

RAMMED EARTH

History:

Earth construction has existed for over 9000 years. Adobe houses have been uncovered in Russian Turkistan dating from 8000 to 6000 BC. The oldest known rammed earth constructions were foundations dating from 5000 BC in Assyria. The Great Wall of China was built of rammed earth 4000 years ago and the core of the Sun Pyramid in Teotihuacan, Mexico was built using 2 million tons of rammed earth between 300 and 900 AD. Today, one third of the human population resides in buildings made of earth.¹

Earth Construction:

Earth can be used for building in a variety of ways. Unbaked, handmade bricks of earth are referred to as Adobe or mud bricks. Unbaked, compressed bricks are often called soil bricks or compressed earth blocks (CEBs). Wet earth can be molded in a variety of ways by hand to form walls, often referred to as cob construction. Earth can be formed, thrown, or sprayed over a frame making a wattle-and-daub structure. Earth can also be heavily compressed within a formwork to make rammed earth walls.

Mix Composition:

Earth for construction, also called loam, is a mixture of clay, silt, sand, and gravel. Clay acts as the binding agent for loam, like cement in concrete, holding together the structural fillers, gravel and sand. Water is added to the mixture to activate the binding forces of the clay. Organic soils, such as top soil, are from plant and animal decomposition and are not usable in earth construction.

Often, other materials are included in earth mixtures as additives. Fibers, including animal or human hair, coconut fiber, sisal, agave, bamboo, straw, or tree needles can be added to the mixture to increase the binding force of the material and decrease the appearance of cracks. Animal products such as blood, urine, manure, casein, and animal glue can also be used to stabilize earth from erosion. Cement or lime can also be added as a water erosion stabilizer. Thermal insulation can be increased by adding porous substances such as straw, reeds, seaweed, cork, saw dust, wood shavings, or husk.²

For rammed earth construction, soil selection and composition is critical. The basic soil composition for rammed earth is roughly 70% sand and gravel, the structural filler, and 30% clay and silt, the binder.³ If the clay content is too high, sand can be added to the mixture. This will also increase the compressive strength of the material. If the clay content is too low, high clay soils can be mixed in to make an optimum mix.

There is a range of acceptable soil mixtures including sandy clays, gravelly clays, and clayey sands. Most soils that are not acceptable can be amended.

1 Gernot Minke, "Building with Earth: Design and Technology of a Sustainable Architecture" (Basel: Birkhauser-Publishers for Architecture, 2006), 11-12.

2 Minke, 39-44.

3 David Easton, "The Rammed Earth House" (White River Junction, VT: Chelsea Green Publishing Company, 2007), 100.

Soil Composition Testing:

A combination of onsite tests can be done to determine the composition of soil.

A **smell test** can determine if there is organic matter in the mixture; pure loam is odorless. The texture of the soil when **tasted** can also reveal the basic soil composition. High clay content produces a sticky or floury sensation in the mouth.

A **wash test**, done by rubbing a damp soil sample between the hands, reveals how sticky the soil is. If the hands can be cleaned by rubbing them, the soil is silty. If the hands require water to be cleaned, the soil is clayey. If, when rubbing the hands together, grains are felt, the soil has a high sand content.

A **sedimentation test** visually displays soil composition in stratified layers. A soil mixture is stirred with high amounts of water in a glass jar. The content is allowed to settle revealing the soil composition. The largest particles settle first, on the bottom, and the clay settles last, on top with the organic material above the clay.

A **ball dropping test** displays the binding strength of specific soils. A ball of soil with a 4 cm diameter is dropped 1.5 meters onto a hard, flat surface. If the ball shows few cracks and generally maintains its shape, flattening only slightly, the soil has a high binding force. This means that the soil has a high clay content and must be thinned with sand. If the ball completely falls apart and disintegrates on impact the binding force is too low and the soil should not be used for construction. If the ball displays deep cracks or moderately falls apart the soil can be used without amending the soil much.

A **ribbon test** or cohesion test also demonstrates the binding strength of the soil. A ribbon, 6mm thick and 20 mm wide, is formed and held in the palm. The ribbon is slid to overhang until it breaks. If the breaking length is more than 20 cm the clay content is too high and if the ribbon breaks after a few centimeters, the soil has too low a clay content. A measure between approximately 8-16 cm suggests a soil with a usable clay content. A more precise version of this test was developed using a rounded board to form and test the ribbon.

