the product and applying Diesel on the surface to retain the brick facing design
2	Ethio Brick Factory	Common brick and Facing	25cmx12cmx6cm	None	None
3	Burayu Brick factory	Common brick and Facing	25cmx12cmx6cm	None	None

4.2.4. Firing during production

The respondents agree that they do not use any temperature sensor device in order to determine appropriate degree of firing of bricks. And they replied they control the temperature simply by observation of color change of bricks in the kiln. Table 4-4 demonstrates factories' major brick production stage which is firing of brick burning.

Table 4-4 Factories Bricks Burning (Firing), energy source and temperature control

No	Name of Brick Factory	Source of Energy for Firing	Time of Burning Bricks in Kiln (In Hr)	How Do U Determine Hrs. Of Firing (Kiln Temperature Sensor Device)	Kiln Temperature Control Mechanism
1	Great wall construction materials Manufacture	Eucalyptus wood	3-4 hr	no sensor,	by experience, looking at the change in color of the brick
2	Ethio Brick Factory	Eucalyptus wood	3-4 hr	no sensor,	by experience, looking at the change in color of the brick
3	Burayu Brick factory	Eucalyptus wood	3-4 hr	no sensor,	by experience looking at the change in color of the brick

4.2.5. Standardization of Brick production

Ethiopian standard agency representative's response regarding bricks manufactures product certification, and licensing is summarized on Table 4-5.

Table 4-5 Ethiopian standard agency replies regarding quality and standardization of brick production

No	Issues Raised to Ethiopian Standard Agency	Replies
1	Names of bricks production Factories registered and gain quality certificate for manufacturing.	None, this is because agency is not giving certificate to those factories producing bricks due to difficulty of certification. The reason given is that there is a difference in daily production of bricks and creating a suitable system is impossible.
2	Follow up of production and standardization of brick production factories.	none obligatory
3	Quality of bricks produced in Ethiopia throughout the past 5 (five) decades	strictly decreasing
4	Tests conducted for bricks at the agency	Dimension tolerance, water absorption, compressive strength and Saturation coefficient

4.3. Field Tests for Clay Bricks

The Field tests of the fired clay bricks were done at factories. The field tests include Visual Inspection, Hardness, Soundness and structure. The result summary and interpretations are shown on Table 4-6.

Table 4-6 Findings of Field test of bricks

Field Test Designation No	Field Tests										
	Visual Inspection				**Hardness**		**Soundness**		**Structure**		
	Bricks are closely inspected for its shape				**When scratched with Finger Nail**		**Two bricks are struck with each other lightly**		**A brick is broken and its structure is examined.**		
	Uniform shape	**Rectangular shape**	**Sharp edges**	**Plain Smooth surface**	**Cannot be easily Scratched**	**No Impression**	**Does not break**	**Emit clear Metallic ringing sound**	**Homogeneous**	**Compact**	**Free from holes, and lumps**
Factory 01	1	1	2	2	2	2	2	2	2	2	2
Factory 02	3	2	3	3	2	2	3	3	3	3	3
Factory 03	3	3	3	3	3	3	3	3	3	3	3

N.B. 1- Represents Perfect Condition

2- Represents Moderate Condition

3- Represents Slightly Poor Condition

Results were given subjectively as there is no standard set out in our country. The basis for the testing and result analysis is existing literature. Accordingly, among the above three bricks factory, bricks from Factory 01 showed better performance regarding field test.

4.4. Laboratory Results

The laboratory test results include the physical properties of the fired clay bricks. The physical properties tests of the fired clay bricks are done at Ethiopian Conformity Assessment Enterprise (ECAE) materials testing laboratory. The tests include test for compressive strength, test for water absorption, and test for efflorescence, test for dimensions' tolerance, and test for saturation coefficient. The data and results are shown in Tables in appendix C. And the result summary and interpretations are shown on Tables 4-7, 4-8, 4-9, and 4-10.

4.4.1. Compressive strength test result

Table 4-7 shows the compressive strength test result of fired clay brick samples from selected factories and their classification of material based on standard. Accordingly based on standard requirement of (ECS 26: 2013) Factory (1), (2) and (3) samples are classified under class B, class C and class D, respectively.

Table 4-7- Compressive strength test result

Lab Des. No	Compressive strength(N/mm^2)				Class of material based on standard requirements (ECS 26:2013)
	Average of 5 bricks		Individual Brick		
	N/mm^2	kgf/cm^2	N/mm^2	kgf/cm^2	
Factory 1	16.2	162	12.6	126	**Class B**
			15.8	158	
			12.9	129	
			21.6	216	
			19.1	191	
Factory 2	9.4	94	10.3	103	**Class C**
			8.2	158	
			8.1	81	
			11.9	119	
			8.4	84	
Factory 3	8	80	9.7	97	**Class D**
			6.7	67	
			9.2	92	
			7.6	76	
			6.7	67	

4.4.2. Dimension test result

Table 4-8 shows the dimension test result of fired clay brick samples from selected factories and their classification of material based on standard. Only clay brick samples from factory two fulfills the nominal dimension of standard requirement.

Table 4-8 Dimension test result

Lab Des. No	Dimensions			Fulfilling the Nominal Dimension of Standard Requirement(ECS 26:2013)
	Average of 20 bricks			
	Height (mm)	Breadth (mm)	Length (mm)	
Factory-1	52.16	115.66	236.81	**X (Doesn't fulfill)**
Factory-2	62.5	116.75	254.16	✓ **(Does Fulfil)**
Factory-3	57.37	119.25	237.51	**X (Doesn't fulfill)**

4.4.3. Efflorescence test result

Table 4-9 shows the results of efflorescence rating, and the result shows Nil for all clay brick samples.

Table 4-9 Test Result of efflorescence rating

Lab Des. No	Company	Efflorescence rating
Factory 1	Company -1	Nil
Factory 2	Company -2	Nil
Factory 3	Company -3	Nil

4.4.4. Water absorption and saturation coefficient test result

Table 4-10 shows the water absorption and saturation coefficient test result of fired clay brick samples from selected factories and their classification of material based on standard. Accordingly, factory (1), (2) and (3) samples are classified under class A, class B and class, respectively, based on standard requirement of (ECS 26: 2013).

Table 4-10 Test Result of water absorption and saturation coefficient

Lab Des. No	Water Absorption (%)				Saturation Coefficient		Class of material based on standard requirements
	24 hrs. immersion		5hrs. Boiling				
	Average of 5 bricks	Individual Brick	Average of 5 bricks	Individual Brick	Average of 5 Bricks	Individual Brick	
Factory 1	17	14	17	15	0.97	0.96	Class A
		17		18		0.98	
		17		17		0.99	
		17		18		0.95	
		18		18		0.98	
Factory 2	19	19	20	19	0.98	0.98	Class B
		16		16		0.98	
		22		23		0.97	
		21		21		0.98	
		19		20		0.98	
Factory 3	20	21	17	32	1.312	0.66	Class C
		21		21		1	
		21		34		1.7	
		18		12		1.6	
		18		11		1.6	

4.5 Summary of the Results

I. Proportioning of raw material, mixing water ratio and firing temperature is largely depending on experience of the workers in all three brick manufacturing companies.

II. Raw materials used by two factories (factory two and three) are quarried clay material. Factory one is using ordinary excavated soil purchased from different suppliers due to lack of permission for quarrying from the local authority since the company is held by foreigners. Even if the raw materials are not quarried clay soils this company (Factory one) manage to produce clay bricks equal and even better quality than other companies by using coal as one of raw material.

III. There is no test conducted either on the raw materials or on the produced brick at different stage of production at all brick manufacturing companies.

IV. At factory two and three after a green brick is produced it is transported to the shades by hand which affects the shape, size and form of end product. However, at factory one green column brick out from the extruder cut in shape twenty (20) pieces at a time and transported with a wheelbarrow without hand contact to the bricks which increase speed of production and also providing better quality of shape, size and form of the end product.

V. At each kiln compartment around 2800 (two thousand eight hundred) bricks are fired and around 5 - 10% is broken resulting from under firing.

VI. The colour of fired brick is partly black and partly brown red coloured bricks which have poor aesthetical values resulted from over firing of the bricks are the usual loss of these factories.

VII. The only types of bricks produced in these factories are faced bricks and solid common bricks and all these products have sizes of 25cm x 12cm x 6cm.

CHAPTER FIVE: Design of Load Bearing Wall Based on the Material Assessment and Cost Comparison

In this chapter typical plan of three-story concrete framed structure apartment building is designed as a loadbearing structure for comparison. The comparison of costs of the construction of the load bearing and the reinforced concrete apartment buildings is fundamental objective this thesis.

5.1. Design of Load Bearing Wall

5.1.1 Basic Design Considerations and Assumption

Load bearing construction is most appropriately used for buildings in which the floor area is subdivided into a relatively large number of rooms of small to medium size and in which the floor plan is repeated on each story throughout the height of the building. These considerations give ample opportunity for disposing load bearing walls, which are continuous from foundation to roof level and, because of the moderate floor spans, are not called upon to carry unduly heavy concentrations of vertical load. For that a suitable 10/90 G+2 reinforced concrete framed saving house building design is selected. The proposal considers the block construction material (brick) and the construction & design methodology (Load Bearing wall) to be an alternative way for solving housing problems.

5.1.2. Benefit of proposal

Brickwork load-bearing structures have been replaced more and more in this century by structures of reinforced concrete and structural steel. Why, then, should we concern ourselves with calculated load-bearing brickwork as a construction material of the present and future? Among many reasons, the fact that brick is made of cheap, abundant raw material that requires little in the way of purification before use and that brick is a low energy material adds the material to be selected among other building materials [3]. The case studies made based on the developed countries have proven that brick have got cost related advantage, At the same time brick bearing wall has a good quality regarding thermal insulating property, low fuel consumption and manufacturing energy consumption.

As the height of a building increases, the construction and design of its load-bearing structure become increasingly complex. This complexity arises from the need to account for additional wind and seismic loads, making both the design and construction more challenging. It is believed that by initially focusing on low-rise buildings, we can gradually progress and attain the technological achievements in this field that developed countries have reached.

In addition, the building of a brick structure, being labour-intensive, will create a job opportunity for many labours. But above all Cost studies carried out in the United States of America, Switzerland, Australia and the United Kingdom have shown that for medium rise apartment buildings load-bearing brick structure may, depending on local conditions, be 10% to 15% cheaper than an equivalent reinforced concrete or steel framed structure.

5.1.3. Verification for Structural Use

5.1.3.1 Introduction

This section contains the structural assessment of implementing the bricks tested in chapter four as masonry wall unit for the construction of an G+2 housing apartment having a total area of 146 m^2 (figure 5-1). For simplification of the analysis and design the only the marked segment of the building is considered as it's the remaining portion symmetric to the one considered.

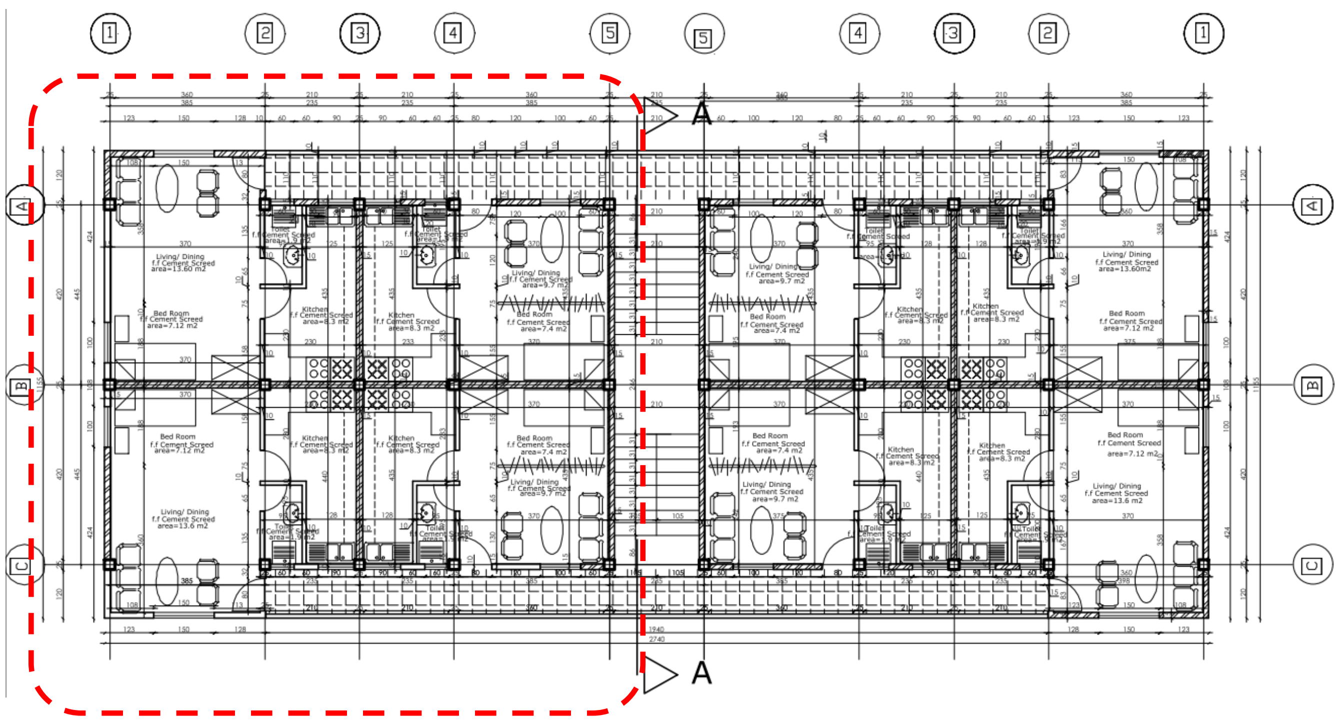

Figure 5-1 - 1st and 2nd floor plan of the building considered.

