SOIL TESTS FOR EARTHBAG

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PART 1: CAN I USE MY SOIL?

Good soil can make strong buildings. Earth with a little clay in it will hold together. Most soils do not need any cement, asphalt, or lime added to harden them. More kinds of soil can be strong in earthbags than in adobe, CEB, or rammed earth. Soil used for roads (called road base) contains just enough clay, can be bought in many places, and usually works well.

Your land may contain different soils. Dig a few small holes in different areas to find out without removing many plants. Are there different layers? Soil scientists often use a long-handled soil augur. This tool helps you to quickly check the soil several feet deep without making a big hole.

Right: Several very different soils and an augur

COLLECTING SOIL

Don't use the top layer of darker soil. The topsoil smells a little moldy and contains rotting leaves and roots. It is good for growing but bad for building because it can rot and compress. Save it out of the way.

You need to see if there will be enough of the same kind of soil to build your building. To build a 3 x 3.6 m (10 x 12') room with 2.4 m (8') high walls will take 44 cubic meters (52 cubic yards) of soil. If you take this from a hillside next to your house, the hole will need to be about 6 x 10m x 1.5m deep at the back. On sloping land some people set the building floor level low enough to use some soil from under the building. On flat land some dig a new cistern to get soil.

Collect enough soil to fill one or two bags and a few extra handfuls for other tests. An average sample mixed from two or three holes is best.

TEST BAG

The best soil test is to make a bag, tamp it, and leave it to cure in the shade and out of the rain for 10- 14 days.

Get a couple leftover woven grain bags. Fill each at least half full. Roll, sew, staple, or pin the top. Lay them flat. Pound each 5- 10 times with a tamper or thick piece of wood.

Then pick each bag up and drop it from 45 cm (18") above the ground. Most good soils will not crumble all loose.

Tamp them again, and let them dry in the shade. (This could take 2 weeks in hot weather or less near the stove).

After they are hardened, open them up to check. A good soil won't break easily. No chunks will break off if you hammer a nail in. It will be hard to dent.

If there are any cracks, they should not be deep enough to cause pieces to break off.

Clues About Soil

While you're waiting for your bags to cure, try to find out more about your soils. Are buildings or roads settling or cracking on this kind of soil? If the same soil holds up a two-story cement block building, it can hold up the weight of a one-story earth building.

A few soils have odd problems. Some dry area soils are white from salts or other chemicals. Some dark soils that used to be salt water swamps turn very acid (and toxic) some weeks after they are dug up. Some warm-climate soils harden permanently into rock. Some clay soils slowly slide downhill, leaving fences and trees that lean. Others that crack in the dry season can swell and break building footings. Any of these might be a problem for earthbags.

If there were any earth buildings in your area find out about the soils used. Elders may remember how others used to work with your soil, even if no one builds with it now. This knowledge is precious.

Squeeze Test

Use the subsoil that is underneath. Pick out any sticks or leaves and stones. Take a small handful of soil. Add a few drops of water (if needed) so it will hold a shape when you squeeze it in your hand.

A soft lump	Still falls apart with added water	A very firm lump
		
Probably a good soil See Drop Test page 3	Needs added clay or extra reinforcing to hold the building together See Sand page 4	A lot of clay Learn about it and test it more See Rich Clay Soils pages 5

DROP TEST

This will tell you if the soil has enough clay for earthbag. Later as you fill bags, use the same test to be sure there's enough moisture in your soil.

Make balls 4 cm (or about 1 ½ inches) in diameter. Use soil just moist enough to hold together. Drop the balls one at a time from a 1.5 m height (about 5') onto something hard. Most of the balls should act the same way.

WEAK SOIL- This soil was squeezed hard
but broke into many little pieces when dropped.
Read about weak and silty soils pages 4 and 10.

SOIL WITH SOME CLAY

This ball split into a few pieces when dropped.
Soils like this usually contain just enough clay and are good for earthbags. Have a look at pages 9 and 10, and build carefully!