An **acid test**, using a 20% solution of HCl, will reveal the level of lime in the soil by producing carbon dioxide shown as efflorescence. A high lime content will produce a strong, long-lasting case of efflorescence. Soils containing lime have a low binding force making them unsuitable for building construction.⁴

Test blocks and cylinders should be constructed and tested in a laboratory to explore soil characteristics including color and texture, resistance to erosion, and compressive strength.

4 Minke, 21-24.

Construction:

Foundation:

A rammed earth wall needs a well-constructed foundation. A common foundation is a rubble trench, extended below the frost line, topped with a cast-in-place concrete beam. In areas with excessive ground water, a drain line should be installed to divert the water away from the walls. The grade beam should be high enough, 3" - 6," to ensure the wall is well above the finished grade.

A typical reinforced concrete footing and stem wall can also be used. However, this will involve a significant amount of concrete as the stem wall must be the thickness of the rammed earth wall, sometimes as thick as 2 feet.

The rammed earth wall sits directly on top of the stem wall or grade beam and can be connected by simply leaving the top surface of the concrete rough for a strong mechanical bond. Keyways can be cast into the stem wall or rebar dowels can extend from the concrete into the rammed earth for extra overturning prevention.⁵

Formwork:

There are many types of rammed earth formwork.

Traditional formwork utilizes stiff boards on both sides of the wall that are held apart and locked together with spacers piercing the wall. The formwork is removed and reassembled horizontally forming courses of earth layers each time the formwork is moved. This method requires attention to shrinkage as the new layer is more moist than the previous layer, causing horizontal and sometimes vertical cracks. This is prevented with the pisé technique, using lime mortar after each course allowing fluctuation during curing.⁶

Rammed earth panels, called the **panel-to-panel system**, utilize shorter sections of formwork that are one storey tall and up to approximately 7.5 feet (2.4 meters) wide. This virtually eliminates horizontal joints and the vertical joints, built in a tongue-and-groove pattern, are sealed after curing and act as expansion joints. The formwork can be reused for each panel.

The **freestanding panel system**, like the panel-to-panel system allows short sections of the walls to be constructed but without the vertical joints. Rather, the panels remain free standing and columns are poured into place, between panels, after curing. The structure acts as a concrete frame with rammed earth infill panels.

A continuous formwork, called the **continuous-wall system**, can also be used creating a seamless and uniform finish. The formwork can also be used, without repositioning, as the formwork for the bond beam. This type of formwork requires more materials than other formwork options.⁷

Another type of formwork is the **"lost formwork"** where a thin masonry wall or stiff thermal insulation is used in place of wooden materials on either one or both sides of the formwork becoming part of the finished wall.⁸

5 Easton, 89.

6 Minke, 52-55.

7 Easton, 117-124.

8 Minke, 57-59.

Earth:

The earth mixture is poured into the forms in 6 inch layers and rammed manually or with a pneumatic rammer until fully compressed. The formwork can be removed immediately after a section is complete.

Openings, Bond Beam, and the Roof:

Door openings, window openings, niches, and fireplaces can all be formed into the rammed earth walls. Volume displacement boxes are used to leave spaces for openings in continuous or traditional formworks.⁹ Panel systems are designed to leave spaces for openings based on the panel module. Lintels made of cast-in place concrete or solid wood can be used to make larger openings. Arches can also be constructed of concrete or rammed earth over doors or windows. Niches and fireplaces can be carved out of the earth during curing or built with formwork.

A cast-in-place bond beam or a steel or wood ring beam is built to link the sections of the wall together. The connection between the earth walls and the bond beam is crucial in tying the roof to the walls. The roof, like the foundation, is necessary in protecting the earth walls from the sun and rain that cause weathering and erosion.

Finishing:

The exterior walls can be finished with paints, water repellants, plasters, or cladding or left exposed.