5.1.3.2. Scope

The design review is based on the following assumptions and criterion

- The verification is based on EC 1996-1 to 3:1999.
- The verification is carried out for the vertical load bearing capacity of the masonry wall based on the test results on chapter four and specifically company no (1) one resulting class B bricks.
- The slab system of the buildings is pre-cast rib slab system with rib blocks as shown in Figure 5-2.

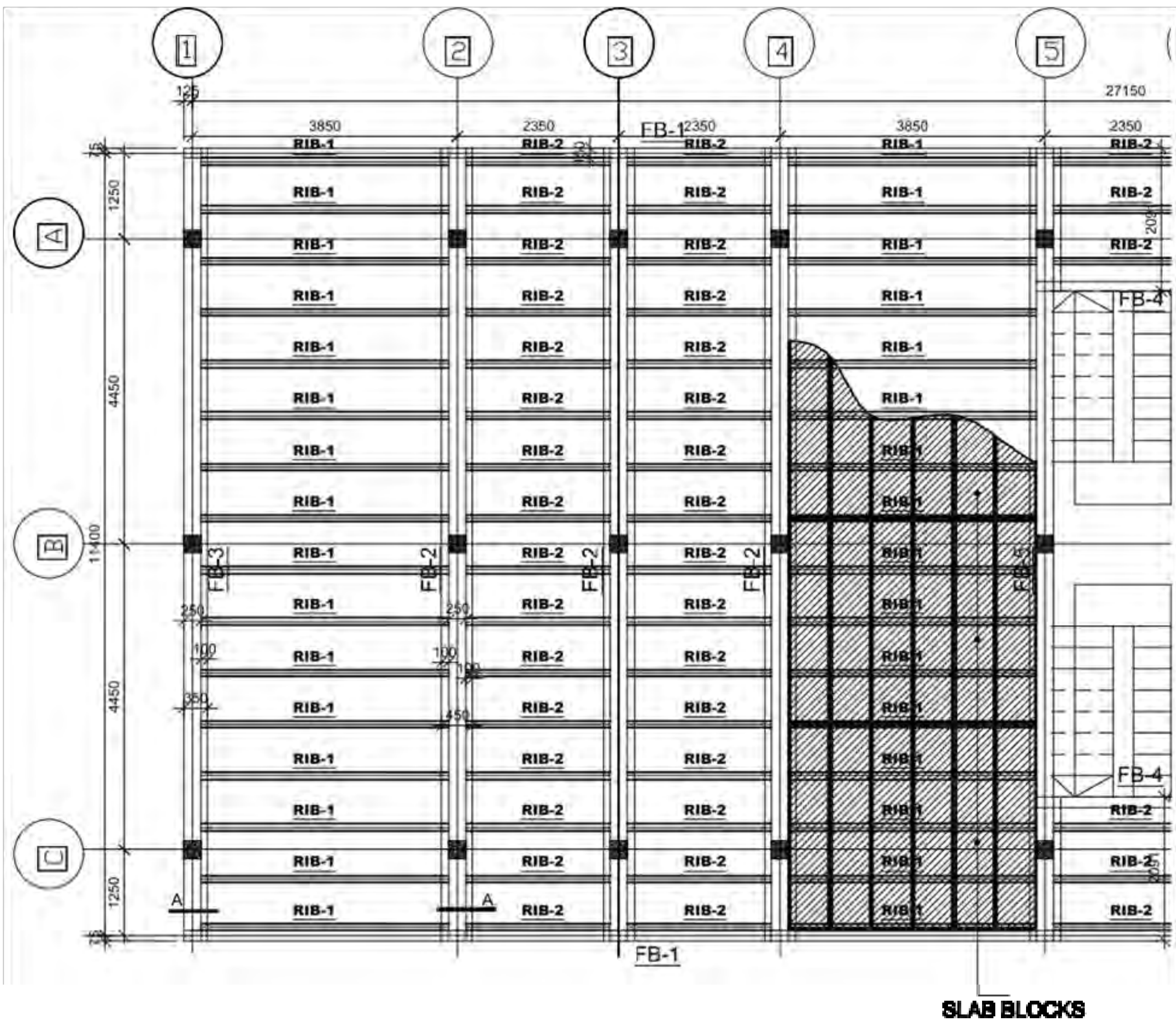

Figure 5-2 – Slab system

5.1.3.2. Conceptual Structural System

In accordance with the architectural function of building, as shown in Figure 5-3, and with minimal effect on the original slab system on Figure 5-2) the following layout of load bearing brick walls and beam system is proposed for the conceptual verification.

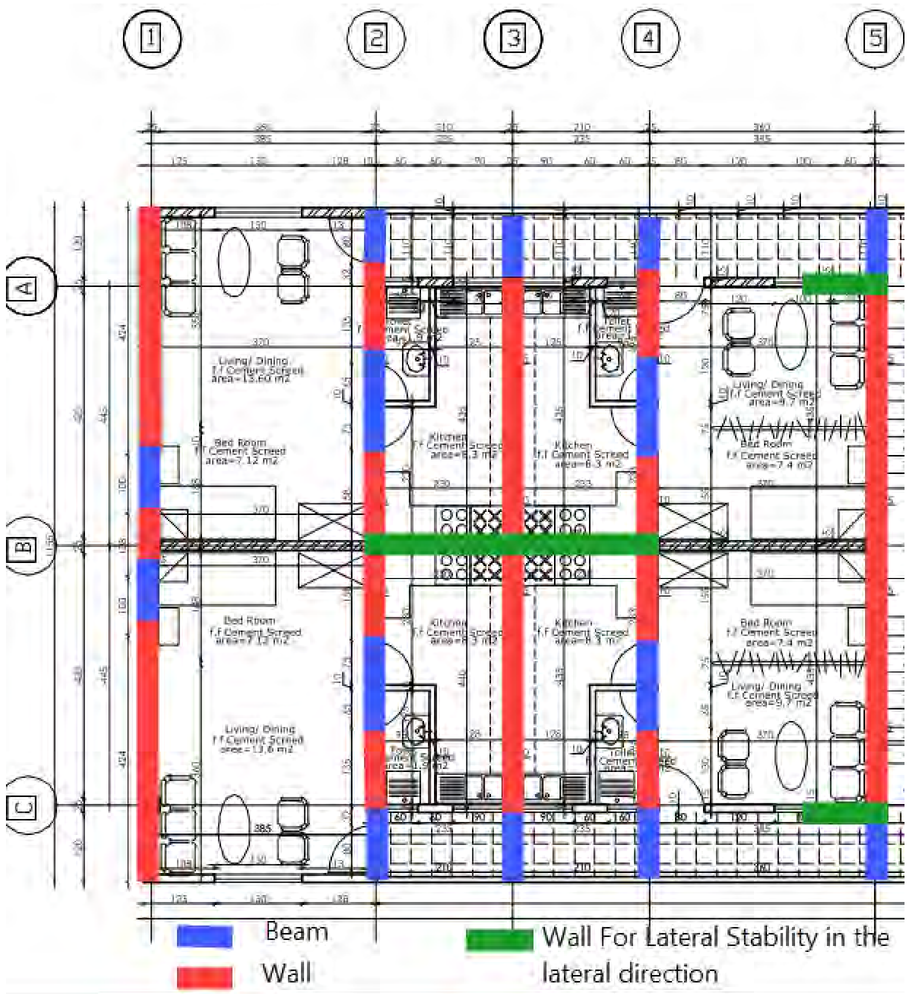

Figure 5-3 – Conceptual structural system layout.

I. The Typical Floor beams have a dimension of 25x40cm
II. The thickness of Brick walls is 25cm
III. The thickness of walls is the same at all storey
IV. Strip footing is size 50 x 30 cm
V. Grade beam is size 20x40 cm
VI. Masonry under grade beam is size (50 cm and 130cm depth)

Design of unreinforced masonry walls using simplified calculation methods, determination of the design load resistance of wall and finite element analysis results are attached on appendix D of this thesis.

5.2. Cost Analysis of the Proposal

5.2.1 Cost Estimating Method

One way to determine the expenses associated with the two construction approaches is by physically building the two apartment buildings at a specific site under controlled experimental conditions using work study methods. However, due to financial and time limitations, this approach has been discarded. Instead, a ***contractor bid estimate method***, which involves creating cost estimates based on completed plans and specifications, taking into account the actual quantities required for both reinforced concrete and loadbearing buildings, is deemed appropriate for the purposes of this thesis.

5.2.2 Estimation of Construction Costs for Load bearing brick structure and reinforced concrete structure

The estimate is based on the preliminary design of brick framed structure and reinforced concrete design attached on appendix D.

The estimated cost to a contractor of carrying out the work is known as the construction cost and is composed of directs cost of carrying out the work to which are added the site overheads (on costs). A direct cost consists of the cost of the resources like materials, labor, equipment, and sub-contractors needed to carry out a specific, well-defined item of work. Site overheads or “on cost” include all of those costs needed to operate the site work production activities that cannot be attributed to direct costs.

5.2.3 Components of the Structures for Cost Estimating

Table 5.1 & Table 5.2 summarize components or items of which the cost comparison is carried out for both type of building type.

Table 5-1 Sub Structure Items/Components under consideration

(A) Load-bearing structure Components		(B) Reinforced Concrete Structure Components	
	A. Sub-Structure /LB		**B. Sub-Structure /RC**
	1.Excavation & Earth Works		**1.Excavation & Earth Works**
	2. Concrete Works		**2. Concrete Works**
1.1	**Reinforced concrete in class C-25**	1.1	Reinforced concrete in class C-25
1.2	**Formwork**	1.2	Formwork
1.3	**Reinforcement steel bars**	1.3	Reinforcement steel bars
	3. Masonry Work		**3. Masonry Work**

Table 5-2 Super Structure Items/Components under consideration

(A) Load-bearing structure Components		**(B) Reinforced Concrete Structure Components**	
	A. Super-Structure /LDB		**B. Super-Structure /RC**
	1. Concrete Works		**1. Concrete Works**
1.1	**Reinforced concrete in class C-25**	1.1	Reinforced concrete in class C-25
1.2	**Formwork**	1.2	Formwork
1.3	**Reinforcement steel bars**	1.3	Reinforcement steel bars
	2. Block Works		**2. Block Works**
2.1	**25cm thick Clay Bricks**	2.1	20cm thick HCB wall for External walling
2.2	**20cm thick HCB wall for** External walling	2.2	15cm thick HCB wall for internal walling
2.3	**15cm thick HCB wall for internal walling**	2.3	10cm thick HCB wall for internal walling
2.4	**10cm thick HCB wall for internal walling**		**3. Finishing Works**
	3. Finishing Works	3.1.	Plastering
3.1.	**Plastering**	3.2.	Gypsum Work
3.2.	**Gypsum Work**		**4. Painting**
3.3.	**Pointing Work**	4.1	Plastic Paint
	4. Painting	4.2	Quartz Paint
4.1	**plastic Paint**		
4.2	**Quartz Paint**		
4.3	Varnish Paint		

Some structural parts and finishing items which were considered the same in the two buildings were not included in the estimation because they have no effect on the comparison. Among structural parts floor slabs, stair case, top-tie beams and from non-structural parts floor tiles, doors and windows, electricity, water supply and drainage systems, also roofing are not considered in the cost comparison.

5.2.4 Breakdown of unit rate for estimates

Cost breakdown for all basic items described on the previous sub topic are carried out to come up with unit rate. The unit price estimated in the breakdown is inclusive of material, labor and on equipment and site overhead and profit by 15% for each item. And the result of the breakdown was taken for the calculation of bill of quantities Tables 5-2.

