93404-1 pdf
Building in Nakuru - low cost housing improvement for Nakuru Town (Kenya)
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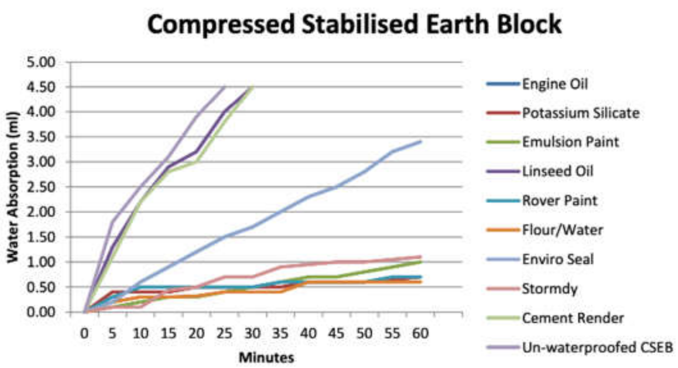
Because there is no mortar to bind them, dry-stacked bricks are vulnerable to shaking during construction. They require strengthening to achieve tolerable plumbness and straightness in walls over 3m long (Figure 4.5) or over 2.5m high.
In Tanzania, cheap farmers' stores are built using concrete partial frames with a centre-to-centre distance of 4.5m to 6.0m and height more than 3.5m. To build a masonry wall to infill the spaces, requires the formation of buttressing piers

A pier is a localised wall thickening, designed to increase a wall's vertical and horizontal stability and lateral strength.   Wall length between piers – 3m

Jonathan Chew – Dissertation- Water resistance
Water absorption is a characteristic of clay and cement content and is often related to the strength and durability of earth blocks, consequently it is important to identify the rate of water absorption of earth blocks (Riza, Rahman and Zaidi, 2011). According to Oti, Kinuthia and Bai. (2009), water absorption rate decreases with increasing age of earth blocks.

Figure 6.4.3 CSEB Comparative Table

Waterproof Agent	*Water absorption (ml/min)*
Flour/Water	*0.09*
Potassium Silicate	*0.11*
Emuslion Paint	*0.11*
Rover Paint	*0.11*
Stormdry	*0.14*
Enviroseal	*0.37*
Engine Oil	*0.37*
Cement Render	*0.55*
Linseed Oil	*0.56*
Un-waterproofed CSEB	*0.60*



Low Cost House Construction Manual Final 071109
The longer the blocks are cured, the higher the final strength of the wall will be.

Structural House Design
The following considerations are important in designing a structurally adequate and durable house:

- Interlocking blocks are recommended, although they may take more experience to use properly
- No vertical joint should be positioned above another vertical joint.
- bamboo or steel reinforcing, in a concrete matrix. Sliced bamboo pieces are sufficient for a one story
- construction.
- Additional reinforcement in and around corners within the bond beam.
- A lightweight roof relative to the entire structure.

- length.
  Windows and doors should not be near corners if not necessary.
- No openings should be greater than 1.2m width.
- At least 1.2m of wall should exist between all doors or windows to maintain vertical wall strength.
- Interior walls in both directions which are load-bearing and similar in design and construction to exterior walls.
- Square or nearly square floor plan (not 'L' shaped or other irregular shapes).
- Strong lintels above all windows and doors which will prevent collapse at these locations.
- Good protection of the wall against water by constructing a big overhang, good drainage and splash protection on the base of the wall.

Place a plastic sheet above the foundation to prevent water and termites from entering the walls. Window openings should also be located in the middle of the wall, away from corners, to make the structure more stable.

