Chapter 7
Codes and Standards on Earth Construction

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Abstract Earthen structures provide solutions to build green and sustainable buildings. Any engineered construction needs guidelines on the production of materials, construction of the structural elements, quality control methods and design guidance. There is lack of universally accepted standards on the production of earth construction materials and construction methods as compared to the standards available on conventional materials. The paper attempts to review the existing standards and norms on the earth construction, and bring out the need for comprehensive standard codes on earth construction. An analysis of the existing standard codes on earth construction has been provided. There are about 70 standards, but there is lack of coherence among the standards and globally acceptable terminology. The paper highlights the points needing attention while developing comprehensive globally applicable standards on different types of construction methods.

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7.1 Introduction

Earthen structures, especially earthen dwellings assume importance in the context of environment conservation and emission reduction. History of earthen constructions can be traced back to the dawn of civilisation. Earth or soil is a mixture of clay minerals and inert materials such as silt, sand and gravel. In addition, minor quantities of impurities such as organic matter, salts, etc. could be present. The soil characteristics are mainly controlled by the type and quantity of clay minerals present. The clay minerals can be grouped under two broad categories: (a) expansive clays and (b) less-expansive clays (called non-expansive clays). The expansive clays possess high swell-shrink characteristics when compared to the non-expansive clays. Generally, soils with non-expansive clays are used for earth construction. The earth construction finds applications in (a) walls, including wall elements and masonry mortars, (b) floor/roof systems, (c) foundations and (d) renderings and plastering. There are different types of earth construction techniques. The earth construction methods used for the walls can be grouped under (a) monolithic walls and (b) masonry walls.

Any engineered construction demands guidelines for the production of materials, construction of the structural elements, thermal comfort and durability of the structures/buildings. Even though earth construction exists since the dawn of civilisation, there is lack of universally accepted standards on the material production and construction methods as compared to the standards available on conventional materials such as concrete, masonry, steel, etc. There are attempts in the recent past (6–7 decades) to develop codes of practice and normative standards for modern earth construction, which can facilitate the building professional to design and construct modern earth buildings. There are a large number of regional and national standards on earth construction. The specifications and information on the earth construction in these standards differ widely. There is a need to take stock of the existing information on the earth construction standards and propose comprehensive and universally applicable ones.

7.2 Earthen Structures and Construction Techniques

The earth or the soil has been used for the construction of varieties of structures: buildings, retaining structures (dams, bunds, etc.), embankments, canals, roads, etc. The buildings consist of construction of different structural elements (foundations, walls, roofs/floors, etc.). Table 7.1 gives the details of the earth construction techniques for each of the building components and the status of codes or standards available. Also, the Table gives possibilities of different earth construction techniques

Table 7.1 Earth construction techniques for buildings

Building component	Types of construction techniques	Status of codes or standards
Foundation	– Rammed earth – Earth mortars	Few codes exist
Masonry walls	– Adobe – Compressed earth – Extruded earth – Cut earth (sod and laterite)	Codes exist for some of the techniques
Monolithic walls	– Cob – Rammed earth – Poured earth – Flowable earth mix concrete	Codes exist for some of the techniques
Infill walls	– Wattle and daub – Bagged earth	No codes
Floors/roofs	– Earth panels – Precast elements – In-situ techniques	No codes
Plastering and renderings/ finishes	– Earth mortars – Plastering/renderings – Clay panels	Few codes exist

for each of these building components. One of the major problems in developing codes/standards is the common terminology for different types of earth construction techniques and earthen materials. There are regional specific terms for some of the modern earth construction techniques and materials. The regional definitions may have to be avoided to suite with the common terminology for the global usage. The common definitions or terminology for earthen materials and earthen structures are as follows.

