D110: Contained Earth Earthbag and Light Upper Walls for Haiti's Seismic Risk

Patti Stouter, BuildSimple.org, August 18, 2021

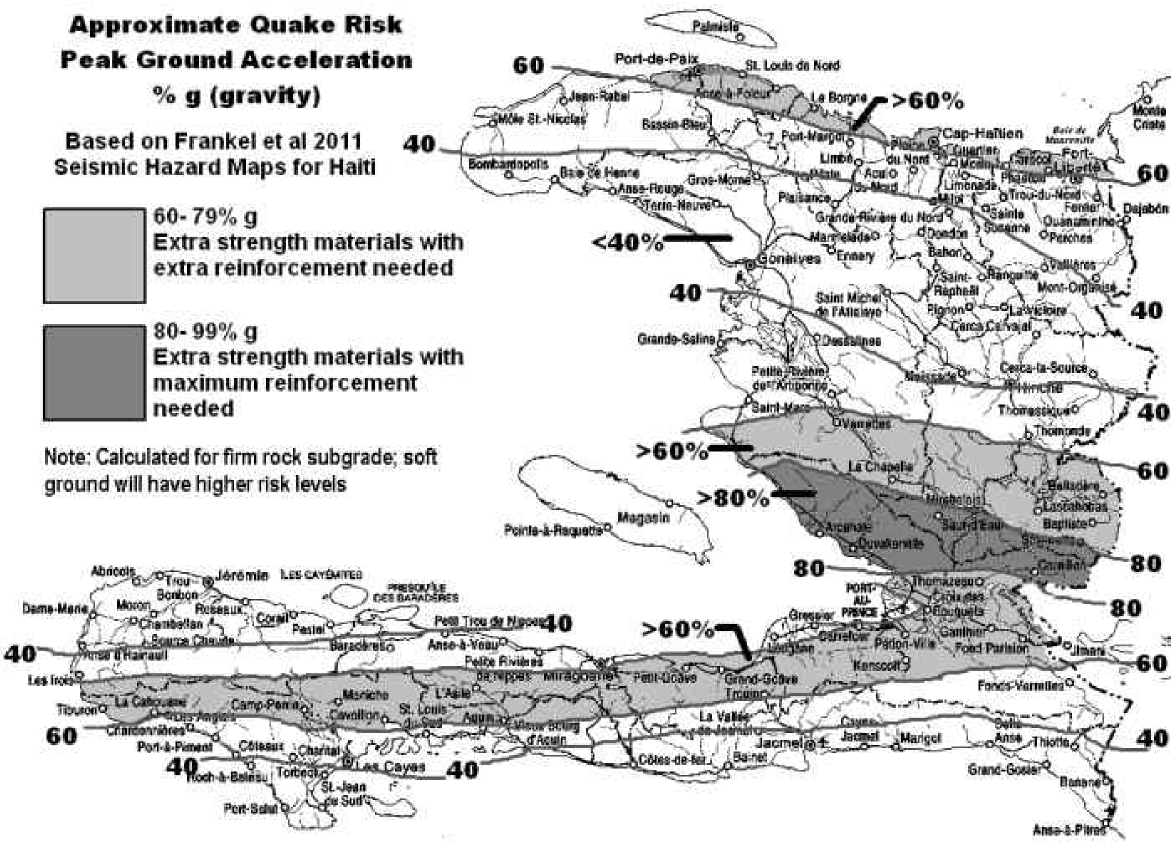
Earthbag and Earthquake Risk Levels

Some previous aid builders used earthbag buildings in Haiti after the 2010 earthquake to reduce costs with low-tech local materials. Earthbag buildings in Nepal also survived 2015 earthquakes near severely damaged areas. Many builders used superior techniques including long tubes filled to higher course heights and extra reinforcement. It is not known how many used reinforced concrete footings.

But vertical earthbag walls can flex and warp, breaking windows and doors and requiring rebuilding. Domes resist earthquakes well unless common cracking of cement stucco weakens roof material. Builders should take advantage of new knowledge to avoid potentially dangerous problems. Designers can choose construction techniques suited to the level of risk at the building site.

