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Compressed stabilized earth blocks — Main element —— Requirements, production and construction

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In order to match with technological development and to keep continuous progress in industries, standards are subject to periodic review. Users shall ascertain that they are in possession of the latest edition

Contents

Foreword

Rwanda Standards are prepared by Technical Committees and approved by Rwanda Standards Board (RSB) Board of Directors in accordance with the procedures of RSB, in compliance with Annex 3 of the WTO/TBT agreement on the preparation, adoption and application of standards.

The main task of technical committees is to prepare national standards. Final Draft Rwanda Standards adopted by Technical committees are ratified by members of RSB Board of Directors for publication and gazettment as Rwanda Standards.

DRS 513 was prepared by Technical Committee RSB/TC 9, *Civil Engineering and Building Materials*.

In the preparation of this standard, reference was made to the following standard (s):

1) ARS 1333 Compressed stabilised earth blocks — Requirements, production and construction

The assistance derived from the above source is hereby acknowledged with thanks.

Committee membership

The following organizations were represented on the Technical Committee on *Civil Engineering and Building Materials* (RSB/TC 9) in the preparation of this standard.

A+ Construction Group Ltd

Africeramics Ltd

Consultants Engineers Group (CEG) Ltd

D&D Resources Ltd

Dutureheza Ltd

Enabel Rwanda

Greenpack Africa Ltd

Integrated Polytechnic Regional Centre (IPRC) — Musanze

Mass Design Group

NP Construction Company (NPCC) Ltd

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Standards for Sustainability (SfS)

Stonecraft Industries Ltd

University of Rwanda — College of Science and Technology (UR — CST)

Rwanda Standards Board (RSB) – Secretariat

Introduction

The building materials and construction industry is one of the most important sectors of economic activity and represents an essential instrument of socio economic development. It provides a wide range of services and capabilities for designing and constructing facilities necessary for economic development.

The major cost of construction is incurred on building materials and most of these building materials are cement products. The ever increasing price of cement coupled with the rise in the price of other construction materials make the construction cost far from the reach of the low and the middle income group of urban dwellers. This has led to research initiatives aimed at finding alternative durable and affordable construction materials for housing construction.

One such material is the compressed stabilised earth block, an improved form of one of the oldest materials used in building construction, adobe. Unfortunately, the quality of compressed stabilised earth blocks in some construction schemes is far from adequate and often materials are wasted in the production process. To extend the use of compressed stabilised earth building blocks to all types of housing e.g. low-cost housing in rural and urban areas and middle income housing in urban areas, production techniques need to be further improved so as to achieve better quality and reduce production costs. In order to do this the following points, need to be considered carefully.

a) Proportions between soil and stabiliser need to be optimized, taking into consideration the specific characteristics of the soil,

b) Compaction pressure applied to the moist soil mix needs to be sufficient so as to produce blocks that are dense and strong with regular surfaces and edges.

c) Block surfaces need to be smooth so that they have the potential to be used without an additional surface coating or render.

The world's oldest earthen building still standing is about 3,300 years old: the Granaries of the Ramasseum in Egypt, which has been built with sun dried bricks (adobes) by Ramses II of the 19th dynasty, around 1,300 BC in a place called Western Thebes. It can still be seen a few kilometres from the western shore of the Nile, opposite Luxor. In India, the oldest earthen building is Tabo Monastery, in Spiti valley - Himachal Pradesh. It was also built with adobes and it has withstood Himalayan winters since 996 AD. [3]

Compressed stabilized earth blocks — Requirements, production and construction

1 Scope

This Draft Rwanda Standard specifies the requirements for cement and/or lime stabilized soil blocks for use in general building construction.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

DRS 547, *Fire classification of construction products and building elements — Classification using data from reaction to fire tests*

DRS ASTM C593, *Standard specification for fly ash and other pozzolans for use with lime for soil stabilization*

RS EAS 18-1, *Cement — Part 1: Composition, specifications and conformity criteria for common cement.*

RS EAS 18-2, *Cement — Part 2: Conformity evaluation*

ISO 12439, *Mixing water for concrete*

ISO 13822, *Bases for design of structures — Assessment of existing structures*

ISO 14688-1, *Geotechnical investigation and testing — Identification and classification of soil — Part 1: Identification and description*

ISO 14688-2, *Geotechnical investigation and testing — Identification and classification of soil — Part 2: Classification principles and quantification of descriptive characteristics*

RS 186- 2, *Fire safety for buildings — Code of practice — Part 2: Details of construction*

3   Terms and definitions

For the purposes of this standard, the following terms and definitions apply.

3.1

stabilized soil blocks

building blocks made by a mixture of soil with a portion of cement and/or lime added as a stabilizer

3.2

nominal size
the size of a coordinating space allocated to a masonry unit including allowances for joints and tolerance

3.3

work size
size of a block specified for its manufacture to which its actual size should comply within specified permissible deviations

3.4

compressive strength
average compressive stress at failure taken when five blocks have been crushed in a compression test machine at a loading rate of 150 kN per unit

3.5

modulus of rupture
nominal transverse breaking strength of the blocks

3.6

facing unit

manufactured masonry unit designed for use where one or more faces will be exposed and for which the specification includes requirements on colour, finish, and other properties affecting appearance

3.7

hollow masonry unit
unit whose net cross-sectional area in any plane parallel to the surface containing cores, cells, or deep frogs is less than 75 % of its gross cross-sectional area measured in the same plane

3.8

solid masonry unit

unit whose net cross-sectional area in any plane parallel to the surface containing cores, cells, or deep frogs is 75 % or more of its gross cross-sectional area measured in the same plane

4 Abbreviatons

— CSEBs   Compressed stabilized earth blocks

— DPC   damp proof course

— DPM   damp proof membrane

— IAQ   Internal air quality

— LCE   light compactive effort

— OMC   optimum moisture content

— RC   reinforced concrete

— PAQ   perceived air quality

— RCC   reinforced cement concrete

5 Materials

5.1 Soils

5.1.1 Characterization of soils

5.1.1.1   The soil used for the manufacture of compressed stabilized earth blocks shall be of a suitable quality, free of deleterious and organic materials graded in accordance with ISO 14688-1.

5.1.1.2   Soils are comprised of four particle types or grades (gravel, sand, silt and clay), which are defined by their size. Gravel, sand and silt are further subdivided into coarse, medium and fine, as outlined in Table 1. The relative proportions of each of these grades govern the properties and suitability of a soil for earth building. Combined silt and clay content is often referred to as the fines content.

5.1.1.3   Gravel and sand are made from different size rock particles, and comprise the stable skeleton of a soil matrix. They lack any cohesive strength and retain their size whether wet or dry.

5.1.1.4   Silt comprises smaller size rock particles but, unlike gravel and sand silt, it does exhibit some limited cohesion and small swelling when wet.

5.1.1.5   Clay is soil is natural binder, sticky when wet and hard when dry. They are very unstable, swelling considerably when wet and often cracking when dry. The expansive nature of clay arises from free water entering spaces between their laminar-plate mineral structure. Kaolinite is the most common and fortunately the most stable of the clay minerals. Very reactive clays, such as montmorillonite, are generally unsuitable in any significant quantity because of their considerable swelling potential.

5.1.1.6   Cohesion is due to the strong bond forces that develop between films of adsorbed water bound to clay plates. In unstabilized earth building, clay is the primary binder and its cohesive strength is necessary to maintain material integrity.

5.1.1.7   Compaction is the densification of soil by packing solid particles closer together through the expulsion of air voids. There is direct improvement in strength and durability with increasing density, hence compacted earth building materials should be compacted at their optimum moisture content to attain their maximum dry density. Dry density depends on the compactive effort used. ISO 17892-2 is used to establish the maximum dry density and its corresponding optimum moisture content under a given standard compactive effort. Optimum moisture content may change with additive use. Dry density of poorly graded soils can be improved by adding particle sizes lacking in the original matrix.

Table 1 — Particle size fractions

Soil fractions	Sub-fractions	Symbols	Particle sizes (mm)
Very coarse soil	Large boulder	LBo	> 630
	Boulder	Bo	> 200 to 630
	Cobble	Co	> 63 to 200
Coarse soil	Gravel	Gr	> 2.0 to 63
	Coarse gravel	CGr	> 20 to 63
	Medium gravel	MGr	> 6.3 to 20
	Fine gravel	FGr	> 2.0 to 6.3
Sand	Sand	Sa	> 0.063 to 2.0
	Coarse sand	CSa	> 0.63 to 2.0
	Medium sand	MSa	> 0.2 to 0.63
	Fine sand	FSa	> 0.063 to 0.2
Fine soil	Silt	Si	> 0.002 to 0.063
	Coarse silt	CSi	> 0.02 to 0.063
	Medium silt	MSi	> 0.006 to 0.02
	Fine silt	FSi	> 0.002 to 0.0063
	Clay	Cl	≤ 0.002

5.1.1.8   Plasticity is the ability of a soil to undergo non-recoverable deformation at constant volume without crushing or cracking, and is due to the presence of clay minerals and/or organic matter. Depending on moisture content, soil may be in a liquid, plastic, or solid state. Soil moisture contents, known as the liquid limit (LL) and the plastic limit (PL), define the transition between liquid and plastic, and plastic and solid states respectively. These limits are determined from separate tests on material passing a 425 m sieve. The moisture range over which a soil behaves plastically is defined by its plasticity index (IP), given by

$$I_P = L_L = P_L$$

ISO 14688-2 classifies the degree of plasticity of fine soils using the following terms:

a)   non-plastic;

1.   low plasticity;

2.   intermediate plasticity;

3.   high plasticity.

5.1.2 Suitability of soils for manufacture of CSEBs

5.1.2.1   Natural soils for earth building shall be taken from subsoil layers found beneath organic topsoil layers, which are typically 100 to 300 mm thick

5.1.2.2   Soil used to make CSEBs shall be free from organic material and other non-soil substances, such as rubbish, deleterious material, etc. While this requirement is the optimum requirement, soils low in organic content not exceeding 2% to 4% are considered suitable to make CSEBs.

NOTE 1   Deleterious material in this context means soil containing salts such as sulphates which interfere with the setting of the binder.

NOTE 2   Organic matter content should be avoided, as this may lead to high shrinkage and possible bio deterioration as well as increasing susceptibility to insect attack. Organic material also interferes with action of stabilizers such as cement.

5.1.2.3   When soils with organic constituents are classified according to their organic content (see Table 2), a distinction is to be made between organic soils and mineral soils with an organic content. Classification of coarse and composite organic soils accumulated in situ is based on the type of organic matter and that of organic soils, on the genetic origin and the degree of decomposition of the organic constituents.

Table 2 — Classification of soils with organic constituents (ISO 14688-2)

Soil	Organic content (≤2 mm) % of dry mass
Low-organic	2 to 6

Medium-organic	6 to 20
High-organic	> 20

5.1.2.3   Soil shall not contain more than two (2) percent soluble salts such as sulphates.

5.1.2.4   The characteristics of soils suitable for rammed earth construction are given in Table 3:

Table 3 — Suitable characteristics of soil for compressed stabilized earth blocks

No.	Characteristic	Limit	Test method	References
(1)	Organic matter	2% to 4%		
(2)	Fine gravel and sand	50% to 70 %		
(3)	Silt	15% to 30 %		
(4)	Clay	5% to 15%		
(5)	Binding strength	80 mm - 120 mm	Roll test	Annex A
(6)	Shrinkage	≤0.05%	Shrinkage test	
(7)	Maximum particle size (MPS)	10-20[a)]		
(8)	Maximum and minimum liquid limits (LL)	25–46		[4]
(9)	Plasticity indexes (PI)	2–30		[4]
(9)	Wet density	1850 to 2100 kg/m^3		[9]
(10)	Dry density	1700 to 2200 kg/m^3		[5]
(11)	Dry compressive strength	1 to 15 MPa		[5]
(12)	Bending strength	0.5 to 2 MPa		[5]
(13)	Thermal resistance (300 mm thick wall)	0.35 to 0.70 m^2.K/W		[5]
(14)	Optimum moisture content	3.5% to 14%		[4]
a) However, particles over 50-100 mm have been successfully used.				

5.2   Water

5.2.1 General

Water used for production of CSEBs should be from a clean source. It should be free from organic material and any other harmful substances. Excessive impurities in water not only may affect setting time and strength, but also may cause efflorescence, staining, corrosion of reinforcement, volume instability, and reduced durability. Therefore, certain optional limits may be set on chlorides, sulphates, alkalis, and solids in the water or appropriate tests can be performed to determine the effect the impurity has on various properties. Some impurities may have little effect on strength and setting time, yet they can adversely affect durability and other properties.

5.2.2 Quality of water

In general, the suitability of water for ramming operations depends upon its origin. The following types may be distinguished:

b) **Potable water**: This water is considered as suitable for use in ramming. Such water needs no testing

c) **Water from underground sources:** This water may be suitable for use in ramming, but shall be tested.

d) **Natural surface water and industrial waste water:** This water may be suitable for use in ramming, but shall be tested.

e) **Recycled water:** Water which is treated up to acceptable limit which is suitable for its intended use.

f) **Rainwater** is generally suitable for ramming if collected in clean containers.

g) Water complying with the requirements of ISO 12439 shall be considered as suitable for the production of CSEBs.

5.3   Soil stabilizers

5.3.1 Objectives of soil stabilization

Stabilization of the soil aims to:

a) reduce the volume of interstitial voids so as to reduce porosity and increase the density

b) increase the cohesion/linking and strength/reinforcement of the soil;

c) reduce the permeability of the soil

d) make the soil water repellent;

e) increase the durability of the soil;

f) reduce the rate of soil shrinking and expansion in less in dry and wet conditions.

5.3.2 Stabilization procedures

5.3.2.1   Mechanical

The soil is compacted and the actions and effect on the soil are:

a)   Density and mechanical strength are increased.

b)   The water resistance is increased.

c)   The permeability and porosity are decreased.

5.3.2.2 Physical

The texture of the soil is corrected by adding or removing aggregates, which are inert materials. The actions and effect on the soil are:

d)   The soil is sieved to remove the coarse particles.

e)   Different soils are mixed to get a better texture.

f)   Gravel or sand is added to reinforce the skeleton.

g)   Clay is added to bind the grains better.

5.3.2.3 Chemical

Processed products, which are active materials, are added to the soil. There will be either a physico-chemical reaction with the grains or the creation of a matrix which binds the coarse grains. The actions and effect on the soil are:

h)   The reaction helps binding the grains of the earth.

i)   The water resistance is increased.

j)   The permeability and porosity are decreased.

5.3.3 Cement stabilization

5.3.3.1   The cement used for the manufacture of stabilized soil blocks shall be ordinary Portland cement complying with RS EAS 18-1. When mixed with water, the calcium silicates in the cement undergo a chemical reaction. They crystallize and create a matrix with the grains of sand and gravel in the soil which limit movement, especially of clay. The main reaction of cement is with the inert particles of sand and gravel. It has a little chemical reaction with clay. Therefore, cement is better suited for sandy and gravely soils, but is considered unsatisfactory for clays. The range of cement content needed for good stabilisation is between 3% and 10% by weight according to soil type.

k)   3 % is the minimum because the grains of cement have the size of silt. Adding less than 3 % of cement will reduce the cohesion of the soil more than it will really stabilise it because there is not enough stabiliser.

l)   5 % as an average gives generally good results. If the soil is well graded, 4 % can also give good results.

The maximum percentage has not really any technical limit. Needles to mention that the more cement is added to the soil, the stronger will the blocks be, especially to water resistance. It is preferable to limit the amount of cement to 8 to 1 0 % for economic reasons. Since adding more than 1 0 % cement will increase the cost dramatically but it will not increase the strength proportionally.

NOTE   For instance, a reinforced concrete "1 cement: 2 sand: 4 gravel" contains about 13% of cement by weight. A soil stabilised with 13 % cement will never have the strength of a concrete but its cost will be prohibitive.

Table 4 — Optimal characteristics of a good soil for cement stabilisation

Grain size distribution	Gravel: 15 %	Sand: 50 %	Silt: 15 %	Clay: 20 %
Plasticity	Plasticity index: Ip = 10 to 20 %		Liquid limit: WL = 20 to 30%	
Sulfate content (as SO4): <2%	Organic matter (Humus): Less than 1 %			
Chlorate content (as Cl): <1 %				

5.3.3.2   Retention and setting time of cement: After adding water, cement starts to crystallize (set). The initial setting is when cement paste loses its plasticity and starts to stiffen. Final setting is when the paste hardens and can sustain minor load. Both times are arbitrary and depend on the cement quality. The initial setting varies also with the moisture content and the temperature. It can be considered as starting 30 to 40 minutes after hydration. Therefore, the retention time for cement shall not be more than 40 minutes. Thus CSEB must be compressed before that time after hydration.

5.3.3.3   Curing time of cement: Once the cement starts to set the crystallisation process goes on for 4 weeks. Therefore, it is indispensable to cure cement for 4 weeks: the cement mix shall never dry for 4 weeks.

5.3.1   Lime stabilization

5.3.1.1 General

**5.3.4.1   The lime used for the manufacture of stabilized soil blocks shall comply with EN 459. The addition of lime causes four basic reactions: cation exchange, flocculation and agglomeration, carbonation, and pozzolanic reactions. The pozzolanic reaction changes plasticity of clay, making lime better suited for clayey soils than sandy soils.

**5.3.4.2   Lime will have more effect on clays which have high plasticity, such as clays from the smectite group, which includes montmorillonite and bentonite. The plasticity of kaolinite will not be so much influenced by lime because its plasticity is rather low. Montmorillonite on the contrary will see its plasticity reduced a lot because of its high plasticity, which synonymous of high capacity of cation exchange. Illite will react moderately with lime and its plasticity will change a little.

NOTE   Quick lime [Calcium oxide (CaO)] cannot be used for CSEB since the exothermic reaction when it hydrates can be dangerous for workers. It is said that adding quick lime as a powder to a humid clayey soil dries it due to this exothermic reaction. But this is not advisable as quick lime is very caustic and can cause burns.

**5.3.4.3   Pozzolanic reaction between lime and clay

a) The pozzolanic reaction is the first one to happen with clay in the soil. The modification of plasticity of clay is due to the pozzolanic reaction with lime. This process starts when water is added to lime and soil. The pozzolanic reaction varies with the type of clay, as mentioned above. This reaction produces stable calcium silicate hydrates and calcium aluminate hydrates as the calcium from lime reacts with the 7lumina-silicates from clay. Lime will create stable chemical bonds between the particles of clay and between the grains of sand and clay through cations exchange.

b) The pozzolanic reaction happens only when the blocks are kept humid and when the temperature is high enough. Below 4-5°C temperature, the pozzolanic reaction will be very much slowed down but it will start again when the temperature rises later on.

c) (In most cases the effect of lime on the plasticity of clay in the soil is almost instantaneous.

d) The calcium ions from lime cause reduction in plasticity. The speed and intensity for the change of plasticity of clay is dependent on the quality of the latter.

e) Kaolinite will undergo a very brief and minor reaction as it is not plastic enough but montmorillonite or other active clays of the smectite group will have a major change in plasticity. Although they will react instantaneously, they will need a longer time to react fully and it is not really possible to mention a time here because of the infinite variations in soil quality.

5.3.1.2 Stabilisation percentage of a good soil with lime

f) 2 % is the minimum because otherwise there will not be enough lime to stabilise active clay.

g) 6 % is an average which gives generally mechanical characteristics similar to 5% cement stabilisation.

h) 10 % is a maximum because adding more lime will reduce the density of the block. Lime is a very light material and as the compressive resistance of the block is directly linked to its volumic mass, the reduction of the density due to an excess of lime will reduce its strength. The over stabilisation with lime does not generally compensate the loss of strength due to treduction of the volumic mass.

Table 5 — Optimal characteristics of a good soil for lime stabilisation

Grain size distribution	Gravel: 15 %	Sand: 30 %	Silt: 20 %	Clay: 35 %
Plasticity	Plasticity index: I_p = 20 to 30 %		Liquid limit: W_L = 25 to 50%	
Sulfate content (SO_4): <0.5%	Organic matter (Humus): Less than 2 %			
Chlorate content (Cl): <0.5 %				

5.3.1.3 Fixation point

With 1 to 3 % of lime added to the soil, the pozzolanic reaction starts and modifies the plasticity of clay. This percentage of lime is the fixation point. Beyond this percentage, any amount of lime added will not change the plasticity but will increase the strength of the soil through a process called carbonation.

5.3.1.4   Retention time of lime

Before reacting with carbon dioxide, lime reacts with clay and changes the clay's plasticity by ionic exchange during the pozzolanic process. Therefore, it is important to keep a certain retention time for lime stabilised soils, in order to let it change the plasticity of clay. The retention time needed varies with the clay quality in the soil:

i)   Soils containing kaolinite are not really affected by lime. The retention time can be minimal like cement.

j)   Soils containing illite react slightly with lime. As their plasticity is not very high, the retention time can be short, from 15 minutes to half an hour.

k)   Soils containing smectite (i.e. montmorillonite, bentonite) have a high plasticity and will react strongly with lime. The retention time can be from 15 minutes to 2 hours. During this time the mix shall be covere9 to limit evaporation.

NOTE   It is important to note that these durations are indicative as there are so many variations in clay and soil qualities that it is not possible to give rigid rules.

5.3.1.5 Setting time and curing time of lime

The second reaction with lime is carbonation which means a reaction between calcium in lime and carbon dioxide of the air. This process happens only when lime dries. This reaction produces calcium carbonate, which is the main component of limestone used to produce lime. This process is very slow, but nevertheless, lime-soil mixes shall not dry rapidly as the pozzolanic reaction needs time to be complete. It has been noted with some clays that if the carbonation process starts too early, it can slow down or stop the pozzolanic process.

The initial curing is similar to cement but it can be slightly shorter: lime stabilised soils shall not dry for at least 1 to 2 weeks after production. After that they can dry freely. The setting process will start with the carbonation.

NOTE   The humid curing time necessary for lime stabilised soils can vary considerably. Some soils may require only 1 week of humid curing, some 2 weeks and other ones up to 4 weeks. After that time, the blocks are left to dry. The full hardening process will continue for several months, though at a lower speed.

5.3.2 Bitumen stabilization

5.3.5.1 There are two ways whereby bitumen can stabilise soil. The first way is a binding process that increases soil strength particularly in granular soils. Generally, small amounts of bitumen (2% to 6%) give the soil cohesion. When these percentages are exceeded the bitumen tends to act as a lubricant separating the particles and thus reducing the strength. The second way is when the bitumen acts as a water repellent. The two mechanisms usually occur together in any soil but to different degrees, depending on the type of soil. Soils suitable for bituminous stabilisation are sandy soils. Clays need large amounts for good results.

5.3.5.2 Bitumen stabilisation is best suited to predominantly sandy or silty soils, as outlined below.

4.3.5.2.1 Suitable soils

a)   Sand + fine gravel content 60% to 90% (max. particle size 6 mm) Silt content 5% to 30%

b)   Clay content 5% to 10%

c)   Plasticity index 0 to 10 (liquid limit 25 to 35)

5.3.5.2.2 Unsuitable soils

a)   Top soils

b)   Highly expansive soils

c)   Alkaline soils

d)   Soils with high organic matter and sulphate content

e)   Soils with mineral salt content sufficient to impair strength and durability;

f)   proposed limit 0.25%.