(a) ***Earth***

Earth is the basic material required for the manufacture of earthen building materials and construction of earthen structures. Another commonly used term for the earth is soil. It is formed due to the weathering process of rocks over a period of millions of years. Earth or soil is a granular material consisting of inert crystalline silica particles and clay minerals. The silica particles are called silt, sand and gravel (depending upon the grain size of the particle). There are different types of clay minerals and the soil or earth characteristics depend upon the type and quantity of clay minerals present in the granular mixture. The clay minerals are responsible for the swell-shrink characteristics of the soil and the strength of the earth or the soil. There are different regional terminologies for the earth or the soil. From the point of view of global standardisation with reference to earthen structures, the term “Earth” can be used.

(b) ***Earth mortar (EM)***

The EM is basically composed of earth and sand. Sometimes fibres (generally natural fibres) are mixed in order to control the shrinkage cracks. The earth mortars find applications in plasters or renders as well as bed joints in the earth block masonry. The earth mortars used for rendering and plastering can contain colouring agents such as natural oils or pigments.

(iii) ***Stabilised earth mortar (SEM)***

The SEM consists of earth, sand and inorganic stabilisers such as cement or lime. Such mortars are used for the construction of masonry using stabilised earth bricks or blocks. The stabilisers and the granular composition of the mix is dictated by the strength and workability characteristics of the mortar.

(iv) ***Earth block (EB)***

The EB is a masonry unit. There are varieties of EB's, such as adobe bricks or blocks, compressed earth blocks (CEB), extruded earth bricks (EEB), cut earth blocks (sod and laterite), etc. Adobe and CEB can be further classified as stabilised adobe and compressed stabilised earth block (CSEB). The stabilised EB's have inorganic binders in addition to the earth based granular mix.

(e) ***Cob (Cb)***

For cob, processed earth mixture in a plastic state is piled up with some tamping to form a monolithic wall. Frequently organic fibres such as straw are mixed while processing the earth mix. Cob wall construction does not require any formwork.

(f) ***Rammed earth (RE)***

RE is a monolithic construction involving compaction of partially saturated soil or earth-aggregate mixture in layers inside a rigid formwork. A layered texture resembling a sedimentary rock is ascertained for the wall. When inorganic stabilisers (such as cement or lime) are added to the earthen mixture it is designated as stabilised rammed earth (SRE).

(g) ***Wattle and daub***

For wattle and daub, processed earth of plastic consistency is applied on either side of a skeleton structure and finished manually to get even surfaces for the wall. Generally, the skeleton structure is made up of unshaped wooden members and wooden sticks. This skeleton is the wattle, which is daubed from both the sides with the processed earth material.

(h) ***Poured earth (PE)***

For poured earth, processed earth in slurry consistency is poured into a formwork and the formwork is stripped after the earth ascertains stiffness. Generally, it is stabilised with an inorganic binder. Alternatively, the mix can fill fibre bags that are piled while the earth/soil is in plastic state to form walls (bagged earth).

(i) ***Flowable earth mix (FEM) concrete***

This is nearly similar to poured earth but for the inclusion of coarse aggregates. Also, this is termed as mud concrete. The FEM concrete is poured into a formwork and can be vibrated like a conventional cement concrete. The stiffness of the formwork used is much less than that used in the rammed earth construction.

(j) ***Earthen or clay panels***

These are thin precast panels (25–30 mm thick) finding application in the partitioning of spaces and cladding the inner surfaces of walls. The composition can be diverse; one of the possibilities is basically the processed earth mixed with the fibres.

Precast earth elements can also be fabricated with some of the previously mentioned techniques.

