Low Cost Housing in Egypt by Using Stabilized Soil Bricks

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Abstract— *Residential housing is one of the major priorities in Egypt. The cost of apartment in different regions can charge the person over budget money and per disability of people the slums appears with uncivilized environment. Construction material like cement consumes a lot of energy to produce final product which make an additional burden on state economy. This paper presents a simple technique to build low-cost housing by using new materials abundantly available in nature with low cost to improve sustainability and green energy. The compressive strength of compressed stabilized earth building bricks depends upon the soil type, amount of stabilizer and the compaction pressure used to form the bricks with dimension of 25x12x6cm. Experimental program was carried out on specimens and seven tests were applied. Each test consists of five masonry prisms assemblage cast with stabilized bricks. These tests are compressive strength, shear strength, in-plane tensile strength, and flexural tensile strength. The results are encouraging and promising to use these bricks in green constructions as low cost housing and national projects. A comparative study approved the cost effectiveness of using the stabilized bricks, as a load bearing wall system, instead of using the traditional skeleton structures by about 34% in case of one story building.*

Keywords— Stabilized Soil, Low Cost Housing, Masonry Buildings, National Projects, Sustainability and Green Energy.

I. INTRODUCTION

Residential housing is one of the major priorities in Egypt. The cost of apartment in different regions can charge the person over budget money and per disability of people the slums appears with uncivilized environmental. Construction material like cement consumes a lot of energy to produce final product which make an additional burden on state economy. Earth is the oldest material used by peoplein construction industry. People have used their native ingenuity to develop forms for the utilization of earth ranging from the extremely simple to highly complex. They have used the material in response to varying resources, social needs and site conditions. With the individual revolution, people had access to machines, easily available fossil fuels and a range of newly developed materials. **(L. Dina et al, 2004)**, stated that new technologies became popular and earth construction skills were lost or regulated to the vernacular builder.

(Emmanuel E. Oshike, 2015), discusses the use of unfired earth for wall construction. A thorough review of literature covering the use of indigenous building materials, especially building with earth was carried out. It was observed that earth has been in use as a wall building material for centuries, in many ways, around the world and particularly in all parts of Nigeria for residential house construction. Then, the practice provided effectively adequate housing stock for the society. However, the drift to cement based construction lead to unaffordable and unsustainable housing presently, resulting in acute housing shortage. Three new earth building techniques: the compressed stabilized earth blocks, the interlocking compressed earth blocks and the rammed were showcased for governments, corporate organizations and private developers to employ in house building. It was concluded that these new earths building materials and methods are adequate and could sufficiently augment the conventional cement based and other construction efforts.

(Noorbaya Mohd Salleh et al, 2014) essentially focused on studying the performance and strength improvement of compressed stabilized earth block (laterite block) to reduce cost of conventional block production. The laterite soil used was from Infrastructure University of Kuala Lumpur (IUKL) and was mixed with fine and coarse aggregates stabilized with Cement and Lime by percentages of 5, 10 and 15 with four different mix ratios. C(i) 50%: 40%: 10%, C(ii) 50%: 35%: 15%, C(iii) 50%: 30%: 20%, C(iv) 50%: 25%: 25%, (C represents Category); these ratios were employed to keep laterite constant up to 50% to determine that which will yield the best sustainable strength. The compressive strength result shows that cement stabilized sample had higher compressive strength than the lime stabilized and that the strength increased as the curing age increases, also compressive strength increases as the content of stabilizer increased. Category (iii) had the highest strength among the other mix categories.

(Hejazi et al., 2012) audited the history, advantages, application; and possible executive problems of using different types of natural and/or synthetic fibersin soil enhancement.**(Pacheco-Torgal & Jalali, 2012)** reviewed some of the environmental benefits associated with earth construction including an overview about its past and present. It also included a review of economic issues, non-renewable resource consumption, waste generation, energy consumption, carbon dioxide emissions and indoor air quality.

II. OBJECTIVE

The scope of this research focuses on studying simple and easy system to build a low-cost housing by using new earthy materials abundantly available in nature with low cost in fabrication. Study the green change of using nature bricks in construction and fabricate it with selective ingredients to get the best possible results is our goal in this research. Finally, this research gives a suitable building unit for the construction in the way of safe and economic values.

