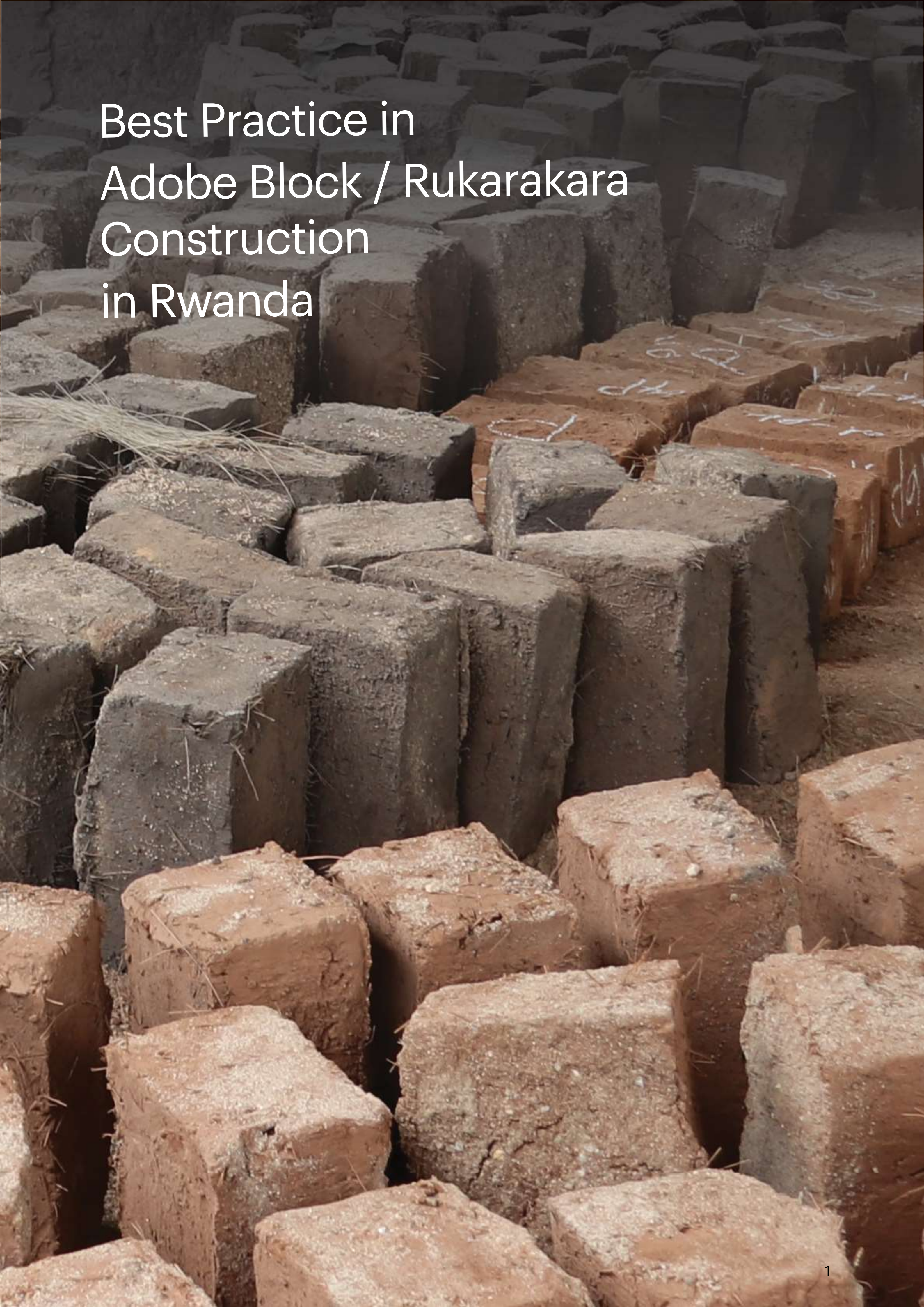
Best Practice in Adobe Block / Rukarakara Construction in Rwanda



Best Practice in Adobe Block / Rukarakara Construction in Rwanda

This document was created by the Local Building Materials Think Tank.

Best Practice in Adobe Block / Rukarakara Construction in Rwanda is a research report which contributed to the development of two regulatory documents:

- RS 484:2022 - Adobe Blocks (Rukarakara) - Specification
- AMABWIRIZA AVUGURUYE Y'UMUYOBOZI MUKURU W'IKIGO CY'URWANDA GISHINZWE GUTEZA_IMBERE IMITURIRE RHA AJYANYE N'IYUBAKISHWA RY'AMATAFARI YA RUKARAKARA *(translation: Technical Guidelines for Adobe Block Construction in Rwanda)*

The specification is available for purchase on the Rwanda Standards Board website. The Technical Guidelines are available for download on the Rwanda Housing Authority Publications page. The Technical Guidelines are based on this report, but have been reduced and refined for regulatory purposes.

Background

In Rwanda, 95% of houses are built with earth. Walls are typically constructed from rukarakara, also known as adobe — an unfired mud brick. While adobe blocks are affordable, locally available, and environmentally sustainable, poor construction practices can result in unsafe, unhygienic, and high-maintenance buildings.

The Local Building Materials Think Tank was developed to contribute to the Government of Rwanda's ongoing efforts through Rwanda Housing Authority and Rwanda Standards Board to transform housing in Rwanda to be safe, durable and affordable, by bringing together parties of complementary experience and expertise.

In 2019, construction with rukarakara / adobe was legalised in the Rwanda Building Code, recognising rukarakara / adobe as an important building material for future housing development. The Local Building Materials Think Tank's first focus area of collaboration was to carry out research and testing in order to develop standards and guidelines for rukarakara / adobe construction in Rwanda.

The **Local Building Materials Think Tank** consisted of the following parties:

- Rwanda Housing Authority
- Rwanda Standards Board
- Rwanda Polytechnic
- MASS Design Group
- EarthEnable
- Greenpact Africa

1.Objective

The objective of this document is to provide best practice guidance for the construction of adobe buildings that are safe, comfortable and affordable.

This document does not prevent the use of other approved construction materials.

1.1 Terms and definitions

- Adobe Block/ "Rukarakara": Air dried masonry unit made from puddled earth/soil mixture of clay, sand and silt with or without organic materials. It sometimes contains fibres and/or stabilizers.
- Header Bond: A masonry unit laid horizontally with the shorter end exposed or parallel to the surface.

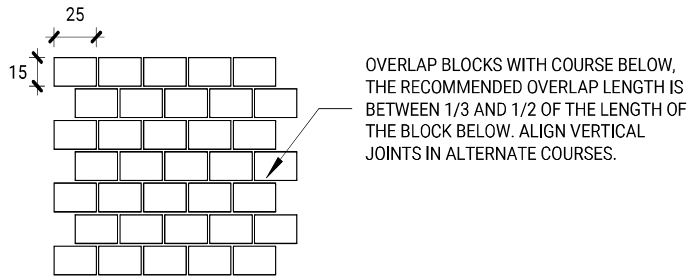


Figure 1. Header bond, shown using 30x25x15 cm blocks

- Stretcher Bond: A masonry unit laid horizontally with the longer edge exposed or parallel to the surface.

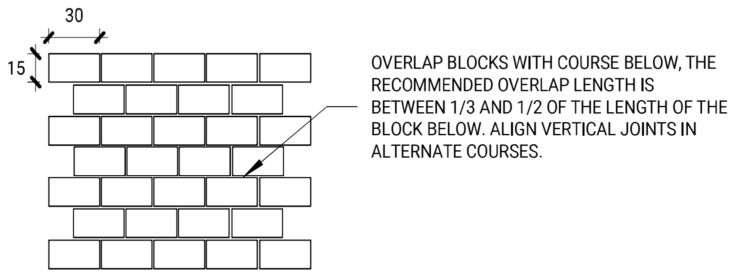


Figure 2. Stretcher bond, shown using 30x25x15 cm blocks

- Foundation: the building elements transmitting forces to the supporting ground.
- Mortar: mixture of binder, fine aggregate and water, which hardens and which is normally used as a jointing product.
- Binder: material used to hold solid particles together in a coherent mass, for example clay.
- Concrete: mixture of aggregate, cement and water, which hardens.

For other definitions relevant to adobe block construction, refer to RS 484.

1.2 Dimensions

All dimensions in this document are in centimetres unless noted otherwise.

1.3 Limitations

This guidance is for application in the construction of Category 2 Buildings in accordance with clause 2.6.5.1.3 of the Rwanda Building Code. Category 2 comprises administrative, residential and commercial buildings except for industrial buildings, hazardous buildings, and health facilities.

Buildings in category 2 are characterised by the following:

- Having total floor area not exceeding two hundred (200) square meters;
- Being non-storeyed and basement free structure;
- Accommodating not more than fifteen (15) people.

Refer to the Rwanda Housing Authority Publication for further information on the use case.

2. Construction planning

2.1 Plot location

No building should be constructed in a hazardous area, such as those stated below:

- Unstable slopes which are prone to landslides;
- River banks and areas susceptible to flooding or excessive erosion;
- Swamps and marshy areas;
- Polluted land such as waste disposal sites or landfills;
- Uncompacted filled areas, including former quarries;
- Slopes steeper than 1 vertical to 3.3 horizontal (slopes steeper than 30%);
- Adjacent to slope cuts that are not supported by well built retaining walls. The appropriate distance between a building and a retaining wall (or vertical soil face) should be the height of that retaining wall (or vertical soil face). However, the minimum distance should be 1.5m (RBC, 2019 clause 1.5.11.3.9.2). More information on retaining walls is found in the next section.

The following diagrams provide guidance for building at the top or bottom of any slope:

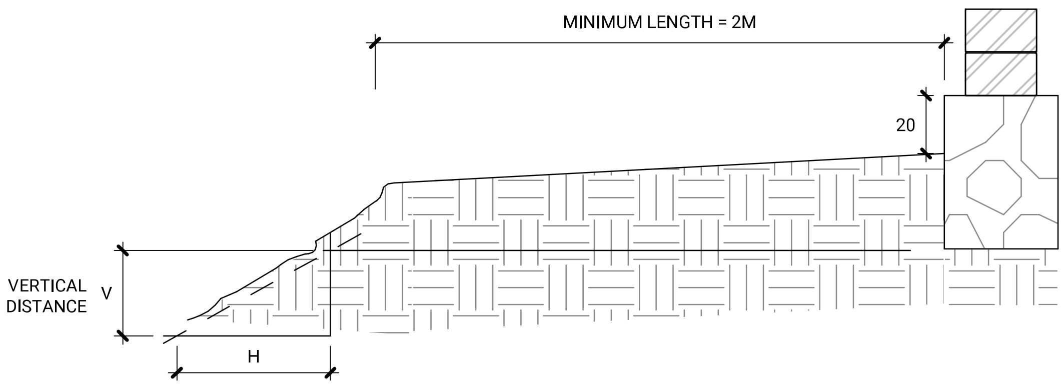


Figure 3(a). Locating a building at the top of a slope

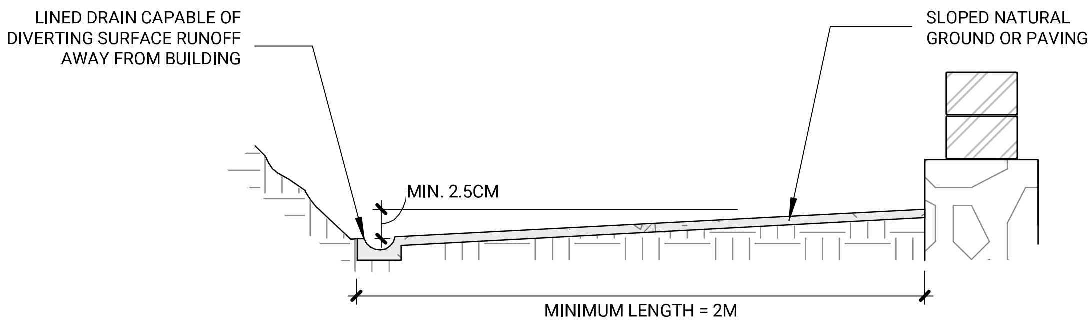


Figure 3(b). Locating a building at the bottom of a slope

Where possible, once a site is selected consider the best siting and orientation of your building. In terms of its relationship to the sun, facing the main/front side of the building towards the south is typically beneficial for comfort in the building.

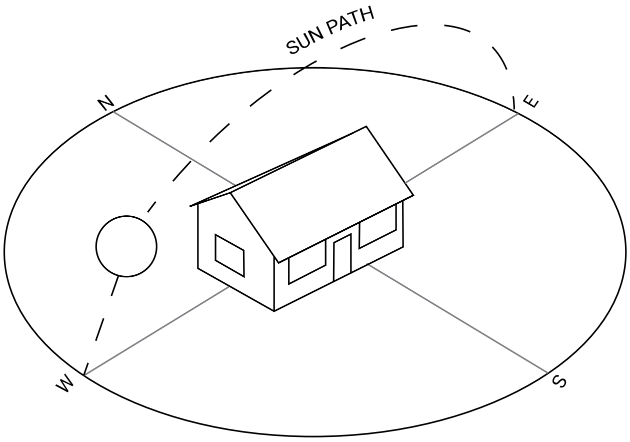


Figure 4. Building orientation

2.2 Retaining walls

Retaining walls may be required to support soil or weathered rock faces, to prevent damage to the house and to maintain sufficient space in the surrounding compound.