But if you are building in the tropics, hold on. Tropical soils like this can contain a lot of clay. Cut a ball with a table knife. If the soil looks shiny and smooth, do a swelling test. See page 8.

RICH CLAY SOIL

This ball flattened with only a few cracks.
This soil has a lot of CLAY, probably 15% or more. See pages 5- 8 and 11- 13.

Shiny balls or ones that leave a big wet mark are too wet.
Add dry soil and retest them until they stop leaving the wet mark.

SAND

Sand bags are not the same as earthbags. They are too likely to slump. Earthbags need to tamp to a solid mass to be strong.

A few unusual sands will set up firm in bags. These were formed from coral or granite and harden by a chemical process. If you have sand, tamp it in a test bag and let it cure for several days to see if it is an unusual sand that will harden.

Above: This sand in the Bahamas from dredged coral set up hard in bags

Sand mixed with shells or shell fragments may be less likely to slump than pure sand. But any low-strength soil must have bracing during construction a structural skin. Read about building with weak soils on page 10.

Sandy soils also sometimes contain salts. The salts in the bag can work their way out through the plaster to make white patches or weaken cement stucco. If you aren't buying washed sand, wash it well.

WEAK SOIL

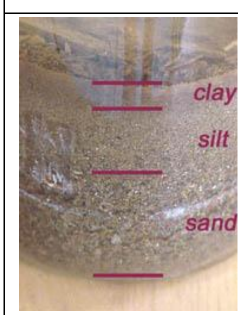
Some soils that form a ball when squeezed still shatter when dropped. They can feel gritty because they have a lot of sand, or feel smooth because they are mostly silt. Either should have clay added so that an earthbag will hold together. This will greatly reduce the cost of reinforcement needed. Read about building with weak soils on page 10.

SILTY SOIL

Silt by itself is very weak because the particles are rounded and do not interlock well. Silt is not very strong to hold up buildings or to make them, and it also doesn't drain well to treat wastewater. Soils with a mix of different particle sizes are strongest. A very silty soil has to have both clay and sand or gravel added.

If you want to be sure whether you are feeling the grit of some fine sand, a shake test will show you.

SHAKE TEST

<table>
<tr><th>VERY SANDY SOIL</th><th>CLAY SOIL</th></tr>
<tr><td>
</td><td></td></tr>
<tr><td>Contains both clay and sand, but also organic matter at the top</td><td>It is hard to tell where the silt ends and the clay begins</td></tr>
</table>

Break up a handful of soil and put it in a bottle with straight sides. Add enough water to cover it and shake well.

If you think your soil has a lot of clay in it, stir in a little salt. It will help the clay to settle in hours to a day instead of 1- 3 days.

Let the bottle sit very still for one minute. The sand particles will settle on the bottom. Mark a line on your bottle or put a rubber band to mark the top of the settled material.

If the water is so cloudy or brown that you can't see anything, leave it for one hour. The silt will be settled too, and sand at the bottom will look grainy. Silt particles are so small they are hard to see.

If you have a lot of time, leave it uncovered after the water clears when the clay is settled. As it dries the clay layer will pull away from the bottle, and show where the silt layer ends.

If you want a quicker answer, stir, time it and very gently pour the different layers off. After one minute pour the liquid on top into another bottle the same size. The thicker or grainy stuff will mostly be sand. Let it set. An hour later, gently pour off the liquid from the second bottle until something thicker is left. That will be the silt.

The organic matter (what is in topsoil) doesn't settle. It will keep floating in the liquid on top. If there is more than a tiny amount floating on top in your bottle, dig deeper for your sample and retest.

Right: Organic material floating on top

Many builders use this kind of shake test to see what proportion of sand, silt and clay is in their soil. It is hard to measure accurate percentages, because particles often grade too gently from one size to the next. But it does tell you if a soil contains these different particles.

