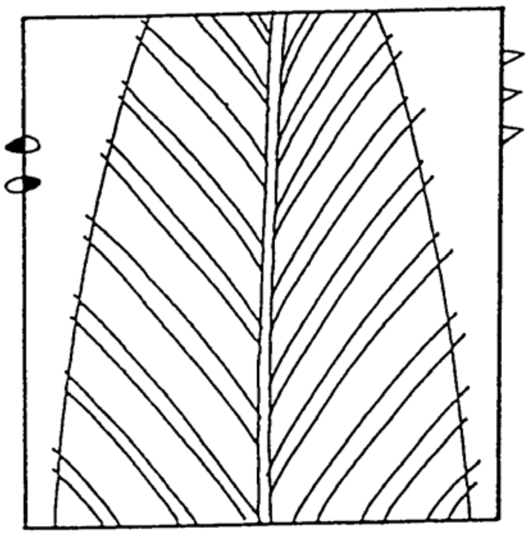
EARTH BUILDING



Waitakere City Council
Te Taiao o Waitakere

Contents

This chapter is part of the Waitakere City Council's Sustainable Home Guidelines. The complete set can be obtained through most libraries or from the Waitakere City Council, Private Bag 93109, Henderson, Waitakere City 0650, New Zealand, phone 09-839 0400, email: info@waitakere.govt.nz.

The guidelines are also available on the council's web site: http://www.waitakere.govt.nz

Earth building around the world

History and use

Earth is an ancient building material that has been used in many different ways around the world for thousands of years. A large part of the world's rural population still lives in earth buildings.

But earth building is not a phenomenon only of the developing world. In France around 15% of the population lives in earth-walled houses. In some regions of Australia such as Margaret River a considerable percentage of the houses are built with walls of unfired earth.

In western countries thousands of luxury earth homes have been built in the last few decades, which demonstrate the many qualities of this natural building material, and give the lie to any association with poverty and inferiority.

In New Zealand early European settlers applied traditional English techniques of earth construction – using predominantly wattle-and-daub, cob and mud brick in the South Island and rammed earth in the North Island. Pompallier House (1841) at Russell is a well-known example of rammed earth construction, which has stood the test of earthquake, storms, and time.

Earth building in New Zealand has undergone a revival in interest. This is reflected in the number of earth buildings that have been erected in the last few decades. There are more than 600 historic earth buildings in New Zealand, and an unknown number but probably several hundred 'modern' earth buildings (less than 30 years old) including a number in Waitakere City.

'Broadgreen', Nelson , a cob mansion built in 1856. Despite breaking many of the design detailing rules for earth building, it has been maintained well, and has survived two major earthquakes without a crack.

Why use earth for building?

Costs, eco-friendliness, aesthetics

Building with earth materials can be a way of helping with sustainable management of the Earth's resources. They can be put in place using simple machinery and human energy. Earth buildings avoid deforestation and pollution, and can achieve low energy costs throughout their lifetime – in the initial manufacture and construction, in their use as homes, and eventually in their recycling back to the earth.

Earth is more time-consuming than conventional design and construction, but for those who are providing their own labour, the time involved in earth construction may be less significant than the money cost of modern materials. Many people also value earth construction for its aesthetic qualities.

Advantages of earth building:
- low cost of materials
- low energy and transportation costs
- can be built personally by the homeowner
- thermal mass for natural heating by the sun
- maintains a balanced indoor climate without extremes of temperature
- a renewable non-toxic resource which can be readily recycled
- low fire risk, non-combustible
- virtually soundproof
- natural warm texture and colours
- allows expression of personal creativity using traditional crafts and skills
- can be shaped by hand into attractively rounded forms and niches
- variable light quality reflected from moulded and textured surfaces

Disadvantages of earth building:
- time and expense required for soil testing, calculations, and reports
- requires more customised design effort
- design limitations, e.g. wall heights, the size of openings for windows and doors, or necessary roof overhangs to provide weather protection
- construction period longer and also weather-dependent
- higher overall contract cost unless you use your own labour

Will my earth home last?

Durability and structural strength, standards

Because earth lacks the consistency and hardness of many manufactured building materials, you need to protect it from the elements. Generally this means by design elements of the building like generous roof overhangs.

While earth construction has reasonable compressive strength, it has relatively low tensile strength to resist the sort of tearing-apart forces that occur in an earthquake. For this reason, walls often need reinforcing and must be designed to minimise tensile stresses – with careful placement of window openings, for instance.

