BRANZ

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EARTH BUILDINGS

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- Earth buildings in New Zealand use well-proven traditional construction methods while also taking advantage of the latest New Zealand-specific building technology.
- The three earth building standards were revised and expanded in 2020. Earth buildings have their own Acceptable Solution for external moisture (E2/AS2).
- Earth buildings typically use locally sourced materials that have low toxicity, are minimally processed and have very low embodied energy.

1 INTRODUCTION

1.0.1 Many countries have earth-building histories developed over thousands of years. In Aotearoa New Zealand, there are earth buildings from the 19th century that are still standing and in use (Figure 1). Earth-building methods have been adapted here into designs that perform well in climate conditions across the country.

1.0.2 Earth buildings have low greenhouse gas emissions throughout their lifetimes, from sourcing (generally done locally), manufacture, transporting, installation and maintenance to end of life, when earth materials are readily reused or recycled. With careful planning, it is possible to build earth houses that have low or net-zero carbon emissions.

1.0.3 If the earth walls are exposed to the building interior, their thermal mass can help maintain comfortable interior temperatures by storing and then releasing heat. Unsealed earthen materials also regulate the building's indoor humidity naturally. The materials are non-toxic.

1.0.4 Although earth construction is sometimes perceived as 'fringe' or 'alternative', it is a durable and resilient construction system. New Zealand standards for earth building were introduced in 1998 and revised and expanded in 2020. The standards state: "There has been no failure reported to date of any earth building built in accordance with this suite of standards."

1.0.5 Many experienced builders and tradespeople have skills that can be transferred to earth buildings. While the standards state that the skilled nature of earth building should not be underestimated, earth-building techniques are mostly relatively straightforward and readily taught. Specialist New Zealand-based architects, engineers and builders are available to advise.

1.0.6 Traditional techniques for building loadbearing earth walls include:

- adobe/mud brick – bricks are cast in open moulds on the ground and air dried
- cob – lumps or cobs are placed onto the wall, stamped or worked into the previous layer and trimmed before rendering
- rammed earth – a moist mix is compacted in thin layers directly into wall panels within a strong, movable and reusable boxing system
- pressed earth – bricks are compressed from a moist mix in manual or engine-operated presses
- poured earth (not so common) – water is added to an earth mix, which is poured into moulds set up directly in place on the wall, and the moulds are removed once the mix is set.

1.0.7 Earth materials with a dry density of 1,400–2,200 kg/m³ are termed heavy earth or heavyweight earth. These are traditional adobe, cob and pressed or rammed earth walls and also poured earth.

1.0.8 Low-density earth used in loadbearing adobe and cob structures uses more fibrous material or low-density

Figure 1. Earth building has a long track record in Aotearoa New Zealand. This cob cottage in Marlborough was built around the early 1860s and restored in the 1960s.

aggregates in the mix and has a density of 800–1,400 kg/m³. Low-density earth walls are easier to build, have better insulation values and can be carbon negative but should be plastered on both sides for serviceability as their surface may be more porous.

1.0.9 The light earth method (LEM) is very low-density and non-loadbearing. It is placed as an infill in structural timber wall framing and can provide thermal and acoustic insulation. The density of LEM earth walls has a range of 200–1,200 kg/m³.

1.0.10 Another traditional method of building using straw bales is covered in BRANZ Bulletin 530 *Straw bale construction*. One of the earth building standards, NZS 4299:2020 *Earth buildings not requiring specific engineering design*, has an informative appendix about straw bale building.

2 BUILDING CODE AND STANDARDS REQUIREMENTS

2.0.1 Council staff may have less experience processing building consent applications for this type of construction, so it is a good idea to involve the local council at an early stage.

2.0.2 As with all buildings, earth buildings must comply with the Building Code. In consent applications, pay particular attention to clauses B1 *Structure*, B2 *Durability*, C1–C6 *Fire safety*, E1 *Surface water*, E2 *External moisture*, E3 *Internal moisture* and H1 *Energy efficiency*.

