# Rammed earth

**Rammed earth walls are constructed by ramming a mixture of selected aggregates, including gravel, sand, silt and a small amount of clay, into place between flat panels called formwork.**

Traditional technology repeatedly rammed the end of a wooden pole into the earth mixture to compress it. Modern technology replaces the pole with a mechanical ram.

Stabilised rammed earth is a variant of traditional rammed earth that adds a small amount of cement (typically 5–10%) to increase strength and durability. Stabilised rammed earth walls need little added protection but are usually coated with an air-permeable sealer to increase the life of the material — it varies with circumstance. Thousands of unstabilised rammed earth buildings around the world have given good service over many centuries.

Most of the energy used in the construction of rammed earth is in quarrying the raw material and transporting it to the site. Use of on-site materials can lessen energy consumed in construction. Rammed earth gives limited insulation but excellent thermal mass.

Rammed earth walls are sometimes known as pisé walls — from the Latin origin *pisé de terre*. First used in Lyons, France, in 1562, the term applied to the principle of constructing walls at least 500mm thick by ramming earth between two parallel frames that were then removed, revealing a completed section of compressed earth wall. While 500mm thick walls can still be constructed if desired, with or without cement, most modern rammed earth walls in Australia are built using cement as a stabiliser and are typically 300mm thick for external walls and 300mm or 200mm for internal walls.

## Performance summary

### Appearance

The colour of rammed earth walls is determined by the earth and aggregate used. The ramming process proceeds layer by layer and can introduce the appearance of horizontal stratification to the walls, which can enhance the overall appearance. It can be controlled as a feature or eliminated.

Aggregates can be exposed and special effects created by the addition of different coloured material in some layers, and elements such as feature stones or objects, alcoves or relief mouldings can be incorporated into rammed earth walls, at a price. Unusual finishes can be achieved by including shapes in the formwork that can be released after the wall has been rammed.

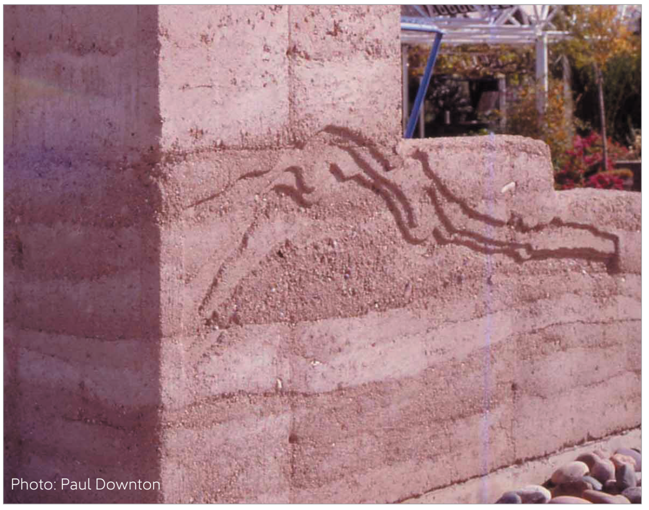
Photo: Paul Downton

Sample wall at the Environmental Research Laboratories in Tucson, Arizona.

Chamfered corners, which allow the walls to be easily released from the formwork, are visible. Brushed finishes help reduce formwork marks that can create a concrete-like appearance, but this is only necessary with fine grain size ingredients.


Photo: Paul Downton

Vertical curves can be formed by carefully ramming along a drawn guideline on the interior of the formwork. Horizontal curves are also possible but require specialised, and therefore expensive, formwork.

## Structural capability

Rammed earth is very strong in compression and can be used for multi-storey loadbearing construction. Research in New Zealand indicates that monolithic earth walls perform better under earthquake conditions than walls made of separate bricks or blocks. A five storey hotel in Queensland is built of stabilised rammed earth. Rammed earth can be engineered to achieve reasonably high strengths and be reinforced in a similar manner to concrete, although horizontal reinforcement is not recommended and excessive vertical reinforcement can cause cracking problems. (see *Construction systems*)

Interesting structural features, including leaning walls, have been constructed in rammed earth. Any difficulties associated with placing and ramming around reinforcement can be eased by careful management of the construction process and need not add significantly to the cost.

Perth rammed earth home.

## Thermal mass

Rammed earth behaves as heavyweight masonry with a high thermal mass. Thermal mass absorbs or 'slows down' the passage of heat through a material and then releases that heat when the surrounding ambient temperature goes down. All other things being equal, a high mass building such as rammed earth remains close to the 24 hour average for the time of year: in many climates this may be too cold or warm for comfort. If heating or cooling is required, the walls need to be insulated to limit energy consumption.