7.3 Developments in Earth Construction Standardisation

Archaeological excavations and surveys indicate evidence of using earthen structures and dwellings in almost all the past civilisations. Even in the modern era, large chunk of people living in earthen dwellings is evident. The earliest forms of documents in conveying the methods and rules for earth constructions are in the form of sketches and paintings [25, 77]. Such documents depict the block sizes, wall thickness, use of plumb, etc. During the 16–19th century period (industrial revolution) developing some standards and codes on earth construction can be seen [77]. After the emergence of steel and concrete, the earth construction works for dwellings decreased due to the dominance of modern materials. After natural or man-made disasters, the need for building homes is acute, in such situations earth has emerged as the easily available local material to build homes. Construction of earthen dwellings after the World War II is an example of this kind. Even a German standard [23] emerged in the 1950s and was later withdrawn in 1971 [77]. Large scale rehabilitation works can be seen in Asia and other parts of the world evidenced by the articles and documents [26, 34, 83]. A revival of interest in earth construction was noticed in the past 6–7 decades, which can be mainly attributed to the interest on the abatement of emissions, creating healthy indoor living conditions, conservation of ecology and environment.

7.4 Types of Earth Building Standards/Codes and Documents

Earth construction standards can be grouped under global, regional and national level standard/code documents. The global standards are formed by the International Standards Organisation (ISO). There are hardly any ISO standards on earth construction. Nevertheless, many national and regional standards on earth construction exist.

The existing standards address certain issues pertaining to some specific earth-based technologies. Any form of earth construction needs information on the following.

1. Earth or soil composition
2. Moulds and machinery
3. Earthen products production or manufacturing details
4. Testing and quality control
5. Design guidance
6. Construction methodology and construction procedure
7. Earthquake resistant guidelines
8. Durability, limitations and maintenance.

Existing codes/standards may not address all the points mentioned above in a comprehensive manner. Table 7.2 outlines the details of the some of the standards/documents available on earth construction. The type of document, group it belongs to and the information on the above-mentioned points are provided in the Table 7.2. Many of the available standards (70) spreading across all the continents were considered [1–16, 19–24, 28–33, 35–37, 40–76, 78–82]. The information and guidelines needed for stabilised and un-stabilised earth constructions differ widely. The information on the above-mentioned points is discussed in the following sections.

7.4.1 Soil or Earth Composition

Since it is not possible yet, to guarantee the performance of earthen material from its composition, the TC recommend that the assessment of soil or earth suitability should rather be made using a performance-based approach on earthen samples and/or structures. For stabilised earth construction (such as CEB and rammed earth), the soil composition, especially limiting values on clay content, provides satisfactory performance in terms of strength and durability.

Soil or Earth composition includes primarily grain size distribution, especially the type and quantity of the clay mineral in the mix. The clay mineral type and its quantity in the soil/earth mix is indirectly judged based on the Atterberg's limits. There shall be limiting numbers for other parameters such as salts, organic matter and pH. The range of values specified in several standards on earth construction under two categories: with or without inorganic stabilisers, are given in Table 7.3. The limits on different properties of soil or earth given are limited. Not many codes/standards specify the limits explicitly and many a times a wide range of values are specified. There is a need for developing comprehensive codes on each type of earth construction technology where a range of values are specified for the soil or the earth properties, which are universally acceptable.

