Using Earth Materials and Simple Techniques for Low Cost Housing

Mireille Kirolos, Abd El Raouf Hassan, Asmaa Mohamed, Hazem El Essawy, Amira El Sherbiny, Minass Asaad, and Mohamed Abou-Zeid
Department of Construction and Architectural Engineering, The American University in Cairo, Egypt.

ABSTRACT:

Half of Cairo's 17 million inhabitants live in informal areas at densities of up to 60,000 people per km^2 [(1)]. These areas are unsafe in which people's lives and health are at risk .As a result of the neglect and poverty, they are living in inhumane housing conditions. The materials their homes are made of mostly deteriorate by time, and offer no shelter and affect negatively on their health. On the other hand, Earth construction is divided into many techniques and categories; its strength is not as high as other construction materials, but has lower cost and simpler structural systems.

The scope of this research is to create a system of housing that is healthier, environmental, and economical to replace the inhumane practices in informal areas that are present at the time being in Egypt. The paper involves recorded results and mechanical characteristics of earth construction method herein referred to as "sand bags". Different types of soils and stabilizing systems are used to reach allowable and reasonable strength with the lowest possible costs using locally available materials.

The materials used in such system are excavated soil, available at hand and environmentally friendly, along with cement and/or lime. Many tests were done on the excavated soil as sieve analysis, compaction, hydrometer, absorption test and compressive strength test. Moreover, compressive strength test was conducted on a model wall made of the sand bag system. Finally, to demonstrate the feasibility of the construction of the sand bag system, a room model was constructed based on suggested approach.

Based upon testing and results, the sand bag system has shown very promising results considering mechanical performance as compressive strength and stability. Moreover, with its ease of application, construction and economic merits, its adoption will be much welcomed by low-income locals living in under privileged housing areas

INTRODUCTION:

Cities in developing countries, including Egypt, face huge housing challenges in attempting to cope with the phenomenon of rapid urbanization. For example, Out of over 3.5 billion people living today in cities, one billion live in informal settlements with no proper shelter [(2)]. On the other hand, most developing countries' ability to cope with such challenges is largely contingent upon their limited resources and the institutional framework in which they operate. [(3)]

Consequently, many studies have been devoted to attempt to solve improper housing using cheap available construction materials as Earth. The use of earth construction started many years ago and there are a lot of techniques that has developed throughout the past several years regarding this type of construction as adobe method, rammed earth and stabilized earth. [(4)] Earth construction is mainly advocated for informal housing as it possess a lot of advantages such as:

- Reduced/No heavy equipment required
- Fast construction
- No specialized labour required

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[1] "Formalizing informal areas in Greater Cairo"
[2] Dr. Marwa A. Khalifa, "Evolution of Informal Settlements Upgrading Strategies in
[3] Christian Arandel, "The Informal Housing Development in Egypt"
[4] "Advantages of Mechanically Stabilized Earth"

- Less site-layout preparation
- Can be built in confined areas
- High seismic load resistance
- Reduced excavation works for footings
- Can be built on poor soil foundation areas

On the other hand, some locals in slump areas in Cairo have been using a method, which involves the above mentioned conventional earth construction methods and called it "sand bags" method. This new method is easy and affordable. The locals have built their one/two storey buildings out of waste fabric bags that are filled with compacted soil. The bags are mainly filled with compacted cement, clay and excavated soil, and are binded using barbed wires. This method was further analysed by designers and found practical (easy to build with no skilled labour required), economic, environmental and structural sound (can resist earthquake, fire, flood, and hurricanes) [(5)]

The objective of this research is to further investigate based on scientific measures and testing the feasibility of using sand bags method and provide an adequate option for housing in informal settlements Different soil mixtures with different proportions of sand, cement, clay, and Aswany clay were studied to provide samples of sand bags. [(6)] Moreover, an attempt is made to use Aswany clay as a binding material instead of cement for more sustainability and cost considerations. All sand bags sample mixtures were then assessed based on their performance and an optimum design is provided. The performance of the different sand bags mixtures will be tested in terms of compressive strength and deflection. Furthermore, a physical model was built with the optimum mixture and aspects as mechanical properties, cost and sustainability are assessed.

