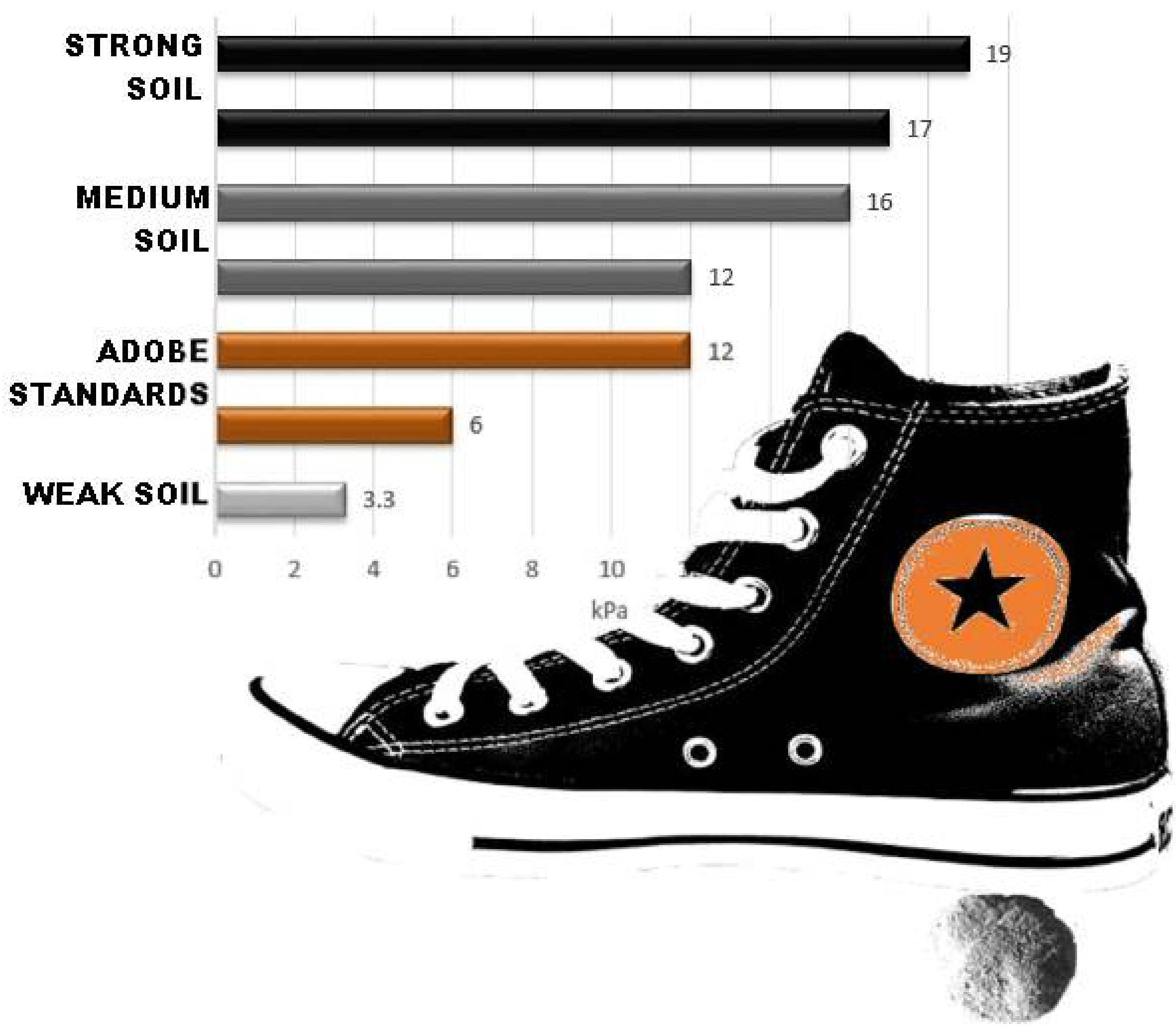
Information About Field Soil Tests

Patti Stouter
Build Simple Inc
www.BuildSimple.org
January 20, 2017



C ONTENTS:

1 TEST DESCRIPTIONS (FIELD TESTS FOR STRENGTH OF BUILDING SOILS HAS MORE DETAIL)

UNIT DROP TEST FOR STRENGTH

NEEDED:

40 gallons/ 150 liters of soil
Six boards
Tamper
A hard surface

PROCESS:

Tamp and cure 6 full-size samples 1 month
Lift to the right height
Drop on a corner on a hard surface

Based on instructions for testing adobe blocks in New Zealand (NZS 4298 p 64).

MAKING SAMPLES

Wet soil 24 hours before making samples.

Fill 6 or more 18”/460 mm wide bags more than half full with damp soil. Tamp each one until it is 15”/ 380 mm wide and 5”/ 125 mm thick. Place each one on a separate board to finish tamping. The finished sample should be between 15- 30”/ 380- 760 mm long to produce accurate test results.

During curing you can move the samples on the boards. For best strength, keep samples in the shade for 4 days. After one day, cut bag off. After several days, if the edges feel firm, turn over. These samples will each weigh about 80 lb/ 36 kg.

CURING

The sample will be completely cured when it does not get any lighter. If you can’t use a dieter’s scale or a shipping scale to check it, let it cure at least one month in a dry location.

Before testing measure 4”/ 100 mm from one corner and mark a line on each sample.

TESTING

Hold a sample up with the marked corner pointing down above a hard surface. To test for NZ Standard soil strength of 190 psi/ 1,3 MPa, hold the sample at 35”/ 900 mm height. To test for NM soil strength of 300 psi/ 2,1 MPa, hold the sample 56”/ 1,4 m height.

A sample passes the test if no more than 4”/ 100 mm breaks off any corner, and it does not break in half.

You cannot test a sample more than once- even if it looks whole, it has been damaged.

Test at least 6 samples. Test 3 samples for NZ standard grade. If they all pass, test the last 3 for the higher NM strength.

If any of the first 3 fail the test for standard grade, drop all of the rest from the lower height. You want 2/3 of them or 4 out of the 6 samples to pass the test. .

BALL CRUSH TEST FOR STRENGTH

NEEDED:

1 quart/ 1 L soil
A small plastic soda bottle
A baking tray or piece of metal
A small flat piece of wood
Shoes for your 132 lb/ 60 kg person

PROCESS:

Pick large gravel out of soil
Make and cure 18 small balls in 24 hours or oven dry
Find a tester the right weight
Stand with shoes on two balls
Stand with shoe on one ball

MAKING SAMPLE BALLS

Spread the soil out and pick out any gravel that is 1/8 inch/ 3 mm or larger. Dampen and mix well. Make 18 balls so you have at least 12 the right size to test.

Make accurate balls 29- 31 mm in diameter. Dry them in an oven at 225° F/ 107° C for 3 hours or more.

Use a bottle cap or a circle template to size. Reject any too big or too small. It does not matter if they are a little bit oblong, or a little flat, as long as the top is rounded.

CHOOSE YOUR TESTER

Find a person who weighs 132 lb/ 60 kg[1]. If someone is a little too light, put a can of food or two in their pocket. The tester should wear shoes with rubber soles.

The tester must shift their weight slowly and gently. Let them hold onto a chair or shoulder to steady themselves. They must not twist (rotate horizontally) their foot on a ball. Tensile strength is much lower than compressive strength of any soil material. Tie the wood to their shoe if the soil is strong.