III. EXPERIMENTAL WORK PROGRAM

3.1.1.Introduction

The experimental study was subjected to evaluate the efficiency of using in-house manufactured bricks made from stabilized soil. The definition of stabilized soil is a mixture of the excavated soil from construction sites and cement as stated in **(Keable, 1996)**. The cement in this mixture is used as a stabilizer material to merge soil particle to form construction unit. Cement was added to the soil with different percentages up to 16% to cover a wide spectrum of the stabilizing material effect. Bricks were manufactured from this soil by using a brick making machine in a brick factory in Cairo governorate region. The manufactured bricks were cured using water spray for continuous fourteen days. Traditional masonry tests (physical/mechanical) were carried out on units and assemblages.

3.1.2. Test of Raw Soil Material

Raw material tests were carried out to get a clear classification for raw soil material according to**(Boulder, Colorado, (1992)/Building code requirements for masonry structures)**. **Figure (1)** shows the standard specifications of stabilized soil used. The exact used raw material was 76% sand and 24% silt/clay after testing it by using soil mechanics analysis complying with **(British Standard BS:1377)**.

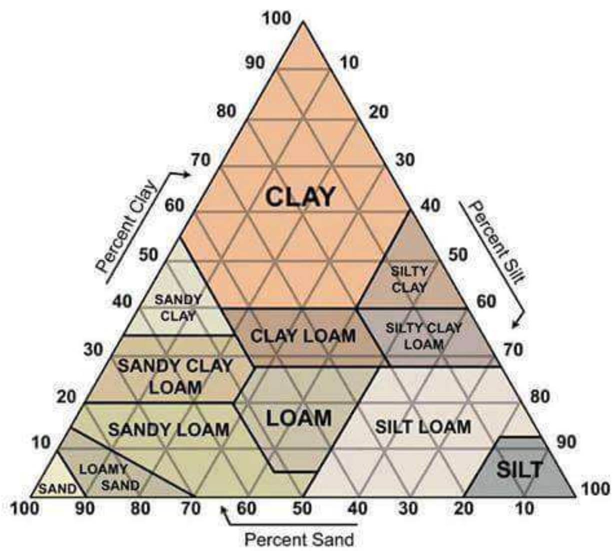

Fig.1: The Ideal Earth Building Mix, (Graeme North, 2008)

The liquid limit of a soil is the moisture content, expressed as a percentage of the weight of the oven dried soil, at the boundary between the liquid and plastic states of consistency. The following **Table (1)** gives results of trials for different water contents.

Table.1: Results of Liquid Limit Test

Trial No.	W_C %	N	Log(N)
1	40.14523	17	1.230449
2	31.19854	23	1.361728
3	23.8914	30	1.477121

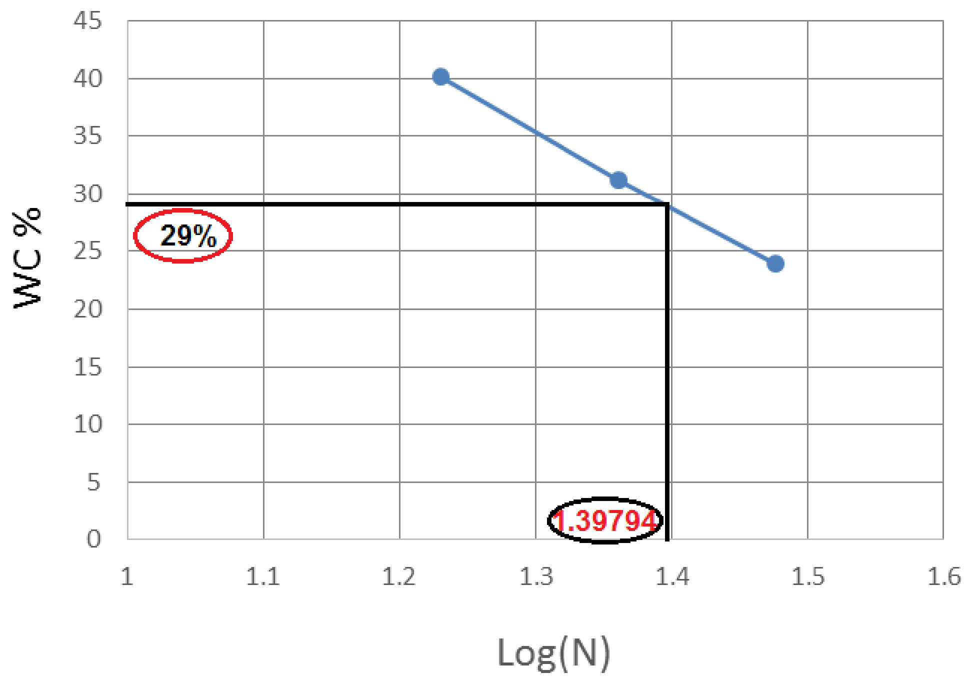

Fig.2: Relationship between Water Content and Log (N)