Used correctly, and in the right climate, the thermal mass of rammed earth can delay heat flow through the building envelope by as much as 10 to 12 hours and can even out daily temperature variations.

Rammed earth walls become effective when the difference between day and night outdoor temperatures is at least 6°C. Where the diurnal range is greater than 10°C, appropriate design can exploit the high thermal mass of rammed earth to very good effect. (see *Thermal mass*)

In cool or cold climates well-located rammed earth walls (e.g. feature walls within a well-insulated envelope) can supply a battery of useful thermal storage. Rammed earth is not recommended for tropical climates where high mass construction can cause a house to hold too much heat and cause thermal discomfort. (see *Thermal mass*)

Building energy efficiency rating tools such as AccuRate include the capability to simulate the combined effects of wall mass and insulation, and also allow comfort in extreme weather conditions to be reviewed, so the building's performance can be optimised.

## Insulation

Insulation is about stopping heat passing through a material rather than slowly absorbing or releasing it. As a corollary to its high thermal mass, rammed earth has limited thermal insulating qualities — similar to an uninsulated fibre cement wall.

Insulation can be added to rammed earth walls with linings but, as a general rule, a 300mm rammed earth wall will not meet Building Code of Australia (BCA) requirements for external wall insulation. Hybrid buildings that use insulated framed external walls with rammed earth internal walls and feature elements can achieve high insulation and high mass.

Under certain design criteria (i.e. simple rectangle with north-facing glass) and in moderate (not temperate) climates, it was just possible to meet the NatHERS overall five star performance standard; however, six stars are now the mandatory minimum under the BCA. (see *Insulation*)

Insulation can also be added within the thickness of a rammed earth wall but this adds to its cost and changes the structural properties of the wall. However, it does provide the benefits of both excellent thermal mass and good thermal insulation in the one wall while retaining the desirable look, texture, feel, acoustics and low maintenance properties of the facing of rammed earth on each side.

The best location for insulation when used in conjunction with rammed earth is on the outside face of the wall, so that the thermal mass is within a contained and controllable external envelope. (see *Passive solar heating; Passive cooling*)

## Sound insulation

One of the best ways to insulate against sound is have monolithic mass, which rammed earth provides very well. It has excellent sound reverberation characteristics and does not generate the harsh echoes characteristic of many conventional wall materials. (see *Noise control*)

## Fire and vermin resistance

There are no flammable components in a rammed earth wall and its fire resistance is thus very good. In tests by the CSIRO a 150mm thick Cinva-rammed earth block wall (similar to rammed earth) achieved a near four hour fire-resistance rating. There is no cavity to harbour vermin and nothing in the material to attract or support them so its resistance to vermin attack is very high.

## Durability and moisture resistance

The basic technology has been around for thousands of years and there are many rammed earth buildings still standing that are centuries old. Rammed earth does possess a generally high durability but all types of rammed earth walls are porous by nature and need protection from driving rain and long term exposure to moisture.

Maintain water protection to the tops and bottoms of walls. Continued exposure to moisture may degrade the internal structure of the earth by reversing the cement stabilisation and allowing the clays to expand. In general, rammed earth does have moderate to good moisture resistance and most modern Australian rammed earth walls do not require additional waterproofing. New water repellent additives that waterproof the walls right through may make rammed earth suitable for very exposed conditions, including retaining walls, but may inhibit the breathability of the material.

Photo: Rammed Earth Constructions Pty Ltd

Rammed earth lends itself to use with timber and natural materials.

## Breathability and toxicity

Provided it is not sealed with material that is impermeable to air molecules, rammed earth maintains its breathability. Finished walls are inert but take care in the choice of waterproofing or anti-dust finishes to avoid adding toxicity to the surfaces.

## Environmental impacts

Rammed earth has potentially low manufacturing impacts, depending on cement content and degree of local material sourcing. Most rammed earth in Australia uses quarried aggregates, rather than the 'earth' it is popularly thought to be made from. On-site materials can often be used but materials need to be tested for their suitability.

The embodied energy of rammed earth is low to moderate. Composed of selected aggregates bound with cementitious material, rammed earth can be thought of as a kind of 'weak concrete'. It may help to understand cement and earth products as being at different points on an energy continuum, with earth at the low end and high strength concrete at the high end. Its cement and aggregate content can be varied to suit engineering and strength requirements.