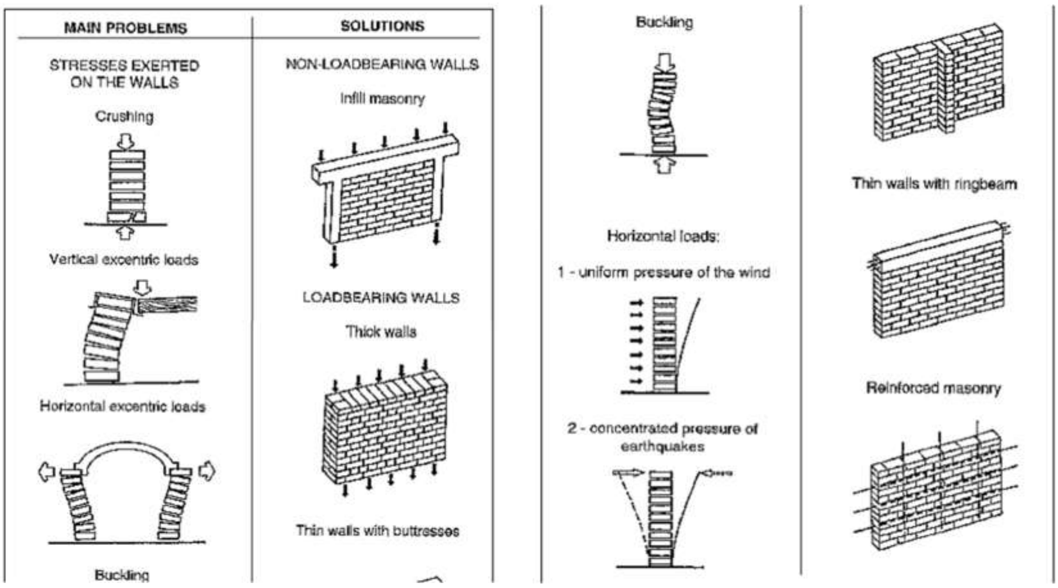
The bond beam is an important part of the structure, as it ties the walls together at the weak openings. The bond beam should be made of high quality 1:2:4 (cement: sand: gravel) concrete with either bamboo or steel reinforcement.

COMPRESSED EARTH BLOCKS: MANUAL OF DESIGN AND CONSTRUCTION
The main problems to resolve - two categories:
structural problems which force one to respect the principles of good
compressive strength and, by contrast, the poor tensile and shearing strength of earth as a building material. In respecting these principles, the designer must choose between appropriate structural designs and construction details.

problems of water and humidity, resulting from what is know as the "drop of water system": erosion, streaming water, splash-back, infiltration, absorption. These problems
make the designer respect certain fundamental principals: protecting the top and the base of the walls ("a good hat and good shoes"), allowing the earth building material to breathe and incorporating suitable details into the design principles.

Solutions
For non-loadbearing walls, infill masonry (of a concrete framework of wooden lattice) limits the risk of crushing occuring.

For loadbearing walls, there are several solutions which enable the forces of excentric loads, of buckling or of horizontal loads to be reduced.
These include:
- using the thickness of the walls;
- improving the stability of thin walls by using buttresses;
- improving the stability of thin walls by using ring-beams;
- adding horizontal and vertical reinforcement to the masonry, (earthquake-resistant systems).



Ring-beam at foundation level
When building on poor soils which are unstable and which may cause differential settling, a foundation ring-beam is recommended. This will stabilize the sides against potential movement in the foundations.

Structural weaknesses of openings
It is important to compensate for shearing stress loads to the lower edge which is transmitted directly down the jambs of the reveals from the lintels.
The following classic mistakes should be avoided:
- making openings too big, placing too great load a on the lintel;
- too many openings of too many different sizes on the same wall, which weakens the wall;
- locating an opening immediately next to the corner of a building, making the corner buckle;
- two openings too close together with too slender an intermediate pier, making the pier buckle;
- insufficiently strong frame jambs, leading to buckling;
- insufficient anchoring of the lintel or of the supporting base into the wall, leading to shearing;
- poor earth block bonding patterns near the openings, leading to cracking through superimposed vertical joints.

Lintel
The lintel is subjected to the high load exerted by the masonry it supports and which it transmits through the frame jambs towards the sill or the threshold of the opening. To eliminate the danger of shearing, it is therefore preferable to increase the length of the part of the lintel which is held in the wall, allowing a minimum of 20 cm for small openings. The jambs must have high compressive strength and care should be taken with this by using earth blocks of equal strength. The construction materials used for lintels include wood or reinforced concrete or even, to preserve the structural homogeneity of the wall, various forms of earth block arches (Dutch, depressed or other) which replace the lintel by helping to transmit loads to the jambs.

Vulnerability to humidity at openings
Structural weakness, most often marked by cracking, leaves the way open for the erosion of openings as a result of vulnerability to humidity. This vulnerability near the frames of openings occurs as a result of the "drop of water system" which refers to the combined effect of water streaming, splashing-back or stagnating.

The weak spots are the bond between the lintel, the jambs, the sill and the masonry. Particular care must be taken with toothings, anchor-points and masonry fixings. Similarly, with rebates and embrasures, as well as with all the fixings of frames, hinges, and sockets.
The following are recommended:
- a drip under the lintel and under the sille, or a system of fillets to project water away. All projections must be avoided;
- solutions to problems of condensation which could arise at thermal bridges;
- reinforced stabilization, rendering, or covering joints in the external facade, flush with the sides of the openings (in high rainfall regions);
- water-proofing under the sill.

