Appendix C

Structural wall design

When a more rigorous approach to that set out in Chapter 6 for checking the structural resistance of rammed earth walls is required, a procedure based on loadbearing masonry design may be used[3,24]. The methodology is based upon a limit state philosophy in which characteristic compressive strengths and factored design loads (actions) are used. Other suitable, recognised and accepted structural design approaches may also be employed.

C.1 Material partial safety factor (γ_m)

A partial safety factor is applied to material property design values to account for variations in materials and quality of work. For example, material properties are often determined using small specimens prepared under laboratory conditions, and so do not include features such as boniness. Criteria influencing the partial safety factor value, together with outline values, are summarised in Table C1. Selection of the partial safety factor is at the engineer's discretion. There are insufficient data to make more specific recommendations. The recommended value for partial safety factor varies between 3 and 6, though design engineers may select alternative values as they consider appropriate. Designers should also consider the possible consequences of failure and likelihood for accidental damage.

Table C1 Values for material partial safety factor (γ_m)

Suggested criteria	(γ_m)
Works carried out by experienced specialist contractor; tried and tested materials; materials from consistent supply or mix; materials tested fully in accordance with provisions of Appendices A and B; full programme of compliance testing during construction; materials well within recommended limits of suitability criteria; material property test results demonstrate consistent repeatable performance	3.0–4.0
Works carried out by general contractor under supervision; untried material with limited laboratory test data; full programme of compliance testing during construction; materials within recommended limits of suitability criteria	4.0–5.0
Works carried out by inexperienced labour under some supervision; untried natural or quarry waste material with limited test data; limited programme of compliance testing; materials marginally comply with recommended limits of suitability criteria; material property test results show some inconsistency	5.0–6.0

C.2 Design for combined compression and bending

The vertical forces and moments are combined at the top and bottom of the wall by regarding the vertical force as acting at a statically equivalent eccentricity (e) at each end. In designing the wall the most unfavourable combination of imposed actions should be considered.

Compressive strength is a function of wall slenderness ratio (S_r), load eccentricity (e), material compressive strength (f_c), and wall section dimensions breadth (b) and thickness (t). Slenderness ratio (S_r) is given by:

$$S_r = h_{ef}/t$$

where the effective height is a function of lateral restraints at the base and top of the wall as follows:

- h = clear wall height between restraints
- h_{ef} = $0.75h$ for a wall laterally supported and rotationally restrained both top and bottom
- h_{ef} = $0.85h$ for a wall laterally supported both top and bottom and rotationally restrained along at least one of these
- h_{ef} = $1.00h$ for a wall laterally supported but rotationally free both top and bottom
- h_{ef} = $2.00h$ for a wall laterally supported and rotationally restrained only along its bottom edge

For sufficient compressive strength the wall must satisfy the following basic requirement:

$$N_d \leq (\Phi f_c \, b \, t)/\gamma_m$$

where:
- N_d = design compressive force
- Φ = capacity reduction factor, dependent on slenderness ratio and load eccentricity, as defined in Table C2
- γ_m = material partial safety factor
- f_c = unconfined material compressive strength

Table C2 Slenderness and eccentricity reduction factor (Φ)

Slenderness ratio* (S_r)	Reduction factor (Φ) Ratio of maximum eccentricity to thickness (e_{max}/t): ≤ 0.05	0.10	0.20	0.30
6	1.00	0.78	0.56	0.32
8	0.94	0.73	0.54	0.29
10	0.88	0.67	0.49	0.25
12	0.82	0.62	0.45	0.22
14	0.76	0.56	0.40	0.18
16	0.70	0.51	0.35	0.15
18	0.64	0.45	0.31	0.11

* Slenderness ratios above 12 (shaded) are greater than recommended for general construction.

C.3 Design for concentrated compression loads

An increase in compressive capacity of up to 50% is permitted in zones under concentrated loads. Though concentrated loads are assumed to disperse through the rammed earth at an angle of 45° from the perimeter of the bearing area of the load, the dispersion cannot extend:

(a) into the dispersion zone of an adjacent concentrated load, or
(b) beyond the physical end of the wall or across movement joints.