Earthbag is a flexible wall material. If soil fill has good strength and barbed wire runs continuous around all corners, it may wiggle and suffer some plaster cracking, but is less likely to collapse than traditional block walls. To date in engineering tests, damaged wall panels have never collapsed. Only when fabric bags or tubes were severely decayed by unplastered exposure to strong sunlight did one test wall lose some material.

The map below shows approximate levels of risk in Haiti.



Haiti's horizontal earthquake motion is likely to be stronger in some areas than the 70% of gravity forces that earthbag buildings survived in Nepal's 2015 earthquakes. Haiti's lowest risk level is for horizontal shaking of 0.4 g (40% as strong as gravity), but even this level is enough to destroy poorly designed and built unreinforced earthen buildings as well as poorly built brick or concrete block buildings.

Earthbag can be compared to building guidelines based on research and structural design for New Zealand, where earthen walls without reinforcement are allowed up to 0.6 g forces on wide reinforced concrete footings if the soil used has moderate strength (188 psi) and plans and detailing are carefully chosen. Since earthbag is weaker but more ductile (flexible and unlikely to suffer sudden strength decline) than the adobe block and rammed earth materials in NZS 4299, current tests indicate that with stronger (300 psi) soil fill conventional earthbag walls (with disconnected rebar inserted at midwall height and wall top) may be comparably suited to areas with 0.4- 0.6 g risk or less. Improved reinforcement is highly recommended for all regions of Haiti.

Earthbag walls consistently resist higher forces before warping when:

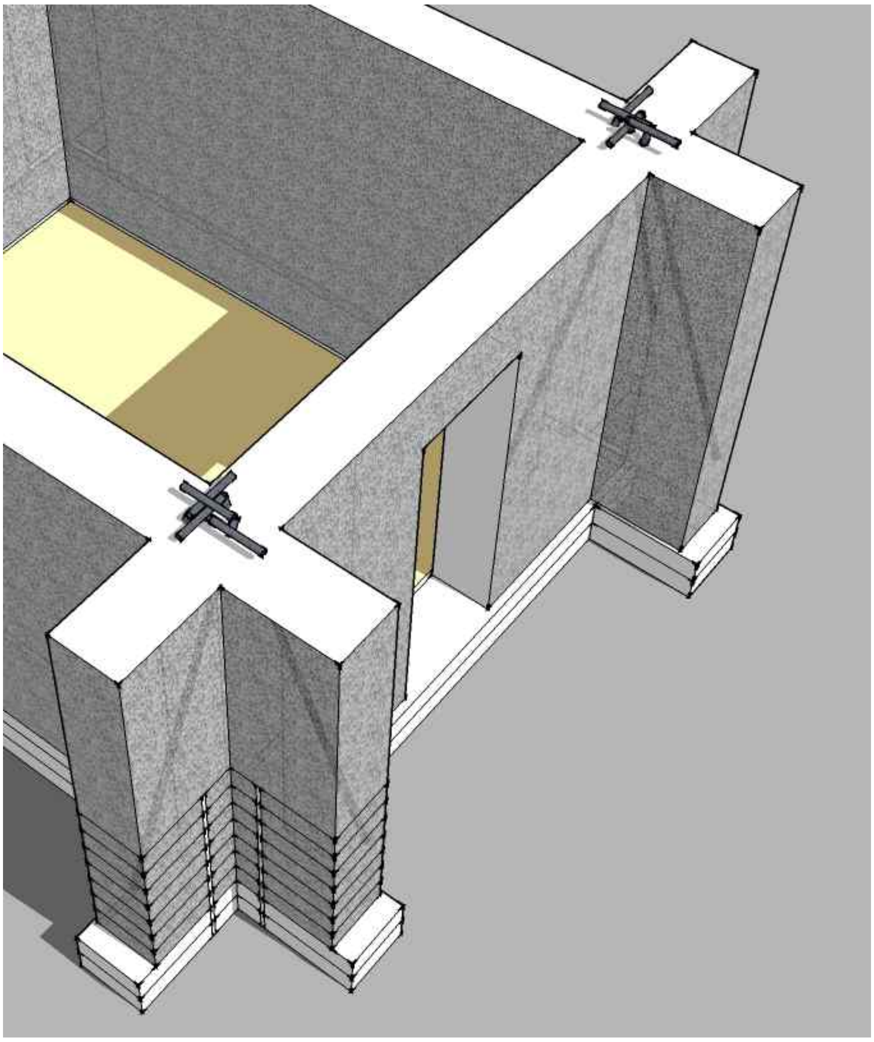
- plans have enough bracing walls
- fill soil is strong (150 psi is minimum, but strength increases greatly if 300 psi fill is used)
- rebar is embedded inside the wall material
- strong plaster or stucco is embedded on mesh wrapped around walls and attached to wall tops and bottoms
- strong bond beams are tightly attached to the top of continuous rebar
- AND the vertical rebar is stiffly embedded in the footing