Table 7.2 Details of earth building standards and documents

S. No.	Standard/document	Region/country	EC type	Information, guidelines and specifications on earth construction							
				Earth	MM	EPP	T&QC	DG	CM	EQ	ML
1	NBDS [64]	Bolivia	Ad	NA	NA	NA	NA	NA	NA	√	NA
2	NBR 8491 [40]	Brazil	CSEB	NA	NA	NA	√	NA	NA	NA	NA
3	NBR 8492 [41]	Brazil	CSEB	NA	NA	NA	√	NA	NA	NA	NA
4	NBR 10833 [42]	Brazil	CSEB	√	√	√	√	NA	NA	NA	NA
5	NBR 10834 [43]	Brazil	CSEB	NA	NA	NA	√	NA	NA	NA	NA
6	NBR 10836 [44]	Brazil	CSEB	NA	NA	NA	√	NA	NA	NA	NA
7	NBR 11798 [45]	Brazil	EFL	NA	NA	NA	√	NA	NA	NA	NA
8	NBR 12023 [46]	Brazil	CSEB	NA	NA	NA	√	NA	NA	NA	NA
9	NBR 12024 [47]	Brazil	CSEB	NA	NA	NA	√	NA	NA	NA	NA
10	NBR 12025 [48]	Brazil	CSEB	NA	NA	NA	√	NA	NA	NA	NA
11	NBR 12253 [49]	Brazil	EFL	NA	NA	NA	√	NA	NA	NA	NA
12	NBR 13553:[52]	Brazil	SRE	NA	NA	NA	√	NA	NA	NA	NA
13	NBR 13554 [51]	Brazil	EC	NA	NA	NA	√	NA	NA	NA	NA
14	NBR 13555 [52]	Brazil	EC	NA	NA	NA	√	NA	NA	NA	NA
15	NBR 16096 [53]	Brazil	EFL	NA	NA	NA	√	NA	NA	NA	NA
16	Nch 3332 [54]	Chile	Ad, RE, WD, EM	NA	NA	NA	NA	√	NA	√	√
18	DIN 18945-08 [20]	Germany	Ad	√	√	√	√	NA	NA	NA	NA
19	DIN 18946-08 [21]	Germany	Ad	√	√	√	√	NA	NA	NA	NA
20	DIN 18947-08 [22]	Germany	Ad	√	√	√	√	NA	NA	NA	NA
21	IS 4332 Part IV [28]	India	SEWT	NA	NA	NA	√	NA	NA	NA	NA

(continued)

Table 7.2 (continued)

S. No.	Standard/document	Region/country	EC type	Information, guidelines and specifications on earth construction							
				Earth	MM	EPP	T&QC	DG	CM	EQ	ML
22	IS 4332 Part–V [29]	India	SEST	NA	NA	NA	√	NA	NA	NA	NA
23	IS 2110 [30]	India	SRE	√	√	√	√	√	√	NA	–
24	IS 13827 [31]	India	Ad, Cb, RE, WD	NA	NA	NA	√	√	√	√	NA
25	IS 1725 [32]	India	CSEB	√	NA	NA	√	√	NA	NA	√
26	IS 17165 [33]	India	CSEB	NA	√	√	NA	NA	√	NA	NA
27	NMX-C-508-ONNCCE [57]	Mexico	CSEB	√	NA	√	√	NA	NA	NA	NA
28	NBC 203 [58]	Nepal	CSEB and others	–	–	–	–	√	√	√	–
29	NBC 204 [59]	Nepal	Cb, Ad, RE,	–	–	–	–	√	√	√	–
30	NZS 4297 [60]	New Zealand	Ad, CEB, RE, PE, SE	NA	NA	NA	√	√	–	√	NA
31	NZS 4298 [61]	New Zealand	Ad, CEB, RE, PE, SE	√	–	–	√	NA	–	√	√
32	NZS 4299 [62]	New Zealand	Ad, CEB, RE, SE	NA			√	√		√	
33	NTE E. 080 [65]	Peru	EC, Ad, RE	√	√	√	√	√	√	√	√

(continued)

Table 7.2 (continued)

S. No.	Standard/document	Region/country	EC type	Information, guidelines and specifications on earth construction							
				Earth	MM	EPP	T&QC	DG	CM	EQ	ML
34	LNEC [37]	Portugal	EC, RE, SRE	√	√	√	√	NA	√	NA	NA
35	UNE 41410 [82]	Spain	CEB, CSEB	√	√	√	√	√	NA	NA	√
36	SLS 1382 Part 1 [74]	Sri Lanka	CSEB	√		√	√	NA			
37	SLS 1382 Part 2 [75]	Sri Lanka	CSEB	√			√	NA			
38	SLS 1382 Part 3 [76]	Sri Lanka	CSEB	√	√	√		√			
39	CID-GCB-NMBC-14.7.4 [19]	USA	All forms of EC				√	√	√	√	
40	ASTM E2392/E2392-10 [16]	USA	All forms of EC	General statements and general guidelines on all aspects							
Earth building documents											
41	EBAA [24]	Australia	Ad, CEB, RE				√		√	√	
42	HB 195 [27]	Australia	Ad, CEB, RE, PE, SE, EFL, EFT	√	√		√	√	√		√
43	Bulletin 5 [18]	Australia	Ad, CEB, RE, SE	√	√	√	√	√	√		√
44	Lehmbau [38]	Germany	Ad, RE, Cb	√	√	√	√	NA	√	NA	√