The wall is designed to satisfy the following condition for each cross-section within the zone of dispersion of the concentrated load:

$$N_d \leq (\Phi_b f_c A_b)/\gamma_m$$

where:
- N_d = design compressive force, including the concentrated load and portion of any other compressive forces acting on the cross-section under consideration
- Φ_b = concentrated bearing factor
- A_b = area beneath bearing taking account of load distribution
- γ_m = material partial safety factor
- f_c = unconfined material compressive strength

The value of Φ_b is taken as follows:

(a) For cross-sections at a distance greater than $0.25h$ below the level of the bearing:

$$\Phi_b = 1.00$$

(b) For cross-sections at a distance within $0.25h$ below the level of the bearing of the concentrated load on the member:

$$\Phi_b = [0.55(1 + 0.5a_1/L)]/(A_{ds}/A_{de})^{0.33} \text{ or}$$

$$\Phi_b = 1.50 + (a_1/L)$$

whichever is less, but Φ_b not less than 1.00, or greater than 1.50,

where: A_{ds} = bearing or dispersion area of the concentrated load at the design cross-section under consideration

A_{de} = effective area of dispersion of the concentrated load at mid-height (see Figure C1)

a_1 = distance from the end of the wall to the nearest end of the bearing area

L = clear length of the wall

L_e = effective length of load dispersal at mid-height of the wall

t = section thickness

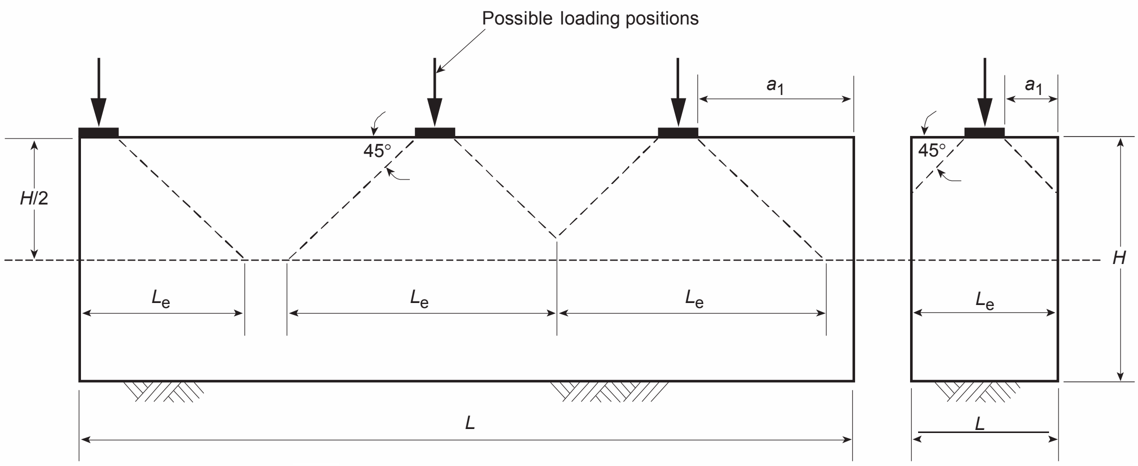

Figure C1 Dispersion of concentrated loads ($A_{de} = L_e t$)

C.4 Design for out-of-plane flexural loads

The design of a rammed earth wall to withstand vertical bending from actions of a short-term transient nature, which include out-of-plane wind loads or similar forces, should either satisfy requirements of combined bending and compression or satisfy:

$$M_d \leq [(f_t / \gamma_m) + f_d]\, Z$$

where:
M_d = vertical design bending moment, including bending action from load eccentricities or bending moments applied at the ends of the wall
f_t = flexural tensile strength of rammed earth
f_d = design compressive stress at the cross-section
γ_m = material partial safety factor
Z = section modulus

C.5 Design for shear

The design of a rammed earth wall cross-section to withstand shear forces is undertaken to satisfy the following relationship under each combination of simultaneously acting design shear force (V_d) and minimum design compressive stress (f_d):

$$V_d \leq (v_o/\gamma_m + \mu f_d)\, A_v$$

where:
v_o = basic shear strength of rammed earth (determined by test – Appendix A.3.6)
A_v = area of cross-section resisting shear
μ = shear factor
γ_m = material partial safety factor