Conventional earthbag is often built on gravel bags with no reinforced concrete in the footings and rebar not stiffly embedded. New detailing shows how to build contained earth (CE) earthbag using spot concrete footings at corners only or confining strips of reinforced concrete attached to gravel bag footings. Special techniques make embedded reinforcement more appropriate for higher seismic risk levels, but are simpler than building reinforced adobe or rammed earth. See booklets B101-B104 free online at BuildSimple.org/Resources under Resources for Builders. Engineers can email for detailed information (pstouterATbuildsimple.org) about recent results that have not yet been published.

Small Houses on Gravel Bags for Moderate Risk Levels

Small single story buildings often used for residences in rural areas may reach medium strengths without expensive reinforced concrete footings. Rebars must be clustered at wall corners in buttresses, and combined with special strapping of lower courses.

Buttresses are short stub walls on the building exterior. They must be no longer than 4’ in seismic risk areas, but 2’ long buttresses may provide enough extra weight and area for diagonal rebars for a small house.



Inserted star rebar cluster at buttressed corner in CE earthbag

Damage from horizontal force causes sections of walls to rotate. Forces pull upward hard on bond beams and/ or upper courses. Use longer versions of the traditional rebar pins inserted at alternating angles clustered in a reinforcement star.

The longest rebar that can be practically inserted into a damp earthbag wall may be about 7’ long. Builders must be very careful to keep the angle correct so the steel does not break out of the wall. Long rebars bounce under a hammer, unless builders hold the rebar in a narrow pipe while starting to insert it. If a tool can be welded from pipe with an end-cap and handles, workers can insert rebar that is above their head, not requiring tall ladders or high scaffolding. If height is not a problem, pre-drill the wall by inserting a smooth smaller diameter pin up to 1- 2’ deep and then removing it using a strong clamp or vise grip.

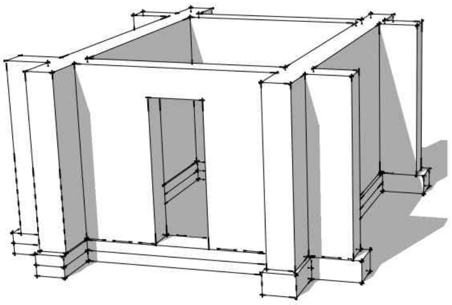
Use rebars that have a 10” long hook bent at 90 degrees on one end. Either embed the hooks all in a reinforced concrete bond beam, or attach them securely to a strong wood bond beam.

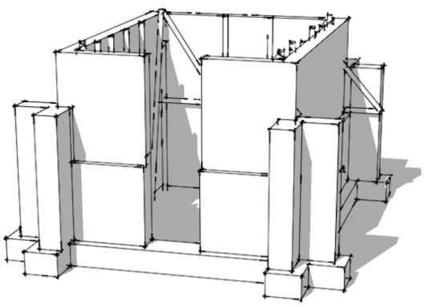
Strong vertical strapping will not resist uplift if connected tightly during construction. Wall material often shrinks during curing, loosening straps. But vertical strapping of the lower walls can be combined with diagonal rebar if the strapping is tightened after wall material has fully dried (usually 2- 4 months). Lay strong wire under the foundation courses and wrap the outside of the wall to several courses above the depth where the diagonal rebar will reach. Leave the two ends facing the wall with the least exposure to sun and protect the wall temporarily with paint of a thin plaster where the wire will be tightened.