Earth Earth composition/grading; *EC* Earth Construction; *MM* Moulds and machinery; *EPP* Earthen product production or manufacturing; *T&QC* Testing and quality control; *DG* Structural design guidance; *CM* Construction methodology and procedure; *EQ* Earthquake resistance design; *ML* Maintenance and limitations; *SEWT* Stabilised earth weathering test; *SEST* Stabilised earth strength test; ***SRE*** Stabilised rammed earth; *Ad* Adobe; *Cb* Cob; *RE* Rammed earth; *WD* Wattle and Daub; *CEB* Compressed earth block; *CSEB* Compressed stabilised earth block; ***PE*** Poured earth; *SE* Stabilised Earth; *NA* Not Applicable; *EFL* Earth floors; *EFT* Earth foundations; *EM* Earth mortar; *SEM* Stabilised earth mortar

Table 7.3 Earth composition parameters specified in different standards/codes

Composition parameter	Unstabilised earth						Stabilised earth					
	Adobe		Rammed earth		CEB		Adobe		Rammed earth		CEB	
	Range	References	Range	References	Range	References	Range	References	Range	References	Range	References
Clay content (%) Silt, sand and gravel (%)	10–12 > 70	NTE E.080 [65]	5–15 > 65	SAZS 724 [73]	≥ 10	UNE 41410 [82]			– > 35	IS 2110 [30]	2–18 > 60	IS 1725 [32], PCH-2–87 [71], SLS 1382 - Part 1 [76]
Liquid limit (%) Plasticity Index (%)									27.0 8.5–10.5	IS 2110 – [30]	≤ 45 < 12	NBR 8491 [40], NBR 8492 [41], NBR 10833 [42], IS 1725 [32]
Organic content (%)												
pH											6 – 8.5	IS 1725 [32], SLS 1382 - Part 1 [76]
Salts			≤ 2	CID-GCB-NMBC -14.7.4. [19], SAZS 724 [73]					≤ 3.0	IS 1725 [32], PCH-2-87 [71]		

7.4.2 Moulds/machinery and Manufacturing Earthen Building Products

Generally, the standards/codes do not provide detailed information on the moulds/machinery used in the production of earthen building products. Some of the codes/standards provide generic information on the moulds/machinery in brief. But some of the earth building documents mentioned in the Table 7.2 provide fairly detailed production techniques for compressed earth blocks, rammed earth and adobe.

7.4.3 Testing/evaluation and Quality Control

Most codes/standards touch upon the issues of testing/evaluation procedures for various properties and quality control aspects. Specifications or procedures for testing/evaluation and quality control aspects of earthen building products pertain to the following:

(1) Dimensions and density
(2) Strength (compression, tension and shear)
(3) Water absorption
(4) Durability

   a. Spray erosion
   b. Mass loss in cyclic wet and dry tests
   c. Expansion/shrinkage.

Procedures for some of the above-mentioned tests have evolved well for the stabilised earth products. Apart from some field tests, the quality control issues are addressed mainly through the limiting values for various tests suggested.

