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A PROPOSED SANDBAG HOUSING UNIT FOR POOR AND DISADVANTAGED AREAS

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Abstract: Providing adequate shelter particularly for the poor in developing countries is a challenging matter. Egypt, as an example, has an estimated 11.8 million living in slums. This led to a need for the proposed solution of constructing a low-cost housing model that can be easily constructed. This study aims at providing a prototype for a one-room shelter using sandbags. Waste sand bags of two types were filled with various contents of sand, as a parameter, and were used to construct a 10 m^2 shelter. Two types of roofing were proposed: one with arched bags of different dimensions while the other was a flat roof with polymeric sheet and wooden purling. An actual physical model was built on site which was useful to carry out a small-scale feasibility study in order to assess the economic merits of the proposed shelter considering materials cost, workmanship, rate of production and the use of land, and environmental merits among others. The study reveals that such prototype has a good potential in slums in the vicinity of desert areas where sand exists in abundance and waste materials and landfills are within short distances. Future work including pilot models and durability testing is highly recommended.

1 INTRODUCTION

One of the most challenging urban issues in Egypt is that vast numbers of inhabitants are living in slums. Egypt is considered to have 40% of its population living in urban areas, with a total number 11.8 million inhabitants living in slums. These slums are identified as unplanned and unsafe areas. The difference between unplanned areas and unsafe areas is that the former are areas built randomly and are not based on sound construction building code, while the latter are areas where its inhabitants are living in severe conditions and are deprived from their basic needs. Unfortunately, in Egypt, at least 1.1 million inhabitants are living in unsafe areas, which is detrimental to the society. In addition to the above mentioned, on the world map, 4 out of 30 of the biggest slums worldwide are found in Cairo. These areas have high residential densities with shortage in infrastructure, services, accessibility and open spaces (Khalifa, 2011). In the current years, there have been many earth construction methods worldwide such as compressive Earth block technique, Adobe technique, Bamboo technique. This study aims to introduce Sandbags technique as an alternative construction method that is environmentally friendly, economical, as well as simple and quick solution for those disadvantaged areas found in Egypt.

Historically, sandbags were first used in the early 1970s by a civil engineer called Michael Tremer. He placed sandbags on sheet metal shack, but he found it unsuitable for living conditions. After the breakdown of the apartheid system in South Africa in 1990, people started to move to camps; therefore, Tremer started implementing the sandbag housing technique to support these people. Michael Tremer and his team further developed the sandbag housing technique, Eco beam Technologies, until 2008, a year that saw a great boom in the use of sandbags as a construction method. Nowadays, an architect, Nader Khalili, has come up with new advanced sandbags techniques (Hart and Geiger 2017). Main factors for using Sandbags houses are ecological, economic, superior material quality and ease of construction.

For ecological reasons, less energy is consumed, as the materials used for constructing sandbags don't go into a process. There is no burning of bricks as found in normal construction techniques, nor production of cement. Also, the sandbags itself doesn't consume energy for production as it has thin thickness and is filled with tiny materials, therefore their energy consumption is negligible. Besides, CO_2 emission is 95% less than a conventional brick wall per every 1 m^2 of sandbag. The material of the bag, polypropylene, is being recycled and the plastering material is also environmentally friendly. Moreover, less transportation of materials is needed. Regarding the economic impact, sandbags housing technique is a cost effective construction method due to the availability of the materials and their low cost. According to the Asian Institute of Management (AIM), the cost of a sandbag house is less by 30%-60% than a normal brick unit. Equally important, Sandbag Technique doesn't require skilled labors .It provides job creation, as males or even females can build it easily. This technique is one of the quickest methods due to the high availability of materials and the method can be easily learnt (Hart and Geiger 2017)

Sandbag houses are being characterized by having Superior Material Qualities. The system is known for its high thermal stability due to the small air spaces between the sand particles. Furthermore, sandbags are good absorbent of sound to give sense of privacy for those areas with narrow spaces. Due to their weight, sandbags are wind resistant, and also they are bullet proof, as the sand material can absorb such impacts. According to California Standards Test, sandbag houses are highly resistant to earthquakes. Not only does plastering of sandbag house provide it with fire resistance characteristic but it also provides it with high impermeability. Sandbags housing technique is a simple construction method due to its ease of construction, ability to be implemented in areas with limited accessibility, less transportation of materials, less site clearance required and ease of storing. Due to the simplicity in construction, it doesn't require electricity during the construction process and amount of water needed is negligible (Hart and Geiger 2017)