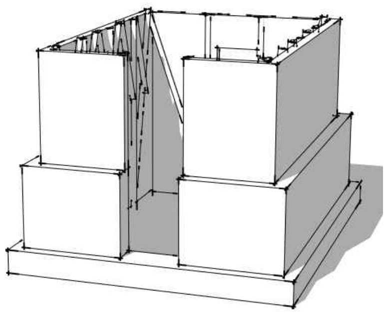
Light-Weight Upper Walls

Masonry walls are costly to reinforce because of the walls' great weight. Even with strong soil fill, earthbag walls must be 15" thick so that one story high walls are stable. These thick walls can be built without reinforcement in areas not subject to earthquakes, but even earthbag courses interlayered with barbed wire must have some tensile vertical reinforcement.

Instead of using higher strength reinforcement, consider building upper walls with lighter materials. The higher weight is during an earthquake, the more damage it causes. Wall tops undergo much higher forces than wall bases. Earthbag can form a stable wall base to resist mechanical damage from vehicles, animals or rodents and support a framework of wood or bamboo that can be covered with a low-strength material such as thin-wall earthbag, straw wattle, trash wattle, or quincha.







Full-height CE earthbag **Narrow-wall earthbag above CE** **Straw wattle above CE**

These different wall materials form a moderate strength wall when plastered. Woven lattice or matting are not considered because they are permeable to weather, rodents and insects. Light-weight walls must be integrally attached to a wall structure either by fine-grained fiber and clay connections or by tying and/ or sewing or lashing components together.

Several materials use light straw clay (LSC), which is a mixture of dried straw dipped in liquid clay and then packed lightly by hand into a confined space, either a mesh tube or a wood form. The form can be moved immediately after packing the damp fibers. Light straw chips uses wood chips, and other material like sugarcane trash, seaweed, or rice husks could be used. LSC is used in Europe and North America for naturally insulating walls. LSC shrinks during the drying process, and the wall structure must either reduce the shrinkage (fine lattice) or allow it (horizontal reeds that can slide downward as panels shrink vertically). When dried and covered with earthen and/ or lime plaster, LSC resists fire and mold. LSC covered with an exterior cement stucco finish should be applied on a light bird netting mesh over layers of earthen and then stabilized earthen plaster and be protected from too much water exposure, since cement attracts water and will expand and contract differently than the earthen and straw components.

- Thin-wall earthbag[1] has more weight than the straw- or trash-based materials but does not have any stability from the bags. Loose sand or dry soil fill fabric bags placed between structural

1 http://www.naturalbuildingblog.com/thin-wall-earthbag-10x-faster-than-typical-earthbag/ shows the first earthbag building, with tubes pinned between thin poles. Eco-beam by Tremeer used metal/ wood vertical trusses to minimize wood and reinforced their walls with wire mesh: http://www.earthbagbuilding.com/articles/eco-beam.htm 'Sandbag construction' by ecobuilders.co.za are not for seismic risk areas because there is little connection between slippery bags and no stucco mesh.

uprights similar to stud walls. One strand of barbed wire per course may be needed in risky areas even if the tubes are surrounded by strong mesh on both sides.

- Wattles are strong extruded plastic mesh tubes used as erosion controls when filled with straw. Wattle tubing is tough and forms a fine mesh if filled tubes are sewn into a blanket.
- Straw wattle or hyper wattle walls are tubes stuffed firmly with dry straw that are sewn into place on the course beneath and then soaked by pouring liquid clay on top. Alternately, straw can be dipped in liquid clay, shaken to drain, and packed into the tube by hand. Courses must be sewn or lashed in place before fill material dries.
- Cleaned trash as infill has been used between mesh curtains but usually requires a lot of cement mortar to unite it into a wall. Glass or plastic bottles are sometimes filled with sand. Trash wattle requires less cement mortar because wattle tubes connect the plastic when sewn together into a tube curtain. Styrofoam trash is easier to compress in tubes than many other types of plastic.