7.4.4 Design Guidance

The design guidance shall address: (1) structural design for gravity, wind and seismic loading; (2) fire safety and accidental damage and (3) thermal performance and moisture movement/buffering. Some standards/codes give information on certain aspects of design guidance. The information on design guidance for earthen buildings, available in the codes/standards, is summarised in Table 7.4. The codes/standards addressing the design guidance are limited. Some codes [32], especially on CEB masonry walls, mention referring to the codes on structural design of masonry. There is hardly any information on the structural design aspects of cob and wattle and daub. There are attempts to evolve design guidance for rammed earth walls. Some documents attempt to follow masonry design philosophy for rammed earth. There is a need for R&D into developing comprehensive design guidance for the earthen structures.

Table 7.4 Design guidance on earthen buildings

Design guidance parameters	Type of earth construction			
	Adobe masonry	CEB masonry	Rammed earth	Wattle and Daub
	Code/References	Code/References		
1. Structural design Design for gravity/wind loading and seismic design	IS 13827 [31], NBC 203 [58], NBC 204 [59]	NBC 203 [58], NBC 204 [59], SLS 1382-Part 3 [76]	IS 13827 [31], IS 2110 [30], NBC 203 [58], NBC 204 [59]	IS 13827 [31]

7.4.5 Construction Methodology and Construction Procedure

Details on construction techniques and construction procedures are essential for the construction of earthen structures. These aspects have been addressed by a large number of codes/standards, especially on adobe, CEB and rammed earth buildings, as detailed in the Table 7.2. Also, several books and manuals on earth construction detail these aspects [1, 18, 24, 25, 27, 77].

7.4.6 Earthquake Resistant Guidelines

There are few codes/standards on earthquake resistant design for earthen buildings [19, 31, 58–62]. Earthquake resistant features common to load bearing masonry buildings are suggested for earthen buildings with load bearing walls. Providing ties at sill, lintel and roof level and strengthening at the corner junctions and openings is commonly suggested as earthquake resistant feature. Another common type of earthquake resistant feature suggested for adobe masonry walls is providing a mesh layer on the two faces of the wall embedded in an earthen or air lime render and plaster. The height of the earthen buildings in severe earthquake zones is restricted to 1–2 storeyed [58, 59].

7.4.7 Durability, Limitations and Maintenance

The durability of unstabilised earthen products is evaluated mainly through accelerated spray erosion test (ASET). There are many attempts by different research groups to standardise ASET. The codes/standards which specify ASET include (NZS 4298 [61], SLS 1382 Part 2 [76]) and generally a limit on the depth of erosion is specified. For stabilised earth products, the durability assessment is carried out by a test measuring mass loss after cyclic wet/dry test and the linear expansion on saturation [32, 76]. For earth plasters a dry abrasion test is also proposed [22].

7.5 Conclusion and Guidelines for Comprehensive Code

There are attempts to develop codes/standards on different types of earthen products for building construction, in different regions across the globe. It appears there are a greater number of attempts in developing the codes/standards on stabilised earth (especially stabilised earth blocks and rammed earth), rather than unstabilised earthen building products. Evolving comprehensive global standards on each one of the earthen products listed in Table 7.1, will be more useful for better promotion of the earth construction. Moreover, it is an absolute necessity to develop new codes and standards in order to encourage the designers to build with earth, as well as to convince the regulatory bodies, which are sometimes reluctant to the use of non-conventional materials [39], that earth is relevant for construction.

Currently many national and regional standards on earth construction exist, but they are not comprehensive in addressing all the existing earth construction techniques and the earthen materials. In the absence of proper regulatory support, the building designers have to fend for themselves [17] leading to difficulties in the building approval processes. Apart from design of buildings there is a need for international laboratory standards in testing the earthen materials and the earthen building products. The new comprehensive global standards should address the following generic items:

1. Earth selection, composition/grading
2. Moulds and machinery
3. Production or manufacturing techniques
4. Testing and quality control
5. Structural design guidance including earthquake resistance design
6. Construction methodology and construction procedure
7. Thermal performance, hygroscopicity and moisture buffering
8. Durability, maintenance and limitations
9. Common glossary on earthen products.

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