Where required, the retaining walls may be reinforced concrete, stone masonry, sand bags, or honeycomb concrete blocks. A reinforced concrete retaining wall should be designed by a structural engineer.

Requirements for other retaining walls are laid out below.

  - Stone masonry (mortared or unmortared): Walls should be built from strong unweathered stone.
  - Stones should be angular, not rounded.
  - For mortared walls, weepholes should be left through the wall at regular intervals to allow water to drain from behind the wall. Weep holes are to be 5cm diameter and spaced 1.5m in both vertical and horizontal directions.
  - The stones should be laid so that they interlock, and joints are staggered vertically. Stone masonry units should be laid so that the longest dimension is in horizontal position.
- Sand bags:
  - A sandbag retaining wall should be formed from sacks filled with soil.
  - Sand bags should be placed at an angle not steeper than 2(v):1(h) for retained heights less than 1.0m high, and not steeper than 1(v):1(h) for retained heights up to 2.0m high.
  - Sand bags should be placed in overlapping layers. The base should be wider than the top for retained heights up to 1.0m. The base should be a minimum of 1.0m wide for retained heights of up to 2.0m.
  - It may be possible to use the same principle with waste materials, such as old tyres infilled with soil, in a similar manner to sand bags.
- Honeycomb concrete blocks:
  - Honeycomb concrete blocks are filled with soil to prevent erosion and support soil slopes.
  - Honeycomb concrete blocks should be placed at an angle not steeper than 2(v):1(h) for retained heights less than 1.5m high; where higher than 1.5m, the slope should be terraced.
  - Honeycomb concrete blocks should overlap each other by 50% of their width.

For any retaining wall regardless of material, the following should be considered to provide a stable and robust solution:

- Bury the toe of the wall at least 30cm below ground level to prevent undermining.
- Typically, to provide stability, build the base of the wall to a width that is around 0.7 times the wall height.
- Slope the front face of the wall backwards.
- Provide surface water drainage to prevent erosion of the soil around the wall.

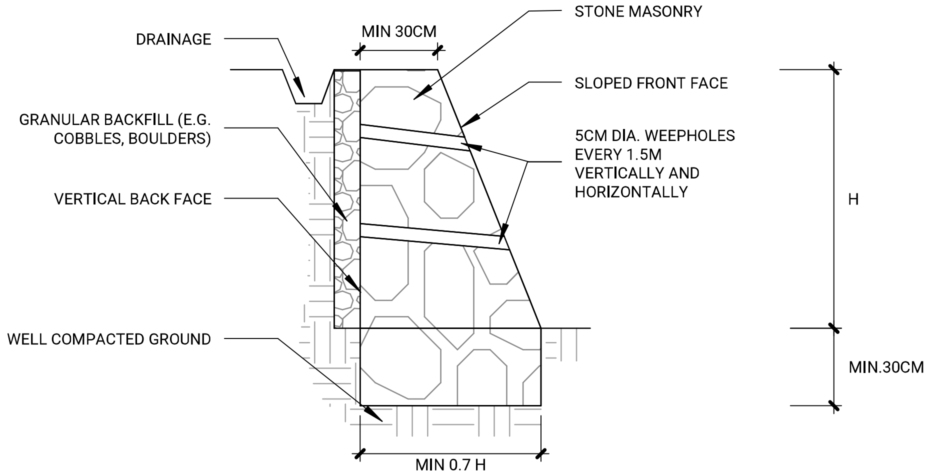


Figure 5(a). Stone masonry retaining wall

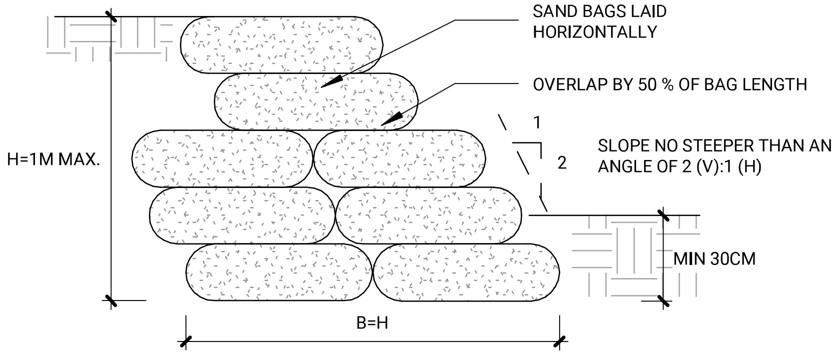


Figure 5(b). Sandbag retaining wall for heights up to 1m

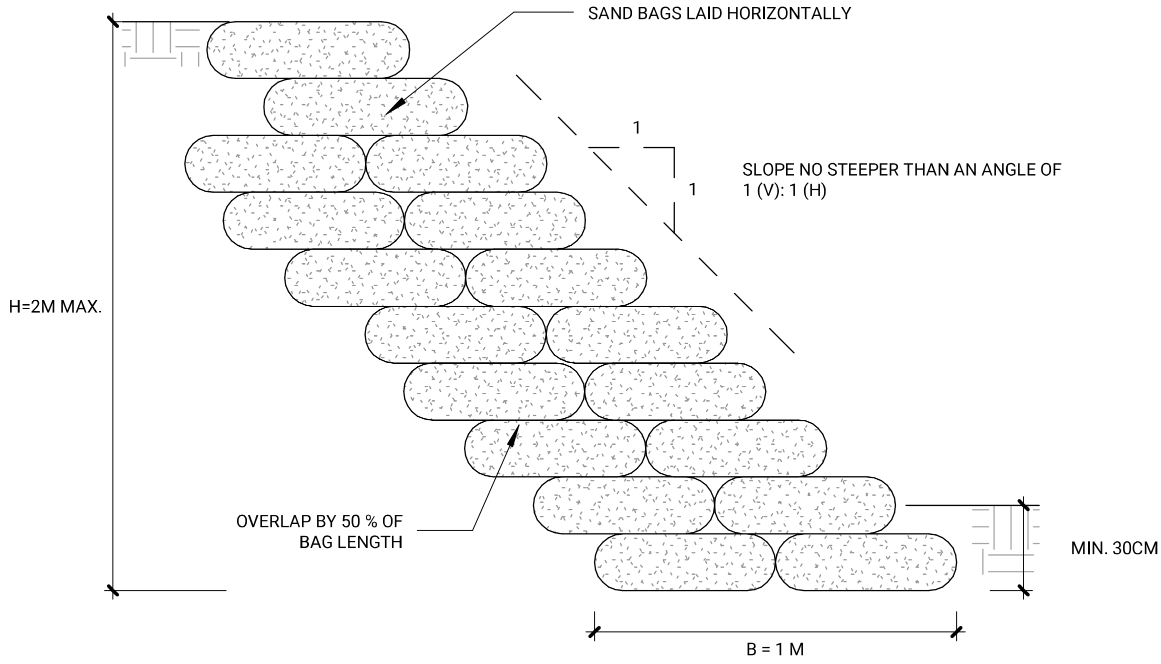


Figure 5(c). Sandbag retaining wall for heights up to 2m

2.3 Drainage

Improper drainage causes differential settlement due to undermining of foundations, which leads to cracking and instability in the walls. It causes rising damp and water ingress. It also increases the risk of flooding in the community. To avoid improper drainage, the following should be respected:

- Ensure water is directed away from the building through these options:
    - Provide a 50cm wide sloped concrete slab which surrounds the building and directs water into a 20cm wide drainage channel. An appropriate concrete mixture is – 1 bag of cement: 2 wheelbarrows of sand: 1.5 wheelbarrow of gravel. 1 bag of cement is 50kgs and 1 wheelbarrow is 70L.

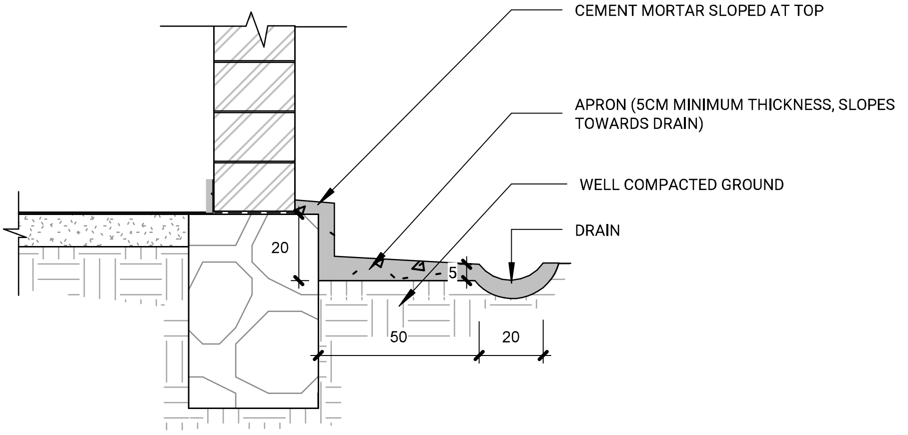


Figure 6. Drainage away from the building through provision of screed

    - Alternatively, the ground may slope away from the house in all directions so water does not flow towards the house and does not pond against the house even in the heaviest rainfall.

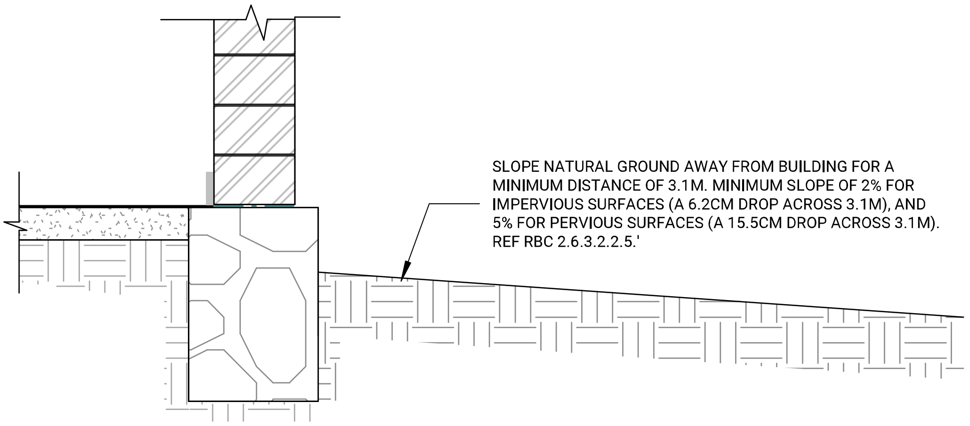


Figure 7. Drainage away from the building through slope of natural ground

- For a house at the bottom of a cut slope, drainage channels should be cut at the top of the slope to channel water away from it.
- Where possible, collect water from the roof for reuse. A water tank overflow should direct water away from the house.
- Roof drainage should be separate from other site drainages. Slightly raise the roof drainage channels above the ground so they do not fill with sediment and overflow.
- Direct the water from the drainage channel into public water drainage system or into a soak pit.
- Roof and ground drainage should be kept clean.

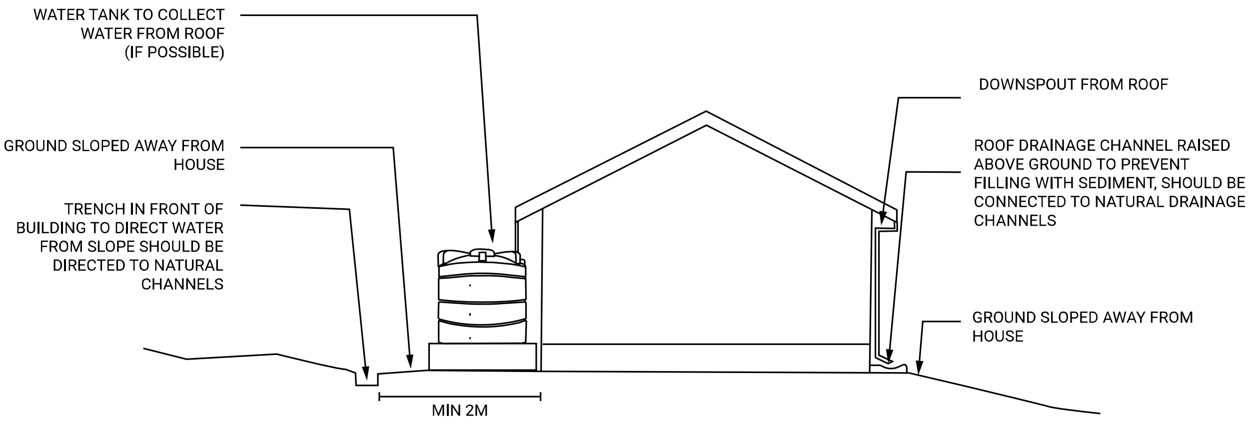


Figure 8. Advised water collection and drainage systems around the building

2.4 Landscaping

Landscaping should respect the provisions of the master plan and ensure the following but not limited to:

- Requirements for zoning landscaping areas are respected;
- If possible, plant trees, grass and shrubs;
- Trees should not be located such that their roots adversely affect the foundations

2.5 Estimating number of blocks required

The number of required adobe blocks should be estimated in advance.