The three main components of sandbags houses are sand, textile bags, and plastering. Sand is naturally available all over the world with unlimited sources. Sand is the main component in construction as it provides the whole system with its advantages. Sand is a good absorbent with high resistance to earthquake, good sound and thermal insulator. The bags are made of polypropylene material which can be found in many local factories. There are main two factors to be considered when selecting the most suitable empty sandbags namely; strength and durability. Tensile strength test is conducted to test the empty sandbags and compression test is conducted to test the filled sandbags. Finally, plastering provides the house with a protective coat that increases its resistance to water, stiffness and strength to resist other environmental factors. Earthen plaster doesn't consume energy and is suitable for living condition (Hart and Geiger 2017)

2 SCOPE OF WORK

The main objective of this study is to construct a low cost housing model using sandbags with minimum incorporation of other materials for walls and roof. The model is assessed for its constructability and economic feasibility for informal settlement in Egypt. A single room unit is constructed with dimensions 3m width, 3.8 m length, 2.5 m height. The mechanical behaviour of the whole structure is examined with roof system stability tests. This project proposes an inexpensive, environmentally friendly and easy constructible housing unit which provides an adequate option for housing in informal settlements, slums, areas. This study presents a limited feasibility study for the model.

3 METHODOLOGY

3.1 Selection of Polypropylene Sandbags Size

Different Sandbag dimensions used are 450mm x 800mm, 550mm x 1100mm, 600mm x 1100mm, and 550mm x 1050mm. Through trial and error, the polypropylene sandbags with dimensions 450mm x 800mm, procured from a local factory were selected due to its space utilization, weight for handling without intense effort and availability in local factories.

3.2 Selection amount of Sand material to fill Sandbags

The sand material is typical sand found in abundance in the region. The amount required to fill each sandbag should be decided for effective and efficient construction rate and to ensure a great strength for the unit. The selected polypropylene sandbags of dimensions 450mm x 800mm were filled with different amount of sand namely; 20kg, 25kg, 30kg, 35kg, 40kg, and 45kg. The sandbags were all sealed at equal distance of 50mm from the edge regardless of the sand weight content. The main target is to have a good surface area of the bag when placed. The sandbag doesn’t have to be full but rather slightly more than half full. The conducted experiments showed that 40kg of sand were suitable to fill the sandbags.

3.3 Material and structure tests

Several tests were conducted to study the behaviour of the empty and filled sandbags and to assess the structural performance and mode of failure. Sieve analysis, specific gravity and absorption test are conducted to check the suitability of the sand. Tensile strength tests were conducted on the empty sandbags. Compressive strength tests were conducted on the filled sandbags. Arch test owas conducted on the roof system.

3.4 Selection roof system

In order to select the most suitable roof system that is economical, available in materials, and has high strength, two different roof systems are examined.

3.4.1 The arch sandbags roof system

Usually, the arch sandbags roof system is used when construction of dome is done using sandbags. The effect of the arch gives stability and effectiveness to the roof system. Wooden formwork was used to for the arched sandbag system in the present work as shown in Figure 1.

3.4.2 High Density Polyethylene Sheets and Recycle Timber Purlin

The other roof system is done using high-density polyethylene sheets on wooden frame and a used wood acting as purlin. The utilized high-density polyethylene in the current project has thickness of 2mm and width of 2m.This type of sheet is impermeable and ensures stabilization for the roof system.

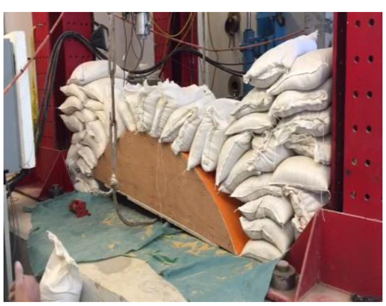

Figure 1: Arched sandbags system

Figure 2: High-density polyethylene sheets on wooden frame roof system

After carrying the economic study, the cost of the sheet proved to be cost effective. Arch test was only conducted to study the effect of arch as a roof system where the selected roof system is the high density polyethylene sheet and recycled timber purlin.