New Zealand's driving rain and high earthquake risk pose a particular challenge. Nevertheless earth architecture can be built to meet the highest standards of structural safety and all the requirements of the New Zealand Building Code. To this end, Standards New Zealand has produced a set of standards for earth buildings – the first comprehensive set of standards of this nature in the world:

> NZS 4297: 1998 *Engineering Design of Earth Buildings*
> NZS 4298:1998 (incl. amendment #1) *Materials and Workmanship for Earth Buildings*
> NZS 4299:1998 (including amendment #1) *Earth Buildings Not Requiring Specific Design.* At the time of writing, the DBH is considering a new Acceptable Solution to further amend NZS 4299, to provide means of compliance with the Building Code with respect to external moisture.

The Standards cover only those techniques that have been well investigated during the renaissance in earth building in New Zealand during the last 25 years. They also contain some information on other methods like cob, in which interest is now being shown.

Steps to an earth building

The design and construction process

The process of earth building usually involves the following steps, not always strictly in this order:

1. Identify the building site and check its suitability for a relatively heavy type of building.

2. Select a preferred earth-building technique (this depends partly on available soil types and partly on the finished appearance you want).

3. Consider the suitability of soils on the site or nearby.

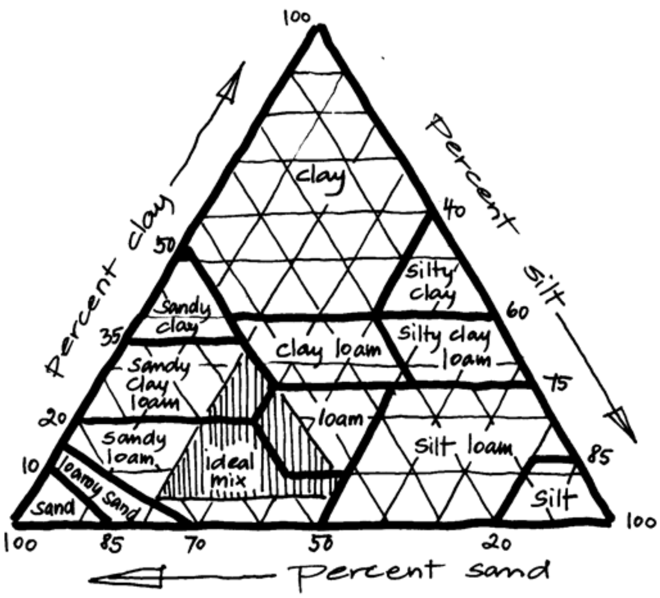
4. Carry out field tests of possible construction soils to check their suitability for the preferred earth-building method. Modify the preferred method if necessary.

5. Prepare suitable samples of earth material and carry out pre-construction testing. Modify the earth material mix as required.

6. Design the building and obtain a building consent from the council.

7. Carry out site work and building construction, including quality control testing as required.

8. Obtain a code compliance certificate from the council.



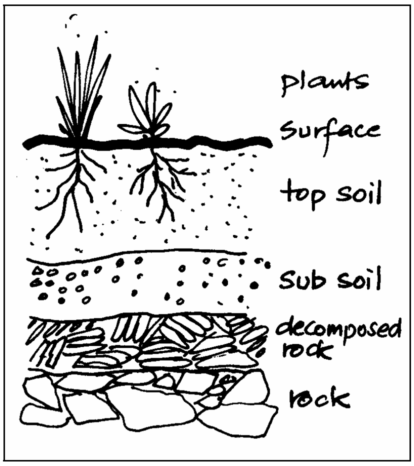
Soil types - the ideal earth building mix falls within the shaded area

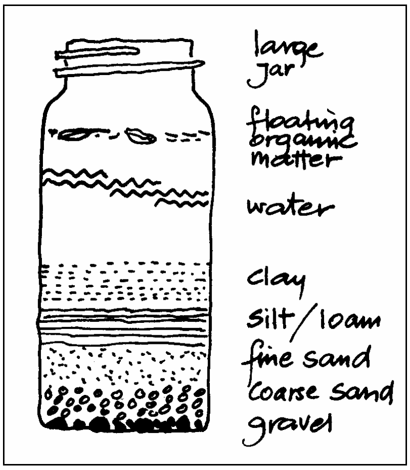
The right earth for the job

Clay content, soil testing

The crucial feature of the soil used for earth building is the clay content. Clays are the smallest soil particles, and it is these which provide the cohesion and waterproofing of the wall. The earth material must contain at least 5% clay to achieve bonding strength. On the other, hand clay swells and shrinks with changes of moisture level, so more than 50% clay content is likely to be unmanageable. Some clay can also be destructively water-reactive in some soils – clay is both the magic and the problematic ingredient in earth building.