1 EXPERMENTAL WORK

1.1 Materials Properties:

The following materials were used for samples preparation
Excavated soil: Soil was excavated at the American university in Cairo facility land, and it was composed of silt, clay and sand
Cement: Ordinary Portland Cement (OPC) type I was used as binding material
Lime: *used as* binding material
Barbed wires: used to bind the earth bags together
Waste Fabric Bags: *Used bags m*ade of woven hard plastic were acquired as waste material from a bakery shop and used as sand bags

1.2 Sample Preparations:

Table 1 shows the different prepared twelve soil combinations made to be used to fill the sand bags. The main difference between the mixtures is the ratio of materials used. Moreover, as shown some mixtures were done without any cement in their design as mixture 11 and 12 in an attempt to reduce costs and enhance sustainability.

After testing the cubes, the most effective mixtures in terms of stability were chosen and designed as sand bags. Since used bags are from waste products, they did not have the same size. Thus, all bags were weighted and their dimensions were measured at time of use as shown in Figure 1.However, since the size of some bags was big and thus would require more materials and space, all bags were modified to have less or more the same width of about 40 cm.

[5] "Formalizing informal areas in Greater Cairo"
[6] "Advantages of Mechanically Stabilized Earth"

Table 1: Distribution detail for each sample mixture

Mixture	*% Clay*	*% Sand*	*% Water*	*% Cement*	*% Aswany*
Mix 1	35	55	7	3	0
Mix 2	35	55	7	0	3
Mix 3	35	54.5	6	1	3.5
Mix 4	40	40	6	14	0
Mix 5	40	32	14	14	0
Mix 6	35	40	21	4	0
Mix 7	40	37	11	0	12
Mix 8	30	40	14	0	16
Mix 9	30	40	20	0	10
Mix 10	25	40	18	7	10
Mix 11	0	60	17	3	20
Mix 12	0	50	17	3	30

Figure 1: Measuring the dimensions of waste bags

After testing the bags and choosing an optimum mixture, a model wall was constructed to test the behaviour of the bags as a system. The wall was built by arranging the bags and barbed wires between each layer of bags, as shown in figure (2), which help in the system being flexible and add friction.

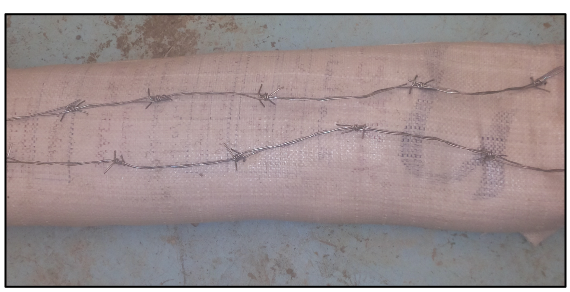

Figure 2: Sand bag with barbed wires

1.3 Test Procedure:

Soil Properties

Various tests were conducted to assess the soil properties such as:
1) Sieve analysis: conducted according to [ASTM C 136 - 01]:
2) Hydrometer: conducted according to [ASTM D 422 – 63]
3) Water content: conducted according to [ASTM D 2116 - 98]
4) Plastic limit & liquid Limit: conducted according to [ASTM D 4318 – 00]
5) Shrinkage limit: conducted according to [ASTM D 427 – 98]

Compressive Strength Test

Done according to (ASTM D2166) on the following:

1) Soil cubes

Different soil combinations of clay, sand and Aswany clay were prepared for compressive testing. The soil specimens were (5*5*5 cm) and tested after 21 days.

2) Sand bags of optimum soil combination

Based on optimum soil combination, sand bags were prepared and tested for compression and deflection after 28-days.

