INFORMATION ABOUT BSI'S GEO-TEXTILE BUILDING MATERIALS

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EARTHBAG

BASIC CONSTRUCTION METHODS

Earthbag uses poly bags or crocheted tubes as forms for solid earthen walls or domed roofs that are tamped and cured in place. Barbed wire is added between courses, and surfaces are plastered. This technique is more resistant to collapse than adobe or CEB, simpler to build than rammed earth, and makes thinner walls than cob or tire walls.

How-to information about earthbag construction is available both online[1] and in books.[2]

Some basics of this type of building:

- 8' high walls 14- 15" thick (4' base walls can be 12" thick)
- Tamp moist bags in place to 75- 85% of original height
- Two strands of barbed wire per course continuous
- Hammer vertical half-inch rebar 12" from openings

Above: Before and after tamping
Below: Wire mesh to reinforce plaster

Extra reinforcement used in hazardous regions:

- Weave barbed wire out corners and up into next course 24" min.
- Strap several courses together
- Add metal pins between courses at stress points
- Reinforced bond beam capping all walls and buttresses
- Mesh reinforces all plaster; tied through wall 24" both ways
- Exterior diagonal rebar bracing tied through wall for shear panels
- Add cement anchors between sandbags to hold barbed wire

[1] See Build Simple info page and slide shows: http://buildsimple.org/earthbag.php. Owen Geiger has a full libaray of short videos online at http://www.youtube.com/user/naturalhouses?feature=watch. Other sites teaching earthbag include www.EarthbagBuilding.com and www.Calearth.org.

[2] Print book: Kaki Hunter and Donald Kiffmeyer, *Earthbag Building: The Tools, Tricks and Techniques* (Gabriola Island BC: New Society Publishers, 2004); Ebook, *The Earthbag Building Guide*, by Owen Geiger, self-published 2012 available at http://www.e-junkie.com/earthbag/product/464619.php .

SOIL TESTING

No building codes refer to earthbags, but some restrict earth construction in general to soils of at least 300 psf. Earthbag and some adobe buildings built of moderate-strength soils have performed well in some regions for decades.

An old adobe dry strength test[3] evaluates strength by making and drying 3/4 inch diameter balls. If some of the balls crack or can be crushed between your thumb and forefinger, the soil is not strong enough.

The two-tiered system of the New Zealand Standards for earth buildings[4] developed for adobe, CEB, and rammed earth may be applicable to earthbags. Standard grade construction allows lower compressive strength[5] for non-engineered modest-sized buildings that meet certain criteria. Simple field tests can evaluate compressive strength. Dry a tamped bag for 7-10 days. Then drop it from 18" onto a hard surface on one corner.

For special grade status drop the unit from 36" height. The soil is strong enough if the block doesn't break in half or lose more than 4" from any corner. Soils laboratory tested for 250 psf compressive strength are allowed used with less stringent safety factors in engineered buildings.

RESEARCH PRECEDENTS

Civil engineers have analyzed the behavior of soil bags for road foundations, dams and retaining walls,[6] but most of these studies used only non-cohesive fill.

Photos at right: Top- Pelly's arch test;
Bottom- Thiart's channel-bag wall

In three research projects by graduate students at Bath University, 80% scale soil bags were filled with sand.[7] At Cape Peninsula University of Technology[8] a student built a full-sized, mesh-plastered wall using channelized sandbags without barbed wire.

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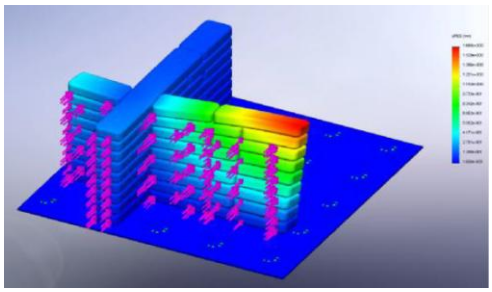
[3] Marcial Blondet et al, *Earthquake Resistant Construction of Adobe Buildings: A Tutorial*, second edition April 2011, Earthquake Engineering Institute, Oakland, CA available at the World Housing Encyclopedia at http://www.world-housing.net/tutorials/wp-content/uploads/2011/06/Adobe_Tutorial.pdf