Some **breathable paints** can be used to protect the walls from moisture but should be renewed periodically: a pure lime wash dries white and provides weather resistance; a lime-casein wash can be used to make the surface wipe resistant; a borax-casein wash acts like the lime wash but produces a darker finish; a colorless casein coating retains the natural color of the earth while increasing its wipe resistance; and other lime washes using urine, clay, animal glue, and other animal products can also enhance weather and wipe stabilization.¹⁰

Other colorless liquids can be applied to make the exterior surfaces of the walls **water-repellant** including silane and siloxanes, silicone resins, siliconates, acrylic resins, silicate ester with hydrophobising additives, and silicates with hydrophobising additives though each can reduce vapor diffusion.¹¹

Lime plasters can be used though they are not recommended for rammed earth walls unless the exterior of the walls are insulated and need stucco. **Cladding** can also be applied with insulation and for moisture protection.

9 Easton, 159.

10 Minke, 98-100.

11 Minke, 101.

Technical Information:

Compressive Strength:

The compressive strength of earth construction depends on the distribution of grain size, the water content, the compaction method of the mixture, and the type of clay mineral used. Generally speaking, the maximum compressive strength of a material is reached if the structural filler, sand and gravel, is distributed for maximum packing volume and the binder, silt and clay, are fully filling the inter-granular spaces of the gravels.

Testing has shown that kneading earth rather than or in addition to compressing earth produces a denser material with a higher compressive strength. An internal electrical reaction of the material structure is triggered by water and movement of the mixture. When compressing material, testing has proven that beating or ramming material, types of dynamic movement that cause vibrations in the structure, produces a higher compressive strength than compacting the material with a static force.

Additives can also increase the compressive strength. Adding 17% by weight Montmorillonite clay such as Kaolinite and Bentonite or lime and cement will increase the compressive strength. However, additions of minerals in amounts lower than 5% can actually decrease the compressive strength of the material. Other organic additives such as urine containing urea and ammonium acetate, can increase the compressive and binding strength as well. Typically, the addition of fibers to reduce shrinkage, such as straw, can decrease the compressive strength though in small amounts can increase tensile strength.

The maximum compressive strength of earth construction ranges from approximately **284 psi** (20 kg/cm²) and **710 psi** (50 kg/cm²). A Factor of Safety of at least 7 is usually used to determine the allowable compressive force of the material. This means the allowable compressive force ranges from **40 psi to 100 psi**. The German standard DIN 18954 allows a permissible compressive force between 42.6 psi (3 kg/cm²) and 71 psi (5 kg/cm²).¹²

Shrinkage and Erosion:

Shrinkage cracks in earth walls should be prevented as increased erosion will occur when exposed to weathering. Shrinkage during drying depends on the mixture's water content, the type of clay and percentage of clay, and the distribution of grain size of the structural filler. For rammed earth, shrinkage is minimal because the soil is only moist, not wet, when compressed.

Rammed earth walls protected with large overhangs and raised on a waterproof foundation should not necessarily need stabilization from erosion. If stabilization is necessary because walls are unusually exposed to weather or because code mandates stabilization, use cement for low clay mixtures and lime for clayey soils. Soda water-glass, a type of glass, plant juices, linseed oil, blood, urine, manure, casein, and animal glue have also been used to stabilize earth.¹³

Insulation and R-Values:

Rammed earth walls have an average of **R-0.25 per inch** of wall thickness.¹⁴ For a **12 inch wall that is R-2.8 to R-3.0**, and for a **24 inch wall that is R-5.6 to R-6.0**. If larger aggregates are used to increase the porosity of the wall, thus increasing the insulating qualities of the material, a 12 inch wall could reach R-4.4 and a 24 inch wall could

12 Minke, 43-47.

13 Minke, 40-42.

14 Easton, 43.

reach R-8.7. This is hardly sufficient for the weather extremes of the upper Midwest. Rammed earth constructions need added insulation on the exterior of the wall, with stucco or cladding, or buried within the wall to maintain comfortable temperatures year round. Insulation can add R-4 to R-8 per inch to the wall (4" of insulation buried between 10 inches of earth results in R-21 to R-37).

Acoustics:

A 20" rammed earth wall with 4" of rigid insulation falls around 60 in STC (Sound Transmission Class) meaning most sounds are inaudible.¹⁵

Fire:

Rammed earth walls are said to be "fire resistant."