5.3.5.3 The main disadvantages of bituminous materials as stabilisers are:

a)   they are not a traditional building material in most developing countries,

b)   bituminous materials are expensive to import,

c)   preparation costs are high (heating, storing and mixing),

d)   heat can have an adverse effect on their binding properties, particularly in hot count

5.3.2.1 Compaction

Two to four MPa is enough and leaves the material a fairly porous structure in order to facilitate the evaporation of volatile solvents while ensuring good dry density. When turning out from the moulds the bitumen acts a release product, the blocks have an attractive appearance with sharp arrises.

5.3.2.2 Curing

Cut-back and emulsion which breaks down rapidly both shorten drying times. It is preferable to allow bitumen-stabilized material to cure in dry air rather than in a moist environment. Compressive strengths are related to the quantity of bitumen used and the duration of the drying period. These two parameters should be determined in advance by means of tests to find out what the optimal values

are. The loss of volatiles is greater for longer curing periods and higher temperatures, and this has a beneficial effect on absorption and expansion. Above 40°C, however, no further improvement is noted.

5.3.3 Gypsum stabilization

The gypsum used for stabilization of CSEBs shall comply with the requirements of applicable Rwanda standard. Gypsum is a good stabiliser for sandy soils.

5.3.4 Pozzolanas stabilization

Pozzolanas are fine silica and alumina rich materials which when mixed with hydrated lime produce cementitious materials suitable for stabilisation and construction needs. The pozzolanas shall comply with the requirements of ASTM C593.

6   Configurations of compressed stabilized earth blocks

6.1   General

6.1.1   Compressed stabilized earth blocks may be produced in different formats and configurations depending on the mould and purpose for the blocks (see Figure 1).
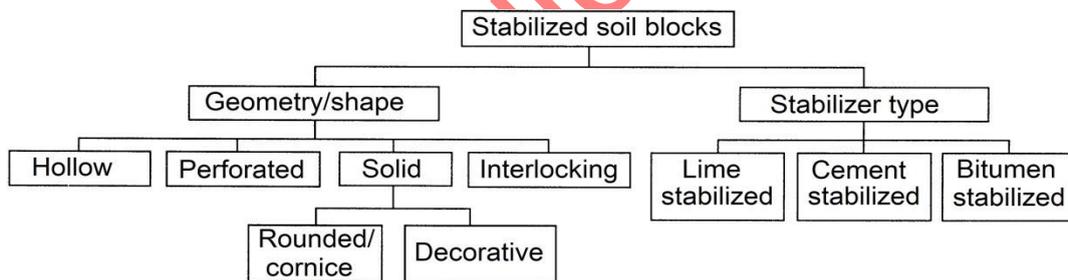
Figure 1 — Formats of compressed stabilized earth blocks dictate the machine type

6.1.2   Possible formats and configurations include the following:

e)   Plain solid blocks

   4.   Hollow blocks

   5.   Interlocking blocks

   6.   Special blocks

6.2 Plain compressed stabilized earth blocks

6.2.1 Plain compressed stabilized blocks shall be considered as those without interlocking features in this standard (see Figure 2)
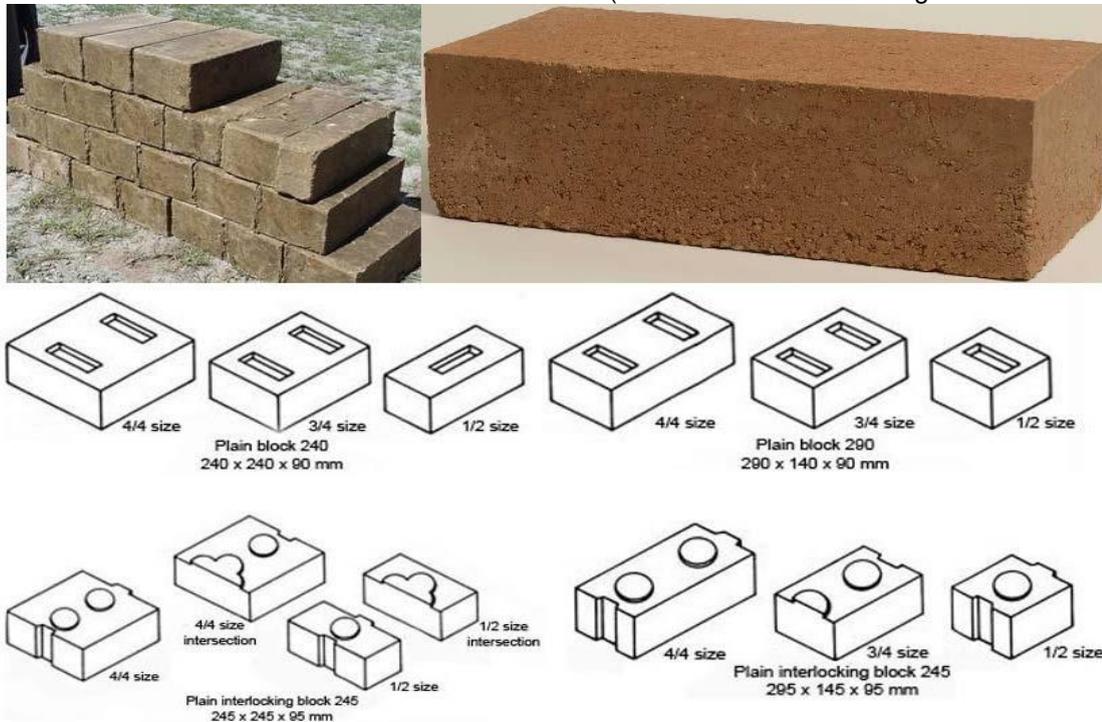
Figure 2 — Typical forms of plain compressed stabilized earth blocks

6.2.1.1 Solid blocks can be used for load bearing masonry up to 3 or 4 floors depending on the building design and the block quality. Solid blocks have normally a rectangular shape but they can also be square, trapezoidal or polygonal.

6.2.1.2 These blocks have the advantage of saving mortar and allowing a fast block laying. They can be used as a single block width for light load bearing structures, or as a double block width for heavy load bearing structures.

6.2.2 Hollow compressed stabilized blocks shall be considered as those whose net cross-sectional area in any plane parallel to the surface containing cores, cells, or deep frogs is 75 % or more of its gross cross-sectional area measured in the same plane (see Figure 3).
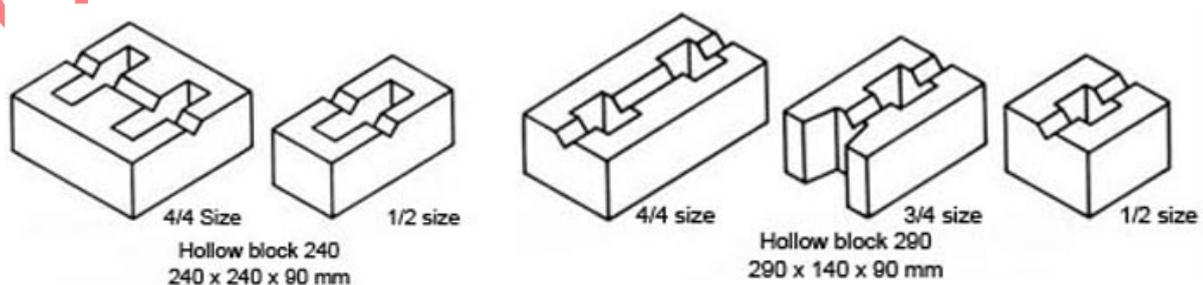
Figure 3 — Typical hollow compressed stabilized block

6.2.2.1   These blocks can support composite columns (reinforced cement concrete in the middle hole) in large format and for light load bearing structures up to 2 floors in light formats.

6.2.2.2   Hollow blocks can also be used for load bearing masonry but for lesser building height. They will have better insulation properties. They are found also in rectangular or square shapes.

6.2.2.3   It presents the advantage of saving reinforced cement concrete.

6.3   Interlocking compressed stabilized earth blocks

6.3.1 General

Interlocking blocks can be solid or hollow. Solid ones can be laid faster by unskilled labour but they cannot be used in seismic zones. Hollow interlocking blocks will be used only for disaster resistance as they have the possibility to be reinforced with reinforced concrete. They can be available in rectangular or square shapes.

6.3.2 The interlocking block principles

The concept of interlocking blocks is based on the following principles:

f)   The blocks were shaped with protruding parts, which fit exactly into recess parts in the blocks placed above, such that they are automatically aligned horizontally and vertically – thus bricklaying is possible without specialised bricklaying skills.

g)   Since the blocks can be laid dry, no mortar is required and a considerable amount of cement is saved.

6.3.3 The interlocking block principles: Asiatic interlocks

(i)   Each block has vertical holes, which serve four purposes:
   (1)   to reduce the weight of the block

   (2)   to insert steel rods or treated iron bar for reinforcement

   (3)   to act as conduit for electrical and water piping

   (4)   to pour liquid mortar (grout) into the holes, which run through the full height of the wall, thus increasing its stability and providing barrier to seepages

(ii)   The length of each block is exactly double its width, in order to achieve accurate alignment of blocks placed at right angles, else, a junction block is required. (iii)   A variety of interlocking blocks have been developed during the past years, differing in shape and size, depending on the required strengths and uses. The system developed has the following shapes and forms:

1) Full blocks (300x 125 - 150x 100 mm) for all standard walls (single or double block thick)

2) Half blocks (150 x 125 - 150 x 100 mm), which can be moulded to size, or made by cutting freshly moulded full blocks in half.

3) Channel blocks, same sizes as full and half blocks, but with a channel along the long axis, into which reinforcing steel and concrete can be placed to form lintels or ring beams.

4) The vertical sides of the blocks can be flat or have recesses, and the vertical grout holes can be square or roun

5) Inserts for elecrical switch housing and conduit as well as water piping outlet can be incorporated.

6) Special blocks for window sills
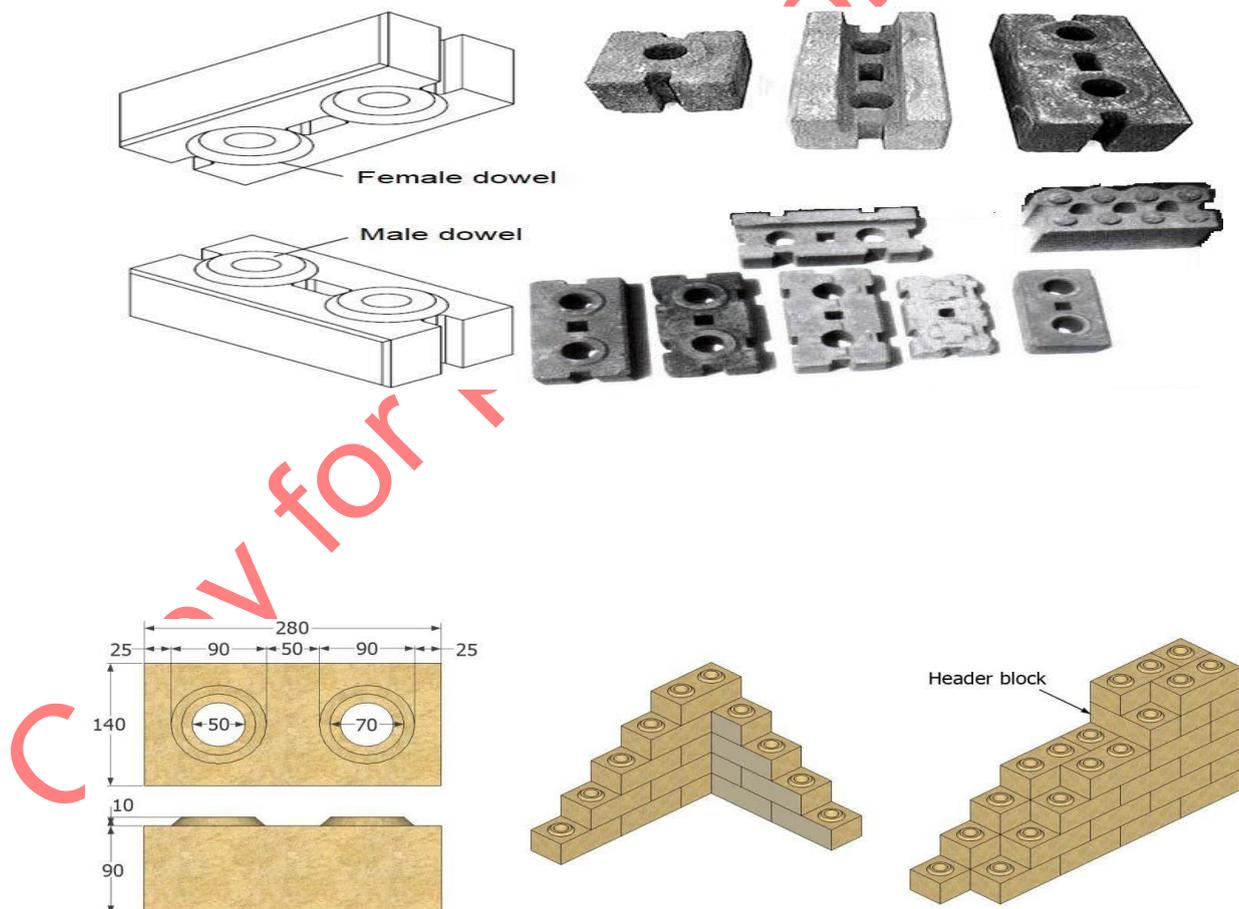
Figure 4 — The Asiatic interlock for compressed stabilised earth blocks

6.3.1   The interlocking block principles: African interlocks

The interlocking blocks have tongues and grooves on the top and bottom surfaces of the blocks respectively to restrain horizontal movement when laying interlocking block on top of one another without the use of mortar joints (see Figure 4). Installing some reinforcement and grouting mortar in the grout holes increases the wall strength. Thus, the wall could be made strong enough to carry upper floor loads similar to conventional load-bearing walls. Construction is simple enough for unskilled labour to build walls without mortar bedding which is great advantage of the interlocking block wall.
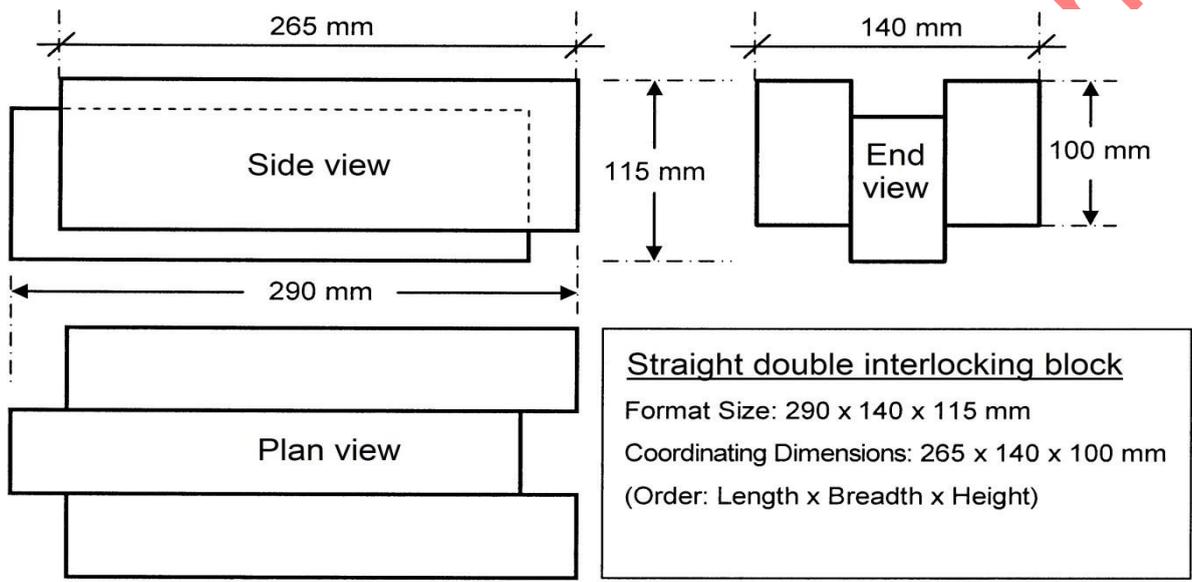
Figure 5 — The African interlock for compressed stabilised earth block

Figure 6 — Curved interlocking blo cks: Used for making water tanks and sanitation facilities

Figure 7 — Straight single interlocking blocks: Contains a larger face, hence less blocks are needed to cover wall area

Figure 8 — Conduit interlocking block

6.3.2 Hollow interlocking compressed stabilized earth blocks: Asiatic interlocks

These blocks are used for building disaster resistant constructions, as they have provisions for vertical and horizontal reinforcing elements. The principle is to reinforce the masonry by grouting a concrete into the holes of the blocks where stands a steel rod at the critical locations (corners, ends, near openings, etc.). Horizontal reinforcements are also cast in blocks with a U shape.

This block can be used for light load bearing structures up to two floors high.

It presents the advantage of saving materials and providing better heat insulation.

The advantage of hollow interlocking CSEB, compared to hollow concrete blocks, is that they offer keys, which interlock in the other blocks. Thus these walls offer more resistance to shear and buildings would be even stronger. They would better resist earthquakes and without major damages.

Compressed stabilised earth blocks have another advantage: they are in most cases cheaper and they are always more eco-friendly than concrete blocks.

4/4 size   4/4 size intersection   4/4 size end

1/2 size   1/2 size intersection   1/2 size U corner   4/4 size U

Hollow interlocking block 245
245 x 245 x 95 mm

4/4 size   4/4 size end   3/4 end

4/4 size U   3/4 size U   1/2 size

Hollow interlocking block 295
295 x 145 x 95 mm

4/4 size   4/4 size end   3/4 size

4/4 size U   3/4 size U   1/2 size

Dry Hollow Interlocking block 300
299 x 150 x 100 mm

4/4 size   3/4 size   1/2 size

Hollow block 390
390 x 190 x 90 mm

6.4 Special compressed stabilized earth blocks

Special blocks are used for various purposes such as hollow round blocks for columns, indentation blocks for provision for electrical conduits, U blocks for casting ring beams, thinner blocks for building vaults and domes, floor tiles, hourdi blocks for floor and roofs, etc. Special blocks are often produced by the basic mould with various kinds of inserts and they are used in different parts of the building.

U shaped blocks are used for precasting the composite lintels and beams, as well as casting plinth and ring beams

Circular-type blocks are used for building composite columns (Reinforced cement concrete in the middle hole). They have the advantage of saving reinforced cement concrete.

Circular-type blocks with four holes are used for building composite columns (Reinforced cement concrete in the 4 holes). They also have the advantage of saving reinforced cement concrete

Special blocks 240
Nominal size = 240 x 240 x 90 mm

Special blocks 290
Nominal size = 290 x 140 x 90 mm
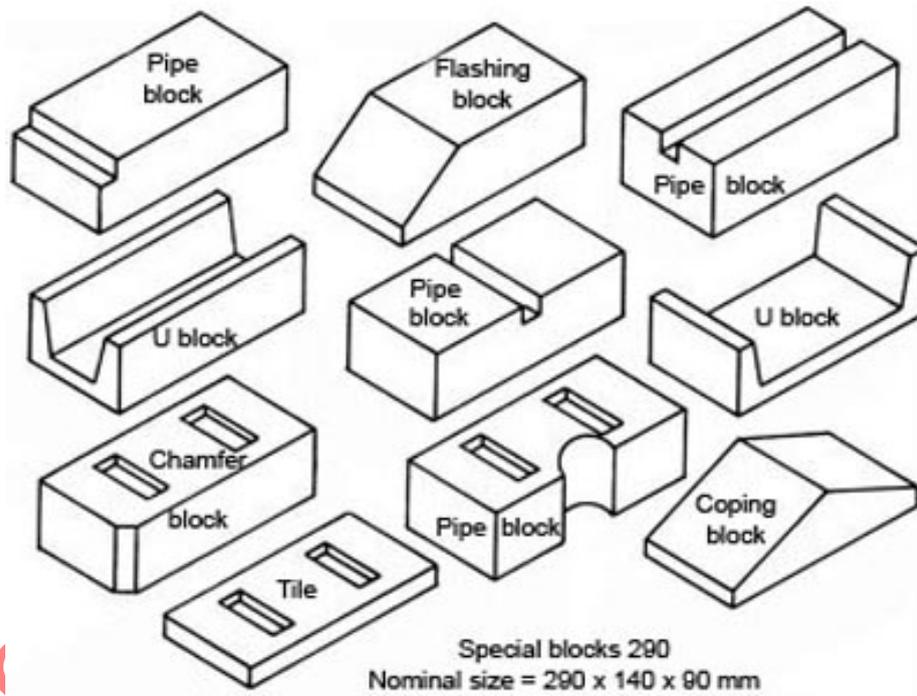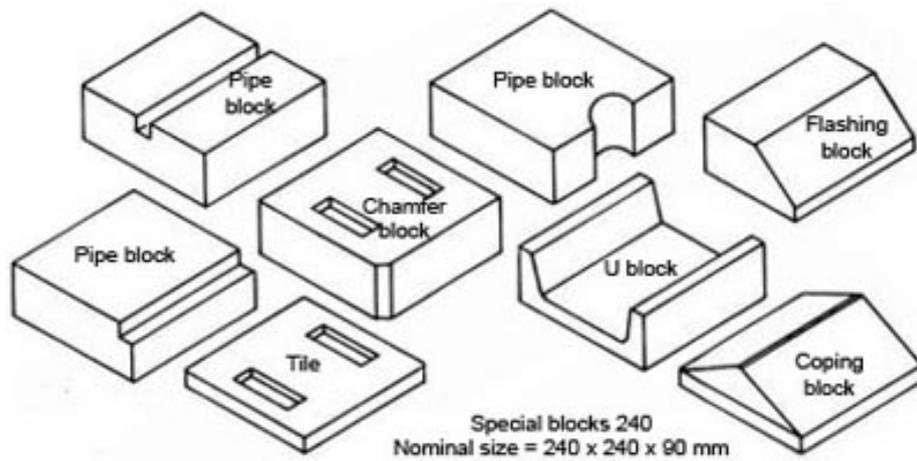
Figure 9 — Special compressed stabilized earth blocks

Figure 10 — Circular-type blocks used for building composite column

7 Production of compressed stabilized earth blocks

7.1 Material preparatory stage

7.1.1 Excavation

7.1.1.1 Topsoil contains organic matter and shall not be used for the production of CSEBs nor any other building purposes.

7.1.1.2 The excavation shall target soil in the subsoil layer found immediately below the top soil which is naturally stable and in many cases the one most suitable for production of ISSB.

7.1.2 Breaking up the soil

In order to obtain a uniform mix of the mineral components, water and stabiliser, lumps more than

200mm in diameter after excavation shall be broken up. Grains with a homogeneous structure, such as gravel and stones, shall be left intact, and those having a composite structure (clay binder) broken up so that at least 50 per cent of the grains are less than 5mm in diameter.

Soil that may be wet shall be dried.

7.1.3 Sieving / screening

Soil containing various sizes of grain, from very fine dust up to pieces that are still too large for use in block production shall be sieved to remove the oversized material, either using a built-in sieve, as with the pendulum crusher, or as a separate operation.

NOTE   The simplest sieving device is a screen made from a wire mesh, nailed to a supporting wooden frame and inclined at approximately 45º to the ground. The material is thrown against the screen, fine material passes through and the coarse, oversized material runs down the front. Alternatively, the screen can be suspended horizontally from a tree or over a pit. The latter method is only suitable in the case where most material can pass through easily otherwise too much coarse material is collected, and the screen becomes blocked and needs frequent emptying.

7.1.4 Proportioning/ measuring out dry materials

7.1.4.1 Before starting production, tests shall be performed to establish the right proportion of soil, stabiliser and water for the production of good quality blocks.