2.0.3 Three New Zealand standards provide tests and results that can be used to demonstrate Building Code compliance in building consent applications. The standards were revised in 2020 to cover a wider range of materials and material densities of 200–2,200 kg/m³, to include lessons learned from the Canterbury and Kaikōura earthquakes and to introduce new sections on earth floors, earth and lime surface coatings and internal adobe brick veneers:

- NZS 4298:2020 *Materials and construction for earth buildings* sets out requirements for using unfired earth and is used in conjunction with the other two standards.
- NZS 4299:2020 *Earth buildings not requiring specific engineering design* covers single-storey earth walled buildings with a light roof and a maximum floor area of 600 m². It can be used for buildings of importance levels 1 and 2 – secondary structures and single family dwellings – in Table 3.2 of AS/NZS 1170.0:2002 *Structural design actions – Part 0: General principles*. The standard applies to earthquakes zones 1, 2 and 3 and wind zones up to and including very high. This standard is described (in the suite of standards) as "the earth building equivalent of NZS 3604 *Timber-framed buildings* but with its coverage limited to foundations, floor slabs and walls". If the building design falls outside the scope (defined in section 1.2 of the standard), consult a structural engineer familiar with NZS 4297:2020.
- NZS 4297:2020 *Engineering design of earth buildings* is for structural engineers, providing compliance pathways for buildings that are outside the scope of NZS 4299:2020. An example is if they have plan eccentricities and/or irregularities in their walls or structural and stiffness requirements for compatibility with other loadbearing elements in the building or they are more than one storey. NZS 4297:2020 covers earth walls not exceeding 6.5 m in height. Many of the structural design principles are similar to those of masonry and concrete, and it is assumed that users of this standard are familiar with design using those materials.

2.0.4 Acceptable Solution E2/AS2 provides a means of compliance for Building Code clause E2 *External moisture* for earth buildings that use NZS 4299. At the time of writing, E2/AS2 cites the 1998 version of the standards. The 2020 standards contain considerable revisions, a wider range of materials and more technical detail, and the engineering advice is more conservative, so consulting them is recommended. E2/AS2 2008 is incorporated into the 2020 standards.

3 SITE CONSIDERATIONS

3.0.1 Soil-bearing requirements are given in section 3 of NZS 4299:2020. Consider the location of the building carefully to avoid differential settling or movement after the building is constructed. Differential settlement can lead to cracks in the finished building or doors jamming.

3.0.2 NZS 4299:2020 states that water can severely damage adobe or lightly stabilised earth wall materials if they are inundated for long periods, so more care is needed in siting earth buildings than for conventional structures. Avoid building on a site where flooding could rise above the underside of the floor slab. Sea-level rise should also be considered when choosing a site. When considering a site, the standard recommends finding out:

- the height above the local river or stream flood level
- the location of flood paths on sloping ground
- whether the site has adequate drainage to prevent water accumulation
- if on a shoreline, the height of the site above the maximum sea or lake water levels combined with the maximum storm wave upwash.

3.0.3 The cleared ground under the floor should be level with or above the cleared ground outside the building for at least 1 m around the perimeter of the building.

3.0.4 The standards include considerations for seismic and wind bracing depending on the location of the site. For earth buildings built to NZS 4299:2020, the provisions for bracing to resist earthquake loads should meet or exceed the requirement for walls to resist wind loads. If in doubt, consult a structural engineer, especially if different earth building or other mixed wall building techniques are included in the same building.

3.0.5 The seismic bracing required will depend on the local earthquake zone rating and the subsoil strength. See section 4 of NZS 4299:2020 to calculate the seismic bracing demand for the building.

3.0.6 Wind loadings on heavy earth walls must be determined in areas likely to experience local wind accelerations, such as in exposed or mountainous areas or in valleys and gorges. Wind loads should be considered for light earth walls. Follow the procedure in NZS 3604:2011 *Timber-framed buildings* section 5.2 to calculate the total wind bracing demand.

3.0.7 You will need to consult a structural engineer if:

- the depth of compacted fill beneath a floor slab or foundation to the cleared ground will exceed 600 mm
- the site is in an extra high wind zone or earthquake zone 4
- local rainfall is likely to exceed 3,000 mm per year
- accumulated snow levels could exceed 500 mm depth at ground level.

