

# Appendix B

## Specification for rammed earth works

*This appendix sets out suggested details for inclusion in a specification for rammed earth works. It is not a complete specification, but concentrates on those aspects specific to rammed earth works. More general items, such as responsibility for documentation management, have not been included. The specification is accompanied by some commentary presented in italics.*

### **1 Scope of rammed earth works to be undertaken**

All rammed earth works shall be constructed with appropriate care, site control and supervision so that the minimum design requirements of this specification are met.

Construction is to include all rammed earth walls from and including the damp-proof course to the top of the rammed earth wall, including installation of holding-down anchors or ties and wall plates.

*This specification may choose to exclude the damp-proof course if installed within a plinth, and fixings such as wall plates and holding-down anchors or ties.*

### **2 Submissions to be made**

The rammed earth mix proposal, including details of soil particle size distribution (determined in accordance with BS 1377-2:1990<sup>[16]</sup>), soil plasticity (BS 1377-2:1990<sup>[16]</sup>), soil mineralogical analysis, heavy manual compaction test (BS 1377-4:1990<sup>[17]</sup>), drying shrinkage (Appendix A.3.4)\*, unconfined compressive strength (Appendix A.3.3), spray erosion resistance (Appendix A.3.7), and abrasion resistance (Appendix A.3.8). Details of test procedures and results to be submitted at least 1 month prior to rammed earth works starting on site.

*Spray erosion resistance and abrasion resistance may be considered optional items for inclusion in a specification.*

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\* Appendix number references are to the appendices in this guide *Rammed earth: design and construction guidelines*.

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**3 Tests to be undertaken by the rammed earth contractor during construction**

*These tests are undertaken to demonstrate compliance of the materials with the specification requirements. These requirements will have been established during initial testing of materials prior to construction.*

Test	Frequency
Particle size distribution	As noted in Section 2 and when material or source is varied
Unconfined compressive strength	<i>To be specified by engineer</i>
Moisture content	<i>To be specified by engineer</i>
In-situ bulk density	<i>To be specified by engineer</i>

*In-situ tests, using sand replacement or another accepted method, may be undertaken to check achieved dry density, though excavation-based methods are very difficult to do without risk of damage to rammed earth works. Indirect methods for assessing quality of works include surface rebound hardness testing such as the Schmidt hammer.*

**4 Notice to inspect**

The contractor shall give at least 48 hours' notice to allow the opportunity to inspect the following:

- (a) Damp-proof course installation
- (b) Construction joints
- (c) Flashings installation

Joints in damp-proofing membranes must be lapped or sealed against moisture penetration. Damp-proofing and flashings should not be breached during construction. Any breach or damage shall be made good. Where necessary to prevent moisture ingress, flashings must project at least 25 mm from the face of the wall.

**5 In-situ rammed earth mix and supply**

Details of the rammed earth mix design(s) must be submitted, by the supplier, to allow a minimum of 1 month for approval.

Materials on site should be handled and stored in a way that ensures that their performance is not impaired. Any materials that have deteriorated sufficiently to impair their performance should be rejected.

**5.1 Compressive strength**

The mix shall achieve a minimum characteristic unconfined cylinder dry compressive strength of  $\square$  N/mm<sup>2</sup> (*strength to be specified by engineer*). Cylinders shall be prepared and tested in accordance with Appendix A.3.3.

**5.2 Mix constituents**

The rammed earth will contain no additives or admixtures (*unless agreed by the engineer*).

The soil grading curve shall meet following limits:

Sand + gravel content	45 to 80% (by mass)
Silt content	10 to 30% (by mass)
Clay content	5 to 20% (by mass)

The maximum aggregate size shall not exceed 6 mm (or 10 mm, 20 mm, 25 mm, 38 mm or 50 mm) (*as specified by the engineer*).

The material shall have a combined organic matter, soluble salt and other deleterious matter content not exceeding 1–2% (*as specified by the engineer*).

The material shall be properly mixed to provide an even and consistent material. Mix proportions of all materials should comply with those specified. Methods used to measure materials should ensure that specified proportions are controlled. Mixing should ensure that all ingredients are evenly distributed throughout the mixture.