Dimensioning the openings
There are certain rules for dimensioning the openings in an earth masonry structure, which do not preclude variety in the design of their shape and size.
- In any one wall, the ratio of voids to total surface area should not exceed 1:3 and voids should be evenly spaced. Too great a concentration of voids or openings which are too large should be avoided, unless the structure has been designed with these in mind.
- The overall length of openings should not exceed 35% of the length of the wall.
- Standard opening spans should be restricted to 1.20 m for standard section lintels. For wider openings, the lintel must be increased in size and it must be more deeply anchored into the wall.
- The minimal distance between an opening and the corner of a building should be 1 m. This distance can, however, be reduced by taking appropriate measures in the construction.
- The width of a pier common to two openings should not be less that the thickness of the wall and should be equivalent to a minimum of 60 cm (two standard blocks). The pier is not loadbearing unless it exceeds 1 m in width (lintel common to two openings for a less wide pier).
- The height of the masonry above the lintel and of the breast below the supporting base should respect a balanced ratio depending on the width of the opening.

NOCMAT_09_Bath_Uni___Gordon_Browne_paper_final
Surface treatments:
Not only can the durability of a block be improved by stabilisation, the application of various coatings will also improve them.

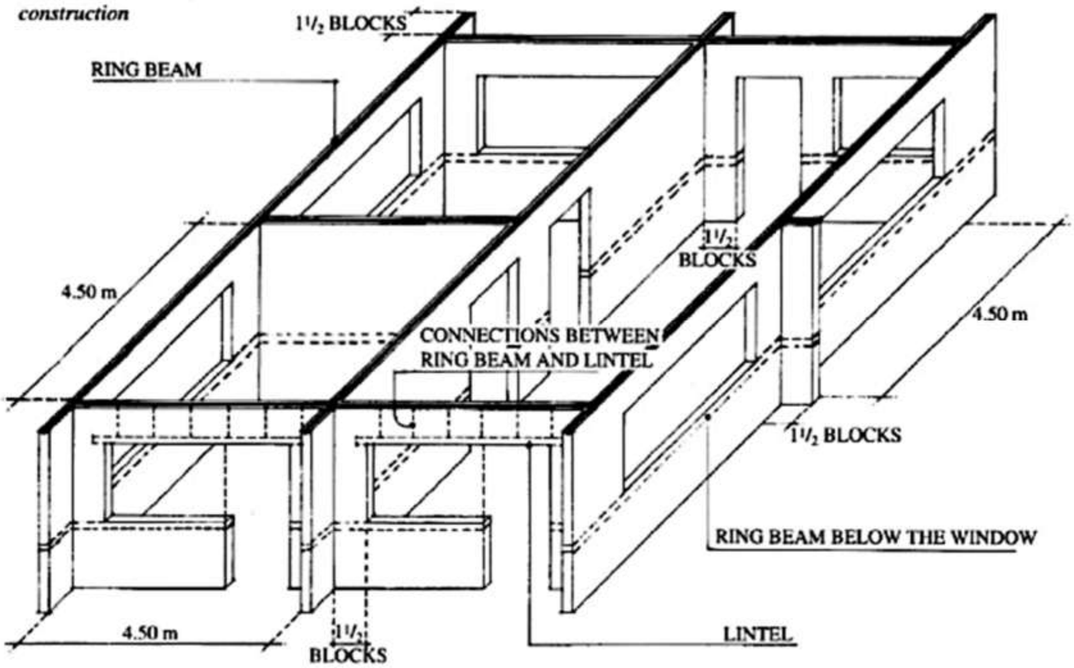
Table 1: League table of drip testing results

Rating	Type of brick	Coating	Depth (mm)	Rating	Type of brick	Coating	Depth (mm)
1st	Cement	Engine Oil	0	7th	Cement	Sand	7
1st	Lime	Engine Oil	0	7th	Lime	Goat Hair	7
1st	Plain	Engine Oil	0	7th	Lime	Sand	7
2nd	Cement	Animal Fat	1	8th	Lime	Cooking Oil	8
3rd	Cement	Goat Hair	2	9th	Lime	Ash	9
3rd	Cement	Gravel	2	10th	Plain	Animal Fat	12
3rd	Lime	Animal Fat	2	11th	Plain	Cooking Oil	20
4th	Cement	Cooking Oil	4	12th	Plain	Gravel	50
5th	Cement	Plain	5	13th	Plain	Plain	100
5th	Lime	Gravel	5	13th	Plain	Goat Hair	100
6th	Cement	Ash	6	13th	Plain	Ash	100
6th	Lime	Plain	6	13th	Plain	Sand	100

Cement stabilised rammed soil blocks were the most moisture resistant and with an additional coating of oil (old engine oil) or animal fat this was significantly improved.