Because earth walls are often made from the sub-soils that are available locally, there is a wide variability in the range of soils that are used. Testing for suitability is an important aspect of earth building. NZS 4298 describes the pre-construction tests required to test soil for suitability. These test for strength, durability, and shrinkage. Quality control testing is also explained. Most of these tests can be done with care by owner-builders rather than needing laboratory tests.





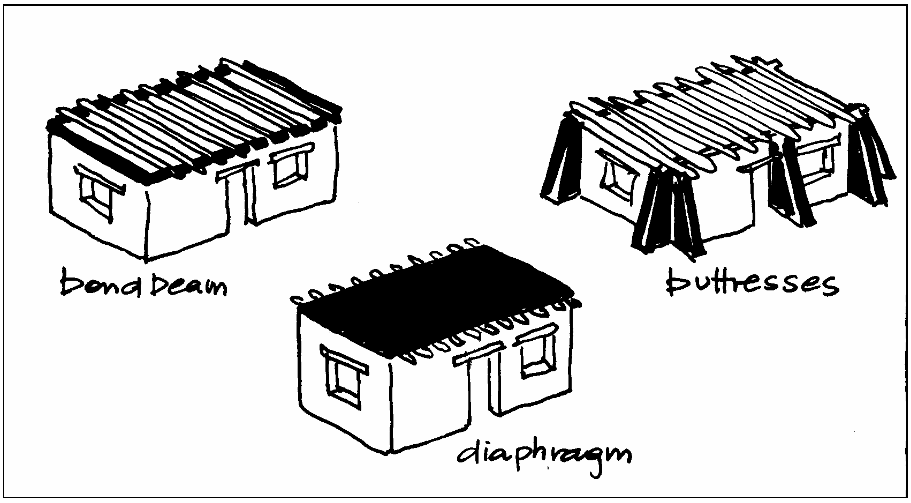
As a first simple test you can drop a handful of sub-soil into a jar of water in which a teaspoon of salt has been dissolved and shake it well. This is a gravity soil separation test. After 24 hours it will separate into layers of -- from the top:

- organic matter (which you don't want),
- the water
- clay 5 to 50% desirable
- silt 20 to 55%
- sand 45 to 80%
- gravel which you can sieve out

This will give you some idea of the proportions of your sub-soil. It is very inaccurate but gives a rough idea of the components. You can modify unsuitable soils or clays by blending or adding sand, gravel, straw, or other clays. However, different earth-building techniques require different soil mixes, so before you begin detailed testing, you should be thinking about that.

Designing an earth building

Structural strength, earthquakes, durability, solar design



Any architectural design should take account of the limitations of the building materials and techniques. Earth is a heavy, fairly low-strength material so it is used to make thick walls of limited height. The upper storey, if any, is usually confined to an attic within the roof space. It helps to have a light roof structure, and to keep window and door openings fairly small and away from the corners of the building.

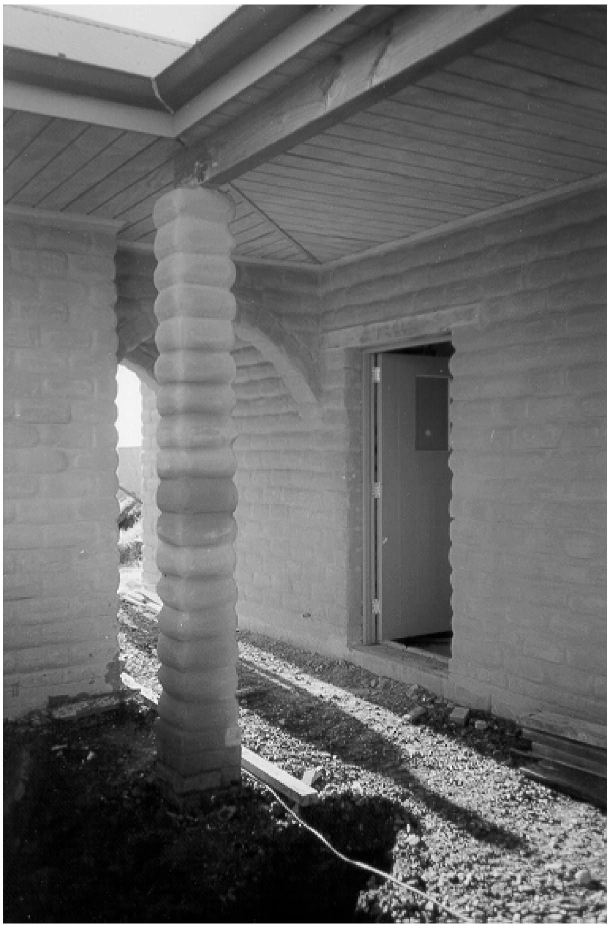
A roughly symmetrical structure will behave more predictably in an earthquake. Small simple buildings can be designed according to the conservative approach set out in NZS 4299 (*Earth Buildings Not Requiring Specific Design*). A more adventurous design will require the engineering analysis outlined in NZS 4297 (*Engineering Design of Earth Buildings*).