Result	Soil Strength
Testing Two Balls:	
Both crush easily	80 psi/ 0,6 MPa
Both crush with most of tester's weight	120 psi/ 0,8 MPa
Both do not crush under the tester's shoe	150 psi/ 1,0 MPa
Testing One Ball:	
Crushes easily	150 psi/ 1,0 MPa
Crushes with half or more of the tester's weight	Standard (NZ) 190 psi/ 1,3 MPa
Does not crush under the tester's shoe Crushes under a piece of wood with half the tester's weight	Special (NZ) Average 260 psi/ 1,8 MPa
Barely crushes under a piece of wood with all the tester's weight	Strong (NM) 300 psi/ 2,1 MPa
Doesn't crush under a piece of wood with all tester's weight	320+ psi/ 2,2+ MPa

Small samples are very variable. After testing all samples, find the average strength.

[1] A slender young man 5'2- 5'3" / 1.57- 1.6 m tall, or woman 5'3 to 5'4"/ 1.6- 1.63 m tall should be this weight.

NEEDED:

2 quarts/ 2 L soil
Paper tubes from 5 rolls of toilet paper
A simple lever made of scrap wood
An accurate size gallon/ 4 L container
A 5 or 6 gallon/ 19- 23 L bucket

PROCESS:

Cut tubes into small lengths
Fill 10 tubes firmly, dry 24 hours, oven cure if needed
Make a lever
Set the first sample under the lever board
Hang a bucket on the board
Slowly fill the bucket with water until the sample crushes

MAKING SAMPLES

Remove any gravel that is 1/4"/ 6 mm or larger.

Fold the tubes flat. Cut them neatly to 1.5"/ 40 mm lengths.

Wet the soil and mix your batch well. Fill the tube with layers of damp soil. Tamp it firmly with fingers.

Squeeze the sample to make it round. Let the samples dry for 8- 12 hours, then oven dry for 4 hours.

TESTING

Use a small 1:6 lever. See companion guide for builders, Field Tests for Strength of Building Soils for instructions on making simple wooden levers.

Set the lever on a flat wall or table higher than the length of your bucket and handle.

Take the cardboard tube off the cured samples. Record the diameter of the top of each sample. Discard any larger than 43 mm or smaller than 39 mm. Average the width of any that are oval shaped.

Hang an empty 2 pound/ 0.9 kg bucket 6 times as far from the fulcrum point as the sample. Add water slowly. Write how many gallons/ liters crushed the sample. Or hang a scale between the lever and the bucket and record the weight.

For strong soil when the hanging bucket is full, add a smaller 1 pound/ 0.45 kg bucket on top of the lever board. Have someone touch the sides of the small bucket to keep it from falling off.

LEVER TEST RESULTS

This test is adapted from instructions for tensile tests in the New Zealand Standards (SNZ 4298 p 68).

Lever Multiplier = Weight Distance/ Pressure Distance

$$\text{Crushing pressure} = \frac{\text{(Weight in bucket + bucket weight +half of lever board weight) * Lever Multiplier}}{\text{area of the sample}}$$

The average crushing pressure from at least 10 samples x 1.8 is a conservative estimate of unconfined compressive strength for tamped samples. For mid range soil strengths (from 260- 320 psi/ 1.8- 2.2 MPa) the unconfined compressive strength (3 samples each of two soils) was actually 1.95 x average crushing pressure.

NEEDED:

Handful of soil
A 10 cm x 10 cm square of metal or plastic
A little oil

PROCESS:

Pick gravel out of soil
Rub a little oil on your square
Spread damp soil on the metal or plastic square
Dry 24 hours or in oven

WHEN SHOULD YOU TEST FOR EXPANSION?

Only strong, smooth clays need this approximate shrink/ swell test.

MAKING TEST

Wet soil well. Soak if needed, mix well. Oil your form. Spread soil 1 cm thick (photo 4). Dry in a warm place or oven.

If the sample cracks, push the cracked pieces together. Push the soil so it lines up on two sides with the edges of the form.

If 3 mm of the form shows on two sides, the soil shrinks 5%.

If more shows, it might damage contained earth. Adding some sand or less sticky soil can reduce shrinking. Measure a new soil mix and try again.

2 HOW STRONG SHOULD SOIL BE?

It depends on where and what you are building. In risky areas, building soil should be as strong as possible, but details of the building plan also increase the need for strong soil.

Need More Strength:	Need Less Strength:
Large rooms like schools	Small rooms in homes
High, thin walls	Thick, low walls
Heavy roofs	Light roofs
Many large openings	Few, small openings

Get a rough idea of the risk level in any country with the GSHAP maps online. Or use more up-to-date local maps.

Right: Details of the year 2000 global GSHAP map (Global Seismic Hazard Assessment Program).

The low risk area[2] is the white and the light green areas circled in the upper image. Well-built unreinforced earthen buildings can be safe up to about 0.3 g earthquake force levels (in the light green areas). Moderate risk is dark green. More risk (yellow, orange) and high risk (reds) areas are circled in the lower map.

Earth Building Codes: New Mexico

In New Mexico, US, where quake risk is mostly in the low range, the earth building code (NM RLD) is very simple. But adobe or rammed earth buildings must use strong earth with an average compressive strength of 300 psi/ 2,1 MPa.

Earth Building Codes: New Zealand

New Zealand (islands southeast of Australia), with many earth buildings and strong earthquakes, based their code on tested wall strengths (Walker 1998). Results after earthquakes show that their code preserves buildings (Morris 2011).

SOIL STRENGTHS:

STANDARD/	NEW ZEALAND:	188 PSI/	1,3 MPA
SPECIAL/	NEW ZEALAND:	260 PSI/	1,8 MPA
STRONG/	NEW MEXICO:	300 PSI/	2,1 MPA

Although the maximum seismic risk shown for the country on the 2000 GSHAP maps is near 2.5 g, the maximum in the

[2] These are all based on 10% chance of exceeding this level every 50 years, called 10% probability of exceedance

populated regions appears to be about 1.5 g, the yellow areas of most GSHAP maps.

'Standard' soil strength in NZ for buildings without engineers is 190 psi/ 1,3 MPa (Standards NZ 4298 and 4299). The earthen building code also allows engineers to design buildings with less reinforcement when they prove that soils used are 'special' strength, or between 250 and 275 psi/ 1,7- 1,9 MPa (Standards NZ 4297 and 4298).

The NZ code specifies footings, bond beams, lintels, and more. It also has a complex system to check plans for adequate shear walls. Under this code, adobe and rammed earth buildings of standard strength can be safe up to 0.58 g force levels without reinforcement (Miller), the level of risk in the middle of the dark green areas of the maps.

New Zealand allows reinforced earth in all higher risk areas.

Their non-engineered code (NZS 4299) covers buildings up to 6500 sf/ 600 m² for housing, office, industrial or warehouse use as long as they are on good soil and not too close to steep slopes. There are limits for rainfall levels, snow loads and maximum wind loading, but these are quite generous. Earthen-walled buildings can have a light roof, heavy roof, a loft above, or a full upper story of wood framing with a light roof.

The bracing needed is determined by wall thickness and height, the distance between bracing lines, and the type of roof and/ or upper story. All of these variables are included in tables.

The reinforced walls of adobe that are approved under NZS 4299 require vertical half inch/ D12 rebar as close as every 30"/ 0.75 m for 3.3 m/ 10' 10" height walls or as far as every 65"/ 1.65 m for 2.4 m/ 7'10" high walls. Horizontal reinforcement can be rebar, plastic geogrid strips, or mesh combs cut from wire mesh, but must bend around vertical rebar. Horizontal reinforcement is added every 2'/ 600 mm in height (or every 3'/ 900 mm in height if rebar is used).