From **Figure (2)**, the moisture content corresponding to the intersection of the flow curve with 25 blow ordinate is the liquid limit of the soil which equal to 29%.This soil with the same properties is available in Egypt with large quantities. The following **Figure (3),** shows the soil classification in Egypt according to its type. The tested soil is marked in the map with elliptical red shape and according to key of map, it's classified as Sand, clay loams with calcareous crusts and sand dunes of the delta lacustrine complex.

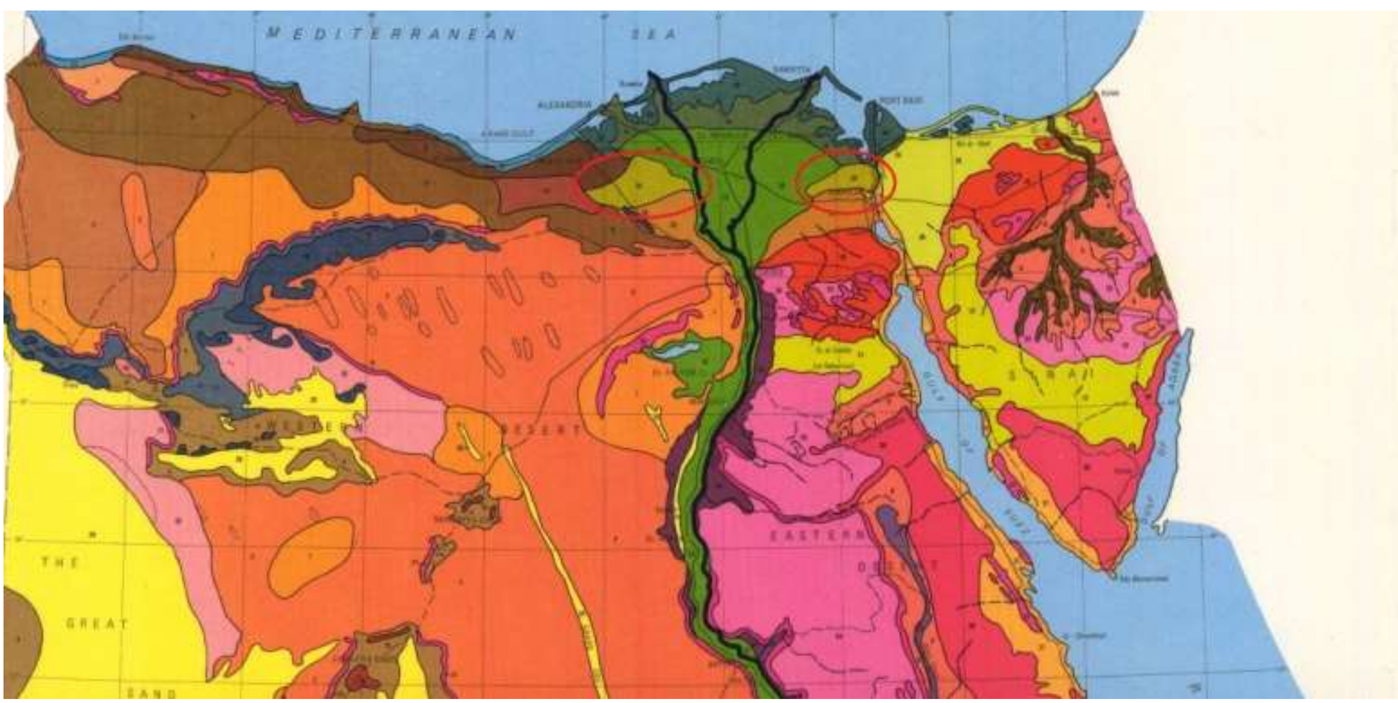

Fig.3: Classification of Soil in Egypt ***(Soil Survey Institute, Wageningen, the Netherlands)***

https://dx.doi.org/10.24001/ijcmes.3.3.1 *ISSN: 2455-5304*

3.1.3. Manufacturing Procedures of Bricks Unit:

Two groups of bricks have been stabilized with different ratios of cement contents. Each percentage consists of five bricks. Group (A) was mixed with cement ratios 8%, 10% and 12% of weight and cast with one layer (mold was filled by one batch of raw material). Second Group (B) was mixed with cement content ratios 4%, 7%, 10%, 13% and 16%of weight and cast with two layers (mold was filled by two batches of raw material) to reduce voids between particles and evaluate the enhancement percentage may be occur to tested bricks. Coloring oxide helps for giving smart colors rather than traditional bricks color. Coloring oxide with ratio up to 0.04% of weight was added to study its effect on bricks behavior. The brick dimensions in the two groups are 25x12x6 in cm.