5.2.5 Total Estimated Costs

The quantity of each element or activity is calculated, using standard method of measurements and their unit cost is estimated, then bills of quantities is prepared, and hence the total estimated costs is determined for both reinforced concrete and the load bearing buildings.

5.2.6. Cost Analysis of the Proposal (load bearing structure vs. RC framed structure)

Based on estimated cost for both type of structures cost for each items under consideration are analyzed. Table 5-3 and Table 5-4 shows in summary the comparison of the results of the two types of structure for sub structure and for super structure respectively.

The total amount of Sub structure cost for both types of structures does not have much difference. However, item no 2.4 Reinforcement steel bars in Table 5-3; load bearing structure has a significant saving comparing with that of reinforced concrete structure.

In addition, Table 5-4 shows Super structure cost comparison of load bearing and reinforced concrete framed structures.

Table 5-3 shows the summary of the results of the cutting exercise for the two types of structure.

Item No.	Type	Unit	Unit Rate	Reinforced Concrete Skeleton Structure		Load bearing Brick Walls Structure	
				Quantity	Price in Birr	Quantity	Price in Birr
A	**SUB – STRUCTURE**						
1	**EXCAVATION & EARTH WORKS**						
1.1	Site clearing	m^2	6.00	147.00	882.00	147.00	882.00
1.2	Bulk excavation in ordinary soil	m^3	80.00	58.80	4,704.00	44.10	3,528.00
1.3	Excavate in ordinary soil for isolated footing	m^3	75.00	40.55	3,041.25	55.89	4,191.75
1.4	Fill around footings and foundation column	m^3	90.00	36.56	3,290.40	47.30	4,257.00
1.5	Backfill under hard core density.	m^3	110.00	41.10	4,521.00	41.10	4,521.00
1.6	Cart away surplus excavated material	m^3	95.00	92.19	8,758.05	82.09	7,798.55
1.7	25cm thick stone hard-core	m^2	130.00	102.76	13,358.80	102.76	13,358.80
Sub Total- 1.1					38,555.50		38,537.10
2	**Concrete work**						
2.1	50mm thick lean concrete class C-5						
a	under Footing Pad	m^2	80.00	10.68	854.40	26.43	2,114.40
b	underground beam	m^2	80.00	17.61	1,408.80	6.21	496.80
c	under Ground floor slab	m^2	80.00	102.76	8,220.80	102.76	8,220.80
2.2	Reinforced concrete in class C-25				-		-
a	In foundation column	m^3	2786.71	1.17	3,260.45	-	-
a	In Footing Pad	m^3	2,786.71	2.82	7,858.52	7.93	22,098.61
b	In 100mm thick ground floor slab	m^2	350.00	102.76	35,966.00	102.76	35,966.00
c	In Ground floor beams	m^3	2,786.71	7.05	19,646.31	4.43	12,345.13
Sub Total- 2.1 & 2.2					77,215.28		81,241.74
2.3	**Provide, cut and fix form work**				-		-
a	to footing pad	m^2	181.87	3.60	654.73	33.48	6,089.01
c	to foundation column	m^2	181.87	18.75	3,410.06	-	-
b	to Ground floor beams	m^2	181.87	35.22	6,405.46	21.90	3,982.95
Sub Total- 2.3					10,470.26		10,071.96
2.4	**Reinforcement steel bars**				-		-
	a) dia. 6mm - 12 mm	Kg	37.02	1,049.69	38,859.66	622.08	23,029.47
Sub Total- 2.4					38,859.66		23,029.47
3	**Masonry work**						
	3.1) Stone Masonry	m^3	1600	44.03	70,448.00	44.1	70,560.00
	3.2) Brick Masonry	m^2	853.35	-	-		-
Sub Total- 2.5					70,448.00		70,560.00
Total Sub Structure Cost					**235,548.70**		**223,440.26**

Table 5-4 Cost Analysis/Comparison

B	**SUPER- STRUCTURE**						
1	**CONCRETE WORK**						
1.1	**Reinforced concrete in class C-25**						
	1) Elevation Column	m^3	2786.71	7.59	21,151.13	-	-
	2) Floor Beam	m^3	2786.71	16.46	45,869.25	3.4	9,474.81
1.2	**Formwork**						
	1) Elevation Column	m^3	181.87	117	21,278.79	-	-
	2) Floor Beam	m^3	181.87	217.11	39,485.80	35.7	6,492.76
1.3	**Reinforcement steel bars**						
	a) dia. 6mm - 12 mm	Kg	37.02	1,345.15	49,797.46	599.28	22,185.42
	Sub Total- 1				177,582.42		38,152.99
2	**BLOCK WORKS**						
2.1	25cm thick Clay Bricks	m^2	853.35	-	-	350.60	299,184.51
2.2	20cm thick HCB wall for External walling	m^2	270.44	270.43	73,135.09	119.52	32,322.99
2.3	15cm thick HCB wall for internal walling	m^2	256.19	270.40	69,273.78	91.88	23,538.74
2.4	10cm thick HCB wall for internal walling	m^2	208.76	96.00	20,040.96	96	20,040.96
	Sub Total- 2				162,449.83		375,087.20
3	**FINISHING WORK**	-					
	3.1. Plastering						
(a)	Internal Wall Plastering	m^2	150.74	1,003.23	151,226.89	495.28	74,658.51
(b)	External Wall Plastering	m^3	158.59	270.43	42,887.49	119.52	18,954.68
	3.2. Gypsum Work				-		
(a)	Internal Wall	m^2	55.36	1,003.23	55,538.81	495.28	27,418.70
	3.3. Pointing Work				-		
(a)	Internal & External Pointing	m^2	56.08	-	-	701.20	39,323.30
	Sub Total- 3				249,653.20		160,355.18
4	**PAINTING**	-					
4.1	Three coat plastic Paint	m^2	62.19	1,003.23	62,390.87	495.28	30,801.46
4.2	Quartz Paint to external Plastered HCB wall	m^2	146.99	270.43	39,750.51	119.52	17,568.24
4.3	Varnish Paint to external pointed brick wall	m^2	28.92	-	-	171.10	4,948.21
	Sub Total- 4				102,141.38		53,317.92
	Total				**691,826.82**		**626,913.29**

5.2.7. Saving in total project cost for the load bearing structure

Table 5-5 shows the summary of the results of the saving in birr and in percentage for the load bearing structure.

Table 5-5 Cost Saving

Item No.	Type	Reinforced Concrete Skeleton Structure	Load bearing Brick Walls Structure	Cost Saving	Cost Saving
		Price in Birr	Price in Birr	Price in Birr	In %
A. SUB – STRUCTURE					
1	**1.EXCAVATION & EARTH WORKS**	**38,555.50**	**38,537.10**	18.40	**0.0%**
2	**Concrete**				
1.1	Reinforced concrete in class C-25	77,215.28	81,241.74	(4,026.46)	**0.0%**
1.2	Form Work	10,470.26	10,071.96	398.30	**3.8%**
1.3	Reinforcement steel bars	38,859.66	23,029.47	15,830.19	**40.7%**
3	**Masonry work**				
3.1	Stone Masonry & Brick Masonry	70,448.00	70,560.00	(112.00)	**0.0%**
Total Sub Structure		**235,548.70**	**223,440.26**	**12,108.43**	**5.1%**
A. SUPER – STRUCTURE					
1	**Concrete**				
1.1	Reinforced concrete in class C-25	67,020.38	9,474.81	57,545.56	**85.9%**
1.2	Form Work	60,764.59	6,492.76	54,271.83	**89.3%**
1.3	Reinforcement steel bars	49,797.46	22,185.42	27,612.04	**55.4%**
2	**Block WORKS**				
2.1	25cm thick Clay Bricks	-	299,184.51	(299,184.51)	**0.0%**
2.2	20cm thick HCB wall for External walling	73,135.09	32,322.99	40,812.10	**55.8%**
2..3	15cm thick HCB wall for internal walling	69,273.78	23,538.74	45,735.04	**66.0%**
2.4	10cm thick HCB wall for internal walling	20,040.96	20,040.96	-	**0.0%**
3	**FINISHING WORK**				
3.1	Plastering & Pointing	194,114.38	132,936.48	61,177.90	**31.5%**
3.2	Gypsum Work	55,538.81	27,418.70	28,120.11	**50.6%**
4	**PAINTING**				
4.1	Three coat plastic Paint	62,390.87	30,801.46	31,589.41	**50.6%**
4.2	Quartz Paint to external Plastered HCB wall	39,750.51	17,568.24	22,182.26	**55.8%**
4.3	Varnish Paint to external pointed brick wall	-	4,948.21	(4,948.21)	**0.0%**
Total Super Structure		**691,826.82**	**626,913.29**	**64,913.53**	**9.38%**

5.2.8. Saving in total project cost for the load bearing structure per meter square

Table 5-6 shows the summary of the results of the saving in birr and in percentage for the load bearing structure.

Table 5-6 Cost saving per square meter

Saving in total Project cost for the load bearing Structure per square Meter			
Item No.	Type	Reinforced Concrete Skeleton Structure	Load bearing Brick Walls Structure
		Price in Birr	Price in Birr
Sub-Structure			
	Total Sub Structure Cost	235,548.70	223,440.26
	Total Area of the building (B)	146	146
	No of Story (C)	3.00	3.00
	Cost per one (1m2) Square meter(A/(B*C))	537.78	510.14
	Cost Saving per one (1m^2) Square meter- In Birr	27.64	
	Cost Saving per one (1m^2) Square meter- In percent%	**5.14%**	
Super-Structure			
	Total Super Structure Cost	691,826.82	626,913.29
	Total Area of the building (B)	146	146
	No of Story (C)	3.00	3.00
	Cost per one (1m2) Square meter(A/(B*C))	1,579.51	1,431.31
	Cost Saving per one (1m^2) Square meter- In Birr	148.20	
	Cost Saving per one (1m^2) Square meter- In percent%	**9.38%**	
Sub-Structure + Super Structure			
	Total Cost (A)	927,375.52	850,353.55
	Total Area of the building (B)	146	146
	No of Story (C)	3.00	3.00
	Cost per one (1m2) Square meter(A/(B*C))	2,117.30	1,941.45
	Cost Saving per one (1m^2) Square meter- In Birr	175.85	
	Cost Saving per one (1m^2) Square meter- In percent%	**8.31%**	

5.2.9. Quantities of the main materials

Table 5-7 summaries the quotation of the calculated constituent materials used in each type of construction method.

Table 5-7 Constituent materials

Item No.	Description	Unit	Reinforced Concrete Skeleton	Load bearing Structure
1	Cement	Qtl	1,835.79	579.45
2	Sand	m^3	113.79	112.06
3	Aggregate	m^3	145.42	134.62
4	Reinforcement bar	kg	2,394.84	1,221.36
5	HCB Wall	Pcs	8,510.75	4,393.75
6	Clay Bricks	Pcs	-	40,319.00
7	Gypsum	Qtl	70.23	34.67
8	Quartz Paint	Gall	45.97	20.32
9	Plastic Paint	Gall	70.23	34.67
10	Varnish	Gall		17.11

Figure 5-4 and Figure 5-5 shows the difference in material consumption in both type of construction methods.