Earthen Building Codes for Structural Design Assistance

Aid organizations are trying earthbag in the aftermath of disasters, in regions with high seismic risk (Geiger, Nordquist). But many engineers are not familiar with structural design for low-strength masonry

Preliminary Soil and Reinforcement Choices for Earthquake Risk				
Risk Level	Level on GSHAP	Color on GSHAP	Types of building	Minimum Soil Strength Recommended
Little hazard	Up to 0.2 g		Unreinforced earth often safe	Standard grade
Some hazard	0.2- 0.3 g			
Medium Low Hazard	0.3- 0.4 g		NZ type unreinforced earth safe	Standard grade for strong plans, stronger for weak plans
Medium hazard	0.4- 0.58 g			
	0.6- 0.8 g		NZ type reinforced earth safe	Special grade/ NZ recommended
More hazard	0.8- 1.6 g			
High hazard	1.6 g- >4.8 g		Check building plans carefully	Strong/ NM recommended
Note: Engineers need to confirm to what hazard level the NZ earth building code is safe above 1.6 g				

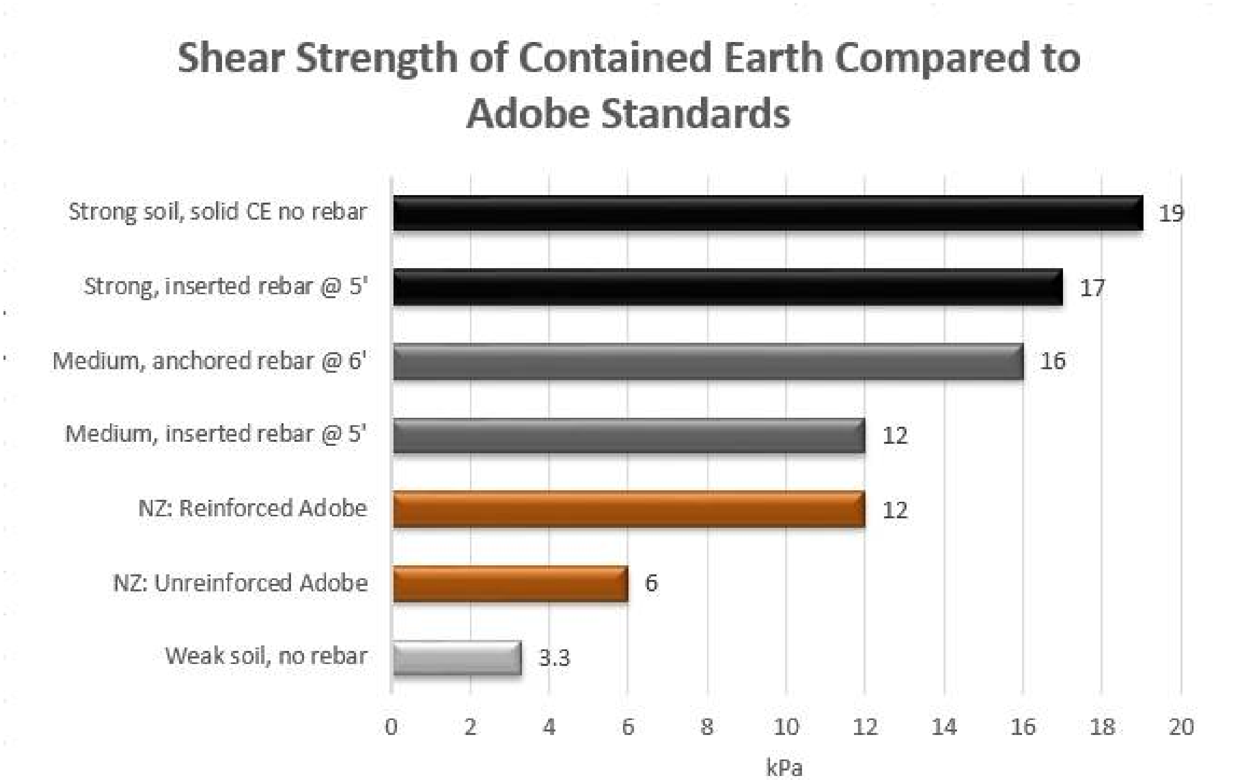
walls like adobe, contained earth, and rammed earth.

When wall shear strengths of other types of earthen walls compare to the shear strengths on which the NZ codes are based, structural design can be comparable. Slight adjustments may be needed to provide for greater wall weights as contained earth is usually 380 mm thick in comparison to 350 mm maximum for adobe.

Adjustments that take into consideration the flexible nature of the common rubble trench footing used under contained earth may have more impact.

The New Zealand standard strength of 190 psi/ 1,3 MPa may be a wise voluntary standard to adopt for contained earth as well as adobe and rammed earth in areas with some quake hazard worldwide.

Although recently some types and soil strengths of contained earth walls proved as strong or stronger than the adobe walls tested for the NZ code (Stouter 2017) the amount and type of reinforcement are important (see graph below). The strong soil in these tests was 320 psi/ 2,2 MPa and the medium soil was 260 psi/ 1,8 MPa, comparable to NZ special and NM required grades.



Good contained earth test results come from well-tamped walls with vertical strapping every 4 courses, overlapping by a course. Plaster embedded in mesh is important for earthen wall resistance to vibration. These tests used a cheap plastic fishnet, but tied it to the strapping that is also tied to the barbed wire. Chicken wire and cement stucco may increase wall strength also over these earth-plastered wall tests.

Weaker soil in unreinforced earthbag walls (without rebar) has shear strength lower than New Zealand's unreinforced adobe walls. Contained earth of very weak soil without rebar may be damaged by low quake forces. Some builders make earthbag walls with solid-weave bags but without barbed wire between courses. This type of wall is not recommended because the very low friction levels between courses will not resist any horizontal forces well, whether earthquakes, floods, or landslides.

Occupancy and Wall Curing

BSI does not know of any shear tests that compare the strength of un-cured or partially cured contained earth walls to fully cured walls. But pull-out testing of the connection between barbed wire barbs and earthbags showed that uncured earthen fill is 50% as strong as fully cured strong fill. Partially cured earthen fill was 70% as well connected to the barbed wire as fully cured fill of the same soil (Stouter2016 *Structural Information About Earthbag*, 15) .

Full strength in earthen materials does not occur until the interior reaches equilibrium moisture content of between 6 and 10% by weight (Minke 28- 29, 32).

Because contained earth walls are built 'green' or with damp soil, these 15"/ 380 mm thick walls cure slowly. In a dry climate they may take several months.

In high seismic risk regions, builders may consider delaying use of the building until the earthen walls have reached some level of curing.

Walls with inserted rebar may be more at risk from stresses before fully cured than walls built with rebar anchored in concrete. The inserted rebar walls may rely more on the strength of barbed wire barb connections to earthen fill. Anchored rebar walls are not damaged by shear forces until the rebar begins to bend at above it's base in the footing or a spot footing.

Bag Curing Stack

One simple way to test for curing is to make several stacks of 3 bags at the same time the final wall courses are set in place. These can be square half-bags, but must be the same size and thickness as the wall courses. Place them inside the building or on the shady side of a wall outside. Shelter them from rain.

Right: Bag stack

Leave the stacks untouched for a month while workers continue with plastering and finishing roofs and trim.

After one month lift the top two bags off to examine the bottom bag. Remove the bag. Does the earthen fill feel damp or cooler than the upper bags? If it does not feel damp or cooler, break the bottom sample in half. Does the interior feel damp or cooler? Does it have a uniform color or is it darker in the middle?

If the bottom sample is noticeably darker or feels cooler to the touch than the top unit, your building walls are not yet cured either. Discard the first stack. In a few weeks check the second stack the same way.

3 MORE ACCURATE TESTS

Earth builders of conventional techniques like adobe and rammed earth usually need sandy loam or sandy clay loam soil. Compressed earth blocks (CEB) often need sandy clay loam.