**5.3 Moisture content**

The moisture content for the rammed earth at time of compaction shall be within  $\pm 1-2\%$  (*as specified by the engineer*) of the agreed optimum moisture content for compaction and handling. A heavy manual compaction test shall be undertaken to determine the optimum moisture content at least 1 month before the start of work. The moisture content shall normally be regularly checked (*ie by drop test, micro-wave oven or carbide meter*) to ensure a consistent and uniform material throughout construction.

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5.4 Drying shrinkage

The drying shrinkage of the rammed earth, measured in accordance with Appendix A.3.4, shall not exceed 0.1% (or 0.2%, 0.5% or 1%) (*as specified by the engineer*).

5.5 Material supply

*In contracts where some or all of the materials are imported.*

The name and address of supply depot(s) is to be submitted before delivery of the material. All delivery notes are to be retained for inspection.

**6 Testing and certification of materials**

6.1 Recording

Representative location of specimens prepared and submitted for testing shall be recorded.

6.2 Test laboratory

All material testing shall be undertaken by an approved laboratory.

6.3 Sampling rates

The rate of materials sampling for testing of the following parameters shall be specified by the engineer: unconfined compressive strength; moisture content at compaction; in-situ density test; drying shrinkage; grading.

6.4 Compression test specimens

Cylinders shall be prepared and tested in accordance with Appendix A.3.3. Cylinders that break during preparation or fail to meet specified requirements shall be retained for inspection.

6.5 Failures

If a rammed earth sample fails to achieve specified requirements following construction or testing, inform the engineer and submit:

- confirmation of the validity of the test results, and
- proposals for further tests, or
- proposals for rectification.

Obtain approval of all such evidence and proposals before proceeding.

**7 Placement and compaction**

## 7.1 Preparation

At time of placement, all surfaces, including shuttering forms which rammed earth is to be compacted against, shall be clean and free of debris and excess water.

## 7.2 Transportation

During transport of rammed earth from mixing area to site for compaction, avoid contamination, segregation, loss of ingredients and excessive evaporation. Cover rammed earth during heavy rain.

## 7.3 Placement

Place loose prepared material in the formwork in courses of even and controlled depth. The maximum depth of loose material is not to exceed 150 mm.

Cold joints between lifts should be protected from excessive drying and scarified before proceeding with further works.

Record the time, date and location of all rammed earth works. During compaction ensure that the temperature of rammed earth does not exceed 30 °C or fall below 5 °C. Do not place against frozen or frost-covered surfaces. The rate of construction should be regulated to minimise risk of deformation or instability.

## 7.4 Compaction

Rammed earth material is to be fully and properly compacted, taking especial care around inserts, formwork corners and at joints. The rammed earth should achieve a minimum dry density of not less than 98% of the heavy manual compaction test maximum dry density.

**8 Drying and protection**

## 8.1 Drying

Protect walls in cold weather from frost damage throughout the drying period. Detailed records of the location and timing of compaction of individual batches, removal of shuttering and removal of coverings are to be maintained on site for inspection.

## 8.2 Protection

Protect walls from direct rainfall, splash-back and runoff by means of roof protection and surface coatings as necessary. Protect walls from abrasion, other physical damage arising from construction works, thermal shock, impact, overloading, movement and vibration. Take care to avoid uneven drying of walls where one face is in direct sunlight and the other shaded, which may lead to leaning or bowing of walls.

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Waterproof sheeting used to protect walls from rain damage should be held clear of the surface to allow air circulation and to allow drying out of the rammed earth walls.

## **9 Formwork**

### **9.1 Construction**

Construct formwork accurately and robustly with adequate supports to produce finished rammed earth to the specified dimensions. Formed surfaces must be free from twist and bow (other than any required cambers), with all intersections, lines and angles being square, plumb and true.

Construct formwork, including joints in form linings and between forms and completed work, sealing joints where necessary. Secure formwork tight against adjacent rammed earth to prevent formations of steps.