Rich Clay Soil

Any clay in a soil will stain your hand, and can not be brushed off.

Soils that contain too much strong clays cause problems in adobe or rammed earth or CEB walls. Because they are exposed any cracking must be kept to a very small amount or moisture will soak deep into the units. But earthbags protected by poly bags and plaster can use soils that contain more clay.

Different clays are very different. Soil with a lot of clay should be tested more, to be sure it does not include too much of a problem kind of clay.

Tropical Clays

Clays in the tropics need to be checked differently than clays in cooler areas. Deep tropical soils that are red or yellow often contain a lot of clay. People used to clays in other areas may be fooled because tropical clays can be much less sticky and flexible (or 'plastic') than clays in other places.

Tropical soils are often deeper and more variable than soils found in cooler climates. Be sure you are testing soil mixed from different parts of your soil dig area.

Many rich clay soils found in the tropics have swelling problems. If a tropical soil cracked a little in the Drop Test and looked shiny like clay when you cut it, you should do the swell test on page 8.

If a tropical soil is very sticky, the ribbon and crush test will tell you how hard it will be to work. It also is a good idea to dry out a little to be sure it doesn't harden into rock-hard laterite, if you haven't seen it dry before.

Expansive Clays

Some clays shrink and swell as they get wet or dry. A really expansive soil can swell 50% to 200% in volume when it is wetted. It takes special care to build earthbag walls with a soil that shrinks and swells a little. Buildings on these soils may also need special foundations.

The ribbon test and crush test below are quick. They may tell you that your cool climate soil won't need a swell test.

Ribbon Test for Rich Clays

Get soil just moist enough to roll. Remove big pieces of grit, and keep it just damp. Shape it into a ribbon about the size of a finger. If a finger width will hold together upright in a piece as long as a hand, the soil may be strong enough to use for adobe, rammed earth, or cob.

To find out just how flexible it is, knead it more to mix it very well and develop its strength. Add enough water to roll it out a little thinner.

Shape it as thin as a pencil- 6mm thick (a little less than 1/4 inch).

Cut off 4 cm (1 ½ inch) length.

If it stays together when you can hold it up, it is a SLIGHTLY PLASTIC soil. It should not have any swelling problems. Read about building with rich clay on pages 11- 13.

Above: This sandy clay fell apart when the pencil size ribbon was lifted

To shape it thinner you may need to roll it on a flat surface or press it into the right shape with a knife.

If you can hold up a 4mm thick piece (a little more than 1/8 inch) it is a MODERATELY PLASTIC soil. You should also do the crush test.

If a very thin, 2 mm thick ribbon holds together (between 1/8 and 1/16 inch) when it is the same length or longer, it is a VERY PLASTIC soil. You must do the crush test below also.

Right: This very plastic clay could be rolled longer than 4 cm.

Crush Test for Rich Clay

To test for strength, find a chunk of dry soil or make a ball of moist soil about 2.5- 3 cm (1 inch) and dry it out. If there are thin platy crusts in the soil, use a piece 1- 1.5 cm long but 0.5 cm thick held the long way.

How easily can you crush the small chunk? Try for a second to crush the soil. The soil's strength will also control how difficult it is to dig up

Right: It took a light squeeze to shatter it. This soil was not even hard.

Left: The gray clay that was very plastic (page 7) could not be squeezed but was easy to crush underfoot. This NY clay did swell (about 30%) and was used to make the stabilized bag shown on page 13

Pressure Needed	Texture	Comparison	Uses	If
Can barely break between thumb and one finger	Hard	Hard as very stale bread	Probably strong enough for earthbag	It is also moderately plastic maybe it will swell: Do the swell test (page 8)
Can break between two hands	Very Hard	Easy to dig out with a pick	Medium to heavy clays good for earthbag, adobe, rammed earth, or CEB	It is also very plastic it probably will swell: check how much (page 8)
Can crush it under foot on floor	Extremely Hard	Must swing a pick over the head to dig it		
Hit gently with a tool to crush	Rigid	Very hard to dig by hand	Some of these very rich clays can work in earthbags	
Hit hard with a mallet to crush	Very Rigid	Slow for a 40 hp backhoe to dig		

Swell Test

If your clay is DRY, put it in a bottle or test tube to see if it swells.