4 EXPERIMENTAL WORK

4.1 Material

The several construction materials utilized in present experimental work are:

- Sand: main component and it available at the site
- Polypropylene Bags: purchased from local factory
- Cement: used for plastering
- Chicken mesh: used to ensure the sticking of the plaster to the wall
- Wire: to determine the perimeter during planning for construction
- Used wood: used to construct frames for the door, the window, and the roof
- Recycled timber: used as a purlin in the roof system
- High density polyethylene sheet: used as roof system
- Wooden formwork: used in the Arch test to place on the sandbag

4.2 Material testing

Testing of material components has been conducted to assess the quality of the materials that are utilized in the experimental setup. The following tests were conducted on sand:

4.2.1 Sieve analysis: [ASTM C33]

To determine the gradation of sand particles and classify sand particles as well graded or poorly graded soil. The equipment needed is the set of standard sieves and sensitive balance.

4.2.2 Specific gravity test: [ASTM C128-01]

Specific gravity is the unit weight of material per unit weight of water. This test is done in order to calculate specific gravity of the sand using volumetric flask and vacuum pump.

4.3 Structure testing

4.3.1 Tensile strength test: [ASTM D5035]

The tensile strength test was conducted to examine the strength and mode of failure of the sandbags polypropylene material. In addition, the test was used obtain the stress-strain curve of polypropylene sandbags material. Universal Testing Machine (UTM) was used for testing. Small samples with rectangular shape of dimensions of 25mm width and 41mm length were due to UTM fixed dimensions. Layers of the same sample material were clamped at the upper and lower clips of the machine to prevent slippage between the sample and the machine’s clip to guarantee uniform tensile test as shown in Figure 3. This tensile strength test was conducted on different number of layers using the same sample.

4.3.2 Compressive strength test

This test is conducted to evaluate the compressive strength on the filled sandbags and to assess the mechanical behavior of the whole structure. 3 samples of sandbags were tested namely; used sandbag of dimension 570mm x 800mm and two new sandbags of dimensions 450mm x 800mm. The three samples were filled with 40 kg sand and the contact dimension of the three samples was unified using steel metal plate. The equivalent contact dimension is 300mm x 600mm. Point load test was applied on the filled sandbags with different up to 650 kN which is maximum capacity allowed for the laboratory equipment.

Figure 3: Tensile test on the sandbags polypropylene material

4.3.3 Arch test

This test is done in order to study the Arch effect on roof system for sandbag unit. In this test, many variables that are affects the structural performance of the system while conducting this test such as the geometry of the arch, the coefficient of friction between the polypropylene sand bags, the degree to which to sand bags are compacted, the shape of the bags after compaction when being placed on the formwork.

The arch geometry was determined through research and a wooden formwork was manufactured to match the required geometry. The formwork was first adjusted under the point load machine using hydraulic jacks. Sandbags were put in place and compacted. Finally, the hydraulic jacks were released allowing the formwork to descend and the arch to rest.

4.4 Construction of the Single Room Model

As stated in the scope of work, a single room of dimensions 3m width, 3.8m length, 2.5m height was constructed using sandbags and cover with high-density polyethylene sheets on wood purlins. The final model is shown in Figure 4.

a) External view of he constructed room

b) Interior view of the constructed room

Figure 4: The constructed single room model

4.4.1 Planning

The volume of sand required for the construction of the room was determined based on the dimension of the constructed room as given in Equation 1. The width of the room walls was considered as 400mm. The volume of sand in each sandbag was calculated as shown in Equation 2. The number of required sandbags was determined by dividing the sand volume by the volume of each bag as given in Equation 3.

[1] Volume of required sand = Wall Width x 2 (Room Length + Room Width) x Room height

[2] Volume per sandbag = Bag Width x Bag Length x Bag Thickness = 0.4 x 0.80 x 0.1 = 0.032 m^3

[3] No. of sandbags required = Volume of required sand / Volume per sandbag

Due to placement of a door framework and a window frames, the numbers of sandbags was decreased. Table 1 summarizes the required sand volumes and number of sandbags needed.