[4] Recommended by the revised ASTM E2392 *Standard Design of Earthen Wall Building Systems,* the New Zealand Standards are introduced in: Hugh Morris, Getty Conservation Institute, New Zealand: Aseismic Performance-Based Standards, Earth Construction, Research and Opportunities, in *Proceedings of the Getty Seismic Adobe Project 2006 Colloquium*. Accessed 10/17/2011 at http://www.getty.edu/conservation/publications_resources/pdf_publications/gsap_part2b.pdf

[5] Standards Council, *New Zealand Standards 4298: Materials and Workmanship for Earth Buildings*, New Zealand : June 2000, p. 64

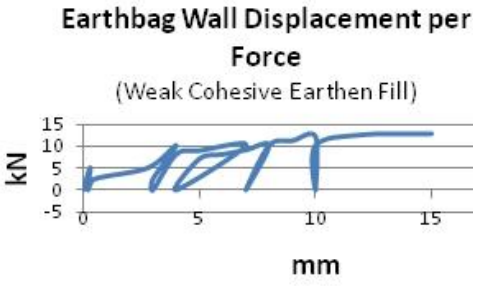
[6] Recent studies include work by Ansari, Aqil, Baer, Krahn, Liu, Lohani, Matsuoka, Matsushima, Singh, Tantono, Xu and many others. A preliminary list is posted by Earthbag Building under Background Information > Geo-synthetics Testing, found near the bottom of the testing page at http://www.earthbagbuilding.com/testing.htm

A Hohai University researcher used a small shake table to prove that sand bags have potential for vibration damping comparable to rubber base isolation systems[9].



Photos at right from top to bottom: Malik's small-scale vibration model, Malik's computer simulation, BSI diagram of elastic earthbag wall.

Since cohesive earthen fill that hardens when cured is an important part of conventional earthbag walls, testing also needs to be done using cured, clay soil earthbag. One Dartmouth College engineering student worked with cohesive soil. Malik created shear tests on two 40% scale walls and vibration tests on six 1/6 scale corners. The corner tests proved accurate to Solidworks computer simulation within 1.5%.[10]



Engineers may need use different formulas to evaluate earthbag than used for brick and concrete masonry. Stability may be more important than limit state conditions for earthbag's flexible wall system. Static diagonal compression on a silty cohesive fill bag wall caused elastic motion when lower loads were removed.

Peak strength may be more relevant to safety issues than deformation in the developing world. Plaster that cracks during vibrations can protect underlying wall structures, and be repaired easily later.[11]

FIBER MESH TUBE

BASIC CONSTRUCTION METHOD

Developing world partners want easier-to-build upper walls to use on strong masonry or earthbag bases. Walls of only 4' or 5' height do not need as much stiffness or strength as 8' high walls.

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[7] Chris Croft, Structural Resistance of Earthbag Housing, unpublished Master Engineering thesis, 2011 available online at http://www.earthbagbuilding.com/pdf/croft.pdf

[8] Ryno Thiart, *Stability of the Sandbag Wall System to Horizontal Load Specified by Agrément,* unpublished dissertation for Cape Peninsula University of Technology faculty of Engineering, 2008

[9] Liu et al, Cyclic Simple Shear Tests on Base Isolation Using Soilbags, *Advanced Materials Research* Vols. 243-249 (2011) pp 893-896 Online available since 2011/May/17 at www.scientific.net

[10] Awais Malik, Design, Analysis and Testing of the $300 House Using Earthbag Construction Techniques, unpublished honors thesis 11/13/2012 at http://buildsimple.org/resources/AwaisMalik_ResearchReport.pdf

[11] Torrealva, Neumann, Blondet, *Earthquake Resistant Design Criteria and Testing of Adobe Buildings at Pontificia Universidad Católica del Perú, p. 6*

Straw-filled wattle is like tubular straw-bales sewn into a mesh matrix. Walls may need to be braced until plastered. Liquid slip made from strong clay is poured over and kneaded into the wall to stiffen it.[12]

This modest strength wall can only support the weight of light roofs for small residences in regions without snow. It may be more suited to hot, dry regions with limited termite damage. Breathable plaster like lime should be used on exterior walls.

Because straw wattles can be progressively wetted with liquid clay as the wall is built, only the topmost row must be kept dry during construction. This means that wattles allow developing world builders used to incremental construction a more fool-proof way to use straw than in straw-bales that must be kept completely dry until roofed.