Any tests for expansion will take more than a day. Some clays soak up water very slowly. It may take more than 24 hours for dry clay to really become wet.

Crush it to a fine powder. Put it in a dry bottle with straight sides. Try to add enough soil to bring it to 9 cm high, tapping a little to settle it. Add just enough water to cover and stir with a stick or nail. Let it sit a full day. See if it swells.

The percent expansion is approximately

$$\frac{\text{final soil height} \quad \text{minus} \quad \text{dry height}}{\text{dry height}}$$

If it ends up about 9.5 cm high, you have about a 5% expansion.

Higher than 10.5 cm will be about 15% expansion.

Above: These test tubes were filled to the same level with different dry soils.

A more accurate way to test for swelling is to take 2 amounts of oven-dried soil that weigh the same. Use two bottles or straight glasses the same size. Drop one soil into water with a little salt, and the other into an equal amount of kerosene or thin cooking oil. Stir them very well and leave them to settle out until the liquid is clear. Then measure the difference in height between the sediments in oil and the sediments in water.

Shrink Test

Some soil scientists say a swell test is more accurate than a shrink test. But if a shrink test is easier, any test is better than nothing.

Spread MOIST soil out thin on a piece of metal and dry it. A metal hoe might work well. Put a little oil on it first. Try to get the soil to cover it exactly, about 1 cm thick. Then dry the hoe in the sun or near the cooking fires until it is very hard.

Left: Haitian clay on a grub hoe

The percentage of shrinkage is approximately

$$\frac{\text{Wet area} \quad \text{minus} \quad \text{dry area}}{\text{dry area.}}$$

On a grub hoe 11 x 22 cm (4.5 x 8.5 inches) you can fit 240 cm^3 of clay. If it shrinks back 1 cm from each edge (like the soil above did) you have 62 ÷ 240 or a 25% expansion.

If it ends up also a little thinner than 1 cm, it's even more expansive.

Part 2: How Do I Build with This Soil?

Plan your building wisely

Earth buildings don't cost much money, but they cost in care and wisdom. Earth is strong, but it needs to be kept up out of the water and given a chance to dry out. An earth building with a good hat (a roof overhang) and good boots (a solid water-resistant base) will last. You can be proud that you are a good builder if you use earth well.

Earth walls without a stabilizer like lime must start above the flooding, rain splash, and inside spills levels. These 'raw' earth walls need protection from extended soaking to stay strong. Build on top of a stone wall, bags filled with gravel, or stabilized earthbags. Always use a moisture barrier or air gap between any cement and raw earth.

Start earth-filled bag walls at least 15 cm (6 inches) above an inside floor and 20- 25 cm (8- 10 inches) or more above the ground outside. If lime or earth plasters are used, stone veneer or tile can protect the lowest meter from rain splashing back. Cool climates may need higher waterproofing where snow often sits against walls.

Strong earthbag buildings must protect the bags from sunlight. This is especially important in places with high risk of earthquake.

Choose a plaster that works well with the soil in your bags and your climate. All soils work well with a lime or earth plaster. On some soils in some climates earthbags can have cement stucco.

Right: Earth plaster can be applied by hand

Plasters

Earth plaster can be sturdy and dust-free. But it wears quickly when wetted, and may take some testing to get right.

Lime plaster resists wear and water better than earth plaster. It hardens more slowly and is less brittle than cement. Lime plasters breathe to let walls dry out, and expand and contract like earth. Cracks can be easily repaired with lime wash painted on or added plaster. Lime plaster is made of hydrated lime mixed with water and then mixed with 3 times (or up to 6 or 10 times for inside plaster) as much sand.