Building with Interlocking Blocks
Almost any type of building can be constructed with interlocking blocks, the main design constraints being that the plan should be rectangular and all wall dimensions and openings must be multipies of the width of the block type used.
All other principles of design and construction, such as dimensioning of foundations, protection against rain and ground moisture, construction of ceilings and roofs, and the like, are the same as for other standard building types.

Figure 6 Principles of interlocking block construction



Structural Guidance Note – ARUP
Durability
In order to achieve durability, it is important that the limitations of unfired earth block construction are understood and considered by both the architect and the engineer, If used correctly there is no reason why they cannot satisfy the typical 50–year design life.
Methods of damage include:

Water:
loss of cohesion – earth construction is soluble in water
splitting due to freeze/thaw cycles
salt deposits which may break down the clay matrix
Impact:
from people, animals, etc
Vegetation:
undermining of wall
plant growth on the surface as a result of damp facilitating
infestation from rodents and insects.

The overarching principle is to protect against water. Earth masonry should never be allowed to sit in water. The "hat and shoes" approach should be followed — the parts of a wall most vulnerable to water are the top and the bottom. Refer to Appendix A: Case studies and Appendix B: Typical details.

Orientation
Walls facing the prevailing wind direction are at greater risk from wind-driven rain and should be well protected. Consider orientating gable ends away as they tend to be more exposed.

Surroundings
A veranda or covered walkway provides additional protection, and should be designed to drain away from the wall.

Vegetation should be kept away from walls.

Drainage
Water must not be allowed to pool at the base of a wall.
The surrounding area should be well drained and graded to prevent surface water collecting.
Consider that hard surfaces cause more splashing.
Gutters and pipes carrying water should be located away from walls if possible in case of leaks. Alternatively they should be checked regularly to ensure speedy repair as part of a maintenance regime (refer to Section 4.7).

Foundations
Earth blocks should only be considered for foundations for very dry, well-drained sites. In this case the blocks should always be stabilised.

Damp-proof course
Earth masonry must be isolated from groundwater and so a damp-proof course should always be included, even when the masonry is located on top of a concrete or fired earth brick foundation.
The damp-proof course should be continuous with the slab protection and generally at least 150mm above ground level.
The material chosen should be flexible in order to accommodate shrinkage of the wall. Suitable materials include bitumen-coated aluminium, copper and copper alloys, lead and zinc, or heavy-duty plastic sheeting.

Base protection
The base of a wall is especially prone to water erosion by splash, standing or pore water. To this end the base of the wall may either be raised up on a base course or protected by a wearing layer.
A base course could consist of fired brick or concrete.
A wearing layer could consist of a stone/cement render as employed at Pajule School, Uganda. Refer to Appendix A: Case studies.

The height of the base course may also depend upon the roof overhang provided.

Roof overhang
Roof overhangs should normally be provided to prevent water impacting on and running down the face of the wall. The length of projection required will vary according to the climate. In areas with extreme weather where wind-driven rain may impact the wall at shallow angles, roof overhangs become less effective. In this case additional measures such as surface protection should be provided.

Surface protection
The requirement for a protective coat or finish may depend on several factors:
1. climate
2. architectural detailing and aesthetic requirements

3. building use
4. acceptable level of maintenance.

Surface protection may be applied internally and externally. It is vital that it is vapour permeable. Refer to Section 3.8.1 for more information.

Corner details

The stability of earth masonry structures depends largely on the stability of their corners. Consider that corners and openings are especially prone to impact damage.

Corners may be strengthened by substituting a harder material, such as stone or burnt brick, for the earth blocks. Alternatively surface protection may be applied.

CASSO Orphanage, Uganda

Key data

double interlocking stabilised soil blocks (ISSBs)

imported murram

reinforced concrete ring-beam at roof level to provide a structural tie during a seismic event

piers formed from ISSBs at regular intervals to provide lateral restraint

load-bearing single-storey construction.