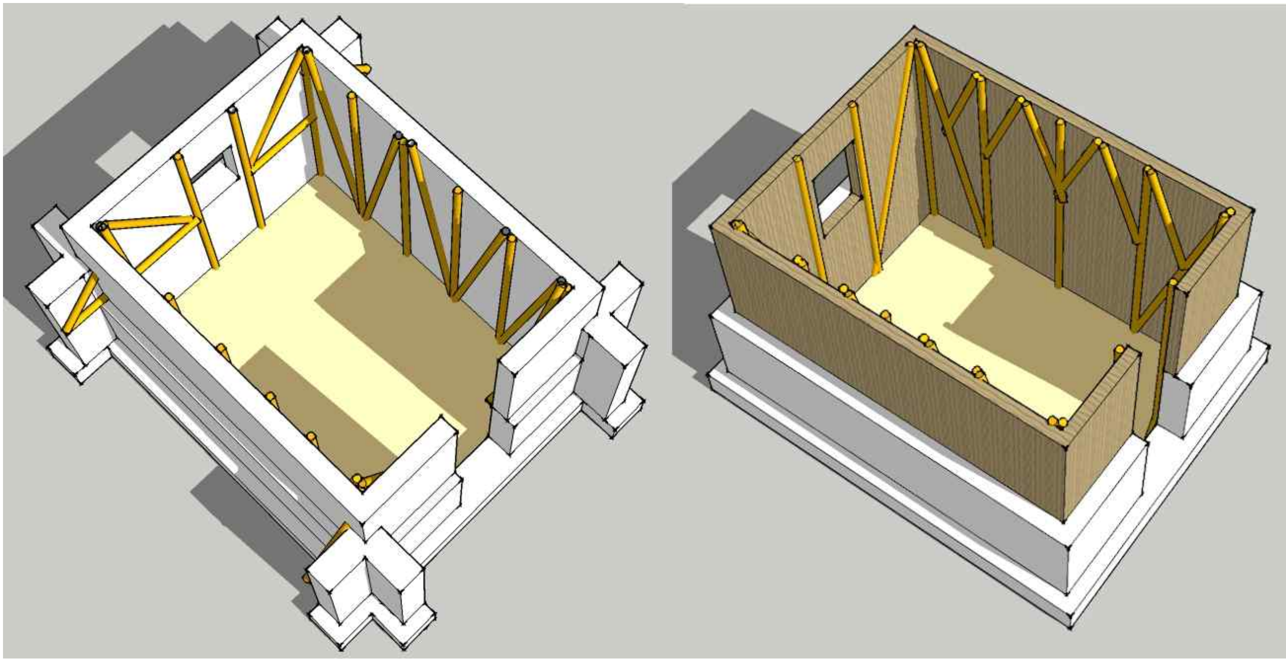
Light straw clay **Straw wattle infill** **Freestanding straw wattle** **Trash wattle**

- In Latin America quincha is used for upper walls or second story walls by working a mix of LSC or a fiber-rich earthen plaster into a lattice of wood and/or reeds. The high-fiber coating makes it more resistant to damage than traditional wattle-and-daub. Because the finished wall can be less than an inch thick it may be more easily damaged by cement stucco than straw wattle.

Stronger structural reinforcement is needed in earthen walls and it must be embedded for best strength. Textured steel rebars will not gradually be devoured or weakened by insects, and steel can also be bent and/ or have attachments welded to the ends. Steel rebar does not function well in loose fill thin-wall earthbag or in LSC walls because elements can easily bow when not embedded. Barbed wire may act as friction between thin-wall courses but can transmit lower forces than in CE earthbag when barbs are held by strong dried cohesive fill.

Developing world building residents are likely to occupy a house for generations, so bio-degradable natural materials should only be used for reinforcement if they can be inspected for damage and replaced in future if needed. Attach them to the interior of the earthen base wall to reduce water damage. Bamboo and wood poles may be locally sourced but attachments must be high strength and allow future pole replacement.

Light wall elements that are not well interconnected need structural elements closer together. Reinforcement sketches below show a typical contrast between different materials. Reinforcement spacing must depend on strength of fills and poles used, the roof weight and on the seismic risk levels. Because thin-wall earthbag (below left) is heavier it should have vertical and diagonal poles spanning from footing to bond beam spaced 2’ or less apart, as well as some horizontal bracing. Lighter well-connected straw wattle (below right) may use verticals spaced 3’ apart with most diagonals above the earthbag height, although corners may benefit from stiffening by pairs of full-height diagonals.



Pole structure for thin-wall earthbag **Pole structure for straw wattle**

Thick earthen walls in earthquake risk areas also require extra buttress walls for bracing that increase wall volumes. Contrast the amounts of materials needed for a small 9’ x 12’ building of different construction techniques (Table 1).

