KATHMANDU UNIVERSITY JOURNAL OF SCIENCE, ENGINEERING AND TECHNOLOGY
VOL. 9, No. I, July, 2013, 200-211

A STUDY ON ECO FRIENDLY COST EFFECTIVE EARTHBAG HOUSE CONSTRUCTION

Rajesh Kumar Jain
Bharat Group of Colleges, Punjab, India
Corresponding author: rajmeerutcity@gmail.com

Received 04 March, 2013; Revised 09 May, 2013

ABSTRACT

This report will highlight the benefits both in terms of CO_2 reduction and cost saving construction. This project will develop rigorous assessment methods and will broaden applications. It is expected that the project will have an impact on construction practice and will lead more research in this area. The weakest specimens tested obtained maximum compressive strengths ranging from 120 kN/m to 140 kN/m, almost 10 times as great as those typically achieved by conventional stud-frame housing in terms of load per metre of wall length. The lowest load deformation response was observed for the G9 specimen group, at 0.7 kN/mm. The strongest and stiffest results were observed for the 3-bag soil-filled specimen, with load deformation responses ranging from 8 kN/mm to 15 kN/mm, and compressive strength two orders of magnitude higher than conventional stud-frame housing, ranging from 1100 kN/m to 1300 kN/m. Strength and stiffness values for medium soil-filled specimens measuring 508 mm x 914 mm were in the same range as the values for the small specimens. There was little difference in stiffness between specimens filled with topsoil and those filled with a 4:1 ratio of topsoil to masonry sand, though small sample size prevents a meaningful statistical analysis of the variance between the two fill materials.

Keywords: Earthbag, Polypropylene , Soil characterization, Compression , Tensile strength

INTRODUCTION

The goal of sustainable construction is to reduce the environmental impact of a constructed facility over its lifetime. Every year millions of new buildings are being constructed and on the name of modernity new construction materials are being introduced. The world today has encountered with global warming and climate change. Besides other contributors, extraction of natural resources as building materials itself consume energy, cause environmental degradation and contribute to global warming. Buildings are the largest energy consumers and greenhouse gases emitters, both in the developed and developing countries. Urgent changes are therefore required relating to energy saving, emissions control, production and application of materials. Immediate suggestion related to use of renewable resources, and to recycling and reuse of building materials is necessary. The composition of green house gases is 76% carbon dioxide CO_2, 13% methane, 6% nitrogen oxide and 5% fluorocarbons. Therefore, CO_2 is a significant contributor for increasing the global temperature. Infrastructure scenario of India showed that total investment has been double in 2011-12 vis-à-vis 2007-08, projected to cross 500,000Cr . The Eleventh Five Year Plan has a special focus on Rural Infrastructure Development. The most serious problem with our industry is that it is a major CO_2 emitter causing global warming. With every ton of cement produced, almost a ton of CO_2 is emitted [6]. In terms of conventional concrete mixtures (i.e. not using fly ash, slag or silica fume), about 480 kg of CO_2 is emitted per cubic metre of concrete or 20 kg of CO_2 per 100 kg of concrete produced. All of this amounts to about 7% of the total CO_2 generated worldwide [7]. Earthbag housing is a simple form of earth-based construction wherein large bags are filled with granular material, compacted and laid horizontally in a running bond to form the core of a wall system. Polypropylene bags are currently favoured by the earthbag building community for their strength, resistance to decay, and affordability, but natural materials such as burlap have also been used. Barbed wire is typically laid in between each course of earthbags to provide shear strength, as the friction between successive courses of bags is low, especially when polypropylene bags are used.

MATERIALS AND METHODS

Mechanical Methods , Maturity Method, Methods based on Acoustics are used to test the properties of material. Due to the relatively recent development of earthbag housing techniques, as well as the informal manner in which most earthbag construction has been performed to date, there exists no commonly accepted standard for testing earthbag assemblies.

Testing Program for earthbags

A testing program was designed which consists of three main sets of tests. The first set is a series of compressive tests of earthbag assemblies intended to determine the load-deflection characteristics of earthbags, as well as how these characteristics change with respect to bag size and soil properties. The second set of tests aimed to characterize the granular materials used to fill the bags in part 1. The third set of tests (“part 3”) involved characterization of the ultimate strength and load deflection characteristics of the polypropylene textile used in the bags tested in part 1.