Table 1: Required Sand Volume

Item	Value
Volume of required sand	13.6 m^3
Volume of sand per bag	0.032 m^3
Number of sandbags required	420 bags

4.4.2 Construction

The construction of the model followed the below sequence of works to ensure proper laying of the sand bags and the functionality of the model.

1. Setting the construction perimeter at the site.
2. Placing the first layer of sandbags
3. Manual compaction of first layer of sandbags
4. Repeat steps 1 and 2 until reaching the required height (2.5m) and the wall system is finished
5. The door framework is placed and stabilized
6. The window framework is placed and stabilized
7. Placing wooden frame at the roof to fix the high density polyethylene sheet
8. Another used wood is placed in the middle to act as purlin
9. High density polyethylene sheet is placed on the wooden frame and purlin
10. Chicken mesh is placed on wall side in order for plastering to take place
11. Plastering process

5 RESULTS

5.1 Results of Material Testing

5.1.1 Sieve analysis: [ASTM C33]

The results obtained are illustrated in Table 2 with the corresponding gradation curve in Figure 5. Figure 5 proves that the sand material used has distribution of particles size, which are well graded, and there is no size missing or improper distribution of sizes. Therefore, sand material used is acceptable and suitable for use. The calculated fine modulus of the sand was 2.074 which falls within the range of 2 to 4.

Table 2: Results for Sieve Analysis Testing

Sieve size	Retained weight (g)	% Retained	% Retained Cumulative	% Passing
#4	3	0.6	0.6	99.4
#8	11	2.2	2.8	97.2
#16	34	6.8	9.6	90.4
#30	111	22.2	31.8	68.2
#50	207	41.4	73.2	26.8
#100	81	16.2	89.4	10.6
#200	19	3.8	93.2	6.8
Pan	5	1	94.2	5.8

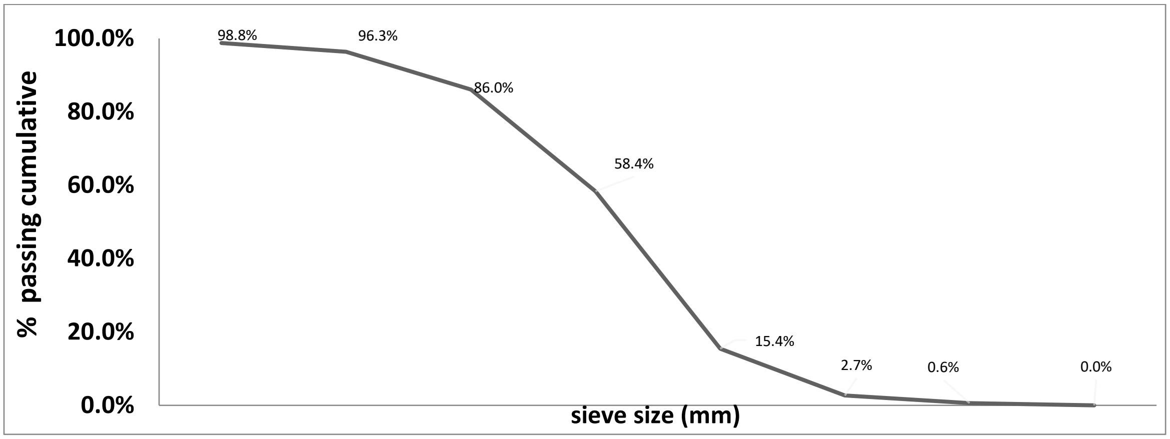

Figure 4: Gradation Curve For Sieve Analysis

5.1.2 Specific gravity test: [ASTM C128-01]

Table 3 shows the results obtained from conducting specific gravity and absorption tests on the sand.

Table 3: Specific Gravity and Absorption Test Results

Item	Value
Bulk Specific Gravity	2.52
Bulk Specific Gravity at SSD	2.54
Apparent Specific Gravity	2.57
Percentage Absorption	0.7%

5.2 Results of Structure Testing

5.2.1 Tensile strength test: [ASTM D5035]

Table 4 shows the input data adjusted to the UTM machine before starting the test.