Table 1: Possible construction materials for 9’ x 12’ x 8’ high houses

	Standard earthbag	Narrow wall earthbag	Wattle on earthbag
Earthen wall thickness	15”	12”	12”
Buttress sizes	2’ x 8’	1.5’ x 5.5’	none
Upper wall thickness	15”	8”	7” or less
Total soil fill volume	28 yards^3	16 yards^3	9 yards^3
Comparative fill	100%	-43%	- 68%
1/4”- 3/8” rebars	170 lf	90 lf	60 lf
Wood/ Bamboo		320 lf 3” dia. poles	240 lf 2-3” dia. poles
Barbed wire	1700 lf	1280 lf	800 lf

The less soil material to be laboriously dug, transported, wetted, stirred, and placed into the fabric containers, the quicker the work progresses. In addition, if heavy material does not need to be lifted above chest height, the labor is much less tiring. This can be important if laborers have poor health, as often caused by parasitic infections or endemic diseases and aggravated by poor nutrition or meager food supplies common in the developing world.

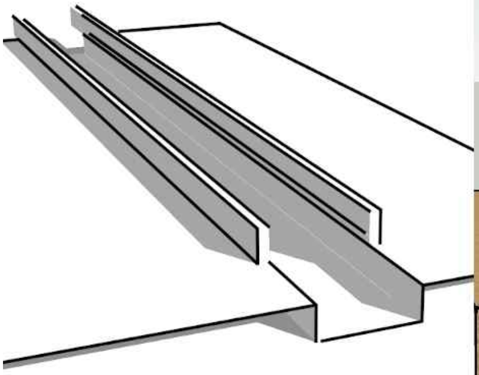
Construction Process for Light Wall on Earthbag Base

Light wall earthbag needs a gabion foundation to hold poles in place but allow drainage below them.

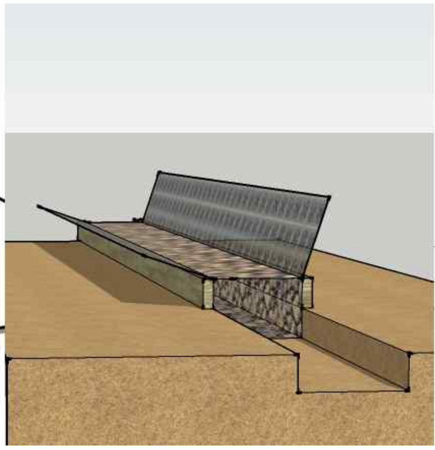
Dig the trench 1.5’ wide. Sides should be formed so the gabion will be at least 12” high, and 6” above the finished grade. Lay cord ties across the trench every 2’. Lay galvanized 4 x 4 reinforcing cloth or plastic storm or construction mesh fencing in the trench. Overlap the mesh at corners so there are no gaps. Fill the trench with gravel and/ or small rocks and tamp to settle them firmly in place. Wrap the mesh around the rocks, pull tight over the rocks and fasten strongly. Remove forms when gabion is stable.

Insert poles into the rocks near the inside of the foundation wall either before building earthbag or after the first course is laid and tamped. Space vertical poles evenly, including one at every corner and at each side of window or door openings. At each vertical pole lay a heavy folded wire across the gabion with two ends extending past the gabion near the pole.

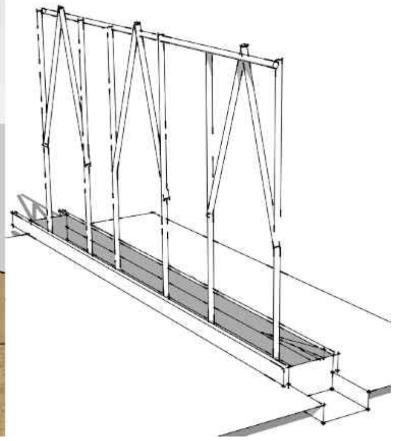
After the first course is tamped tie the cord tightly over the first course to hold it strongly to the gabion.