Compressive Tests of Unplastered Earthbags

It was based on a modified version of ASTM E 447.. Polypropylene bags were in three different nominal sizes: 457 mm X 762 mm, 508 mm X 914 mm, and 635 mm X 1016 mm (hereafter referred to as the “small”, “medium” and “large” bag sizes).

Soil Characterization

All granular materials were analyzed according to the provisions in ASTM D 421, as well as ASTM D 422. (Table 2 &3).

Tensile Testing of Polypropylene Bag Fabric

Initial testing was done under the requirements of ISO 13934-1 (Table 4).

RESULTS AND DISCUSSION

Bag size can vary, depending on manufacturer and builder preference, but the most common size for housing construction is approximately 457 mm wide and 762 mm long (nominally specified as 18”X30”). This particular size is sometimes colloquially known as a “50 Pound Bag” [5]. This size has been accepted by the earthbag community as having an optimal balance of strength and workability, based on construction experience. According to the Unified Soil Classification System (USCS), silt and clay particles are those with diameters less than 0.075mm, sand particles have diameters between 0.075 and 4.75 mm, and gravel particles have diameters between 4.75 and 76.2 mm [2]. This system does not differentiate silt and clay particles based on diameter, but rather on the minerals which make up the particles(Figure5). Silt particles are generally quartz-based, whereas clay minerals are made up of complex aluminum silicates[2]. For all types of earthen construction, the fraction of soil made up of clay particles is particularly important since clay acts as a binding agent. Higher clay content results in higher cohesion, since clay particles typically have a net negative charge that attracts positively charged particles to their surface [2]. However, clay also displays certain properties which are undesirable for earthen construction. Specifically, it has a tendency to swell and shrink with high or low moisture contents, respectively. The amount of volume change between a saturated and dry clay can be anywhere from 100% to 2000%, depending on the specific clay minerals present [5]. This volumetric instability suggests that there is some upper bound for clay content, beyond which increases in cohesiveness are outweighed by high instability. Currently, the accepted optimal range for clay content in earthbag soils is between 5% and 30% [5], though very little quantitative testing has been done to verify this range. Particle size distribution is important for its effects on cohesion and stability (and subsequently compressive strength) as mentioned above, but there are also serviceability concerns associated with the particle size distribution curve of a particular soil. Specifically, the amount and rate of deflection of an earthbag wall under service loads is likely to be affected by the relative fractions of sand and clay particles. In aggregate, sand particles are much less compressible than clay particles, and they typically reach maximum compressive deformation quickly upon being loaded. Clays, on the other hand, tend to be highly compressible, and deform much slower than sands under load [9]. In a structural context, this means clay-rich soils have the potential to exhibit greater deformations due to long-term dead loads than soils with leaner clay fractions. An examination of the effects of particle size distribution on the service behaviour of earthbag structures has not yet been conducted in any formalized manner. In order to bring earthbag construction in to the mainstream for both developing and developed contexts, knowledge of service state behaviour is critical, since housing residents typically demand durable structures with a minimum of cracks, and are not likely to have confidence in a technology with poorly understood long-term response to loading (Figure 6,7). To date, laboratory testing of earthbag technology has been virtually nonexistent. This report presents the compressive tests using polypropylene bags of an unspecified size, and three different fill materials described as sand, dirt and rubble.

Earthbag construction

Earthbag construction is an inexpensive method to create structures which are both strong and can be quickly built (Figure 3). It is a natural building technique that evolved from historic military bunker construction techniques and temporary flood-control dike building methods. The walls can be curved or straight, domed with earth or topped with conventional roofs. Curved walls provide good lateral stability, forming round rooms and/ or domed ceilings like an igloo. Buildings with straight walls longer than 5 m (16.4 ft) in length need either intersecting walls or bracing buttresses or piers added. International standards exist for bracing wall size and spacing for earthen construction in different types of seismic risk areas, most notably the performance-based standards of New Zealand recommended by the ASTM International in their Standard Guide for Design of Earthen Wall Building Systems E2392 / E2392M 10e1. Until more complete structural testing is available to co-relate earthbag bracing need and performance to adobe, cement-stabilized buttresses and mortar anchors to hold barbed wire at stress points can be used for public buildings in high seismic risk areas.