Table 4: The Default Dimension inserted to UTM machine

Description	Dimension
Geometry	Rectangular
Width	25mm
Thickness	0.4mm
Length	41mm
Final Width	10mm
Final Thickness	0.2mm
Final Length	100mm

Figures 6 through 9 show the obtained stress-strain curves from one layer, two layers, three layers, and four layers sandbags tests The obtained ultimate tensile strength for the four types was 115 MPa, 85 MPs, 85 MPa, and 100 MPa respectively.

The Stress-Strain curves show that the samples did not experience sudden failure it was rather a ductile one. This adds to the advantage of using polypropylene material as the bags that will be used in construction. As the layers used in the test increase, the ultimate tensile stress decrease. The reason is that the UTM is very sensitive while drawing the graph. For instance, if two layers are tested, once any of the two layers starts to fail, it records it as its ultimate value (critical case) and stops taking any further higher readings.

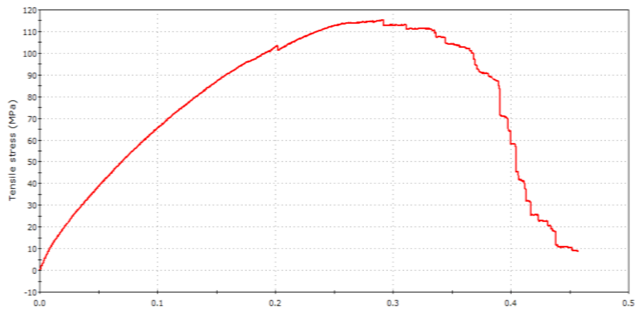

Figure 6: Stress-strain curve of one sandbag layer

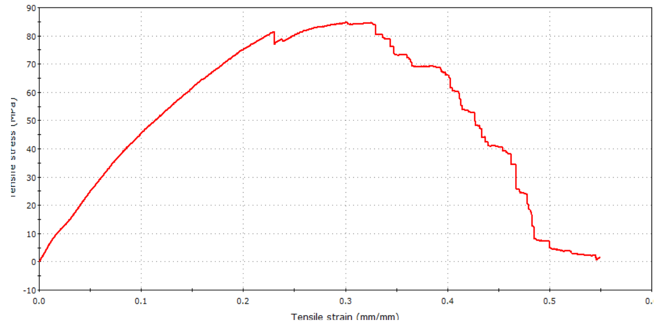

Figure 7: Stress-strain curve of two sandbag layers

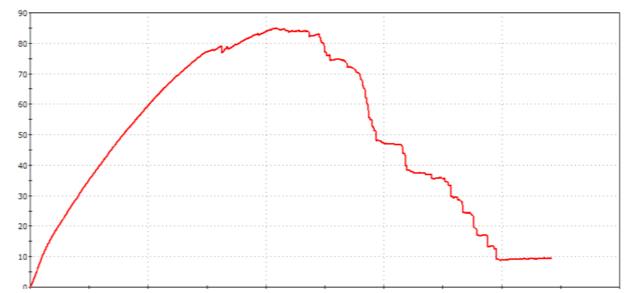

Figure 8: Stress-strain curve of three sandbag layers

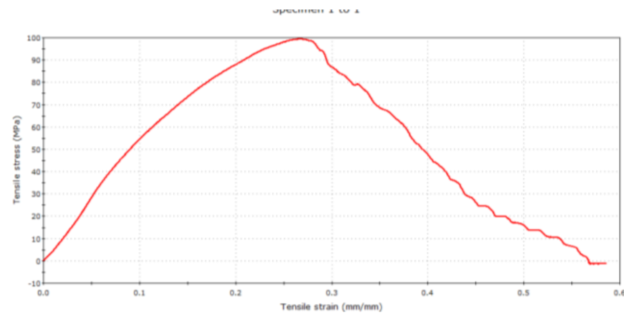

Figure 9: Stress-Strain Curve of four sandbag layers

5.2.2 Compressive strength test

Table 5 shows the most suitable and efficient type of polypropylene bag to be used in construction. Point load test was applied on Sample 1 with maximum capacity 45 tons and didn't show any failure at trial 1. At trial 2, same sample, under point load test with maximum load capacity of 65 tons still no failure has occurred, but the technician stopped the machine to avoid apparatus damage. In sample 3, the used bag under point test with maximum capacity of 62 tons showed failure. The used Polypropylene sandbag can still be used as it withstood a capacity of 62 tons before failure and for its economic impact, but it lacks availability. Therefore, the new polypropylene sandbag was chosen among the other types.