The formula below should be used to estimate:

$$\text{Nr. of blocks} = \frac{\text{Height of the wall}}{\text{Height of block}} \times \frac{\text{Total length of the wall}}{\text{Length of block (stretcher bond) or width of block (header bond)}}$$

When estimating, do not remove openings in order to cater for wastages and half sized blocks. One wheelbarrow of soil makes 5-6 blocks.

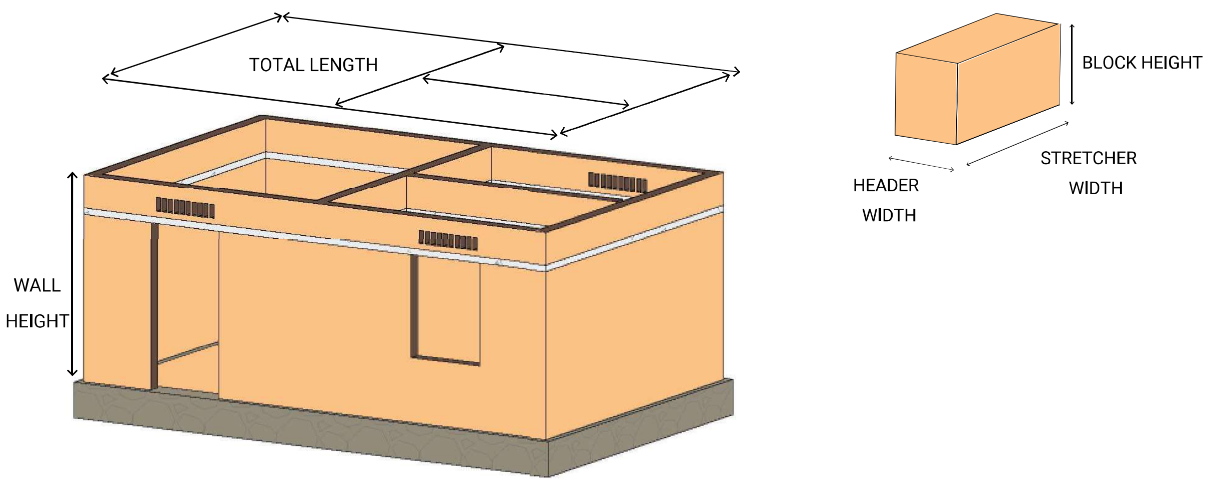


Figure 9. Method for calculation of required total number of blocks

3. Adobe block making

3.1 Block dimensions

Adobe blocks should have the following dimensions:

- Maximum 30, 25, and 15 cm as length, width and depth respectively. Larger blocks should not be used because they are more susceptible to cracking and harder to handle.
- Minimum 20, 20 and 10 cm as length, width and depth respectively. Smaller blocks should not be used because they cannot achieve the minimum wall thickness of 20cm.

3.2 Soil for adobe block making

The recommended particle size distribution for adobe blocks is: Gravel and Sand 30-80%, Silt 10-30% and Clay 10-40%.

The Snake Test and Wash Test (Appendix A) may be used to determine the suitability of soil. These tests should be performed by experienced trained masons who understand the local soil behaviour. The Snake Test and Wash Test should be considered as a guide to soils which are likely to be suitable for block making. Soils which marginally fail the tests may still be acceptable providing that trial blocks pass the Block Drop Test (see Section 3.9).

Mixing different soils may be required to achieve a suitable soil mix. An appropriate mix of soils may be determined using local knowledge from experienced trained masons and the tests in Appendix A.

The selected soil should be free from:

- Organic matter. This can typically be achieved by removing the topsoil.
- Soluble salts, soaps, oils, and other chemicals which may negatively impact health or adobe block strength
- Aggregates larger than 2.5cm

3.3 Fibres

Fibres between 5-7cm long may be added to reduce block cracking. Fibre length should not exceed 10cm. The quantity of fibres depends on the type of soil and can be determined through trial blocks, however a recommended starting value is 2kg of fibre per 50 blocks, assuming 30x20x15cm block size.

The trial blocks should be inspected after a week of curing. If blocks are still highly cracked it is recommended to increase the quantity of fibres. The type of fibres may be determined based on local knowledge from experienced trained mason and they should not rot, breakdown or sprout in the block. Fibres like ishinge are proven to work well.

3.4 Water

- Water to be used should be from a clean source such as rain collection, public water network, boreholes, rivers and lakes.
- Mixing water should not contain soaps, detergents, oil, harmful chemicals or sewage.

3.5 Mould

The mould may be made in wood or metal with dimensions corresponding to the block dimensions as stated in Section 3.1. The mould should have handles for easy handling (lifting) when making blocks.

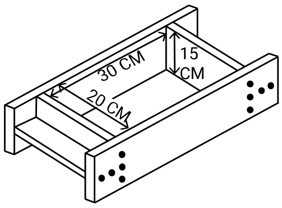


Figure 10. Maximum recommended block mould dimensions

3.6 Adobe block making yard

The adobe block making yard should be:

- Protected from direct sunlight and rain
- Flat, dry and levelled
- Well drained so that water does not stagnate or come into contact with blocks
- Blocks should be raised off the ground during rainy season, unless the yard is completely covered

3.7 Block making

Prior to making the blocks, the soil should be prepared by removing all debris, sharp objects and gravel larger than 2.5cm.

The volume of water required depends on the soil type and environmental conditions. The soil should be thoroughly mixed with water to provide an even consistency. To ensure an even distribution of moisture, mud to be used may be batched and mixed at least 12 hours before making blocks. This should not be done if cement or lime stabilisers are used.

The optimal amount of water in a mud paste should be determined by taking a handful of the mixture and squeezing to see how wet it is in the hand, and how much mud exits through the fingers. Refer to Table 1 for examples of mud which is too wet, too dry and of optimal moisture content.

Too wet	**Too dry**	**Optimal moisture**
When the mud is squeezed almost all of it will exit through the fingers. Afterwards the palm of the hand is still wet.	When the mud is squeezed very little mud will exit through the fingers. Afterwards the palm of the hand is dry.	When the mud is squeezed some thick mud will exit through the fingers. Afterwards some mud sticks to the palms of hands.
		
		

Table 1. Determining optimal moisture content of mud

The fibres should be thoroughly mixed into the mud. They can be mixed in before or after adding water to the soil.

Figure 11. Mixing of mud with fibres

It is recommended that the mud is hand compacted into the mould laid in three equal layers. Extra care is needed while compacting in the corners.

a) Compacting mud into mould in 3 layers

b) Once compacted, sprinkling the top with water

c) Smoothing top surface with water to finish

d) Cleaning mould once complete

Figure 12. Sequence of block manufacture

3.8 Curing

Excessive exposure to strong sun can accelerate surface drying on adobe blocks and cause cracking. Adobe blocks should therefore be air dried, not sun baked. They should be shaded from strong sunlight, especially in the first 4 days of curing, but still having adequate airflow around the blocks. If curing in a shaded area is not possible, in the case of strong sunlight the blocks may be covered with grass, banana leaves, a layer or soil or sand to prevent immediate cracking.

Adobe blocks should be protected from rain and surface water throughout the curing and construction period. If protecting from rain using a plastic sheet, avoid placing it such that it limits airflow, as shown in Figure 13. To protect blocks from surface water during rainfall, the blocks should be raised off the ground, or a bund and drainage channels should be provided around the curing area.

Blocks should be flipped onto their side when strong enough to turn, the rotation of the blocks should be done every 3-4 days for even drying. Depending on the size of block and the weather, curing time varies but should be a minimum of 14 days. Blocks should not be used in construction before they are fully cured. When they are cured, the block has the same color as dry soil they were made from, and when tapped with a coin they produce a 'clear ring'. When stacking dry blocks, avoid exceeding 7 rows high.

Figure 13. Block curing through air drying

3.9 Block testing

To understand the strength of the blocks, at least 20 trial blocks should be made using the same materials and techniques that would be applied in the the making of all blocks.

Test the trial blocks using the Block Drop Test. The test procedure and pass and fail criteria are provided in Appendix B.

Another round of testing should be done if changes occur in the mixture or making process, including but not limited to:

- Soil from another location is used.
- The type of soil in the pit has clearly changed, often indicated by colour or particle size.
- Fibre type or quantity is changed.

At the end of the drying period, it should be possible to handle blocks without crumbling or them being easily damaged. Cracks less than 3mm in width are typically acceptable. Not more than 10% of blocks in a wall should contain cracks wider than 3mm and longer than 7.5cm or, irrespective of the crack length or width, deeper than 1cm along any part of the crack.

4. Construction

4.1 Earthquake Hazard Level

Rwanda is considered a moderately seismic zone, and the earthquake hazard level varies across the country. In the regions of higher seismicity (for example the western province and the volcanic region) additional measures are advised in these guidelines and should be considered.

4.2 Foundation

4.2.1 Founding Level

The foundation trench should be formed by excavating down until competent ground is reached. Competent ground level varies, but the founding level should not be less than 40cm from existing ground level.

Foundation depth may be reduced if deemed appropriate by a civil or geotechnical engineer. In addition to competent ground level, the Engineer should consider factors such as erosion risk, slopes, surrounding drainage channels and potential for future development involving excavations next to the foundations.

The following are indications of **unsuitable soil** for founding:

- Rubbish/trash, building rubble, or other signs that the material is not natural ground
- Roots or other organic material
- Soft cohesive soil that can be easily moulded or crumbled in the hand
- Loose sand or gravel with obvious voids
- Very wet soil

Competent soil may be assessed by some of the following methods in Table 2:

Soil type	Observation indicating competent ground
All soils	Requires a pick for excavation - cannot be dug with a hoe or spade
Fine soils (clays and silts)	Particles not visible to the eye. If you add water, it will be possible to roll the soil to a ball between your hands. Soil will stick to your hands.
Coarse soils (sands and gravels)	Particles will be easily identifiable by eye. If you add water, it will not be possible to roll the soil to a ball. The soil will easily brush from your hands.

Table 2: Methods to assess whether ground is competent for founding

4.2.2 Masonry and concrete foundation

The construction of a robust foundation should consider the following:

- After excavating the foundation trench, the foundation should be constructed with a minimum depth of 40cm from existing ground level, a minimum height of 20cm above final external ground level and a minimum of 40cm wide. Foundation size may be reduced if deemed appropriate by a civil or geotechnical engineer, considering the factors listed in 4.2.1.
- In regions of higher seismicity, the width of the foundation should be extended to 50cm. Refer to Section 4.11 for prioritization of seismic interventions.
- The foundation should be built from stone masonry or concrete.
- The minimum batching proportions of mortar for stone masonry construction should be 1 bag of cement to 4 wheelbarrows of sand, 1 bag of cement is 50 kgs and 1 wheelbarrow is 70L.
- Alternative foundation options for example rubble trench foundations may be designed by a civil or geotechnical engineer.
- Adobe blocks should not be used as foundation materials.
- Inside walls are vulnerable to water ingress through floor mopping. The base of the walls should be protected by adding a cement plaster or sealed earth plaster skirting to a height of at least 7cm. Furthermore, the blocks may be elevated above internal floor level by laying one course of fired bricks.