Earth buildings require stable sites which do not flood and which ideally provide some weather protection from the erosive effect of driving rain. Adequate weather protection is very hard to achieve on sites with extreme wind, like some of Auckland's West Coast beach settlements.

Earth building design has been adapted to the climatic conditions here in New Zealand. The traditional earth-building requirements for 'good boots and a good hat' are even more important in New Zealand. Foundations that prevent splashing and rising damp, and generous eaves or verandas are essential. It is crucial to refer to NZS 4299 Section 2.10 early on in the design process to ensure good weather protection.

Earth walls are thick enough to meet the insulation required in this part of New Zealand (under NZS 4218: *Energy Efficiency - Small building envelope*). And earth, because of its mass, acts as a 'thermal flywheel,' balancing out extremes of temperature.

However, the presence of large eaves and small window openings works against solar heat gain. An experienced earth-building architect can assist with a design that works not only for structure and durability, but also for passive solar design and an aesthetic treatment worthy of an earth building.



Roofs and floors

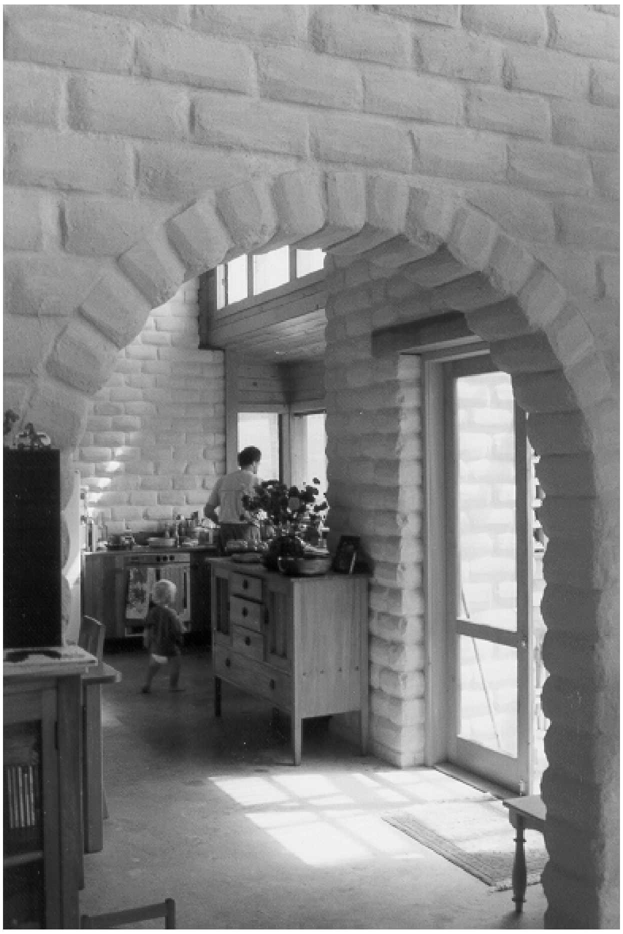
Vault or dome structures enable whole spaces to be enclosed with little material other than earth. However, such roof structures would be difficult to design for earthquake loading except over a very small space.

An alternative is to cover a specially designed roof structure with a layer of planted or grassed earth. This can integrate a house both visually and ecologically into its natural landscape. It is also heavy, however, and it is asking quite a lot of earth walls to hold up an earth roof.

Earth roofs are not covered by the Earth Building Standards, and because of the engineering required to hold up heavy roofs of this nature, it takes professional advice to design them.

Earth floors are usually made from mud bricks, pressed bricks or poured earth. As with all in-situ techniques, shrinkage is a vital issue. You need to find some method of dealing with the cracks, whether by simply filling them as they occur, or laying the material in a way that will control shrinkage.

The Earth Building Standards (NZS 4298) has a section on earth floors for guidance.