3) Sand bags wall

Finally, a wall system was built with an aspect ratio to a full size wall of (3 m wide and 2.5 m high) and tested for compression to determine the behaviour of the bags when acting in a system. Vertical load testing was done and the allowable and maximum loads were calculated

2 RESULTS AND DISCUSSION

2.1 Soil Testing

Table 2 presents the gradation of the clay and sand found in the excavated soil. The results of the sieve analysis of clay soil shows that most of the percentage passing 10 is the greatest one and the percentage passing sieve # 200 is the least. This means that the clay soil contains small percentage of fine particles and thus will not retain too much water in the mixture. Moreover, based on the overall gradation of the soil, the clay soil is considered well graded. As for the sieve analysis of the sand soil, the percentage-passing sieve # 100 is the maximum percentage, which means that the sand is not grainy.

Regarding the moisture content, Table 3 shows the results of moisture content of the soils. The moisture content of the sand is the maximum as sand absorbs a lot of water, while the clay and Aswany clay moisture content is allowable which will help in the mixture design.

For the plastic and liquid limits of different soil types, Table 4 shows the results and both the liquid and plastic limits are within the acceptable limits. The shrinkage limit for the Aswany clay was further calculated and the result shows that the limit is acceptable as it is less than both the plastic and liquid limits and it satisfies the required results, which means that the soil will not cause sudden failure in the samples.

Table 2: Sieve analysis of clay and sand

Sieve No.	*% Passing Cumulative*	
	Clay	Sand
#10	88%	1.76%
# 20	84%	3.76%
# 40	78%	8.8%
# 60	73%	24.1%
# 100	64%	37.8%
# 200	11%	16.32%

Table 3: Water content (moisture) of soil

Soil Type	*Moisture%*
Clay	29
Sand	42
Aswany Clay	23

Table 4 Results of plastic and liquid limits

Soil Type	*Plastic Limit %*	*Liquid Limit %*	*Shrinkage Limit %*
Clay	17.7	27	
Aswany Clay	29.3	48.5	23.8

2.2 Compressive strength:

Table 5 shows the average compressive strength of the 12 combination soil cube samples after 21 days. Based on results, 5 mixtures were chosen based on best compressive strength performance, which are mixture 5, 7,8,10 and 12. Their soil combination was shown in Table 1. Waste Bags were further prepared with the chosen 5 soil combinations and tested for 28 days compressive strength and deflection. Also waste bags measurements and weight was recorded. All results are shown in Table 6:

Table 5: Average compressive strength of soil specimens

Soil Combination	1	2	3	4	5	6	7	8	10	11	12
Average Compressive Strength (MPa)	0.5	0.2	0.6	1.7	1.8	3.1	2.7	2.9	3.7	3.2	2.9

Table 6: Results of Compressive and Deflection of Sand Bags

Mixture	Height (cm)	Weight (Kg)	Length (cm)	Width (cm)	Compressive Strength (MPa)	Deflection (mm)
Mix 5	9	30.5	55	42	65	0
Mix 7	8	26.5	38	45	23	36.3
Mix 8	7	25.5	55	40	62	24
Mix 10	8	27.5	42	40	63	22.8
Mix 12	8	28	42	42	41	40

From shown results, the sand bags have shown very promising compressive strength results with acceptable deflection ranges. The stability of the bags was highly affected by the mixture parameters, width of bags and the use of barbed wires. Controlling the mixture parameters and the size of the bags are the main tools that assist the load bearing targeted strength.
Moreover, compressive strength test was done on a model wall built with an aspect ratio of (75 cm * 22 cm * 44 cm) and is shown in Figure 3. The compressive strength was calculated using Equations 1 and 2 and resulted in 21 MPa. Then, the maximum force the wall can withstand per meter run was also calculated using Equation 3. The allowable force was 141-kilo newton per meter run.

$M_x = N.e$ Equation (1)

$O'_{max} = N/A + M_x Y / I_X$ Equation (2)

$P_{all} = O'_{max} * b * 1000/1.20 * 2 * 1000$ Equation (3)

Factor of safety for eccentricity (1.20) — Factor of safety (2) — To KN (1000)

Where

M_x = the moment around the x-axis
N = the vertical load applied
A = Area of the wall
O'_{max} = Maximum Stress Applied
b= The Width of the Wall
Y= Half the Width of the Wall
e = Eccentricity
I_x = Moment of Inertia
P_{all} = The allowable load

Figure 3: Compressive Testing of Model Wall

3 ROOM MODEL

Finally, a model room of dimensions 3*3*3m was also built for checking the feasibility of construction and stability of the system. Figure 4 shows the progress of the construction work. The room was built at the university facilities and the sand bags were made of the same soil excavation extracted for the foundation.

