
Rammed earth: design and construction guidelines

Peter Walker, *University of Bath*

Rowland Keable, *In Situ Rammed Earth Co Ltd*

Joe Martin, *JM Architects*

Vasilios Maniatidis, *University of Bath*

Contents

Preface	ix
Acknowledgements	x
1 Introduction	1
1.1 Scope of guidelines	1
1.2 What is rammed earth?	2
1.3 Brief history and development	3
1.4 Advantages and limitations of rammed earth	10
1.5 Structure of the guidelines	16
2 Preliminary design considerations	17
2.1 Applications	17
2.2 Influence of rammed earth on other construction activities	22
2.3 Building control	24
2.4 Contractual considerations	27
3 Materials for rammed earth construction	29
3.1 Raw materials	29
3.2 Soil characteristics	31
3.3 Soil compaction	33
3.4 Additives	34
3.5 Soil selection	35
3.6 Physical characteristics	38
4 Construction of rammed earth walls	45
4.1 Preparation	45
4.2 Building	51

(continued)

5	Details for rammed earth construction	61
5.1	General	61
5.2	Footings and base details	61
5.3	Openings and supports	65
5.4	Protection given by roofs	69
5.5	Protective coatings	70
5.6	Services	74
5.7	Fixings	75
5.8	Thermal insulation	75
5.9	Acoustic separation	75
5.10	Construction tolerances	78
6	Engineering design of rammed earth walls	79
6.1	Design requirements	79
6.2	Properties of rammed earth for design	79
6.3	Simplified design for structural adequacy	81
6.4	Deformation	84
7	Maintenance and repair of rammed earth	85
7.1	Weathering and deterioration	85
7.2	Maintenance of rammed earth walls	88
7.3	Defects in new construction	89
7.4	Repairs to rammed earth	93
8	Future of rammed earth	95
Appendices		
A	Physical properties of rammed earth	99
B	Specification for rammed earth works	111
C	Structural wall design	119
D	Stabilised rammed earth	125
Contact addresses		131
Glossary		133
References		137
Bibliography		139
Index		143

Figures

- 1 Rammed earth wall construction at the Eden Project, Cornwall
- 2 Construction of a rammed earth wall
- 3 Rammed earth wall finish, Chapel of Reconciliation, Berlin
- 4 Traditional rammed earth building, Morocco
- 5 Seven-storey rammed earth building, Weilburg, Germany (c1820)
- 6 Rammed earth building, Rhone Valley, France
- 7 Rammed earth walling at the Alhambra, Granada, Spain
- 8 Victorian five-storey rammed chalk houses, Winchester, Hampshire (c1840)
- 9 Victorian rammed chalk building, Andover, Hampshire
- 10 Rammed chalk house, Amesbury, Wiltshire (c1920)
- 11 Eden Project Visitors Centre, Cornwall
- 12 AtEIC Building, Centre for Alternative Technology, Machynlleth, Powys
- 13 Wall at Chelsea Flower Show 2000
- 14 Woodley Park Sports Centre, Skelmersdale, Lancashire
- 15 Rammed chalk walls, Kindersley Centre, Sheepdrove Estate, Berkshire
- 16 Bird-in-Bush Nursery, London
- 17 Mount Pleasant Ecological Business Park, Porthtowan, Cornwall
- 18 Altar, Chapel of Reconciliation, Berlin
- 19 Rammed earth wall, Brandenburg, Germany
- 20 Rammed earth wall, Zeesen, Germany
- 21 Stabilised rammed earth house, Rural Studio, Alabama, USA
- 22 Stabilised rammed earth house, Western Australia
- 23 Dragons Retreat, Devon (stabilised rammed earth)
- 24 Jasmine Cottage, Norfolk (stabilised rammed earth)
- 25 Compaction layers in rammed earth
- 26 Tooled finish in rammed earth
- 27 Prefabricated rammed earth walls
- 28 Rammed earth floor
- 29 Rammed earth floor, Mount Pleasant Ecological Park, Porthtowan, Cornwall
- 30 Office desk, Engineers HRW office, London
- 31 Rammed earth wall construction under cover, Centre for Alternative Technology
- 32 Compaction layers in rammed earth
- 33 Pneumatic rammer
- 34 Manual rammer
- 35 Relationship between compaction moisture and dry density
- 36 Grading limits for rammed earth soils
- 37 Propping of walls during drying
- 38 Traditional timber formwork
- 39 Cantilevered formwork
- 40 Australian proprietary static formwork
- 41 Proprietary concrete static formwork
- 42 Timber formwork
- 43 Timber formwork for curved wall