Choosing the earth-building technique

A great variety of earth building techniques has evolved in different parts of the world in response to local soil, weather and earthquake conditions. You need to consider which building process you will use – whether the walls are to be built in-situ or made into bricks first, and whether you will employ a contractor or do the building yourself.

Different techniques also give quite different opportunities in terms of the shapes you can build, the degree to which you can sculpt the walls, and the appearance of the finished walls. However, once the material is in place in the walls, it tends to act in much the same way in terms of structural and practical performance.

The Earth Building Standards have been written to accommodate the most popular forms of earth buildings currently used in New Zealand: rammed earth, poured earth, adobe or mud brick, and pressed brick. Two methods currently being explored in New Zealand – in-situ adobe and cob – are discussed in a less rigorous way.

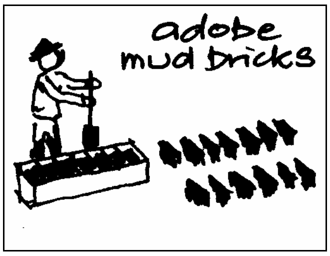
Cob, an old technique, is being revived and used again as advances in engineering analysis (largely as a result of the standards writing collaboration) enable rational engineering solutions to be applied to these structures.

Other methods are not included because they are not currently used, are experimental, or there is insufficient data available to 'standardise' the construction. Nevertheless, there are promising experiments with reinforcing materials like recycled paper fibre, and many of our earth buildings that have stood the test of earthquake, storms, and time are built of systems not currently used, like wattle-and-daub, mud-and-stud, or post-and-beam.

You may still be able to obtain a building consent for one of these alternative techniques; check with the council.

The required testing procedures for the various techniques of earth building are contained in the Standards. The following sections outline the basic characteristics of each technique.

Adobe (mud bricks)



Mud brick or adobe building is an ancient technique dating back at least to Jericho (8300 BC). The oldest continually inhabited structures in the world are adobe. Some built in North America around 900 years ago are still in use.

Mud bricks are probably the simplest and easiest form of earth building. Most of the shrinkage takes place in the brick itself before the walls are built, so shrinkage cracking is much less of a problem. The bricks can be cast from a greater variety of soils, and can cope with more clay content than is suitable for the in-situ techniques.

You cast mud bricks in open moulds on the ground, using a blend of earth, aggregates, straw and water, with the consistency of cake mix. You can withdraw the moulds either straight away or the next day.

Once they are firm enough you lift the bricks onto their sides, trim them, and then stack them to air dry and cure. You can cast different shapes of bricks to create wedges for corners or arches, 45-degree corners, or rebates for jambs. You can cut holes in newly cast bricks for reinforcing or services.

You lay the bricks up into the wall with a mortar similar to the brick consistency, although modified sometimes for shrinkage and workability (often by adding sand).
The finished walls are bagged as they are laid, a practice whereby the mortar mix is rubbed thinly into and over the walls to fill in gaps and cracks.

Often a mud render is applied as a surface coating. This coating will sometimes have a dust retardant in it – a traditional and successful mixture uses clay and sand mixed with fresh cow manure or paper fibre. You can also use wallpaper size or boiled linseed oil as an anti-dust protector. The wall surface tends to be a bit uneven unless plastered. It has a "soft" look, although the material is quite hard when dry.

Sometimes adobe bricks are stabilised with the addition of aggregates to improve durability. Mortar shrinkage is more of a problem with this type of construction than shrinkage of the bricks themselves. The necessary tests for adobe bricks and mortars are detailed in NZS 4298.

New mixes for mud bricks using wood fibres and paper (cellulose) pulp are making very robust bricks that are less dense, giving bricks with much better insulation properties than dense bricks. Similar mixes are also proving very good for cob mixes. Manufacturers are setting up to make mud bricks in the Auckland/Northland region.

Stabilisers

Several of the earth building techniques discussed here rely on additives such as cement, lime or asphalt as stabilisers of the clay particles and even, sometimes, as the major binding agent. Earth building relies on the binding effects of clay to hold material together. If a building technique does not use the binding action of clay as part of the process or finished product, then it is not earth building. However, the reaction between clay and water can be of concern with some soils, so the use of some form of stabiliser may be necessary to give adequate performance. These stabilisers may take the form of aggregates or other natural additives. There is some controversy in earth building circles about the use of energy-intensive stabilisers such as cement in earthen materials, to make what may be regarded as poor-quality concrete. One reviewer of this page *(Graeme North)* said: "My major conclusion, after 35 years in the business, about the use of stabilisers is this: *If you are building in an area where good earth building can be done with unstabilised material then there is no reason or possible excuse for using stabilisers."* For further discussion see http://www.ecodesign.co.nz/mudBrickCob&Stabilisers.shtml

Rammed earth (pisé)

Rammed earth (or pisé) is an ancient technique that has been dated back to at least 7000 BC in Pakistan. It has been used in many structures around the world, most notably in parts of the Great Wall of China. Although most earth buildings are single- or two-storied, a five-storey hotel was built in Corralben, Australia.