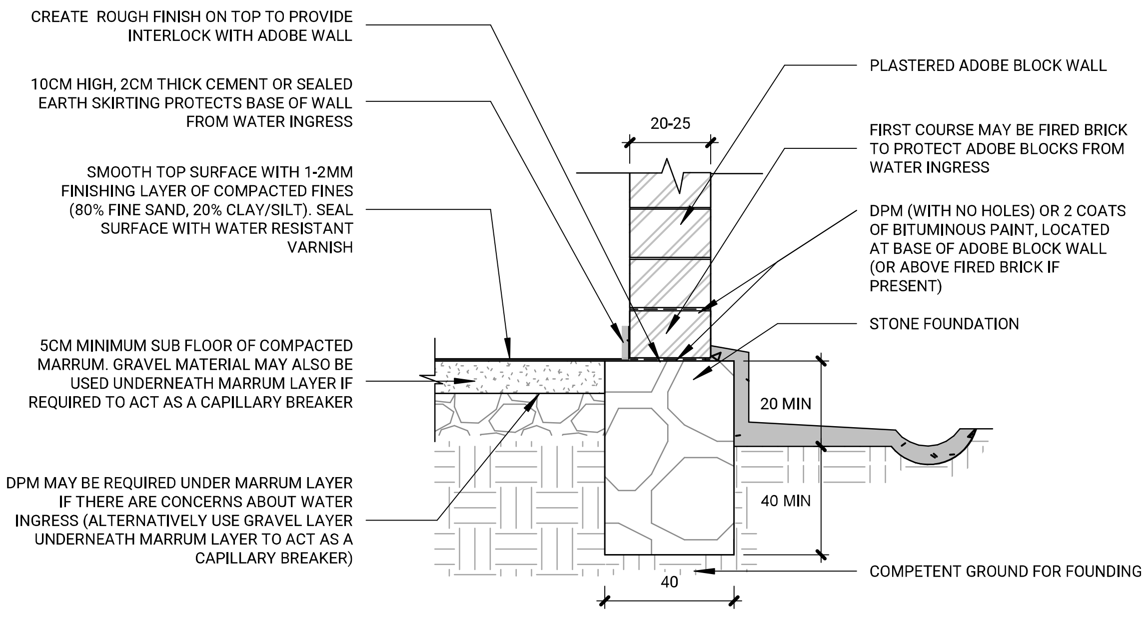


Figure 14(a). Construction of stone masonry foundation (section)

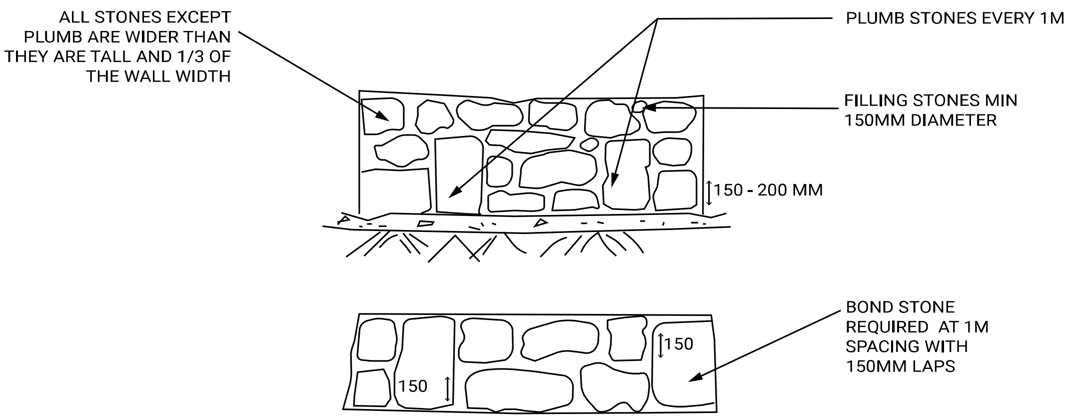


Figure 14(b). Construction of stone masonry foundation (elevation and plan)

4.2.3 Ground beam

A reinforced concrete ground beam should be built on top of the masonry foundation for buildings in high seismic zones in order to tie the foundations together. Refer to Section 4.11 for prioritization of seismic interventions.

In addition to its seismic benefits, a ground beam also reduces the extent of cracking in the walls in the event of any foundation settlement. Therefore, a reinforced concrete ground beam is recommended for structural stability of all buildings.

The depth of ground beam should be at least 25cm in areas of higher seismicity. If it is not possible to provide a 25cm deep grade beam, or in regions of low seismicity, a smaller grade beam of 12.5cm deep may be used.

The concrete for the ground beam should be mixed using the the ratio of 1 bag cement, 1 wheelbarrow of sand and 2 wheelbarrows of gravel; 1 bag of cement is 50 kgs and 1 wheelbarrow is 70L. The ground beam should be continuous around the building perimeter.

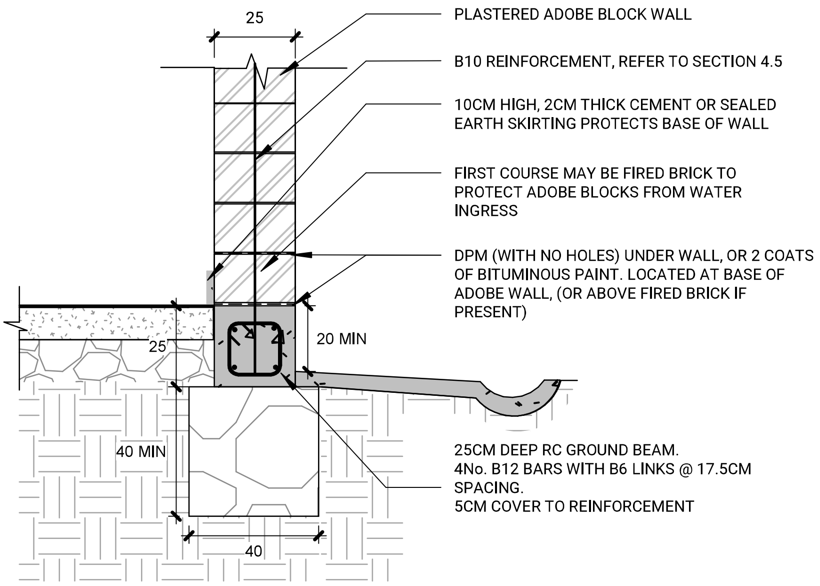


Figure 15. Ground beam in seismic areas

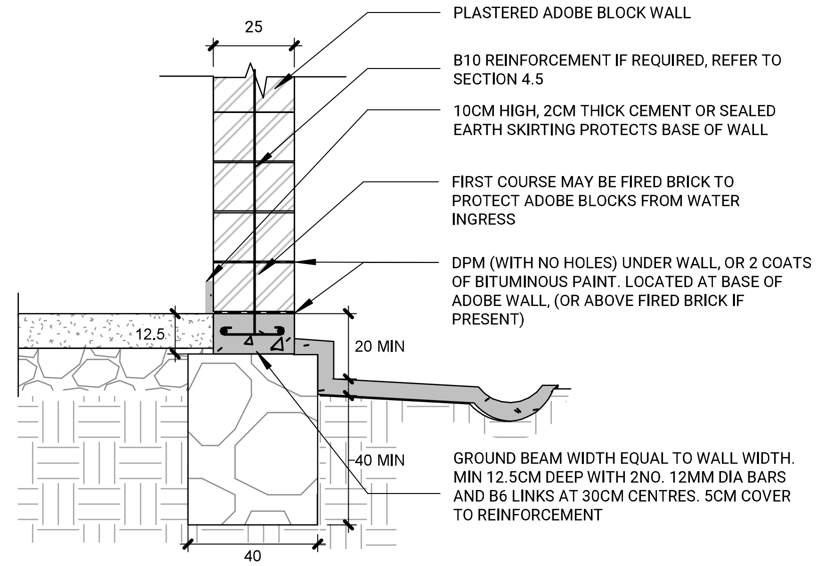


Figure 16. Minimum requirements for ground beam

4.3 Waterproofing and anti-termite

In order to prevent water ingress and termite access the following should be implemented:

- Apply a rough finish on top of foundation to create interlock with adobe wall.
- On top of the rough finish above, a damp proof membrane (DPM/DPC) or other impervious material should be provided. Refer to Figure 14.
- Avoid constructing on top of former termite colonies, unless termite colonies are fully dug out, sprayed with anti-termite and the area filled with stones up to the level of the base of the foundation trench.
- The application of anti-termite treatment should be carried out in accordance with the manufacturer's instructions.
- Materials containing cellulose such as dried grass, cardboard, piles of organic materials, etc. should be removed from trenches, foundation, and surrounding areas.
- Ensure the building has adequate ventilation through ventilated blocks and operable windows to remove moisture and humidity from the building, which termites favour.
- Monitor the structure and surrounding area throughout its life and if termites are observed near the structure apply anti-termite treatment again.

4.4 Walls

Effective construction of adobe walls should consider the following:

- Construct walls using the typical stretcher or header bonds, applying a layer of mortar (1-2cm thick) between blocks.
- Mortar may be:
    - earth-based of similar composition to the block.
    - stabilised earth-based cement, hydrated lime mixed with earth, only to be used with stabilized blocks
- Start block laying from the corners, build a maximum of 5 layers of blocks per day for walls to develop some strength. The wall should be left for 1-2 days to develop strength before building on it again.
- When mixing mortar remove gravel or other particles which are bigger than the half of the mortar layer width.
- Use the following details for wall junctions:

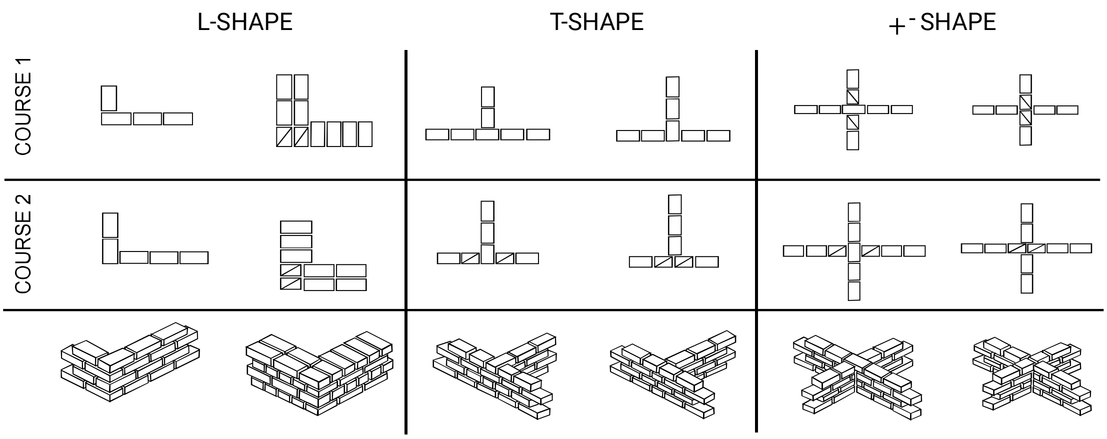


Figure 17(a). Block details at wall junctions

- Unless designed by a structural engineer, the maximum distance between return walls should be 5.0m. If the return walls are 2.5m or further apart and the walls are less than 25cm wide a column (pier) should be provided half way between the return walls. The pier thickness should be twice the thickness of the wall and a minimum of 41cm wide (2x 20cm blocks and a 1cm mortar joint).

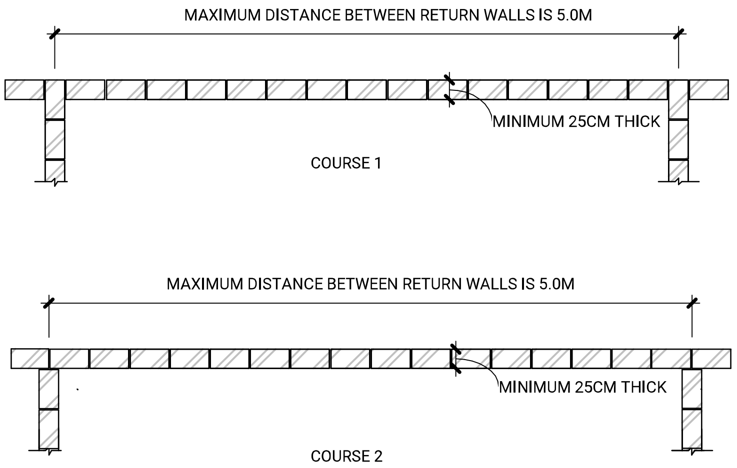


Figure 17(b). Block laying pattern-no pier

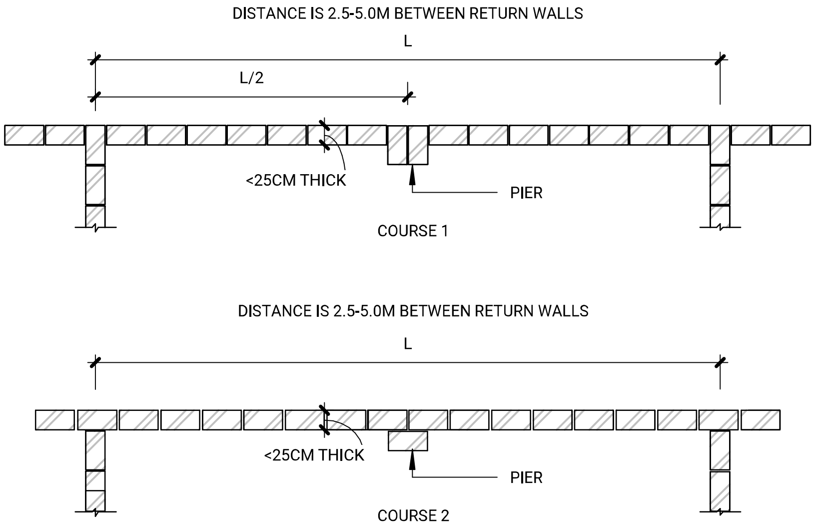


Figure 17(c). Block laying pattern-with pier

The height of walls should be limited as follows.A ring beam should always be provided. Additionally, the following requirements should be considered based on seismicity:

- For areas of low seismicity:
  - Gable roofs: Maximum storey height of 2.85m. Maximum gable wall height of 3.6m with a capping beam.
  - Monopitch roofs: Maximum storey height of 2.85m. Maximum front wall height of 3.6m with a capping beam.
  - Hipped roofs: Maximum storey height of 2.85m. Maximum central wall height of 3.6m with a capping beam.
  - Additional height may be achieved through roof trusses or timber framing on top of adobe walls.
- For areas of high seismicity:
  - Walls should be reinforced. Refer to Section 4.5 for details.
  - Gable roofs: Maximum storey height of 2.85m. Maximum gable wall height of 3.40m with a capping beam.
  - Monopitch roofs: Maximum storey height of 2.85m. Maximum front wall height of 3.40m with a capping beam.
  - Hipped roofs: Maximum storey height of 2.85m. Maximum central wall height of 3.40m with a capping beam.
  - Additional height may be achieved through roof trusses or timber framing on top of adobe walls up to a maximum building height of 3.6m.