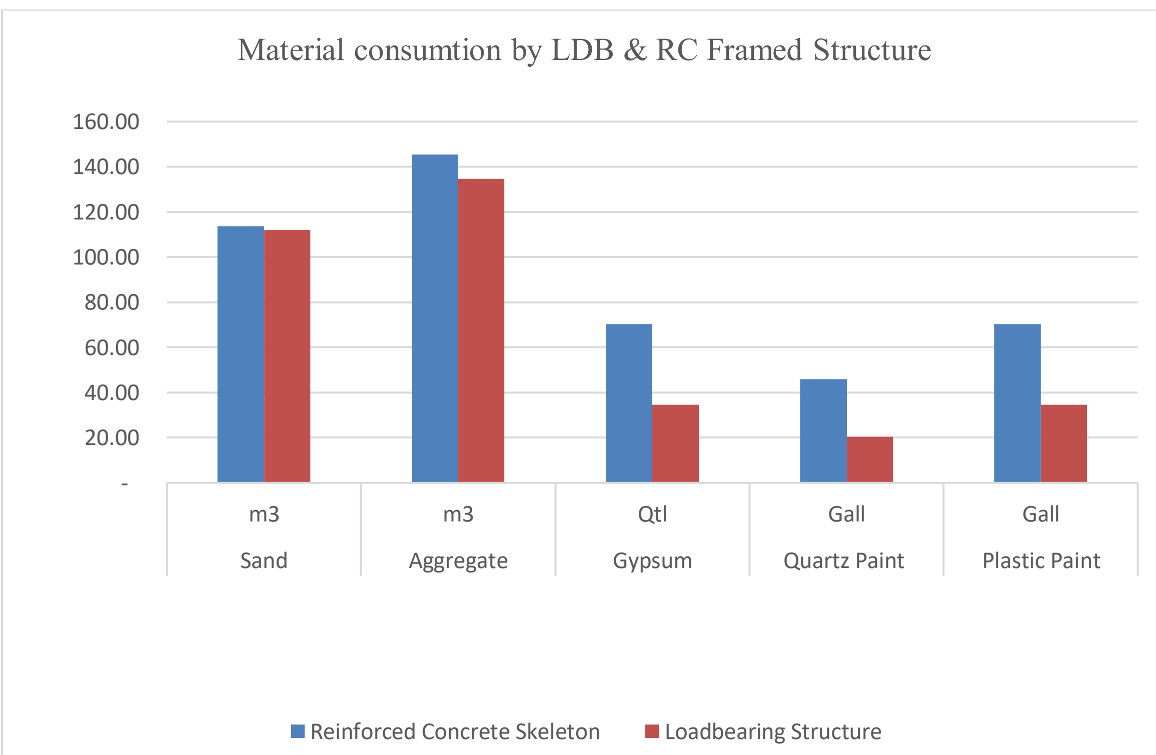

Figure 5-4 Material consumption

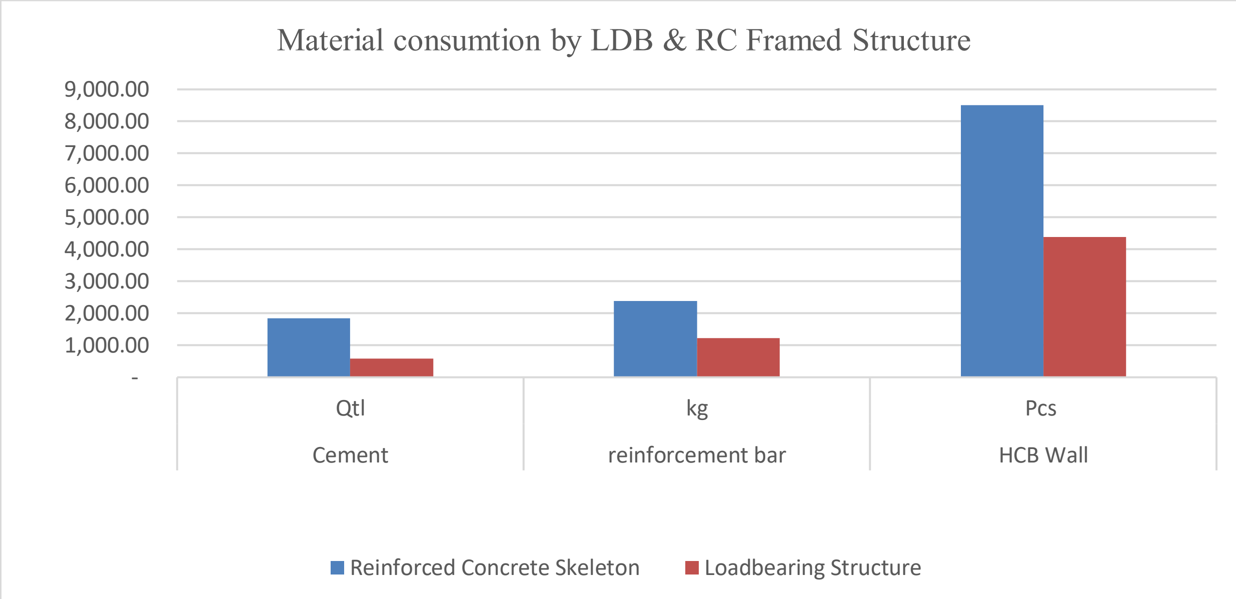

Figure 5-5 Material consumption

5.2.10. Saving in materials for the load bearing Structure

Table 5-6 computes the saving in the materials when designed as a loadbearing structure in absolute quantities and as a percentage taking reinforced concrete skeleton as a base.

Table 5-6 saving in constituent material

Item No.	Description	Unit	Reinforced Concrete Skeleton	Loadbearing	Save in Quantities	Save in %
1	Cement	Qtl	1,835.79	579.45	1,256.34	**68.4%**
2	Sand	m^3	113.79	112.06	1.73	**1.5%**
3	Aggregate	m^3	145.42	134.62	10.80	**7.4%**
4	reinforcement bar	kg	2,394.84	1,221.36	1,173.48	**49.0%**
5	HCB Wall	Pcs	8,510.75	4,393.75	4,117.00	**48.4%**
6	Clay Bricks	Pcs	-	40,319.00	(40,319.00)	**0.0%**
7	Gypsum	Qtl	70.23	34.67	35.56	**50.6%**
8	Quartz Paint	Gall	45.97	20.32	25.65	**55.8%**
9	Plastic Paint	Gall	70.23	34.67	35.56	**50.6%**
10	Varnish	Gall	-	17.11	(17.11)	**0.0%**

CHAPTER SIX: Conclusion and Recommendation

6.1. Conclusions

1. The quality of bricks produced is classified as class B, C and D in terms of compressive strength, water absorption and efflorescence. Also, the test results indicate that the brick samples don't fulfil the dimension tolerance of the standard. Thus, the qualities of bricks shall be improved to meet the requirement.
2. Raw materials have a significant effect on the quality of fired clay bricks. Addition of coal as a raw material improves the compressive strength of clay bricks also decreases the firing temperature.
3. Bricks production factories in and around Addis Ababa doesn't get quality certification for manufacturing of bricks from standard agency since the certification process closed in addition there is no continuous follow up of production and standardization of bricks produced.
4. Three storey load bearing building can be built from mechanized fired clay brick.
5. When the apartment building is designed and constructed as load bearing structure, there is saving in all materials except for the fired clay bricks and varnish paint. The saving in materials results in saving in cost of construction in general which makes the load bearing structure more economical than the reinforced concrete skeleton.
6. The saving in major construction materials such as cement, reinforcement steel, hollow concrete block, gypsum, quartz paint and plastic paint is to be noted. For the proposed project substructure saving for load bearing brick building is 5.14 which has reduced the cost by only 27.64 (Twenty-Seven and 64/100) birr per square meter. On the other hand, Superstructure saving for load bearing brick building is 9.38% for this project which has reduced the cost by only 148.20 (One Hundred Forty-Eight and 20/100) birr per square meter.
7. The overall saving is 8.31 % of total costs for this project which has reduced the cost by 175.85 (One Hundred Seventy-Five and 85/100) birr per square meter.
8. This is manifested in the analysis that there is saving in both materials and cost when using load bearing structure instead of reinforced concrete building and use of load bearing structure saves money.

6.2. Recommendations

1. The concerned government authority should establish standard of brick production process and quality control mechanism and certify products before they are sold to public use.
2. Addition of coal increase compressive strength of brick, thus, all factories should attempt this or other mechanisms to upgrade their product.
3. The encouragement of the load bearing structure will result in the establishing number of modern factories for brick and clay product in Ethiopia.
4. Further studies and proposals should be forwarded about bricks and load bearing brick wall structure and new techniques and applications should be forwarded to fully exploit brickwork capabilities.

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APPENDIX A: INTERVIEW QUESTIONNAIRES

ADDIS ABABA UNIVERSITY

SCHOOL OF CIVIL and ENVIRONMENTAL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING CONSTRUCTION TECHNOLOGY and MANAGEMENT STREAM

SURVEY INTERVIEW QUESTIONS FOR BRICK MANUFACTURING COMPANIES

1-Company profile

- Name of the company________________________________
- Years of establishment_______________________________
- Type of ownership

  Local government owned ☐ local private ☐ foreign ☐
- Certification from local authorities if any: ________________Year: _____________
- Average number of workers for the recent 10 years:

  Total_________________ Female_______________ Male___________
- The educational qualification of key personnel _________________________________
- Annual production capacity: Total production capacity_______________
- Types of brick produced ________________________,_________________________,

  ________________________,_________________________,____________________

2- **Material**

- What are the raw materials used for the brick manufacturing?

  ____

  ____
- Where is the source of raw materials?

  ____

  ____

  ____
- How do you select raw materials?

  ____

  ____
- How do you test raw materials?

  ____

  ____

- How do you test raw materials?

____

____

- How raw materials are transported and stored?

____

____

3- Material preparation, blending, proportion

- What main activities are done in raw materials preparation? How do you blend the raw materials and what is their proportion?

____

____

____

- What proportion of water you use for mixing the blended raw materials? How do you blend the raw materials and what is their proportion?

____

- How do you know/test the mix proportions?

____

- Please list any problem related to material production and utilization?

____

____

- Is there any cost that you pay for the raw materials?

  If no, ____

4. Production processes

- What are the steps for brick manufacturing?

____

____

____

____

____

____

- Do you use any kind of additional raw material or technology to improve the quality of brick manufactured (like colour, surface texture, strength and so on)? If yes what is the technology?

- What are the energy sources for firing?
- How long you fire bricks during production?
- How do you control the amount of temperature during firing?

5. **General questions**:

- What are the social, political and economic problems you encountered?
- Is there any market problem?
- Do you test the quality of the end product? If yes, what types of tests are done?
- What is your opinion about the quality of bricks produced in Ethiopia?

ADDIS ABABA UNIVERSITY

SCHOOL OF CIVIL & ENVIRONMENTAL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING CONSTRUCTION TECHNOLOGY & MANAGEMENT STREAM

Survey Questionnaire for Ethiopian standards Agency

1. Does your company perform standardization for construction materials such as bricks? If no, please specify your reason.

If yes what are the tests you conduct to know and standardize the quality tests of bricks? And can you provide me some of quality test results?

____

____

____

____

____

2. Please specify the names of brick Production Company registered and renewed their license for the manufacturing of bricks in Ethiopia.

1)__________________2)__________________

3)__________________4)__________________

5)__________________6)__________________

if none, please specify the reason

____

____

____

____

4. What is your opinion about the quality of bricks produced in Ethiopia throughout the past 5 decade?

____

____

____

5. Bricks are the oldest building materials made from the most abundant raw material. Do you think the bricks produced currently can be used as a load bearing wall material?

APPENDIX B: PICTURES

Picture B-1 Stock piled raw materials at Ethio Bricks

Picture B-2- Molded and cut clay bricks stay under shade to dry before firing - Ethio Bricks

Picture B-3 Artificial Drying of clay bricks

Picture B-4- Firing holes and heat absorber to transfer to artificial dryer

Picture B-5-Green Brick Column from the Extruder

Picture B-6- Pug mill mixer

Picture B-7- Primary Mixer

Test for burnet clay bricks

Picture B-8- Dimensional tolerance test for company 1

Picture B-9-Dimensional tolerance test for company 2

Picture B-10- Dimensional tolerance test for company 3

Picture B-11 Samples from Factory 1, 2 & 3 for Compressive strength test

Picture B-12-Coping the brick surface for Compressive strength test

Picture B-13 Compressive strength test for clay brick samples from three companies

Instrument Reading [KN]	Standard Reading [KN]	Correction [KN]	Error [%]	Repeatability [%]
0	0.0	0.0	....	...
50	45.7	-4.3	9.50	4.95
100	94.2	-5.8	6.17	1.35
150	143.5	-6.5	4.54	2.10
200	192.8	-7.2	3.75	0.68
250	241.6	-8.4	3.46	1.50
300	291.6	-8.4	2.89	0.39
400	391.7	-8.3	2.13	0.90
500	491.2	-8.8	1.80	0.61
600	589.5	-10.5	1.78	0.37
800	788.4	-11.6	1.47	0.25
1000	987.9	-12.1	1.23	0.09
1200	1187.8	-12.2	1.03	0.21
1400	1386.2	-13.8	0.99	0.23
1600	1585.6	-14.4	0.91	0.13
1800	1785.6	-14.4	0.81	0.06