5.2.3 Arch test

The arch test has failed, as during descending of Sandbags arch, it goes down with the formwork until it reached the ground level. The arch failed under its own weight because of the insufficient friction between the Sandbags and the geometry of the arch.

Table 5: Compressive Strength Test Analysis

Sample	Sandbag Type	Sandbag size (cm)	Sand Weight (kg)	Filled Sandbag Dimension (cm)	Initial Contact size (cm)	Load (kN)
1	New polypropylene	45 x 80	40	40 x 9 x 70	30 x 60	450 (no failure)
2	New Polypropylene	45 x 80	40	40 x 9 x 70	30 x 60	650 (no failure)
3	Used Polypropylene	57 x 80	40	50 x 10 x 70	32 x 60	620 (failure)

6 ECONOMIC ANALYSIS

An economic analysis was conducted on the constructed model to assess the feasibility of sandbag construction. The analysis was done with the assumption of having sand available on site, having unskilled labor to construct, no need for transportation as all materials available on site and all materials obtained from local suppliers. The study done was on the model with dimensions 3.8m x 2.9m to calculate the average square meter price. From Table 6, the total cost is equal to 1,240 LE, while the unit cost is 124 LE/m^2. From Table 7, the total cost is equal to 2,640 LE, while the unit cost is 264 LE/ m^2.

Table 6: Results for In-Place Construction Case

Items	Quantity	Price/Unit (LE)	Total (LE)
Polypropylene bags	420	1	420
Man days (Filing bags)	3	100	300
Man days (Construction)	4	100	400
Sand	12 m^3	-	-
HDPE	10 m^2	12	120
Wood purlin (Waste wood)	12 m	-	-
Plastering	24 m^2	-	-
Transportation	-	-	-

Table 7: Results for General Construction Case

Items	Quantity	Price/Unit (LE)	Total (LE)
Polypropylene bags	420	1	420
Man days (Filing bags)	3	100	300
Man Days (Construction)	4	100	400
Sand	12 m3	30	360
HDPE	10 m2	12	120
Wood purlin	12 m	10	120

This sandbag housing technique guarantees the use of available materials in abundance as well as waste materials. Also, this method assess in recycling and reuse of the materials. Equally important, it has little use of Carbon dioxide gas, and it might consider negligible with less energy consumed during construction.

7 CONCLUSION

Based on the materials, methodology, and other parameters associated with this work, it can be concluded that low cost housing remains as one of the most challenging issues not only in Egypt but in other parts of the world for decades to come. Sandbags can be considered as alternative method for constructing a low cost, small size unit for poor and disadvantaged areas. The construction of 12 m^2 sandbag room can be relatively easily conducted with the use of waste bags nearby using fine aggregates and small amount of polyethylene sheets. This small scale project pinpoints a relatively low cost housing for the poor sandbag that costs 124 LE/ m^2 (8 $/ m^2). Evidence exists from our work that sandbag housing is a step to a greener structure that involves less use of non-environmental friendly materials. The sandbag unit developed should be considered as an adaptable and flexible alternative unit in a sense that it can be disassembled and reused with minimal to no loss of the original materials and components.

8 RECOMMENDATIONS

In light of the challenges encountered in this research, the following is recommended to applicators.

- National small and medium entrepreneurs to apply sandbag housing technique in construction

- Use this work as an initial guide in application, like the homogeneity of bags and soil compaction
- Consider applying this model in informal areas in the vicinity of abundant sand sources as well as landfills to increase the economic benefit

On the other hand, further research is needed to cover the following domains:

- Study the possibility of creating sandbag filling plant to enhance productivity based on a simple concept
- Develop a structure analysis of applying a multi-story unit
- Further studies on applying an arch system roof system as well as other roofing systems
- Further testing to assess thermal insulation capability of unit
- Conducting exposure and durability tests to aggressive conditions such as heavy rains, sulphate attack and other chemicals
- Extended testing to fire resistance and sound absorption resistance

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