7.1.4.2 To ensure uniformity in the compressed stabilised earth blocks produced, the weight or volume of each material used in the block making process shall be measured at the same physical state for subsequent batches of blocks. The volume of soil or stabiliser should ideally be measured in dry or slightly damp conditions.

7.1.4.3 After establishing the exact proportion required of each material, a measuring device shall be built for each material. The dimensions of each measuring box should be such that their content, when full, is equivalent to the proportion which should be mixed with other materials measured in other gauge boxes.

NOTE 1   Alternatively, a simple gauge box may be used for all materials. In this case, the amount of material for the production of a given batch of blocks may be measured by filling and emptying the gauge box a number of times for each separate material. For example, a batch of blocks may require ten gauge boxes of soil for one gauge box of stabiliser. Water may be measured in a small tank or container.

NOTE 2   It is advisable to mix enough materials to allow the block-making machine to operate for approximately one hour. Thus, the volume of the mixed material will depend on the hourly output of the block making equipment.

7.1.5 Mixing

7.1.5.1 Dry materials shall be mixed first until they are a uniform colour, then water is added and mixing continued until a homogeneous mix is obtained. Mixing may be performed by hand on a hard surface, with spades, hoes, or shovels.

NOTE   It is not only important to measure the optimum proportion of ingredients, but also to mix them thoroughly. Mixing brings the stabiliser and soil into direct contact, thus improving the physical interactions as well as the chemical reaction and cementing action. It also reduces the risk of uneven production of low quality blocks. Various types and sizes of mixing equipment are available on the market.

7.1.5.2 Wet mixing shall commence by adding a little water at a time, sprinkled over the top of the mix and the wet mix turned over with a suitable tool until all the water has been mixed in.

7.1.5.3 When lime is used as a stabiliser, the mix shall be allowed to stand for a short while before moulding starts to allow better moistening of soil particles with water.

7.1.5.4 When cement is used for stabilisation, the mix shall be used for moulding quickly because cement starts to hydrate immediately after it is wetted and delays will result in the production of poor

quality blocks. For this reason the quantity of cement-sand mix should not exceed what is needed for one hour of operation.

NOTE   A concrete mixer, even if available, will not be useful for mixing the wet soil, since the latter will tend to stick on the sides of the rotating drum. If machinery is to be used for mixing, it should have paddles or blades that move separately from the container. However, field experience shows that hand-mixing methods are often more satisfactory, more efficient and cheaper than mechanical mixing, and are less likely to produce small balls of soil that are troublesome at the block moulding stage.

7.1.6 Quantity of materials needed

7.1.6.1 The exact amount of stabiliser necessary shall be established for any particular project.

7.1.6.2 The optimum water content (OMC) for any particular soil shall be determined experimentally.

NOTE 1   The fraction of lime or cement usually varies between 5% to 8% by weight. The moisture level varies widely with the nature of the soil. An approximate estimate of about 15% by weight is often assumed.

NOTE 2   Compressed stabilised earth building blocks are usually larger in size than traditional burnt bricks. A typical block size is 290 x 140 x 90mm. Its production will need about 7.5 to 8.5kg of materials depending on the compaction pressure. In practice, the above quantities of soil, stabiliser, and water will vary depending upon the type and properties of the soil. A single storey building with a floor area of 50 m^2 will require about 3000 blocks.
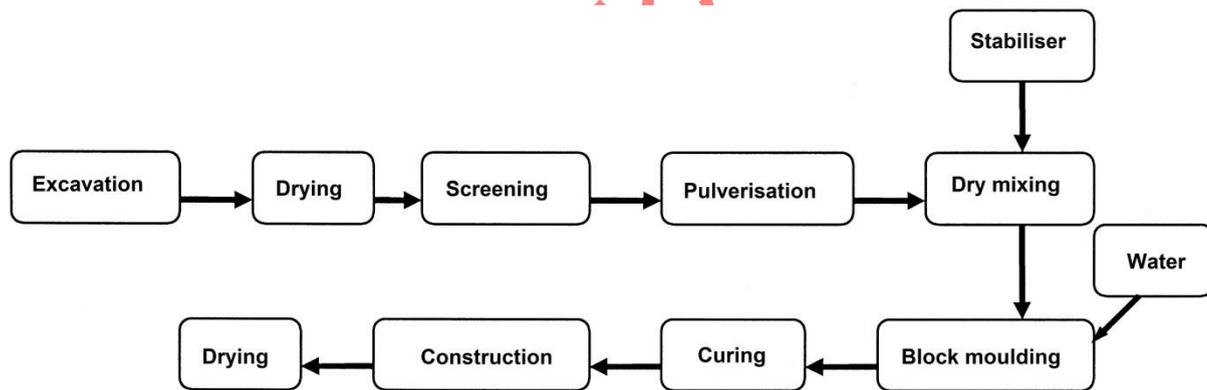
Figure 11 — Production process of compressed earth blocks

7.2 Moulding compressed stabilized earth blocks

7.2.1 General considerations for block production

7.2.1.1   Many aspects should be taken into consideration before launching an operation to produce compressed stabilised earth building blocks:

amount and type of stabiliser required,

soil properties and its suitability for stabilisation,

building standards and hence quality of blocks required,

load bearing requirements of construction i.e. single storey or more.

7.2.1.2   The compressive strength of a compressed earth block depends not only on soil type, but also on the type and amount of stabiliser, the moulding pressure, and the curing conditions.

7.2.2 Testing soil prior to block production

7.2.2.1   The soil mix shall be checked for each batch of blocks so as to attain the optimum moisture content (OMC). To ensure this, two simple field tests shall be carried out as follows:

(a)   Take a handful from the soil mix for block production and squeeze it in the hand, the mix should ball together. When the hand is opened, the fingers should be reasonably dry and clean.

(b)   Drop the ball sample onto a hard surface from a height of about one metre. If the sample:

    (i)   completely shatters, this shows that it is not sufficiently moist,

    (ii)   squashes into a flattened ball or disc on impact with the hard surface, this implies too high a moisture content,

    (iii)   breaks into four or five major lumps, this shows that the moisture contents or the soil mix is close to the optimum moisture content (OMC).

7.2.2.2   To manufacture blocks of uniform size and density, precautions shall be taken to fill the mould with the same amount of mix for each compaction by using a small wooden box as a measuring device.

NOTE   To facilitate development of the pressed blocks and to ensure good neat surfaces it is advisable to moisten the internal faces of the machine mould with a mould releasing agent (reject oil) which can be applied with either a rag, brush or spray.

7.3   Curing

7.2.3.1   To achieve maximum strength, compressed stabilised earth blocks shall be subjected to a period of damp curing, where they are kept moist to avoid rapid loss of moisture which could lead to shrinking and cracking.

NOTE 1   In practice, various methods are used to ensure proper curing. Such methods include the use of plastic bags, grass, leaves, etc. to prevent moisture from escaping.

NOTE 2   After two or three days, depending, on the local temperatures, cement stabilised blocks complete their primary cure. They can then be removed from their protective cover and stacked in a pile, as shown in Figure 11. As the stack of blocks is built up, the top layer should always be wetted and covered, and the lower layer should be allowed to air-dry to achieve maximum strength. Alternatively, freshly moulded blocks can be laid out in a single layer, on a non-absorbent surface, and covered with a sheet to prevent loss of moisture.

7.2.3.2   The required duration of curing shall be dependent on the type of soil and, more significantly, which type of stabiliser is used. With cement stabilisation, it is recommended to cure blocks for a minimum of three weeks. The curing period for lime stabilisation should be at least four weeks.

7.2.3.3   Compressed stabilised earth blocks should be fully cured and dry before being used for construction.
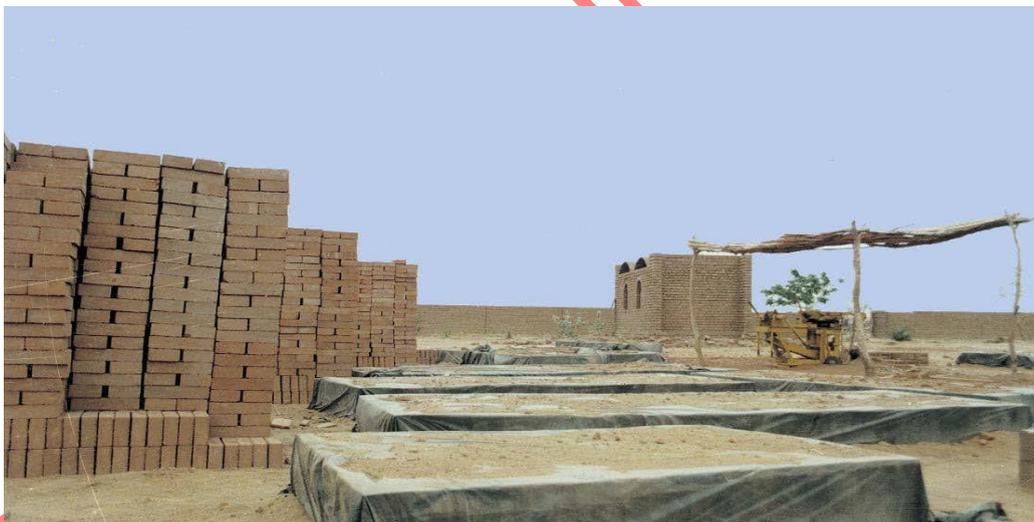
**Figure 12 — Brick
curing**

7.3.1 Sizes of compressed stabilised earth blocks

7.2.4.1   The sizes of compressed stabilized earth blocks shall be in conformity with national building codes and regulations with respect to compressive strength, thermal and acoustic insulation and fire resistance among other parameters.

7.2.4.2   The sizes shall be selected from those provided in clause 7.1.

7.4   Production of compressed stabilized earth blocks: Pulverisers

7.4.1 General

Pulverisers are used to enable one to obtain an earth where at least 50% of the particles held together by clay (lumps or nodules) will be less than 5 mm in diameter.

7.4.2 Typology

Pulverizers are sub-divided into two families: crushers and grinders.

7.4.2.1   Crushers

These enable conglomerate particles (bonded by clay) to be broken down, but leave homogenous particles (stones, gravel) intact. They do not modify the particle size distribution of the soil.

7.4.2.1.1   Jaw crushers

This type of pulverizer comes with one or two motorized or manual jaws, fitted with a simple reciprocating motion mechanism. The double jaw motorized systems may be able to fragment stones, in which case they are regarded as grinders. Manual systems are best suited to fine, dry soils.

7.4.2.1.2   Squirrel cage crushers

These are motorized and consist of one or two "squirrel cages" with metal bars, turning at high speed in opposite directions close to one another. This type of pulveriser is better suited to fine soils, but may also work with moist soil.

7.4.2.2   Grinders

These will break down both conglomerate particles and homogenous particles and will therefore modify the grain size distribution of the soil to varying degrees, depending as much on the type of soil as on the equipment.

7.4.2.2.1   Propeller grinders

These are motorized and similar to compost shredding machines. If the soil contains too much gravel, the propellers will rapidly wear. They are best suited to dry soils. The propellers may be placed either vertically or horizontally.

7.4.2.2.2 Cutter or hammer grinders

These are motorized and consist of steel blades swinging around an axis which in turn rotates around a main central axis. They are suitable for gravelly and dry soils. The extent of grinding will depend on the power and speed of the motor.

7.4.3 Technical performance

All pulverisers enable one to prepare dry soil but only rarely do they perform well with wet soils which require high speed impact. For less efficient pulverisers, it can be useful to place a screen which removes the coarsest particles as they are ejected. The pulverization system used should be easy to clean, as it can become coated in wet, compacted soil. Delicate parts should be protected from dust.

7.4.4 Mobility

Pulverisers should preferably be easy to move around the production area in order to be able to adapt to the volume of earth, raw or prepared.

7.5 Production of compressed stabilized earth blocks: Screens

7.5.1 Typology

7.5.1.1 Fixed sieves

The most frequently used screening system is manual and consists of a metallic mesh fixed to a rigid frame of wood or metal. This frame is either fixed at an angle by rigid legs, or suspended almost horizontally from a superstructure.
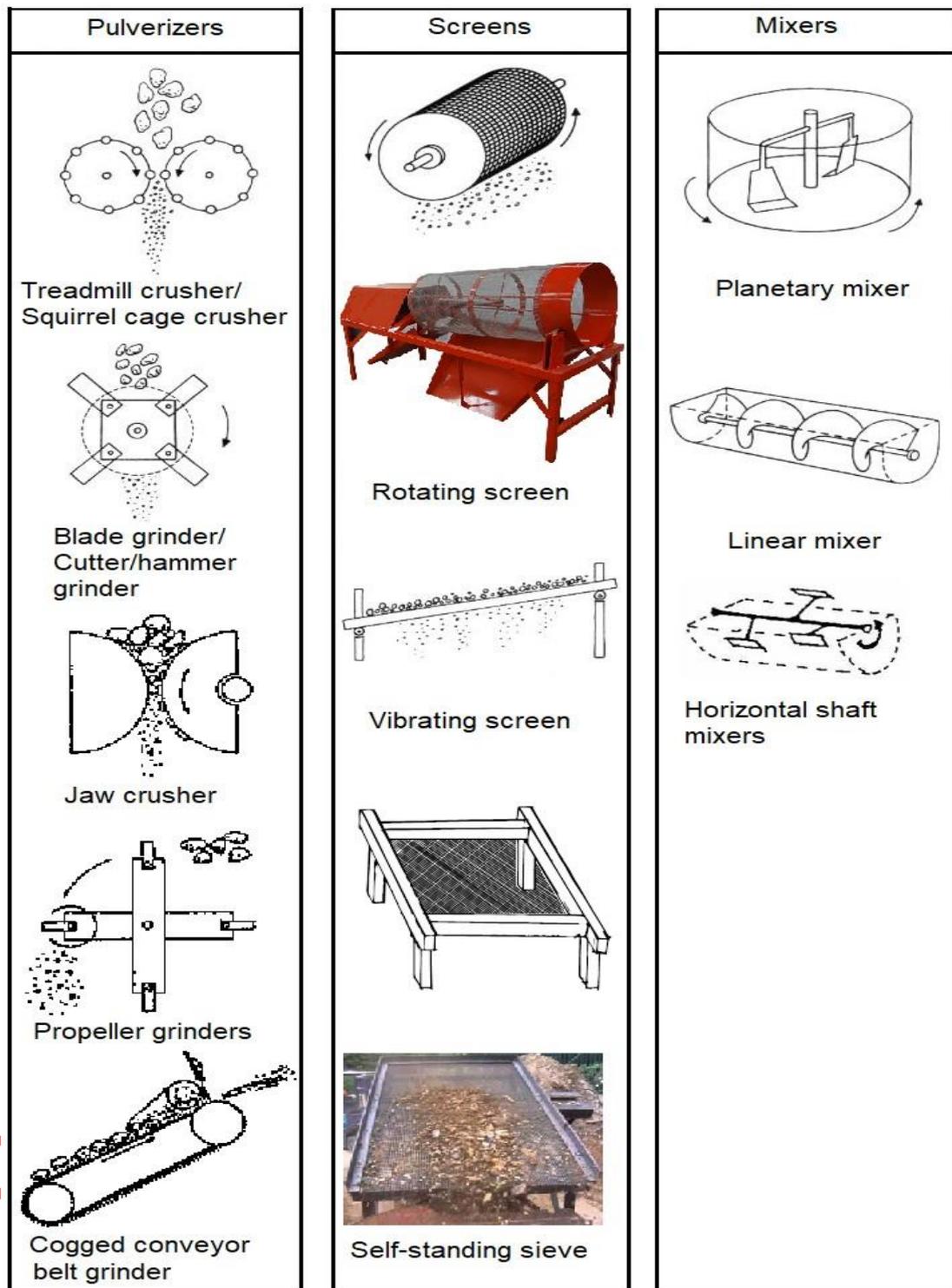
Figure 13 — Pulverisers, screens and mixers for soil preparation

7.5.1.2 Rotating screens

These consist of a metal or wire netting cylinder, rotated by hand or by motor, and are simple to make. Soil can be screened successively through screens of different sizes. The resulting fractions can then be mixed back together in the required proportions.

7.5.1.3 Vibrating screens

These are motorized and consist of a single vibrating screen or a combination of several screens, usually fitted one above the other. Vibrating screens are generally intended for large production units.

7.5.2 Technical criteria

7.5.2.1 Soil particle size distribution

For compressed earth block production, the fraction of the soil of less than 15 or 20 mm in diameter, and sometimes even less than 5 mm, is used, depending on the technical specifications of the press, which determine those of the finished products. 5 mm for presses which are sensitive to compression and for hollow blocks with relatively thin sides (30 to 50 mm); 15 to 20 mm for presses less sensitive to compression (hyper compression) and intended for the manufacture of solid blocks. For any given soil, the most efficient systems are those which reject the minimum amount on screening.

7.5.2.2 Moisture content of the soil

The systems which perform best enable soil to be sifted in a dry, moist, or even wet state.

7.5.2.3 Filling and exit points

Their design should allow for easy filling and emptying out into a wheelbarrow or conveyor belt.

7.5.2.4 Wear and tear and maintenance

All the bearings, motors and other sensitive items should be perfectly protected from dust. Replacing the screen grid itself must be easy. Their design should allow for easy filling and emptying out into a wheelbarrow or conveyor belt.

7.5.2.5 Mobility

Wheels can be a useful feature in non-integrated units, as they make the screen easier to move or transport so as to adapt to the volume of untreated and/or prepared earth.

7.6 Production of compressed stabilized earth blocks: Mixers

7.6.1 General

The mixing process is particularly important for the final quality of the product. Mixing should first of all be done in the dry state. The mixed soil shall be wetted evenly by adding water as a fine spray, as a mist, or as high-pressure steam, according to the construction technique and the level of sophistication employed.

7.6.2 Typology

7.6.2.1 Horizontal shaft mixers

These are motorized and consist of a number of blades mounted on a horizontal rotating shaft ·which turns within a horizontal cylindrical drum, often quite small in si

7.6.2.2 Planetary mixers

These are motorized and consist of blades fixed to a vertical rotating shaft which turns inside a drum. The blade movement is more or less complex depending on the level of sophistication of the mechanisms. There are even models where it is the drum which rotates.

7.6.2.3 Linear mixers

These are motorized and made up of a series of blades forming a discontinuous or continuous helical screw, which turns inside a horizontal or vertical drum. The most sophisticated horizontal systems have a double drum fitted with two shafts.

7.6.3 Technical criteria

7.6.3.1 Quality and mixing time

Mixers used to prepare soil intended for the production of compressed earth blocks must be capable of mixing it for a duration of 2.5 to 4 minutes, if an optimum result is to be obtained. The systems used should on no account produce soil stuck together in the form of lumps. The moving parts inside the mixers' drums should be designed so that the soil can in no circumstances impede their operation.

7.6.3.2 Wetting

If the mixer is fitted with a watering system, this will allow water to be added in the form of a fine spray.

7.6.3.3 Power and capacity

The power taken up by the mixing of soil is significantly greater than that used to mix concrete. The usable capacities of vertical axis mixers claimed by the manufacturers are often given for mixing concrete and should be considerably reduced for soil. It should be noted that the quoted capacity gives the

volume of the drum. The volume of soil which can be mixed is in the order of 50% of the volume of the drum. The wave of soil lifted by the mixer blades as they rotate is higher than that of concrete, so the mixer walls need to be significantly (approximately 20%) higher too.

7.6.3.4 Feeding and delivery

Access for feeding should be easy (a fixed ramp, platform or conveyor belt). Emptying out should be able to be done directly either into a wheelbarrow, or into the feeding hopper of the press, or onto a conveyor belt.

7.6.3.5 Safety

Mixers should be fitted with a protective grill and possibly with an automatic cut-off system which operates if the grill is opened. The emptying system should preferably be fitted with a safety device, making it impossible, for example, for someone to put their hand into the mixer.

7.6.3.6 Wear and tear and maintenance

Mixers should be extremely resistant to wear and tear by abrasion, particularly when used with lateritic soils. This applies equally well to the drum as to the blades or other mixing devices such as disks. The shape of the blades should be examined to ensure that they penetrate well into the mix causing as little abrasion as possible, but moving it along as much as possible. Earth is highly abrasive, particularly when lateritic. It is useful if the blades are easily replaceable and readily available as spare parts.

7.6.3.7 Mobility

In certain cases, wheels can be useful to avoid having to move too much soil around

7.7 Production of compressed stabilized earth blocks: Presses

7.7.1 General

For the production of compressed earth blocks, the action of the presses consists in pressing the particles closer together. This densification is obtained by applying compaction forces, static or dynamic, depend upon several essential variables in order to work efficiently. The format of the compression machines depends on the product formats as highlighted in Clause 5 (Figures 14 - 18).

Figure 14 — Auram Press 3000 manual compressed brick making machine

Figure 15 — Interlocking compressive block making manual hand machine
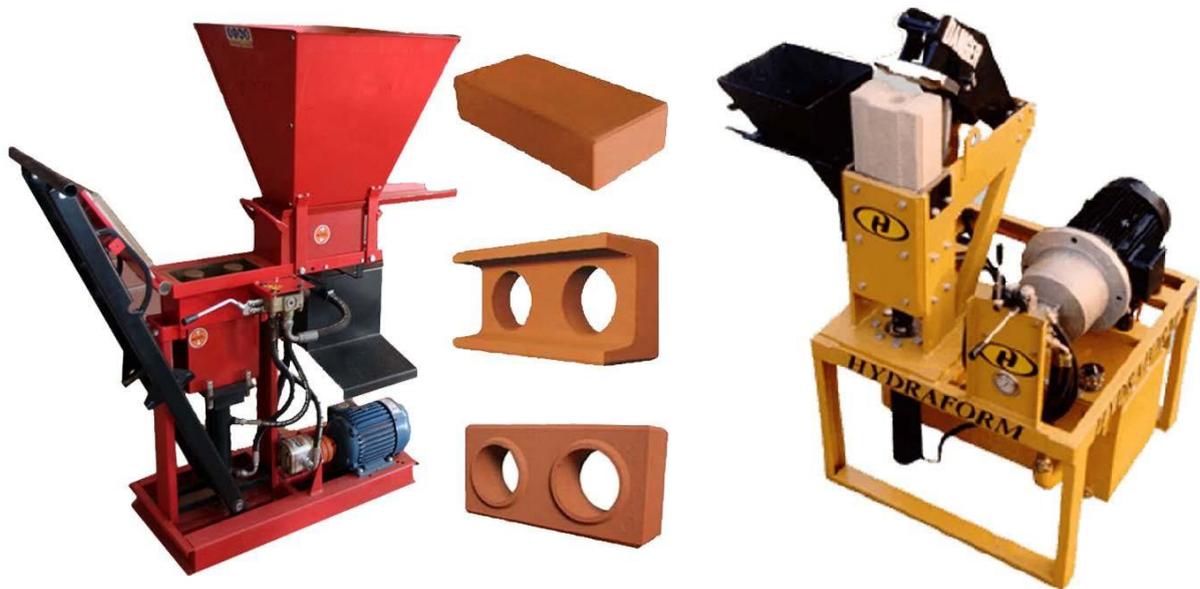
Figure 16 — Motorized interlocking clay brick making machine

Figure 17 — Interlocking compressive block making mobile machines

Figure 18 — Interlocking compressive block making fixed machine

7.7.2 Typology

7.7.2.1 Manual presses

Only compressing and turning out operations are carried out by the machines which are operated by hand (Figures 14 to 15).