Above: Very fine cracking like this is normal in lime plaster, and is sealed with lime wash in future.

Portland cement is stiffer than earth or lime plasters, and more likely to crack. It attracts water, and doesn't dry out well. If it cracks, it cannot easily be repaired. Adobe buildings in areas with frost start to decay after cement stucco is added on top.

Right: This cement stucco was not done properly, and is going to be difficult to repair.

PLASTERS NEEDED FOR DIFFERENT BAG FILLS

	Region:	Warm Humid Areas	Warm Dry Areas	Areas with Frost
Fill for Firm bags	Soil with maximum clay	Lime or earth plaster only	Earth plaster (or optional: lime plaster or cement stucco)	Wall must breathe- lime or earth plaster only
	Soil with medium clay	Cement stucco, lime or earth plaster		
	Soil with minimum clay			Lime or earth plaster with cement stucco one side
	Stabilized earthbags	Can make buildings moldy	Cement stucco, lime or earth plaster	
Semi-solid fill[1]	Gravel or rubble bags near ground level	Cement stucco to protect from rain/ splashback	Strong lime plaster (optional: cement stucco)	Cement stucco to protect from snow/ rain
	Angular light gravel (pumice or scoria)	Reinforced cement stucco or lime plaster with a strong structural mesh and cement anchors to fasten barbed wire[3]		
Loose fill[2]	Loose Sand or Weak Soil	Reinforced cement stucco structural skin with cement anchors to fasten barbed wire		
	Rice hulls, etc.	Too moldy	Infill only- not structural	

[1]Gravel bag footings have rebar spiked through them to hold them in place. Pumice or scoria requires extra vertical rebar unless it is angular enough to settle well and not roll and is used in a non-seismic risk region.
[2]Bags filled with these are not really earthbags and must be reinforced differently.
[3]Barbed wire, important for tensile strength, is not held well by loose fill. Anchors are a small block of cement located occasionally between bags to keep wire from pulling out.

BUILDING WITH WEAK SOIL

An earthbag wall more than 90 cm (3 feet) high built with weak soil or normal sand needs temporary braces as well as barbed wire and vertical reinforcement. It must be tamped, even though it won't harden up.

Extra steel rebar attached on each side will strengthen earthbag walls made with loose fill. The building must be plastered inside and out with a strong layer of reinforced cement stucco.

IMPROVING WEAK SOIL

A weak soil can become strong if you add clay to it. Try 9: 1 or 9: 2 sand: strong clay. Test different combinations with a Drop Test (page 3) to see what works well enough.

But a weak soil that does not contain sand is a very silty soil. It must have both clay and sand added, at least 7:1:2 (silty soil: clay: sand or gravel).

Always do several tests with different mixes to find out the simplest or cheapest way to make the bags strong. Add just enough clay to make a bag hold together well.

Never add the clay in lumps. It is best to dry and crush lumps of sticky clay finely to mix in. Or soak the clay until it is almost liquid and stir it in very well.

Right: A bag of sandy soil with 2 cm clay lumps is still flexible after repeated tamping. The sandy fill inside never mixed with the interior clay lumps.

If clay is not available, a weak soil can be stabilized. See page 13.

Building with Rich Clay

Rich clays can be hard to work and must have earth or lime plasters that allow the walls to breathe. Earthbag walls of rich clay may be more flexible until hardened. But when they firm up they are very strong.

Left: Unstabilized clay in bags can form strong arches

When very rich clay soils are tamped, they compress more than sandy or silty soils. This means a house may need more bags and more work to complete in a rich clay soil. Clay-filled earthbags may require more pressure or longer tamping. Earthbag walls of rich clay may be more flexible until hardened. But when they firm up they are very strong.

Walls containing clay survive best if they can dry out completely between wettings. In a place with frost, it is very important to let clay bag fill dry out. Be careful what plaster you put on a rich clay. Check the chart on page 10.