Drum Machine was used for manufacturing the building units under the effect of hydraulic pressure of 25 kg/cm^2. During filling process the template machine vibrate the soil in molds to reduce voids between particles of used soil to get the optimum compaction. The top surface of the mold was smoothed off by trowel or scraper to remove unwanted materials from the surface. **Figure (4)** shows the final product of cast stabilized bricks.

Fig.4: Cast Stabilized Bricks

3.1.4.EvaluationofCompressive Strength of different Brick Units:

The bricks were sprinkled with water daily (curing process) for fourteen days then tested after twenty-eight days of casting. The bricks were placed at the centre of the loading platform of universal testing machine (UTM)and were tested under pure compression. The test results for these specimens are indicated as shown below in **Table (2)** and **(3)**.

Table.2: Average Compressive Strength of Group(A)

No. of Group	Cement Percentage	Average Comp. Strength (kg/cm^2)
Group (A-1)	8%	25.48
Group (A-2)	10%	27.32
Group (A-3)	12%	29.22

Table.3: Average Compressive Strength of Group (B)

No. of Group	Cement Percentage	Average Comp. Strength (kg/cm^2)
Group (B-1)	4%	18.01
Group (B-2)	7%	36.69
Group (B-3)	10%	43.37
Group (B-4)	13%	45.96
Group (B-5)	16%	51.15

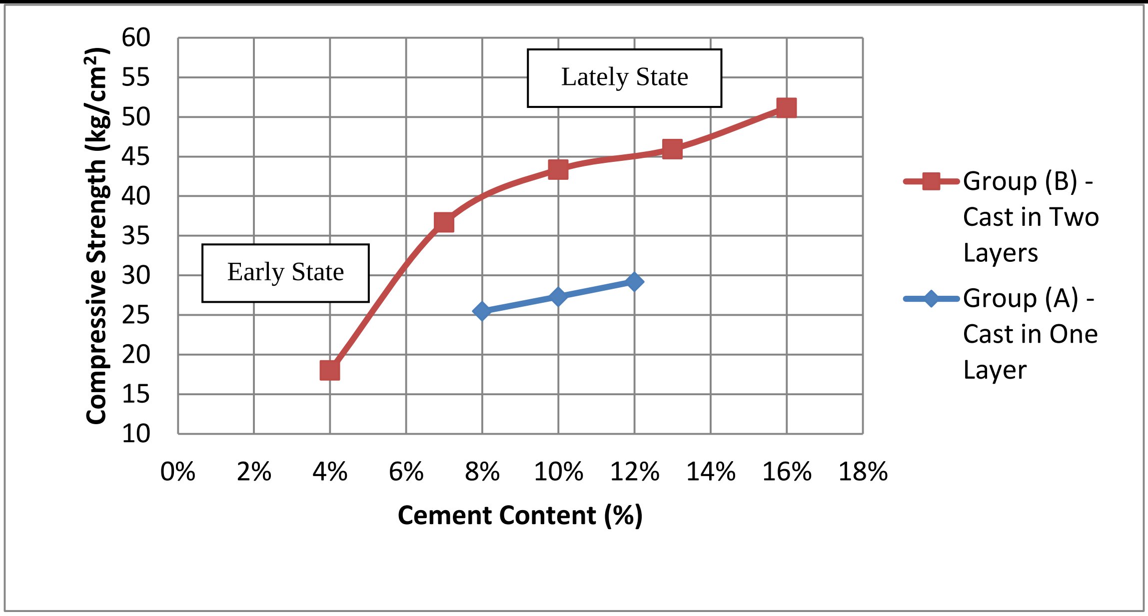

Fig.5: Compressive Strength of Specimens for Group (A) and Group (B)

From **Figure (5)**, Group (A) recorded the lowest values in this test because brick units manufactured with one layer only of raw material. By increasing cement content, compressive strength gives small rate of increasing with little valuable improvement of bricks behavior. On the other hand, group (B), enhanced by 160% due to casting with two layers of raw material. Increasing cement content, also, increase the performance of brick units to absorb more energy. In lately state, (13% to 16% cement content) of the relationship, the curve increased with small rate compared to early state (4% to 7% cement content), so that, cement content percentage of 12% and 16 % proved to be useless and non-effective. Hence, it is preferred to use cement ratio for stabilization equal to 10%.