To improve both friction between each row of bags and finished wall tensile strength barbed wire is often placed between the courses(Figure 4). Twine is also sometimes wrapped around the bags to tie one course to the next, serving to hold the in-progress structure together and add strength. Rebar can easily be hammered into walls to strengthen corners and opening edges and provide more resistance against overturning. The structure is typically finished with plaster, stucco or adobe both to shed water and to prevent any degradation from solar radiation. This construction technique can be used for emergency shelters, temporary or permanent housing and barns..

Environment friendly

All walls constructed for housing will allow some movement of air and heat at the same time creating some resistance to these flows based on the individual component R values of the wall system' s U value (Figure 4, Table 5). Thermal resistance is referred to as an (R) value, while the reciprocal of R is the conductivity (C) of the wall material.

$C= 1 / R$

The rate of heat and air flow is a useful concept in understanding the comparisons of wall materials and their thermal conductance. The thermal transmittance is the surface resistance plus the rate of heat transferring per unit of measurement through the wall, denoted as a (U; the thermal transmittance) value, also referred to as the reciprocal of the sum of the system R values.

$U= 1 / R1 + R2+\dots Rn$

The emissivity (ع) or thermal absorptivity (α) of a wall is dependent on its material make-up, density, mass (thickness), ambient air temperatures (on both sides of the wall), and solar radiation. Once the thermal capacity (*cp*) of a wall and the time or rate of energy movement is known, then a comparison of wall types can be considered on a level plane for efficiencies.

The U factor is the capacity of a material to transfer heat or cold. The U value and the mass are useful information to consider for more equitable comparisons. Based on the R value alone, there is no comparison of the R values of SB walls (R3 to R19 per inch, depending on the construction) to that of RE walls which have poor thermal resistance (R0.4 per inch) [1]. The wood by itself without insulation and moisture barrier will have a higher resistance to heat transfer. Wood has a lower R value than fiberglass insulation, for example, based on the relative thickness of the two materials. For example; a 2x4 of wood has an R value of 1.25 per inch totaling a 4.375 component R value (Commonwealth Scientific and Industrial Research Organization (CSIRO), 2000). The inclusion of thermal mass in building design is only a part of an integrated approach to sustainable design.

Earthbag Building Insulation

Energy performance on most buildings can be improved with insulation, including those made of earth such as adobe and earthbag structures. Although most earthen structures are located in hot, dry climates, there is increasing demand for low-cost, eco-friendly earth building techniques in cold climates. This article explores innovative methods for insulating earthbag buildings, which extends their building range to cold regions. Recycled polystyrene (Styrofoam) is another good possibility. Another possibility is adding foam board or foam insulation on the exterior of earthbag walls, as explained in the 4th option.The table below compares the approximate R-values of five low cost insulating materials that could be used in earthbags. (The first column in the table is the insulative value per inch; the second column shows the R-value for a typical 15" thick earthbag wall.)

Material -- R-value/inch -- R-value/15"
Rice hulls -- R-3 -- R-45
Perlite -- R-2.7 -- R-40
Vermiculite -- R-2.13 -- R-32 to 36
Extruded polystyrene -- R-3.6 to R-4.7 -- R-54 to R-70
Molded polystyrene (low density) -- R-3.85 – R-58

Plastic bags recycled into plastic bags .if plastic does not break down for a thousand years, this building is sure to last several lifetimes. Ofcourse covered with adobe or plaster, so that the plastic does not offgas or degrade.Dunbar & Wipplinger[3] observed ultimate stresses for sand,rubble and soil-filled earthbags of 0.30 MPa, 0.40 MPa, and 2.14 MPa, respectively. By comparison, the stresses range from 1.10 MPa to 2.98 MPa for crushed granite filled specimens, and 2.33 MPa to 2.98 MPa for both sandy soil and topsoil filled specimens, for the 3-bag configuration most similar to the West Point tests. The tests are not indicative of specimen failure, but rather the limitations of available testing equipment.