Note: Corrected value = Instrument reading + correction

Picture B-14- Calibration of compressive strength test machine

Picture B-15- 24hr oven dying for water absorption test - Step 1

Picture B-16 - 24hr immersion in cold water for water absorption test - Step-2

Picture B-17-24 hour boiling at 105° - Step-3

Picture B-18- 24 hr Immersion in 2.5cm depth distilled water

APPENDIX C: LABORATORY TEST RESULTS

3. LABORATORY TEST RESULTS

3.1 COMPUTATION OF MEAN COMPRESSIVE STRENGTH TEST RESULT FOR BRICKS

Factory 1							
No	**Dimension**		**Area [cm2]**	**Failure Load**	**Correction**	**Failure Load- after correction**	**Compressive Strength**
	Length	Breadth	LxW	[KN]		[KN]	[MPa]
1	235	115	27025	348	-8.4	339.6	12.6
2	234	114	26676	429	-8.3	420.7	15.8
3	235	112	26320	349	-8.4	340.6	12.9
4	235	112	26320	579	-10.5	568.5	21.6
5	233	112	26096	507	-8.8	498.2	19.1
Factory 2							
No	**Dimension**		**Area [cm2]**	**Failure Load**	**Correction**	**Failure Load- after correction**	**Compressive Strength**
	Length	Breadth	LxW	[KN]		[KN]	[MPa]
1	250	116	29000	308	-8.4	299.6	10.3
2	254	116	29464	249.1	-8.4	240.7	8.2
3	236	115	27140	226.5	-7.2	219.3	8.1
4	236	123	29028	355	-8.3	346.7	11.9
5	256	117	29952	258.7	-8.4	250.3	8.4
Factory 3							
No	**Dimension**		**Area [cm2]**	**Failure Load**	**Correction**	**Failure Load- after correction**	**Compressive Strength**
	Length	Breadth	LxW	[KN]		[KN]	[MPa]
1	238	119	28322	282.4	-8.4	274	9.7
2	234	117	27378	191.3	-7.2	184.1	6.7
3	232	116	26912	255.8	-8.4	247.4	9.2
4	240	118	28320	224.9	-8.4	216.5	7.6
5	231	116	26796	188.9	-7.2	181.7	6.8

4.2 COMPUTATION OF DIMENTION TEST RESULT FOR BRICKS

Factory 1			
Description of task parameter	length(mm)	breadth (mm)	height(mm)
Row No 1	4736	2318.85	1046
Row No 2	4736.5	2308	1040.5
Average -40 Bricks	4736.25	2313.425	1043.25
Dimension per pcs	236.81	115.67	52.16
Factory 2			
Description of task parameter	length(mm)	Breadth (mm)	height(mm)
Row No 1	5055.64	2312	1125
Row No 2	5111	2358	1375
Average -40 Bricks	5083.32	2335	1250
Dimension per pcs	254.17	116.75	62.5
Factory 3			
Description of task parameter	length(mm)	breadth mm)	height(mm)
Row No 1	4750	2385	1145
Row No 2	4750.3	2385	1150
Average -40 Bricks	4750.15	2385	1147.5
Dimension per pcs	237.51	119.25	57.38

4.3 COMPUTATION OF WATER ABSORPTION AND SATURATION TEST RESULT FOR BRICKS

Factory 1						
No	WEIGHT			24 HRS (W2-W1)/W1	5HRS (W3-W1)/W1	Saturation coefficient
	W1	W2	W3	LxW	[KN]	
1	1892	2156	2166	14	14.5	0.97
2	2021	2373	2381	17.4	17.8	0.98
3	2173	2532	2536	16.5	16.7	0.99
4	1947	2274	2291	16.8	17.7	0.95
5	1889	2228	2233	17.9	18.2	0.98
Factory 2						
No	WEIGHT			24 HRS (W2-W1)/W1	5HRS (W3-W1)/W1	Saturation coefficient
	W1	W2	W3	LxW	[KN]	
1	2352	2797	2805	18.9	19.3	0.98
2	2323	2686	2693	15.6	15.9	0.98
3	2275	2778	2793	22.1	22.8	0.97
4	2120	2559	2567	20.7	21.1	0.98
5	2448	2924	2933	19.4	19.8	0.98
Factory 3						
No	WEIGHT			24 HRS (W2-W1)/W1	5HRS (W3-W1)/W1	Saturation coefficient
	W1	W2	W3	LxW	[KN]	
1	2085	2528	2756	21.2	32.2	0.66
2	2058	2499	2495	21.4	21.2	1.01
3	2031	2453	2730	20.8	34.4	0.6
4	2276	2694	2541	18.4	11.6	1.59
5	2315	2723	2571	17.6	11.1	1.59

W1= Weight of brick measured after Oven Drying for 24 hr

W2= Weight of brick measured after 24hr immersing in cold water

W3= Weight of Brick measured after 5hrs of boiling

APPENDIX D: VERIFICATION FOR STRUCTURAL USE

Loading

Own weight

Own weight, of all structural elements are calculated based the dimensions provided and the unit weight of reinforced concrete is taken as 25kN/m^3.
Unit weight of brick is taken as 21kN/m3.

Finishing and Installation

A superimposed permanent load of 1.2kN/m^2 is taken to account for the floor and ceiling finish and installations.

Partition

A superimposed permanent load of 1.0kN/m^2 is taken to account for partition.

Imposed Load

In accordance to EN-1991-1-1:2001 category A (Areas for domestic and residential activities) is found to represent the building. And this corresponds to an imposed area load of 2.0kN/m^2. The roof is taken to be Category H, with 0.40kN/m^2 imposed load acting.

Earthquake

Out of the scope.

Wind load Analysis

Out of the scope.

Load Combination

Please refer section **Error! Reference source not found.**. for the complete list of load c ombination used in accordance to;

EN-1990:2001	Basis of structural Design, and Actions on Structures
EN-1996-1-3:1999	Design of Masonry Structures

Materials

Concrete:

Concrete Grade C-25

f_{cuk}	**25**	Mpa
f_{ck}	**20**	Mpa
f_{ctm}	**2.21**	Mpa
f_{ctk}	**1.55**	Mpa
γ_c	**1.50**	
f_{cd}	**11.33**	Mpa
f_{ctd}	**1.03**	Mpa
E_{cm}	**29.00**	Gpa

Reinforcement:

ID	**Material Designation**	**F_{yk} [MPa]**	**E [GPa}**	**γ_s**
1	S300 (transverse/shear reinforcement)	300	200	1.15
2	S400 (Longitudinal reinforcement)	400	200	1.15

Brick

	f_{yk} [N/mm²]	**E_s [kN/mm²]**
	16.2	36

Design Load Combinations

The values of actions which occur simultaneously are combined as follows:

Persistent and transient design situation

Ultimate Limit State

General Format - $\sum \gamma_G G_k + \sum \gamma_{Qi} \psi_{0i} \times Q_{ki}$

$1.35 \times G_k + 1.5 \times Q_k$

FE Model

3D finite element model was done for the selected block using ETABS 2016 V0.3. The columns and beams were modeled as frame elements with cross section and material property in accordance to the specification in the structural drawings. The slab elements on the floor levels were modeled as ribbed slab system in accordance with the current drawing.