Brick units were cast with constant value of cement content 10% of weight and cast by two layers for the next mechanical/physical properties. Coloring oxide with ratio up to 0.04% of weight was used and specimens (with/without coloring oxide) were tested under the effect of pure compression to observe the variation in results. It's seems that, no significant variation observed on bricks performance. The wet compressive strength was recorded as 36.73kg/cm^2(less than dry compressive strength by 15%) and dry splitting tensile strength recorded from test was 1.77 kg/cm^2.

The density of brick unit is 1.89t/m^3. Also, the percentage of water absorption is 21.36% and 22.56% for normal (immersed in water for twenty-four hours) and five hours boiling water, respectively. From physical/mechanical properties the specified stabilized bricks are classified as Grade MW according to **(ASTM C62-89a, 1990)**

3.2.Manufacturing Assemblage and Testing of Specimens:

Experimental program was carried out to produce specimens with 10% cement content (cast with two layers) and seven tests were taken into consideration to apply. Each test consists of five repeated specimens (masonry prism bricks)according to **(Boulder, Colorado, (1992)/Building code requirements for masonry structures)**. These tests are compressive strength test of brick masonry, triplet shear strength test, In-plane tensile strength tests (parallel, normal and diagonal to the bed joints), and flexural tensile strength test(normal and parallel to the bed joints). Houses with one or two floors (A case-study, as will be stated later) less effect due to lateral loads and for this reason, brick masonry compressive, shear and tensile stresses are only analyzed in this research. (UTM) of capacity 1000 KN was used for the testing of prism specimens. To comply with**(ASTM E:518),** five prisms of each brick–mortar combination were built with four bricks (25cmx12cmx6cm) and three (1cm) horizontal mortar joints. Three different types of mortar were used to select the optimum value according to compressive strength behavior, mortar type M, S and N with cement to sand 1:4, 1:4.5, and 1:6 mix proportions, respectively. The final dimensions of tested specimens are (25cmx12cmx27cm) as shown in **Figure (6)**.

Fig.6: Cast Specimens for Compressive Test

After curing process, compressive strength tests of assemblages were conducted. It was found that, the average compressive strength of assemblages for mortar type M, S and N after twenty-eight days were 43.83 kg/cm^2, 34.3 kg/cm^2 and 28.1 kg/cm^2,respectively.The mortar type (M) was selected for the next different tests because its gives the optimum value. Three bricks (triplet setup, **(Venkatarama Reddy et al, 2008)**) were joined in the long face by mortar type (M) to obtain shear strength along mortar bed joint as shown in **Figure (7)**.Brick assemblages of size (51cmx29cmx12cm) with mortar type (M) were tested according to (**ASTM E:519)** of in-plane tensile strength (parallel, normal and diagonal) to bed joints. The Layers of cement mortar having joint thickness ranged from 1cm to 1.5cm. **Figure (8)** shows the cast specimens before testing.

Fig.7: Cast Specimens for Bed Joint Shear Test

Fig.8:Final Cast Assemblages

The basic test of flexural parallel and normal to bed joints developed to determine flexural tensile strength and illustrated by follows (**ASTM E:518)**.In this experimental study, assemblage of sizes 103cmx29cmx12cm joined with cement mortar type (M) were tested. Joints thickness ranged from 1cm to 1.5cm and good mortar filling was taken into consideration. Specimens were stored in the laboratory in normal conditions as shown in **Figure (9)**.

Fig.9: Stabilized Brick Prisms for Flexural Test

IV. TEST RESULTS

4.1.1. Compressive Strength of Brick Masonry:

The compressive strength of a wall generally depends on the strength of the brick units used and the mortar type. The assessment of the combined strength of these elements will also be affected by the degree of quality control exercised in manufacture and construction in addition to the slenderness ratio (effective height or length to the effective thickness of the wall). The following **Figure (10)** presents the ability of cement mortar type (M) to confirm the bond between brick units as stated before in [**3.2 Manufacturing Assemblage and Test of Specimens**].