4 DESIGNING FOR DURABILITY

4.0.1 NZS 4297:2020 makes a comment (C3.2.1) that "earth walls are particularly susceptible to moisture ... it is important that any design considers the need to protect earth walls from excessive moisture". The biggest risk is wind-driven rain.

4.0.2 Figure 2.1 in NZS 4299:2020 shows a flow chart to assist with durability design.

4.0.3 Roof overhangs of a minimum 600 mm all around the building are recommended to protect the exterior of the earth walls. These also provide shade in summer. See section 2.7 of NZS 4299:2020 for detailed calculations of roof overhangs. Additional weather protection can be provided by coating, but this is not a substitute for overhanging eaves.

4.0.4 There must be a damp-proof course between the foundation and the base of the earth wall.

4.0.5 The finished floor level inside must be a minimum 150 mm above exterior paved or unpaved ground.

5 WALL MATERIALS

5.0.1 Materials for creating earth walls and earth bricks are mixed thoroughly in proportions depending on the building technique. Materials include the following:

- Clay-bearing subsoils – clay minerals are essential for binding the materials together.
- Aggregate or filler – small gravel, course and fine sand added as necessary. Silt is also present in many subsoils.
- Water of potable quality.
- Admixtures and stabilisers – straw and other natural fibres such as wood shavings as well as sand and gravel. These control instabilities in the clay, improve the durability, control cracking and limit shrinkage during drying. The length of any fibres must be less than half the finished wall thickness.

5.0.2 Soils vary considerably across the country. It is essential to use earth that contains a reasonable amount of clay. All soils must be tested to ensure they are suitable for how they will be used in the building. The appendices in NZS 4298:2020 describe simple soil tests that can be performed on site to identify suitable soils, which are abundant in New Zealand. After a suitable soil has been identified, it is important to also test the materials created from it (bricks, mortar and plasters). Making test samples of wall panels can also be helpful.

5.0.3 Adding cement to mixes is not generally required. In recent practice, some earthen mixes were stabilised using cement (<15% by volume), especially mixtures with low clay content and a high proportion of sand. (More than 15% cement puts the mixtures outside the scope of the standards.) However, where possible, current expert advice is to move away from cement-stabilised earth as these mixes can fail and do not have the low-carbon or the same humidity-regulating benefits of mixes made without cement. If cement is used and there is virtually no clay in the mix, refer to the requirements of the masonry standard.

5.0.4 There must be adequate moisture in the mixture to bind the clay with the aggregate. Stronger earth building materials are created by taking appropriate care during mixing.

5.0.5 Earthen materials are weak in tension, so earth walls need reinforcement. The standards cover the use of steel rods and mesh and polypropylene mesh for reinforcement.

5.0.6 The thermal conductivity (k-value) of earth walls ranges with density from 0.1 to 1.36 W/m°C. The thermal resistance of an earth wall is proportional to its thickness and density. To calculate the R-value for earth walls, see NZS 4299:2020 section 2.8.1. Low-density and LEM walls are more insulating than heavy earth walls because they have higher levels of organic material or low-density aggregates inside them.

5.0.7 If you plan to use several earth building systems or other mixed wall building systems in the same building, specific design by an engineer will be required.

5.1 BRICK-BASED CONSTRUCTION

5.1.1 Adobe bricks are cast into moulds using a stiff but pourable mix. Pressed-earth bricks are made in manual or machine-operated presses and are often, but not necessarily, stabilised with cement.

5.1.2 Bricks should be fully cured and dried before use. The mortar used will generally be similar to the brick material. An exception is that sand/lime/cement mortars must be used for cement-stabilised pressed-earth bricks. Bricks are moistened before laying.

5.1.3 Adobe and pressed bricks can be cored (by drill or moulding) to provide space for vertical reinforcement or services.

5.1.4 A maximum of four courses of adobe bricks can be laid per day.

5.1.5 Low-density adobe walls (800–1,400 kg/m^3) should be finished with a hydrated lime plaster coating.

5.2 COB CONSTRUCTION

5.2.1 Cob construction involves lumps or cobs thrown onto the wall on continuous horizontal courses, stamped or worked into the previous layer, then trimmed and rendered. Cob can be shuttered to shape the vertical wall faces.