The capping beam should be similar to the ring beam - refer to Section 4.6 for more details. Where wall reinforcement is required refer to Section 4.5 for bar size and spacing.

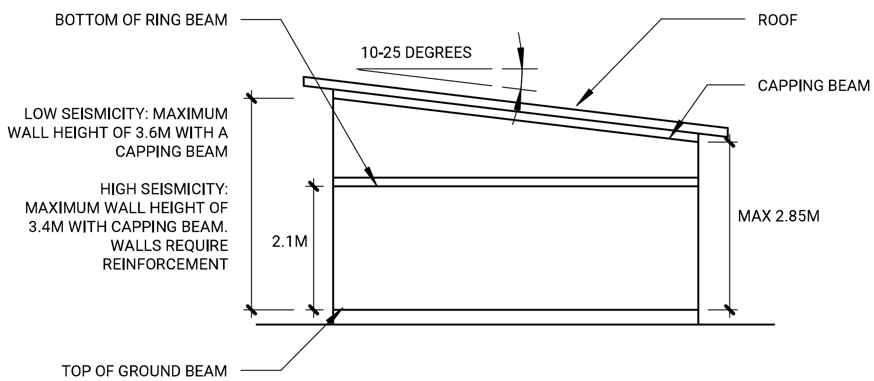


Figure 18(a). Height limitations - monopitch roof

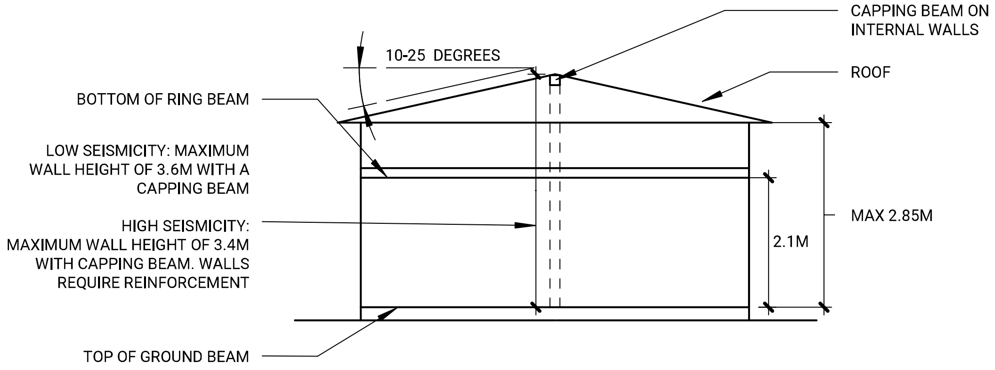


Figure 18(b). Height limitations - hipped roof

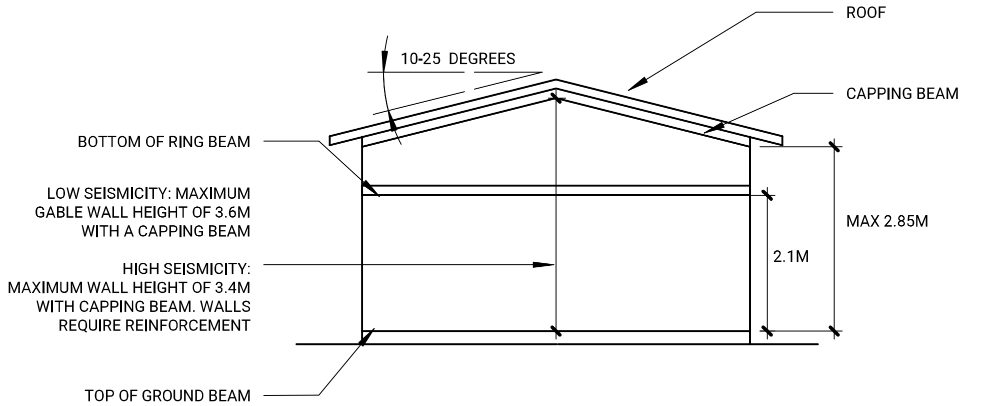


Figure 18(c). Height limitations - gable roof

4.5 Wall reinforcement

In regions of higher seismicity (refer to Section 4.1) the walls should be reinforced with either:

- Steel rebar, or
- Galvanized wire ladders.

Refer to Section 4.11 for prioritization of seismic interventions.

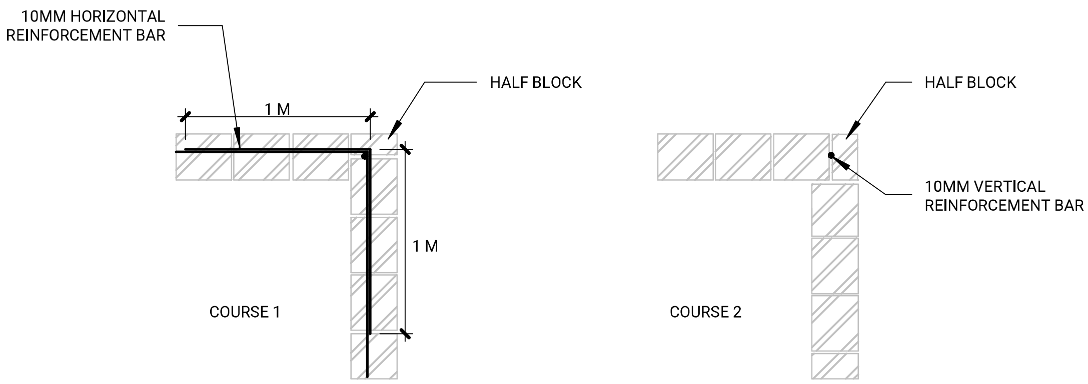


Figure 19(a). Wall corner reinforcement in plan

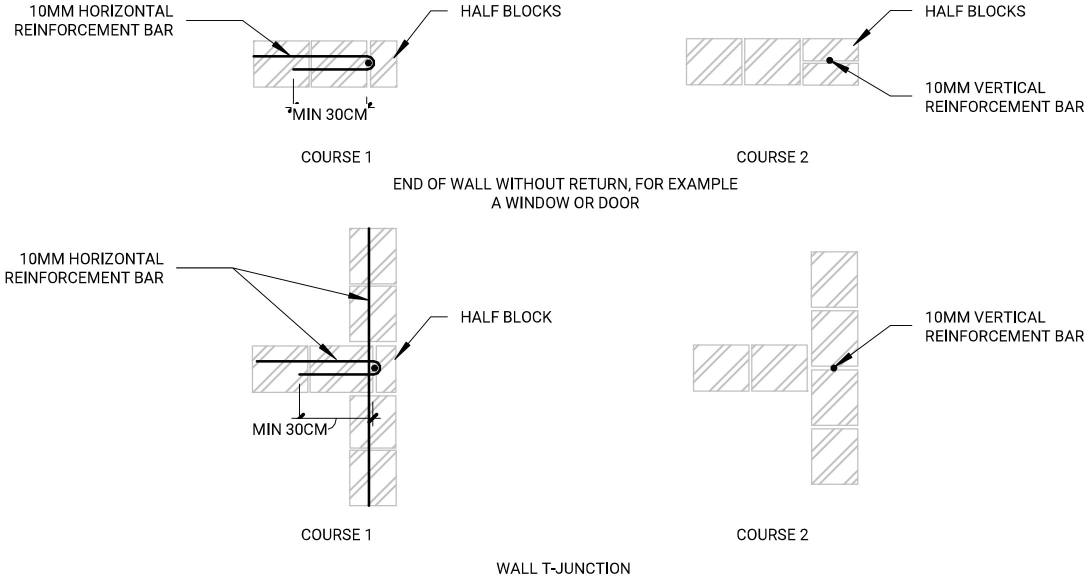


Figure 19(b). Wall reinforcement in plan

4.5.1 Steel rebar

If reinforcing with steel rebar, 10mm bars should be used in both the vertical and horizontal directions as shown in Figure 20.

Likewise, walls should be reinforced with 10mm bars at wall junctions and around openings as shown in Figure 21.

The vertical bars should be anchored into the ring beam and ground beam. Horizontal bars should be tied to the vertical reinforcement. Horizontal bars at wall corners should extend a minimum of 1m into adjacent walls.

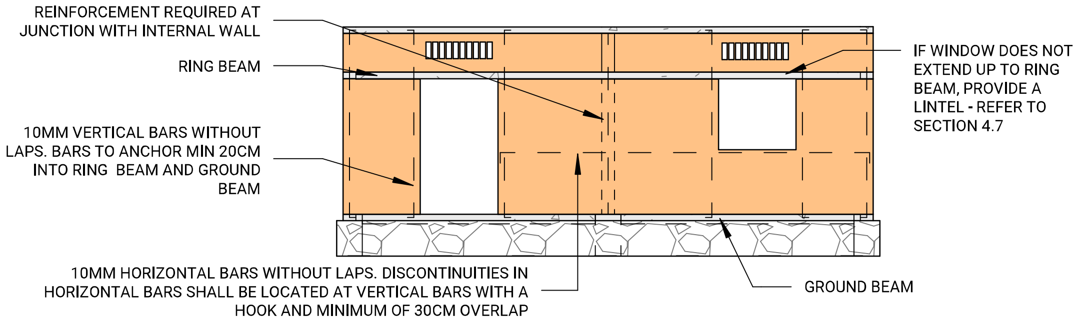


Figure 20(a). Wall reinforcement elevation

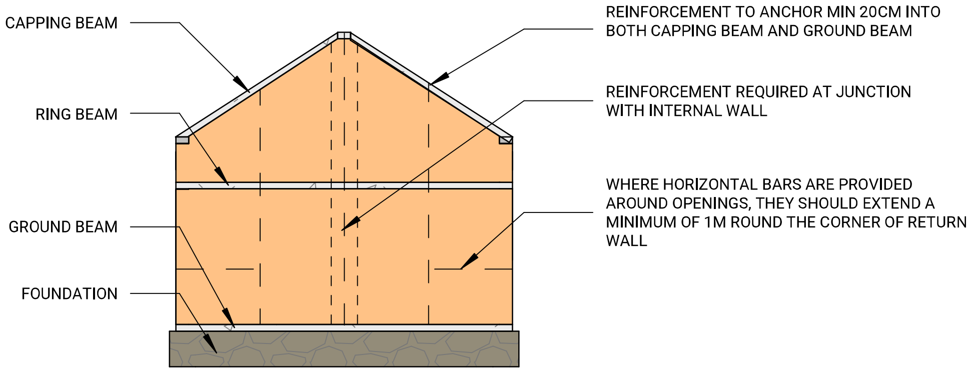


Figure 20(b). Wall reinforcement elevation

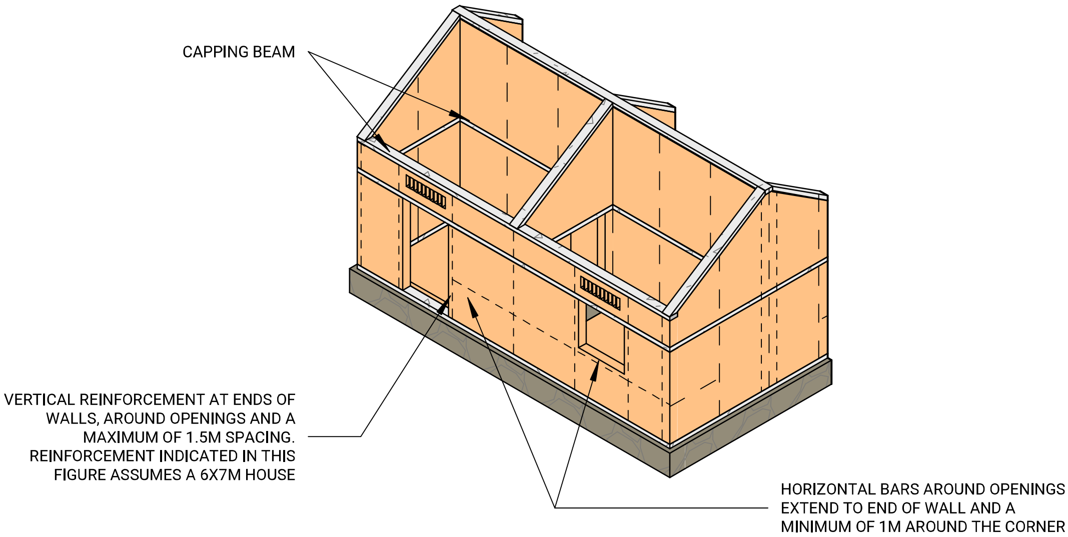


Figure 21. Wall reinforcement in 3D

4.5.2 Galvanized wire ladders

The use of galvanized wire ladders involves making ladder-like strips from galvanized wire to act as reinforcement. The strips should be 2.5mm thick and have 2mm thick horizontal ties at intervals of 30cm. For a 25cm wide wall, the wire ladder must be 20cm wide.