(A) (B) (C)

Fig.10: Crack Pattern

4.1.2.Shear Strength along Mortar Bed Joints:

This test gave a clear indication of the failure mode in case of shear force. It was apparent that the loading conditions were initiated by shear failure between the brick/mortar in **Figure (11)**. The calculated shear strength of tested assemblage is 5.89 kg/cm^2.

Fig.11:Test Specimens Showing Failure Mode

4.1.3.In-Plane Tensile Strength Parallel, Normal and Diagonal to the Bed Joints:

The splitting tension test is very useful for developing an understanding of the factors affecting in-plane tensile strength of masonry. The most effective factor is the orientation of internal generated tension load parallel, normal or diagonal associated with the mortar bed joints due to compression load. The results of splitting tensile strength and failure modes are sensitive to applied principal stresses to bed joints. **Figure (12)** represent failure of specimen due to debonding in bed joints. **Figure(13)** shows that, the failure happened in head joints in addition to excessive cracks in stabilized brick units. **Figure (14)**illustrate cracks in bed and head joints due to the orientation of internal generated tension load for stabilized brick assemblage.

From **Figure (15),** it is shown that, in-plane tensile strength parallel to the bed joints (angle of testing zero) has maximum tensile strength equal to 2.08 kg/cm^2, in-plane tensile strength normal to the bed joints (angle of testing 90º) has low tensile strength equal to 1.11 kg/cm^2, in-plane tensile strength diagonal to the bed joints (angle of testing 45º) is 1.93 kg/cm^2.

Fig.12: Crack Pattern (Parallel to Bed Joint)

Fig.13: Crack Pattern (Normal to Bed Joint)

Fig.14: Combined Cracks through head and bed joints

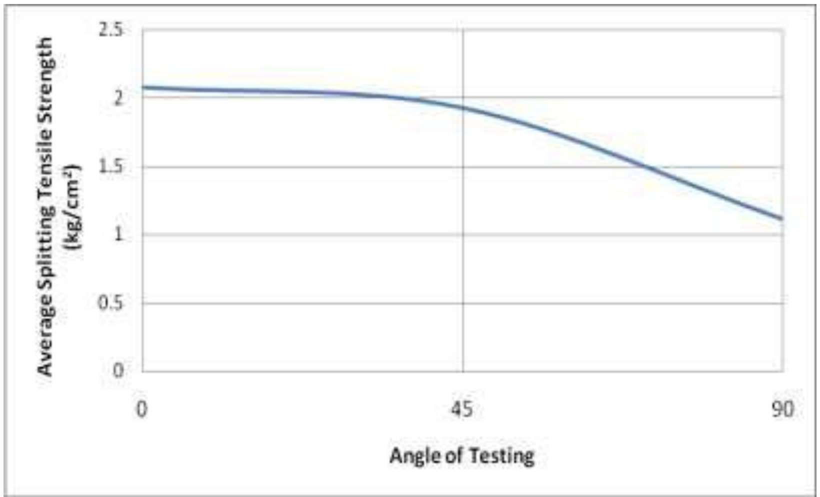

Fig.15: In-Plane Tensile Strength of Assemblages

4.1.4.Flexural Tensile Strength for the Out-of-Plane Bending:

It is widely accepted that failure of masonry is mostly governed by the difference in behavior of mortar and unit. It is worth to be mentioned that, mortar is usually softer and weaker than brick units. **Figure(16)**and **Figure (17)**shows the mode of failure and crack pattern. It seems that, the crack pattern in case of generated internal tension load parallel to bed joint started with debonding in bed and head joints followed by crushing in brick units. The failure happened in bed and head joints in case of generated internal tension load normal to bed joint. The results of flexural tensile strength in case of parallel/normal to the bed joints recorded 3.52 kg/cm^2 and 1.64 kg/cm^2, respectively.