Adobe/mud brick walls under construction.

Most cob mixes must be left for at least 12 hours after first being mixed and then mixed again before using.

5.2.2 Cob can be added to the wall (generally at 200–300 mm per day) as long as the drying cob beneath can take the weight and not bulge. Cob is placed around vertical reinforcement as work proceeds, and horizontal reinforcement is placed in layers actively built during a day.

5.2.3 Low-density cob (800–1,400 kg/m³) should be finished externally with hydrated lime plaster and internally with earth plaster.

5.3 RAMMED EARTH CONSTRUCTION

5.3.1 Rammed earth walls are built one segment at a time directly onto the wall by compacting moist earth in 100–150 mm layers in strong boxing. These walls usually contain a lower ratio of clay than earth bricks used in adobe and cob methods to lower shrinkage rates. Portland cement may be added. These walls are built in panels.

5.3.2 Work with rammed earth materials is more involved than other earth wall techniques. It is important to maintain the correct moisture level just before compaction. Materials must be compacted to 98% of their maximum dry density. Different compaction methods can be used as long as the required level of compaction is reached. Boxing should be strong enough to resist ramming pressure.

5.3.3 For cement-stabilised rammed earth, the mix must be placed and rammed within 45 minutes if mixing the cement with water or damp earth. Older (stale) mixes may be repurposed in new mixes as long as they comprise 30% or less of the new mix.

5.3.4 Cracking may be caused by localised shrinkage or inadequate building practices. Uncontrolled cracks appearing on both sides exceeding 3 mm wide are not acceptable, and the wall panel must be replaced. The standards provide shrinkage limits and guidance on the placement of control joints to manage cracking.

5.4 POURED EARTH AND IN SITU ADOBE

5.4.1 For poured earth techniques, water is added to the mix until it is pourable into moulds directly on the top of the wall. The mix is worked to ensure there are no gaps or spaces. The top surface of the wall is well keyed and moistened to receive the next layer. In situ adobe is similar except the mix is stabilised by cement and the moulds used are smaller and brick-sized. Shrinkage control is critical for the success of these methods, and specialised boxing methods are often used.

5.4.2 Most soils should be soaked for 12 hours before moulding. Clay lumps larger than 12 mm should be removed. Aggregate materials can be up to 25 mm diameter. If cement is used, it is added just before the mix is placed. This must be used within 45 minutes of the cement coming into contact with moisture. Like rammed earth construction, stale mixes can be repurposed as up to 30% of a fresh mix.

5.4.3 A maximum height of 450 mm can be added per day. Moist cure each section over a minimum of 7 days by covering with fabric and keeping it damp.

5.5 LIGHT EARTH METHOD WALLS

5.5.1 LEM walls are built into loadbearing double-stud or thicker single-stud timber framing. The earthen material does not have a primary loadbearing role so footings are not required. At the base of the wall, timber bottom plates should be supported by a foundation designed to NZS 3604:2011. Appendix D of NZS 4299:2020 covers LEM construction. It gives information but is not mandatory.

5.5.2 The earth component of a LEM wall should be 150–300 mm thick and should have enough clay content to bind the mix together. The organic matter used can include the stalks of wheat and other cereal crops but should not include pea straw, hay or materials containing leaf matter, seed, visible decay or insects. Wood shavings and sawdust from durable tree species, reeds and hemp shiv can also be used.

5.5.3 The framing that is not exposed to the weather should be naturally durable timber or radiata pine treated to at least H1.2. The timber can be painted with asphaltic or other paint to reduce moisture taken up. This allows quicker construction as the timber members need to be dry before linings are fixed. For all earth walls, timber used for lintels, top plates and bond beams that is exposed to the exterior but protected by roof overhangs should be either heartwood of a naturally durable species or sapwood (including radiata pine) treated to H3.1. Lintels not protected by overhangs should be H3.2 radiata pine. Appendix D of NZS 4299:2020 includes a risk matrix for design to resist moisture in LEM construction.