Rammed earth walls are formed from soil that is just damp enough to hold together. The soil is tamped between shutters with manual or pneumatic rammers. The mix is dry enough that once the material is rammed into place and a wall panel completed, the shuttering can be removed immediately. Rammed earth walls are limited to the shapes that can be built with removable shuttering, so the building should be designed to make practical and effective use of the available shuttering.

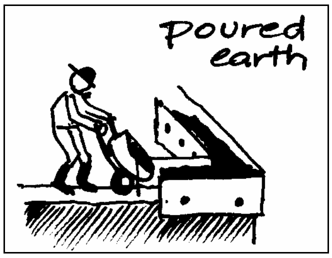
The walls are often left as they are, 'off the form,' and can reveal a natural-looking strata pattern from the ramming process. Consistent workmanship is critical for both the appearance and the strength of rammed earth walls, so site work has to be of high quality. An area of wall that is not mixed or rammed correctly can ruin a whole panel.

One difficulty with the rammed earth method is that strict limits have to be placed on shrinkage to eliminate cracking. Many soil types need sand to be added to reduce shrinkage. Pre-construction tests for shrinkage and the appropriate limits are detailed in NZS 4298, which also outlines compression and durability tests, and a simple on-site test for moisture content.

Often cement or hydrated lime is added to improve durability, but successful structures are built using suitable soils without such additives. A sandy crumbly soil (with a clay content around 15-30%) is best, as it is easily worked and has minimal shrinkage.

The shuttering is best designed so that whole wall panels can be built in one go, thus eliminating joints within panels as much as possible.

Poured earth



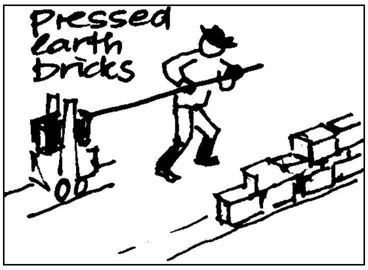
This technique involves mixing water with the earth until it can be poured it into moulds without creating voids – typically about cake-mix consistency. The mix is placed into moulds set up directly in place on the wall, and once it has set the mould is removed.

The mix used in this technique has much higher moisture content than rammed earth, so the shrinkage is potentially much higher. This means that the soil mix has to be carefully controlled to avoid unsightly and structurally damaging cracks opening up as the material dries. Sometimes the moulds are set up in a castle-like pattern, and the intervening gaps are filled with a second pour after some shrinkage has taken place with the setting of the first pour.

Shuttering systems developed in Australia are now available here. They limit the size of each poured earth section, and by controlling the sequence of pours fine walls can be created. The shapes of walls are constrained by the shuttering used, but they can be arranged quite flexibly. The surface of the work is often dominated by the size of the cast units, and is usually fairly smooth unless rubbed or modified after the shuttering is removed.

Often this technique uses around 10% cement in the product to assist with durability and shrinkage control. Appropriate tests for this technique are detailed in NZS 4298.

Pressed earth brick

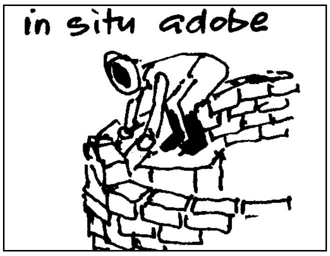


Pressed earth brick is one of the more modern additions to the earth building scene, dating from the 19th century. Making compressed earth bricks in manually or engine-operated presses is now a widespread practice around the world.

The bricks are made from a dry mix, often stabilised with up to 10% cement. The compression given by the machine compacts the soil particles together to make dense regular shaped bricks, usually around 300 x 300 x 130 mm in size. Most presses will enable some variety of shapes to be made so holes for reinforcing and rebates for window jambs can be pre-formed, but bricks of a different size are usually difficult to produce. The bricks can be produced on-site using a manual ram, or bought from a manufacturer. Earth bricks are currently being produced commercially in the Auckland region. Earth bricks with a high cement content trucked to your site don't score so well on the energy conservation scale.