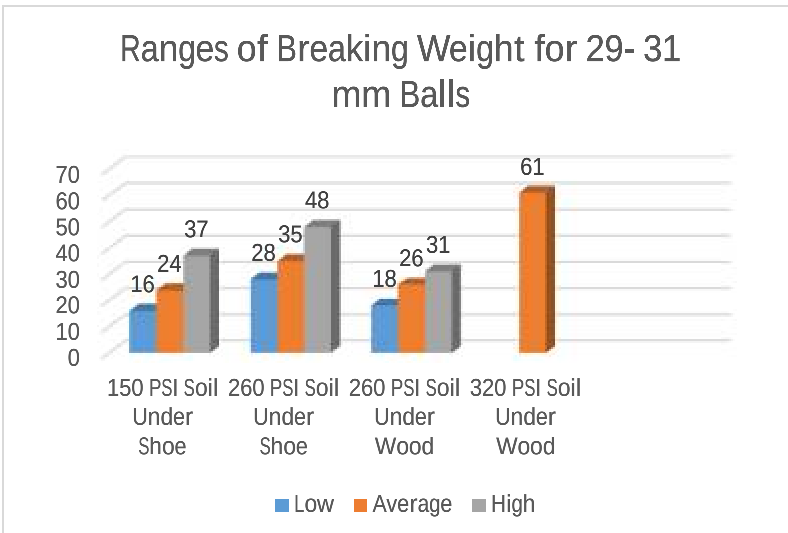
Contained earth (a cohesive soil, damp, tamped technique in the earthbag family of geo-textile materials) can use a wider range of soils. Some loams, clay, clay loams, and sandy clay can be used. For earthbag as a whole, almost any soil has been used, but loamy sands and silt loams have lower cohesion and lower compressive strength that requires different reinforcement.

All soil materials are naturally variable. But strength testing can provide meaningful strength ranges very useful to structural designers.

Soil purchased at different times or dug from different locations may be very different. Always test samples mixed from different parts of the soil piles or dig areas.

SMALL SAMPLES

Small samples and simple tests don't give you exact results. Small samples vary even more in strength than full-size samples. By testing many samples and finding the average strength, you get a better glimpse of how strong the soil may be in a full-size wall.



Testing only a few samples will leave you unsure whether your results happened to be stronger samples from a medium strength soil, or weaker samples from a strong strength soil. Create enough samples and figure out the averages so that your soil tests have some validity.

BALL CRUSH TEST: TESTING

<u>Check your bucket weights</u>. In any tests where a 5 or 6 gallon/ 19 or 23 L bucket is placed on or hung from the lever, it should weigh 2 pounds/ 0,91 kg.

A small bucket should weigh 1 pound/ 0.45 kg. If your buckets are lighter, add that much more weight. If they are heavier, add less water.

<u>Check your tester's weight</u>. If they cannot visit a doctor's office or a business with a shipping scale, use a lever. Use a 5'/ 1.5 m long board as a lever. Place the weight 3 x as far from a pivot stick than the person.

If the tester weighs 132 pounds, the bucket will tip the board level when it holds 4 gallons and 2 quarts. If the tester weights 60 kg, the board will lift the tester when the bucket holds a little more than 16 liters.

Know exactly how big your balls are. Print a circle template and write exactly how large each circle is to the outside edge. Place your ball on one circle. If much hangs over past the circle edge, the ball is bigger than that circle. Try it on a bigger circle.

Improve accuracy by using a scale under your tester's foot. A shipping scale is more accurate than a home dieter's scale. You will need a second person to watch the scale. The tester has to move very slowly and gradually shift more and more weight on to the foot or feet resting on the ball or balls.

Using a scale may let you see some differences between different strength small ball samples, but it is still less precise than TP Tube tests.

TP Tube Crush Test: Testing

Use a fish scale to record weight instead of water volume. 50 pound/ 23 kg digital scales may not be too expensive where tourists like to fish. Tie the scale to the lever board with a strong wire or cord. Then hang your bucket from the scale.

For best accuracy, figure out the crushing strength of each sample, and then add them together to find out the average strength (copy the table below).

Average Soil Compressive Strength from TP Tube Crushing Test				
Sample Number	Sample Diameter in mm	How Many Gallons or Liters to Crush?	Compressive Strength from Table 4, 5, or 6 (next page)	Comments
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
Circle the lowest strength, then add all the other strengths together:				Note: this size sample with most of its gravel sometimes fails too soon. Don’t count the weakest sample.
Divide this by the number of samples added in:				
Average soil strength =				

Use the information in Table 4, 5 or 6 on the next pages to figure out average strengths of your fist-sized sample tests.

TABLE 4: APPROXIMATE COMPRESSIVE STRENGTH OF TP TUBE SAMPLES
Metric Water Volumes with a 1:6 Lever

39- 39.9 mm			40- 40.9 mm			41- 41.9 mm			42- 43 mm	
Crushes at	MPa		Crushes at	MPa		Crushes at	MPa		Crushes at	MPa
9 liters =	1,06		9 L =	1,01		9 L =	0,96		9 L =	0,91
10 L =	1,15		10 L =	1,09		10 L =	1,04		10 L =	0,99
11 L =	1,23		11 L =	1,17		11 L =	1,12		11 L =	1,07
12 L =	1,32		12 L =	1,26		12 L =	1,20		12 L =	1,14
13 L =	1,41		13 L =	1,34		13 L =	1,28		13 L =	1,22
14 L =	1,50		14 L =	1,43		14 L =	1,36		14 L =	1,29
15 L =	1,59		15 L =	1,51		15 L =	1,44		15 L =	1,37
16 L =	1,67		16 L =	1,59		16 L =	1,52		16 L =	1,45
17 L =	1,76		17 L =	1,68		17 L =	1,60		17 L =	1,52
18 L =	1,85		18 L =	1,76		18 L =	1,68		18 L =	1,60
19 L =	1,94		19 L =	1,84		19 L =	1,76		19 L =	1,67
20 L =	2,03		20 L =	1,93		20 L =	1,84		20 L =	1,75
21 L =	2,12		21 L =	2,01		21 L =	1,92		21 L =	1,83
22 L =	2,20		22 L =	2,10		22 L =	2,00		22 L =	1,90
23 L =	2,29		23 L =	2,18		23 L =	2,08		23 L =	1,98
						24 L =	2,16		24 L =	2,06
									25 liters =	2,13

TABLE 5: APPROXIMATE COMPRESSIVE STRENGTH OF TP TUBE SAMPLES
US Water Volumes with a 1:6 Lever

39- 39.9 mm		40- 40.9 mm		41- 41.9 mm		42- 43 mm	
Crushes at	PSI	Crushes at	PSI	Crushes at	PSI	Crushes at	PSI
2 gallon, 1 qt =	124	2 g, 1 qt =	118	2 g, 1 qt =	112	2 g, 1 qt =	107
2 g, 2 qt =	136	2 g, 2 qt =	129	2 g, 2 qt =	123	2 g, 2 qt =	117
2 g, 3 qt =	148	2 g, 3 qt =	140	2 g, 3 qt =	134	2 g, 3 qt =	127
3 g =	159	3 g =	151	3 g =	144	3 g =	138
3 g, 1 qt =	171	3 g, 1 qt =	163	3 g, 1 qt =	155	3 g, 1 qt =	148
3 g, 2 qt =	183	3 g, 2 qt =	174	3 g, 2 qt =	166	3 g, 2 qt =	158
3 g, 3 qt =	195	3 g, 3 qt =	185	3 g, 3 qt =	176	3 g, 3 qt =	168
4 g =	207	4 g =	197	4 g =	187	4 g =	179
4 g, 1 qt =	219	4 g, 1 qt =	208	4 g, 1 qt =	198	4 g, 1 qt =	189
4 g, 2 qt =	231	4 g, 2 qt =	219	4 g, 2 qt =	209	4 g, 2 qt =	199
4 g, 3 qt =	243	4 g, 3 qt =	230	4 g, 3 qt =	219	4 g, 3 qt =	209
5 g =	254	5 g =	242	5 g =	230	5 g =	220
5 g, 1 qt =	266	5 g, 1 qt =	253	5 g, 1 qt =	241	5 g, 1 qt =	230
5 g, 2 qt =	278	5 g, 2 qt =	264	5 g, 2 qt =	252	5 g, 2 qt =	240
5 g, 3 qt =	290	5 g, 3 qt =	275	5 g, 3 qt =	262	5 g, 3 qt =	250
6 g =	302	6 g =	287	6 g =	273	6 g =	261
		6 g, 1 qt =	298	6 g, 1 qt =	284	6 g, 1 qt =	271
				6 g, 2 qt =	295	6 g, 2 qt =	281
				6 g, 3 qt =	305	6 g, 3 qt =	291
						7 gallons =	302