7.7.2.2 Motorized presses

Only compressing and turning out operations are carried out by the machines which are motorized

(Figure 16).

7.7.2.3 Mobile production units

These production units are easily transportable. Not only the compressing and turning·out operations but also the preparation the material and/or the evacuation of the finished products are motorized or even automated.

7.7.2.4 Fixed production units

These production units are particularly difficult to transport. Not only the compressing and turning out operations but also preparation of the material and/or the evacuation of the finished products are motorized or even automated.

7.7.3 Technical criteria

7.7.3.1 Press descriptions

Certain machines can produce a complete range of components (blocks, large and small paving tiles, roofing tiles, etc.). For each of these products, one must request:

its denomination;

its geometrical description;

plans;

photos.

Manufacturers often provide reports of experimental tests or technical opinions concerning the products manufactured by their machines. Great care should be taken to check the validity of these documents.

7.7.3.2 Block dimensions

Compressed earth blocks shall comply with the dimensions set out in Clause 7.1. It is recommended that the vertical direction in which the block will be laid should be apparent from its dimensions or shape, and this should generally and preferably be the direction of compression during production. This is particularly true for load-bearing walls.

7.7.3.3 Dimensions of other products

For the other finished products, one must request:

h)   complete dimensions (l x w x h);

i)   tolerances;

j)   void ratio (% of frogs and hollows

k)   typical dry mass;

l)   geometrical description;

m)   diagrams;

                7.   photos.

7.7.3.4   Surface effects

Certain methods of compressing and removing the block leave the exposed faces of the products very smooth, while others leave them rough. Surface roughness on the faces of blocks which are to have a mortar or render applied helps the mortar or render to adhere. Smooth surfaces are preferable for masonry which will remain exposed.

7.7.3.5   Hollows

It is useful to be able to produce blocks with all kinds of hollows (frogs, partial or through perforations, etc.). Hollows can increase the coefficient of thermal insulation, reduce the weight of the block, allow spaces for reinforcement or wires to be introduced, etc. The volume of such hollows is generally limited to approximately 30% (percentage of voids) of the total volume of the product. The particle size distribution of the soil should be suited to the thickness of the sides in order to avoid mechanical weaknesses and to ensure that the appearance of the product remains good. The sides will generally have a minimum width of 3 cm.

7.7.3.6   Energy source

The operation of presses can call for a human energy source (manual presses) or a mechanical one (presses with electrical or thermal motors).

7.7.3.7   Energy consumption

Energy consumption must be taken into account, particularly in terms of fuel supply and frequent electricity cuts. Where continuous production is imperative, it is often preferable to opt for a multiple energy source (e.g. electrical motors linked both to the mains supply and to an emergency back-up generator.)

7.7.3.8   Compression

Compression may be static, dynamic by vibration, dynamic by impact, or mixed, which combines some of the other types of compression.

7.7.3.9   Available force

This is the force potentially available to compress the soil, a force which can be used as required: applied to a small or a large surface for example. This parameter does not therefore express the performance of a press, but allows it to be situated within a certain range.

7.7.3.10 Compression pressure

The potential of the press can be better appreciated by considering its compression pressure. This is the pressure which is theoretically applied to the soil and it expresses the link between the usable force and

the surface area to which it is applied (to one or more blocks). The presses are classified as per the table below.

Table 1: Classification of presses

Classification	Pressure
very low pressure	1 to 2 MPa
low pressure medium pressure	2 to 4 MPa 4 to 6 MPa
high pressure	6 to 10 MPa
mega-pressure	20 to 40 MPa and over

7.7.3.11 Available pressure at the end of compression

This is the pressure which is actually applied to the soil at the end of the compression. Pressure at the end of compression is measured after allowing for all the losses of pressure due to the effects of operation, friction and inertia.

7.7.3.12 Compression ratio

In practice the compression ratio is defined by the relationship between the depth of the mould before compression and the depth after compression. For blocks approximately 10 cm in height, the compression ratio should preferably be at least 1.65, and ideally nearer to 2, this figure rarely being attained. The value of the compression ratio can be distorted by too great a depth of mould, which means that the mould is never entirely filled.

Loose earth placed in the mould has a dry density which varies between 1000 and 1400 kg/m^3. Compressed, it should have a dry density of at least 1700 kg/m^3 and can reach 2300 kg/m^3, depending on the soil used and on the compression applied.

7.7.3.13 Compression speed

Production imperatives can impose high speeds. The minimum compression time limit, however, is of the order of 1 to 2 sec. for 10 cm blocks, if the risk of lamination is to be avoided. If compression is carried out too quickly, it must be interrupted after precompression in order to let the compressed air escape. This precompression, which enables the soil to be rapidly placed in the mould, is carried out at a relatively

low pressure. The final compression is then carried out at a much lower speed. The compression speed is all the more critical the higher the compression pressure and the lower the operating play between the piston and the mould, which makes it difficult for the air squeezed out of the earth to escape.

8   Requirements for compressed stabilized earth blocks

8.1.1 Dimensions and tolerances

8.1.1.1   Dimensions

Dimensions of stabilized soil blocks shall comply with Table 5.

Table 6 — Standard formats of stabilized soil blocks

Length (mm)		Width (mm)		Height (mm)
Nominal size	Work size	Nominal size	Work size	Nominal/Work size
200	190	75	65	55 to 65
200	190	00	90	75 to 90
230	220	230	220	115
250	240	250	240	90 to 100
300	290	100	90	80 t0 95100 to 115
300	290	150	140	100 to 115
400	390	150	140	105 to 150
400	390	200	190	190
400	390	250	240	200

8.1.1.2   Tolerances

The maximum dimensional deviations for stabilized soil blocks measured in accordance with Annex A

shall be as specified in Table 6.

Table 7 — Dimensional tolerances for stabilized soil blocks

Dimension	Maximum dimensional deviations	
Length	+ 1 mm	- 3 mm
Width	+ 2 mm	- 1 mm
Height	+ 1 mm	- 3 mm
Surface smoothness sides	+ 1 mm	- 1 mm
Compression surface	+ 3 mm	- 1 mm

8.2 Dry compressive strength

The dry compressive strength at 28 days when tested in accordance with Annex B shall be not less than the value for the declared class in Table 7.

8.3 Wet compressive strength

When stabilized soil blocks are tested in accordance with Annex B, the minimum average wet compressive strength at 28 days shall be not less than the value for the declared class in Table 7.

8.4 Modulus of rupture

Also known as the bending or flexural strength, the rupture strength when determined in accordance with Annex C shall be not less than the values for the declared class in Table 7.

8.5 Water absorption

The water absorption of stabilized soil blocks when determined as described in Annex D shall not exceed the values for the declared class in Table 7.

8.6 Density

The density of blocks when determined in accordance with Annex E shall be not less than the values for the declared class in Table 7.

8.7 Weathering and durability of CSEBs

When subjected to the weathering test carried out in accordance with Annex J the maximum loss of mass shall not exceed 15 per cent.

Durability of SSB buildings is a major concern expressed by the users of SSB technology. Several accelerated test methods have been devised to assess the durability of SSBs, including: (i) the spray erosion test; (ii) the drip test; (iii) the alternate wetting and drying test; and (iv) the linear expansion on saturation test.

8.8 Shrinkage cracks

Shrinkage cracks shall not be more than the levels for the declared class of CSEBs in Table 7 and shall not exceed in length 50 per cent of the block dimension to which they are parallel; where they are not parallel, their projected length shall be measured.

NOTE   Good site practice is the key to prevent unnecessary shrinkage. This means avoiding moisture being absorbed by earth materials prior to construction. However, materials should be selected that have an appropriate shrinkage limit and earth masonry elements should be designed so that shrinkage movement is dissipated rather than focused.

8.9   Visual inspection

All blocks on visual inspection shall be free of broken edges, honey combing and such other defects as would interfere with the proper placing of the blocks or impair the strength or permanence of construction

Table 8 — Requirements for compressed stabilized earth blocks

Properties	Requirements		
	Class A	**Class B**	**Class C**
Dry compressive strength @28days, MPa, min	5 to 12	4 to 5	3 to 4
Wet compressive strength @28days, MPa, min	3 to 4	2 to 3	1.5 to 2
Dry bending/flexural strength/rapture modulus @28days, MPa,	0.5 to 1	0.4 to 0.8	0.3 to 0.6
Dry shear strength @28days, MPa, min	0.4 to 0.6	0.3 to 0.5	0.2 to 0.3
Tensile strength @28 days, MPa, min	>2	1 to 2	0.5 to 1
Density, kg/m^3	1900 to 2200	1800 to 1900	1700 to 1800
Water absorption @ 28days, % by weight	8 to 10	10 to 12	12 to 15
Poisson's ratio, μ	0 to 0.15	0.15 to 0.35	0.35 to 0.50
Moisture movement (%)	0.02 – 0.2		
Thermal conductivity, , W/mC	0.23 to 0.46	0.46 – 0.81	0.81 – 0.93
Specific heat, C, KJ/kg	1.00 – 0.85	0.85	0.65 – 0.85
Modulus of elasticity, MPa	700-1000		
Coefficient of thermal expansion, mm/mC	<0.010	0.01 – 0.015	
Swell after saturation (24-hour immersion), mm/m	0.5 – 1	0.5 – 1	1 – 2
Shrinkage (due to natural air drying), mm/m	<0.2	0.2 – 1	1 – 2
Permeability, mm/sec	1.10^{-5}		
Lag time (for 40 cm thick wall), d, hours	>12	10 – 12	5 – 10
Coefficient of acoustic attenuation (for 40 cm thick wall at 500	>60	50	40
Coefficient of acoustic attenuation (for 20 cm thick wall at 500	>6	50	40
Damping coefficient (40 cm thick wall), m, %	<5	5 - 10	10 - 30
Susceptibility to efflorescence	Very low	Low	Average
Durability upon exposure to weather	Excellent	Good	Average
Fire resistance	Excellent	Good	Average
Flammability	Very poor	Poor	Average
Speed of flame spread	Very slow	Slow	Average
Uniformity of dimensions (individual finished products)	Excellent	Good	Average

8.10 Fire resistance of compressed stabilized earth blocks

8.10.1 The fire reaction characteristics of clay masonry units shall be as indicated in RS 186

8.10.2 Building materials shall be classified into *nonflammable* (Building Material Class A) and *flammable* (Building Material Class B) in terms of their fire performance as per DRS 547. Earth masonry materials may be used in walls designed to have a fire resistance, if their incombustibility is demonstrated by having either:

(i)   less than 1% organic content, or

(ii)   density over 1700 kg/m^3, or

(iii)   specific fire test data.

8.10.3 The fire resistance rating of clay masonry units shall be determined in accordance Annex R.

NOTE   The fire performance of earth building materials is of particular relevance when natural and artificial organic aggregates are used in the production of light clays. Common organic aggregates which could affect the fire performance of earth building materials are chopped straw, wood chips, wood shavings, sawdust, and crushed cork. To be classified as Building Material Class A1 (nonflammable) earth building materials are allowed to have a homogeneously distributed organic aggregate content ≤1 % of the mass or volume, whichever is greater.

8.11 Thermal characteristics of compressed stabilized earth blocks

8.11.1 Thermal insulation/conductivity

The thermal performance of compressed stabilized earth blocks shall be in compliance with the values declared for the classes provided in Table 7.

NOTE 1   Earth masonry generally has poor insulating qualities, due to its high density, with thermal conductivity increasing in relation to material density (Figure 19). Light earth construction, which does have relatively good insulating qualities, is non- structural, clay-bound, light fibre, which is primarily a monolithic fill material, rather than masonry.

NOTE 2   More common earth masonry products have high thermal conductivity. Relatively dense bricks of 1900 kg/m^3 will have a conductivity of around 1 W/m K, while materials with a high fibre content giving a density around 1500 kg/m^3 will have a conductivity of around 0.65 W/m K.

NOTE 3   Typically, figures given for thermal conductivity are for 'dry' materials. Higher levels of relative humidity can increase conductivity and it is normal, in reality, to have some variation in material conductivity, both in different locations in the building and in the same place at different times.
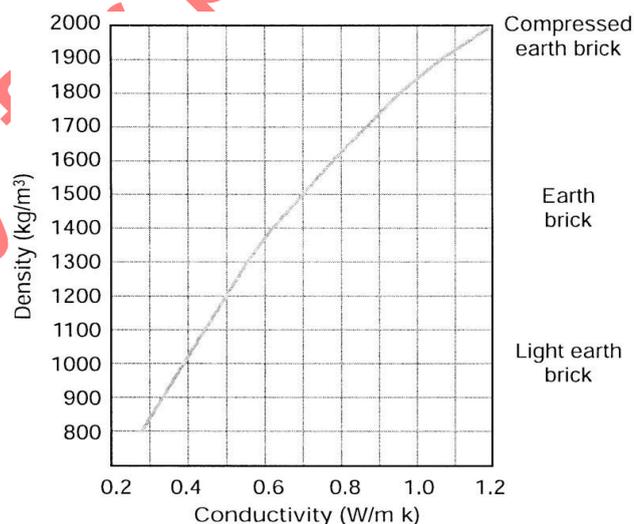

Figure 19 — Indicative relationship of earth materials density to thermal conductivity

8.11.2 Thermal capacity, mass and lag

The ability of earth masonry to absorb and release, store and delay the flow of heat is a complex phenomenon that is key to its contribution to the creation of thermal comfort.

Earth masonry has a specific heat capacity of 800–1000 J/kg K, increasing with material density. These figures are comparable with concrete.

Thermal diffusivity, the rate at which heat flows through a material, is where earth materials seem to perform well. Although rates vary with prevailing hygro-thermal conditions, earth can have very high thermal lag or inertia, related to the absorption capacity of its pore structure.

8.11.3 Acoustic characteristics of compressed stabilized earth blocks

Earth masonry, being a relatively dense, solid construction, generally has good acoustic attenuation properties, with specific levels being a product of thickness, density and the quality of construction.

Density and acoustic attenuation

Some proprietary products carry specific acoustic test data, but a good prediction of theoretical performance can be made on the basis of density, which is usually within a range of 1200–2000 kg/m^3, and wall thickness (Table 9).

Table 10 — Indicative acoustic insulation values for earth masonry walls

Wall thickness(mm)	Earth brick density(kg/m^3)	Sound reduction index (SRI) (dB)
130	1500	46
240	1500	53
365	1500	57

9   Construction with compressed stabilized earth blocks

9.1 Types of buildings

8.1.1   The type of building shall be identified in relation to the function or intended use of the building as follows:

n) Residential buildings/dormitories/hotels/residences

o) Education (daycare facilities for children, schools)

p) Public buildings (public agencies, administration, museums)

q) Cultural and recreational facilities (playgrounds, zoos, art spaces, open space structures) (e) Religious/sacred buildings

r) Commercial buildings/warehouses

s) Buildings for the spa and health sector

t) Buildings for agriculture/horticulture

u) Facilities/buildings providing protection

8.1.2 Detailed occupancy classifications are provided in building regulations and shall form the basis for selecting specific design parameters.

9.2 Types of wall

9.2.1 Compressed earth block masonry enables one to build either loadbearing walls, both thick and thin, or non-loadbearing walls such as partitions which divide up the space within a building. This simple classification offers great architectural flexibility.

9.2.2 Main problems: The main problems result from the nature of the stresses which are applied to the walls, viz.:

(i) Crushing: under the effect of the weight of the wall itself or of a concentrated vertical load.

(ii) Vertical excentric loads resulting from a tensile force (bending out at floor level, for example).

(iii) Horizontal excentric loads resulting from the pressure of a vault on the walls for example.

(iv) Buckling resulting from the accumulated effect of a load stress and from the settling of a wall which is too thin and too high by comparison for example.

(v) Horizontal loads. These fall into two kinds. On the one hand the uniform pressure of winds on the walls, and on the other the concentrated pressure of earthquakes (i.e. high tensile and bending stress).

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

(i) using the thickness of the walls;

(ii) improving the stability of thin walls by using buttresses;

(iii) improving the stability of thin walls by using ring-beams;

(iv) adding horizontal and vertical reinforcement to the masonry, (earthquake-resistant systems).

9.3 Types of structure: Essential rules of good practice

(i) Knowing the material, its physical characteristics, properties and mechanical performances.

(ii)   Knowing the particularities of the earth building technique employed, the special equipment it requires and the specific ways in which it is applied.

(iii)   Adopting simple building systems which are compatible with the way of using the material:

good compressive strength, poor tensile, bending and shearing strengths.

(iv)   Adopting design principles and building solutions which are proper to building with earth, taking care to protect the parts of the building which are exposed to the main causes of degradation (water for example).

(v)   Ensuring that the execution of the building work is carefully carried out.

9.4   Foundations and footings

9.4.1 Two types of problem

Particular care should be taken with the foundations and footings of a compressed earth block building and the building should be protected from two main types of problem:

(a)   structural problems,

(b)   problems linked to humidity.

These problems arise due to:

(i)   the very nature of the material, which are vulnerable to inherent structural risks or to humidity which can cause very serious damage

(ii)   external factors — differential settling, landslides, and natural disasters such as earthquakes and floods — which will be even more damaging if the building has been badly designed or built.

9.4.2 Choosing a system of foundations and footings

The choice of foundations and footings should above all be well-suited to the nature of the ground, the nature of the building (private or open to the public), the nature of the loads and permissible overloads, the climatic constraints of the environment (rain, snow, wind, etc.), the building principles of the structure (the type and thickness of wall, whether or not there is a cellar or a sanitary pit, etc.).

NOTE   Users of this standard should make references to existing technical literature for details on construction aspects with illustrations which are listed in the bibliography such as [21].

9.4.3 Water and humidity

Appropriate measures shall be taken to eliminate problems posed by water and humidity, particularly at the base of walls and at the level of foundations and footings. In particular, the following problems shall be addressed:

9.4.3.1 Problems with foundations: At the base of the walls, from the foundations upwards, the danger of capillary rise can stem from several sources: seasonal fluctuations in the water table, water retention by plants or shrubs growing too close to the walls, damage to the clean water supply or waste water system, absence of drainage, a damaged drainage system, or stagnation of water at the base of the walls. A lengthy period of humidity can weaken the base of earth walls, notably when the material loses its cohesion and passes from a solid to a plastic state. The base of the wall may then no longer be able to support the loads and will be in danger of collapsing. Humidity also encourages the emergence of saline efflorescence which attack the materials and hollow out cavities where small animals can nest (insects, rodents, etc.) and this can further aggravate the process of wearing away which has already started.

9.4.3.2 Problems with footings: Above the natural ground level, the base of the wall can be attacked by water. This can be due to water splashing back, waterspouts, badly designed or damaged gutters, puddles being splashed by passing vehicles, washing the floors inside, morning condensation (or dew), a roadway gutter flowing too close to the wall, surface waterproofing (cement pavement) which prevents evaporation from the soil, a water-proofing render which causes moisture to be trapped between the wall and the render or the growth of parasitical flora (such as moss) and saline efflorescence.

9.4.3.3 Infiltration without accumulation: This humidity risk is very common where the foundations are built on a permeable site, the geotechnical composition of which is predominantly sand and/or gravel. This type of site ensures good drainage away from the building. When it rains, water infiltrates rapidly from the surface to underground. This infiltrated water does not therefore get the chance to accumulate and stay in contact with the foundations. There is therefore no risk of sufficient capillary rise to reach the wall and cause damage.

Since the water disappears very quickly underground, all that needs to be done is to evacuate as quickly as possible the same amount of remaining water which penetrates towards the foundations. In this case, the foundations and footings can be subjected to the weak capillary risk resulting from the infiltration, but they must without fail be able to withstand the risks of water flow and/or water splash- back occurring at the base of the structure, at the surface. The use of materials such as stone, fired brick or rendered sand-cement block can reduce this risk. Any rendering can be restricted to the interior surface of the footing in order to leave the way open for evaporation towards the outside to occur and to avoid any humidity traces on the inside. It is not necessary to use impermeable materials for the foundations nor to install a drainage system.

9.4.3.4 Infiltration with temporary accumulation: This risk frequently occurs in cohesive clay or silty soils. If the way the foundation is built is combined with good surface drainage, in the form of an incline draining water away from the building, then this humidity risk is less great. In a cohesive soil, water penetrates less quickly from the surface to underground and towards the infill material. The latter, when it consists of permeable material (sand and gravel, for example) will only accumulate water temporarily, but this water will have difficulty in disappearing from the adjacent cohesive soil. Nevertheless, this kind of temporary accumulation can result in water suction occurring in the foundations for a short time.

Since in this case the cohesive soil absorbs water, good surface drainage is required in order to evacuate water from the vicinity of the building. A pavement or banking up may suffice but care must be taken not

to make these impermeable to migrations of humidity or moisture. This is unfortunately what often occurs when, with the best of intentions, a pavement made of too high dosage cement is built. This prevents even the small amount of water which remains at the level of the foundations from escaping, since it is trapped by the impermeable surface and so naturally moves towards the footings and the base of the wall. There is no need to use an impermeable render, or even a bitumen one, on the vertical face of the foundations, nor to build impermeable foundations, nor even a deep drainage system, since the water accumulation is only temporary. The structure must be allowed to breathe.

9.4.3.5 Infiltration with prolonged accumulation: This risk can occur in all types of soil with poor surface drainage, even permeable, sandy and or gravelly soils when the ground slopes towards the building (a situation to be avoided at all costs). In this event, the slope acts as a captor and accumulator of water, which then stays in prolonged contact with the foundations. Capillary rise follows, and this can be significant during the rainy season. This capillary rise, depending on the design of the building, can even reach the footings and the base of the wall. Serious damage can occur.

When there is a danger of prolonged water infiltration, the water must be intercepted before it penetrates underground and evacuated as quickly as possible. The principle of drainage is perfectly appropriate here. Drains can be built right against the foundations but then the external vertical surface of the foundations will have to be rendered or made impermeable. They can also be installed at a distance in the order of one metre from the foundations, but on condition that they are located deeper than the foundations. These more distant drains are more efficient if they are used in conjunction with an evacuation incline at the base of the wall and if the top layer of the drain layer is bowl-shaped to aid evacuation. It is also prudent to add a horizontal anti-capillary barrier (e.g. polythene, bitumen, or high dosage mortar) between the footing and the earth block wall.

9.4.3.6 Capillary rise with or without infiltration: The most serious humidity risk occurs when the structure is in contact with or in close proximity to the water table. When the foundations are directly in contact with this water table, capillary action is continuous. This phenomenon is all the more sensitive when the soil is cohesive as the latter, once saturated with water, remains in a permanents/ate of humidity. In a permeable soil when the foundations are always above the level of the ground water, a normal cycle of evaporation can take place and the danger is less, but still present. The permanent exposure of the foundations to the risk of capillary rise represents a great danger of damage to the base of the structure.

Permanent capillary rise occurs when the source of humidity is permanently present and occurs on both sides of the foundations which are in contact with the water table. On the outside, this humidity occurs as a result of the accumulated effect of rain and capillary rise. On the inside, it occurs as a result of capillary rise. Drains must be built against the foundations (which should be water-resistant) and even under the floor covering of the ground-floor if this is directly on the ground. Distant drains are not recommended. Water-proof horizontal barriers are also needed between the footing and the earth block wall. If the floor covering is directly on the ground it can be laid on a water-proof film which is itself unrolled on a rough surface of stones and rolled gravel which acts as an anti-capillary barrier. It is preferable to previously dig up the ground supporting the building and make sure that some permeable materials (e.g. gravelly-sandy soil) are present. If the building is over a sanitary pit, this must be ventilated.