Straw mesh tubes may also be very useful for emergency shelters in regions with access to straw. The walls can last for years if an earthen or lime plaster is maintained, but can be easily disassembled. Straw tubes are light and easy for women and children to help build. If courses are sewn together well this wall can greatly reduce the ever-present danger in refugee camps of rape and abduction through fabric walls.

Photos at right: Top- Straw wattle wall in Albuquerque NM, Bottom- Straw wattle on earthbag with rebar in Haiti by HCDP

RESEARCH PRECEDENTS

When soaked with clay slip, straw wattle walls share some characteristics of the light straw clay used as 10" thick infill. Researchers have established that light clay has good tensile strength and can have an r-value of 1.3 to 1.8 per inch.[13]

In warm, humid regions fragrant vetiver grass repels and sickens termites. With this type of straw, fiber mesh walls will have increased resistance to insect attack. A grain silo was built by researchers in Thailand using rolls of vetiver straw wrapped in string and clay.[14] A similar concept developed for wheat and rice straw in the US by Strawjet formed structural columns out of cables of straw.[15]

[12] P. Stouter, Building Natural Fiber Tube Walls, Build Simple Inc., 2013, accessed online at http://buildsimple.org/resources/Building%20with%20Mesh%20Tube.pdf 12/12/13

[13] Forest Products Laboratory, Engineering Report of Light Clay Specimens, accessed online 12/12/13 at http://www.designcoalition.org/articles/Lansing-LHJ/research/FPLreport.pdf and J. Thornton, Initial Material Characterization of Straw Light Clay, Canada Mortgage and Housing Corporation, 2004 accessed online 12/12/13 at ftp://ftp.cmhc-schl.gc.ca/chic-ccdh/Research_Reports-Rapports_de_recherche/eng_unilingual/CHIC-Initial%28w%29.pdf.

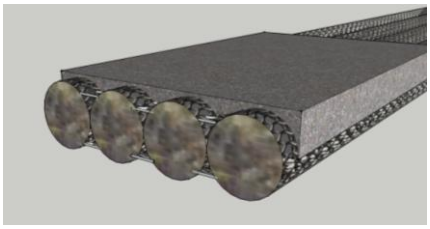
BSI has found that a 7" thick straw wattle wall with some plaster shows some thermal mass characteristics, but also has an r-value of approximately 3.[16]

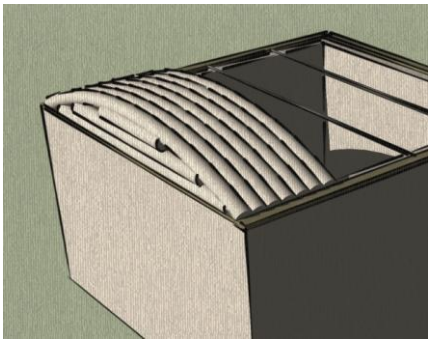
Recycled Plastic Mesh Tube

Less information exists about trash-filled tubes.[17] This technique is under development.

Many poor people live in slums on or near trash heaps. In crowded urban slums the only local materials available may be kinds of trash. Trucking costs are usually too high to bring soil in from the surrounding regions for building.

Light-weight materials for roofing are greatly needed in the developing world. Where foam trash is available, mesh tubes can make very light but resilient forms for a thin waffled concrete layer above.





Photos at right, top to bottom: HCDP worker testing trash wattle, Cross-section view of wattle with cement, Prototype to replace earthen flat roofs in seismic regions.

Plastic trash does not have the fire retardant qualities so desirable for cold region houses with internal stairways. It may have slightly increased fire resistance with thick earthen plaster layers, but should never be used to hold up a loft or second story. For small houses in warm regions where rooms exit directly onto porches or the outside and the issue of fire retardant is less pressing.

Research Precedents

Developing world builders have used painstaking processes of filling plastic bottles with sand or film plastic to use for both structural or infill walls.[18] Little testing has been done on bottle wall strength.

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[14] T. Hengsadeekul and P. Nimityongskul, Construction of Paddy Storage Silo Using Vetiver Grass and Clay, Assumption University of Thailand, Journal 7 (3), January 2004, accessed online 12/12/13 at http://www.journal.au.edu/au_techno/2004/jan04/vol7num3_article04.pdf.