6 WALL CONSTRUCTION

6.0.1 Earthen walls must be built to 280 mm minimum/450 mm maximum thickness (NZS 4299:2020) and be reinforced. Wall reinforcement can be provided by using vertical steel reinforcing bars and incorporating horizontal steel or polypropylene mesh built into the layers of the walls during the build.

6.0.2 Whether loadbearing or not, earthen walls must be built onto a continuously reinforced concrete footing, including under doors and windows, and be secured at the top by bond beams.

6.0.3 The concrete footing should be continuous around the perimeter of the building. The depth of the footing below cleared ground level should be at least 200 mm or 150 mm in firm weathered rock or 100 mm into rock. Footings should sit on good ground. They should always be level but can be stepped where needed.

6.0.4 A concrete or fired brick nib is provided at the top of the footing and capped by a damp-proof course or treatment on which the earth walls sit – see NZS 4298:2020 and 4299:2020 details.

6.0.5 The specifications for bond beams including connections depend on:
- the method used to build the earth wall (adobe, cob etc.)
- the earthquake zone where the building is located
- whether the walls connect to a structural diaphragm or not.

6.0.6 Do not build earth walls in temperatures below 2°C. Frost and sub-zero temperatures can damage the outer wall surface if not fully dry. Cover if damage from heavy rain or pooling water is likely.

7 COATINGS

7.0.1 The surface finish of exterior walls must shed water effectively but must also be permeable to moisture vapour. Applied coatings that trap or hold water inside an earth wall may affect durability and are not permitted. Most acrylic or latex paints are not suitable for earth walls. See NZS 4298:2020 section 8 for further details of suitable finishes.

7.0.2 Interior surfaces in kitchens, bathrooms and laundries that are likely to be splashed regularly must be fitted with impervious splashbacks. Surfaces adjacent to sanitary fixtures and appliances where there is a risk of splashing or contamination must be wipeable.

7.0.3 Outside of splash zones, as long as the ventilation meets the requirements of Building Code clause G4 *Ventilation*, earth surfaces inside a house are not required to be impervious to moisture and earth walls can be left uncoated. They are naturally hygroscopic, meaning they absorb excess humidity and release it when the air is drier. This means earth walls moderate indoor humidity naturally and condensation is unlikely to form on them.

7.0.4 Some types of earth wall can be dusty and benefit from a surface coating to improve serviceability. Lower-density walls, including LEM walls, low-density adobe and low-density cob, work better with a higher-density surface that will be harder wearing. These should have an exterior lime plaster and then lime, earth or gypsum plaster on indoor wall surfaces.

7.0.5 Options for external surface coatings include:
- earth plasters – traditional finishes for adobe and cob walls, usually applied in two to three coats
- bagging or rubbing a clay slurry into and over the surface – this is most suitable for adobe buildings as the coating is thin enough to retain the brickwork pattern underneath
- whitewash, limewash and lime plaster – care must be taken when applying lime over earthen materials – seek specialist advice.

7.0.6 For coatings on LEM walls, see NZS 4299:2020 Appendix D, section D7 *Plaster*.

8 INTERNAL BRICK VENEER

8.0.1 Internal adobe brick veneer can be applied to buildings constructed to NZS 3604:2011 with light wall cladding (Figure 2). Internal earth veneer can provide benefits of thermal mass and humidity regulation. They can be coloured and carved for aesthetic purposes.

Figure 2. Adobe brick veneer being added to an interior wall.

Colours and textures can be added using pigments and minerals in earthen plasters.

Half-height adobe brick veneer.

8.0.2 Internal adobe brick veneers have specific framing and installation requirements. See section 12 of NZS 4299:2020.

8.0.3 If the veneer includes pressed or cement-stabilised earth bricks, consult a structural engineer.

8.0.4 The standard does not support the use of external earth-brick veneers.

9 MAINTENANCE AND REPAIRS

9.0.1 When repairing earth walls, use the same material they were built from. Normal maintenance tasks include:
- repairing wall surfaces and/or coatings
- removing any moisture sources that could lift the moisture content of the earth walls – these may include plumbing or roof leaks, build-up of exterior ground levels, compromises in the damp-proof course and channelling of rainwater
- ensuring the shelter on site is maintained so that it provides similar protection to that present when the building was designed and built.

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