9.4.4 Choice of materials and specifications

When digging foundation trenches, the first thing is to dig them as regularly and cleanly as possible. This means both looking for good ground, as far as possible, without having to dig too deep (which costs more) and making sure the sides of the trenches are straight. Traditional principles of laying out a building using

wooden stakes and strings are very useful for ensuring that the foundation trenches are correctly traced out.

The second thing is to avoid allowing the newly-dug trenches to be exposed to bad weather for too long. This is why 4 to 5 cm of blinding concrete, dosed at 150 kg/m³, is recommended at the bottom of the trench. This will also help to start off the masonry work of the foundations. On top of this blinding concrete, the body of the foundations can be built from stones, fired bricks, full sand-cement blocks, cement or cyclopean concrete, and in exceptional cases from compressed earth blocks stabilized at

10% if the risk from humidity is not too great. The footings can also be built from stone, fired bricks, rendered sand-cement blocks, cyclopean concrete masonry or compressed earth blocks stabilized at

8% there is not too much risk of humidity occurring as result of splashback. Concrete foundations should be dosed at 200 kg/m³; if they contain reinforcement, at 250 kg/m³; and if they consist in a reinforced concrete footing plate or ground-beam, at 300 kg/m³. In the latter case, the quantity of steel can be estimated at between 50 and 70 kg/m³, including 25 to 40 kg for the transverse reinforcement which absorbs tensile stress.

9.4.5 Using cyclopean concrete

For cyclopean concrete foundations, rubble stones are incorporated in successive layers of cement mortar which coats each layer of stone with a covering at least 3 cm thick. This type of structure is perfectly suitable for a low-cost construction on good ground, but must be well done. Notably, the rubble stones should not touch each other, nor be located only at the sides of the foundations, in which case the central part of the foundation would be filled only with mortar, giving a weak structure.

Stones which take up the whole width of the foundation should be laid at regular intervals, forming a kind of toothing.

The other aspect to be considered is how much cement to use in cyclopean concrete which should be dosed at 250 kg/m³ (250 kg of cement, 400 litres of sand and 800 litres of gravel). Once the rubble stones have been laid in layers of concrete, 1 m³ of cyclopean concrete ultimately contains less cement that solid concrete (approximately 125 kg) which is interesting from an economic point of view. All in cases, the total width of the foundations should be at least 40 cm, and at least 20 cm thicker than the wall thickness, divided between both sides of the wall faces starting from the longitudinal axis. The height of the body of the foundations should be at least equal to half the width. If the foundations require an anti-capillary water-proof layer, this can be made using highly dosed cement mortar (500 kg/m³), bitumen-based paint or a bitumen or plastic film if these materials are available.

Cyclopean concrete can continue to be used for the footings; above the foundations, in which case the cyclopean concrete must be shuttered and the stones placed right up against the shuttering. The principle of toothing stones (approximately every 60 cm and in alternate rows - one at each corner and one in the middle) to ensure the solidity of a cyclopean concrete footing should be carefully checked on site.

9.4.6 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. These movements are essentially vertical, and as a result the foundation ring-beam will be designed like a beam with vertical bending moment. Such a ring-beam therefore has to be a beam with reinforcement

running from top to bottom. At the same time if the body of the foundations is mainly built from masonry, it is possible to reduce the amount of steel used. By locating the reinforced concrete ring-beam halfway up the body of the foundations, one can assume that there is an area of compression above and below this reinforced steel and the whole can therefore act in both directions. This means using masonry which has perfect compressive strength and hollow sand-cement blocks cannot be used.

The principle of using a ring-beam in the foundations cannot be applied to small, single-storey buildings founded on good to medium strength soils (rocky soils, compact sandy-gravelly soils, or cohesive soils) and if loads are evenly distributed. In other cases, it is preferable to use the solution of a reinforced concrete ring-beam which is integrated into the foundations.

9.5 Openings

9.5.1 Good structural bonding

Care should be taken with the structural bonding of frame openings with CEB walls in order to limit the danger of cracking which could lead to water infiltration and therefore a process of erosion.

9.5.2 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:

(i)   making openings too big, placing too great load a on the lintel;

(ii)   too many openings of too many different sizes on the same wall, which weakens the wall;

(iii)   locating an opening immediately next to the corner of a building, making the corner buckle;

(iv)   two openings too close together with too slender an intermediate pier, making the pier buckle;

(v)   insufficiently strong frame jambs, leading to buckling;

(vi)   insufficient anchoring of the lintel or of the supporting base into the wall, leading to shearing;

(vii)   poor earth block bonding patterns near the openings, leading to cracking through superimposed vertical joints.

9.5.3 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.

9.5.4 Sill

This serves notably, for a window, to absorb the loads transmitted by the reveal jambs. Reinforcement can be added below the sill. Another problem to resolve is that of the breast shearing. A preferable solution is to use dry joints between the breast and the wall, so that the window frame is in fact built in the same way as a doorway, and the breast added later. The dry joints can be filled in later when the initial shrinkage and settlement of the masonry has occurred.

9.5.5 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:

(i)   a drip under the lintel and under the sill, or a system of fillets to project water away. All projections must be avoided;

(ii)   solutions to problems of condensation which could arise at thermal bridges;

(iii)   reinforced stabilization, rendering, or covering joints in the external facade, flush with the sides of the openings (in high rainfall regions);

(iv)   water-proofing under the sill.

9.5.6 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.

(i)   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.

(ii)   The overall length of openings should not exceed 35% of the length of the wall.

(iii)   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.

(iv)   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.

(v)   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).

(vi)   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.

9.5.7 Materials for the reveals

As with any construction system using small masonry elements, with compressed earth block construction it is perfectly possible to use the same material for the reveals of openings as for the walls. If this is done, it is preferable to use stabilized compressed earth blocks in order to ensure good resistance to any risk of vulnerability to humidity and in compression, particularly for the jambs. A compressed earth block arch can replace a lintel and the supporting base can be made from fired brick or from concrete. Whatever is used, a frame made from blocks must be perfectly coursed in order to guarantee the quality of the bonding and thus overcome the risk of structural weakness.

The other standard solution is to built a complete reveal in wood the width of which in section is equal to the thickness of the wall, taking care to dimension the anchoring of the lintel and of the sill into the masonry correctly (the anchor should be at least equal to the length of a block.)

Other solutions, which combine, for example, the use of a fired brick masonry with compressed earth block masonry, are possible, giving great flexibility in use and an attractive appearance, but great care should be taken in applying these.

9.5.8 Fixings and anchorings

Fixing ready-made frames of doors and windows directly into compressed earth block masonry must without fail be well anchored. Vibrations and blows as the woodwork is handled can cause cracking to occur. Similarly, the fixing must be compatible with the maintenance, repairs and possible replacement of the woodwork without damaging the structure of the wall.

Two solutions are possible:

Holding the ready-made frames in place as building the masonry is built up and anchoring them in mortar (using barbed wire or anchor-points).

Integrating wooden blocks, («gringos blocks»), into the coursing of the masonry frames. These then make it easy to nail, plug or screw in ready-made frames.

9.5.9 Protecting the frames

Reveals must be protected from the risk of erosion resulting from the "drop of water system", and from wind which can be very significant in an area liable to cracking. Taking great care when building the reveals of openings, good structural bonding of the materials making them up and the improvement which surface stabilization or rendering all around the reveals (whitewash or paint) can provide, are capable of guaranteeing this protection.

In a 2-storey building and in the case of facades which are exposed to the prevailing winds' first floor openings are more exposed than those at ground floor level, particularly at their sill. The exposed parts should be stabilized and care should be taken to ensure that the sills of the first floor openings do not project too far (risk of erosion due to turbulence). Waterproofing should also be used between the lower edge of the opening and the CEB wall, as well as drip-stones or fillets underneath the lintel and the sill.

9.5.10 Woodwork

This should be very carefully made and if possible include drip ledges under the lintel, supporting pins and a way of evacuating condensation. It is always preferable to locate woodwork flush with the exterior facades to eradicate the "drop of water system" as much as possible. Care must also be taken when fixing the hinges of shutters and with any kind of external occultation.

9.6   Reinforcement

9.6.1 Need for reinforcement

Systems for reinforcing earth block walls have been developed in order to improve the resistance of earth buildings to earthquakes with the use of vertical and horizontal reinforcement being part of the building codes for countries prone to earthquakes. The building systems exploited use the principle of a wooden or steel ring-beam sunk into the walls, and also reinforcement of the corners of walls and opening frames. The existence of reinforcement considerably improves the tensile and bending strength of the masonry.

9.6.2 Special blocks

Reinforcement shall be done using special blocks with channels, hollows or holes which allow the incorporation of vertical and horizontal reinforcement reinforcing elements.

9.6.3 Upper ring-beams

The ring-beam is the ultimate earthquake resistant building system. Indeed if there is no ring-beam, any other earthquake resistant building approach is rendered practically useless, particularly with thin, high walls. The ring-beam ensures good transmission of loads and allows a highly organized masonry structure to be formed.

Horizontal and vertical ring-beams are the reinforcement systems most used. They can sometimes consist in very localized reinforcement, located in the weakest parts of the masonry structure, either at the corners, or at the reveals of openings. Such localized reinforcement is most often sunk into mortar beds and is made of wood, steel, metal mesh or grids.

The part played by the reinforcement is particularly important to ensure the stability of compressed earth block masonry, as it is for all types of masonry using small building elements (e.g. fired bricks). It remains indispensable even in regions which are not exposed to seismic risk particularly for thin wall construction.

Reinforcement reduces the danger of cracking which is the effect notably of differential settling, shrinkage; swelling, thermal expansion, rotation or shearing stress (at openings and walls junctions), stress caused by the pressure of flooring, the lateral force of the wind, sloping roofs, arches or vaults. Reinforcement enables the harmful effects of these stresses to be reduced by containing the wall in all directions, continuously.

The main role of reinforcement is to bond the walls together, notably to absorb horizontal loads, as vertical loads are absorbed by the foundations. This bonding effect can be ensured only if the reinforcement is perfectly connected to the wall and if it is perfectly rigid and impossible to deform, particularly to ensure good tensile strength.

Reinforcement can also be used for other purposes to reduce deformations due to the risk of buckling (in which case it is preferable to locate it at an intermediate height in the masonry, under the lower edge of the openings or at the level of the lintel), to ensure that loads are evenly distributed, to provide a continuous lintel or to serve as a support and anchor-point for the floors and roof.

9.6.4 Reinforcement materials

The main materials used are wood, steel and concrete. These materials must possess good adherence with the earth block masonry to ensure the efficiency of the reinforcement. Reinforcement made of wood (bamboo, eucalyptus) or of steel are generally laid in a bed of mortar within the thickness of the walls. Steel must be correctly tied, especially at the corners of walls and sufficiently well covered with concrete. Concrete reinforcement is either poured at the top of the thickness of the wall (leaving the problem of a thermal bridge to be resolved), or into special hollow blocks or used in a block bonding system of lost formwork.

9.6.5 Thin masonry

For thin walls buttresses can be integrated into the facades, notably at the corners and in the vicinity of the reveals of large openings. The walls are also horizontally reinforced at the level of the floors and/or the roof and these upper and lower reinforcements are linked together by vertical elements at the corners and at adjacent walls.

For gable-end walls, integrating a pillar into the axis of the wall, taking care with precise bonding and toothing with the wall masonry ensures good reinforcement. This pillar makes the wall panel rigid and improves its resistance to wind pressure. Reinforcement at the base of the gable-end wall absorbs the wall loads.

9.7   Floors: Structures

9.7.1 Compressed earth block floors

Most commonly, compressed earth block masonry is intended to support floors of standard design, with wooden beams, or precast concrete beams covered with sand-cement or fired bricks, or even load-bearing concrete floors, either shuttered in place or prefabricated and placed on reinforcements. But compressed earth blocks allow floors to be made using the building principle of jack-arches on concrete or wooden beams, or even on steel.

9.7.2 Requirements and constraints

9.7.2.1   General

From a structural point of view, a floor must withstand static loads caused by use, concentrated loads (and the danger of point-loading) and should transmit these loads down to its support in the load- bearing compressed earth block wall. These loads, through the support, should be evenly spread and directed towards the centre of gravity of the load-bearing wall.

From the point of view of finishings, apart from the structural aspect, there is the floor (above) and the ceiling (below). The floor should be hard-wearing, with a carefully finished flat surface which is easy to maintain and durable. The under-face of the ceiling should also be attractively finished.

9.7.2.2   The floor-wall bonding

The bonding of a floor with its support (wall or pillars) is ensured by a base which also transmits loads to the support. The main problems are as follows:

v)   **Point-loading:** this occurs when the base is too small and when it fails to transmit loads evenly. It takes the form of differential stresses and cracks. To avoid this risk, the surface area of the base should be increased and the loads should be brought back to the centre of gravity of the support.

w)   **Rotation:** this occurs when the floor flexes. One can then observe lifting, loads no longer being central, cracks and crushing of the support. To prevent rotation, the correct ratio of load to span to section must be re-established and the floor must be laid on a ring-beam.

x)   **Dimensional variations:** generally, these have a thermal origin or result from differential flexing between the floor and its support.

y)   **Thermal bridge:** this arises because of the variation in hydrous and thermal behaviour of the materials of which the floor and wall are made and provokes condensation. Avoiding direct contact between the body of the floor beams and the wall, reinforcement integrated into the wall leaving an external earth block cladding, limits this risk.

9.7.2.3 Laying the floors

The best way to ensure that floors are carefully laid is to leave gaps beforehand to receive the beams or their bases in the wall. This problem should be taken into account as soon as the working plans for the structure are being prepared, notably during the coursing of the building plans. On site, the most important problem to resolve is that of protecting the floor structures from rain in order to avoid any water infiltration.

9.7.2.4 Jack arches and vaulting

A compressed earth block floor made of jack arches acts like lost formwork. This is a solution which reduces the amount of sand, gravel, cement and reinforcements used compared with concrete floor systems.

Vaulting floors have the advantage of making the compressed earth block work in compression with bending stresses being taken up by the wooden, concrete or steel beams or struts. The span for receiving the beams varies from 0.50 m for small systems to 2 m for the largest which can require the use of metal tie-rods. CSEB vaulting rests on the lower wings of the IPNs or on the spines of the concrete struts. A small curve (1/1 0 of the span) allows the struts to take up the stresses well. The floor is finished by filling in with stabilized earth concrete or light concrete. These floors are still, however, heavy, and the load they exert must be evenly spread and transmitted to the bases.

Building vaulting can be done using formwork, most often sliding formwork, or without shuttering using a laying technique similar to that of the Nubian vault (successive inclined courses) or on a plank supported by props (located in the axis of the vault) and on which the blocks are placed on either side of the axis.

9.8 Roofing

9.8.1 General

The roof shall serve the following purposes:

(i)   It must be strong enough to remain in place;

(ii)   It must not leak;

(iii)   It must provide protection so that water running off the roof will not run down the sides of the earth wall.

9.8.2 Design considerations

Roof designs may take the following forms:

(i)   **Flat roofs** with a maximum gradient of 10, mostly found in hot regions which are not subject to rainstorms.

(ii)   **Pitched roofs** with broad eaves (minimum 30 cm): drain rainwater very well and are particularly well suited to earth structures. These roofs are also suitable for use in tropical cyclone regions (minimum gradient 30°).

9.8.3 Water protection

9.8.3.1 The roof shall provide protection of the walls from water entry, cause water to be discharged away from the base of the wall, protect the surface of the wall against vertical rain and provide shade.
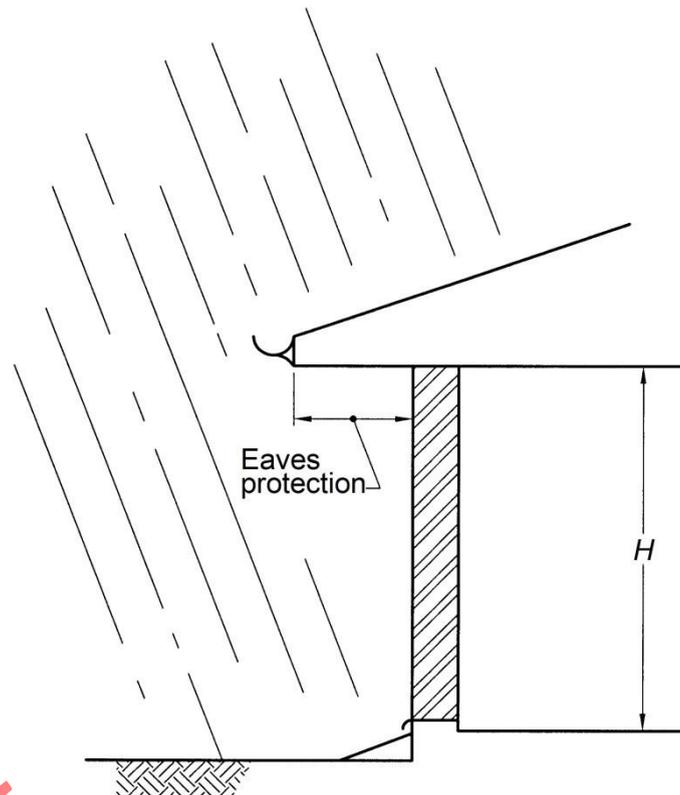
Figure 20 — Protection from eaves projection

A roof with enough overhang

A water drip strip above windows and doors

A sloped window sill

Waterproof plaster to 2 layers above foundation level

A layer of tar to prevent water sucking

A foundation that rises above ground level

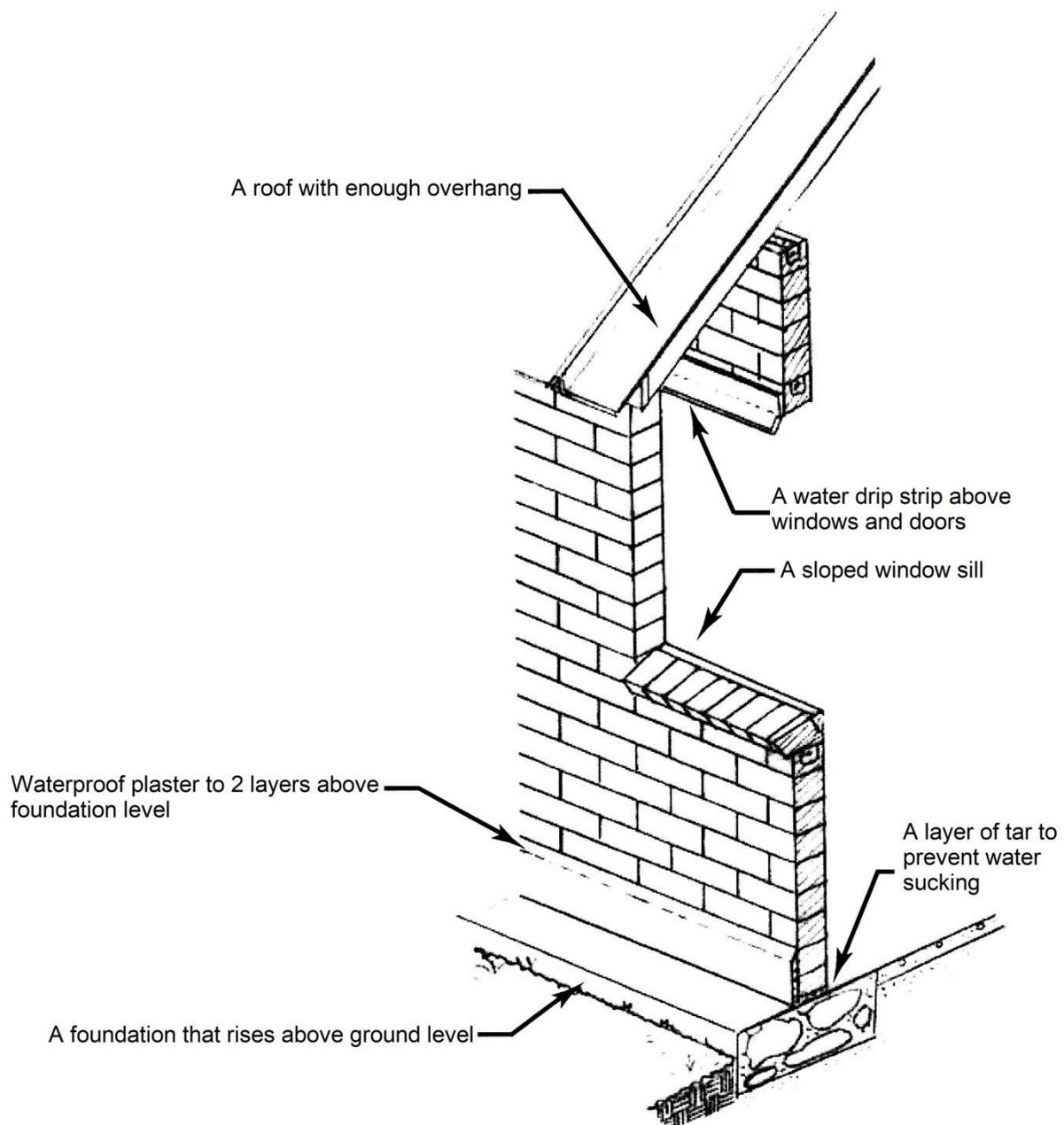**Figure 21** — Characteristics of a good water resistant system

9.8.3.2 The roof must be built rapidly and not too long after the rest of the construction work. If it rains during the construction of the roof, the tops of the exposed walls must be well protected. One must always allow for the possible failure of the roof and make the tops of the walls water-tight. There is a suitable pitch for every roof covering.

9.8.3.3 Reducing this pitch may lead to leaks as the result of inadequate drainage, standing water or infiltration by water. Saw-tooth roofs are to be avoided as are roofs with two adjacent slopes having low edges, unless the use of wide sloping gutters is envisaged.

9.8.3.4 The joints of damp-proofing must be properly executed. Walls of which the upper portion forms a gable are to be avoided as they make flashing and mortar infilling necessary and this is not always reliable. The flashing for roofs supported by gable walls should be executed by means of a strip of rendering or wearing surface consisting of stones or burnt bricks which affords protection against water splash.

9.9 Finishes

9.9.1 General

A compressed earth block wall with a good bonding pattern and built with high quality mortar binding together all the elements in all directions and resistant to erosion, is not permeable. One can therefore manage without a render and ultimately reduce the cost of construction as well as the amount of cement used. If, for one reason or another, such protection is needed, then it must be applied following the guidelines for application which we specify below. Above all, the protection must remain supple and moisture permeable to avoid the risk of it peeling off or separating.

9.9.2 Conditions of application

(a)   **Removing dust:** The wall to which a render is to be applied must be free of all loose, crumbly or dusty material. It should be carefully brushed (using a metal brush.)

(b)   **Moistening:** The wall must not absorb the water contained in the render or it will not set or harden so well and it will stick less well. The wall must therefore be moistened in order to avoid capillary suction occurring, but it should not be too wet as a film of water at the surface would limit the adherence of the render.

9.9.3 When to apply the render

An earth wall must never be rendered before:

The shrinkage of the masonry during drying out has stabilized and the water and moisture has completely dried out. This can take several weeks.

The wall has been allowed to settle. This means waiting for all structural work to be complete, including all the loads of floors and roofs.

9.9.4 Application conditions

Do not render in very cold or very hot weather. Avoid driving rain, direct sun, violent winds or very dry conditions. Slightly humid weather is ideal.

Apply the render in panels of 10 to 20 m² at a time and complete each facade in one day.

Take care with the edges (corners) and reveals of openings. On a mixed support (earth and wood), incorporate a mesh nailed on. Do not render right down to ground level (capillary suction).