Form foundation trench



Fill mesh with small rocks



Insert poles in rocks

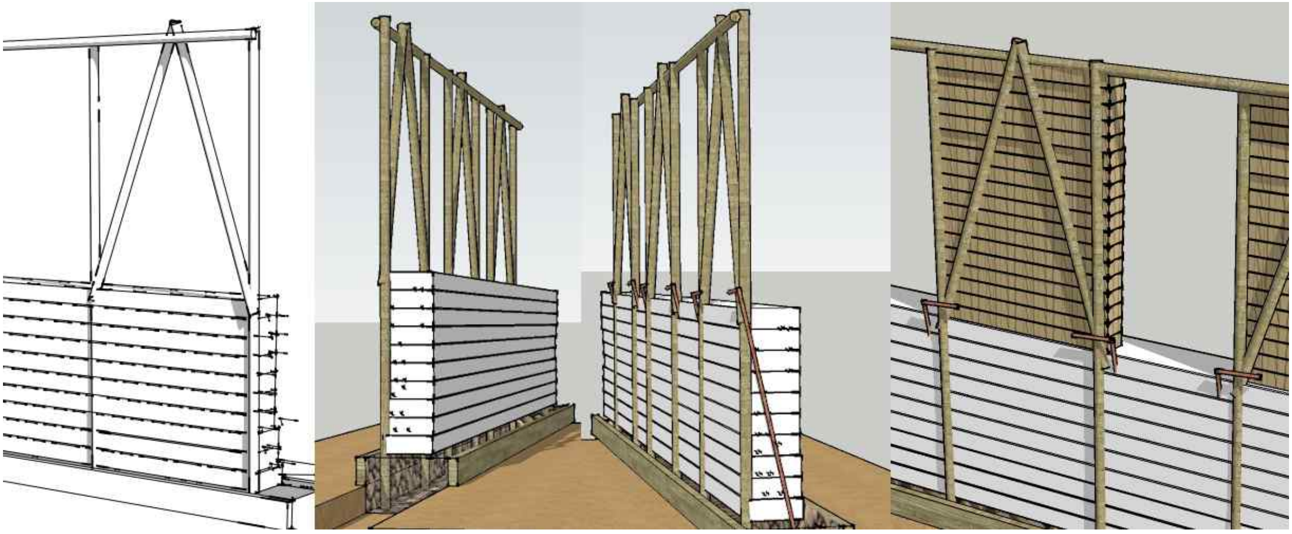
Lay two strands of barbed wire on the first course near the poles. Overlap ends of strands in the middle of building walls, always run the barbed wire continuous around corners.

Build CE earthbag to 3.5’ height, placing barbed wire where it will not interfere with rebar pins. Brace poles to maintain plumb despite tamping forces and check level and plumb while finishing tamping. Bend a 90 degree hook 10” long on each pin. On the last earthbag course insert a pin at each vertical. After the pin is inserted, pull the folded wire toward the vertical pole so that the wire bend catches the inserted rebar. Form loops in both ends and tie tightly between the loops around the pole.

Use lashing, strong wire ties or bolts and nuts to attach diagonals to the vertical poles. Use a strong bond beam at the wall top. Attach it well to the other poles and provide bracing at corners.