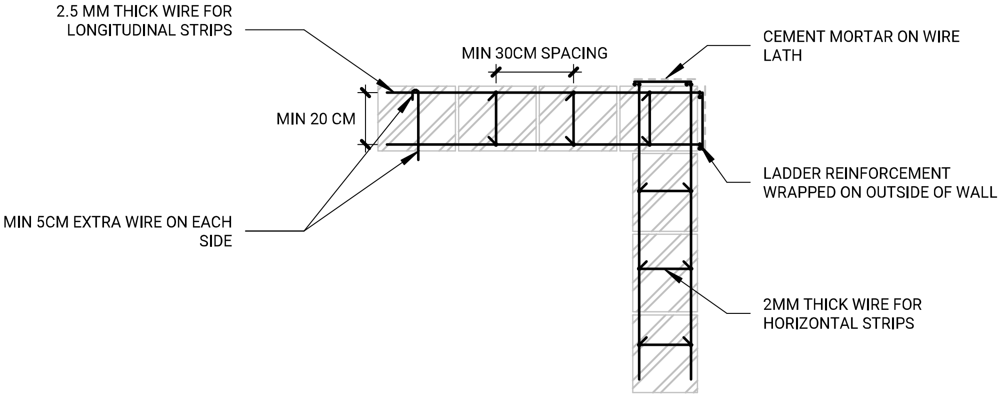


Figure 22. Galvanized wire reinforcement in plan

The reinforcement should be applied at all wall ends and along all window and door openings, with a minimum overlap of 60cm at the ends of the reinforcement.

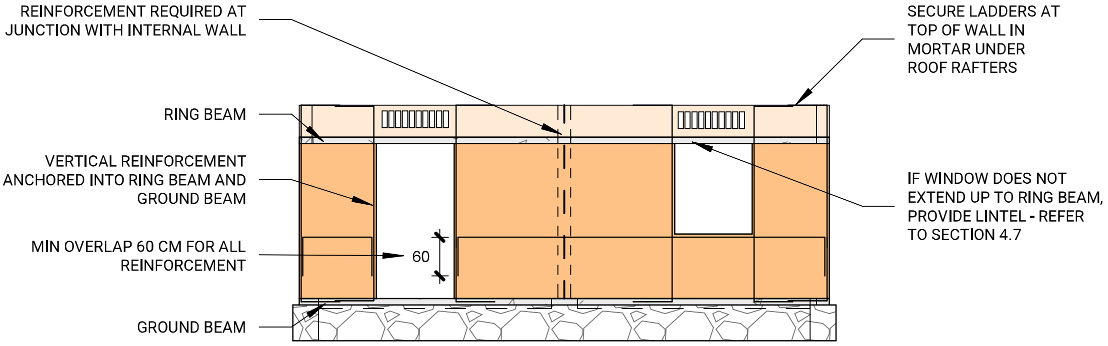


Figure 23. Galvanised wire reinforcement in elevation

4.6 Ring beam

The ring beam is the most important seismic reinforcing measure, and should be constructed as per the following recommendations:

- Provide a ring beam above all perimeter and internal walls.
    - For unreinforced walls it should be provided at 2.1m high (dimensioned from top of ground beam to underside of ring beam), continuous above doors and windows.
    - Unless an alternative solution is justified by a structural engineer, a wall of 45cm-60cm high should be built on top of the ring beam in order to keep the ring beam in position, and provide security to the roof which is connected to the ring beam.
    - For reinforced walls it should be provided between 2.1 and 2.75m high (dimensioned from top of ground beam to underside of ring beam) to achieve a maximum storey height of 2.85m. Provide lintels if ring beam does not align with the top of openings.
- The ring beam may be timber, reinforced concrete or galvanized wire ladder. In regions of higher seismicity zone, it should be reinforced concrete.
- The ring beams should be of the following sizes:
    - Concrete: minimum of 25cm wide (assuming a 25cm wide wall) x 12.5cm deep with 2x 12mm diameter rebars and 6mm diameter links at 40cm centres. Cover to reinforcement should be 5cm. The concrete mix should be the same as the ground beam.

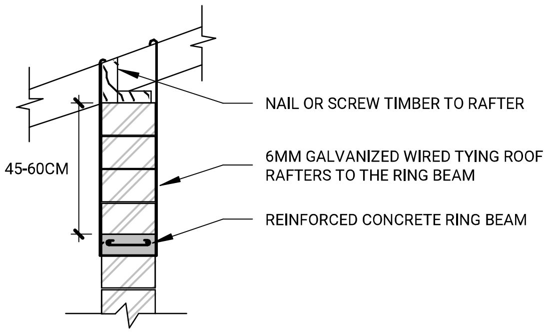


Figure 24. Reinforced concrete ring beam

    - Timber: minimum of 20cm wide (or equal to width of wall where possible) x 5cm deep solid timber or smaller solid members nailed together every 20cm.

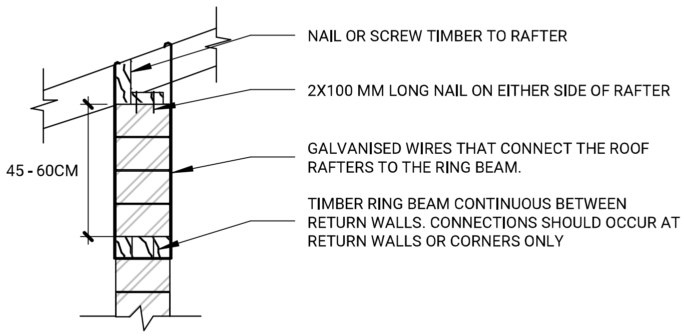


Figure 25 . Timber ring beam

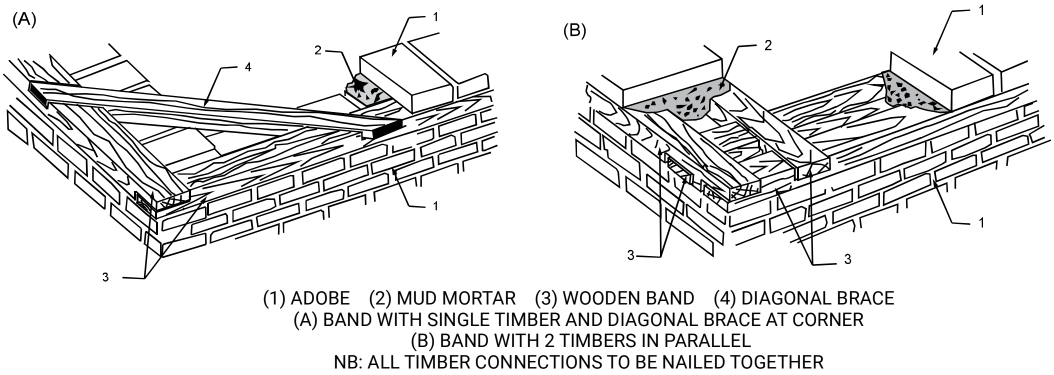


Figure 26: Corner details of ring beam

4.7 Lintels

Lintels are required to support the upper walls across openings such as windows and doors. They should be built from timber or concrete. Where timber is used as the ring beam, depending on the size of the ring beam, an additional member may be required to span across openings in accordance with details below. Where concrete is used, the ring beam may also be used as a lintel provided it is the appropriate depth. Examples shown in Figures 27 and 28.

- Timber Lintels
    - 10cm deep lintel for maximum 0.9m span
    - 15cm deep lintel for maximum 1.5m span
    - 20cm deep lintel for maximum 2.1m span
    - Minimum20 cm wide
    - Bearing on walls = 30cm minimum

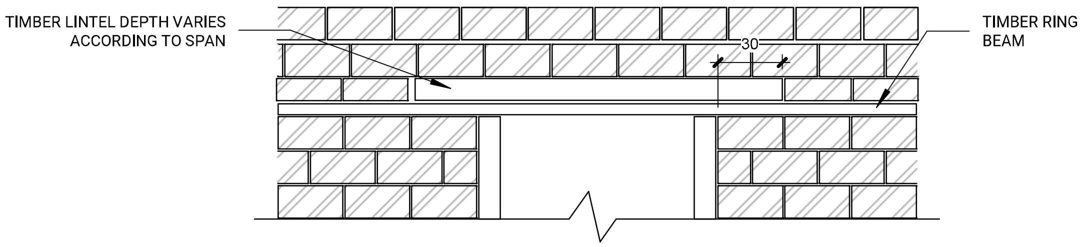


Figure 27. Timber lintels

- Reinforced concrete lintels
    - 12.5cm deep lintel with 2x 12mm diameter reinforcement for maximum 1.2m span (no change required from reinforced concrete ring beam)
    - 15cm deep lintel with 2x 16mm diameter reinforcement for maximum 2.7m span
    - Minimum 25cm wide
    - Cover to reinforcement = 5cm
    - Bearing on walls = 30cm

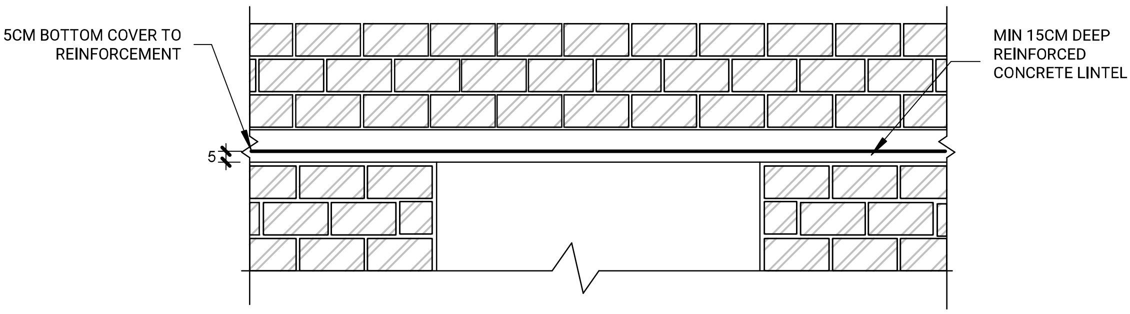


Figure 28. Reinforced concrete lintels

4.8 Roof

- The roof should be covered with clay tiles, metal sheets, or other equally durable and water-resistant materials.
- In order to prevent water ingress, the minimum slope for clay tiles should be 18 degrees and minimum slope for metal sheets should be 10 degrees. The maximum slope of the roof should be 25 degrees (equivalent to a slope of 47%).
- The roof should be supported by trusses or rafters:
    - Fabricate trusses from timber nailed together or steel welded together. The roof should be constructed by a trained and certified carpenter or welder. If using trusses, place them on a timber wall plate on top of the adobe walls to distribute the load more widely.
    - Connections/splices mid-span should be avoided.
- To secure the roof, each truss/rafter should be tied to the ring beam to resist wind uplift. There are many methods of creating this tie but Figure 24 and Figure 25 illustrate this principle for timber and concrete ring beams.
- The roof should be tied using strong materials such as galvanised steel cables/wires that connect the roof truss/rafter under the ring beam.
- A greater roof overhang offers better protection to the wall and increases the life of the building. The minimum roof overhang should be 50cm from the outside face of the wall. For best protection, the roof overhang may be the height of the wall divided by 3.
- Gutters may be provided to carry roof water away from the building in controlled manner. Where used, gutters should be at least 10cm wide, with a slope of 1 in 200 and should be kept clean.

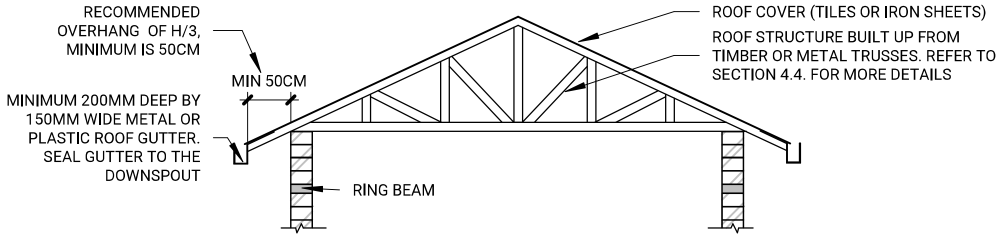


Figure 29. Truss details - timber or metal

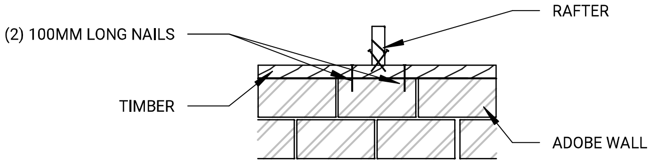


Figure 30. Roof to wall connection

4.9 Doors and windows

- All the doors and windows should be made of timber or appropriate metals.
- To avoid weakening the wall, the length of wall between two openings should not be less than 1m.
- Openings within 1m of building corners should be avoided. Refer to Figure 34.
- Window sills may be concrete or timber and should direct water away from the wall.