As such, it is possible that actual ultimate strengths may be observed in a significantly higher range. For the taller specimens, stresses ranged from 0.35 MPa to 0.45 MPa for the 6- bag specimens, and 0.27 MPa to 0.32 MPa for the 9-bag specimens (Figure 8,9). These values suggest that there is some agreement between the soil-filled specimen results, at least in terms of the general range of strengths observed for soil-filled earthbags (>2 MPa). Riley & Palleroni [8] cited a typical strength range of 12 kN/m to 18 kN/m for typical residential construction using 38 mm x 140 mm stud framing. Straw bale housing has been shown to compare favourably with conventional stud framing, with published strength values ranging from 20 kN/m to 80 kN/m for plastered straw bale specimen tests [10], and 30 kN/m for full-scale (2.44 m x 2.44 m) wall tests [10]. The values for soil-filled specimens are an order of magnitude higher, ranging from 1123 kN/m to 1327 kN/m. This clearly demonstrates the adequacy of earthbag technology for use in housing applications from a strength perspective. Even the weakest specimens observed outperformed the published strength values of conventional housing by a factor of nearly 10. This confirms the notion that excessive deflection is likely to govern the design of earthbag structures, highlighting the need for an examination of the stiffness of plastered earthbag assemblies. Beyond the quantitative results the specimens confirm that earthbag construction is a low-technology building technique which can be easily learned by those not trained in the construction trades. This, combined with the high strength values observed for all small specimens, suggests that small (457 mm x 762 mm) bags are the optimal size for earthbag construction, providing a good balance between strength and ease of manipulation.(Table 6, 7).

Table 8 presents a summary of embodied energy values for several common construction materials, taken from Hammond & Jones [4]. The value for rammed earth is presented, as there is currently no published value for earthbags. This is likely to be an overestimate of the embodied energy of the soil fraction of earthbag housing, as it is not necessary to construct formwork or use mechanized compaction devices for earthbag housing, as is required of rammed earth. It should be noted that the embodied energy of polypropylene is much higher than all other common building materials presented in Table 8 but also that polypropylene makes up a small fraction of the total mass of an earthbag wall. The results of the tests also clearly highlight the effect of stack height on earthbag specimen strength and stiffness. The data suggest that earthbag strength and stiffness decay exponentially as stack height increases. An inverse relationship between stack height and specimen strength and stiffness (in terms of kN/mm) makes intuitive sense, since an equivalent deflection will compress a short specimen more as a percentage of its total height than the same deflection applied to a taller specimen.The above discussion of the relative merits of straw bale, earthen and bamboo housing in the context of material availability, climactic suitability, trades availability and architectural preference indicates that earthen housing is the most suitable choice for housing construction in the coastal region .

There exists an opportunity for the implementation of alternative construction techniques in developing countries, and specifically in south Asia. The wide availability of alternative construction materials, coupled with the generally inexpensive and low-technology nature of their related construction techniques, makes them well suited to use in developing countries. Housing may also be suitable, though significant attention should be paid to moisture-related concerns, wet climate.

Figure-1-Folded and pinned bag closure

Figure-2- Earthbag Construction

Figure-3- Earthbag Construction

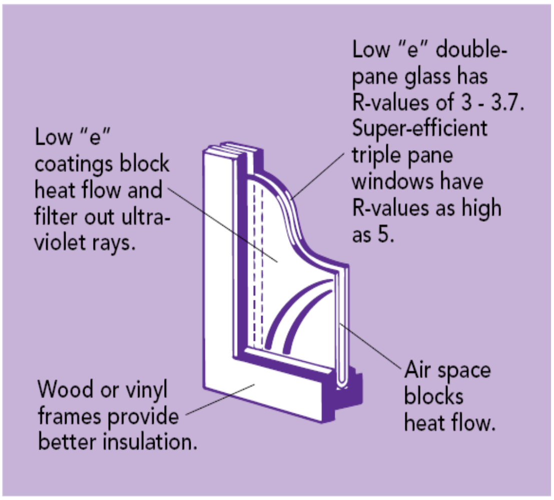

Figure-4- Comparison of the R values of SB walls

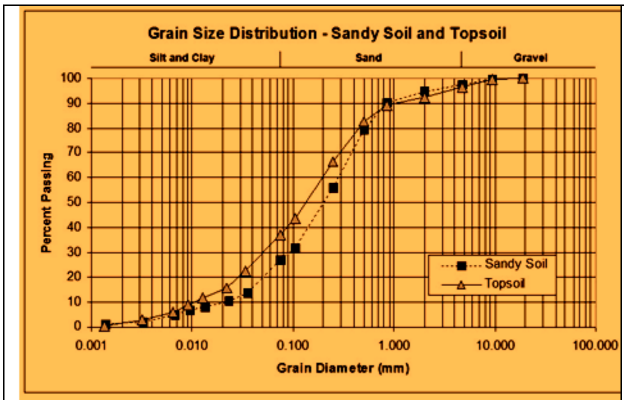

Figure-5-Grain size distribution curve results for sandy soil and topsoil.