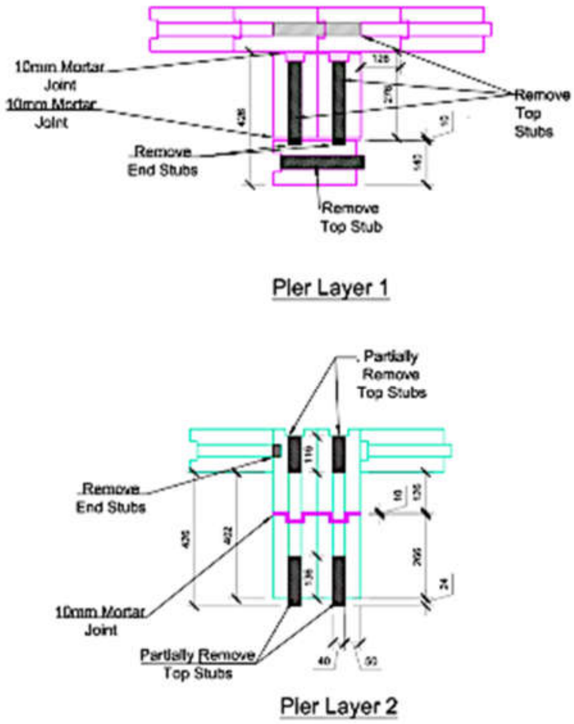
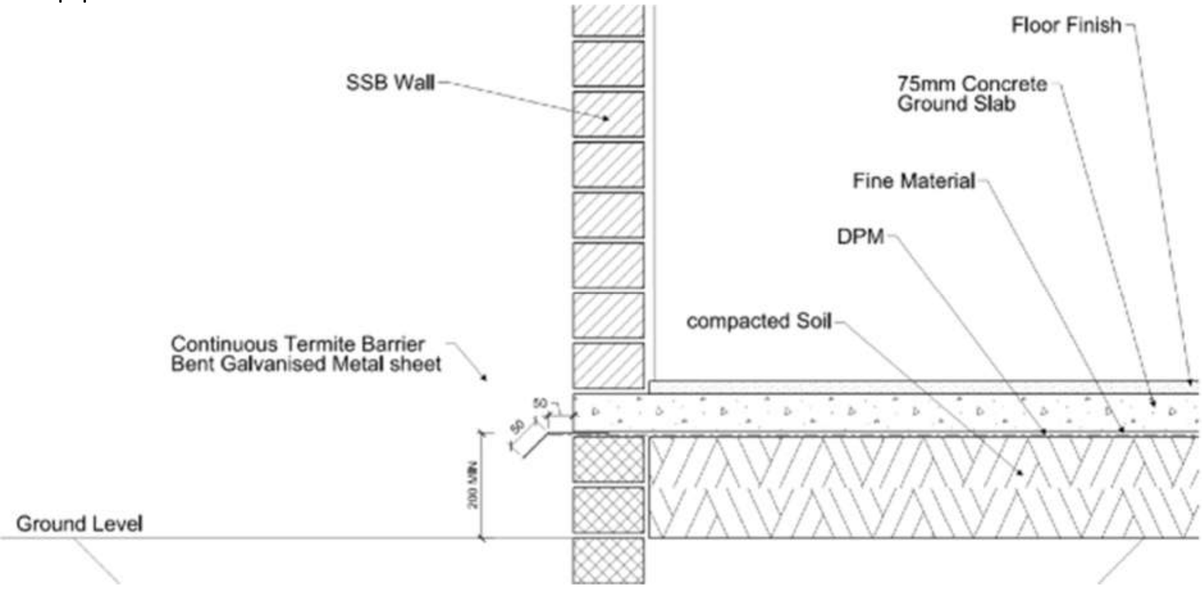


Fig A31. Pier details.