Building on Swelling Clay Soil

Very expansive soils can swell 50% or even as much as 200%. Worldwide these soils cause more damage to buildings than any other problem.

It is safest to ask an engineer exactly what to do for each specific condition. To build on top of a swelling clay soil, he may tell you to pre-soak the footing area, and to make sure the foundation is entirely on the same clay. Rubble footings and/or gravel bag foundation walls may resist damage better than reinforced concrete because they can flex.

Some ways to prevent swelling soil damage to footings include raising the building a little higher than normal. A deeper footing with some non-expansive backfill added above the problem soil may help, since soil 1 meter (40 inches) deep stays more the same amount of wetness through the year. And once a building is finished, don't water plants or plant trees within about 5 m (15 feet) of the house. Tree roots can dry out soil.

Using Swelling Clay Soil to Build

We don't know enough yet to say just how much swelling is too much for fill in earthbags.

Different types of earth construction recommend using soil that will shrink from 1- 3% maximum. But earthbag walls do not rely on bonds with mortar for strength. They could swell or shink a little without losing strength. Because the units of earthbags are held in place by barbed wire and bags, they have built-in expansion joints.

It may be wise to stabilize the lowest 3 feet or 1 m of an exterior wall if it must be built with a somewhat expansible clay.

Some expansive clays become non-expansive if they are well compacted when somewhat wet. They will still shrink while curing, but will not swell again. This would be worthwhile testing if builders can be careful to tamp all of the walls equally well. A heavy clay soil can make a very strong wall.

Expansive clays do not swell because of humidity. They must be soaked with liquid water to swell. So if a building can have a good water-repellant finish and avoid plumbing leaks inside the walls, an expansive clay could be used even if it is not stabilized by tamping. The hardest question is how to plaster it.

Cement stucco on an expansive clay wall is probably not a good idea, even in a frost-free area. Because cement is a stiff material, a single stucco leak could trigger spreading swelling that could crack all the stucco off.

Architect and author Paulina Wojciechowska has built many earthbag buildings in Poland and other parts of the world using very rich clays. She has not had any problems so far. She recommends a lime plaster. First use earth with clay and straw to fill the gaps and even the wall. The second coat is thinner, with less clay and some lime. The finish coat can be standard lime plaster.

We know of one builder who filled earthbags with a very expansive clay. After they dried, he attached a corrugated metal wall covering. This utility building has had no problems, and is very strong. A wall of the same clay unprotected from rain and frost also resisted decay very well. Maybe he tamped it so well that it won't swell again.

If working with expansive clays, any wood, metal or glass should not be set in place and attached until the building is completely dry. An expansion joint between window and door frames and the bags could help prevent cracking in the event of a temporary leak in the plaster.

Improving Rich Clay Soil

A clay soil that is hard to handle or expansive can be improved by thinning the problem soil with sand, by adding aggregate like gravel, rubble, or shells, or by adding fiber to prevent swelling. Machine-powered mixers are very useful for mixing soil, but are not necessary. A tarp can also be used.

Right: Two people pull a tarp back and forth to mix soil

Sand can provide the coarse grains missing from a very sticky clay and make it easier to handle. Adding a quarter to an equal amount of sand to the soil can reduce the amount that a clay soil expands.

Up to 50% of an earthbag's fill can consist of a larger aggregate if the soil is a heavy clay that will hold the bag together. Light gravels are available in volcanic regions and can add better insulation value. They also make lighter bags that are much easier to work with.

Fibers are also helpful to reduce swelling, but must be chosen for the climate. Straw or other natural materials mixed with very damp soil in a humid climate may start to mold before the earth can dry. Chopped straw pre-treated with lime wash and dried may be calcified enough to form a significant part of the bag fill without being vulnerable to termites or mold.

Plastics or waste materials may be useful as fibers in humid areas with high levels of termite activity. 4 cm long plastic fibers ½ or 1% by volume can reduce the expansion of a problem soil by 30%.