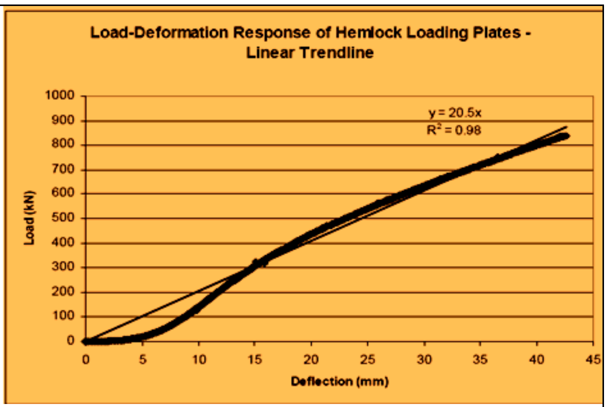

Figure-6-Load versus deformation plot for hemlock plates, with

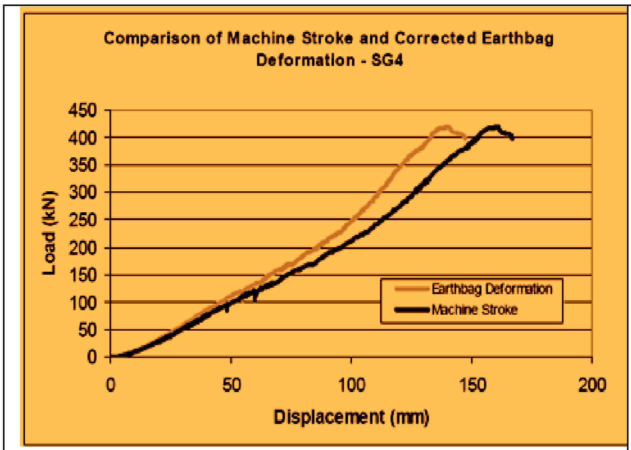

Figure-7-Load versus machine stroke and load versus earthbag deformation, specimen SG4.