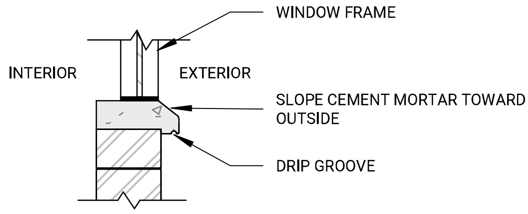


Figure 31. Window sill details

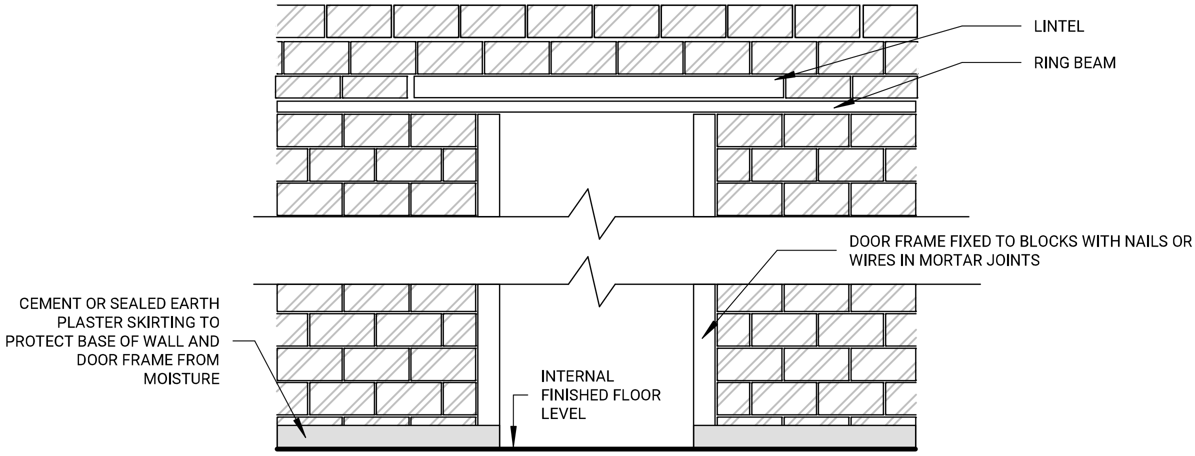


Figure 32.Door frame

- Every room should have at least one operable window. Provide windows on opposing walls for cross ventilation where possible. The minimum window area should be equivalent to 5% of the room floor area.
- For health reasons, an operable window should be located close to any cooking areas. Where possible, an opening may be provided at a high level in the cooking space as well as at the occupied level.
- Ventilation blocks or louvres should be provided above the ring beam, and should cover 1m length per room or above every window.

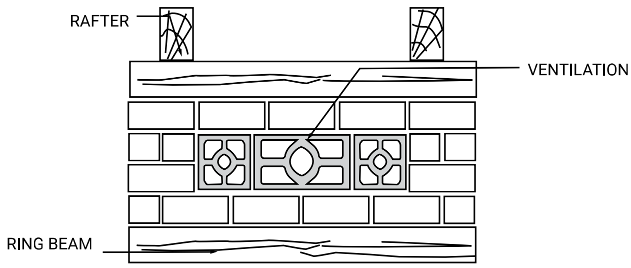


Figure 33. Ventilation blocks

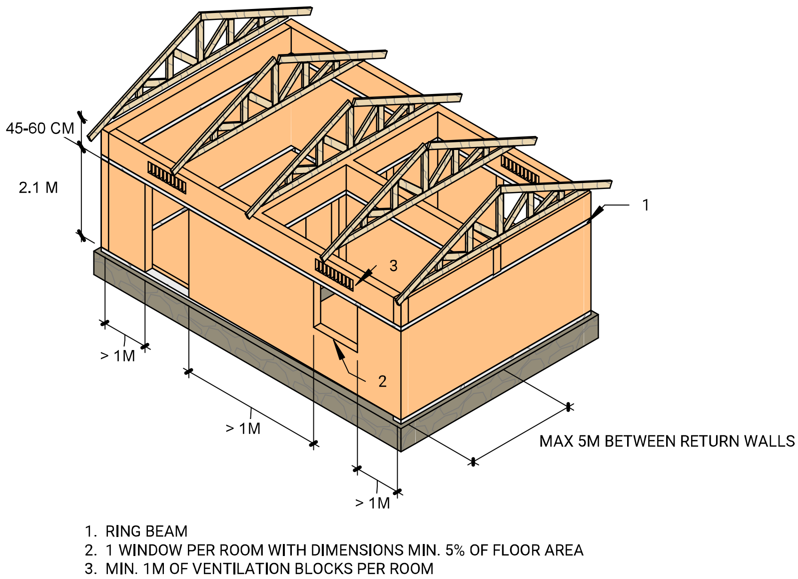


Figure 34. Best practice configuration of walls and openings

4.10 Veranda (Porch)

- Unless otherwise specified by a structural engineer, the veranda should be supported by columns that are spaced at not more than 2.5m apart. Provide foundations under the columns, refer to Section 4.2 for guidance.
- Column should be made of either:
  - Rectangular concrete column with a minimum of 20cm wide reinforced with at least 4x 12mm diameter rebar and 6mm diameter links at 30cm centres;
  - Circular concrete column with at least 20cm diameter reinforced with at least 6x 12mm diameter rebar and 6mm diameter links at 30cm centres;
  - Fired brick with bonding pattern per Figure 35; or
  - Timber or steel that is capable of supporting the loads.

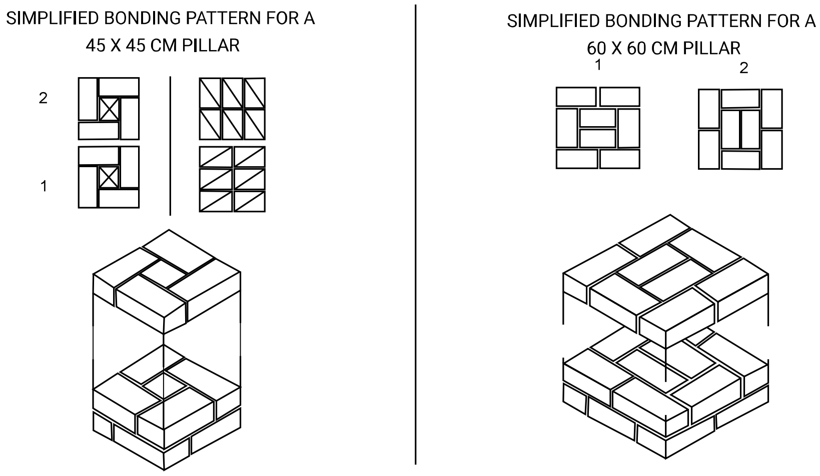


Figure 35. Bonding patterns for fired brick columns

- Beams on top of the columns should follow the requirements for lintels.
- Appropriate layouts integrating a veranda are shown in Figure 36. Otherwise, this guidance generally assumes a rectangular plan with walls along all four edges. For other configurations consult a structural engineer.

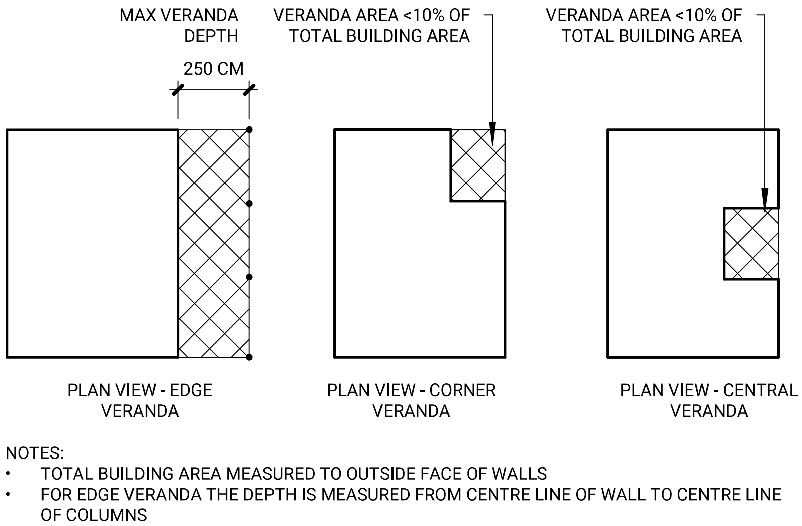
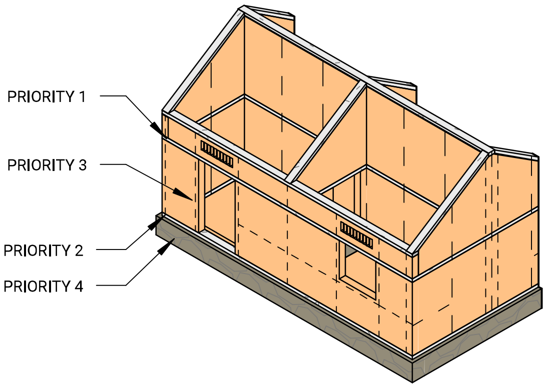


Figure 36. Veranda layouts

4.11 Priority building elements for seismic performance

As highlighted in Section 4.1 the earthquake hazard level varies across Rwanda. In order to improve the performance of adobe buildings during an earthquake across the country specific interventions have been recommended. In the regions of higher seismicity (such as the western province and the volcanic region) additional measures are advised. Whilst all are recommended to ensure stability during an earthquake, see Figure 37 for advised prioritisation of these interventions.



ORDER OF PRIORITY OF BUILDING ELEMENTS FOR SEISMIC PERFORMANCE

PRIORITY 1: A RING BEAM IS THE MOST IMPORTANT SEISMIC REINFORCING ELEMENT. IT MAY BE TIMBER OR CONCRETE. IN REGIONS OF HIGHER SEISMICITY, CONCRETE IS RECOMMENDED. REFER TO SECTION 4.6. A CAPPING BEAM IS ALSO NECESSARY TO RESTRAIN THE WALLS ABOVE THE RING BEAM AND CAN BE USED TO SECURE THE ROOF RAFTERS. REFER TO SECTION 4.4. THIS IS NOT REQUIRED IF THE ROOF HEIGHT IS ACHIEVED THROUGH TRUSSES OR TIMBER FRAMING.

PRIORITY 2: A GROUND BEAM TIES THE FOUNDATIONS TOGETHER AND ENSURES THAT THE WALLS ACT AS ONE DURING AS EARTHQUAKE. IT ALSO SECURES THE WALL REINFORCEMENT - SEE PRIORITY 3. IN REGIONS OF HIGHER SEISMICITY A LARGER GROUND BEAM SIZE IS RECOMMENDED - REFER TO SECTION 4.2.3.

PRIORITY 3: WALL REINFORCEMENT SUPPORTS THE WALLS AGAINST IN-PLANE AND OUT-OF-PLANE SEISMIC LOADS. THIS IS ONLY RECOMMENDED IN REGIONS OF HIGHER SEISMICITY. REFER TO SECTION 4.5

PRIORITY 4: IN REGIONS OF HIGHER SEISMICITY A WIDER FOUNDATION IS RECOMMENDED. REFER TO SECTION 4.2.2.

Figure 37. Priority building elements in a higher seismicity region

4.12 Parapets

To avoid instability, parapets should be appropriately restrained. In cases where the parapet extends above the roof level, a beam should be provided where the roof sheet meets the wall. In areas of high seismicity, an additional beam should be provided on top of the parapet to stabilize it. Figure 38 provides parapet details with concrete or timber beams.

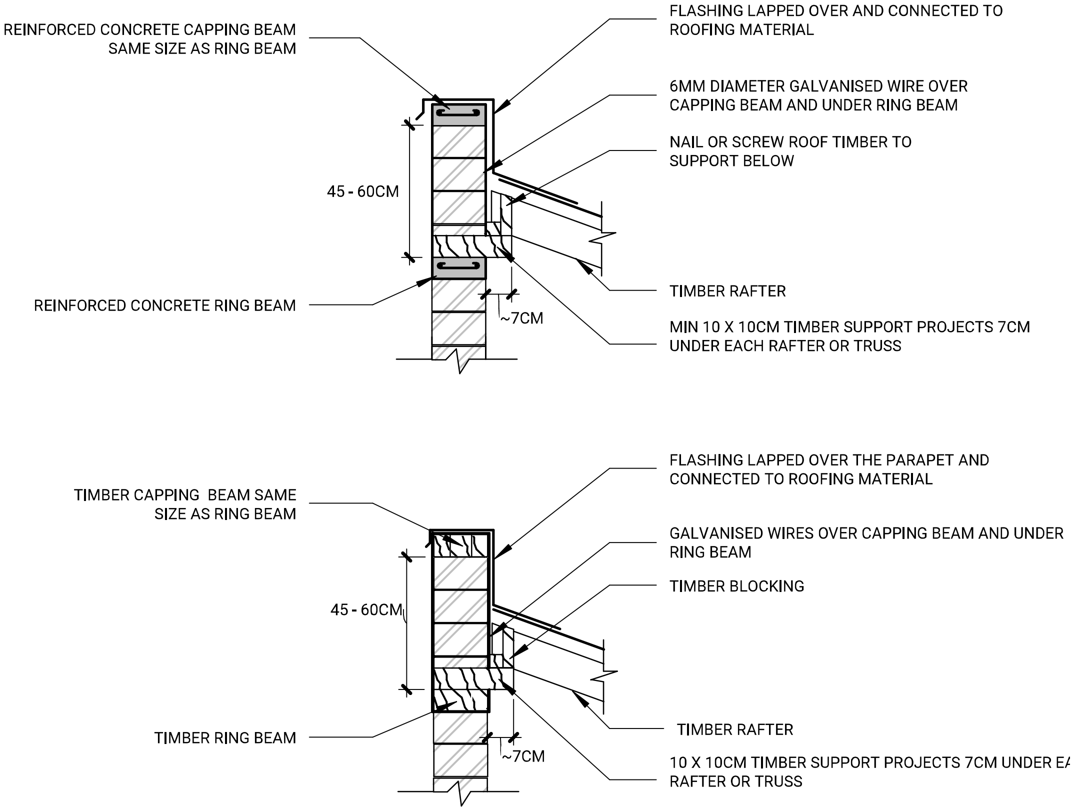


Figure 38.Parapet details

4.13 Wall protection against water and abrasion

When exposed to weather, adobe blocks are very susceptible to water erosion, which may reduce structural integrity by reducing the width of the wall over time. Abrasion is also particularly common at corners of buildings and doorways, which are areas key to the structural integrity of buildings.