Avoid allowing the render to dry out too quickly by spraying water onto the surface in the morning and/or evening for the first few days.

Table 11 — Various areas of application for renders, distempers paints and impregnations on outside or inside walls

Areas of application	Outside	Inside
Without protection	yes	yes
Quick-lime-based render	yes	yes
Hydraulic cement or lime render	not to be used	yes
Gypsum plaster render	to be avoided	yes
Lime wash	yes	yes
Cement slurry	yes	yes
Paint	to be avoided	yes
Water-proof treatments	not to be used	not to be used
Water-repellent treatments	to be avoided	to be avoided
Highly diluted varnishes	to be avoided	yes
Highly diluted wood glue	to be avoided	yes

9.9.5 Renders

Renders are generally applied in three layers, but sometimes two layers suffice. The compositions of the renders are provided in Table 12.

The first layer, known as a rough coat or "primer", is made up of a fairly fluid mortar which is thrown with force onto the support using a trowel. Between 3 and 5 mm thick, the surface of this layer is rough so that the next layer will stick more easily.

The second layer, known as the "coating" or the "body of the render" is applied a few days after the primer (minimum 2 days) in one or two passes. This layer is 8 to 20 mm thick and is carefully smoothed using a ruler; it should. display no cracks.

The third layer, known as the "finishing render", completes the rendering process and fills any shrinkage cracks which might have appeared in the coating. It is applied when the coating has completely dried out. It is only a few mm thick and it can be finished with a plasterer's hawk without applying too much pressure.

Table 12 — Composition of lime-based renders or lime-cement-sand renders

Lime-based render	Volume of lime	Volume of cement	Volume of sand
First layer	1	-	1.5
Second layer	1	-	2.5
Third layer	1	-	3.5
First layer	2	1	4

Second layer	2	1	6
Third layer	2	1	9

9.10 Installing technical systems

9.10.1 Designing the system

There are three main rules to be followed:

(i)   The systems must be as centralized as possible.

(ii)   Any incorporation of pipelines for supplying and removing fluids into the walls must be avoided.

(iii)   Making grooves in the walls to take electricity cables should be avoided.

Following these three rules necessarily implies that the technical installations must be designed in advance and not on site, at the last minute.

9.10.2 Electricity

Electrical systems are either visible or integrated into the masonry.

Visible systems are either cables, or casings, or electrical skirting boards. The main problem is how to attach them. There are several solutions:

Maximum use can be made of materials other than earth, such as wood or visible cement for example: wires can be run along skirting boards, then up alongside wooden frames, along the ceiling, the ring-beam or other building systems.

Wooden blocks of the same size as the earth blocks can also be used, integrated into the bonding pattern. Wedge-shaped pieces of wood can be integrated into the bonding pattern in the thickness of the mortar joints where cables are to be run. Then all that needs to be done is to attach collars or pins to them.

One can also mould special sand-cement blocks of the same size as the earth blocks and then fix the cables to these using rawl-plugs
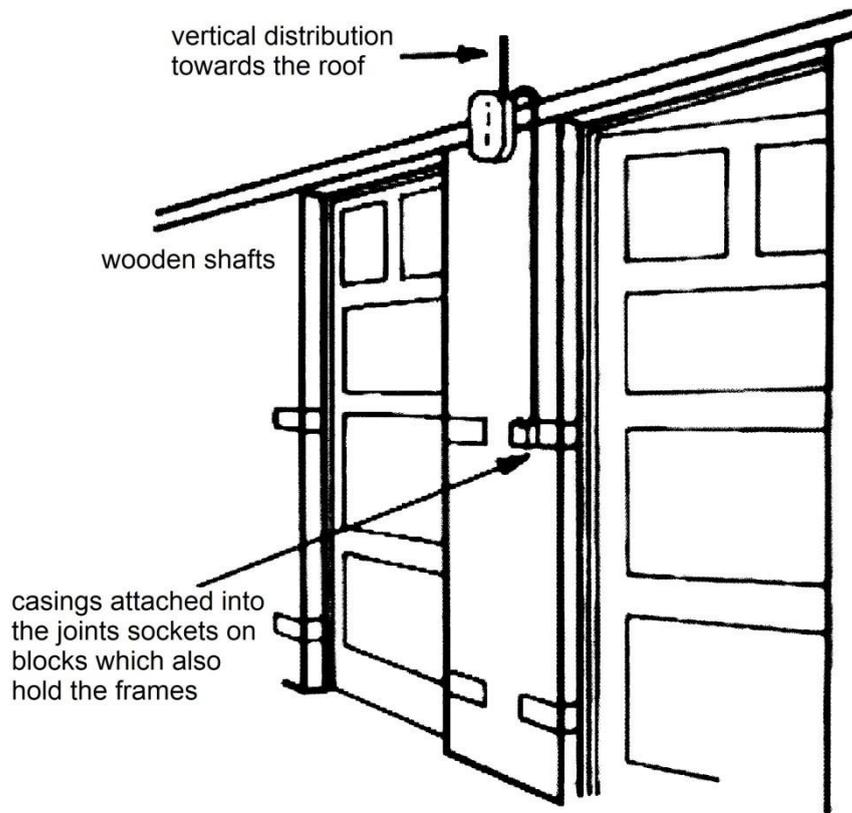
Figure 22 — Attaching cables near wooden frames

Integrated into the walls: The cables are protected by casings which are integrated into the thickness of the walls during construction and the junction boxes are integrated into the surface of the walls. The casings can be run horizontally in special hollow blocks or behind grooved skirting boards. Gaps can also be left in the ring-beam and these then covered up using a joint-cover on the facade. Maximum use must be made of wooden frames to run casings vertically. The integration of plug sockets, light switches, and junction boxes can be done by cutting into the blocks and then fixing them with mortar or using special blocks moulded in sand-cement, incorporating the sockets and tubing to connect the cable

electricity distributed from
above: thin wooden bands
alongside the wooden
door and window frames

light switches fixed to
the wooden frames

electrical sockets
fixed to skirting
boards

System using wooden frames
and horizontallintels
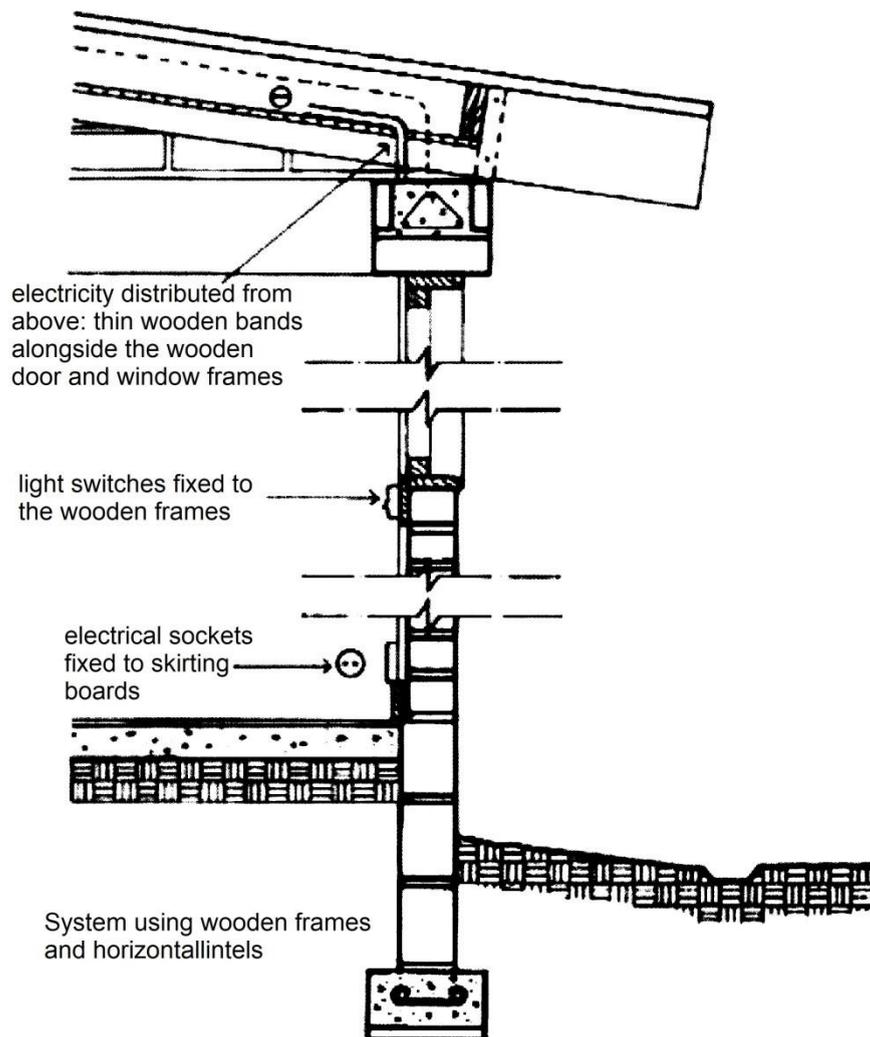
Figure 170 — Vertical sections showing the integration of the electrical network alongside the woodwork and skirting boards

9.10.3 Plumbing

9.10.3.1 Water supply

The pipework should be integrated into the thickness of the floor to the maximum extent possible and where pipes pass through the walls, a protective pipe-sleeve should be used. Any other pipes, horizontal or vertical, should remain visible and the same principle as for electrical cables can be used for attaching them to the surface of the walls.

9.10.3.2 Water removal

The principle is the same as for water supply but inspection hatches must be included with very long pipes, and where there are bends or junctions.

9.10.3.3 Bathrooms

The walls close to bathroom fittings (hand-basin, shower, bath) must without fail be rendered or tiled. A floor syphon should also be fitted to make it easier to clean the floor and to evacuate water in the event of a leak. Good ventilation is also recommended to avoid condensation

Annex A
(normative)
Roll and soap tests

A.1. The roll test

A.1.1. Purpose

To find if the soil is suitable for rammed earth (see Figure A.1).

A.1.2. Procedure

A.1.2.1   Take a handful of unsieved soil, moisten, make into a ball, and leave to dry in the sun. If it falls apart it has too little clay, and is thus unsuitable for rammed earth: look for another soil source.

A.1.2.2   If the ball remains together when dry, crush the soil to remove any lumps. Add water slowly. Make a ball and place it on hard ground. Take a 10 mm diameter reinforcing bar, 500 mm long, and stand it vertically, with its end resting on the middle of the ball of damp soil. Let it sink in under its own weight. (Do not push it). When the bar sinks in exactly 20 mm the water content is right for doing the test.

A.1.2.3   Take enough of the damp soil to form a ball in your hands; then between your hands form into a roll 25 mm thick and 200 mm long. Place the roll on a table, and push it gently over the edge. Measure how long it gets before it breaks off. Check the length of the piece that drops.

A.1.3. Result

If the roll breaks off less than 80 mm, there is not enough clay. If the roll breaks off longer than 120 mm, there is too much clay.

NOTE   Any other suitable test method can be used.

A.2. The soap test

A.2.1. Purpose

To find out if the soil is mainly clay or silt (see Figure A.1).

A.2.2. Procedure

Take a handful of the soil you are testing, and damp it slightly in a bowl. Take a lump of this soil and rub it between your hands as if washing them with soap.

A.2.3. Result

(1)   If the soil sticks to your hands and washes off only with difficulty, the soil contains too much clay; it may need mixing with another soil before it can be used for rammed earth.

(2)   If the soil does not stick much and washes off easily, the soil is sandy or silty; it may be usable for rammed earth as it is.

The 'roll' test

Ensure the soil is damp

Dry in sun

Poor soil

Good soil

① Make a ball

② 10 mm reinforcing rod   500mm   20mm

③ Form into a roll 200mm long

④ 200mm   25mm   80 - 120mm

The 'soap' test

① Dampen soil
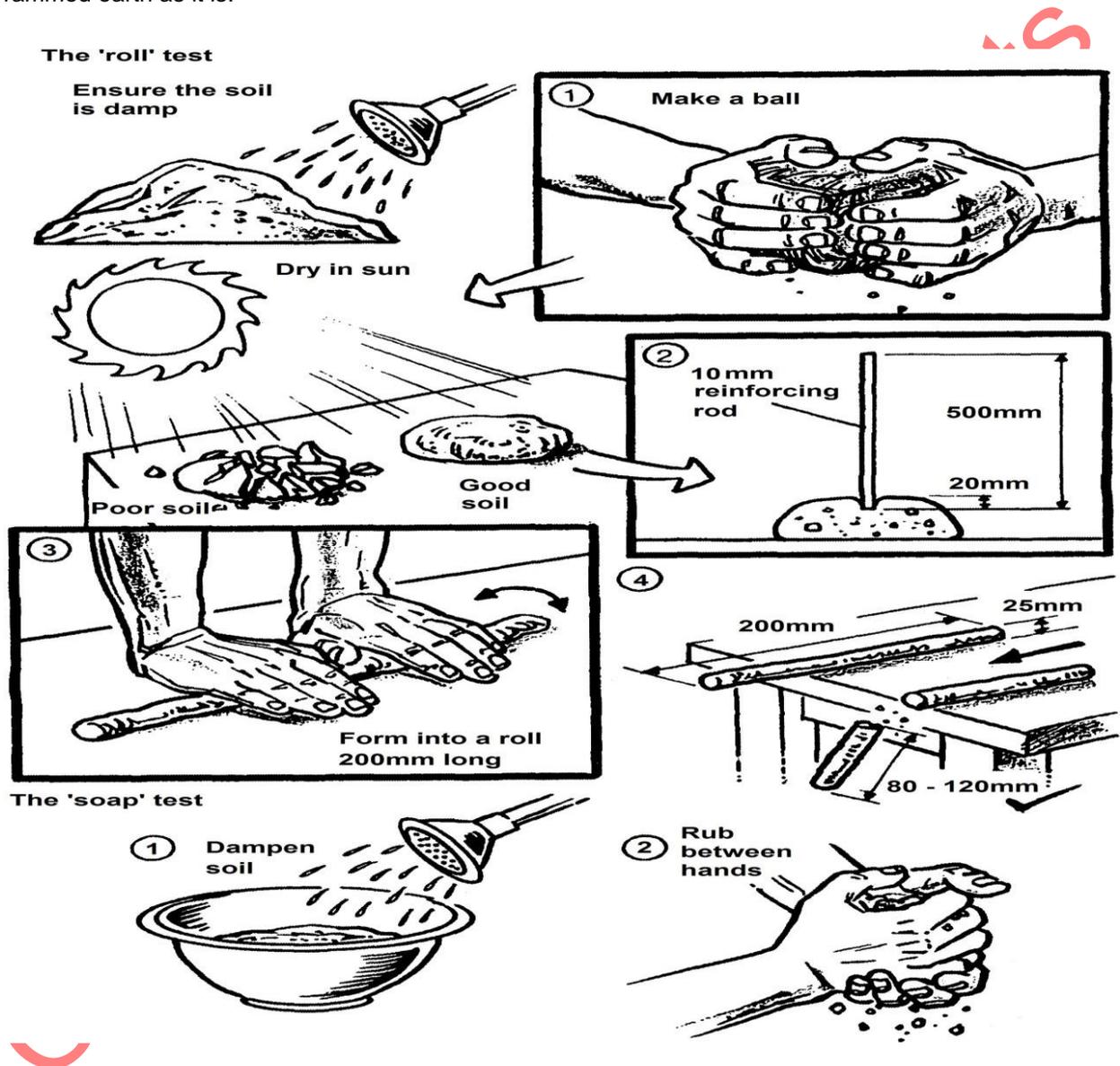
② Rub between hands

Figure A.1: The 'Roll' and 'Soap' Tests

Annex B
(normative)
The drop test

B.1 **Purpose**

To find the optimum moisture content (OMC)/Ideal Water Content (IWC) and to check this during construction.

B.2 **Procedure**

B.2.1 Take soil that has had some water added to it. Squeeze the damp soil into a ball 40 mm diameter in your hand.

Then, with your arm straight out at 1.5 m high (shoulder-level) , drop the soil ball onto a smooth clean piece of plywood (minimum 12 mm thick) placed on level ground and observe the result:

(a)   if the soil stays in one piece it is too wet, leave it to dry a while and try again;

(b)   if the soil breaks into many pieces it is too dry, add water and try again;

(c)   when the dropped ball breaks into only a few pieces it is close to the OMC and suitable for use

   (see Figure B.1).

NOTE   When stabilizing with cements, slightly more water is required than shown by the 'drop' test.

B.2.2 Continue to use the 'drop' test to check the water content of the soil as it is being used.

NOTE   When stabilizing with lime, slightly more water is required than shown by the 'drop' test. Do tests as usual then add roughly 10% more water than the test indicates.

NOTE 2   A more detailed way of finding the OMC/ IWC is by testing the dry density of the material after compaction through a range of water contents.
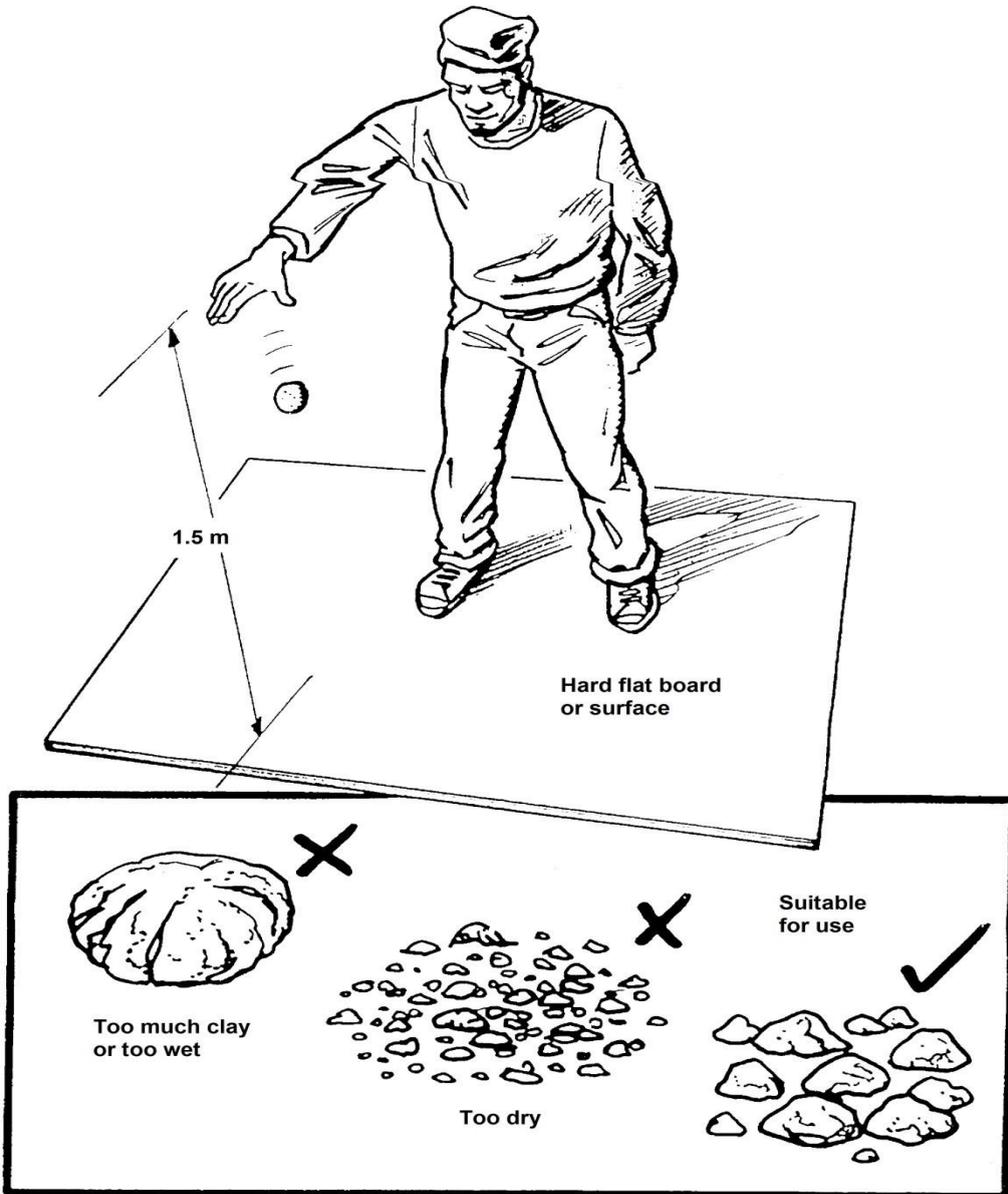
Figure B.1 — Illustration of the drop test

Annex C
(normative)
Soil testing methods for small-scale production of CSEBs
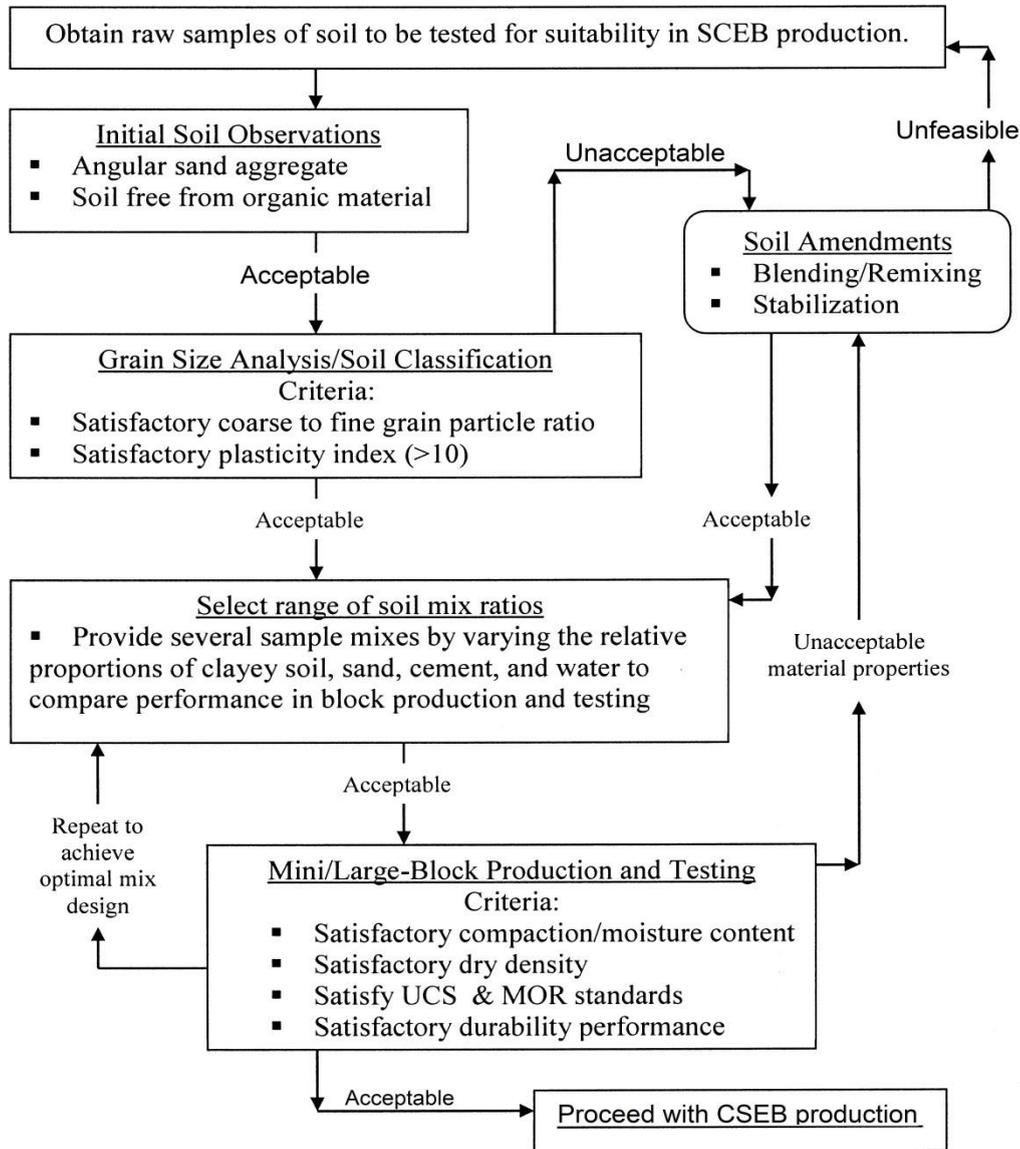
Figure C.1—Testing methodology for determining soil suitability in SCEB production

Annex D
(normative)
Measurement of dimensions

D.1 Test specimens

20 blocks shall be selected at random for test. They shall be used for dimensional checks and other tests as described.