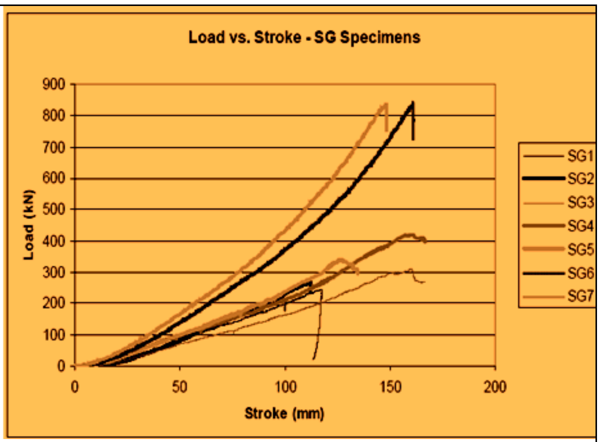

Figure-8-Load versus stroke, all SG specimens

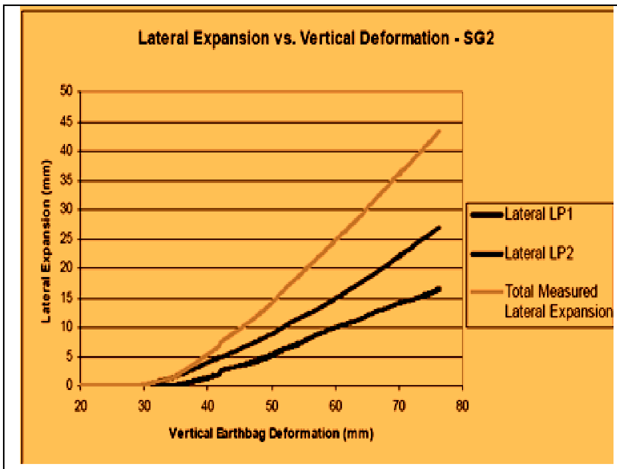

Figure-9-Lateral expansion versus vertical earthbag deformation, specimen SG2

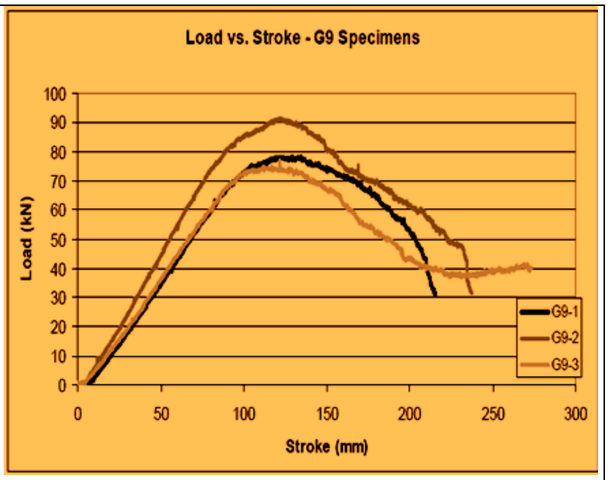

Figure-10-Load versus stroke, G9 specimens

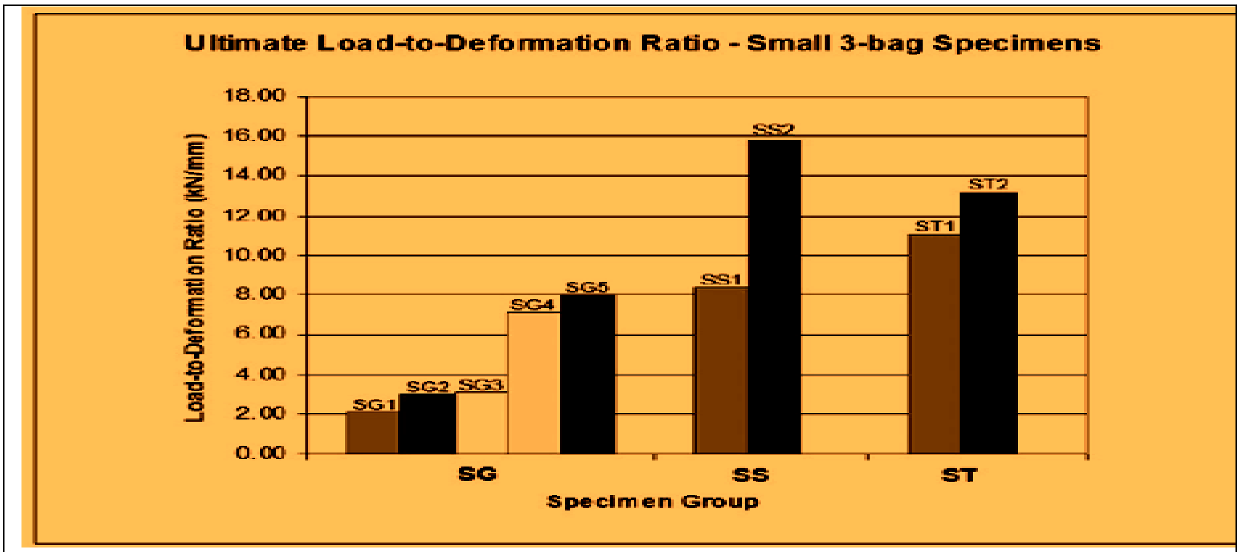

Figure-11-Stiffness of SG, ST and SS specimens as measured by ratio of ultimate load to deformation at ultimate

Table-1-Densities, Specific Heat and Thermal in a Range of Materials

Material	**Density** (Kg/m³)	**Specific heat** (kJ/kgK)	**Volumetric heat capacity** Thermal mass (kJ/m³K)
Water	1000	4.186	4186
Concrete	2240	0.920	2060
AAC¹	500	1.100	550
Brick	1700	0.920	1360
Stone (Sandstone)	2000	0.0900	1800
Fiber Cement Sheet (compressed)	1700	0.900	1530
Earth Wall (Adobe)	1550	0.837	1300
Rammed Earth	2000	0.837	1673
Compressed Earth Blocks	2080	0.837	1740

AAC; Autoclaved Aerated Concrete is a precast structural product made with all-natural raw materials

Table-2-Specifications given in ASTM C 144 for the allowable particle size distribution of masonry sand.