Being hard, dense and regular, earth bricks can be laid up very precisely to form geometric shapes, or laid more loosely depending on the aesthetic results required. These bricks are the nearest thing in earth building to concrete blocks in design and finish considerations.

You can sometimes use a sand/cement/earth mix for the mortar, although often a mix of hydrated lime, cement and sand performs better. Necessary tests are detailed in NZS 4298.



In-situ adobe

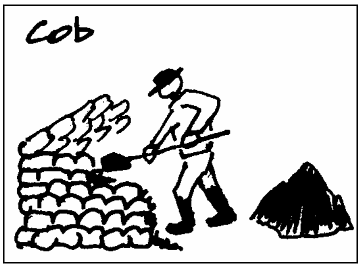
Very free-form walls are possible with this technique, and the surface finish can vary enormously depending on the skill and whim of the craftsperson doing the finishing work.

You use a wet mix about the consistency of stiff cake mix, and cast it into place in a wall using a small sheet metal mould (typically about 300 x 300 x 150 mm high). The mould is removed immediately and the brick is 'worked' against previous work to create good bonding and to give the desired surface finish.

Once again, shrinkage is the critical issue, although the working and compression of the brick's surface as it dries overcomes some of the material's shrinkage. Again, cement, hydrated lime or asphalt additives are often used.

Strict limits have to be placed on shrinkage to eliminate cracking. Suggested pre-construction tests for shrinkage and the appropriate limits are given in an appendix to NZS 4298, but lack of experience means that definitive 'standards' are not yet appropriate with this technique.

Cob

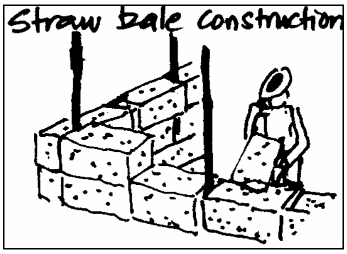


Cob is an old technique that offers the potential to create very sculptural wall shapes. Many of the old cob cottages in the South Island have survived from the last century.

For cob construction you mix straw and often small gravel into a sandy soil. You form the mixture into lumps or cobs, which you then throw on to the wall and stamp or work into the previous layer. The rough surface is later trimmed up, and usually rendered to give a smooth surface. The result is often a softly undulating surface, which can follow whatever shape you choose to build into the wall. Cob builds extra thick or curved walls easily, and it is common for them to taper inwards towards the top.

This technique is also very shrinkage-sensitive and a mixture has to be found that minimises shrinkage. Because of the comparative lack of modern experience in New Zealand with cob, it is included in the Earth Building Standards only as an informative section, so careful analysis of materials and design is required. However, many successful cob buildings have now been built and the use of other fibres such as wood and cellulose, or aggregates such as pumice is proving useful to make less dense and better insulating walls than traditional cob mixes.

Strawbale construction



Strawbale houses have enormously good insulation values, and you can build them with relative ease and speed. They may be load-bearing, but more often they incorporate a post-and-beam frame. The bales are finished with a coat of plaster – often earth-based.

The design issues are similar to earth buildings, but the need to avoid moisture and weathering is even more crucial. The bales must be dry before installation and remain dry throughout their life, as once wet they are more likely to compost than dry out. The construction detailing and plaster coatings make or break straw bale construction.

Straw bale houses were developed in America and are rising in popularity. However the Earth Building Standards Committee declined to write a strawbale standard at this stage because of the very small number of built examples in New Zealand or Australia to "standardise". If you wanted to build a strawbale house you would need to engage an experienced designer, and do the analysis to apply for a building permit as an "Alternative Solution" under the Building Code. Some councils use the following paper as a guide: http://www.ecodesign.co.nz/strawbale.shtml

Other types of construction

The following construction techniques are very common historically, and are experiencing a revival in parts of Europe. Although well-maintained New Zealand examples have stood the test of time, the techniques are seldom used here nowadays and are not covered by the New Zealand Standards.

Light earth involves tamping a clay mix containing a lot of straw or other fibres and/or light weight aggregates such as pumice or scoria into a timber or post–and-beam framework and then cladding or plastering both faces. This method uses the good insulation qualities of the aggregates and gives it the fireproofing of clay. The drawback is that the timber framework can require quite a lot of timber and the material needs a water resistant cladding or plaster of some kind and an internal plaster finish. The end result is that the earth/straw mixture is acting mostly as a form of insulation. A post and beam structure can allow the erection of the protective roof first, and light earth mud bricks can be pre-made and laid up quickly.