Fig.16: Crack Pattern (Parallel to Bed Joint)

Fig.17: Crack Pattern (Normal to Bed Joint)

V. ANALYSIS AND DISCUSSION

From test results, the compressive strength of bricks assemblage joined with mortar type (M) gives the highest strength, thanks to the high strength and low workability of mortar type M, and thus resulting in more confinements of the units that enhances the overall strength of the assemblage. The shear strength of bricks assemblages 13.5% of bricks assemblage compressive strength. The in-plane tensile strengths are 5%, 2.5% and 4.5% of bricks assemblage compressive strength for parallel, normal and diagonal to bed joint, respectively. The out-of-plane flexural tensile strength are 8% and 4% of bricks assemblage compressive strength for parallel and normal to bed joint. The stabilized bricks assemblage achieved a good performance when loaded parallel to bed joint and the crack pattern happened in mortar and this reflect the good quality and confirm the idea for using this soil in construction units because it produces strong unit. The physical and mechanical obtained properties from testing are almost compatible with the minimum requirements of suitable clay bricks according to **Egyptian Code of Practice, ECP-204.**

VI. ECONOMICAL VIEW

The following **Table (4)**shows the average compressive strength for tested stabilized bricks in comparison to the average compressive strength of different standard Egyptian bricks in addition to taking the cost of production factor into point of view. The results give a high priority to use stabilized bricks because the highly compressive strength is not necessary for small house with one floor, also, the cost of it give us a good deal with construction competition.

Table.4: Standard Properties to Unit Cost
(Price List with Egyptian Pounds, July, 2016)

Test Category for Assemblage	Stabilized Bricks	Sand Bricks	Clay Bricks	Cement Bricks
Compressive Strength of Brick Masonry	45kg/cm^2	200kg/cm^2	100kg/cm^2	250kg/cm^2
Cost Per 1000 Bricks	240 L.E	760 L.E	500 L.E	830 L.E

Housing unit with an area of 70 m^2 was put forward by the official government in Egypt consists of (1) reception, (2) bed room, (1) bathroom, (1) kitchen as show in **Figure (18)** to solve housing problem. It is studied a short quantity surveying case to compare the cost between both of skeleton and proposed load bearing stabilized bricks structural system types as shown in **Table (5), (6) and (7)**.The concrete dimensions for skeleton and load bearing wall system are calculated according to **Egyptian Code of Practice, ECP-203 and ECP-204,** respectively.

https://dx.doi.org/10.24001/ijcmes.3.3.1 *ISSN: 2455-5304*

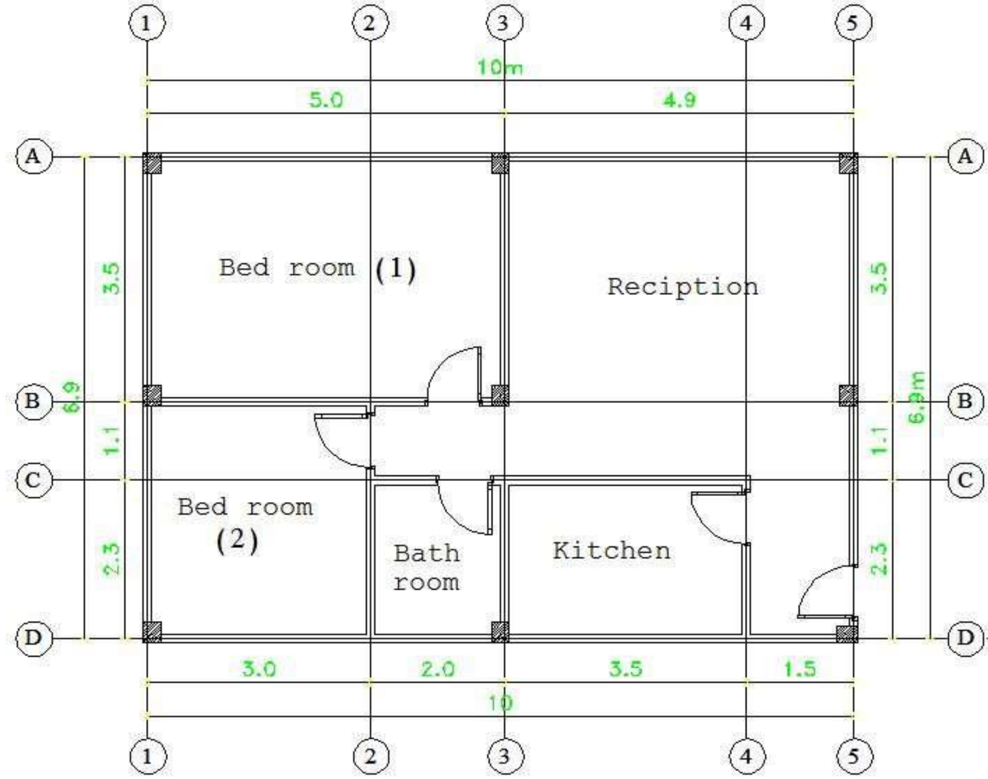

Fig.18: Housing unit with an area of 70 m²

Table.5: Short Quantity Surveying on Skeleton Type
(Calculated by Egyptian Pounds-Costing rates for July, 2016)