44	Through-bolted formwork
45	Small forced-action screed mixer
46	Pan-style concrete mixer
47	Skid steer loader
48	Rotavator mixer
49	Pneumatic compaction of a stabilised rammed earth wall
50	Compaction using sheeps-foot roller
51	Movement joints
52	Protection of new works
53	Damp-proof course
54	Base details
55	Water damage at the base of a wall
56	Full-height opening between panels
57	Arched opening
58	Opening details
59	Wall plate details
60	Eaves details
61	Peeling failure of sodium silicate protective coating
62	Preferential weathering of sodium silicate treated wall, exacerbated by under compaction
63	Clay plaster, Woodley Park Sports Centre
64	Movement joints in lime render
65	Plan view of embedded electrical services
66	Back box
67	Insulation details
68	Typical vertical movement joint details
69	Limiting thickness for free-standing and supporting walls
70	Simple rules for openings in rammed earth walls
71	Surface weathering from rainfall
72	Concentrated rainwater flow damage
73	Abrasion damage to vulnerable corners in a stabilised rammed earth wall
74	Walls should be protected from other construction activities
75	Colour variation
76	Textural variation in a rammed earth panel
77	Boniness
78	Formwork patterning
79	Surface cracking
80	Patch repair
81	Plucking damage
82	Surface dusting
83	Efflorescence in a stabilised rammed earth wall
84	Genesis Project, Somerset College of Arts and Technology
85	WISE Project, Centre for Alternative Technology, Wales
A1	Shear testing of rammed earth wall panel
A2	Spray erosion test
A3	Abrasion test
C1	Dispersion of concentrated loads
D1	Brimington Bowls Club Pavilion, Chesterfield, stabilised rammed earth
D2	Stabilised rammed earth stables, Ashley, Northamptonshire

Preface

This publication is believed to be a landmark in that it represents the first guidance document for rammed earth construction published in the UK. It has been compiled as part of Partners-in-Innovation project *Developing rammed earth wall construction for UK housing* funded by the Department of Trade and Industry (DTI). The 30-month project has been led by the University of Bath and In Situ Rammed Earth Co Ltd, working together with Engineers HRW, JM Architects, Knauf Insulation and Mark Lovell Design Engineers as contributing industrial partners. Advisory steering group members included representatives from Bristol City Council, BRE, Day Aggregates, The Ecology Building Society, Feilden Clegg & Bradley Architects, International Heritage Conservation and Management, Grimshaw Architects, Simmonds Mills Architect-Builders and Somerset Trust for Sustainable Development.

The project has included an experimental investigation of material properties, including thermal conductivity testing, structural testing of walls and columns, a worldwide review of rammed earth construction publications and a pilot case study project. As a result we believe that these guidelines represent the current state-of-the-art best practice in rammed earth construction as applicable to the UK. We hope that they will promote and lead to a greater use of rammed earth wall construction and encourage its future development. We welcome feedback and comments for future editions. Finally, we wish to express our sincere thanks to all who have helped to make this publication a reality.

Peter Walker
Rowland Keable
Joe Martin
Vasilios Maniatidis

1 Introduction

1.1 Scope of guidelines

For most building designers, rammed earth walling is a novel, innovative and unfamiliar material and construction technique. These guidelines have been compiled with the specific aim of informing, developing and promoting the use of rammed earth wall construction in the UK as a high-quality and sustainable building technology for walls in housing and other low- and medium-rise buildings. Specifically, the guide seeks to encourage the greater use of rammed earth, free from additives such as cement, as an alternative, sustainable and beautiful wall building material.

These guidelines for rammed earth cover general design considerations, material properties, testing and selection, engineering design, wall construction, construction details, and maintenance and repair procedures. A glossary, reference list and bibliography are also included.

Note on stabilised rammed earth

Stabilised rammed earth is an alternative form of wall construction that uses the rammed earth technique, but includes cement, primarily as an additive to change the material's physical characteristics. Stabilisation enhances material durability and wet strength, but at the expense of using cement, a major contributor to global CO₂ emissions. Much of the guidance given here for rammed earth construction is applicable to stabilised rammed earth as well. Where the approaches differ, in material selection for example, these variances are briefly outlined in Appendix D. Further guidance on stabilised rammed earth is also available elsewhere^[1,2,3].

1.2 What is rammed earth?

Rammed earth is a form of unbaked earthen construction used primarily to build walls. Other applications include floors, roofs and foundations. Recently it has also been used for furniture, garden ornaments and other features. Rammed earth is formed by compacting moist sub-soil inside temporary formwork (Figures 1 and 2). Loose moist soil is placed in layers 100–150 mm deep and compacted. Traditionally, manual rammers have been used for compaction but nowadays pneumatically powered dynamic rammers are commonly used. Once the soil has been adequately compacted the formwork is removed, often immediately after compaction, leaving the finished wall to dry out. Walls are typically 300–450 mm thick, but this can vary widely according to design requirements.

Rammed earth walls often exhibit a distinctive layered appearance as a result of the construction process, corresponding to the successive layers of soil compacted within the formwork (Figure 3). This attractive appearance is



(Grimshaw architects; In Situ Rammed Earth; 1999)

Figure 1 Rammed earth wall construction at the Eden Project, Cornwall



Figure 2 Construction of a rammed earth wall

2.1.5 Pre-formed rammed earth

In recent years, in line with the general move towards off-site fabrication of building elements, pre-formed or prefabricated rammed earth has developed. To date, prefabrication has been used by only a very small number of specialist overseas practitioners^[8], and the wider use of pre-formed rammed earth is largely unproven in the UK. Prefabrication potentially allows higher-quality factory construction of elements under sheltered conditions whilst also minimising on-site construction time. Examples to date include large wall blocks (Figure 27) as well as 100–200 mm thick cladding panels. Although costs are likely to increase, owing to transportation and lifting requirements, the use of prefabricated rammed earth is likely to increase in forthcoming years.