Wattle and daub starts with a lattice-work of light branches or timber. An earth/plaster mix is then "daubed" onto the lattice-work, forced into the gaps, and finished to give a serviceable surface.

In the **post-and-beam** technique, a timber structure is built first, and then earth wall panels, either of brick or monolithic construction, are built between the posts and beams. The earth is generally not load-bearing. This is a very practical form of construction – the roof can go on before the walls – but there may be some engineering difficulties with differential shrinkage and with achieving earthquake-resistant connections between the earth panels and the timber structure.

Surface finishes

There are a variety of surface coatings suitable for earth building, but none of them take the place of good primary weather protection achieved by good design, detailing and construction. And you cannot use a surface coating to improve the performance of any earth material in the durability tests outlined in NZS 4298.

Surface coatings are better viewed as aesthetic coatings rather than weather protection. They can also help with dust prevention (although this is not a concern with most earth mixes) and sometimes with localised waterproofing.

Hydrated lime or gypsum-based plasters or washes are usually most sympathetic to earth building and least liable to failure. An earth plaster that may incorporate sand and fibres such as chaff, paper pulp or cow dung (fresh) will offer a natural and durable finish. Cement based renders need careful application. They are not usually recommended, because without suitable mechanical fixing they can separate from the wall itself due to differential expansion and contraction, and they are not as breathable as other alternatives mentioned here.

Because of the wide variability of materials used in earth buildings, surface coatings appear in the Standards as information only.

An earth home designed by Graeme North

Further information

Advice at the Waitakere City Council:

Phone the call centre (09) 839 0400, ask for the Eco Design Advisor.

In print

Earth Building Standards are available from the Standards Association of New Zealand: (*Private Bag 2439, Wellington*), or from its website www.standards.co.nz:

NZS 4297 *Engineering Design of Earth Buildings*
NZS 4298 *Materials and Workmanship for Earth Buildings*
NZS 4299 *Earth Buildings Not Requiring Specific Design.*

Earth Building Association reference list

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Building with Earth	Minke	Birkhauser	2006
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Built by Hand	Steen, Steen, Komatsu	Gibbs Smith	2003
The New Strawbale Home	Wanek	Gibbs Smith	2003
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NZS 4298 Materials & Workmanship for Earth Buildings	Standards NZ	Standards NZ	1998
NZS 4299 Earth Buildings Not Requiring Specific Design	Standards NZ	Standards NZ	1998
NZS 4297 Specific Design of Earth Walled Buildings	Standards NZ	Standards NZ	1998
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Out of the Ground	Miles Allen	Dunmore Press	1997
The Rammed Earth House	David Easton, Chelsea Green		1996
Earth Construction, a Comprehensive Guide	Houben & Guillaud	IT Publishers	1994
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Adobe and Rammed Earth Construction	P McHenry		1984
Adobe, Build it Yourself	P McHenry		1984
The Passive Solar Energy Book	Edward Mazria	Rodale Press, Emmaus, Pa.	1979
A Pattern Language	Christopher Alexander et al.	Oxford University Press	1977

Buildings of Earth & Straw - Structural Design for Rammed Earth and Strawbale Architecture	Bruce King	
The Cobbers Companion	M Smith, Cob Cottage Co.	
The Cob Builders Handbook	Becky Bee	
Mudbrick Notes	Brian Woodward	Earthways NSW Aust.
Your Energy Efficient House	A. Adams, Garden Way	

On the web

http://www.earthbuilding.org.nz The website of the Earth Building Association of New Zealand. The Earth Building Association of New Zealand (EBANZ – *P.O. Box 1452, Whangarei,)* hires books and videos and organises displays of earth buildings, training, educational workshops, publications, research, testing and promotion. It also puts out magazines and you can subscribe to an e-news

http://www.smarterhomes.org.nz is a mine of up-to-date and independent information. Designed for the general public, it's easy to use, has case studies, and includes features such as Homesmarts, a calculator you can use to find information relevant to your needs or simply to run a home-health check.

If there are questions you can't find answers to on Smarterhomes, www.level.org.nz goes into more depth and is aimed at the design and building industries, with drawings and links to Building Code compliance documents.

Further information can be obtained from the contributing writer for this chapter of the Waitakere City Council's *Sustainable Home Guidelines*:

Graeme North - Registered Architect, chairman of the Standards New Zealand Technical Committee for Earth Building, inaugural chairman of EBANZ. http://www.ecodesign.co.nz

This website has a paper on the use of cement in earth and on moisture and strawbale building.

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