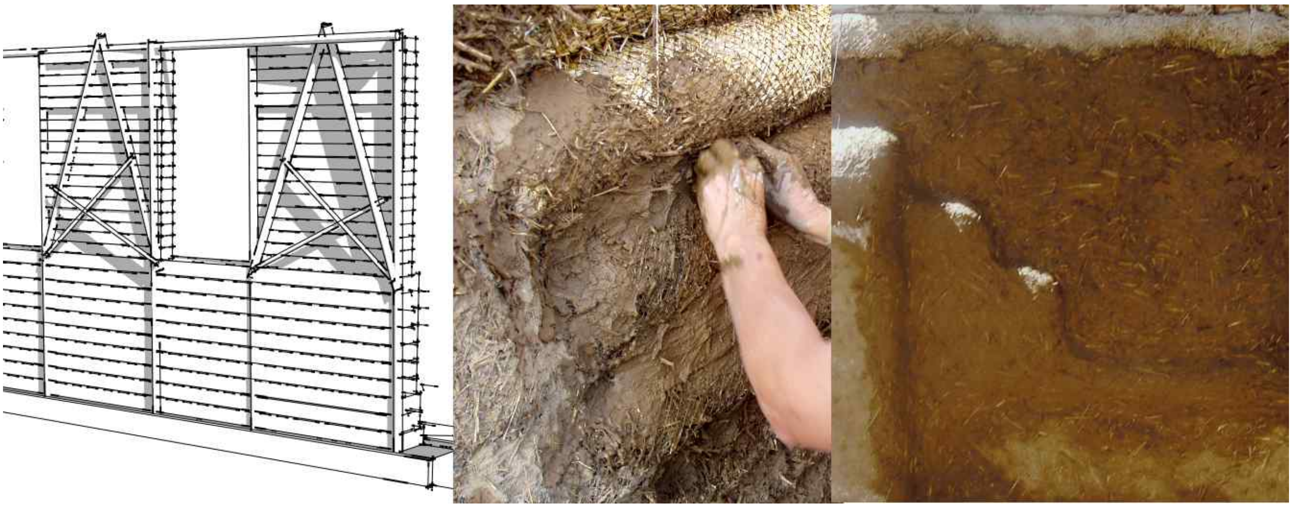
The earthbag and foundation can be plastered before the rest of the wall is finished. Use a water-resistant material like cement stucco or hydraulic lime plaster. An alternate material to reduce the need for cement or lime would be to use a rock veneer held in place with a strong earthen mortar. When the mortar has fully dried, cover the visible mortar in the cracks between the rocks with a small amount of cement stucco or lime plaster. If the owner watches for growing cracks and keeps the rock veneer in repair the earthbag fabric will be well protected against sun damage.

Add straw wattle on top of the earthbag, lashing each tube well to the structure and to the course below. If tubes are filled damp they must be placed immediately before drying. If wetting the courses with liquid clay after they are attached into the wall, squeeze to work the clay inside, but stop before the course starts to firm up. Do not squeeze a damp course to over flatten it as it looses strength and volume. Sew the courses in place and stop handling the fill material until it has had 24 hours to dry.



Attach poles above earthbag **Locate wire** **Insert pins at poles** **Add straw wattle**

Attach additional reeds and/ or thin poles if desired to stiffen the straw wattle and work straw-rich earthen plaster onto the straw wattle surfaces to level. Use bolts or metal strapping over the pin hooks so that the rebar pins cannot move up or down the poles.



Extra stiffening **Work plaster into mesh** **Leveled and sculpted surface**

Finish the wall with a water-resistant plaster on the exterior surface of the straw wattle. A straw wattle wall will be tough if it is well attached to the structure and has plaster worked into the tube mesh. It can make a firm wall but will not be as hard as an earthen wall.

Maintenance to Avoid Strength Loss

In seismic risk areas always protect fabric containers so that if wall cores are ever damaged, the fill material remains in place. Paint or plaster or cover fabric containers with tarps if exposed to sunlight more than a week at high altitude or near the equator. UV-protected material can be valuable.

Raw (unstabilized) natural earth walls can have significant strength if they are well-dried. Keep roofs in good repair to keep water from leaking onto wall tops and into walls.

Plaster or stucco finish layers provide more than half the initial resistance to damage of an earthbag wall. Use cord ties from barbed wire on CE base walls to attach mesh that wraps the entire walls inside and out. Use additional cord ties or wires under the footing to attach mesh to the foundation and tack mesh to wood bond beams or embed it in concrete. Keep plaster layers in good repair.

Anywhere that ties are used to hold poles in place, consider using a bend of heavy wire that ends in loops. If the loops are just visible emerging between the courses, lashing cord can be replaced. Plaster can cover the lashing and the wire loops but builders repairing the wall in the future can uncover and reuse the wire loops.

Earthen materials dry out best if they are not totally enclosed by Portland cement-type stucco. Provide earthen plasters on interior walls, or learn how to make lime plaster. Hydraulic (type S) lime dries out well and lets wall cores breath to moderate humidity. Lime ingredients must be handled carefully- keep it out of eyes and off of hands. Use lotion and rubber gloves, and keep a vinegar and water bowl nearby so builders can dab any skin that gets spatters to prevent burns which may start painless but can damage skin after a half hour. Lime plaster is worth it because unlike cement stucco it does not often crack on earthen walls, and new plaster to touch up cracks bonds well to old plaster even in thin layers. If you have type S lime for plaster do not be tempted to add even a little cement. Be patient, lime plaster walls harden slowly over time and become harder and harder as they age.