¹⁵ Terra Firma Builders, "Portfolio, Healthy Home Features and Specifications," <http://www.terrafirmabuilders.ca/Portfolio/envirohome-features.html>.

Resources:

Books:

The Rammed Earth House: Revised Edition

by David Easton

http://www.amazon.com/dp/1933392371/ref=nosim?tag=hartworkscom-20&link_code=as3&creativeASIN=1933392371&creative=373489&camp=211189

Earth Architecture

by Ronald Rael

http://www.amazon.com/dp/1568987676/ref=nosim?tag=hartworkscom-20&link_code=as3&creativeASIN=1568987676&creative=373489&camp=211189

Martin Rauch: Rammed Earth / Lehm und Architektur / Terra cruda

by Otto Kapfinger

http://www.amazon.com/dp/3764364610/ref=nosim?tag=hartworkscom-20&link_code=as3&creativeASIN=3764364610&creative=373489&camp=211189

The Rammed Earth House

by David Easton and Cynthia Wright

http://www.amazon.com/dp/0930031792/ref=nosim?tag=hartworkscom-20&link_code=as3&creativeASIN=0930031792&creative=373489&camp=211189

Building with Earth: Design and Technology of a Sustainable Architecture

by Gernot Minke

http://www.amazon.com/dp/3764374772/ref=nosim?tag=hartworkscom-20&link_code=as3&creativeASIN=3764374772&creative=373489&camp=211189

Adobe and Rammed Earth Buildings: Design and Construction

by Paul Graham McHenry

http://www.amazon.com/dp/0816511241/ref=nosim?tag=hartworkscom-20&link_code=as3&creativeASIN=0816511241&creative=373489&camp=211189

Buildings of Earth and Straw: Structural Design for Rammed Earth and Straw-Bale Architecture

by Bruce King

http://www.amazon.com/dp/0964471817/ref=nosim?tag=hartworkscom-20&link_code=as3&creativeASIN=0964471817&creative=373489&camp=211189

Earth Construction Handbook: The Building Material Earth in Modern Architecture

by Gernot Minke

http://www.amazon.com/dp/1853128058/ref=nosim?tag=hartworkscom-20&link_code=as3&creativeASIN=1853128058&creative=373489&camp=211189

Earth Building

by Laurence Keefe

http://www.amazon.com/dp/0415323223/ref=nosim?tag=hartworkscom-20&link_code=as3&creativeASIN=0415323223&creative=373489&camp=211189

The Good House Book: A Common-Sense Guide to Alternative Homebuilding

by Clarke Snell

http://www.amazon.com/dp/1579902812/ref=nosim?tag=hartworkscom-20&link_code=as3&creativeASIN=1579902812&creative=373489&camp=211189

Earthbuilders Encyclopedia: The Master Alphabetical Reference for Adobe and Rammed Earth

by Joe Tibbets

http://www.amazon.com/dp/0962188506/ref=nosim?tag=hartworkscom-20&link_code=as3&creativeASIN=0962188506&creative=373489&camp=211189

Rammed Earth Structures: A Code of Practice

by Julian Keable

http://www.amazon.com/dp/1853393509/ref=nosim?tag=hartworkscom-20&link_code=as3&creativeASIN=1853393509&creative=373489&camp=211189

Websites:

EarthArchitecture.org

<http://www.eartharchitecture.org/>

Features information on earth building, books, and workshops.

Rammed Earth Blog

<http://rammedearth.blogspot.com/>

Very informative blog features case studies and construction photos.

Terra Firma: Earth Building Company

<http://www.earthhomes.com/>

Terra Firma Builders

<http://www.terrafirmabuilders.ca/>

References:

Easton, David. "The Rammed Earth House." White River Junction, VT: Chelsea Green Publishing Company, 2007.

Minke, Gernot. "Building with Earth: Design and Technology of a Sustainable Architecture." Basel: Birkhauser-Publishers for Architecture, 2006.

Terra Firma Builders. "Portfolio, Healthy Home Features and Specifications," <http://www.terrafirmabuilders.ca/Portfolio/envirohome-features.html>.