Malawi schools

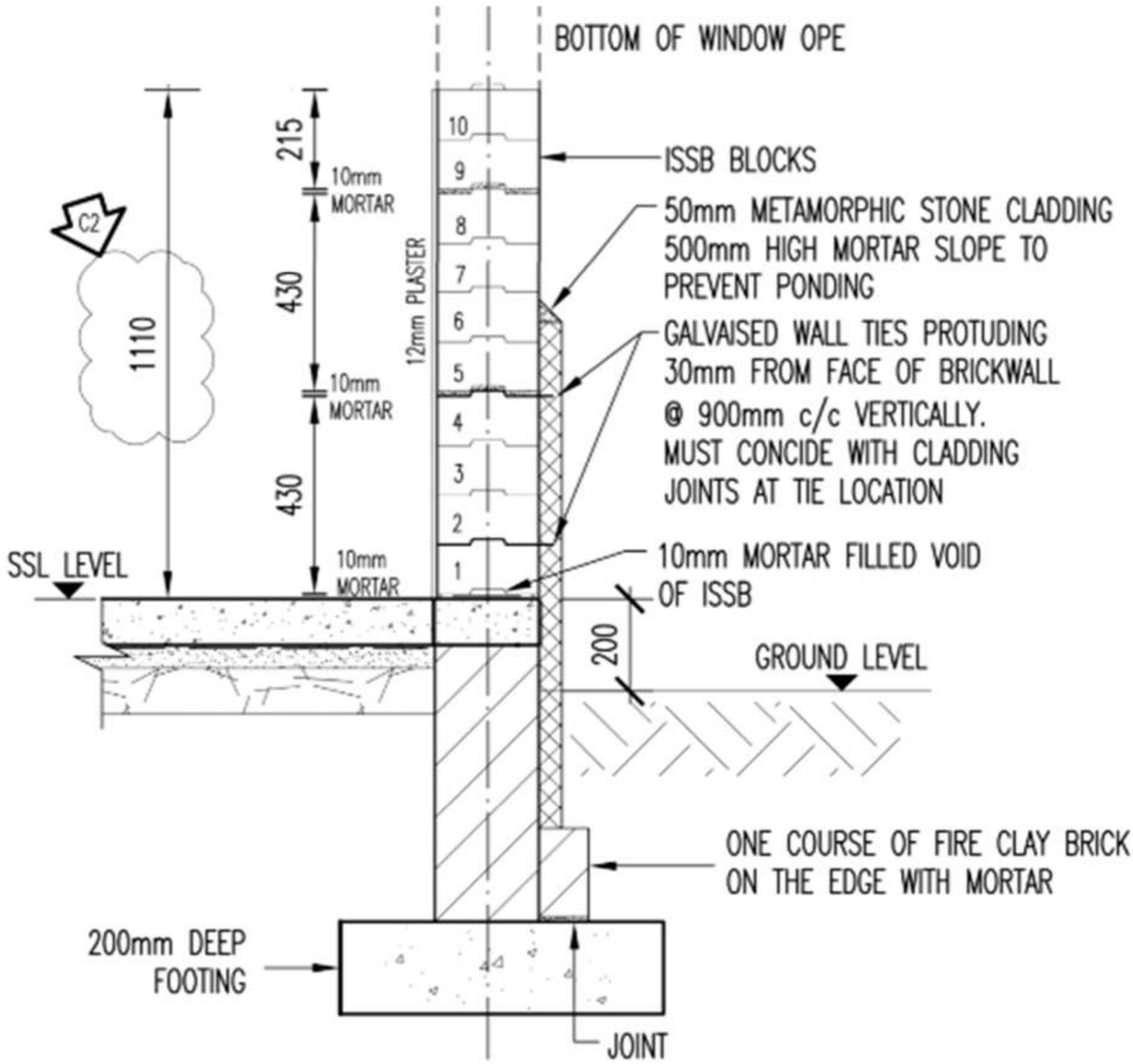
Key data
compressed stabilised soil blocks, Cinva–ram block press,
site-won soil
290mm×140mm×100mm
load-bearing single-storey
reinforced concrete floor slab with fired brick foundation

Damp-proof course and termite nib.



Pajule Secondary School, Uganda

Key data
double interlocking stabilised soil blocks with mortar in every fourth bed typically, site-won soil
290mm×140mm×115mm
large roof overhang – building surrounded by a veranda
600mm high stone cladding at base
concealed reinforced concrete ring beam formed through modified block type.



Nonconventional and vernacular construction materials

The base course is bonded with mortar up to one course above the floor level. The middle courses are dry-stack up to lintel level. The top three courses are again bonded with mortar to form a ring beam at the top of structure as shown in Fig. 8.17. Alternatively, a reinforced concrete ring beam could be cast at the top.

The CSEB material starts from about 0.5 m above ground level. The best practice for CSEB is to keep it permanently dry.

The absence of a bonding agent in the joints between masonry units makes the wall structure flexible and assists in alignment during construction.