Sieve No.	**Diameter (mm)**	**Percent Passing**			
		Natural Sand		**Recycled Sand**	
		Lower Bound	Upper Bound	Lower Bound	Upper bound
4	4.75	100	100	100	100
8	2.36	95	100	95	100
16	1	70	100	70	100
30	0.6	40	75	40	74
50	0.3	10	35	20	40
100	0.15	2	15	10	25
200	0.075	0	5	0	10

Table-3-Results of particle size distribution analysis of sandy soil and topsoil

Sandy Soil		Topsoil	
Grain Diameter (mm)	**Percent Passing**	**Grain Diameter(mm)**	**Percent Passing**
19.050	100	19.050	100.00
9.525	99.54	9.525	99.49
4.750	97.47	4.750	96.52
2.000	94.62	2.000	92.14
0.850	90.2	0.850	89.28
0.500	79.4	0.500	82.56
0.250	56.24	0.250	66.44
0.106	31.97	0.106	43.46
0.075	26.97	0.075	37.29
0.0357	13.9	0.0337	22.57
0.0227	10.62	0.0218	15.80
0.0133	7.92	0.0127	11.85
0.00939	6.95	0.00909	9.03
0.00667	4.82	0.00647	6.21
0.00329	2.12	0.00321	2.63
0.00137	1.35	0.00134	0.38

Table-4-Tensile properties of Geotextiles by the Wide Width Strip method (ASTM D 4595-05)

Individual data						Average	S.D	% C.V
Breaking Strength(kN/m)	6.8 6.7	6.9	6.8	6.8	6.3	6.7	0.2	3.2
Breaking Strength(Ib/in)	38.8 38.3	39.4	38.6	38.7	35.8	38.3	1.3	3.2
Elongation at Break(%)	27.3 29.6	29.8	28.5	29.7	29.0	29.0	1.0	3.3
Strength at 5% Elongation(kN/m)	2.7 1.7	2.4	2.5	2.1	2.1	2.3	0.4	15.8
Strength at 5% Elongation(Ib/in)	15.1 9.5	13.5	14.0	12.0	11.9	12.7	2.0	15.6

Strength at 10% Elongation(kN/m)	4.3 3.5	4.1	4.2	3.8	3.7	3.9	0.3	8.0
Strength at 10% Elongation(Ib/in)	24.6 19.8	23.4	23.7	21.8	21.1	22.4	1.8	8.1
Cross Direction								
Breaking Strength(kN/m)	6.6 6.8	6.8	7.0	7.0	6.9	6.9	0.2	2.2
Breaking Strength(Ib/in)	37.6 38.8	38.7	40.2	39.9	39.5	39.1	0.9	2.4
Breaking Strength(kN/m)	6.6 68	6.8	7.0	7.0	6.9	6.9	0.2	2.2
Breaking Strength(Ib/in)	37.6 38.8	38.7	40.2	39.9	39.5	39.1	0.9	2.4
Elongation at Break(%)	25.6 25.7	26.6	28.6	27.1	27.5	26.9	1.7	4.2
Strength at 5% Elongation(kN/m)	2.1 2.1	2.2	2.1	2.1	2.1	2.1	0.0	1.9
Strength at 5% Elongation(Ib/in)	12.1 12.2	12.3	12.0	11.8	12.0	12.1	0.2	1.5
Strength at 10% Elongation(kN/m)	3.9 3.9	3.9	3.9	3.9	3.9	3.9	0.0	0.0
Strength at 10% Elongation(Ib/in)	22.2 22.2	22.5	22.2	22.2	22.2	22.2	0.2	0.2

Table-5-Measured lateral-to-vertical deformation ratio and associated R2 value for specimens SG2-

Specimen	Calculated Lateral-to- Vertical Deformation Ratio	R2 Value of Trend Line
SG2	1.023	0.996
SG3	0.735	0.994
SG4	0.789	0.996
SG5	0.744	0.999