Although in principle it is a low greenhouse gas emission product, transport and cement manufacture can add significantly to the overall emissions associated with typical modern rammed earth construction. The most basic kind of traditional rammed earth has very low greenhouse gas emissions but the more highly engineered and processed variants may be responsible for significant emissions in their manufacture. For example, a 300mm rammed earth wall with 5% cement content has the equivalent of 15mm thickness of cement, equivalent to over 100mm of concrete (which mainly comprises sand and aggregate).

## Buildability, availability and cost

Rammed earth is an in situ construction method. Although its buildability is good, formwork for rammed earth demands good site and logistics planning to ensure that other trades are not adversely affected in the building program. Services should be well planned in advance to minimise difficulties. After walls have been rammed in place, conduits for pipes and wires can be provided much as in other masonry construction, but may impact on surface finishes.

Basic materials for rammed earth making are readily available across Australia, but cement and formwork may have to be transported long distances, increasing environmental and economic costs. Testing of local aggregates and potential mixes is essential if not using a proprietary system.

Proprietary approaches to rammed earth help guarantee consistency and predictable performance but come at a cost. The cost of a professional rammed earth building is comparable to other more conventional good quality masonry construction, but it can be more than twice as expensive as a rendered 200mm wide AAC block wall. (see *Autoclaved aerated concrete*)

Rammed earth is particularly well established in Western Australia and is thus an economical option in that state. Most states have experienced builders who understand its potential and limitations but because it is not a common construction material outside of WA its relative rarity and specialist nature tends to be reflected in its relatively high cost. It typically requires high levels of control over material sourcing and batching, and expensive formwork. A key element in controlling costs is to design walls as simple panels and to avoid unnecessary complexity. Traditional rammed earth using human power for ramming and simple wooden formwork can be low cost (and low energy) but this is rarely a realistic option.

There are good networks in Australia including a broad based national organisation, the Earth Building Association of Australia (EBAA), which is a not for profit organisation 'formed to promote the use of Unfired Earth as a building medium throughout Australia'.

# Typical domestic construction

## Construction process

Stabilised rammed earth is made by compacting a mixture of gravel, sand, silt, clay (and often cement) between formwork in a series of layers approximately 100mm thick. The traditional rammed earth was just that, and was often dug from the same site as the building it was destined for, but the materials for modern stabilised rammed earth come primarily from quarries.

The modern process of making stabilised rammed earth is both labour intensive and highly mechanical, requiring the use of powered rams.

Photo: Paul Downton

Ramming the earth.

## Typical details

All structural design should be prepared by a competent person and may require preparation or checking by a qualified engineer. Qualified professionals, architects and designers bring years of experience and access to intellectual property, and can save house builders time and money as well as help ensure environmental performance. All masonry construction has to comply with the Building Code of Australia and Australian Standards. For example, all masonry walls are required to have movement/expansion joints at specified intervals.

## Footings

Conventional concrete slab or strip footings are generally used, subject to soil conditions.

## Frames and bond beams

Complex, more elaborately engineered structures may require reinforcement or frames that work in concert with the loadbearing capacity of rammed earth. Simple and commonly built rammed earth buildings do not.

## Loadbearing walls

Rammed earth has fair-to-good compressive strength and it is common to make rammed earth a loadbearing construction.

The rammed earth walls revealed.

## Formwork

Marine grade plywood and steel sheets are both used in making formwork, which is superficially similar to the formwork used for in situ concrete, but with its own specific requirements.

Propping and temporary stays are required in the construction process and these may impact on other site work if the structure includes elements other than just rammed earth. Walls are built in sections and the rise of each level of formwork is often visible in the final finish. As the wall rises it is possible to take out the lower portions of formwork provided the wall has set strongly enough.

## Joints and connections

Walls are built in panels of approximately 3.5m in length with flexible joints to comply with building rules requirements for masonry structures. When a wall consists of more than one panel a recess is built into the end of the first wall. The second wall then moulds into this to lock the walls together for lateral stability.

## Fixings

Most conventional masonry fixings work with rammed earth walls; they usually need to be set in at about twice the depth normally used for concrete.

## Openings

Openings can be made without lintels with spans of up to 1m in stabilised walls subject to strength and engineering requirements. Specialised formwork can be made to create features such as pointed arches or circular windows, and the formwork can often be reused.

## Finishes

The off-form finish of stabilised rammed earth generally requires no additional finish. A clear water-repellent coating may be needed in some instances and non-stabilised rammed earth walls should be protected by eaves, overhangs or render, as they are more prone to erosion. Walls can be wire brushed shortly after being released from the formwork to eliminate the visual impact of the joins between the formwork and achieve an appearance closer to monolithic sandstone. Selection of the ingredients for rammed earth also affects final appearance.

## References and additional reading


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