TABLE 6: APPROXIMATE COMPRESSIVE STRENGTH OF TP TUBE SAMPLES
Imperial Water Volumes with a 1:6 Lever

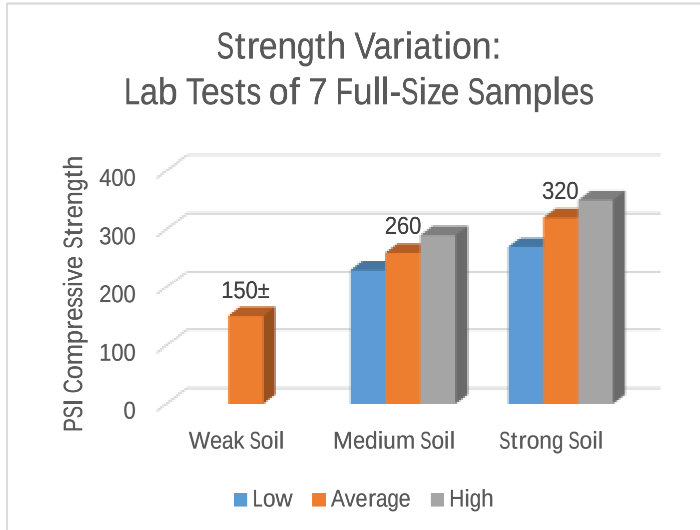
39- 39.9 mm			40- 40.9 mm			41- 41.9 mm			42- 43 mm	
Crushes at	PSI		Crushes at	PSI		Crushes at	PSI		Crushes at	PSI
1 gallon, 3 qt. =	117		1 g, 3 qt. =	111		1 g, 3 qt. =	105		1 g, 3 qt. =	101
2 gallons =	131		2 gallons =	124		2 gallons =	118		2 gallons =	113
2 g, 1 qt =	145		2 g, 1 qt =	138		2 g, 1 qt =	131		2 g, 1 qt =	125
2 g, 2 qt =	159		2 g, 2 qt =	151		2 g, 2 qt =	144		2 g, 2 qt =	137
2 g, 3 qt =	173		2 g, 3 qt =	165		2 g, 3 qt =	157		2 g, 3 qt =	150
3 g =	188		3 g =	178		3 g =	170		3 g =	162
3 g, 1 qt =	202		3 g, 1 qt =	192		3 g, 1 qt =	183		3 g, 1 qt =	174
3 g, 2 qt =	216		3 g, 2 qt =	208		3 g, 2 qt =	195		3 g, 2 qt =	187
3 g, 3 qt =	230		3 g, 3 qt =	219		3 g, 3 qt =	208		3 g, 3 qt =	199
4 g =	244		4 g =	232		4 g =	221		4 g =	211
4 g, 1 qt =	259		4 g, 1 qt =	246		4 g, 1 qt =	234		4 g, 1 qt =	223
4 g, 2 qt =	273		4 g, 2 qt =	259		4 g, 2 qt =	247		4 g, 2 qt =	236
4 g, 3 qt =	287		4 g, 3 qt =	273		4 g, 3 qt =	260		4 g, 3 qt =	248
5 g =	301		5 g =	286		5 g =	273		5 g =	260
			5 g, 1 qt =	300		5 g, 1 qt =	285		5 g, 1 qt =	272
						5 g, 2 qt =	298		5 g, 2 qt =	285
						5 g, 3 qt =	311		5 g, 3 qt =	297
									6 gallons =	309

4 How Accurate are These Tests?

Build Simple ran many tests on four basic types of soil of different strengths to create these field tests.

Full-size Laboratory Tests

Laboratory unconfined compressive strength tests were performed on 8 full-size tamped, cured samples to compare field tests to actual soil strength (Amec 2016).



Samples used soil that had been soaked for 24 hours or more. They were cured in the shade for 4 days, since BSI testing of half-scale units showed slight strength declines for samples dried in the sun or oven cured without 4 days of shade curing.

Samples cured for a month or more. Complete curing (no more weight loss) was confirmed by weighing samples daily, and rechecked after kiln curing by the testing laboratory. Test protocol followed ASTM C67 used to test adobe blocks.

BSI's weak soil is a weak silt loam with only 3% coarse sand and 7% aggregate, mostly less than 1/8"/ 3 mm even before removing larger pebbles. By hand texturing it appears to have some fine sand, but possibly more silt than sand. It can firm up in an earthbag, but at 150 psi/ 1,03 MPa is weaker than the New Zealand Standard strength. A single lab test leaves this as an approximate value.

The three remaining soils all share a sandy loam texture, despite varying compressive strength.

For the medium and strong soils three samples each were lab tested.

BSI's medium soil ranges from 230 to 290 psi/ 1,6- 2,0 MPa. The tested average strength is near the average of New Zealand 'special' strength at 260 psi/ 1,8 MPa. This is a local fill dirt that feels very gritty with 19% coarse sand and 20% fine aggregate and 18% coarse aggregate larger than 1/8"/ 3 mm. It has enough aggregate that it is difficult to reshape in small ball samples, needing at least slight tamping to allow full cohesion around the many large particles.

BSI TESTED SOILS:

WEAK:	150 PSI/	1,03 MPA	(1 SAMPLE)
MEDIUM:	260 PSI/	1,8 MPA	(AVERAGE OF 3 SAMPLES)
STRONG:	320 PSI/	2,2 MPA	(AVERAGE OF 3 SAMPLES)
VERY STRONG:	370 PSI/	2,6 MPA	(1 SAMPLE)

BSI's strong soil ranges from 270- 350 psi/ 1,9- 2,4 MPa. The tested average strength passes the New Mexico code soil strength requirement at 320 psi/ 2,2 MPa. It was purchased from a local adobe maker in October 2016. It contains 16% coarse sand, 19% fine aggregate and 21% coarse aggregate larger than 1/8"/ 3 mm.

Some tests also used a very strong soil. A single lab test showed an approximate strength of 370 psi/ 2,6 MPa. This strong soil was mostly the strong adobe soil with small proportions of added low-strength clay and sharp sand. Soil strength is maximized by including all particle sizes, not just by adding strong clay.

Some contained earth samples made of the weaker and medium strength soils broke when turned during curing. They cannot be handled for several days, even when drying in mid-summer Albuquerque heat and desert dryness. The two stronger soils are easier to handle while curing, usually can be turned over in about 24 hours.

Small Sample Tests

These tests were developed from instructions by adobe researchers to make 200 mm balls and crush them between thumb and forefinger (Bureau of Indian Standards 6.1, and Blondet 5).

Different people have great variation in finger strength. BSI tested larger balls to be crushed under the palm, and the force variation was also great between individuals accustomed to heavy work and others with less calloused hands. Larger balls were tried, but the use of bare feet was not included to avoid the same kind of muscle and/ or toughened sole variation.