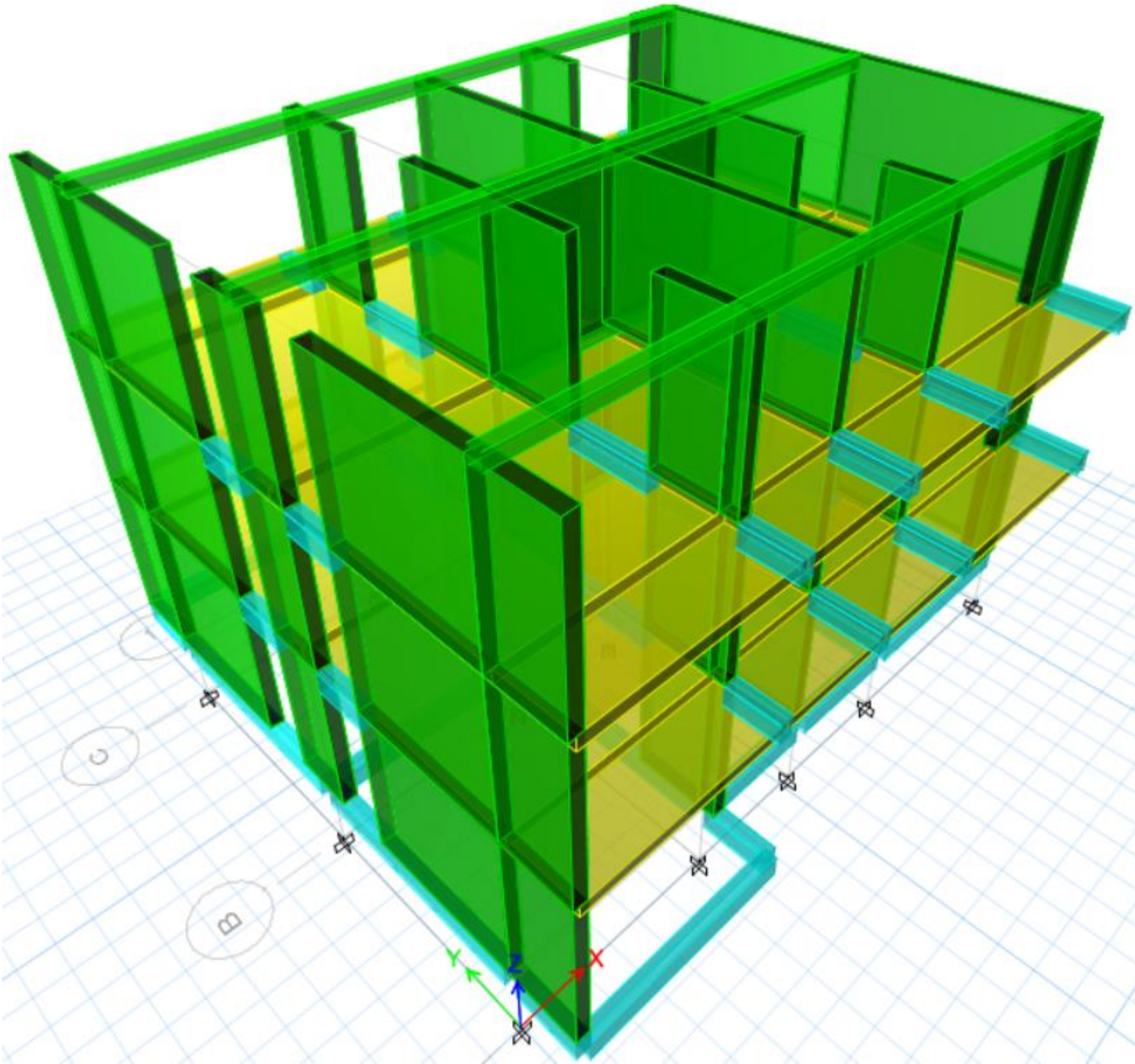


Figure 0-1 3D FE Model

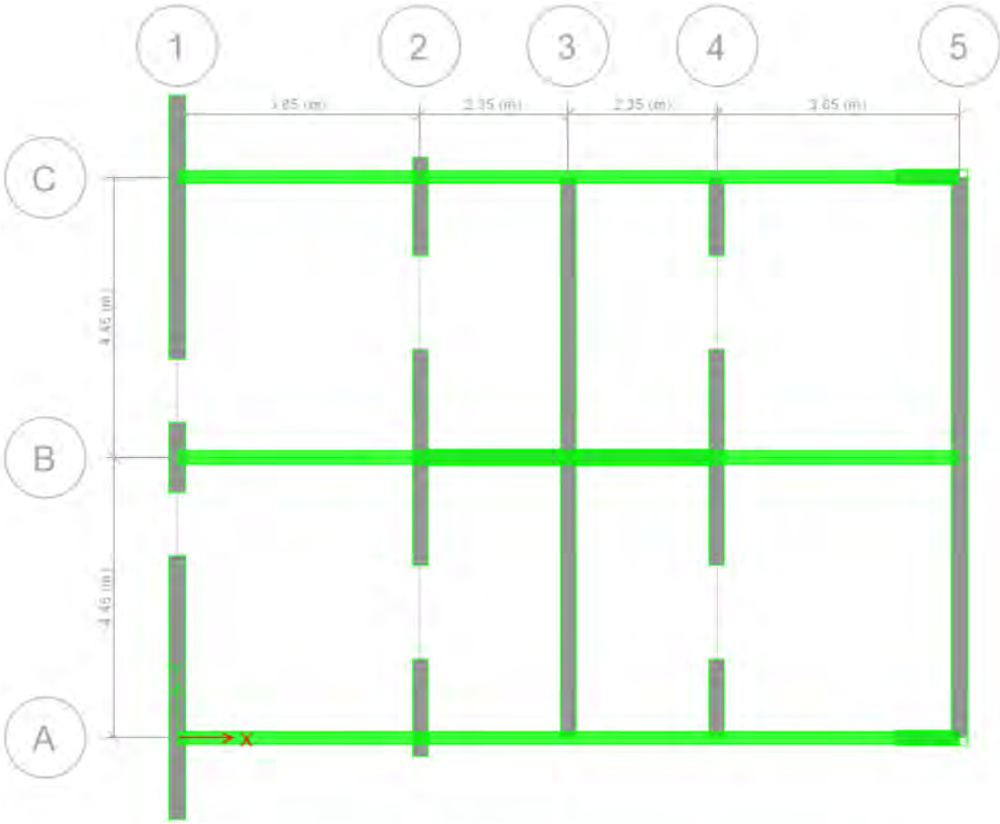


Figure 0-2 Roof FE Model

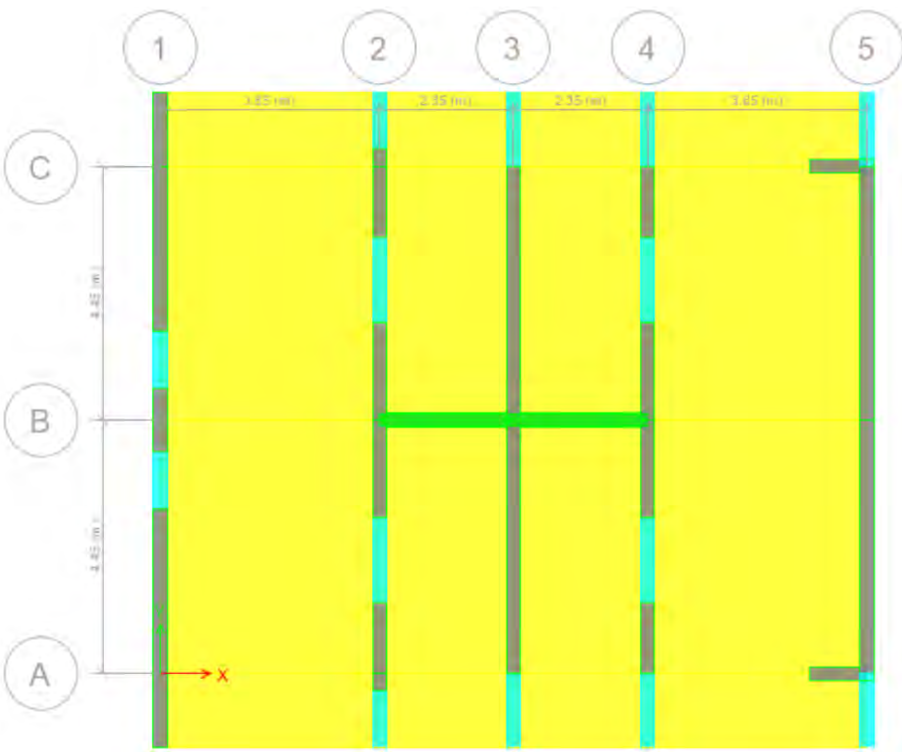


Figure 0-3 1st and 2nd Floor FE Model

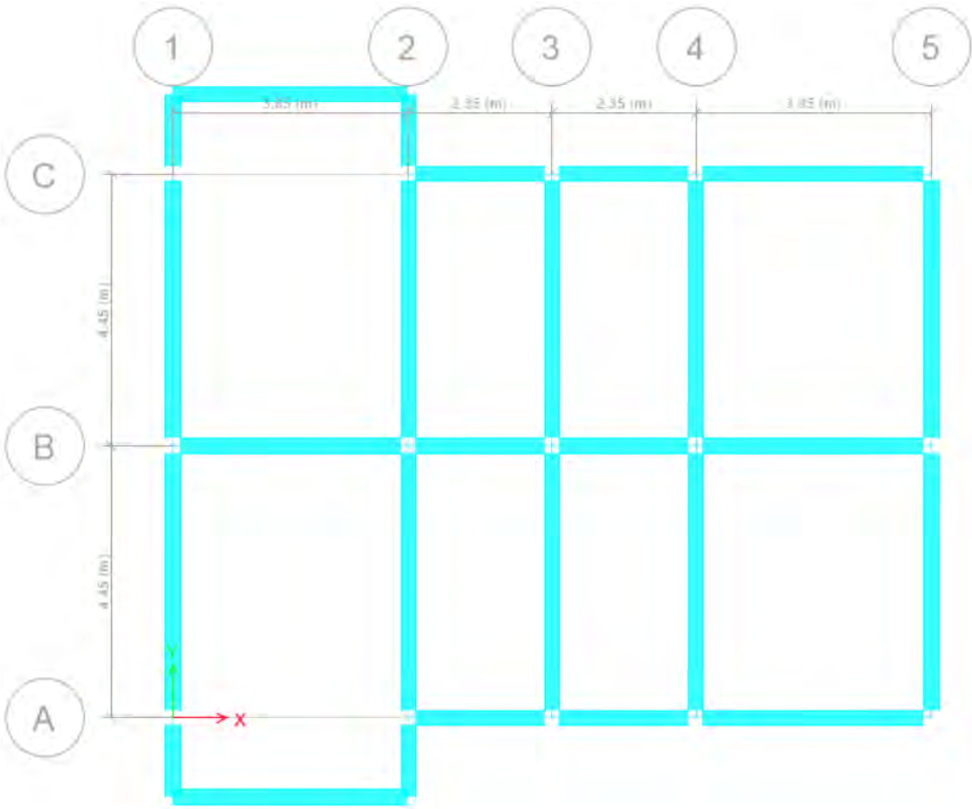


Figure 0-4 Ground Floor FE Model

Design of unreinforced masonry walls using simplified calculation methods

Conditions for simplified calculation method

The implementation of the simplified calculation approach in accordance to EN 1996-3:1999 is possible if and only if the following criteria are satisfied.

- Height of the building above ground is less than 20m.
- The span of the floors and roof supported by the walls does not exceed 7m.
- The clear storey does not exceed 3m.
- The thickness of walls is the same at all storeys.
- The characteristic values of variable actions on the floors or roofs do not exceed 5.0kN/m^3.
- No actions other than those listed are applied.
- The walls are to be laterally restrained by the floors and roof in the horizontal direction at right angles to the plane of the wall, either by the floors and roof themselves or by suitable methods.
- The final creep coefficient $\Phi_\infty$of the masonry does not exceed 2.0.

Determination of the design load resistance of wall

Under ULS the vertical load resistance of the wall N_{Rd}, should be greater than the design vertical load on the wall N_{Sd}. Hence, it is opted to calculate the load resistance of the a 1m long brick wall and compare its resistance with the FE model analysis output for verification.

$$N_{Rd} = \frac{\phi \cdot f_k \cdot A}{\gamma_M}$$

Where: Φ is the capacity reduction factor allowing for the effect of slenderness and eccentricity of the loading.

$$\phi = 0.85 - 0.0011\left(\frac{h_{ef}}{t_{ef}}\right)^2$$

$$\phi = 0.85 - 0.0011\left(\frac{0.75 \times 2.9}{0.2}\right)^2 = 0.72$$

f_k =16.2N/mm^2

γ_m= is the partial factor for the material. Which is 2.2 for the brick classification per the lab test result and class 1 manufacturing assumption.

A is the net area of the masonry, taking into account any openings.

A = 1000mm, x 200mm =200,000mm^2.

Therefore N_{Rd} = **1060kN** per 1 meter length of the brick wall.

For the analysis result of the FE model no wall carries a load greater than 1060kN per 1 meter length of the brick wall.

FE analysis result

Wal/Pier Label

The axial load carried by each brick wall segment are computed and read from the FE analysis by assigning pier labels for each segment as shown in **Error! Reference source not found.**.

The internal action forces carried by each wall is summarized on **Error! Reference source not found.**.

The results indicate that the axial load can be safely carried by the proposed brick wall.

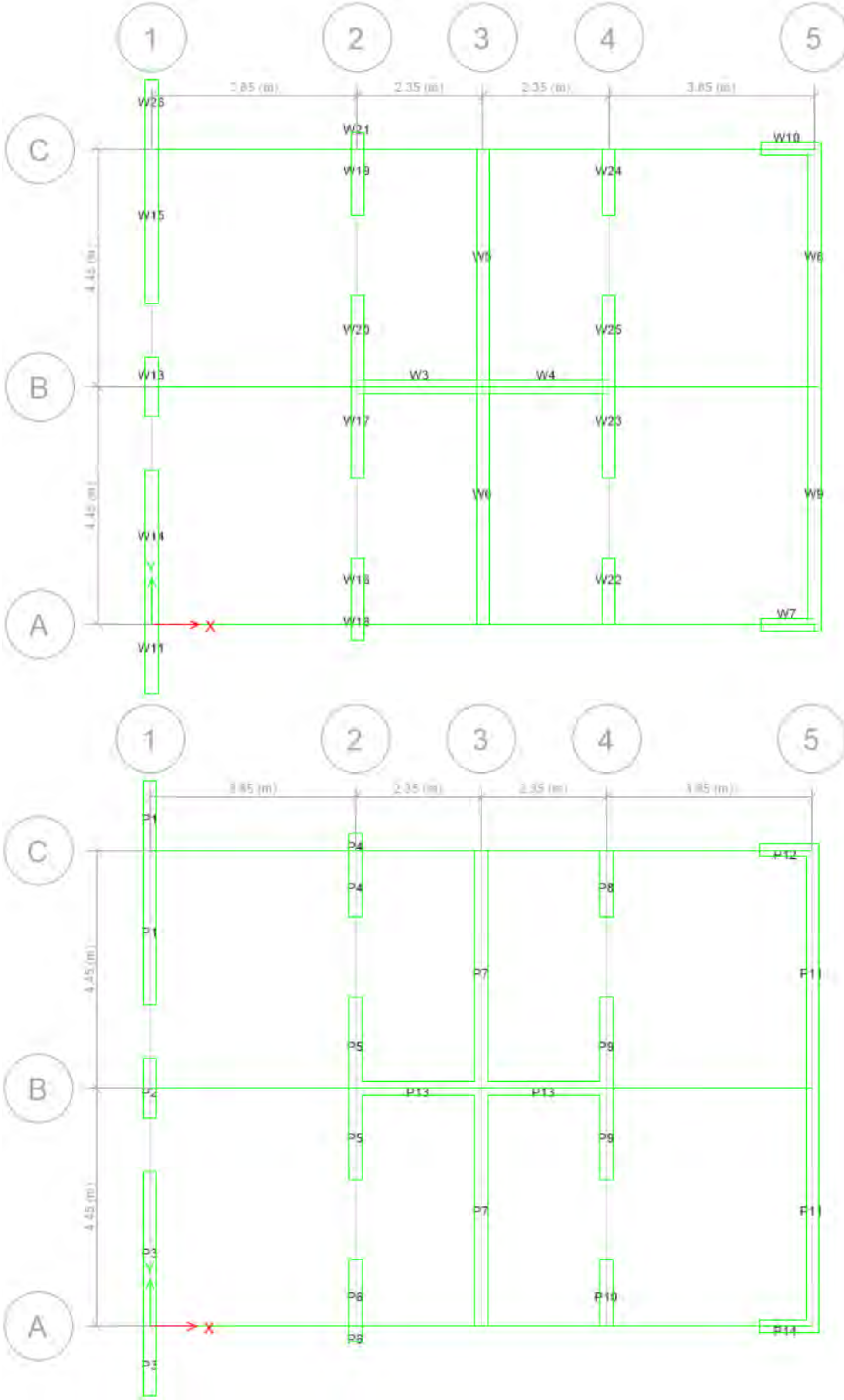


Figure 0-5 Wall and Pier Label

Table 0-1 Axial load carried by each wall/pier

Story	*Pier*	*Load Case/Combo*	*Location*	*P*
1st floor	P1	Gravity ULS	Bottom	-438.476
1st floor	P2	Gravity ULS	Bottom	-322.101
1st floor	P3	Gravity ULS	Bottom	-438.476
1st floor	P4	Gravity ULS	Bottom	-257.868
1st floor	P5	Gravity ULS	Bottom	-636.852
1st floor	P6	Gravity ULS	Bottom	-257.868
1st floor	P7	Gravity ULS	Bottom	-989.649
1st floor	P8	Gravity ULS	Bottom	-230.208
1st floor	P9	Gravity ULS	Bottom	-565.284
1st floor	P10	Gravity ULS	Bottom	-230.208
1st floor	P11	Gravity ULS	Bottom	-1095.63
1st floor	P12	Gravity ULS	Bottom	-123.376
1st floor	P13	Gravity ULS	Bottom	-1262.4
1st floor	P14	Gravity ULS	Bottom	-123.376