Hydraform Headquarter South Africa

ASIA - Hydraform building specs - simple rules

- First course above slab or damp proof course to be bedded in mortar. Blocks in this leveling course are to be leveled in all directions and to be at the same level as adjacent blocks.
- Blocks to be dry stacked in stretcher bond until lintel level, usually 2.1m above internal floor finish.
- Windows and doorframes to be secured using lugs bent to joint level.
- Reveals to windows to be plastered.
- 75mm pre-stressed concrete lintels to be used over doors, windows and openings. Lintel bearing length on each side of the opening should not be less than 300mm.
- Gaps between block work and steel window or doorframes to be filled with mortar.
- All intersections between walls to be built using alternating half blocks.
- All corners to be build using half blocks cross- bonded.
- Gap between lintels and block work above lintel should be filled with mortar.
- Ring beam to be constructed at top of wall by bedding all block work above lintel level in mortar. Mortar joints to be between 10 and 15mm. Brickforce to be placed in all mortar joints. Brickforce to be 2.2mm longitudinal wires at 130mm centers. Brickforce to over lap at corners and intersections. A minimum of 4 mortar joints are needed to form a ring beam.
- No chasing to be done in ring beam.
- Horizontal wind bracing in the plane of the ceiling to be to professional engineers design.

Roof and Roof Anchorage

- One 4mm diameter galvanised steel wire anchor tie per rafter to be placed through mortar joint at a minimum of 4 courses below the top of the wall.
- Roof to be to professional engineers design.

Services

- Services can be wall mounted on all walls or stored in vertical rebates chased into the wall below ring beam level. Chasing to be vertical only and to a depth not exceeding 50mm.

Mortar

- All mortar to be class II mortar having a minimum 28 days compressive strength of 7MPa in respect of laboratory tests and 5MPa for on site work tests. A mix of one bag (50kg) of cement (42,5MPa) to three wheelbarrows(3 x 65litres) of building sand is suggested.