D.2 Apparatus

D.2.1 Go/Not Go Gauges

GO/NOT GO gauges as shown in Figure D.1. The length gauge shall be appropriate to the specified length, width and height of block.

All dimensions are in millimetres
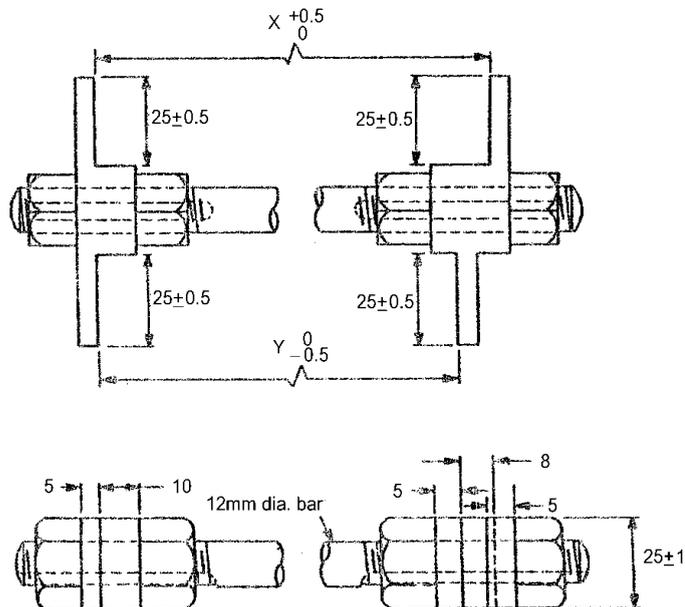
Figure D.1   GO/NOT GO gauges for checking length and height of blocks

NOTE 1   *x* is the specified dimensions of the block plus 3 mm, and *y* is the specified dimension of the block minus 5 mm.

NOTE 2   Keys are used for keeping fittings at both ends in the same plane.

D.2.2   External callipers

D.2.3   A rule graduated to 1 mm, for use with the callipers

D.3 Procedure

D.3.1 Length and height

Check the compliance of each block for length at the four corners of the end faces (*see* Figure D.2 (*a*)) using a GO/NOT GO gauge.

Similarly, check the compliance of each block for height at six points (*see* Figure D.2 (*b*)). The height of a block is the smallest of the three dimensions, i.e. width, length and height. The length and height of each block shall be reported as the respective average to the nearest mm.

A.2.4.   Width

Measure the width of each block to the nearest mm at seven random positions as shown in Figure D.2 (*c*) using the callipers and rule. Calculate and report the average of the seven results to the nearest mm.

(a) Four positions for checking
length of whole blocks

(b) Six positions for checking
height of whole blocks
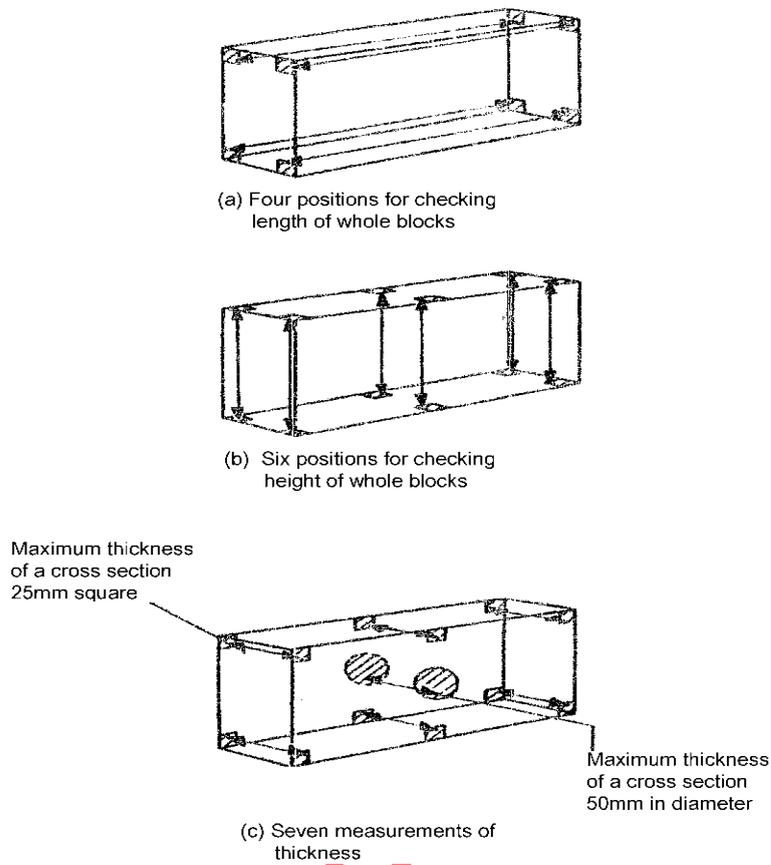

(c) Seven measurements of
thickness

Figure D.2 — Checking and measuring dimensions of blocks

D.4 Reporting

Report the average length, height and width of the blocks.

Annex E
(normative)
Determination of compressive strength

E.1 Test specimens

Ten whole blocks shall be selected at random from the sample after carrying out the dimensional checks. Five blocks shall be used for dry compressive strength and another five for wet compressive strength.

E.2 Principle

E.2.1   Dry Compressive Strength — A unit is placed in a compression testing machine and subjected to increased compression until it fails. The compressive strength is calculated from the maximum load.

E.2.2   Wet Compressive Strength — A unit is immersed in water for a specified period of time. The unit is then tested using the same principles as E.2.1.

E.3 Apparatus

E.3.1   **Loading machine** — A compression loading machine either hydraulic or screw type with adequate capacity and capable of applying the loads at rates specified in E.4.

The machine shall be fitted with two steel platens, which shall be self-aligning.

The bearing faces of both platens should exceed the test specimen by not less than 15 mm in length and breadth and shall not depart from a plane by more than 0.06 mm. Should the bearing faces of the platens be smaller than required, steel plates of adequate size may be placed centrally between them and the test specimen. Their thickness shall be equal to at least one-third of the greater difference in dimension between the machine platen and the test specimen, when centrally placed but not less than 25 mm.

E.3.2   **Measuring Rule** — A rule that can be read accurately to 1.0 mm over the dimensions of the units being tested.

E.3.3   **Water Bath** — A water bath of sufficient size to hold the specimens without them touching each other and sufficient depth to ensure that the specimens will be completely immersed in water for the full duration of the test.

E.4 Dry compressive strength

E.4.1   **Procedure** — The procedure of each specimen shall be as follows:

(a)   Measure and record the following dimensions, to the nearest millimetre.

   (i)   The width (B) of each specimen as described in D.3;

   (ii)   The length (L) of each specimen as described in D.3.

(b)   Clean and wipe the surfaces of the test specimen removing all loose debris. Clean the bearing surfaces of the platens on the testing machine, and any steel plate to be placed between the specimen and the platen.

(c)   Place the specimen between two pieces of 3 mm in plywood, the length and width of which shall exceed the corresponding dimensions of the specimen by less than 25 mm; each

plywood sheet shall be used only once. The specimen shall be placed in the testing machine such that the centre of the bed face coincides with the loading axis of the machine.

(d)   Apply the load without shock and increase it continuously at a uniform rate of 150 kN/min until failure occurs.

(e)   Observe and record the maximum load (W_D) at failure.

E.5 Wet compressive strength

Procedure — The procedure for each specimen shall be as follows:

(a)   Measure and record the following dimensions to the nearest millimetre:

    (i)   The width (B) of each specimen as described in D.3;

    (ii)   The length (L) of each specimen as described in D.3.

(b)   The specimens shall be immersed in water at 15 C to 30 C for 24 h.

(c)   The specimen shall be removed from the water bath. They shall then be wiped clean with a piece of cloth.

(d)   The procedure for compression testing shall proceed as described in E.4.1 to E.4.1 (d).

(e)   Observe and record the maximum load (W_W) at failure.

E.6 Calculation of results

The compressive strength of each specimen (dry or wet) shall be calculated from the following expression:

$$C_D = \frac{W_D}{A} \text{ or } C_w = \frac{W_W}{A}$$

where,

C =   dry compressive strength in N/mm^2;

C =   wet compressive strength in N/mm^2;

W_D =   total load at which the dry specimen fails, in Newtons;

W_W =   total load at which the wet specimen fails, in Newtons;

A =   the smaller bed face area, in square millimetres; and

     =   BL, taken for whichever of the two bed faces produces the smaller area.

E.7 Reporting

Report the average of the compressive strength; either dry or wet of the five specimens.

Annex F
(normative)
Determination of modulus of rupture

F.1 Test specimens

Five whole blocks shall be selected at random from the sample after carrying out dimensional checks.

F.2 Principle

Five blocks are tested by applying a load through two bars, with the specimen laid flatwise, until the specimen fails. The maximum bending moment is used to calculate the lateral modulus of rupture.

F.3 Apparatus

F.3.1 Loading machine — A testing machine either hydraulic or screw type with adequate capacity and capable of applying the loads at rates specified in F.4.4.

The machine shall be fitted with support bars and loading bars which will permit the loading or test specimens as simple beams as shown diagrammatically in Figure F.1. The support and loading bars shall be not less than 25 mm and not more than 40 mm in diameter, parallel and normal to the axis of the specimen.

F.3.2 A rule that can be read accurately to 1.0 mm over the dimensions of the units being tested.

F.4 Procedure

F.4.1 Measure and record the following dimensions, to the nearest millimetre:

(i) The width (b) of each specimen.

(ii) The length (depth) (d) of each specimen.

(iii) The distance (l) between the supporting bare in the testing machine (*see* Figure F.1).
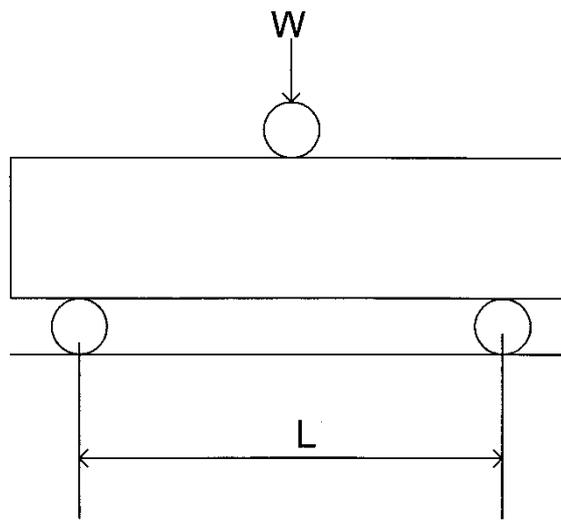
Figure F.1 — Arrangement for determination of modulus rupture

F.4.2   Support the test specimen flatwise on a span approximately 25 mm less than the basic unit length.

F.4.3   Bring the loading bar, which shall be at mid span of the specimen to bear on the upper surface of the specimen.

F.4.4   Apply the test load, without shock, at a uniform rate of 3 kN/min until failure occurs.

F.4.5   Observe the maximum load (*W*) carried by the specimen.

F.5 **Calculation of results**

The modulus of rupture of each specimen, shall be calculated from the following expression:

Modulus of rupture,

$$S = \frac{3Wl}{2bd^2}$$

$$\text{Mod} \qquad \frac{}{2bd^2}$$

where,

S =   stress in specimen at midspan, in N/mm^2;

W =   maximum load at failure, in Newtons;

l =   distance between the supports, in mm;

b =   width, face to face, of the specimen in mm; and

d =   depth, bed face to bed face, of the specimen, in mm.

F.6 Reporting

Report the average of the modulus of rupture of the five specimens

Annex G
(normative)
Determination of water absorption

G.1 **Test specimens**

Five blocks shall be selected at random from the sample after carrying out dimensional checks.

G.2 **Principle**

A block is saturated by immersion in water for a specified period of time. The specimen is then dried and the amount of water absorbed is then determined and used to calculate the percentage water absorption.

G.3 **Apparatus**

G.3.1 **Balance** — A balance sensitive to within 1 g.

G.3.2 **Drying oven** — A thermostatically-controlled drying oven capable of maintaining temperature of 105 5 C.

G.3.3 **Water bath** — A water bath of sufficient size to hold the specimen without them touching each other and sufficient depth to ensure that the specimens will be completely immersed in water for the full duration of the test.

G.4 **Procedure**

(a) Immediately after sampling, the specimens shall be reweighed to the nearest gram, and the mass shall be recorded as m_1.

(b) The specimens shall then be immersed in water at 15 C to 30 C for 24 h.

(c) The specimens shall be removed from the water. They shall then be wiped with a piece of cloth; and within 3 minutes after removing from the water, the mass of the saturated specimen shall be determined by weighing to the nearest gram. Record the saturated mass as m_2.

(d) The saturated specimens shall be dried in a ventilated oven at 105 5 C for not less than

24 h and until two successive weighings, at intervals of 2 h show an increment of loss not

greater than 0.2 per cent of the last previously determined weighing weight of specimen. Record the mass of the oven dry specimen as m_1.

G.5 **Calculation of results**

Water absorption — The water absorption (per cent) for each specimen shall be calculated from the following expression:

$$A_w \quad \frac{m_2 \; m_1 \times 100}{m_1}$$

where,

A_W = percentage water absorption;

m_1 = mass of oven dry specimen, in grams; and

m_2 = mass of saturated specimen after immersion in water in grams.

G.6 **Reporting**

Report all results separately for each unit and as average for the five units.

Annex H
(normative)
Determination of density

H.1 Test specimens

Select at random three blocks from the sample for testing. Carry out the dimensional measurements as described in Annex A, noting the average length, height and width of each block.

H.2 Apparatus

H.2.1 Drying oven — Thermostatically-controlled drying oven capable of maintaining temperature at 105 5 C.

H.2.2 Calculation of volume — Calculate the gross volume of the blocks to the nearest 250 mm3 by multiplying the average thickness by the average length and height of the block.

H.3 Procedure

Dry the three specimen blocks for at least 24 h in a ventilated oven at 105 5 C.

Cool the blocks to ambient temperature and weigh. Repeat these steps until the mass lost in one cycle does not exceed 0.05 kg.

H.4 Calculation of density

$$C_b = \frac{M}{V}$$

where,

C_b = block density (in kg/m^3);

M =   oven dry mass (in kg); and

H.5 **Reporting**

Report the density to the nearest 10 kg/m^3.

Annex I
(normative)
Weathering test

I.1 **Test specimens**

Two whole blocks shall be selected from the sample of blocks obtained as described under Annex A, after carrying out the test for dimensional compliance. The blocks shall be designed 'Specimen A' and Specimen B', respectively.

I.2 **Apparatus**

I.2.1   Balance — A balance or a scale of 20 kg capacity, sensitive to 50 g.

I.2.2   Drying ovens — Two thermostatically-controlled drying ovens; one capable of maintaining temperature at 105 5 C and the other capable of maintaining temperature at 70 5 C.

I.2.3   Water bath — A suitable tank for submerging specimens in water at room temperature.

I.2.4   Wire scratch brush — A brush made of 50 mm x 1.6 mm flat with 0.40 mm wire bristles assembled in 50 longitudinal rows and 10 transverse rows of bristles on 200 mm x 60 mm hardwood block.

I.3 **Procedure**

I.3.1   Oven dry specimen A at 105 5 C for at least 12 h or to constant mass. From this weight, calculate the oven-dry weight (W_i) of Specimen A. Carry out further operations on Specimen B only.

I.3.2   Submerge specimen B in water at room temperature for 6 h. Remove and immediately place it in an oven at 70 C for 42 h and remove. Brush all areas of the specimen twice with the wire scratch brush. Hold the brush with the long axis of the brush parallel to the longitudinal axis of the specimen or parallel to the ends as required to cover all areas of the specimen. Apply these strokes to the full height and width of the specimen with a firm stroke corresponding to approximately 1.5 kg force (*see* note). Eighteen to twenty vertical brush strokes are required to cover the sides of the specimen twice and four strokes are required on each end.

NOTE   Measure the pressure as follows:

Clamp a specimen in a vertical position on the edge of a platform scale and set the scale at zero. Apply vertical brushing strokes to the specimen and note the force necessary to register approximately 1.5 kg.

I.3.3 The procedures described in J.3.2 constitutes one cycle (48 h) of the weathering test. Continue the procedure for 12 cycles. After 12 cycles of test, dry the specimen to constant weight at

105　5 C and determine the final oven-dry weight (W_f) of the specimen. The data collected permits calculations of the soil-cement loss of the specimen after the prescribed test of 12 cycles.

I.4　**Calculation of results and reporting**

J.4.1 Calculate the soil-cement loss of the specimen as a percentage of the originally calculated oven-dry weight (W_i) of the specimen as follows:

$$\text{Soil-cement loss, per cent} = \frac{W_i\ W_f}{W_i}\ \times 100$$

Annex J
(normative)
Determination of drying shrinkage and expansion on rewetting

J.1 Coverage

This annex provides methods for determining the drying shrinkage and expansion on rewetting of aggregate concrete masonry units.

J.2 Apparatus

a) **Oven**. A forced-draught drying oven capable of maintaining a temperature of 50-55 °C and a relative humidity of 15-25 %, and of size such as to allow a free air space of width at least 20 mm around each test specimen.

   NOTE   This relative humidity may be maintained by the inclusion of trays of saturated calcium chloride solution. The trays should provide a total exposed area of at least 1 m^2 per 1 m^3 of volume of oven and should contain sufficient solid calcium chloride to show above the surface of the solution throughout the test.

b) **Gauge**. A gauge capable of measuring the gauge length of the test specimens to an accuracy of 0.002 mm.

c) **Steel balls**, of nominal diameter 6 mm.

d) **Desiccator**. A desiccator that is large enough to accommodate the test specimens and that contains a saturated solution of calcium chloride (see the NOTE in (a) above).

J.3 Preparation of test specimens

a) Cut from each of the six units a test specimen of length (parallel to the length of the unit), approximately 200 mm and cross-section at least 70 mm × 25 mm.

b) Using an epoxy-resin compound, so fix a steel ball into the centre of each end of each specimen that half of the surface of the ball protrudes.

c) After the resin has set sufficiently for the specimen to be handled, clean the exposed surfaces of the steel balls, and grease them to prevent corrosion.

d) Use the outer extremities of the balls as reference points.

J.4 Procedure: Drying shrinkage

J.4.1   Immerse the test specimens in clean water maintained at a temperature of 22-25 °C, for a period of 4 d.

J.4.2   Remove the specimens from the water and wipe off any excess water with a damp cloth, wipe the grease from the steel balls and immediately measure the length between the reference points (measurement A).

J.4.3   After measuring the distance regrease the steel balls and dry the specimens in the drying oven for a period of at least 48 h. (Do not place wet specimens in the oven together with partially dried specimens.)

J.4.4   Remove the specimens from the oven, allow them to cool to a temperature of 22-25 °C in the desiccator, wipe the grease from the steel balls and again measure the length between the reference points.

J.4.5   Repeat this drying and cooling procedure (but using drying periods of 24 h) until the difference between consecutive measurements is less than 0.004 mm.

J.4.6   Take the final reading as the dry length (measurement B).

J.4.7   Calculate the drying shrinkage of each specimen, and record the arithmetic mean of the six individual results as the average drying shrinkage of each unit and check for compliance with the relevant requirements of 8.8.

J.4.8   Calculation

Calculate the drying shrinkage of each specimen as follows:

$$\text{Drying shrinkage, \%} = \frac{(\text{measurement A} - \text{measurement B})}{\text{gauge length}} \times 100$$

where the gauge length is the dry length (measurement B rounded off to the nearest 1 mm) minus 12 mm.

Record the individual results to the nearest 0.001 % and the average result to the nearest 0.01 %.

J.5   Procedure: Expansion on re-wetting test

J.5.1   Test specimens: Use the six test specimens previously used in the test for drying shrinkage.

J.5.2   After completion of the test for drying shrinkage, regrease the steel balls and immerse the test specimens in clean water maintained at a temperature of 22-25 °C, for a period of 4 d.

J.5.3   Remove the specimens from the water and wipe off any excess water with a damp cloth, wipe the grease from the steel balls, and immediately measure the length between the reference points (measurement A). Regard this as the final wet length.

J.5.4   Use the dry length obtained in K.4.6 as measurement B.

J.5.5   Calculate the expansion on re-wetting of each specimen, and the arithmetic mean of the 6 individual results as the average expansion on re-wetting of the units and check for compliance with the requirement of 6.8.

J.5.6   **Calculation:** Calculate the expansion on re-wetting of each specimen as follows:

$$\text{Expansion on re-wetting, \%} = \frac{(\text{measurement A} - \text{measurement B})}{\text{gauge length}} \times 100$$

where the gauge length is the dry length (measurement B rounded off to the nearest 1 mm) minus 12 mm.

J.5.7   Record the individual results to the nearest 0.001 % and the average result to the nearest

0.01 %.

Annex K
(informative)
Peripheral equipment

K.1 Hand tools

Whether the press is manual or motorised, some hand tools will be needed. Obviously a motorised press will need mioimum hand. tools, especially for soil diooino and preparation. The following list of hand tools is mostly for a manual press. Note that the volume of containers, such as buckets and wheelbarrows, shall be known as they are used to transport and measure materials.

Soil digging and preparation: Crew bars, pickaxes, shovels, hoes, pans, buckets, wheelbarrows, sieve and UV stabilised plastic tarpaulins

Soil mixing: Buckets, wheelbarrows, hoes, shovels, water can, barrels and hose pipe

Initial curing: Plastic sheet for covering the fresh blocks and water can or bucket

Final stacking and curing: Flat wheelbarrows to move the 2 days old blocks, buckets and strips of jute clothe for covering the blocks.

Quality control: Pocket Penetrometre, block height gauge, field block tester

K.2 Motorised tools

These tools are mostly for motorised presses. Though manual presses could have advantage of using motorised equipment for soil preparation, it is unusual to have a motorised pulveriser or mixer with manual presses, mostly for economical reasons. Depending on the degree of integration of the production line, some hand tools will also be required, as mentioned in the list of the precedent paragraph.

Soil digging and preparation: Excavator, pulveriser or crusher, mechanical sieve (vibrating or rotating), loader, truck

Soil mixing
Mixer: note that mixers for CSEB can be planetary (pan mixer), linear (helical screw) or with horizontal shaft.

Concrete mixers are not appropriate for CSEB as the mix is only humid and the rotating drum creates balls.