Photo: Martin Rauch

Figure 27 Prefabricated rammed earth walls

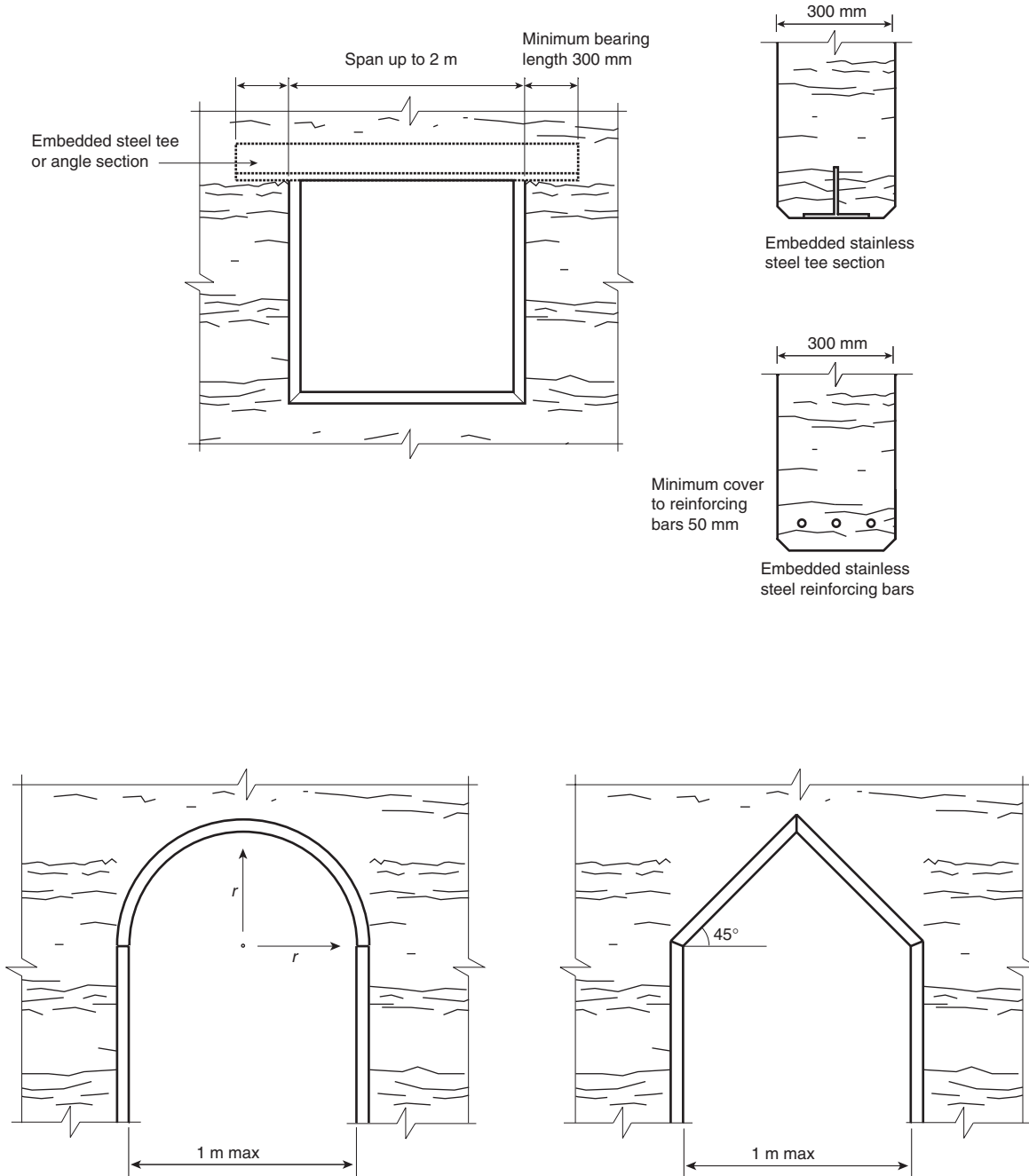


Figure 58 (continued) Opening details

8 Future of rammed earth

Although the combined number of UK rammed earth and stabilised rammed earth structures is presently believed to be no more than several hundred, the last decade has seen a significant renewal of interest, driven primarily by the demands for more sustainable building. Over the past 25 years a few thousand stabilised rammed earth buildings have been built in Australia.

Recent applications of rammed earth in the UK have been varied, including visitors centres, a sports hall, a business park development, a children's nursery, a conference centre, as well as a prize-winning exhibition wall at the Chelsea Flower Show. New rammed earth projects currently under development include the Genesis Project at the Somerset College of Arts and Technology in Taunton (Figure 84), a 200-seat lecture theatre in the WISE Project at the Centre for Alternative Technology in Wales (Figure 85), and the Aykley Heads Development in County Durham.



(Architype)

Figure 84 Genesis Project, Somerset College of Arts and Technology