Figure 4: Progress of the Construction of the built Room Model

The construction of the model room involved the following:

1. The soil was excavated for 0.25 meters to build a small type of foundation
2. The excavated soil was then used for filling the sand bags
3. The sand bags were cut in place to required dimensions and filled by excavated soil using basic tools with soil combination of mixture 12
4. Compaction of sand bags was made manually using old molds.
5. The walls were built by laying the sand bags in a row and connecting them by a barbed wire
6. The door and the windows formworks were laid while the building was in progress
7. The building was plastered using the same mixture of excavated soil used in the bags
8. Since the mortar was not well binding to the wall, roughing the surface of the bags was essential

The construction was as expected simple and feasible. No heavy equipment nor any skilled labors were required. Furthermore, the construction was fast, although the area was very confined. Most importantly, the system was sound and stable.

4 Conclusions:

Based on above research and experimental work, sandbag system has proven to be very practical and feasible for low-income housing. Soil combination of mixture 12 could be recommended for use as it has shown the most optimum results. It is composed of (Aswany clay: clay: sand: water) with the following ratios of (2.5:1:5:1.5) respectively.

Moreover, in this mixture the Aswany clay has fully replaced the Portland cement, which further advocates the mixture in terms of being environmentally friendly and economic while maintaining adequate compressive strength.

Sandbag system can provide a platform for more research and studies to be done for improving the housing conditions of underprivileged locals living in slum and informal areas. These systems should acquire certain properties for example the structural requirements, as well as ease of application and low costs while maintaining structural stability.

5 Recommended Future research:

Its ease of application and economic merits while maintaining mechanical properties as strength and stability will make its adoption very much endorsed for informal under privileged housing areas. A full house model with adequate roof materials as well as full construction and finishing should be considered

- A wider scope of tests needs to be conducted using variable materials, bag sizes and in combination with other binding materials
- Model pilot houses using earth materials need to be promoted to invite the community and applicators to incorporate it in their work
- The civil society and the NGOs should join hands with construction industry in implementing such technique and other technique to alleviate the severity of informal settlements

6 References:

“Advantages of Mechanically Stabilized Earth Walls.” *About.com Construction*. N.p., n.d. Web. 25 Feb. 2014.

“Formalizing Informal Areas in Greater Cairo: Management Training for Senior Governorate Officials (P Wakely, B Mumtaz, S Meikle) | DPU Associates.” N.p., n.d. Web. 25 Feb. 2014.

“SB13 - ID 56 - Presentation.pdf.” Web. 26 Feb. 2014.

“WP82.pdf.” Web. 26 Feb. 2014.

Earth bag/Super Adobe House Construction. N.p., 2012. Film.

Fathy, Hassan. *Architecture for the Poor: An Experiment in Rural Egypt*. University of Chicago Press, 2010. Print.

Lal, A. K. *Hand Book of Low Cost Housing*. New Age International, 1995. Print.

McHenry, Paul Graham. *Adobe and Rammed Earth Buildings: Design and Construction*. University of Arizona Press, 1989. Print.

Minke, Gernot. *Earth Construction Handbook: The Building Material Earth in Modern Architecture*. Wit Press, 2000. Print.

Pyla, Panayiota I. “Hassan Fathy Revisited: Postwar Discourses on Science, Development, and Vernacular Architecture.” *Journal of Architectural Education* 60.3 (2007): 28–39. *CrossRef*. Web. 16 Feb. 2014.

Zami, Mohammad Sharif, and Angela Lee. “Economic Benefits of Contemporary Earth Construction in Low-Cost Urban Housing – State-of-the-Art Review.” *Journal of Building Appraisal* 5.3 (2010): 259–271. *www.palgrave-journals.com*. Web. 25 Feb. 2014.