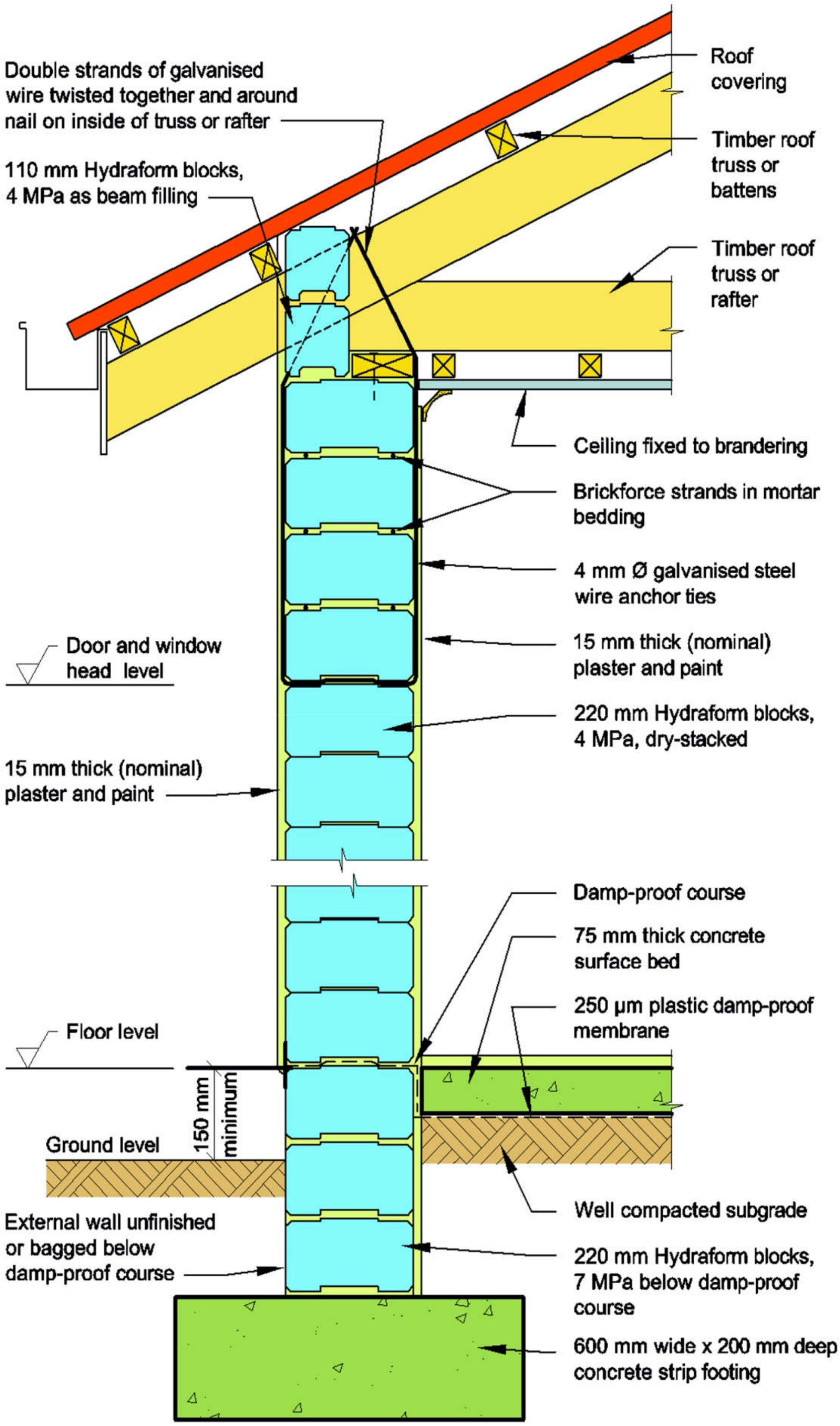


Figure 1: Typical section through foundation, external wall and roof

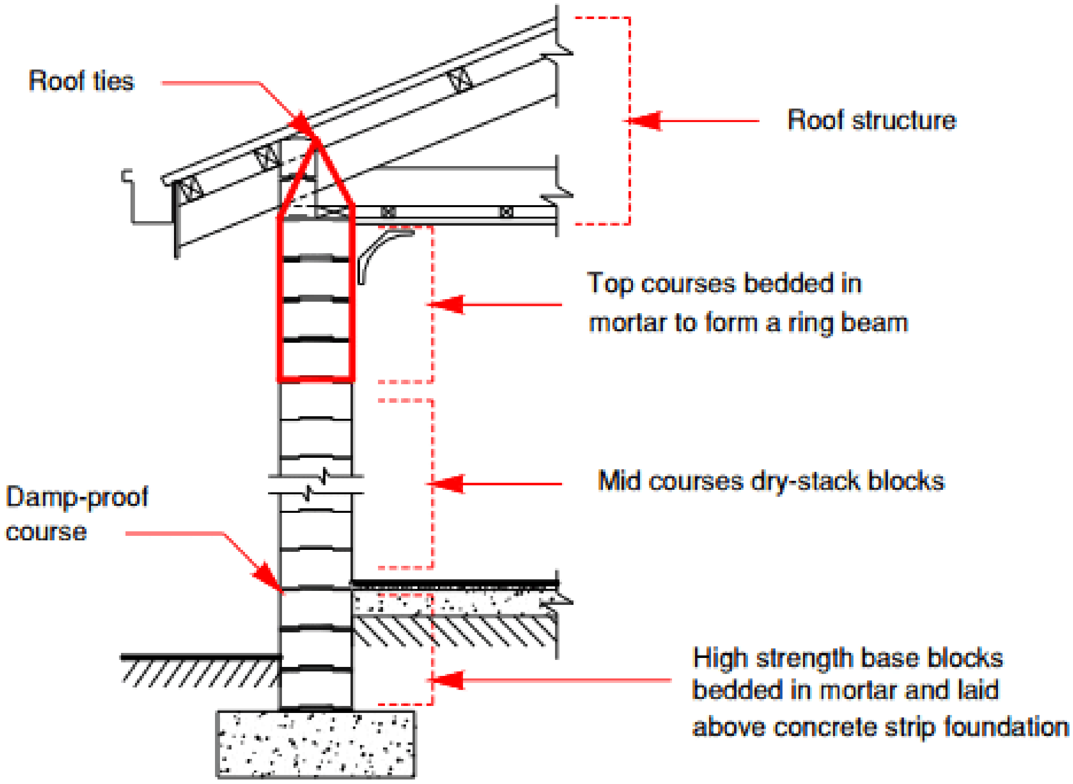


Figure - 2.7: Typical construction detail of Hydraform dry-stack system

A Best Practices Manual for Using Compressed Earth Blocks - Indian Country

Figure 10. Window Bucks Installed

After the door bucks are set, the first course of CMU blocks or CEBs, based on the design for the area climate, can be laid directly on the foundation. For CMUs, this step is usually done with cement or mortar. For CEBs, a contractor grade construction adhesive affords the best bond