Initial curing: Manual forklift and palettes

Final stacking and curing: Belt conveyor, motorised forklift and palettes

Quality control: Compression testing machine

Annex L
(informative)
Production lines

L.1 Types

Various types of production lines can be set up depending on the needs. Five types of production lines are generally considered and they are linked with the type of presses, the integration of peripheral motorised machinery and the scale of production:

Type 1 = Totally manual

It is the minimum set up with only 1 manual press, light or heavy. The rest of the equipment is manual.

The infrastructure is minimal. It is often the type of production line for a construction site.

Type 2 = Half manual and half motorised

Two manual presses are used along with a motorised mixer and the infrastructure is more elaborated.

A motorised crusher/pulveriser or mechanised sieve can also be integrated.

Type 3 = Fully motorised

The production unit is totally mechanised but with separate machinery:

A motorised press is used with a motorised crusher/pulveriser or mechanised sieve and a motorised mixer.

The built infrastructure is larger.

Type 4 = Mobile unit

An automated unit integrates all machinery in a single machine with large infrastructure:

Sieve, motorised mixer, the pressing unit and belt conveyor

Note that a motorised crusher/pulveriser can be part of the set up but it is most of the time separate

equipment because of the disturbance in terms of noise and dust.

Mechanised transport need also to be integrated with loader, forklift and truck.

Type 5 = Semi-industrial plant

They have generally a lot of separate machinery which can include:

Motorised crusher/pulveriser, mechanised sieve, mixers, multi mould pressing units, belt conveyors, and mechanised transport with loaders, forklifts and trucks.

It has the large infrastructure of a plant.

Annex M
(normative)
Fire resistance testing of clay masonry units

DRS 547, *Fire classification of construction products and building elements — Classification using data from reaction to fire tests*

ASTM E119-2007, *Standard test methods for fire tests of building construction and materials*

M.1 Introduction

The performance of walls, columns, floors, and other building members under fire exposure conditions is an item of major importance in securing constructions that are safe, and that are not a menace to neighbouring structures nor to the public. Recognition of this is registered in the codes of many authorities, municipal and other. It is important to secure balance of the many units in a single building, and of buildings of like character and use in a community; and also to promote uniformity in requirements of various authorities throughout the country. To do this it is necessary that the fire-resistive properties of materials and assemblies be measured and specified according to a common standard expressed in terms that are applicable alike to a wide variety of materials, situations, and conditions of exposure.

Such a standard is found in the methods that follow. They prescribe a standard exposing fire of controlled extent and severity. Performance is defined as the period of resistance to standard exposure elapsing before the first critical point in behaviour is observed. Results are reported in units in which field exposures can be judged and expressed.

The methods may be cited as the "Standard Fire Tests," and the performance or exposure shall be expressed as "6-h," "4-h," "2-h, "1-h," " "½-h", etc.

When a factor of safety exceeding that inherent in the test conditions is desired, a proportional increase should be made in the specified time-classification period.

M.2 Coverage

M.2.1   The test methods described in this fire-test-response standard are applicable to assemblies of masonry units and to composite assemblies of structural materials for buildings, including bearing and other walls and partitions, columns, girders, beams, slabs, and composite slab and beam assemblies for floors and roofs. They are also applicable to other assemblies and structural units that constitute permanent integral parts of a finished building.

M.2.2   It is the intent that classifications shall register comparative performance to specific fire-test conditions during the period of exposure and shall not be construed as having determined suitability for use under other conditions or after fire exposure.

M.2.3 This standard is used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not by itself incorporate all factors required for fire hazard or fire risk assessment of the materials, products or assemblies under actual fire conditions.

M.2.4 These test methods prescribe a standard fire exposure for comparing the test results of building construction assemblies. The results of these tests are one factor in assessing predicted fire performance of building construction and assemblies. Application of these test results to predict the performance of actual building construction requires the evaluation of test conditions.

M.3 **Significance and use**

M.3.1 This test method is intended to evaluate the duration for which the types of building elements noted in N.2.1 contain a fire, retain their structural integrity, or exhibit both properties during a predetermined test exposure.

M.3.2 The test exposes a specimen to a standard fire controlled to achieve specified temperatures throughout a specified time period. When required, the fire exposure is followed by the application of a specified standard fire hose stream. The test provides a relative measure of the fire-test-response of comparable building elements under these fire exposure conditions. The exposure is not representative of all fire conditions because conditions vary with changes in the amount, nature and distribution of fire loading, ventilation, compartment size and configuration, and heat sink characteristics of the compartment. Variation from the test conditions or specimen construction, such as size, materials, method of assembly, also affects the fire-test response. For these reasons, evaluation of the variation is required for application to construction in the field.

M.3.3 The test standard provides for the following:

M.3.3.1 For walls, partitions, and floor or roof test specimens:

M.3.3.1.1 Measurement of the transmission of heat.

N.3.3.1.2 Measurement of the transmission of hot gases through the test specimen.

M.3.3.1.3 For load bearing elements, measurement of the load carrying ability of the test specimen during the test exposure.

M.3.3.2 For individual load bearing members such as beams and columns:

M.3.3.2.1 Measurement of the load carrying ability under the test exposure with consideration for the end support conditions (that is, restrained or not restrained).

M.3.4 The test standard does not provide the following:

M.3.4.1   Information as to performance of specimens constructed with components or lengths other than those tested.

M.3.4.2   Evaluation of the degree by which the specimen contributes to the fire hazard by generation of smoke, toxic gases, or other products of combustion.

M.3.4.3   Measurement of the degree of control or limitation of *the passage of* smoke or products of combustion through the specimen.

M.3.4.4   Simulation of the fire behaviour of joints between building elements such as floor-wall or wall-wall, etc., connections.

M.3.4.5   Measurement of flame spread over surface of specimen.

M.3.4.6   The effect on fire-resistance of conventional openings in the test specimen, that is, electrical receptacle outlets, plumbing pipe, etc., unless specifically provided for in the construction tested.

M.4 **Control of fire tests**

A.2.5. **Time-temperature curve**

The conduct of fire tests of materials and construction shall be controlled by the standard time-temperature curve shown in Figure N.1. The points on the curve that determine its character are:

1000°F (538°C)   at 5 min

1300°F (704°C)   at 10 min

1550°F (843°C)   at 30 min

1700°F (927°C)   at 1 h

1850°F (1010°C)   at 2 h

2000°F (1093°C)   at 4 h

2300°F (1260°C)   at 8 h or ove

NOTE 1   *Recommendations for recording fuel flow to furnace burners*—The following provides guidance on the desired characteristics of instrumentation for recording the flow of fuel to the furnace burners. Fuel flow data may be useful for a furnace heat balance analysis, for measuring the effect of furnace or control changes, and for comparing the performance of assemblies of different properties in the fire endurance test.

Record the integrated (cumulative) flow of gas (or other fuel) to the furnace burners at 10 min, 20 min, 30 min, and every 30 min thereafter or more frequently. Total gas consumed during the total test period is also to be determined. A recording flow meter has advantages over periodic readings on an instantaneous or totalizing flow meter. Select a measuring and recording system to provide flow rate readings accurate to within ±5 %.

Report the type of fuel, its higher (gross) heating value, and the fuel flow (corrected to standard conditions of 16°C and 30.0 in. Hg) as a function of time.
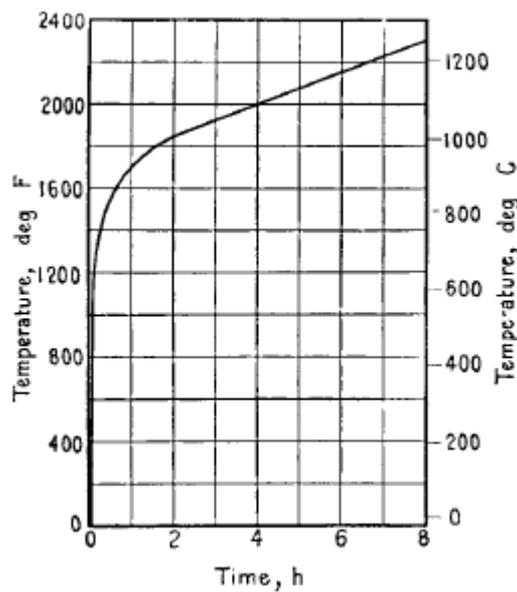

Figure M.1 — Time-temperature curve

M.4.1 **Furnace temperatures**

M.4.2.1   The temperature fixed by the curve shall be the average temperature from not fewer than nine thermocouples for a floor, roof, wall, or partition and not fewer than eight thermocouples for a structural column. Furnace thermocouples shall be symmetrically disposed and distributed to show the temperature near all parts of the sample, the thermocouples being enclosed in protection tubes of such materials and

dimensions that the time constant of the protected thermocouple assembly lies within the range from 5.0 to 7.2 min. The exposed length of the pyrometer tube and thermocouple in the furnace chamber shall be not less than 305 mm. It is not prohibited to use other types of protecting tubes or pyrometers that, under test conditions, give the same indications as the above standard within the limit of accuracy that applies for furnace-temperature measurements.

M.4.2.1.1   For floors and columns, the junction of the thermocouples shall be placed 305 mm away from the exposed face of the sample at the beginning of the test and, during the test, shall not touch the sample as a result of its deflection.

M.4.2.1.2   For walls and partitions, the thermocouples shall be placed 152 mm away from the exposed face of the sample at the beginning of the test, and shall not touch the sample during the test, in the event of deflection.

M.4.2.2   The temperatures shall be read at intervals not exceeding 5 min during the first 2 h, and thereafter the intervals shall not exceed 10 min.

M.4.2.3   The accuracy of the furnace control shall be such that the area under the time-temperature curve, obtained by averaging the results from the pyrometer readings, is within 10 % of the corresponding area under the standard time-temperature curve shown in Figure N.1 for fire tests of 1 h or less duration, within 7.5 % for those over 1 h and not more than 2 h, and within 5 % for tests exceeding 2 h in duration.

M.4.2 **Temperatures of unexposed surfaces of floors, roofs, walls, and partitions**

M.4.3.1   Temperatures of unexposed surfaces shall be measured with thermocouples or thermometers placed under dry, felted pads. The wire leads of the thermocouple or the stem of the thermometer shall have an immersion under the pad and be in contact with the unexposed surface for not less than 89 mm. The hot junction of the thermocouple or the bulb of the thermometer shall be placed approximately under the centre of the pad. The outside diameter of protecting or insulating tubes, and of thermometer stems, shall be not more than 8 mm. The pad shall be held firmly against the surface, and shall fit closely about the thermocouples or thermometer stems. Thermometers shall be of the partial-immersion type, with a length of stem, between the end of the bulb and the immersion mark, of 76 mm. The wires for the thermocouple in the length covered by the pad shall be not heavier than 1.02 mm and shall be electrically insulated with heat-resistant and moisture-resistant coatings.

NOTE 1   For the purpose of testing roof assemblies, the unexposed surface shall be defined as the surface exposed to ambient air.

NOTE 2   Under certain conditions it may be unsafe or impracticable to use thermometers.

M.4.3.2   Temperatures shall be recorded at not fewer than nine points on the surface. Five of these shall be symmetrically disposed, one to be approximately at the centre of the specimen, and four at approximately the centre of its quarter sections. The other four shall be located to obtain representative information on the performance of the construction under test. The thermocouples shall not be located closer to the edges of the test specimen than one and one-half times the thickness of the construction, or 305 mm. Exception: those cases in which there is an element of the construction that is not otherwise represented in the remainder of the test specimen. The thermocouples shall not be located opposite or on top of beams, girders, pilasters, or other structural members if temperatures at such points will be lower than at more representative locations. The thermocouples shall not be located over fasteners such as screws, nails, or staples that will be higher or lower in temperature than at a more representative location if the aggregate area of any part of such fasteners on the unexposed surface is less than 1 % of the area within any 152-mm diameter circle, unless the fasteners extend through the assembly.

M.4.3.3   Temperature readings shall be taken at intervals not exceeding 15 min until a reading exceeding 100 °C has been obtained at any one point. Thereafter the readings may be taken more frequently at the discretion of the testing body, but the intervals need not be less than 5 min.

M.4.3.4   Where the conditions of acceptance place a limitation on the rise of temperature of the unexposed surface, the temperature end point of the fire endurance period shall be determined by the average of the measurements taken at individual points; except that if a temperature rise 30 % in excess of the specified limit occurs at any one of these points, the remainder shall be ignored and the fire endurance period judged as ended.

M.5 **Classification as determined by test**

M.5.1   **Report of results**

M.5.1.1   Results shall be reported in accordance with the performance in the tests prescribed in these test methods. They shall be expressed in time periods of resistance, to the nearest integral minute. Reports shall include observations of details of the behaviour of the material or construction during the test and after the furnace fire is extinguished, including information on deformation, spalling, cracking, burning of the specimen or its component parts, continuance of flaming, and production of smoke.

M.5.1.2   Reports of tests involving wall, floor, beam, or ceiling constructions in which restraint is provided against expansion, contraction, or rotation of the construction shall describe the method used to provide this restraint.

M.5.1.2.1   Describe the physical details of the restraint system and provide information to define the longitudinal and rotational resistance of the test specimen by the restraint system.

M.5.1.2.2   Describe the restraint conditions with regard to the free movement of the test specimen prior to encountering resistance to expansion, contraction or rotation.

N.5.1.3   Reports of tests in which other than maximum load conditions are imposed shall fully define the conditions of loading used in the test and shall be designated in the title of the report of the test as a restricted load condition.

M.5.1.4   When the indicated resistance period is ½ h or over, determined by the average or maximum temperature rise on the unexposed surface or within the test sample, or by failure under load, a correction shall be applied for variation of the furnace exposure from that prescribed, where it will affect the classification, by multiplying the indicated period by two thirds of the difference in area between the curve of average furnace temperature and the standard curve for the first three fourths of the period and dividing the product by the area between the standard curve and a base line of 20 °C for the same part of the indicated period, the latter area increased by 30 °C·h (1800°C·min) to compensate for the thermal lag of the furnace thermocouples during the first part of the test. For fire exposure in the test higher than standard, the indicated resistance period shall be increased by the amount of the correction and be similarly decreased for fire exposure below standard.

NOTE   The correction can be expressed by the following equation:

$$C \quad 2I(A \quad A_s)/3(A_s \quad L)$$

where:

C	= correction in the same units as I,
I	= indicated fire-resistance period,
A	= area under the curve of indicated average furnace temperature for the first three fourths of the indicated period,
A_s	= area under the standard furnace curve for the same part of the indicated period, and
L	= lag correction in the same units as A and A_s 30°C·h (1800°C·min).

M.5.1.5   Unsymmetrical wall assemblies are tested with either side exposed to the fire, and the report shall indicate the side so exposed. When both sides are tested, the report then shall so indicate the fire endurance classification applicable to each side.

M.6 **Test specimen**

M.6.1   The test specimen shall be representative of the construction that the test is intended to assess, as to materials, workmanship, and details such as dimensions of parts, and shall be built under conditions representative of those applied in building construction and operation. The physical properties of the materials and ingredients used in the test specimen shall be determined and recorded.

M.6.2   The size and dimensions of the test specimen specified herein shall apply for rating constructions of dimensions within the range employed in buildings. When the conditions of use limit the construction to smaller dimensions, the dimensions of the specimen shall be reduced proportionately for a test qualifying them for such restricted use.

N.6.3   Specimens designed with a built-up roof shall be tested with a roof covering of 3-ply, 6.8-kg type felt, with not more than 54 kg per square (9 m^2) of hot mopping asphalt without gravel surfacing. Tests of assemblies with this covering do not preclude the field use of other coverings with a larger number of plys of felt, with a greater amount of asphalt or with gravel surfacing.

N.6.4   Roofing systems designed for other than the use of built-up roof coverings shall be tested using materials and details of construction representative of field application.

M.7 **Conduct of fire tests**

M.7.1   Fire endurance test

M.7.1.1   Continue the fire endurance test on the specimen with its applied load, if any, until failure occurs, or until the specimen has withstood the test conditions for a period equal to that herein specified in the conditions of acceptance for the given type of construction.

M.7.1.2   Continue the test beyond the time the fire endurance classification is determined when the purpose in doing so is to obtain additional data.

M.7.2   Hose stream test

M.7.2.1   Where required by the conditions of acceptance, a test shall be conducted to subject the test specimen described in N.7.2.2 or N.7.2.3 to the impact, erosion, and cooling effects of a hose stream. The water pressure and duration of application shall be as prescribed in Table N.1.

M.7.2.1.1   Exemption

The hose stream test shall not be required in the case of test specimens having a resistance period, indicated in the fire-resistance test, of less than 1 h.

Table N.1 — Conditions for hose stream test

Resistance period	Water pressure at base of nozzle, psi (kPa)	Duration of application, min/(9 m^2) exposed area
8 h and over	45 (310)	6
4 h and over if less than 8 h	45 (310)	5
2 h and over if less than 4 h	30 (207)	2½
1½ h and over if less than 2 h	30 (207)	1½
1 h and over if less than 1½ h	30 (207)	1
Less than 1 h, if desired	30 (207)	1

M.7.2.2   The hose stream test shall be conducted on a duplicate test specimen.

M.7.2.2.1   The duplicate test specimen shall be exposed to the effects of the hose stream immediately after being subjected to a fire-resistance test for a time period of one-half the fire-resistance classification period determined from the fire-resistance test on the initial test specimen.

M.7.2.2.2   The length of time that the duplicate test specimen is subjected to the fire-resistance test shall not exceed 1 h.

M.7.2.3 Optional program

As an alternative procedure, conduct the hose stream test on the initially tested specimen immediately following its fire-resistance test.

M.7.3   Protection and conditioning of test specimen

M.7.3.1   Protect the test specimen during and after fabrication to assure its quality and condition at the time of test. It shall not be tested until its final strength has been attained, and, until an air-dry condition has been achieved in accordance with the requirements given in M.7.3.1.1 through M.7.3.1.3. Protect the testing equipment and sample undergoing the fire test from any condition of wind or weather, that is capable of affecting results. The ambient air temperature at the beginning of the test shall be within the range of 10 to 32 °C. The velocity of air across the unexposed surface of the sample, measured just before the test begins, shall not exceed 1.3 m/s, as determined by an anemometer placed at right angles to the unexposed surface. When mechanical ventilation is employed during the test, an air stream shall not be directed across the surface of the specimen.

M.7.3.1.1   Prior to fire test, condition constructions with the objective of providing a moisture condition within the specimen representative of that in similar construction in buildings. For purposes of standardization, this condition is established at equilibrium resulting from drying in an ambient atmosphere of 50 %

relative humidity at 23 °C. However, with some constructions, it is difficult or impossible to achieve such uniformity. Accordingly, where this is the case, specimens are tested when the dampest portion of the structure, the portion at 152-mm depth below the surface of massive constructions, has achieved a moisture content corresponding to drying to equilibrium with air in the range of 50 to 75 % relative humidity at 23 ± 3 °C. In the event that specimens dried in a heated building fail to meet these requirements after a 12-month conditioning period, or in the event that the nature of the construction is such that it is evident that drying of the specimen interior is prevented by hermetic sealing, these moisture condition requirements are waived, and the specimen tested when its strength is at least equal to its design strength.

M.7.3.1.2   Avoid drying procedures that will alter the structural or fire endurance characteristics of the specimen from those produced as the result of drying in accordance with procedures given in M.7.3.1.1.

M.7.3.1.3   Within 72 h prior to the fire test information on the actual moisture content and distribution within the specimen shall be obtained. Include this information in the test report.

M.8 Tests of bearing walls and partitions

M.8.1 Size of specimen

The area exposed to fire shall be not less than 9 m^2, with neither dimension less than 2.7 m. The test specimen shall not be restrained on its vertical edges.

M.8.2 Loading

Throughout the fire endurance and hose stream tests, apply a superimposed load to the specimen to simulate a maximum load condition. This load shall be the maximum load condition allowed under nationally recognized structural design criteria unless limited design criteria are specified and a corresponding reduced load is applied. A double wall assembly shall be loaded during the test to simulate field use conditions, with either side loaded separately or both sides together. The method used shall be reported.

NOTE   The choice depends on the intended use, and whether the load on the exposed side, after it has failed, will be transferred to the unexposed side. If, in the intended use, the load from the structure above is supported by both walls as a unit and would be or is transferred to the unexposed side in case of collapse of the exposed side, both walls should be loaded in the test by a single unit. If, in the intended use the load from the structure above each wall is supported by each wall separately, the walls should be loaded separately in the test by separate load sources. If the intended use of the construction system being tested involved situations of both loading conditions described above, the walls should be loaded separately in the test by separate load sources. In tests conducted with the walls loaded separately the condition of acceptance requiring the walls to maintain the applied load shall be based on the time at which the first of either of the walls fail to sustain the load.

M.8.3 Conditions of acceptance

M.8.3.1   Regard the test as successful if the following conditions are met:

M.8.3.1.1   The wall or partition shall have sustained the applied load during the fire endurance test without passage of flame or gases hot enough to ignite cotton waste, for a period equal to that for which classification is desired.

M.8.3.1.2   The wall or partition shall have sustained the applied load during the fire and hose stream test as specified in Clause 8.10, without passage of flame, of gases hot enough to ignite cotton waste, or of the hose stream. The assembly shall be considered to have failed the hose stream test if an opening develops that

permits a projection of water from the stream beyond the unexposed surface during the time of the hose stream test.

M.8.3.1.3   Transmission of heat through the wall or partition during the fire endurance test shall not have been such as to raise the temperature on its unexposed surface more than 139 °C above its initial temperature.

M.9 **Tests of non-bearing walls and partitions**

M.9.1 **Size of specimen**

The area exposed to fire shall be not less than 9 m^2, with neither dimension less than 2.7 m. Restrain the test specimen on all four edges.

M.9.2 **Conditions of acceptance**

M.9.2.1   Regard the test as successful when the following conditions are met:

M.9.2.1.1   The wall or partition has withstood the fire endurance test without passage of flame or gases hot enough to ignite cotton waste, for a period equal to that for which classification is desired.

M.9.2.1.2   The wall or partition has withstood the fire and hose stream test as specified in Clause 8.10, without passage of flame, of gases hot enough to ignite cotton waste, or of passage of water from the hose stream. The assembly shall be considered to have failed the hose stream test if an opening develops that permits a projection of water from the stream beyond the unexposed surface during the time of the hose stream test.

M.9.2.1.3   Transmission of heat through the wall or partition during the fire endurance test shall not have been such as to raise the temperature on its unexposed surface more than 139 °C above its initial temperature.

Annex N
(informative)
Advantages and disadvantages of interlocking blocks

N.1 Advantages of interlocking block

(i)   Construction with interlocking block saves time and ample amount of mortar concrete compared to conventional masonry block laid with mortar

(ii)   Areas prone to earthquake uses hollow interlocking block with the strength improved with grout and reinforcement throughout the height of the wall to resist the effect of earthquake, thus, providing adequate structural stability against collapse

(iii)   Having formed the base course, other course can be assembled by unskilled labour

(iv)   Dismantling of the blocks in case of temporary structure does not incur much damages as in blocks laid with mortar

(v)   Cost of construction is relatively less.

N.2 Disadvantages of interlocking block

(i)   A standard skilled masonry labour is required to ensure proper horizontal and vertical alignment of the blocks, and that the corner and junction (T-joints) are right angled, especially at the base course

(ii)   Due to wind and rain seepage effect the block wall need be rendered

(iii)   The mould, palettes groove or/and protrusion edge may affect the dimension of the block; consequently hamper the alignment and stability of the wall, if not adequately observed

(iv)   It is difficult to maintain the required tight tolerances for accurate construction of large walls or other structures through the moulding and cutting steps.

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