Table -6-Summary of test results for SG and MG specimens

Test	Ultimate Load (kN)	Earthbag Deformation at Ultimate (mm)	Stress at Ultimate (MPa)	Stiffness at Ultimate (kN/mm)	Load per Metre (kN/m)
SG1	n/a	n/a	n/a	n/a	n/a
SG2	n/a	n/a	n/a	n/a	n/a
SG3	311	145	1.10	2.15	489
SG4	421	140	1.49	3.00	663
SG5	341	110	1.21	3.11	537
SG6	840	118	2.98	7.12	1320
SG7	839	105	2.97	7.98	1320
MG1	501	166	1.39	3.03	669
MG2	715	165	1.98	4.32	954
MG3	630	186	1.74	3.38	841
MG4	785	161	2.17	4.87	1050
MG5	842	146	2.33	5.78	1120

Table 7-Test results for polypropylene textile, machine direction

Specimen	Breaking Strength (kN/m)	Elongation at Break (%)	Load at 5% Elongation	Load at 10% Elongation	Specimen	Breaking Strength (kN/m)
M1	6.8	27.3	2.7	4.3	C1	6.6
M2	6.9	29.8	2.4	4.1	C2	6.8
M3	6.8	28.5	2.5	4.2	C3	7.0
M4	6.8	29.7	2.1	3.8	C4	7.0
M5	6.3	29.0	2.1	3.7	C5	6.9
M6	6.7	29.6	1.7	3.5	C6	6.8
Mean	6.7	29.0	2.3	3.9		6.9
Standard Deviation	0.2	1.0	0.4	0.3		0.2

Table-8-Embodied energy values for common construction materials

Material	Embodied Energy (MJ/kg)
Concrete	0.99
Brick	3.0
Softwood	7.4
Gypsum (for use in drywall or plaster)	1.8

Rammed Earth	0.45
Polypropylene Textile	99.2

CONCLUSION

From an ultimate limit states perspective, however, failure of the plaster skins is not likely to impact the ultimate strength of the earthbags themselves. Earthbag housing is a structurally sound technology in the context of vertical compressive loads, further knowledge of plastered behaviour, behaviour under in-plane and out-of-plane shear loading, as well as behaviour under uplift forces, is required in order to develop comprehensive, empirically based design recommendations for earthbag housing. With regard to constructability and material availability, earthbag housing is a very attractive construction technique. The advantages include high strength, lightweight, improved resistance to corrosion and fatigue, superior damage tolerance and the ability to be tailored to meet specific applications, compared to traditional steel and reinforced concrete structures.

REFERENCES

1. Chalfoun N V & Michal R J, Thermal performance comparison of alternative building envelop systems;An analysis of five residences in the community of CIVANO (2003).
2. Das B M, Fundamentals of Geotechnical Engineering, Second Edition”,Thomson Canada Limited, Toronto, Ontario, Canada (2005).
3. Dunbar R & Wipplinger L, PrismTesting of Polypropylene Earthbags.Unpublished report, West Point Military Academy (2006).
4. Hammond G & Jones C, Inventory of Carbon and Energy, Version 1.5 Beta.;Available online: http://people.bath.ac.uk/cj219/ (2006).
5. Hunter K & Kiffmeyer D, Earthbag Building. New Society Publishers,Gabriola Island, British Columbia, Canada (2004).
6. Klein, Manfred & Donald Rose, Development of CME National Emission Guidelines for Cement Kilns in CANMET/ACZ International Symposium on Sustainable Development of the Cement and Concrete Industry, editor V.M. Malhotra, Ottawa,1998; Oct pp. 16-3 (1998).
7. Malhotra, V M, Making Concrete Greener with Fly Ash. Concrete International, 21(5), (1999)61-66.
8. Riley D & Palleroni S, Community-built Housing Solution: A Model Strawbale Home Design.Unpublished report.Available online: http:// www. nibs.org /BETEC/ Pres/ riley (1999).
9. Terzaghi C, Principles of Soil Mechanics: V-Physical Differences Between Sand and Clay. A History of Progress. Selected US Papers in Geotechnical Engineering, American Society of Civil Engineers, 1(1923).
10. Vardy S, MacDougall C ,Magwood C & Spick A, The Design and construction of the 4C’s Building. Journal of Green Building.1(2)(2006),49.