Other fibers used to reduce cracking and expansion in rich clay soils include horse dung, human and animal hair, needles from evergreen trees, or fiber from coconuts, sisal, agave or bamboo.

Adding material to rich clays takes energy. Some people loosen and dampen the soil, throw sand or soil on, and have cattle or horses trample it in. Others chop it with a hoe, spread it thinly on a tarp and crush it with their feet when it is dry.

Left: Working long straw into an infill plaster layer by hand

Stabilizing Soils

If available soils are not very strong some people add lime or cement to them. Stabilizers like these make earth blocks permanent so that they cannot be recycled. They will not soak up water or be damaged as easily by water.

This 'brown cement' costs more than soil with clay added. Because earthbag walls are wide, it takes a lot of cement. At least a half bag of cement will be needed for each 30 cm (one foot) length of standard wall (2.4 m / 8' high wall 38 cm/ 15 inches thick). So a single 3 x 3.6m (10 x 12 foot) room would require about 22 bags of pure Portland cement for the walls.

Ash is also a mild cementing agent. Ash from burning sugar cane waste or rice hulls, or fly ash from industrial waste can be cheap and effective. Fly ash may need care in handling because it sometimes contains toxic heavy metals. Fly ash and bitumen may make CEB or rammed earth walls slightly toxic. Because earthbags are covered in plaster, they may be safer than exposed earth units containing this type of stabilizer.

A stabilized earthbag wall will resist flooding and can have any kind of stucco or plaster. An engineer can design its structure more like a cement or masonry building. But a stabilized earth wall will receive more condensation and get moldier in humid places than 'raw' or unstabilized earth walls will. It may not be as strong in a quake because it will stiffer.

Clay soils should have some lime added before Portland cement. Because stabilizing soil is a chemical process based on the particular soil minerals, different tests should be made to find the cheapest way to stabilize a particular soil.

Right: This strong bag was formed of a very plastic, rigid clay with a small amount of sand and wood ash (20: 2: 1). It holds a nail securely, and can even support weight when upright.

Because clay is the material that holds earth construction together, stabilizers will not necessarily increase the strength of clay bags. Adding Portland cement and lime will make a building that needs less protection from flooding or leaks. But it will also create a building that is less flexible and more prone to moldiness.

NOTE

This is part of an information series developed by the team at www.earthbagstructures.com. Check the website for the latest updates, including test results to fine-tune earthbag for seismic areas and building code compliance. Short videos demonstrating construction are also available at http://www.youtube.com/user/naturalhouses/.

This document relies heavily on the expert advice of Owen Geiger and Kelly Hart. Many thanks as well to Nadir Khalili for beginning this technology, and the many other earthbag builders who share their wisdom.

Contact Owen at strawhouses@yahoo.com or Patti Stouter at handshapedland@yahoo.com for free plan review or project advice. We may also be able to refer builders or engineers experienced with earthbag. We have several free plans available, and can help with custom plans. We also welcome comments and help to translate how-to manuals like this.

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Swelling Clays: Compacting to stabilize: George Reeves, Sims, I., Cripps, J.C. (eds.), *Clay Materials Used in Construction*, (Bath, UK: Geological Society of London, 2006) 101 and 114; Swelling clays don't swell with humidity: Minke 24

Rich Clays: Plaster recommendations from Paulina Wojciechowska, personal email to the author; Fibers in soil: Minke 40

Engineers or architects may be interested in these general earth building codes although earthbag structures may perform somewhat differently than the traditional earth block or rammed earth that they specify:
ASTM E2392/E2392M – 10[g]: *Standard Guide for Design of Earthen Wall Building Systems*, W. Conshohocken, PA: 2010 available online at www.astm.org
The ASTM document recommends NZS 4299/1998: *Earth Buildings Not Requiring Specific Design* available online at www.standards.co.nz