Confirm positions and details to ensure that alterations to and decisions about the size and location of inserts, holes and chases are not made without the knowledge and approval of the engineer. Fix inserts or box out as required in correct positions before placing rammed earth. Form all holes and chases.

No metal part or device for securing forms, such as ties, is to remain within the completed rammed earth.

No release agents (*unless otherwise specified*) are to be used on the formwork faces.

### **9.2 Striking of formwork**

Strike formwork without disturbing, damaging or overloading the structure, and without disturbing props. Notwithstanding other clauses in this specification and any checking or approvals by the engineer, the responsibility for safe removal of any part of the formwork and any supports without damaging the structure, rests with the rammed earth contractor.

### **9.3 Formed finishes**

All finished and visible surfaces on rammed earth walls should be free from cracks exceeding 3 mm in width, mechanical damage, sections of loose friable material (soft spots), staining, and open bolt-holes.

Wall finishes shall meet minimum agreed variations with respect to colour, texture, boniness, flatness, formwork patterning, allowable cracking, extent of patching and repairs, and the number and style of cold joints. Any defect should not impair either the form or the function of the wall. All repairs should be undertaken using colour-matched similar materials. The visible surface standard of the completed wall, including all repairs, should be measured against that of an agreed test wall or other agreed reference finish.

The completed work is to produce an even finish with panels arranged in a regular pattern as a feature of the surface. Abrupt irregularities are not to be greater than 2 mm. Gradual irregularities, expressed as maximum permissible deviation from a 1 m straight edge, are to be not greater than 5 mm. Formwork tie holes to be in an approved regular pattern, filled with matching earth.

#### Construction tolerances

Horizontal position of any rammed earth element specified or shown in plan at its base or at each storey level	±10 mm
Deviation within a storey from a vertical line through the base of the member	±10 mm per 3 m of height
Deviation from vertical in total height of building (from base)	±15 mm per 7 m of height
Deviation (bow) from line in plan in any length up to 10 m	±10 mm per 5 m of length
Deviation from vertical at surface against which joinery is to be fitted	±10 mm
Deviation from design wall thickness	±10 mm
Position of individual rammed earth formwork panels	± 5 mm

The walls are to be inspected for compliance with this specification □ weeks (*normally between 4 and 12 weeks*) after construction, to allow adequate drying of the walls, and following installation of protective coatings.

#### 10 Movement joints in rammed earth

Movement joints likely to open as the material shrinks should be constructed in such a way as to prevent ingress of moisture and to remain airtight. Repairs may be undertaken using earthen materials or suitable proprietary fillers.

Movement joints likely to close (thermal expansion or articulation) should be clean and free from any hard or incompressible material for the full width and depth of the joint before any joint-filling material is inserted.

All joints are to be accurately located, straight and well aligned, truly vertical or horizontal or parallel with the setting out lines of the building.

The contractor shall prepare a detailed layout of construction joints for approval by the engineer prior to any rammed earth being placed. Joints are to be formed accurately. Modifications to joint design are to be approved by the engineer before proceeding.

Formed joints are to be constructed using rigid forms or stop ends designed to avoid temporary bending or displacement.

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**11 Worked finishes in rammed earth**

Tops of rammed earth walls are to be constructed sufficiently flat and level ( $\pm 20$  mm) to receive a timber wall plate bedded in mortar, a reinforced concrete ring beam or other specified fixture.

**12 Fixings, fittings and embedded items in rammed earth**

Fixings are to be located a minimum of 150 mm from the edge of any wall.

*Provision should be made as the work proceeds for all partitions, straps, beams, trusses, plates, and the like which are to be built or keyed into the wall, so as to minimise subsequent cutting or chasing of the wall. In rammed earth it is often easier to fix items such as straps and ties after wall construction is completed. Proprietary fixing types and methods of installation to be specified here.*

**13 Completion and maintenance**

Contractor is to provide a maintenance manual describing care and maintenance of the walls.

*Details on types and methods of application of protective coatings, renders and other finishes to be provided here.*