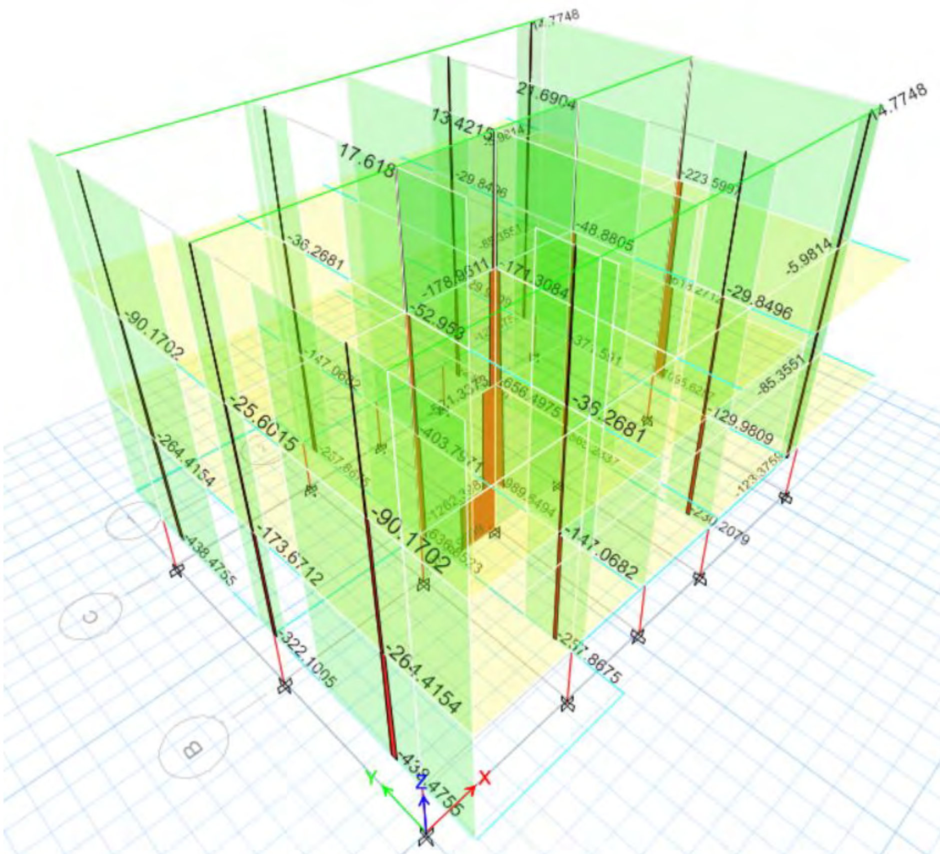


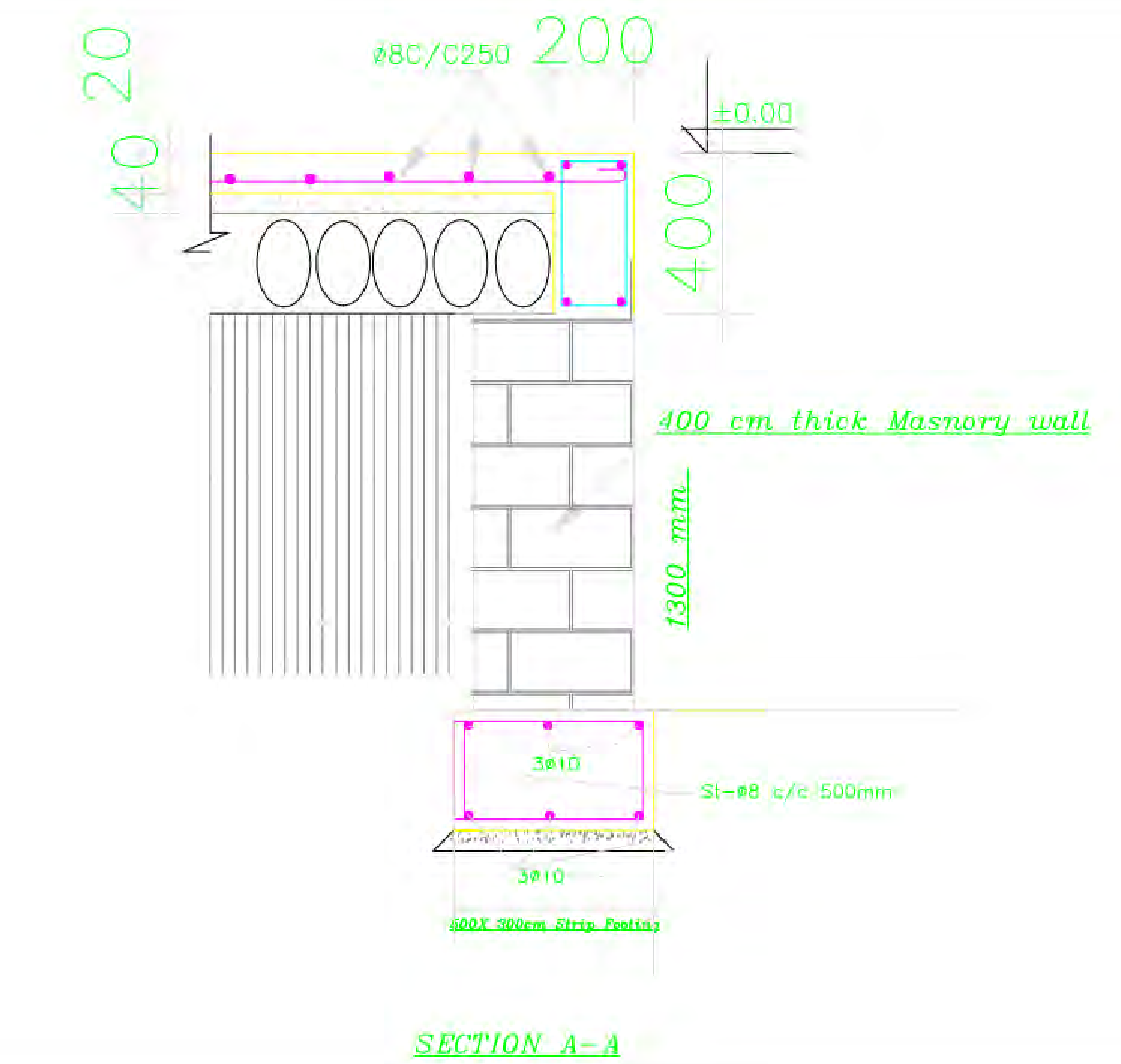
Figure 0-6 FE Analysis Results

Foundation Design

Two alternatives can be considered for the foundation design depending on the location at which these buildings are to be constructed;

a) Strip Foundation
b) Masonry wall foundation

Here, the use of strip foundation is considered. The depth and the dimensions of the strip foundation are dependent on the soil type. Assuming an allowable bearing capacity of 200kPa at a foundation depth of 2.0m from normal ground level and considering the maximum line load of 234.4kN/m ((on Wall22 or P10 as shown on Figure 1 8), the following strip foundation is proposed with dimension and reinforcement), the following strip foundation is proposed with dimension and reinforcement.



APPENDIX E: COST ESTIMATION

Table E-1 Cost Estimation for load bearing wall building

BILL OF QUANTITY

Project: G+2 Residential Building (Load bearing Brick structure Building)

ITEM	DESCRIPTION	UNIT	TAKE OFF QTY	UNIT PRICE	TOTAL PRICE
A. SUB – STRUCTURE					
	1.EXCAVATION & EARTH WORKS				
1.1	Site clearing and removing of the top 200mm thick soil	m^2	147.00	6.00	882.00
1.2	Bulk excavation in ordinary soil not exceeding 150cm from NGL allowing 25cm working space on each side.	m^3	44.10	80.00	3,528.00
1.3	Excavate in ordinary soil for isolated footing to a depth exceeding 270cm but not exceeding 3500 cm allowing 25cm working space on each side.	m^3	55.89	75.00	4,191.75
1.4	Fill around footings and foundation column to maintain the desired level with 50% selected borrowed and 50% from excavated site non expansive material and compact in layers not exceeding 20cm.	m^3	47.30	90.00	4,257.00
1.5	Backfill under hard core with non-expansive selected material from quarry and compact in layers not exceeding 20cm thick by sprinkling water to insure 95% modified AASHTO dry density.	m^3	41.10	110.00	4,521.00
1.6	Cart away surplus excavated material to a distance not exceeding 5Km's. but not exceeding 20Km's.	m^3	82.09	95.00	7,798.55
1.7	25cm thick sound basaltic or equivalent stone hard-core finished and blinded with crushed stone.	m^2	102.76	130.00	13,358.80
TOTAL CARRIED TO SUMMARY …………….					**38,537.10**
	2.Concrete work				
2.1	50mm thick lean concrete class C-5				
a	under Footing Pad	m^2	26.43	80.00	2,114.40
b	underground beam	m^2	6.21	80.00	496.80
c	under Ground floor slab	m^2	102.76	80.00	8,220.80

2.2	Reinforced concrete in class C-25 (with a 28-day 150mm cube crushing strength of 25MPa), cast into formworks and vibrated around rod reinforcement bars. (Formwork & reinforcement bars are measured separately.) in: "Type of cement to be ordinary Portland cement (OPC 42.5N or above)"				
a	In Footing Pad	m^3	7.93	2,786.71	22,098.61
b	In 100mm thick ground floor slab	m^2	102.76	350.00	35,966.00
c	In Ground floor beams	m^3	4.43	2,786.71	12,345.13
2.4	Provide, cut and fix in position sawn seasoned timber form work made up of minimum 2mm thick sheet metal & folded thickness of 50mm whichever is appropriate;				
a	to footing pad	m^2	33.48	181.87	6,089.01
b	to Ground floor beams	m^2	21.90	181.87	3,982.95
1.7	Mild steel reinforcement according to structural drawings. Price includes cutting, bending, placing in position and tying wire.				
a	Diam. 6mm deformed bar	kg	189.49	37.02	7,014.85
b	Diam. 8mm deformed bar	kg	129.25	37.02	4,784.67
c	Diam. 10mm deformed bar	kg	191.11	37.02	7,074.71
d	Diam. 12mm deformed bar	kg	112.24	37.02	4,155.24
e	Diam. 14mm deformed bar.	kg	-	37.02	-
TOTAL CARRIED TO SUMMARY …………….					**114,343.16**
3	**Masonry**				
3.1	Stone Masonry	m^3	44.10	1,600.00	70,560.00
TOTAL CARRIED TO SUMMARY …………….					**70,560.00**
Grand Total Birr					**223,440.26**

ITEM	DESCRIPTION	UNIT	TAKE OFF QTY	UNIT PRICE	Total price for take off
	SUPER-STRUCTURE				
	1. CONCRETE WORKS				
1.1	Reinforced concrete in class C-25 (with a 28-day 150mm cube crushing strength of 25MPa), *"Type of cement to be ordinary Portland cement".*				
	1) Floor Beam	m^3	3.4	2,786.71	9,474.81
	Total Birr - to item 1.1				**9,474.81**
1.2	Provide, cut & fix in position Swan zigba wood formwork for:				
	a) Floor Beam	m^2	35.7	181.87	6,492.76
	Total Birr - to item 1.2				**6,492.76**
1.3	Reinforcement steel bars according to structural drawing. Price includes cutting, bending, placing in position and tying wires.				
	a) dia. 8mm deformed bar	kg	-	37.02	-
	b) dia. 10mm deformed bar	kg	416.33	37.02	15,412.54
	c) dia. 12mm deformed bar	kg	182.95	37.02	6,772.88
	c) dia. 14mm deformed bar	kg	-	37.02	-
	Total Birr - to item 1.3				**22,185.42**
	2. BLOCK WORKS				
2.1	25cm thick Clay Bricks	m^2	350.60	853.35	299,184.51
2.2	20cm thick HCB wall for External walling	m^2	119.52	270.44	32,322.99
2..3	15cm thick HCB wall for internal walling	m^2	91.88	256.19	23,538.74
2.4	10cm thick HCB wall for internal walling	m^2	96	208.76	20,040.96
	Total Birr - to item 2				**375,087.20**
	3.FINISHING WORK				
	3.1. Plastering				
(a)	Internal Wall Plastering	m^2	495.28	150.74	74,658.51
(a)	External Wall Plastering	m^2	119.52	158.59	18,954.68
	3.2. Gypsum Work				
(b)	Internal Wall	m^2	495.28	55.36	27,418.70
	3.3. Pointing Work				
(C)	Internal & External Pointing	m^2	701.20	56.08	39,323.30
	Total Birr - to item 3				**160,355.18**
	4.PAINTING				
4.1	Three coat plastic Paint to internal Plastered Wall	m^2	495.28	62.19	30,801.46
4.3	Quartz Paint to external plastered wall	m^2	119.52	146.99	17,568.24
4.2	Varnish Paint to external pointed brick wall	m^2	171.10	28.92	4,948.21
	Total Birr - to item 4				**53,317.92**
					626,913.29

Table E-2 Cost Estimation for Reinforced Concrete structure building

BILL OF QUANTITY

Project: G+2 Residential Building (Concrete Structure Building)