Some adobe codes (and some earthbag builder trainers) also recommend that a 132- 154 pound/ 60- 70 kg person stand on top of a cured block set over a 10"/ 250 mm span (Bureau of Indian Standards 6.3).

BSI has tested and calculated the strength of this type of test (Stouter, Ernstsen May 2016 42- 46). We followed protocols for the Modulus of Rupture type test in the New Zealand Standards (NZS 4298 66). A 2-1/4" x 9-1/2"/ 57 x 242 mm cross-sectional block has to be 15"/ 380 mm long to be able to span 12"/ 300 mm if it is 300 psi/ 2,2 MPa or equivalent to NM required soil strength. A standard/ NZ grade soil of 188 psi/ 1,3 MPa strength must hold up the same 130 pound/ 59 kg person over a 9"/ 230 mm span (see top photo at right).

Contained earth builders do not make units before construction. In addition, it is difficult to make small units in custom width bags of the right thickness (see photo at bottom right).

Samples this long and thin also require very careful handling. If the samples are thicker they will need even longer spans, because the span should be four times the sample thickness.

Curing may take between two weeks and a month. Even with oven curing, the samples require at least five days to process, too long to be practical for many builders.

Small Ball Tests

For all small samples, soils were not pre-soaked, and samples were speed cured to replicate worst-case conditions for hurried builders and designers.

BSI completed 5 series of tests comparing balls of size ranging from 22- 40 mm and comparing soils with aggregate to soils sifted through window screen. These samples egg-sized or smaller were broken underfoot on a digital scale with the crushing force recorded.

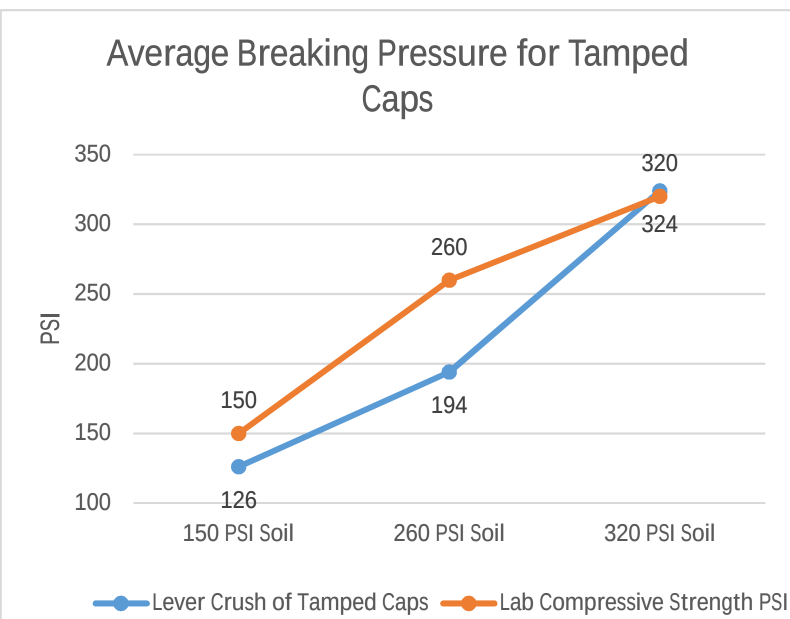
Density of samples influences test strength, but small egg-size samples are hard to make to uniform density with crude hand tools. The most uniform small sample tests involved soil tamped into a wine or oil bottle cap and used a small lever.

Right: 22 mm balls and bottle cap samples

So that builders can test without a lever or bucket weights, round balls were chosen. The bottle cap samples need much higher pressures to crush than can be developed under a shoe. Crushing small caps under a lever was neither simple enough for the basic field test, or accurate enough to replace the larger fist-sized toilet paper tube sample tests.

The 132 pound/ 60 kg tester weight was chosen for two reasons. It is an average weight for short men and women in many countries of the developing world. It also falls at the dividing line between shoe crushing of medium soils, but still is heavy enough to crush strong soils of the New Mexico standard with wood only.

Since the biggest challenge of this test is to produce uniform size balls, we compared the laboratory tests of soils first to the small caps to establish a comparison between full-size results and small samples. The breaking forces needed for small balls of various diameters were then compared to test results from the small caps.

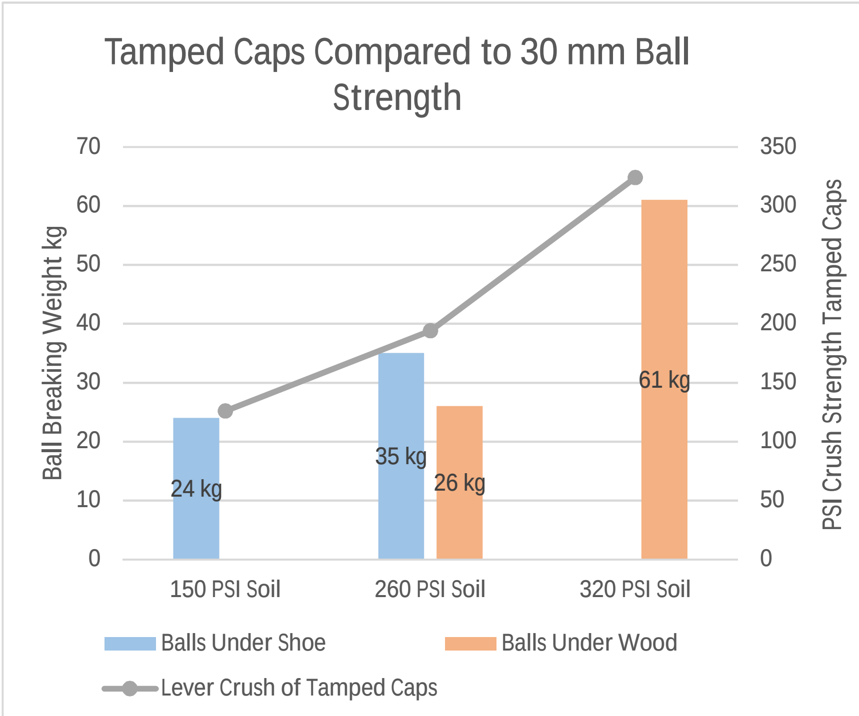


Balls of low and medium strength soils are close in performance. We recommend that soils tested under a shoe for Special/ NZ strength of 260 psi/ 1,8 MPa should be confirmed with a repeat test using wood.

The performance of 30 mm balls under rubber shoes showed them breaking under slight weight for the BSI weak soil, and barely breaking under half the tester weight for BSI medium soil. The medium strength balls also broke under slight weight when tested singly under wood, and the strong soil barely broke under the full tester's weight under wood. Intermediate values in the result charts have been interpolated.

Balls can also be broken under metal if you want to differentiate strong from very strong soils.