[15] Strawjet has an office in Talent, Oregon and a website at www.strawjet.com.

[16] P. Stouter, Mesh Tube Wall Testing, Build Simple Inc., 2013 accessed online 12/12/13 at http://buildsimple.org/resources/Mesh%20Tube%20Testing.pdf.

[17] P. Stouter, About Tube Walls and Roofs, Build Simple Inc., 2013 accessed online at http://buildsimple.org/resources/About%20Tube%20Walls%20and%20Roofs.pdf 12/12/13. See also www.facebook.com/buildsimple for more recent projects.

[18] Connect Green, Environmental News about Eco-Tec in Honduras, see http://www.connect-green.com/tag/eco-tec/. Similar built in Nigeria. Non-structural bottle schools by Hug It Forward, see http://hugitforward.org/,

COMPRESSED RECYCLED BLOCKS

BASIC CONSTRUCTION METHOD

Plastic is baled in a hand press, stacked with vertical rebar pinning, and post-tensioned with wire to strengthen. This 'Ubuntu-blox' technique was developed by Harvey Lacey with help from Owen Geiger. [19]

Photos at right from top to bottom:
Ubuntu-blox at SMU Engineering and Humanity Week,
Plastered Ubuntu-blox house, Port au Prince, Haiti,
Lacey's vetiver-root compressed block

Blocks must be plastered to reduce flammability and protect from UV light. Blocks of foam trash have a high insulation value.

RESEARCH PRECEDENTS

A small building of Ubuntu-blox has passed a shake table test to the equivalent of an 8.1 quake without structural damage.[20]

COMPRESSED FIBER BLOCKS

BASIC CONSTRUCTION METHOD

This is a version of light straw clay for higher compressive strength at corners or in bearing walls for small buildings. The use of other agricultural waste must also be investigated, since many regions have waste roots, stems and twigs that could bring the tensile strength of fiber to an earthen block.

RESEARCH PRECEDENTS

Harvey Lacey has used vetiver root agricultural waste to make blocks in southern Haiti.

A few researchers have experimented with variants of CEBs using straw.[21] Instead of stirring fibers into soil, BSI would like to try pressing the fibers dry and soaking in clay slip. More research is needed.

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[19] P. Stouter, What Are Ubuntu-Blox? Online at http://buildsimple.org/resources/1-%20What%20are%20Ubuntu-Blox.pdf.

[20] National Technical Systems, Plano Texas, Official Ubuntu-Blox House 7.0-8.0+ Shake Table Test, video online at http://www.youtube.com/watch?v=ex6bJ_0oShg. See also P. Stouter, What Are Ubuntu-Blox?, online at

[21] Reinke, Architectural Engineering Integration Characteristics of Compressed Stabilized Earth Blocks, grant application accessed online at http://www.unomaha.edu/orca/doc/fuse/samples/fuse_reinke_2012.pdf on 12/12/13. And Alcalde, Vianney, Bayard, Gaspe and Romano; A Study on the Effect of Effectiveness of Hay-Fiber

ABOUT BUILD SIMPLE INC.

BSI is a 501(c)3 non-profit located in Placitas NM.

BSI founder Patti Stouter was trained in landscape architecture and worked on site and interior renovation plans for a family business. She now works with NPOs from Haiti, Latin America, Western Africa, the Middle East and Asia.

Patti began working on developing world buildings in 2007 under architects with Wycliffe Associates. She has been advising aid workers on alternative building methods since 2010. She is pleased to have helped with more than 20 buildings in Haiti to date, including health clinics, school buildings, homes, and businesses. Her Haitian Wisdom booklet and a draft revision are two of the few sources for information about the vernacular architecture of Haiti.

In 2011 she won first place by vote in the $300 House Contest sponsored by the Harvard Business Review. She has acted as a consultant to engineering students at several universities in the US and Europe, and lectured at EarthUSA 2011. She is eager to mentor other engineering students testing natural materials.

Stabilized Compressed Earth Blocks as Load-Bearing Walls accessed online at http://prezi.com/trxj9ybgzvck/a-study-on-the-effectiveness-of-hay-fiber-stabilized-compressed-earth-blocks-as-load-bearing-walls/ On 12/12/13