Items	**Dimensions A*B*H (m)**			**No.**	**Quantity (m^3)**	**Unit Cost (L.E/m^3)**	**Total Cost (L.E)**
Plain Concrete Footings (160cmx160cmx40cm)	1.6	1.6	0.4	9	9.216	280	**2581**
Reinforced Concrete Footings (F1) (80cmx80cmx40cm)	0.8	0.8	0.4	9	2.304	1800	**4147**
Reinforced Concrete Ground Beam (S1) (20cmx40cm)	33.9	0.2	0.4	-	2.712	1800	**4882**
Reinforced Concrete Columns (C1) (20cmx20cm)	0.2	0.2	4	9	1.44	1800	**2592**
Reinforced Concrete Beams (B1) (12cmx40cm)	56.7	0.12	0.4	-	2.7216	1800	**4899**
Bricks	52	1	4	55b/m^2	11440 brick	0.9	**10296**
					Total Cost		**29397**

Table.6: Short Quantity Surveying on Load bearing wall Type
(Calculated by Egyptian Pounds-Costing rates for July, 2016)

Items/Activities	Dimensions L*B*H			No.	Quantity (m^3) or (unit)	Unit Cost (L.E)	Total Cost (L.E)
Plain Concrete Footings (Strap)	52	1.5	0.3	-	23.4	250	**5850**
Bricks for Footing	48	1	1	142b/m^2	6816	-	-
Bricks for Walls	54	1	4	55b/m^2	11880	-	-
Cement (ton)	-	-	-	-	7.79	800	**6232**
Raw Material Transporting (ton)	-	-	-	-	70.11	50	**3506**
Sills	54	0.25	0.15	-	2.025	1800	**3645**
					Total Cost		**19233**

*****Reinforced concrete slabs are constant with the same value in the two systems.

Table.7: Final Cost of Housing Unit for Each Type
(Calculated by Egyptian Pounds, July, 2016)

Type	Total Cost
Skeleton type	**29397 L.E**
Load Bearing Wall (Stabilized Bricks)	**19233 L.E**

It is found that, the stabilized soil bricks are an effective technique in reducing construction cost by about 34% than the traditional construction technique. Also, the final building can be cast more quickly, and this is another valuable cost reduction source by saving time that costs a lot. Besides, the units would be manufactured with attractive colors and ecofriendly than traditional buildings, which means good appearance of the building without the need for plastering and paints, thus adding extra money saving with almost about 10% of the total cost. Therefore, it is fair to say that the use of the stabilized soil bricks in constructing this type of housing presented in this paper reduces construction cost by about 40%.

VII. CONCLUSIONS

Stabilized soil bricks have most of advantages for building construction such as: low cost of raw materials, low energy consumption, no pollution and negligible energy consumption thus further benefiting the environment by saving biomass fuel and transportation costs, can be built personally by the home owner with **(TARA-Balram Machine)**, natural warm texture and colors, allows expression of personal creativity using traditional skills and can be shaped by hand into attractively rounded forms and niches. Based on the test results presented herein, the following conclusions are drawn:

1. By increasing cement content ratio from 10% to 16%, the obtained compressive strength of specified bricks can reach up to 44kg/cm^2 and 52kg/cm^2, respectively. These values are suitable for using in low cost housing according to different codes.
2. For specified stabilized bricks with dimension of 25x12x6 in cm, the observed test results of samples at different cement ratio's proved that 12% and 16% of cement percentage are waste and non-effective, so it is preferred to use cement ratio for stabilization equal to 10% with two layers of brick casting.
3. Cast of assemblages with mortar type (M), recorded the optimum value in case of compressive strength.
4. The Shear strength of bricks assemblage is 13.5% of bricks assemblage compressive strength. The in-plane tensile strengths are 5%, 2.5% and 4.5% of bricks assemblage compressive strength for parallel, normal and diagonal to bed joint. The Flexural tensile strengths are 8% and 4% of bricks assemblage compressive strength for parallel and normal to bed joint.
5. Using specified stabilized bricks can reduce the cost of construction by about 40% in comparison to traditional systems.

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