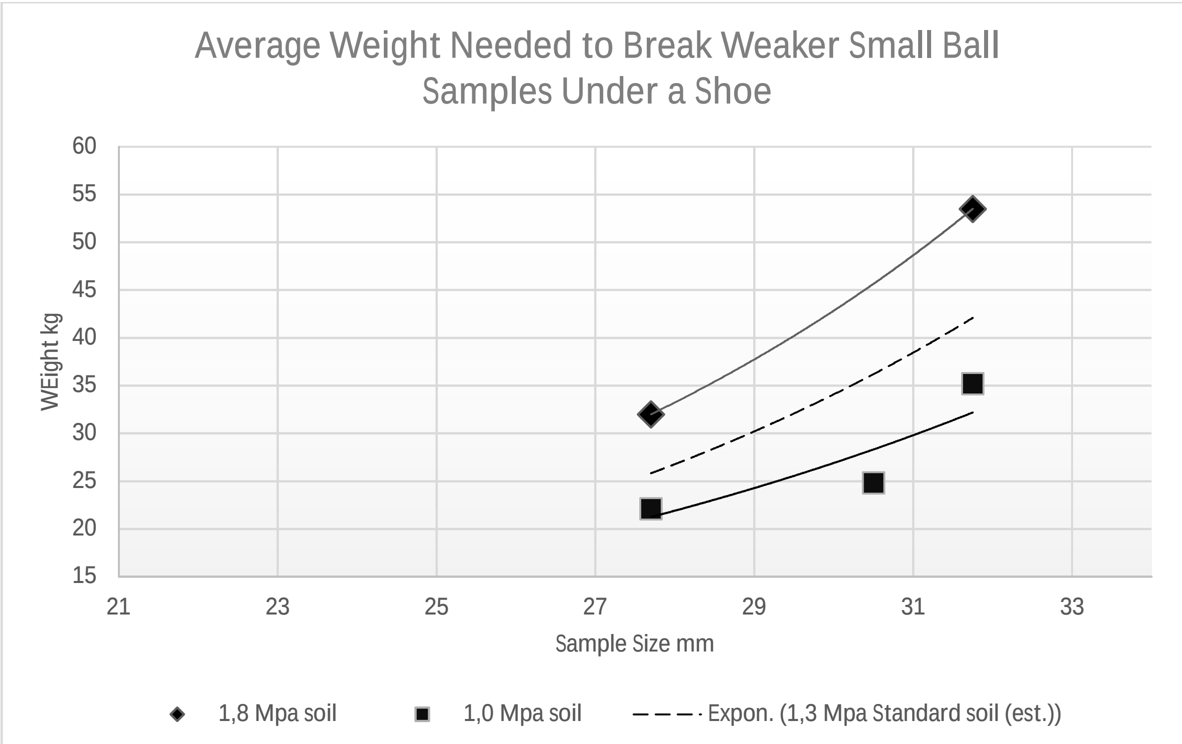
For most builders any soil stronger than 300 psi/ 2,1 MPa is a very good thing, but may not influence building design. Stronger soil strengths may be too difficult to maintain during the entire length of the construction process. Remember, you are trying to establish minimum or average soil strengths that your builders can maintain for the entire wall building process.

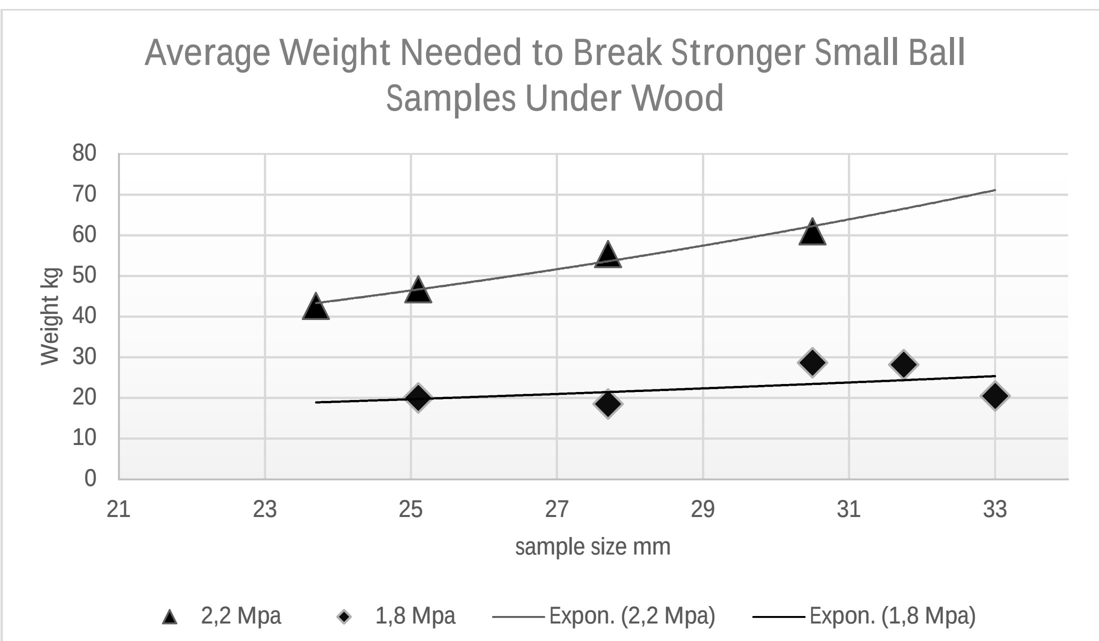


Left: 14 or more round samples and 16 bottle-cap samples were tested for each of the four soils during the second series of tests.

Crush Weights of Small Balls

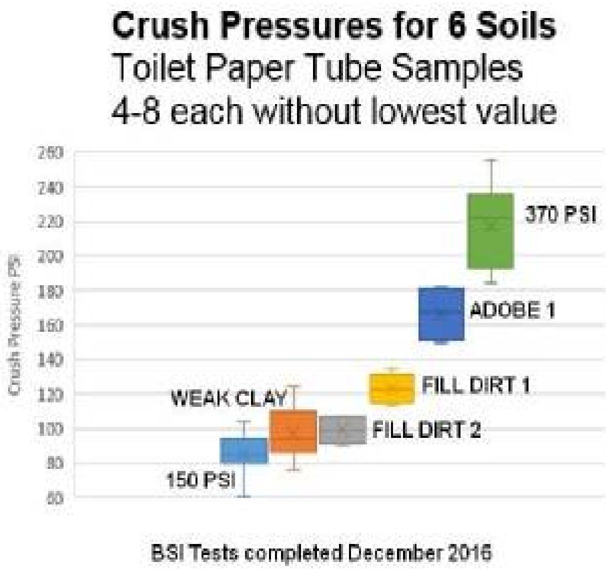
The crushing weight needed for small balls increases as approximate diameter increases.





TP TUBE TESTS

For toilet paper tube size samples we completed two separate series of tests and compared crushing under a piston to crushing with a lever.



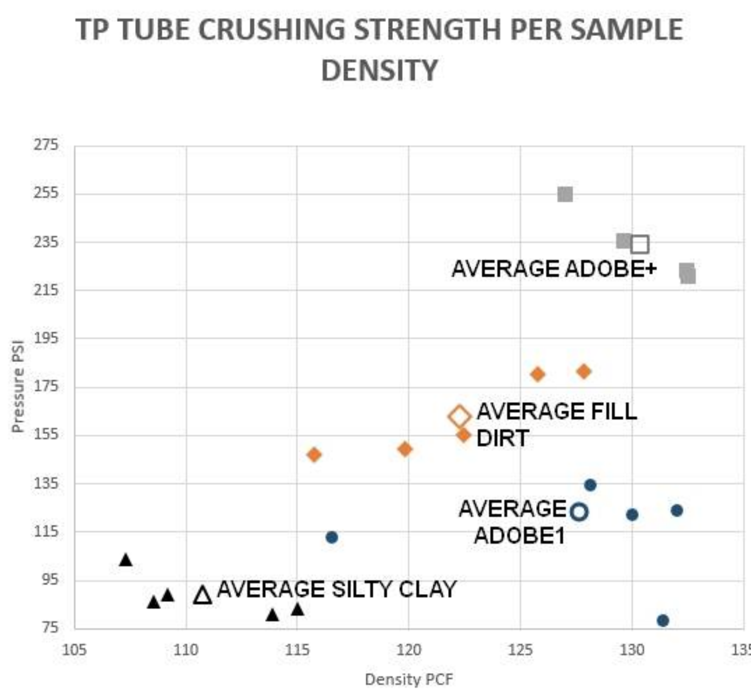
For most types of soil, the TP Tube crush tests shown at left had a small amount of variation.