To protect the walls from erosion and abrasion, a sacrificial protection layer, typically an earth plaster, should be applied to both internal and external walls.

Additional layers of plaster may be added to improve durability. To maintain the wall, whenever the adobe blocks are exposed, the plaster should be re-applied.

4.14 Finishes

Research shows that it is advisable to protect adobe block walls with plaster once construction is complete. The following recommendations are to be applied to protect the structure from erosion caused by rain.

Layer 1: Mud plaster

- Mud plaster is applied to achieve a level surface and should only be applied after the mortar appears completely dry.
- Holes in the wall should be filled with pieces of block, not mud plaster.
- A good soil for mud plaster should have high sand content (40-80%) to reduce the likelihood of cracking. Use the soil wash test in Appendix A to understand the granular quantity of the soil being used.
- Before applying mud plaster to an area, the wall should be gently dampened with water to improve bond.
- Mud plaster should have the same water content and consistency as that of the adobe blocks when the blocks were made.
- Application of mud plaster starts from the top of the wall and continues downwards.
- The surface texture of the mud plaster should be rough in texture for the second layer of sand plaster to properly adhere to it. Though mud plaster may crack, the cracks should not be so significant that they allow the mud plaster to easily fall away.
- The thickness of mud plaster varies between 1-4 cm depending on how much mud is required to level the surface of the wall, but the thickness should be as close to 1cm as possible to achieve a smooth level.

Figure 39. Example of poor quality mud plaster and mud constituent come off - to be avoided

Figure 40. A good mud plaster has fewer cracks and mud constituent doesn't come off

Mud plaster with excessive cracks (as shown) are likely to lead to the mud plaster peeling off the wall easily, and therefore should be avoided.

Layer 2: Water resistant plaster

Research shows that protecting the adobe blocks with another layer of water-resistant plaster will protect the blocks. It is advisable to apply it in a smooth layer only after the mud plaster appears completely dry. This is approximately 4 days outside or 7 days inside, but timing may vary depending on season, ventilation, thickness, initial moisture content and soil type so it is important the plaster is completely dry - appearing the same as the dry material. Each layer of plaster should allow moisture to escape from inside so that trapped moisture does not build up and condense behind the plaster layer, exerting pressure and leading to the front plaster layer peeling off. Two types of water-resistant plaster are advisable - stabilised with linseed oil or stabilised with cement. These two types of plasters cannot be combined, people can either use linseed oil or cement plaster.

1. Linseed oil sand plaster

For this plaster linseed oil is the main stabilizer that binds sand particles and provides strength to the plaster. Linseed oil plaster breathes and allows trapped moisture to escape, therefore it is the recommended approach. It is particularly important for buildings which have general issues with moisture due to poor drainage, no roof overhang, no foundation etc.

- The soil should have a high sand content in the range of 75-85% to reduce the likelihood of cracking. A clay content of 25-15% is needed to bind the sand.
- Mixing ratios of soil to water vary depending on the initial moisture content of the soil, but it varies from 1:6 to 1:8 (volume of water to soil). The goal is to have a similar consistency as the viscosity of mud for the adobe block.
- After mixing, before applying sand plaster to an area, check to see if mud plaster is fully dried, and gently dampen with water to improve the bond.
- Plaster is applied on the wall from top to downward.
- If plaster develops desiccation cracks or shows signs of damage as it dries then it needs to be repaired by preparing additional plaster, using a trowel and wooden float to fill cracks, and re-floating that area again.
- A thickness of about 1 cm is required but can go up to 2 cm to achieve a completely smooth and well levelled wall.
- After the sand plaster is completely dry, the linseed oil layer is applied at a rate of 0.2L per sqm for a smooth surface texture. It is applied in two layers (the first coat is 0.15L per sqm and the second coat is 0.05L per sqm) simultaneously. The second coat is applied to cover any areas that are uneven from the first coat.

2. Cement sand plaster

For this plaster, cement is the main stabilizer of plaster which binds sand particles and provides strength to the plaster. Be aware that cement plaster does not breathe as easily as linseed oil plaster - which makes it hard for trapped moisture between plaster and wall to escape. Therefore when using cement plaster it is important to incorporate into the building construction some moisture prevention measures as laid out in this document. These include proper drainage, the optimal size of roof overhang, a stone masonry foundation with a DPM on top, and protection at the base of the wall. If these interventions are not respected, cement plaster is expected to eventually peel off as moisture builds up between the wall and the plaster.

- Sand with a clay content of under 25% should be used to reduce the likelihood of cracking.
- The ratio should be 1 bag of cement to 4 wheelbarrows of sand.
- When adding water the goal is to have a similar consistency as the viscosity of mud for the adobe block.
- Apply steps 3-6 from the “Linseed Oil Sand Plaster” section.

Figure 41. Picture showing how mud plaster and cement plaster don’t bind together. Hence cement plaster comes off.

Roughcast plaster

For the outside wall, roughcast is highly recommended for the durability of plaster because it protects the previous layer and its surface texture doesn’t expose the entire surface of plaster to runoff water on the wall.

Appendix A- low tech soil tests

The Snake Test and Wash Test may be used to determine if the soil is appropriate for making adobe blocks

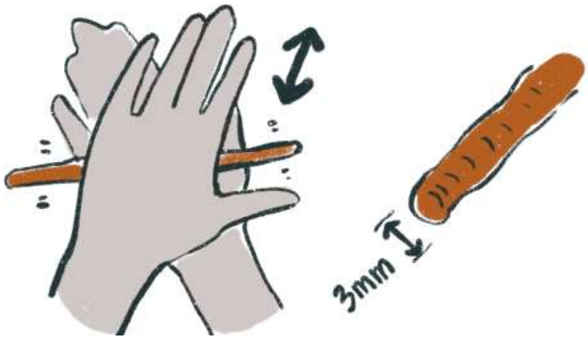
Snake test

Perform the snake test using the methodology below:

The purpose of the snake test is to check the plasticity of soils. Being plastic means that they have a noticeable amount of clay. To do that:

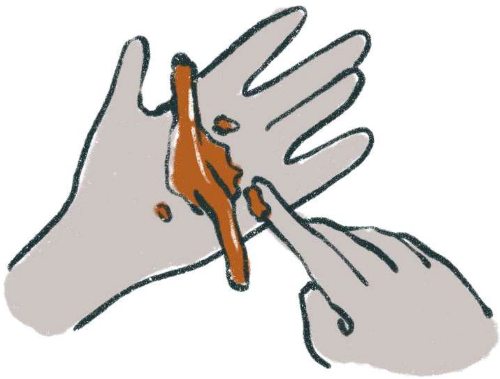
- Place a small amount of wet soil free from gravel between palms.
- Confirm the moisture content is correct according to Table 1.
- Roll the soil until it forms a long, round thread; the aim is to achieve the thinnest thread possible.
- A thread of 3mm diameter means the soil is likely to be suitable. However, if the soil rolls to a thread less than 10mm diameter it may also be suitable. This is because the ability to roll a thin thread depends not only on the soil but also on the experience and technique of the mason doing the test.
- If it fails to be rolled into such a thread, the soil is not plastic and therefore not recommended for making adobe blocks.
- Where this is the case, the soil can be mixed with a finer soil in order to increase plasticity, and this test should be repeated.

Typical process is presented below.



As a note, it is essential to make sure that the soil is not too dry or too wet. If it is too dry, it may crumble in hands immediately after starting to roll it, and if it is too wet, it may tend to stick to hands resisting to get rolled between palms of hands.

Too dry



Too wet

Soil Wash Test

If it passes the snake test (i.e. the soil sample can be rolled into a 3mm diameter thread), the wash test should be performed in accordance with the methodology below to work out the percent amount of coarse material (sand and gravel) in the soil. Materials required:

- Soil, roughly 3kg
- Weighing scale of 0.1kg accuracy
- At least 2m² plastic sheet
- 2 buckets
- 1L bottle for measuring water

Procedure

1. Take a representative sample of soil of about 3kg, free from vegetation debris and other organic material.
2. Weigh the soil with a scale and record its (wet) weight (Ww)
3. Air dry the soil sample for at least 48h preferably in the sun. Try to disperse the soil over a large plastic sheet so that soil thickness does not exceed 5 mm.

4. Every 1 to 2 hours turning it in all directions to allow even drying

5. Weigh the soil after drying process and record its dry weight (Ws)

6. Put the dry soil into a bucket and add water little by little while mixing to break clumped soil. You will need to add about 6 litrer of water

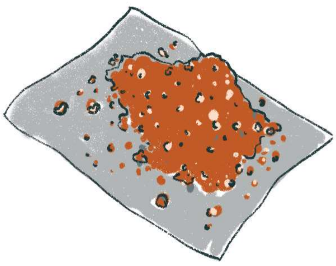
7. Once all clumped soil has been broken, agitate vigorously using a hand for about 1min. The mixture should look homogenous, there should be no remaining clumps of soil, and instead it should be possible to feel sand grains and gravel pieces.

8. After agitation, leave the mixture to stand for about 1 minute. The coarser material will settle to the bottom of the bucket and the fines will remain in suspension

9. Pour out the slurry (i.e. fines in suspension) gently into another bucket and stop when you reach the deposit which looks like a thick slurry at the bottom of the bucket.

10. Add water and repeat the process from step 6 to step 9 and until you remain with clean coarse material as a deposit at the bottom of the bucket. The water should appear clear.

11. Air dry the material on a plastic sheet preferably in the sun for at least 4 hours or until it is visually dry. Weigh the dry amount of coarse material and record its weight (Ds).



12. Work out the percent amount of coarse material (sand and gravel) in the soil as (Ds/Ws)x100

If the amount of coarse material in the soil is within the recommended values in this document then the soil is recommended for adobe blocks and trial blocks should be made. If the amount of coarse material in the soil is outside the recommended values in this document, which is 30 to 80%, the soil is not recommended for adobe blocks.

Appendix B - Drop test

The drop test may be used to indicate the strength of a block.

Procedure

1. Select a block that is fully cured.For this test the block should have a length of between 1 and 2 times its width.
2. Drop the block onto its corner as shown in Figure 39 from a height of 90cm onto a hard surface, such as compacted earth.

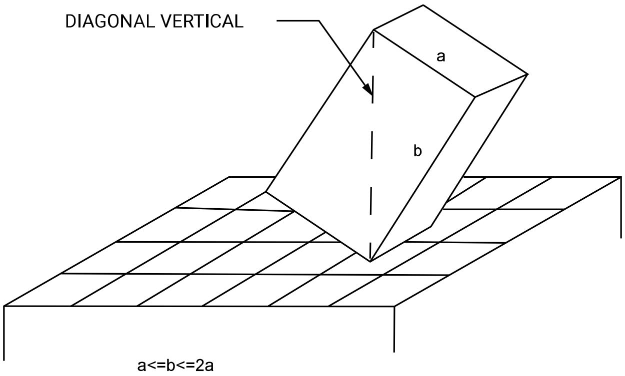


Figure 42. Orientation of earth blocks prior to dropping

Figure 43(a).Measuring a height of 90 cm

Figure 43(b). Dropping block on its corner

Figure 43(c). Completed test

Result

The block should pass the test if the following criteria are met:

- The block should pass the test if the following criteria are met:
- It does not shatter or break into approximately equally sized pieces
- There should not be a piece broken off that has a dimension either:
    - Greater than the smallest dimension of the block. For instance if the block has dimensions 30x20x10cm, then the maximum allowable size of the broken piece is 10cm.
    - Greater than 15cm.

The following are recommendations based on the pass rate of at least 20 blocks.

Above 80% pass rate: blocks perform well

60-80% pass rate: block is acceptable but recommend improvements, such as mixing with another soil to improve the properties and testing again

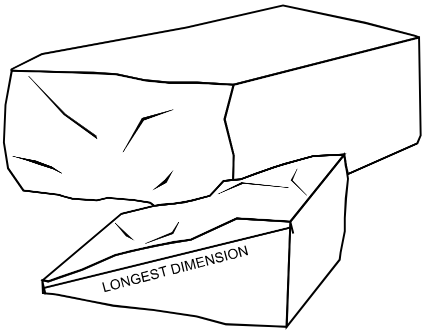
< 60% pass rate: strongly recommend not using the soil. Mixing with a significant percentage of another soil may improve the properties. Test again after mixing.

Shattered block: fail

Block broken in half: fail

Figure 44. Example of failed blocks

Small piece broken off block corner: see right for how to measure



How to measure broken piece - if less than 150mm: pass

Figure 45.How to measure the broken piece dimension

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