ITEM	DESCRIPTION	UNIT	TAKE OFF QTY	UNIT PRICE	TOTAL PRICE
A. SUB – STRUCTURE					
	1.EXCAVATION & EARTH WORKS				
1.1	Site clearing and removing of the top 200mm thick soil	m^2	147.00	6.00	882.00
1.2	Bulk excavation in ordinary soil not exceeding 150cm from NGL allowing 25cm working space on each side.	m^3	58.80	80.00	4,704.00
1.3	Excavate in ordinary soil for isolated footing to a depth exceeding 270cm but not exceeding 3500 cm allowing 25cm working space on each side.	m^3	40.55	75.00	3,041.25
1.4	Fill around footings and foundation column to maintain the desired level with 50% selected borrowed and 50% from excavated site non expansive material and compact in layers not exceeding 20cm.	m^3	36.56	90.00	3,290.40
1.5	Backfill under hard core with non-expansive selected material from quarry and compact in layers not exceeding 20cm thick by sprinkling water to insure 95% modified AASHTO dry density.	m^3	41.10	110.00	4,521.00
1.6	Cart away surplus excavated material to a distance not exceeding 5Km's. but not exceeding 20Km's.	m^3	92.19	95.00	8,758.05
1.7	25cm thick sound basaltic or equivalent stone hard-core finished and blinded with crushed stone.	m^2	102.76	130.00	13,358.80
TOTAL CARRIED TO SUMMARY …………….					**38,555.50**
	2.Concrete work				
2.1	50mm thick lean concrete class C-5				
a	under Footing Pad	m^2	10.68	80.00	854.40
b	underground beam	m^2	17.61	80.00	1,408.80
c	under Ground floor slab	m^2	102.76	80.00	8,220.80
2.2	Reinforced concrete in class C-25 (with a 28-day 150mm cube crushing strength of 25MPa), cast into formworks and vibrated around rod reinforcement bars. (Formwork & reinforcement bars are measured separately.) in: "Type of cement to be ordinary Portland cement (OPC 42.5N or above)"				
a	In foundation column	m^3	1.17	2,786.71	3,260.45
a	In Footing Pad	m^3	2.82	2,786.71	7,858.52
b	In 100mm thick ground floor slab	m^2	102.76	350.00	35,966.00
c	In Ground floor beams	m^3	7.05	2,786.71	19,646.31

2.4	Provide, cut and fix in position sawn seasoned timber or wrot iron form work made up of minimum 2mm thick sheet metal & folded thickness of 50mm whichever is appropriate;				
a	to footing pad	m^2	3.60	181.87	654.73
c	to foundation column	m^2	18.75	181.87	3,410.06
b	to Ground floor beams	m^2	35.22	181.87	6,405.46
1.7	Mild steel reinforcement according to structural drawings. Price includes cutting, bending, placing in position and tying wire.				
a	Diam. 6mm deformed bar	kg	210.80	37.02	7,803.82
b	Diam. 8mm deformed bar	kg	159.04	37.02	5,887.69
c	Diam. 10mm deformed bar	kg	-	37.02	-
d	Diam. 12mm deformed bar	kg	462.29	37.02	17,114.08
e	Diam. 14mm deformed bar.	kg	217.56	37.02	8,054.07
					126,545.20
3	**Masonry**				
3.1	Stone Masonry	m^3	44.03	1,600.00	70,448.00
	TOTAL CARRIED TO SUMMARY …………….				**70,448.00**
	Grand Total Birr				**235,548.70**

ITEM	DESCRIPTION	UNIT	TAKE OFF QTY	UNIT PRICE	TOTAL PRICE
	SUPER-STRUCTURE				
	1. CONCRETE WORKS				
1.1	Reinforced concrete in class C-25 (with a 28-day 150mm cube crushing strength of 25MPa), "Type of cement to be ordinary Portland cement".				
	a) elevation columns	m^3	7.59	2,786.71	21,151.13
	b) Floor Beam	m^3	16.46	2,786.71	45,869.25
	Total Birr - to item 1.1				**67,020.38**
1.2	Provide, cut & fix in position Swan zigba wood formwork for:				
	a) elevation columns	m^2	117	181.87	21,278.79
	b) Floor Beam	m^2	217.11	181.87	39,485.80
	Total Birr - to item 1.2				**60,764.59**
1.3	Reinforcement steel bars according to structural drawing. Price includes cutting, bending, placing in position and tying wires.				
	a) dia. 6mm plain bar	kg	114.55	37.02	4,240.72
	b) dia. 8mm deformed bar	kg	131.54	37.02	4,869.43
	c) dia. 10mm deformed bar	kg	81.44	37.02	3,015.06
	d) dia. 12mm deformed bar	kg	291.62	37.02	10,795.74
	e) dia. 14mm deformed bar	kg	726.00	37.02	26,876.52
	Total Birr - to item 1.3				**49,797.46**
	2. BLOCK WORKS				
2.1	20cm thick HCB for External walling	m^2	270.43	270.44	73,135.09
2.2	15cm thick HCB wall for internal walling	m^2	270.40	256.19	69,273.78
2.3	10cm thick HCB for External walling	m^2	96.00	208.76	20,040.96
	Total Birr - to item 2				**162,449.83**
	3.FINISHING WORK				
	3.1. Plastering				
(a)	Internal Wall Plastering	m^2	1,003.23	150.74	151,226.89
(b)	External Wall Plastering	m^2	270.43	158.59	42,887.49
	3.2. Gypsum Work				
(a)	Internal Wall	m^2	1,003.23	55.36	55,538.81
	Total Birr - to item 3				**249,653.20**
	4.PAINTING				
4.1	Three coat plastic Paint to internal Gypsum Plastered wall	m^2	1,003.23	62.19	62,390.87
4.2	Quartz Paint to external plastered wall	m^3	270.43	146.99	39,750.51
	Total Birr - to item 4				**102,141.38**
	Grand Total Birr				**691,826.82**

Constituents Material Calculation for Load Bearing Brick Structure

Ref	Description	unit	Qty of work in m3	cement Qty in Quintal	Sand Qty in M^3	Coarse Aggregate Qty in M^3	Re-bar Kg	HCB in Pcs	Bricks In Pcs	Gypsum in Quintal	Quartiz Paint in Gallon	Plastic Paint in Gallon	Varnish Paint In Kg
Sub Structure													
1.1	**Reinforced concrete in class C-25**												
	1) Lean Concrete	m^2	135.4	203.10	67.70	115.09							
	2) C-25 concrete	m^3	22.64	81.4896	11.318	16.977							
1.3	**Reinforcement steel bars**												
	1) Super Structure - dia. 6mm - 12 mm	kg	622.08				622.08						
2	**WALL WORKS**												
	2.2) 50cm thick masonry wall	m^2	44.10	3.09	0.88			551.25					
Super Structure													
1.1	**Reinforced concrete in class C-25**												
	1) Floor Beam	m^3	3.4	12.24	1.7	2.55							
1.3	**Reinforcement steel bars**												
	1) Super Structure - dia. 6mm - 12 mm	kg	599.28				599.28						
2	**WALL WORKS**												
2.1	25cm thick Clay Bricks	m^2	350.60	70.12	17.53				40,319.00				
2.2	20cm thick HCB wall for External walling	m^2	119.52	8.37	2.39			1,494.00					
2..3	15cm thick HCB wall for internal walling	m^3	91.88	6.43	1.84			1,148.50					
2.4	10cm thick HCB wall for internal walling	m^2	96	3.168	1.152			1,200.00					
3	**FINISHING WORK**												
	3.1. Plastering												
(a)	Internal & External Wall Plastering	m^2	614.80	184.44	6.15								
	3.2. Gypsum Work												
(b)	Internal Wall	m^2	495.28							34.67			
	3.3. Pointing Work												
(C)	Internal & External Pointing	m^2	701.20	7.01	1.40								
4	**PAINTING**												
4.1	Three coat plastic Paint	m^2	495.28									34.67	
4.2	Quartz Paint to external Plastered HCB wall	m^2	119.52								20.32		
4.3	Varnish Paint to external pointed brick wall	m^2	171.10										17.11
Total Material Consumption - 1 Block (G+2 , 146m^2 Apartment Building)				**579.45**	**112.06**	**134.62**	**1,221.36**	**4,393.75**	**40,319.00**	**34.67**	**20.32**	**34.67**	**17.11**

Constituents Material Calculation for RC Framed Structure

Ref	Description	unit	Qty of work in m3	cement Qty in Quintal	Sand Qty in M^3	Coarse Aggregate Qty in M^3	Re-bar Kg	HCB in Pcs	Bricks In Pcs	Gypsum in Quintal	Quartz Paint in Gallon	Plastic Paint in Gallon	Varnish Paint In Gallon
Sub Structure													
1.1	**Reinforced concrete in class C-25**												
	1) Lean Concrete	m^2	131.05	196.58	65.53	111.39							
	2) C-25 concrete	m^3	21.32	76.7376	10.658	15.987							
1.3	**Reinforcement steel bars**												
	1) Super Structure - dia. 6mm - 12 mm	kg	1,049.69	1,049.69			1,049.69						
2	**WALL WORKS**												
	2.1) 25cm thick Clay Bricks	m^2		-	-				-				
	2.2) 50cm thick masonry wall	m^2	44.03	3.08	0.88			550.38					
Super Structure													
1.1	**Reinforced concrete in class C-25**												
	1) Elevation Column	m^3	7.59	27.324	3.795	5.6925							
	2) Floor Beam	m^3	16.46	59.256	8.23	12.345							
1.3	**Reinforcement steel bars**												
	a) dia. 6mm - 12 mm	kg	1,345.15				1,345.15						
2	**WALL WORKS**												
2.1	20cm thick HCB wall for External walling	m^2	270.43	18.93	5.41			3,380.38					
2.2	15cm thick HCB wall for internal walling	m^3	270.40	18.93	5.41			3,380.00					
2..3	10cm thick HCB wall for internal walling	m^2	96.00	3.168	1.152			1,200.00					
3	**FINISHING WORK**												
	3.1. Plastering												
(a)	Internal & External Wall Plastering	m^2	1,273.66	382.10	12.74								
	3.2. Gypsum Work												
(b)	Internal Wall	m^2	1,003.23							70.23			
4	**PAINTING**												
4.1	Three coat plastic Paint	m^2	1,003.23									70.23	
4.2	Quartz Paint to external Plastered HCB wall	m^2	270.43								45.97		
Total Material Consumption - 1 Block (G+2 , 146m^2 Apartment Building)				**1,835.79**	**113.79**	**145.42**	**2,394.84**	**8,510.75**	-	**70.23**	**45.97**	**70.23**	-

Table E-5 Material cost as of March – 2017- used for Cost Break down

Item	Type of Material	Unit	Material cost	Transport	Loading & Unloading	Total Cost/unit
1	Cement (OPC)	Qtl	325	40.00	4	369.00
2	Cement (PPC)	Qtl	220	40.00	4	264.00
2	Sand	m3	314.29	150.00	0	464.29
3	Gravel	m3	385.00	100.00	0	485.00
4	Reinforcement (Abyssinia)	kg	22	0.25	1.5	23.75
5	Black wire	kg	25	0.01	0.01	25.02
6	HCB 20cm	pcs	10.5	1.67	0.5	12.67
7	HCB 15cm	pcs	9.5	1.67	0.5	11.67
8	HCB 10cm	pcs	8	1.47	0.5	9.97
9	Brick wall	pcs	4.1	0.20	0.25	4.55
10	Gypsum	qtl	200	52.00	4	256.00
11	Plastic Paint	Gallon	245	1.2	0.02	246.22
12	Quartz Paint	Gallon	490	1.2	0.02	491.22
12	Varnish	kg	67.9	1.2	0.02	69.12

N.B Material cost does not include VAT

Table 2-6 Analysis of Labour Cost used for cost break down

CLASSIFICATION	Monthly Salary	DAILY RATE	HOURLY RATE	INDEXED HOURLY LABOUR. COST
I - TRADEMEN CLASS				
Forman	7000	233.33	40.83	49.00
Mason	-	250.00	43.75	52.50
Mixer operator	-	90.00	15.75	18.90
Vibrator operator	-	80.00	14.00	16.80
Carpenter	-	250.00	43.75	52.50
Bar Bender	-	180.00	31.50	37.80
Gypsum Worker	-	200.00	35.00	42.00
Plasterer	-	200.00	35.00	42.00
Painter	-	200.00	35.00	42.00

II - SKILLED CLASS				
Laborer I (Concrete)		100.00	12.50	15.00
Chiseler I (Concrete)		90.00	11.25	13.50
Helper I (Assistant Carp./Mason)		140.00	17.50	21.00
Helper II (Assistant bar bender)		100.00	12.50	15.00
Helper III (Assistant to Plasterer/Painter/ Gypsum Worker)		95.00	11.88	14.25

III -UNSKILED CLASS				
Laborer II		70.00	8.75	10.50