The two fill dirt samples included in the test results above were purchased from the same supplier a few weeks apart.

The lab tests of the fill dirt and of this adobe soil and a second adobe soil all used more recent batches of soil. When TP Tube test results of the both fill dirts and both adobes were averaged together, they matched the range of laboratory compressive strength values well.

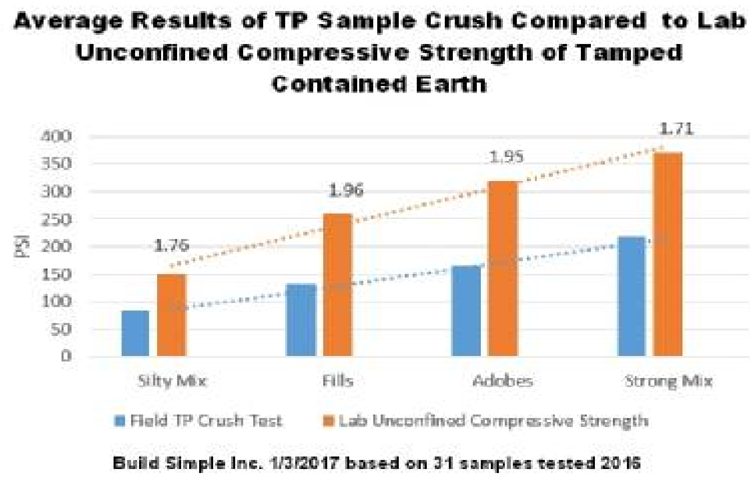
Sample density does affect these fist-sized samples (see graph below right). Different soils compress more or less easily in these small tests. It is difficult to provide uniform compaction even in these cardboard-formed tests. But the range of strength variance from less dense to more dense is still less than the difference between these 150, 260, and 320 PSI strength soils.

For the toilet paper tube size samples, we often had outliers lower than most other values. We assume that some fist-sized samples crush too easily because of flaws like aggregate near the surface. Always leave out the one lowest value from the toilet paper tube test results. Average the rest of the result values.



The four soil types shown at right are the four that were laboratory tested, with average results from 150- 370 psi.

For 39- 43 mm diameter TP tube samples, a conservative estimate of the compressive strength of a soil is the pressure needed to crush, multiplied by 1.8. For mid-range values between 260 psi and 320 psi a multiplier of 1.9 may be more realistic.



Using These Field Tests for Evaluating Adobe Soils

Earthbags might be stronger than adobe blocks of the same soil if they are compacted more. But Contained earth walls are not tamped with specific pressures like rammed earth, and may on average be close to the strength of adobe blocks made from the same soil.

Contained earth is often tamped down about 20% in height, but this involves little actual compression. The individual units go from a loose fill condition that is high and not too wide to a flatter, wider shape of firm solidified fill.

Some earthbag builders recommend soil damper than the OMC or optimum moisture content identified for rammed earth and CEBs. A damper bag can be tamped but will weep liquid clay to dirty the bag. More moisture and the bag 'jellies' up. It bounces and does not compact to a flatter, wider dimension. Yet some builders report that these higher courses are stronger when cured (Hunter, Kiffmeyer 18).

Adobe blocks tested by BSI range from 108- 114 pcf/ 1740- 1900 kg/ m³. It is difficult to precisely measure volume of rounded earthbags, but onetamped bag sample of the same soil and one of another soil ranged from 97- 118 pcf/ 1556- 1890 kg/ m³, lower density than the adobe.

BSI finds that our block-type samples of adobe soil compressed 20% average in a wooden form for uniform flexile strength tests range from 110- 125 pcf/ 1700- 2000 kg/ m³ density. Tamping in a wooden form without a bag increases density, but tamping in bags may not.

This is consistent with the earthen unit density reported by Minke, from 106- 137 pcf/ 1700- 2200 kg/m³ (p. 21) including both adobe blocks and rammed earth.

BSI's flexile tensile tests (Modulus of Rupture using a slow pressure increase from a hand powered jack) showed a comparable strength between 4 unstabilized adobe blocks and some samples made from a different batch of soil purchased from the same adobe yard. But different batches of soil from the same yard have tested with about 20% strength variation over the past year. More testing is needed to clearly establish the relationship between adobe block and tamped contained earth unit strength.

Adobe builders using the toilet paper tube test may get more accurate results for adobe block strength if they wet the soil more and pour it into the cardboard tubes.

5 When You Test A Lot of Samples

Filling buckets takes time. If you need to test many of these samples, it might be time to make a testing frame.

For small tests of earthen materials, a strong wood frame and a hand jack used for auto repair work well.

Most one-piece hydraulic jacks cannot have a pressure gage added on. Find a jack that has a fitting for adding a pressure gage.

This hand-pumped jack uses several different size pistons and can use different gages. A jack rated for 5 tons of pressure is enough with a small piston to crush mini-samples, or to break half size samples.

Use your strongest wood and many strong screws for a testing frame.We used a pipe clamp to attach a piece of plywood to our piston, then added slots in the top of the frame to hold the piston in place between tests.

A vertical guide of 2 metal pipes is shown keeping the pressure pipe and piston from going out of plane during a test. Guides can be very handy for splitting cylinders, but they are not necessary for crushing toilet paper tube size samples or breaking 2- 3” thick samples over a span.

A piston larger than 1”/ 25 mm diameter is useful if you intend to split 4”/ 100 mm diameter cylinder samples also. These Brazilian splitting tensile tests are reported to be more reliably related to compressive strength than the common Modulus of Rupture tests (Schroeder 2016 item 5218, Ramanathan 1973).

BSI finds that 4” diameter soil samples are also easier to handle than flat blocks, and can be reliably compressed to more uniform densities in a form made from a plastic pipe.

6 MORE INFO ABOUT SOILS, SOIL TESTS, AND EARTH BUILDING

BSI has a series of soil testing slide shows that will be changed during 2017 to include these new field tests. The slide shows include more information on the characteristics of different soils, and simple tests to measure shrink/ swell potential of clay soils. Check them out online at http://buildsimple.org/soil-tests.php.

Always check BSI's resources page for the latest test results and related guidelines at http://buildsimple.org/resource-lists.php. Developing voluntary guidelines is a long process.

Builders and designers may also be interested in reviewing the types of site soil conditions that might cause problems. If no civil engineers are available to give advice about your site, at least review BSI's simplified information about site soil evaluation in Evaluating Soils for Warm Climate Sites.

BSI welcomes researchers interested in soil strength for natural building to share research and builders worldwide to give comments or suggestions to improve techniques. Please contact Patti Stouter: pstouterATbuildsimple.org.

We suggest that any researchers or writers discussing their work, begin by describing the soil they work with in terms of texture. The instructions for hand texturing soils are simple (University of California Davis IPO 2010 and Colorado State Extension). Good instructions in video and in pdf form are online. If scientists use these standard soil descriptors in addition to providing particle size analysis, it will simplify understanding between builders and designers and researchers.

7 ACKNOWLEDGEMENTS

This instruction manual would not have been possible without help from many sources:

Thanks to the Creator for making soils and physics follow repeatable laws!

Thanks to Christian Ernstsen for a sacrificial June and July of 2016 when he came from Denmark to New Mexico to learn and ended up teaching much about testing despite temperatures consistently above 100 F. The TP Tube test concept and the wooden lever without a hinge are his brain children.

Thanks to Owen Geiger and Kelly Hart and to Kateryna Zemskova for ongoing involvement in teaching inexpensive natural building and sharing knowledge worldwide.

Thanks to engineers like Hugh Morris and Gabriel Miller who are willing to discuss and give advice about new earthen building materials.

And finally, thanks to the growing body of supporters of Build Simple Inc. who use and help refine construction techniques, and who provide funds and impetus for testing.

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